Beginning Software Engineering

Rod Stephens

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ROD STEPHENS started out as a mathematician, but while studying at MIT, he discovered how much fun programming is and he's been programming professionally ever since. During his career, he has worked on an eclectic assortment of applications in such fields as telephone switching, billing, repair dispatching, tax processing, wastewater treatment, concert ticket sales, cartography, and training for professional football players.

Rod has been a Microsoft Visual Basic Most Valuable Professional (MVP) for more than a decade and has taught introductory programming courses. He has written more than two dozen books that have been translated into languages from all over the world, and he's written more than 250 magazine articles covering Visual Basic, C#, Visual Basic for Applications, Delphi, and Java.

Rod's popular VB Helper website (`www.vb-helper.com`) receives several million hits per month and contains thousands of pages of tips, tricks, and example programs for Visual Basic programmers. His C# Helper website (`www.csharphelper.com`) contains similar material for C# programmers.

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Thanks also to technical editor Brian Hochgurtel for giving me the benefit of his valuable experience.

Special thanks to Mary Brodie at `gearmark.blogs.com` for letting me use her quote in Chapter 13, "Iterative Models."

CONTENTS

INTRODUCTION

> *Programming today is a race between software engineers striving to build bigger and better idiot-proof programs, and the universe trying to build bigger and better idiots. So far the universe is winning.*
>
> —Rick Cook

With modern development tools, it's easy to sit down at the keyboard and bang out a working program with no previous design or planning, and that's fine under some circumstances. My VB Helper (`www.vb-helper.com`) and C# Helper (`www.csharphelper.com`) websites contain thousands of example programs written in Visual Basic and C#, respectively, and built using exactly that approach. I had an idea (or someone asked me a question) and I pounded out a quick example.

Those types of programs are fine if you're the only one using them and then for only a short while. They're also okay if, as on my websites, they're intended only to demonstrate a programming technique and they never leave the confines of the programming laboratory.

If this kind of slap-dash program escapes into the wild, however, the result can be disastrous. At best, nonprogrammers who use these programs quickly become confused. At worst, they can wreak havoc on their computers and even on those of their friends and coworkers.

Even experienced developers sometimes run afoul of these half-baked programs. I know someone (I won't give names, but I also won't say it wasn't me) who wrote a simple recursive script to delete the files in a directory hierarchy. Unfortunately, the script recursively climbed its way to the top of the directory tree and then started cheerfully deleting every file in the system. The script ran for only about five seconds before it was stopped, but it had already trashed enough files that the operating system had to be reinstalled from scratch. (Actually, some developers believe reinstalling the operating system every year or so is character-building. If you agree, perhaps this approach isn't so bad.)

I know another experienced developer who, while experimenting with Windows system settings, managed to set every system color to black. The result was a black cursor over a black desktop, displaying black windows with black borders, menus, and text. This person (who wasn't me this time) eventually managed to fix things by rebooting and using another computer that wasn't color-impaired to walk through the process of fixing the settings using only keyboard accelerators. It was a triumph of cleverness, but I suspect she would have rather skipped the whole episode and had her two wasted days back.

For programs that are more than a few dozen lines long, or that will be given to unsuspecting end users, this kind of free-spirited development approach simply won't do. To produce applications that are effective, safe, and reliable, you can't just sit down and start typing. You need a plan. You need … <drumroll> … software engineering.

This book describes software engineering. It explains what software engineering is and how it helps produce applications that are effective, flexible, and robust enough for use in real-world situations.

This book won't make you an expert systems analyst, software architect, project manager, or programmer, but it explains what those people do and why they are necessary for producing

high-quality software. It also gives you the tools you need to start. You won't rush out and lead a 1,000-person effort to build a new air traffic control system for the FAA, but it can help you work effectively in small-scale and large-scale development projects. (It can also help you understand what a prospective future boss means when he says, "Yeah, we mostly use Scrum with a few extra XP techniques thrown in.")

WHAT IS SOFTWARE ENGINEERING?

A formal definition of software engineering might sound something like, "An organized, analytical approach to the design, development, use, and maintenance of software."

More intuitively, software engineering is everything you need to do to produce successful software. It includes the steps that take a raw, possibly nebulous idea and turn it into a powerful and intuitive application that can be enhanced to meet changing customer needs for years to come.

You might be tempted to restrict software engineering to mean only the beginning of the process, when you perform the application's design. After all, an aerospace engineer designs planes but doesn't build them or tack on a second passenger cabin if the first one becomes full. (Although I guess a space shuttle riding piggyback on a 747 sort of achieved that goal.)

One of the big differences between software engineering and aerospace engineering (or most other kinds of engineering) is that software isn't physical. It exists only in the virtual world of the computer. That means it's easy to make changes to any part of a program even after it is completely written. In contrast, if you wait until a bridge is finished and then tell your structural engineer that you've decided to add two extra lanes, there's a good chance he'll cackle wildly and offer you all sorts of creative but impractical suggestions for exactly what you can do with your two extra lanes.

The flexibility granted to software by its virtual nature is both a blessing and a curse. It's a blessing because it lets you refine the program during development to better meet user needs, add new features to take advantage of opportunities discovered during implementation, and make modifications to meet evolving business needs. It even allows some applications to let users write scripts to perform new tasks never envisioned by developers. That type of flexibility isn't possible in other types of engineering.

Unfortunately, the flexibility that allows you to make changes throughout a software project's life cycle also lets you mess things up at any point during development. Adding a new feature can break existing code or turn a simple, elegant design into a confusing mess. Constantly adding, removing, and modifying features during development can make it impossible for different parts of the system to work together. In some cases, it can even make it impossible to tell when the project is finished.

Because software is so malleable, design decisions can be made at any point up to the end of the project. Actually, successful applications often continue to evolve long after the initial release. Microsoft Word, for example, has been evolving for roughly 30 years. (Sometimes for the better, sometimes for the worse. Remember Clippy? I'll let you decide whether that change was for the better or for the worse, but I haven't seen him in a while.)

The fact that changes can come at any time means you need to consider the whole development process as a single, long, complex task. You can't simply "engineer" a great design, turn the

programmers loose on it, and walk off into the sunset wrapped in the warm glow of a job well done. The biggest design decisions may come early, and software development certainly has stages, but those stages are linked, so you need to consider them all together.

WHY IS SOFTWARE ENGINEERING IMPORTANT?

Producing a software application is relatively simple in concept: Take an idea and turn it into a useful program. Unfortunately for projects of any real scope, there are countless ways that a simple concept can go wrong. Programmers may not understand what users want or need (which may be two separate things), so they build the wrong application. The program might be so full of bugs that it's frustrating to use, impossible to fix, and can't be enhanced over time. The program could be completely effective but so confusing that you need a PhD in puzzle-solving to use it. An absolutely perfect application could even be killed by internal business politics or market forces.

Software engineering includes techniques for avoiding the many pitfalls that otherwise might send your project down the road to failure. It ensures the final application is effective, usable, and maintainable. It helps you meet milestones on schedule and produce a finished project on time and within budget. Perhaps most important, software engineering gives you the flexibility to make changes to meet unexpected demands without completely obliterating your schedule and budget constraints.

In short, software engineering lets you control what otherwise might seem like a random whirlwind of chaos.

WHO SHOULD READ THIS BOOK?

Everyone involved in any software development effort should have a basic understanding of software engineering. Whether you're an executive customer specifying the software's purpose and features, an end user who will eventually spend time working with (and reporting bugs in) the finished application, a lead developer who keeps other programmers on track (and not playing too much Flow Free), or the guy who fetches donuts for the weekly meeting, you need to understand how all the pieces of the process fit together. A failure by any of these people (particularly the donut wallah) affects everyone else, so it's essential that everyone knows the warning signs that indicate the project may be veering toward disaster.

This book is mainly intended for people with limited experience in software engineering. It doesn't expect you to have any previous experience with software development, project management, or programming. (I suspect most readers will have some experience with donuts, but that's not necessary, either.)

Even if you have some familiarity with those topics, particularly programming, you may still find this book informative. If you've been focusing only on the pieces of a project assigned to you, you still need to learn about how the pieces interact to help guide the project toward success.

For example, I had been working as a programmer for several years and even taken part in some fairly large development efforts before I took a good look at the development process as a whole. I knew other people were writing use cases and deployment plans, but my focus was on my piece of

the project. It wasn't until later, when I started taking a higher-level role in projects that I actually started to see the entire process.

This book does not explain how to program. It does explain some techniques programmers can use to produce code that is flexible enough to handle the inevitable change requests, easy to debug (at least your code will be), and easy to enhance and maintain in the future (more change requests), but they are described in general terms and don't require you to know how to program.

If you don't work in a programming role, for example if you're an end user or a project manager, you'll hopefully find that material interesting even if you don't use it directly. You may also find some techniques surprisingly applicable to nonprogramming problems. For example, techniques for generating problem-solving approaches apply to all sorts of problems, not just programming decisions. (You can also ask developers, "Are you using assertions and gray-box testing methods before unit testing?" just to see if they understand what you're talking about. Basically, you're using gray-box testing to see if the developers know what gray-box testing is. You'll learn more about that in Chapter 8, "Testing.")

APPROACH

This book is divided into two parts. The first part describes the basic tasks you need to complete and deliver useful software. Things such as design, programming, and testing. The book's second part describes some common software development models that use different techniques to perform those tasks.

Before you can begin to work on a software development project, however, you need to do some preparation. You need to set up tools and techniques that help you track your progress throughout the project. Chapter 1, "Software Engineering from 20,000 Feet," describes these "before-the-beginning" activities.

After you have the preliminaries in place, there are many approaches you can take to produce software. All those approaches have the same goal (making useful software), so they must handle roughly the same tasks. These are things such as gathering requirements, building a plan, and actually writing the code. The first part of this book describes these tasks. Chapter 1 explains those tasks at a high level. Chapters 2 through 11 provide additional details about what these tasks are and how you can accomplish them effectively.

The second part of the book describes some of the more popular software development approaches. All these models address the same issues described in the earlier chapters but in different ways. Some focus on predictability so that you know exactly what features will be provided and when. Others focus on creating the most features as quickly as possible, even if that means straying from the original design. Chapters 12 through 14 describe some of the most popular of these development models.

That's the basic path this book gives you for learning software engineering. First learn the tasks you need to complete to deliver useful software. Then learn how different models handle those tasks.

However, many people have trouble learning by slogging through a tedious enumeration of facts. (I certainly do!) To make the information a bit easier to absorb, this book includes a few other elements.

Each chapter ends with exercises that you can use to see if you were paying attention while you read the chapter. I don't like exercises that merely ask you to repeat what is in the chapter. (Quick, what are some advantages and disadvantages of the ethereal nature of software?) Most of the exercises ask you to expand on the chapter's main ideas. Hopefully, they'll make you think about new ways to use what's explained in the chapter.

Sometimes, the exercises are the only way I could sneak some more information into the chapter that didn't quite fit in any of its sections. In those cases, the questions and answers provided in Appendix A are like extended digressions and thought experiments than quiz questions.

I strongly recommend that you at least skim the exercises and think about them. Then ask yourself if you understand the solutions. All the solutions are included in Appendix A, "Solutions to Exercises."

WHAT THIS BOOK COVERS (AND WHAT IT DOESN'T)

This book describes software engineering, the tasks that you must perform to successfully complete a software project, and some of the most popular developer models you can use to try to achieve your goals. It doesn't cover every last detail, but it does explain the overall process so that you can figure out how you fit into the process.

This book does not explain every possible development model. Actually, it barely scratches the surface of the dozens (possibly hundreds) of models that are in use in the software industry. This book describes only some of the most popular development approaches and then only relatively briefly.

If you decide you want to learn more about a particular approach, you can turn to the hundreds of books and thousands of web pages written about specific models. Many development models also have their own organizations with websites dedicated to their promotion. For example, see `www.extremeprogramming.org`, `agilemanifesto.org`, and `www.scrum.org`.

This book also isn't an exhaustive encyclopedia of software development tricks and tips. It describes some general ideas and concepts that make it easier to build robust software, but its focus is on higher-level software engineering issues, so it doesn't have room to cover all the clever techniques developers use to make programs better. This book also doesn't focus on a specific programming language, so it can't take advantage of language-specific tools or techniques.

WHAT TOOLS DO YOU NEED?

You don't need any tools to read this book. All you need is the ability to read the book. (And perhaps reading glasses. Or perhaps a text-to-speech tool if you have an electronic version that you want to "read." Or perhaps a friend to read it to you. Okay, I guess you have several options.)

To actually participate in a development effort, you may need a lot of tools. If you're working on a small, one-person project, you might need only a programming environment such as Visual Studio, Eclipse, RAD Studio, or whatever. For larger team efforts you'll also need tools for project

management, documentation (word processors), change tracking, software revision tracking, and more. And, of course, you'll need other developers to help you. This book describes these tools, but you certainly don't need them to read the book.

CONVENTIONS

To help you get the most from the text and keep track of what's happening, I've used several conventions throughout the book.

SPLENDID SIDEBARS

Sidebars such as this one contain additional information and side topics.

WARNING *Boxes like this one hold important information that is directly relevant to the surrounding text. There are a lot of ways a software project can fail, so these warn you about "worst practices" that you should avoid.*

NOTE *These boxes indicate notes, tips, hints, tricks, and asides to the current discussion. They look like this.*

As for styles in the text:

- Important words are *highlighted* when they are introduced.
- Keyboard strokes are shown like this: Ctrl+A. This one means you should hold down the Ctrl key (or Control or CTL or whatever it's labeled on your keyboard) and press the A key.
- This book includes little actual program code because I don't know what programming languages you use (if any). When there is code, it is formatted like the following.

```
// Return true if a and b are relatively prime.
private bool AreRelativelyPrime(int a, int b)
{
    // Only 1 and -1 are relatively prime to 0.
    if (a == 0) return ((b == 1) || (b == -1));
    if (b == 0) return ((a == 1) || (a == -1));

    int gcd = GCD(a, b);
    return ((gcd == 1) || (gcd == -1));
}
```

(Don't worry if you can't understand the code. The text explains what it does.)

- Filenames, URLs, and the occasionally piece of code within the text are shown like this: `www.csharphelper.com`.

ERRATA

I've done my best to avoid errors in this book, and this book has passed through the word processors of a small army of editors and technical reviewers. However, as you'll learn several times in this book, no nontrivial project is ever completely without mistakes. The best I can hope for is that any remaining errors are small enough that they don't distract you from the meaning of the text.

If you find an error in one of my books (like a spelling mistake, broken piece of code, or something that just doesn't make sense), I would be grateful for your feedback. Sending in errata may save other readers hours of frustration. At the same time, you'll be helping me provide even higher quality information.

To find the errata page for this book, go to `www.wrox.com/go/beginningsoftwareengineering`. Then, on the book details page, click the Book Errata link. On this page you can view all the errata submitted for this book and posted by Wrox editors. A complete book list including links to each book's errata is also available at `www.wrox.com/misc-pages/booklist.shtml`.

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p2p.wrox.com

Another excellent way to submit feedback and ask questions about the book is through the P2P forums at `p2p.wrox.com`. (P2P stands for "Programmer to Programmer," but because this book isn't just for programmers, I hereby declare that P2P stands for "Person to Person" in this context.)

These forums are a web-based system for you to post messages relating to Wrox books and related technologies, and to interact with other readers, technology users, and authors (like me). The forums offer a subscription feature to e-mail you topics of interest of your choosing when new posts are made to the forums. Wrox authors, editors, other industry experts, and readers are present on these forums.

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2. Read the terms of use and click Agree.
3. Complete the required information to join as well as any optional information you want to provide and click Submit.
4. You will receive an e-mail with information describing how to verify your account and complete the joining process.

JOIN THE FUN

You can read messages in the forums without joining P2P, but to post your own messages, you must join. If you join, Wrox won't spam you. (At least they never have in the past.) They just want to make sure Internet trolls don't make posts in your name.

After you join, you can post new messages and respond to messages the other readers post. You can read messages at any time on the web. If you would like to have new messages from a particular forum e-mailed to you, click the Subscribe to this Forum icon by the forum name in the forum listing.

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IMPORTANT URLS

Here's a summary of important URLs related to this book:

- `www.wrox.com/go/beginningsoftwareengineering`—This book's web page.
- `p2p.wrox.com`—Wrox P2P forums.
- `www.wrox.com`—The Wrox website. Contains errata and other information. Search for books by title or ISBN.
- `RodStephens@CSharpHelper.com`—My e-mail address. I hope to hear from you!
- `www.CSharpHelper.com`—My C# website. Contains thousands of tips, tricks, and examples for C# developers.
- `www.vb-helper.com`—My Visual Basic website. Contains thousands of tips, tricks, and examples for Visual Basic developers.

CONTACTING THE AUTHOR

If you have questions, suggestions, comments, just want to say "Hi," want to exchange cookie recipes, or whatever, e-mail me at `RodStephens@CSharpHelper.com`. I can't promise that I'll be able to help you with every problem, but I do promise to try.

DISCLAIMER

Software engineering isn't always the most exciting topic, so in an attempt to keep you awake, I picked some of the examples in this book for interest or humorous effect. (If you keep this book on your nightstand as a last-ditch insomnia remedy, then I've failed.)

I mean no disrespect to any of the many talented software engineers out there who work long weeks (despite the call for sustainable work levels) to produce top-quality applications for their customers. (As for the untalented software engineers out there, their work can speak for them better than I can.)

I also don't mean to discount any of the development models described in this book or the people who worked on or with them. Every one of them represents a huge amount of work and research, and all of them have their places in software engineering, past or present.

Because this book has limited space, I had to leave out many software development methodologies and programming best practices. Even the methodologies that *are* described are not covered in full detail because there just isn't room.

If you disagree with anything I've said, if you want to provide more detail about a topic, or if you want to describe the techniques and variations that you use to build software, I beg you to join this book's Wrox P2P forum and tell everyone all about it. The people on that forum are trying to improve their development skills, so we'd all love to hear what you have to say. (In fact, learning and improving the development process is a stated *requirement* for many agile methodologies, so joining the forum is practically mandatory!)

Finally I mean no disrespect to people named Fred, or anyone else for that matter. (Except for one particular Fred, who I'm sure retired from software development long ago.)

So get out your reading glasses, grab your favorite caffeinated beverage, and prepare to enter the world of software engineering. Game on!

PART I

Software Engineering Step-by-Step

- **CHAPTER 1:** Software Engineering from 20,000 Feet
- **CHAPTER 2:** Before the Beginning
- **CHAPTER 3:** Project Management
- **CHAPTER 4:** Requirement Gathering
- **CHAPTER 5:** High-Level Design
- **CHAPTER 6:** Low-Level Design
- **CHAPTER 7:** Development
- **CHAPTER 8:** Testing
- **CHAPTER 9:** Deployment
- **CHAPTER 10:** Metrics
- **CHAPTER 11:** Maintenance

Software and cathedrals are much the same. First we build them, then we pray.

—Samuel Redwine

In principle, software engineering is a simple two-step process: (1) Write a best-selling program, and then (2) buy expensive toys with the profits. Unfortunately, the first step can be rather difficult. Saying "write a best-selling program" is a bit like telling an author, "Write a best-selling book," or telling a baseball player "triple to left." It's a great idea, but knowing the goal doesn't actually help you achieve it.

To produce great software, you need to handle a huge number of complicated tasks, any one of which can fail and sink the entire project. Over the years people have developed a multitude of methodologies and techniques to help keep software projects on track. Some of these, such as the *waterfall* and *V-model* approaches, use detailed requirement specifications to exactly define the wanted results before development begins. Others, such as *Scrum* and *agile techniques*, rely on fast-paced incremental development with frequent feedback to keep a project on track. (Still others techniques, such as *cowboy coding* and *extreme programming*, sound more like action adventure films than software development techniques.)

Different development methodologies use different approaches, but they all perform roughly the same tasks. They all determine what the software should do and how it should do it. They generate the software, remove bugs from the code (some of the bugs, at least), make sure the software does more or less what it should, and deploy the finished result.

> **NOTE** *I call these basic items "tasks" and not "stages" or "steps" because different software engineering approaches tackle them in different ways and at different times. Calling them "stages" or "steps" would probably be misleading because it would imply that all projects move through the stages in the same predictable order.*

The chapters in the first part of this book describe those basic tasks that any successful software project must handle in some way. They explain the main steps in software development and describe some of the myriad ways a project can fail to handle those tasks. (The second part of the book explains how different approaches such as waterfall and agile handle those tasks.)

The first chapter in this part of the book provides an overview of software development from a high level. The subsequent chapters explain the pieces of the development process in greater detail.

1

Software Engineering from 20,000 Feet

There are two ways of constructing a software design. One way is to make it so simple that there are obviously no deficiencies. The other way is to make it so complicated that there are no obvious deficiencies. The first method is far more difficult.

—C.A.R. Hoare

WHAT YOU WILL LEARN IN THIS CHAPTER:

- The basic steps required for successful software engineering
- Ways in which software engineering differs from other kinds of engineering
- How fixing one bug can lead to others
- Why it is important to detect mistakes as early as possible

In many ways, software engineering is a lot like other kinds of engineering. Whether you're building a bridge, an airplane, a nuclear power plant, or a new and improved version of Sudoku, you need to accomplish certain tasks. For example, you need to make a plan, follow that plan, heroically overcome unexpected obstacles, and hire a great band to play at the ribbon-cutting ceremony.

The following sections describe the steps you need to take to keep a software engineering project on track. These are more or less the same for any large project although there are some important differences. Later chapters in this book provide a lot more detail about these tasks.

REQUIREMENTS GATHERING

No big project can succeed without a plan. Sometimes a project doesn't follow the plan closely, but every big project must have a plan. The plan tells project members what they should be doing, when and how long they should be doing it, and most important what the project's goals are. They give the project direction.

One of the first steps in a software project is figuring out the requirements. You need to find out what the customers want and what the customers need. Depending on how well defined the user's needs are, this can be time-consuming.

WHO'S THE CUSTOMER?

Sometimes, it's easy to tell who the customer is. If you're writing software for another part of your own company, it may be obvious who the customers are. In that case, you can sit down with them and talk about what the software should do.

In other cases, you may have only a vague notion of who will use the finished software. For example, if you're creating a new online card game, it may be hard to identify the customers until after you start marketing the game.

Sometimes, you may even be the customer. I write software for myself all the time. This has a lot of advantages. For example, I know exactly what I want and I know more or less how hard it will be to provide different features. (Unfortunately, I also sometimes have a hard time saying "no" to myself, so projects can drag on for a lot longer than they should.)

In any project, you should try to identify your customers and interact with them as much as possible so that you can design the most useful application possible.

After you determine the customers' wants and needs (which are not always the same), you can turn them into requirements documents. Those documents tell the customers what they will be getting, and they tell the project members what they will be building.

Throughout the project, both customers and team members can refer to the requirements to see if the project is heading in the right direction. If someone suggests that the project should include a video tutorial, you can see if that was included in the requirements. If this is a new feature, you might allow that change if it would be useful and wouldn't mess up the rest of the schedule. If that request doesn't make sense, either because it wouldn't add value to the project or you can't do it with the time you have, then you may need to defer it for a later release.

CHANGE HAPPENS

Although there are some similarities between software and other kinds of engineering, the fact that software doesn't exist in any physical way means there are some major differences as well. Because software is so malleable, users frequently ask for new features up to the day before the release party. They ask developers

to shorten schedules and request last-minute changes such as switching database platforms or even hardware platforms. (Yes, both of those have happened to me.) "The program is just 0s and 1s," they reason. "The 0s and 1s don't care whether they run on an Android tablet or a Windows Phone, do they?"

In contrast, a company wouldn't ask an architectural firm to move a new convention center across the street at the last minute; a city transportation authority wouldn't ask the builder to add an extra lane to a freeway bridge right after it opens; and no one would try to insert an atrium level at the bottom of a newly completed 90-story building.

HIGH-LEVEL DESIGN

After you know the project's requirements, you can start working on the high-level design. The high-level design includes such things as decisions about what platform to use (such as desktop, laptop, tablet, or phone), what data design to use (such as direct access, 2-tier, or 3-tier), and interfaces with other systems (such as external purchasing systems).

The high-level design should also include information about the project architecture at a relatively high level. You should break the project into the large chunks that handle the project's major areas of functionality. Depending on your approach, this may include a list of the modules that you need to build or a list of families of classes.

For example, suppose you're building a system to manage the results of ostrich races. You might decide the project needs the following major pieces:

- Database (to hold the data)
- Classes (for example, Race, Ostrich, and Jockey classes)
- User interfaces (to enter Ostrich and Jockey data, enter race results, produce result reports, and create new races)
- External interfaces (to send information and spam to participants and fans via e-mail, text message, voice mail, and anything else we can think of)

You should make sure that the high-level design covers every aspect of the requirements. It should specify what the pieces do and how they should interact, but it should include as few details as possible about how the pieces do their jobs.

TO DESIGN OR NOT TO DESIGN, THAT IS THE QUESTION

At this point, fans of extreme programming, Scrum, and other incremental development approaches may be rolling their eyes, snorting in derision and muttering about how those methodologies don't need high-level designs.

continues

(continued)

Let's defer this argument until Chapter 5, "High-Level Design," which talks about high-level design in greater detail. For now, I'll just claim that every design methodology needs design, even if it doesn't come in the form of a giant written design specification carved into a block of marble.

LOW-LEVEL DESIGN

After your high-level design breaks the project into pieces, you can assign those pieces to groups within the project so that they can work on low-level designs. The low-level design includes information about *how* that piece of the project should work. The design doesn't need to give every last nitpicky detail necessary to implement the project's major pieces, but they should give enough guidance to the developers who will implement those pieces.

For example, the ostrich racing application's database piece would include an initial design for the database. It should sketch out the tables that will hold the race, ostrich, and jockey information.

At this point you will also discover interactions between the different pieces of the project that may require changes here and there. The ostrich project's external interfaces might require a new table to hold e-mail, text messaging, and other information for fans.

DEVELOPMENT

After you've created the high- and low-level designs, it's time for the programmers to get to work. (Actually, the programmers should have been hard at work gathering requirements, creating the high-level designs, and refining them into low-level designs, but development is the part that most programmers enjoy the most.) The programmers continue refining the low-level designs until they know how to implement those designs in code.

(In fact, in one of my favorite development techniques, you basically just keep refining the design to give more and more detail until it would be easier to just write the code instead. Then you do exactly that.)

As the programmers write the code, they test it to make sure it doesn't contain any bugs.

At this point, any experienced developers should be snickering if not actually laughing out loud. It's a programming axiom that no nontrivial program is completely bug-free. So let me rephrase the previous paragraph.

As the programmers write the code, they test it to find and remove as many bugs as they reasonably can.

TESTING

Effectively testing your own code is extremely hard. If you just wrote the code, you obviously didn't insert bugs intentionally. If you knew there was a bug in the code, you would have fixed it before you wrote it. That idea often leads programmers to assume their code is correct (I guess they're just naturally optimistic) so they don't always test it as thoroughly as they should.

Even if a particular piece of code is thoroughly tested and contains no (or few) bugs, there's no guarantee that it will work properly with the other parts of the system.

One way to address both of these problems (developers don't test their own code well and the pieces may not work together) is to perform different kinds of tests. First developers test their own code. Then testers who didn't write the code test it. After a piece of code seems to work properly, it is integrated into the rest of the project, and the whole thing is tested to see if the new code broke anything.

Any time a test fails, the programmers dive back into the code to figure out what's going wrong and how to fix it. After any repairs, the code goes back into the queue for retesting.

A SWARM OF BUGS

At this point you may wonder why you need to retest the code. After all, you just fixed it, right?

Unfortunately fixing a bug often creates a new bug. Sometimes the bug fix is incorrect. Other times it breaks another piece of code that depended on the original buggy behavior. In the known bug hides an unknown bug.

Still other times the programmer might change some correct behavior to a different correct behavior without realizing that some other code depended on the original correct behavior. (Imagine if someone switched the arrangement of your hot and cold water faucets. Either arrangement would work just fine, but you may get a nasty surprise the next time you take a shower.)

Any time you change the code, whether by adding new code or fixing old code, you need to test it to make sure everything works as it should.

Unfortunately, you can never be certain that you've caught every bug. If you run your tests and don't find anything wrong, that doesn't mean there are no bugs, just that you haven't found them. As programming pioneer Edsger W. Dijkstra said, "Testing shows the presence, not the absence of bugs." (This issue can become philosophical. If a bug is undetected, is it still a bug?)

The best you can do is test and fix bugs until they occur at an acceptably low rate. If bugs don't bother users too frequently or too severely when they do occur, then you're ready to move on to deployment.

EXAMPLE Counting Bugs

Suppose requirements gathering, high-level design, low-level design, and development works like this: Every time you make a decision, the next task in the sequence includes two more decisions that depend on the first one. For example, when you make a requirements decision, the high-level design includes two decisions that depend on it. (This isn't exactly the way it works, but it's not as ridiculous as you might wish.)

Now suppose you made a mistake during requirements gathering. (The customer said the application had to support 30 users with a 5-second response time, but you heard 5 users with a 30-second response time.)

If you detect the error during the requirements gathering phase, you need to fix only that one error. But how many incorrect decisions could depend on that one mistake if you don't discover the problem until after development is complete?

The one mistake in requirements gathering leads to two decisions in high-level design that could be incorrect.

Each of the two possible mistakes in high-level design leads to two new decisions in low-level design that could also be wrong, giving a total of 2 × 2 = 4 possible mistakes in low-level design.

Each of the four suspicious low-level design decisions lead to two more decisions during development, giving a total of 4 × 2 = 8 possible mistakes during development.

Adding up all the mistakes in requirements gathering, high-level design, low-level design, and development gives a total of 1 + 2 + 4 + 8 = 15 possible mistakes. Figure 1-1 shows how the potential mistakes propagate.

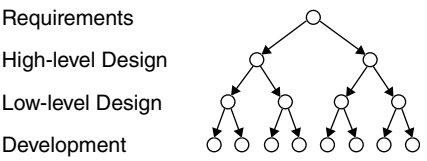


FIGURE 1-1: The circles represent possible mistakes at different stages of development. One early mistake can lead to lots of later mistakes.

In this example, you have 15 times as many decisions to track down, examine, and possibly fix than you would have if you had discovered the mistake right away during requirements gathering. That leads to one of the most important rules of software engineering. A rule that is so important, I'll repeat it later in the book:

The longer a bug remains undetected, the harder it is to fix.

Some people think of testing as something you do after the fact to verify that the code you wrote is correct. Actually, testing is critical at every stage of development to ensure the resulting application is usable.

DEPLOYMENT

Ideally, you roll out your software, the users are overjoyed, and everyone lives happily ever after. If you've built a new variant of Tetris and you release it on the Internet, your deployment may actually be that simple.

Often, however, things don't go so smoothly. Deployment can be difficult, time-consuming, and expensive. For example, suppose you've written a new billing system to track payments from your company's millions of customers. Deployment might involve any or all of the following:

- New computers for the back-end database
- A new network
- New computers for the users
- User training

- On-site support while the users get to know the new system
- Parallel operations while some users get to know the new system and other users keep using the old system
- Special data maintenance chores to keep the old and new databases synchronized
- Massive bug fixing when the 250 users discover dozens or hundreds of bugs that testing didn't uncover
- Other nonsense that no one could possibly predict

WHO COULD HAVE PREDICTED?

I worked on one project that assigned repair people to fix customer problems for a phone company. Twice during live testing the system assigned someone to work at his ex-wife's house. Fortunately, the repair people involved recognized the address and asked their supervisors to override the assignments.

If psychics were more consistent, it would be worth adding one to every software project to anticipate these sorts of bizarre problems. Failing that or a working crystal ball, you should allow some extra time in the project schedule to handle these sorts of completely unexpected complications.

MAINTENANCE

As soon as the users start pounding away on your software, they'll find bugs. (This is another software axiom. Bugs that were completely hidden from testers appear the instant users touch the application.)

Of course, when the users find bugs, you need to fix them. As mentioned earlier, fixing a bug sometimes leads to another bug, so now you get to fix that one as well.

If your application is successful, users will use it a lot, and they'll be even more likely to find bugs. They also think up a slew of enhancements, improvements, and new features that they want added immediately.

This is the kind of problem every software developer wants to have: customers that like an application so much, they're clamoring for more. It's the goal of every software engineering project, but it does mean more work.

WRAP-UP

At this point in the process, you're probably ready for a break. You've put in long hours of planning, design, development, and testing. You've found bugs you didn't expect, and the users are keeping you busy with bug reports and change requests. You want nothing more than a nice, long vacation.

There's one more important thing you should do before you jet off to Cancún: You need to perform a post-mortem. You need to evaluate the project and decide what went right and what went wrong. You need to figure out how to make the things that went well occur more often in the future. Conversely, you need to determine how to prevent the things that went badly in the future.

Right after the project's completion, many developers don't feel like going through this exercise, but it's important to do right away before everyone forgets any lessons that you can learn from the project.

EVERYTHING ALL AT ONCE

Several famous people have said, "Time is nature's way to keep everything from happening all at once." Unfortunately, time doesn't work that way in software engineering. Depending on how big the project is and how the tasks are distributed, many of the basic tasks overlap—and sometimes in big ways.

Suppose you're building a huge application that's vital to national security interests. For example, suppose you want to optimize national energy drink ordering, distribution, and consumption. This is a big problem. (Really, it is.) You might have some ideas about how to start, but there are a lot of details that you'll need to work out to build the best possible solution. You'll probably need to spend quite a while studying existing operations to develop the user requirements.

You could spend several weeks peppering the customers with questions while the rest of the development team plays *Mario Cart* and consumes the drinks you're studying, but that would be inefficient.

A better use of everyone's time would be to put people to work with as much of the project that is ready to roll at any given moment. Several people can work with the customers to define the requirements. This takes more coordination than having a single person gather requirements, but on big projects it can still save you a lot of time.

After you think you understand some of the requirements, other team members can start working on high-level designs to satisfy them. They'll probably make more mistakes than they would if you waited until the requirements are finished, but you'll get things done sooner.

As the project progresses, the focus of work moves down through the basic project tasks. For example, as requirements gathering nears completion, you should finalize the high-level designs, so team members can move on to low-level designs and possibly even some development.

Meanwhile, throughout the entire project, testers can try to shoot holes in things. As parts of the application are finished, they can try different scenarios to make sure the application can handle them.

Depending on the testers' skills, they can even test things such as the designs and the requirements. Of course, they can't run the requirements through a compiler to see if the computer can make sense of them. They can, however, look for situations that aren't covered by the requirements. ("What if a shipment of Quickstart Energy Drink is delayed, but the customer is on a cruise ship and just crossed the International Date Line! Is the shipment still considered late?")

Sometimes tasks also flow backward. For example, problems during development may discover a problem with the design or even the requirements. The farther back a correction needs to flow, the greater its impact. Remember the earlier example where every problem caused two more? The requirements problem you discovered during development could lead to a whole slew of other undiscovered bugs. In the worst case, testing of "finished" code may reveal fundamental flaws in the early designs and even the requirements.

REQUIREMENT REPAIRS

The first project I worked on was an inventory system for NAVSPECWARGRU (Navy Special Warfare Group, basically the Navy SEALs). The application let you define equipment packages for various activities and then let team members check out whatever was necessary. (Sort of the way a Boy Scouts quartermaster does this. For this campout, you'll need a tent, bedroll, canteen, cooking gear, and M79 grenade launcher.)

Anyway, while I was building one of the screens, I realized that the requirements specifications and high-level design didn't include any method for team members to return equipment when they were done with it. In a matter of weeks, the quartermaster's warehouse would be empty and the barracks would be packed to the rafters with ghillie suits and snorkels!

This was a fairly small project, so it was easy to fix. I told the project manager, he whipped up a design for an inventory return screen, and I built it. That kind of quick correction isn't possible for every project, particularly not for large ones, but in this case the whole fix took approximately an hour.

In addition to overlapping and flowing backward, the basic tasks are also sometimes handled in very different ways. Some development models rely on a specification that's extremely detailed and rigid. Others use specifications that change so fluidly it's hard to know whether they use any specification at all. Iterative approaches even repeat the same basic tasks many times to build ever-improving versions of the final application. The chapters in the second part of this book discuss some of the most popular of those sorts of development approaches.

SUMMARY

All software engineering projects must handle the same basic tasks. Different development models may handle them in different ways, but they're all hidden in there somewhere.

In fact, the strengths and weaknesses of various development models depend in a large part on how they handle these tasks. For example, agile methods and test-driven development use frequent builds to force developers to perform a lot of tests early on so that they can catch bugs as quickly as possible. (For a preview of why that's important, see the "Counting Bugs" example earlier in this chapter and Exercise 4.)

The chapters in Part II, "Development Models," describe some of the most common development models. Meanwhile the following chapters describe the basic software engineering tasks in greater detail. Before you delve into the complexities of requirements gathering, however, there are a few things you should consider.

The next chapter explains some basic tools that you should have in place before you consider a new project. The chapter after that discusses project management tools and techniques that can help you keep your project on track as you work through the basic software engineering tasks.

EXERCISES

1. What are the basic tasks that all software engineering projects must handle?
2. Give a one sentence description of each of the tasks you listed for Exercise 1.
3. I have a few customers who do their own programming, but who occasionally get stuck and need a few pointers or a quick example program. A typical project runs through the following stages:
   a. The customer sends me an e-mail describing the problem.
   b. I reply telling what I think the customer wants (and sometimes asking for clarification).
   c. The customer confirms my guesses or gives me more detail.
   d. I crank out a quick example program.
   e. I e-mail the example to the customer.
   f. The customer examines the example and asks more questions if necessary.
   g. I answer the new questions.

   Earlier in this chapter, I said that every project runs through the same basic tasks. Explain where those tasks are performed in this kind of interaction. (For example, which of those steps includes testing?)
4. List three ways fixing one bug can cause others.
5. List five tasks that might be part of deployment.

WHAT YOU LEARNED IN THIS CHAPTER

- All projects perform the same basic tasks:
  1. Requirements Gathering
  2. High-level Design
  3. Low-level Design
  4. Development
  5. Testing
  6. Deployment
  7. Maintenance
  8. Wrap-up
- Different development models handle the basic tasks in different ways, such as making some less formal or repeating tasks many times.
- The basic tasks often occur at the same time, with some developers working on one task while other developers work on other tasks.
- Work sometimes flows backward with later tasks requiring changes to earlier tasks.
- Fixing a bug can lead to other bugs.
- The longer a mistake remains undetected, the harder it is to fix.
- Surprises are inevitable, so you should allow some extra time to handle them.

2

Before the Beginning

It's not whether you win or lose, it's how you place the blame.

—Oscar Wilde

WHAT YOU WILL LEARN IN THIS CHAPTER:

- The features that a document management system provides
- Why documentation is important
- How you can easily archive e-mails for later use
- Typical types of documentation

Before you start working on a software project, even before you dig into the details of what the project is about, there are preparations you should make. In fact, some of these can be useful even if you're not considering a software project.

These tools improve your chances for success in any complicated endeavor. They raise the odds that you'll produce something that will satisfy the application's customers. They'll also help you survive the process so that you'll still be working on the project when the accolades start rolling in.

Typically, you'll use these tools and techniques throughout all of a project's stages. You'll use them while you're gathering requirements from the customer, during the design and programming phases, and as you roll out the final result to the users. You'll even use them after you've finished releasing an application and you're considering enhancements for the next version.

The following sections describe some beginning-to-end tools that you can use to help keep team members focused and the project on track.

DOCUMENT MANAGEMENT

A software engineering project uses a lot of documents. It uses requirements documents, use cases, design documents, test plans, user training material, lunch menus for team-building exercises, resumes if the project doesn't go well, and much more. (I'll describe these kinds of documentation in later chapters.) Even a relatively modest project could have hundreds or even thousands of pages of documentation.

To make matters more confusing, many of those are "living" documents that evolve over time. In some projects, the requirements are allowed to change as the project progresses. As developers get a better sense for which tasks will be hard and which will be easy, the customers may want to revise the requirements to include new, simple features and eliminate old, complicated features.

As the project progresses, the customers will also get a better understanding of what the system will eventually do and they may want to make changes. They may see some partially implemented feature and decide that it isn't that useful. They may even come up with new features that they just plain forgot about at the beginning of the project. ("I know we didn't *explicitly* say you need a way to log into the system, but I'm quite sure that's going to be necessary at some point.")

CHANGE CONTROL

If you let everyone make changes to the requirements, how can you meet them? Just when you satisfy one requirement, someone can change it, so you're not done after all. (Imagine running after the bus in the rain while the driver cackles evilly and checks the side mirror to make sure he's going just a little faster than you're running.) Eventually, the requirements need to settle down so that you can achieve them.

Allowing everyone to change the requirements can also result in muddled, conflicting, and confusing goals and designs. This is more or less how laws and government spending bills are written, so it shouldn't be a surprise that the results aren't always perfect. ("Yes, you can have a $3,000 study to decide whether people should carry umbrellas in the rain if I can have my $103,000 to study the effects of tequila and gin on sunfish." Someone really should spend a few dollars to study whether that kind of budget process is efficient.)

To keep changes from proliferating wildly and becoming hopelessly convoluted, many projects (particularly large ones) create a *change control board* that reviews and approves (or rejects) change requests. The board should include people who represent the customers ("We really *need* to log in telepathically from home") and the development team ("The best we can do is let you log in on your cell phone").

Even on small projects, it's usually worthwhile to assign someone as the final arbiter. Often that person is either a high-ranking customer (such as the executive champion) or a high-ranking member of the development team (such as the project lead).

During development, it's important to check the documentation to see what you're supposed to be doing. You need to easily find the most recent version of the requirements to see what the application should do. Similarly, you need to find the most recent high-level and low-level designs to see if you're following the plan correctly.

Sometimes, you'll also need to find older versions of the documentation, to find out what changes were made, why they were made, and who made them.

FONT FIASCO

To understand the importance of historical documentation, suppose your application produces quarterly reports showing projected root beer demand. At some point the requirements were changed to require that the report be printed in landscape mode with a 16-point Arial font.

Now suppose you're working on the report to add new columns that group customers by age, weight, ethnic background, car model, and hat size. That's easy enough, but now the report won't fit on the page. If you could bump the font size down to 14-point, everything would fit just fine, but the 16-point Arial requirement is killing you.

At this point, you should go back to the requirements documents and find out why the font requirement was added. If the requirement was added to make it easier to include reports in PowerPoint slides, you may be able to reduce the font size and your boss can live with slightly more crowded slides during his presentations to the VP of Strategic Soft Drink Engineering.

Another option might be to continue producing the original report for presentations and create a new expanded report that includes the new columns for research purposes.

It's even possible that the original issue was that some developers were printing reports with the Comic Sans font. Management didn't think that looked professional enough, so it made a font requirement. They never actually cared about the font size, just the typeface. In that case, you could probably ask to change the requirement again to let you use a smaller font, as long as you stick with Arial.

Unless you have a good document history, you may never know why and when the requirement was changed, so you won't know whether it's okay to change it again.

Meanwhile, as you're changing the font requirement to allow 12-point Arial, one of your coworkers might be changing some other part of the same requirement document (perhaps requiring that all reports must be printed in renewable soy ink on 100% post-consumer recycled paper). If you both open the document at the same time, whichever change is saved second will overwrite the other change, and the first change will be lost. (In programming terms, this is a "race condition" in which the second person wins.)

To prevent this type of conflict, you need a document control system that prevents two people from making changes to the same document at the same time.

To handle all these issues, you need a good document management system. Ideally, the system should support at least the following operations:

- People can share documents so that they can all view and edit them.
- Only one person can edit a document at a given time.
- You can fetch the most recent version of a document.
- You can fetch a specific version of a document by specifying either a date or version number.
- You can search documents for tags, keywords, and anything else in the documents.
- You can compare two versions of a document to see what changed, who changed it, and when the change occurred. (Ideally, you should also see notes indicating why a change was made; although, that's a less common feature.)

Following are some other features that are less common but still useful:

- The ability to access documents over the Internet or on mobile devices.
- The ability for multiple people to collaborate on documents (so they can see each other making changes to a shared document).
- Integration into other tools such as Microsoft Office or project management software.
- Document branches so that you can split a document into two paths for future changes. (This is more useful with program code where you might need to create two parallel versions of the program. Even then it can lead to a lot of confusion.)
- User roles and restricted access lists.
- E-mail change notification.
- Workflow support and document routing.

Some document management systems don't include all these features, and some of these aren't necessary for smaller projects, but they can be nice to have.

The following sections describe some special features of different kinds of documentation that you should save.

HISTORICAL DOCUMENTS

After you've installed some sort of document management system, you may wonder what documents you should put in it. The answer is: *everything*. Every little tidbit and scrap of intelligence dealing with the project should be recorded for posterity. Every design decision, requirements change, and memo should be tucked away for later use.

If you don't have all this information, it's too easy for project meetings to devolve into finger-pointing sessions and blame-game tournaments. Let's face it; people forget things.

(I'm writing Chapter 2 and I've already forgotten what Chapter 1 was about.) Not every disagreement has the vehemence of a blood feud between vampires and werewolves, but some can grow that bad if you let them. If you have a good, searchable document database, you can simply find the memo where your customer said that all the monitors had to be pink, pick the specific shade, and move on to discuss more important matters.

Collecting every scrap of relevant information isn't quite as big a chore as you might think. Most of the information is already available in an electronic form, so you just need to save it. Whenever someone sends an e-mail about the project, save it. Whenever someone makes a change request, save it. If someone creates a new document and doesn't put it in the document repository, put it there yourself or at least e-mail it to yourself so that there's a record.

The only types of project activity that aren't usually easy to record electronically are meetings and phone calls. You can record meetings and phone calls if you want a record of everything (subject to local law), but on most projects you can just type up a quick summary and e-mail it to all the participants. Anyone who disagrees about what was covered in the meeting can send a follow-up e-mail that can also go into the historical documents.

It's also well worth your effort to thrash through any disagreements as soon as possible, and sending out a meeting summary can help speed that process along. The biggest purpose of documentation is to ensure that everyone is headed in the same direction.

E-MAIL

Memos, discussions about possible change requests, meeting notes, and lunch orders are all easy to distribute via e-mail. Storing those e-mails for historical purposes is also easy: Simply CC a selected e-mail address for every project e-mail. For example, you could create an e-mail address named after the project and copy every project message to that account.

Suppose you're working on project CLASP (CLeverly Acronymed Software Project). Then you would create an e-mail account named CLASP and send copies of any project e-mail to that account.

> **TIP** *I've had project managers who extracted every project e-mail into text files and tucked them away in a folder for later use. That lets you perform all sorts of other manipulations that are tricky inside an e-mail system. For example, you could write a program to search the files for messages from the user Terry that include the words "sick" and "Friday." I've even had project managers who printed out every e-mail; although, that seems a bit excessive. Usually just having the e-mails saved in a project account is good enough.*

Sometimes, it's hard for team members to easily find project-related e-mails in the daily spamalanche of offers for cheap Canadian prescriptions, low interest rates guaranteed by the "U.S. National Bank," letters from your long lost Nigerian uncle, and evacuation notices from your Building Services department.

To make finding project e-mails easier, you can prefix their subjects with an identifier. The following text might show the subject line for an e-mail about the CLASP project.

```
[CLASP] This week's meeting canceled because all tasks are ahead of schedule
```

Of course, if you receive an e-mail with this subject, you should suspect it's a hoax because all tasks have never been ahead of schedule in the entire history of software engineering. I think the day the term "software engineering" was coined, its definition was already a week overdue.

You can further refine the subject identifier by adding classes of messages. For example, `[CLASP.Design]` might indicate a message about design for the CLASP project. You can invent any message classes that you think would be useful. Following is a list of a few that may come in handy.

- `Admin`—Administration
- `Rqts`—Requirements
- `HLDesign`—High-level design
- `LLDesign`—Low-level design
- `Dvt`—Development
- `Test`—Testing
- `Deploy`—Deployment
- `Doc`—Documentation
- `Train`—Training
- `Maint`—Maintenance
- `Wrap`—Wrap-up

> **TIP** *It doesn't matter what subject line tags you use, as long as you're consistent. Make a list at the beginning of the project and make sure everyone uses them consistently.*

You could even break the identifier further to indicate tasks within a message class. For example, the string `[CLASP.LLDesign.1001]` might indicate a message regarding low-level design task 1001.

> **TIP** *Some e-mail systems can even use rules to route particular messages to different folders. For example, the system might be able to copy messages with the word CLASP in the title into a project e-mail folder. (Just don't spend more time programming your e-mail system than on the actual project.)*

If team members use those conventions consistently, any decent e-mail system should make it easy to find messages that deal with a particular part of the project. To find the test messages, you can search for `[CLASP.Test`. To find every CLASP e-mail, search for `[CLASP`.

An alternative strategy is to include keywords inside the message body. You can use a naming convention similar to the one described here, or you can use something more elaborate if you need to. For example, a message might begin with the following text to flag it as involving the testing, bug reports, and login screen.

```
Key: Test

Key: Bugs

Key: Login
```

Now you can search for strings like `Key: Bugs` to find the relevant messages.

In addition to making e-mails easy to find, you should take steps to make them easy to distribute. Create some e-mail groups so that you can distribute messages to the appropriate people. For example, you may want groups for managers, user interface designers, customers, developers, testers, and trainers—and, of course, a group for everyone.

Then be sure you use the groups correctly! Customers don't want to hear the developers argue over whether a b+tree is better than an AVL-tree, and user interface designers don't want to hear the testers dispute the fine points of white-box versus beige-box testing. (In one project I was on, a developer accidentally included customers in an e-mail that described them in less than flattering terms. Basically, he said they didn't really know what they needed. It was true, but they sure didn't like hearing it!)

CODE

Program source code is different from a project's other kinds of documents. Normally, you expect requirements and design documents to eventually stabilize and remain mostly unchanged. In contrast, code changes continually, up to and sometimes even beyond the project's official ending date.

That gives source code control systems a slightly different flavor than other kinds of document control systems. A requirements document might go through a dozen or so versions, but a code module might include hundreds or even thousands of changes. That means the tools you use to store code often don't work particularly well with other kinds of documents and vice versa.

Source code is also generally line-oriented. Even in languages such as C# and Java, which are technically not line-oriented, programmers insert line breaks to make the code easier to read. If you change a line of source code, that change probably doesn't affect the lines around it. Because of that, if you use a source code control system to compare two versions of a code file, it flags only that one line as changed.

In contrast, suppose you added the word "incontrovertibly" to the beginning of the preceding paragraph. That would make every line in the paragraph wrap to the following line, so every line in the paragraph would seem to have been changed. A document revision system, such as those provided by Microsoft Word or Google Docs, correctly realizes that you added only a single word. A source code control system might decide that you had modified every line in the paragraph.

What this means is that you should use separate tools to manage source code and other kinds of documents. This usually isn't a big deal, and it's easy to find a lot of choices online. (In fact, picking one that every developer can agree on may be the hardest part of using a source code control system.)

Ideally, a source code control system enables all the developers to use the code. If a developer needs to modify a module, the system checks out the code to that developer. Other developers can still use the most recently saved version of the code, but they can't edit that module until the first developer releases it. (This avoids the race condition described earlier in this chapter.)

Some source code control systems are integrated into the development environment. They make code management so easy even the most advanced programmers don't mess it up too often.

CODE DOCUMENTATION

Something that most nonprogrammers (and quite a few programmers) don't understand is that code is written for people, not for the computer. In fact, the computer doesn't execute the source code. The code must be compiled, interpreted, and otherwise translated into a sequence of 0s and 1s that the computer can understand.

The computer also doesn't care what the code does. If you tell it to erase its hard disk (something I don't recommend), the computer will merrily try to do just that.

The reason I say source code is written for people is that it's people who must write, understand, and debug the code. The single most important requirement for a program's code is that it be understandable to the people who write and maintain it.

Now I know I'm going to get a lot of argument over that statement. Programmers have all sorts of favorite goals like optimizing speed, minimizing bugs, and including witty puns in the comments. Those are all important, but if you can't understand the code, you can't safely modify it and fix it when it breaks.

Without good documentation, including both design documents and comments inside the code, the poor fool assigned to fix your code will stand little or no chance. This is even more important when you realize that the poor fool may be you. The code you find so obvious and clever today may make no sense at all to you in a year or even a few months. (In some cases, it may not make sense a few hours later.) You owe it to posterity to ensure that your genius is properly understood throughout the ages.

To that end, you need to write code documentation. You don't need to write enormous tomes explaining that the statement `numInvoicesLost = numInvoicesLost + 1` means you are adding 1 to the value `numInvoicesLost`. You can probably figure that out even if you've never seen a line of code before. However, you do need to give yourself and others a trail of breadcrumbs to follow on their quest to figure out why invoices are being sent to employees instead of customers.

Code documentation should include high- and low-level design documents that you can store in the document repository with other kinds of documentation. These provide an overview of the methods the code is using to do whatever it's supposed to do.

Code documentation should also include comments in the code to help you understand what the code is actually doing and how it works. You don't need to comment every line of code (see the

`numInvoicesLost` example again), but it should provide a fairly detailed explanation that even the summer intern who was hired only because he's the boss's nephew can understand. Debugging code should be an exercise in understanding the code and figuring out why it isn't doing what it's supposed to do. It shouldn't be an IQ test.

JBGE

There's a school of thought in software engineering that says you should provide code documentation and comments that are "just barely good enough" (*JBGE*). The idea is that if you provide too much documentation, you end up wasting a lot of time updating it as you make changes to the code.

This philosophy can reduce the amount of documentation you produce, but it's an idea that's easy to take too far. Most programmers like to program (that's why they're not lawyers or doctors) and writing and updating documentation and comments doesn't feel like writing code, so sometimes they skip it entirely.

A software engineering joke says, "Real programmers don't comment their code. If it was hard to write, it should be hard to understand and harder to modify." Unfortunately I've seen plenty of code that proves the connection between poor documentation and difficult modification.

I worked on one project that included more than 55,000 lines of code and fewer than 300 comments. (I wrote a program to count them.) And if there were design documents, I never heard about them. I'm sure the code made sense when it was written, but modifying it was next to impossible. I sometimes spent 4 or 5 days studying the code, trying to figure out how it worked before changing one or two lines. Even after all that time, there was a decent chance I misunderstood something and the change added a new bug. Then I got to remove the change and start over.

I worked on another project that included tons of comments. Probably more than 80 percent of the lines of code included a comment. They were easy to ignore most of the time, but they were always there if you needed them.

After we transferred the project to the company's maintenance organization, the folks in the organization went on a JBGE bender and removed every comment that they felt wasn't absolutely necessary to understand the code. A few months later, they admitted that they couldn't maintain the code because —…drumroll…— they couldn't understand it. In the end, they put all the comments back and just ignored them when they didn't need them.

Yes, excessive code documentation and comments are a hassle and slow you down, so you can't rush off to the next task, but suck it up and write it down while it's still fresh in your mind. You don't need to constantly update your comments every time you change a line of code. Wait until you finish writing and testing a chunk of code. Then write it up and move on with a clear conscience. Comments may slow you down a bit, but I've never seen a project fail because it contained too many comments.

JBGE, REDUX

JBGE is mostly applied to code documentation and comments, but you could apply the same rule to any kind of documentation. For example, you could write barely enough documentation to explain the requirements. That's probably an even bigger mistake than skimping on code comments.

Documentation helps keep the whole project team working toward the same goals. If you don't spell things out unambiguously, developers will start working at cross-purposes. At best you'll lose a lot of time arguing about what the requirements mean. At worst you'll face a civil war that will destroy your team.

As is the case with code documentation and comments, you don't need to turn the requirements into a 1,200-page novel. However, if the requirements are ambiguous or confusing, pull out your thesaurus and clarify them.

JBGE is okay as long as you make sure your documentation actually is GE.

You can extend the JBGE idea even further and create designs that are just barely good enough, write code that's just barely good enough, and perform tests that are just barely good enough. I'm a big fan of avoiding unnecessary work, but if everything you do is just barely good enough, the result probably won't be anywhere near good enough. (Not surprisingly, no one advocates that approach. The JBGE philosophy seems to be reserved only for code comments.)

Some programming languages provide a special kind of comment that is intended to be pulled out automatically and used in text documentation. For example, the following shows a snippet of C# code with XML comments:

```
/// <summary>
/// Deny something bad we did to the media.
/// </summary>
/// <param name="type">What we did (Bug, Virus, PromisedBadFeature, etc.)</param>
/// <param name="urgency">High, Medium, or Low</param>
/// <param name="media">One or more of Blog, Facebook, Friendster, etc.</param>
private void PostDenial(DenialType type, UrgencyType urgency, MediaType media)
{
    ...
}
```

The comment's `summary` token explains the method's purpose. The `param` tokens describe the method's parameters. The Visual Studio development environment can automatically extract these comments into an XML file that you can then process to produce documentation. The result doesn't explain how the code works, but if you do a good job writing the comments, it does explain the

interface that the method displays to other pieces of code. (Visual Studio also uses these comments to provide help pop-ups called IntelliSense to other developers who call this code.)

As is the case when you write code documentation and other comments, you don't need to constantly update this kind of information as you work on a method. Finish the method, test it, and then write the comments once.

APPLICATION DOCUMENTATION

All the documentation described so far deals with building the application. It includes such items as requirements and design documents, code documentation and comments, meeting and phone call notes, and memos.

At some point you also need to prepare documentation that describes the application. Depending on the eventual number and kinds of users, you may need to write user manuals (for end users, managers, database administrators, and more), quick start guides, cheat sheets, user interface maps, training materials, and marketing materials. You may even need to write meta-training materials to teach the trainers how to train the end users. (No kidding, I've done it.)

In addition to basic printed versions, you may need to produce Internet, screencast, video, and multimedia versions of some of those documents. Producing this kind of documentation isn't all that different from producing requirements documents. You can still store documents in an archive. (Although you may not be able to search for keywords in a video.)

Although creating this material is just another task, don't start too late in the project schedule. If you wait until the last minute to start writing training materials, then the users won't be able to use the application when it's ready. (I remember one project where the requirements and user interface kept changing right up until the last minute. It was somewhat annoying to the developers, but it practically drove our lead trainer insane.)

SUMMARY

Documentation is produced throughout a project's lifespan, starting with early discussions of the project's requirements, extending through design and programming, continuing into training materials, and lasting even beyond the project's release in the form of comments, bug reports, and change requests. To get the most out of your documentation, you need to set up a document tracking system before you start the project. Then you can effectively use the project documents to determine what you need to do and how you should do it. You can also figure out what was decided in the past so that you don't need to constantly rehash old decisions.

Document control is one of the first tools you should set up when you're considering a new project. You can use it to archive ideas before you know what the project will be about or whether there will even be a project. Once you know the project will happen, you should start tracking the project with project management tools. The next chapter describes project management in general and some of the tools you can use to help keep a project moving in the right direction.

EXERCISES

1. List seven features that a document management system should provide.

2. Microsoft Word provides a simple change tracking tool. It's not a full-featured document management system, but it's good enough for small projects. For this exercise, follow these steps:

   a. Create a short document in Word and save it.

   b. Turn on change tracking. (In recent versions of Word, go to the Review tab's Tracking group and click Track Changes.)

   c. Modify the document and save it with a new name. (You should see the changes flagged in the document. If you don't, go to the Review tab's Tracking group and use the drop-down to select Final: Show Markup.)

   d. On the Review tab's Tracking group, click the Reviewing Pane button to display the reviewing pane. You should see your changes there.

   e. In the Review tab's Tracking group, open the Track Changes drop-down and select Change User Name. Change your user name and initials.

   f. Make another change, save the file again, and see how Word indicates the changes.

3. Microsoft Word also provides a document comparison tool. If you followed the instructions in Exercise 1 carefully, you should have two versions of your sample document. In the Review tab's Compare group, open the Compare drop-down and select Compare. (I guess Microsoft couldn't think of synonyms for "compare.") Select the two versions of the file and compare them. How similar is the result to the changes shown by change tracking? Why would you use this tool instead of change tracking?

4. Like Microsoft Word, Google Docs provides some simple change tracking tools. Go to `http://www.google.com/docs/about/` to learn more and to sign up. Then create a document, save it, close it, reopen it, and make changes to it as you did in Exercise 1.

   To view changes, open the File menu and select See revision history. Click the See more detailed revisions button to see your changes.

5. What does JBGE stand for and what does it mean?

WHAT YOU LEARNED IN THIS CHAPTER

- Documentation is important at every step of the development process.
- Good documentation keeps team members on track, provides a clear direction for work, and prevents arguments over issues that were previously settled.
- Document management systems enable you to:
  - Share documents with other team members.
  - Fetch a document's most recent version.
  - Fetch an earlier version of a document.
  - Search documents for keywords.
  - Show changes made to a document.
  - Compare two documents to show their differences.
  - Edit a document while preventing someone else from editing the document at the same time.
- A simple way to store project history is to create an e-mail account named after the project and then send copies of all project correspondence to that account.
- You can use e-mail subject tags such as `[CLASP.Rqts]` to make finding different types of project e-mails easy.
- Types of documentation may include:
  - Requirements
  - Project e-mails and memos
  - Meeting notes
  - Phone call notes
  - Use cases
  - High-level design documents
  - Low-level design documents
  - Test plans
  - Code documentation
  - Code comments
  - Extractable code comments
  - User manuals
  - Quick start guides
  - Cheat sheets

- User interface maps
- Training materials
- Meta-training materials
- Marketing materials

- JBGE (Just Barely Good Enough) states that you should provide only the absolute minimum number of comments necessary to understand the code.

3

Project Management

Effective leadership is putting first things first. Effective management is discipline, carrying it out.

—Stephen Covey

WHAT YOU WILL LEARN IN THIS CHAPTER:

- What project management is and why you should care
- How to use PERT charts, critical path methods, and Gantt charts to create project schedules and estimate project duration
- How you can improve time estimates
- How risk management lets you respond quickly and effectively to problems

Part of the reason you implemented all the change tracking described in the preceding chapter is so that you have historical information when you're writing your memoirs. It's so you know what happened, when, and why.

In addition to this peek into the past, you also need to keep track of what's going on in real time. Someone needs to track what's happening, what should be happening, and why the two don't match. That's where project management comes in.

Many software developers view management with suspicion, if not downright fear or loathing. They feel that managers were created to set unrealistic goals, punish employees when those goals aren't met, and take credit if something accidentally goes right. There are certainly managers like that, and Scott Adams has made a career out of making fun of them in his *Dilbert* comic strip, but some management is actually helpful for producing good software.

Management is necessary to ensure that goals are set, tracked, and eventually met. It's necessary to keep team members on track and focused on the problems at hand, without becoming distracted by inconsequential side issues such as new unrelated technology, impending layoffs, and *Angry Birds* tournaments.

On smaller projects, a single person might play multiple management roles. For example, a single technical manager might also handle project management tasks. On a really small project, a single person might perform every role including those of managers, developers, testers, and end users. (Those are my favorite kinds of projects because the meetings and arguments are usually, but not always, short.)

No matter how big the project is, however, management tasks must be performed. The following sections describe some of the key management responsibilities that must be handled by someone for any successful software development project.

EXECUTIVE SUPPORT

Lack of executive management support is often cited as one of the top reasons why software projects fail. This is so important, it deserves its own note.

> **NOTE** *To be successful, a software project must have consistent executive management support.*

The highest-ranking executive who supports your project is often known as an *executive champion* or an *executive sponsor*.

Robust executive support ensures that a project can get the budget, personnel, hardware, software, and other resources it needs to be successful. It lets the project team specify a realistic schedule even when middle management or customers want to arbitrarily shorten the timeline. Managers with limited software development experience often don't understand that writing quality software takes time. The end result isn't physical, so they may assume that you can compress the schedule or make do with fewer resources if you're properly motivated by pithy motivational slogans.

Unfortunately, that usually doesn't work well with software development. When developers work long hours for weeks at a time, they burn out and write sloppy code. That leads to more bugs, which slows development, resulting in a delayed schedule, greater expense, and a low-quality result. Not only do you fail to achieve the desired time and cost-savings, but also you get to take the blame for missing the impossible deadlines.

Executive support is also critical for allowing a project to continue when it encounters unexpected setbacks such as missed deadlines or uncooperative software tools. In fact, unexpected setbacks are so common that you should expect some to occur, even if you don't know what they will be. (Donald Rumsfeld would probably consider them "known unknowns.")

Overall the executive champion provides the gravitas needed for the project to survive in the rough-and-tumble world of corporate politics. It's a sad truth that different parts of a company don't

always have the same goals. (In management-speak, you might say the oars aren't all pulling in the same direction.) The executive champion can head off attempts to cancel a project and transfer its resources to some other part of the company.

In cases like those, work can be somewhat unnerving, even if you do have strong executive support. I once worked on a project where both our executive champion and our arch nemesis were corporate vice presidents directing thousands of employees. At times I felt like a movie extra hoping Godzilla and Mothra wouldn't step on us while they slugged it out over Japan. After two years of unflagging support by our champion, we finished the project and transferred it to another part of the company where it was quite successful for many years.

Executive champion duties include:

- Providing necessary resources such as budgets, hardware, and personnel
- Making "go/no-go" decisions and deciding when to cancel the project
- Giving guidance on high-level issues such as how the project fits into the company's overall business strategy
- Helping navigate any administrative hurdles required by the company
- Defining the business case
- Working with users and other stakeholders to get buy-in
- Providing feedback to developers about implemented features
- Buffering the project from external distractions (such as the rest of the company)
- Refereeing between managers, users, developers, and others interested in the project
- Supporting the project team
- Staying out of the way

The last point deserves a little extra attention. Most executives are too busy to micromanage each of the projects they control, but this can sometimes be an issue, particularly if the executive champion is near the bottom of the corporate ladder. If you are an executive champion, monitor the project to make sure it's headed in the right direction and that it's meeting its deadlines and other goals, but try not to add extra work. As Tina Fey says in her book *Bossypants*, "In most cases being a good boss means hiring talented people and then getting out of their way."

However, studies have shown that more engaged executives result in more successful projects, so don't just get things started and then walk away.

PROJECT MANAGEMENT

A *project manager* is generally the highest-ranking member of the project team. Ideally, this person works with the team through all stages of development, starting with requirements gathering, moving through development and testing, and continuing until application rollout (and sometimes even beyond into future versions).

The project manager monitors the project's progress to ensure that work is heading in the right direction at an acceptable pace and meets with customers and other stakeholders to verify that the finished product meets their requirements. If the development model allows changes, the project manager ensures that changes are made and tracked in an organized manner so that they don't get lost and don't overwhelm the rest of the team.

A project manager doesn't necessarily need to be an expert in the users' field or in programming. However, both of those skills can be extremely helpful because the project manager is often the main interface between the customers and the rest of the project team.

Project manager duties include:

- Helping define the project requirements
- Tracking project tasks
- Responding to unexpected problems
- Managing risk
- Keeping users (and the executive champion) up-to-date on the project's progress
- Providing an interface between customers and developers
- Managing resources such as time, people, budget, hardware, and software tools
- Managing delivery

MYRIAD MANAGERS

There are a lot of kinds of project managers in addition to software project managers. Construction, architecture, engineering, and other fields have project managers. Just about any activity that involves more than a few people needs someone to perform project management duties, even if that person isn't called a project manager.

This book even has a project manager extraordinaire, Adaobi Obi Tulton; although her title is project editor. She makes sure I'm turning chapters in on time, passes chapters to various technical and copy editors, and generally guides the book during its development.

In practice, some project managers are promoted from the developer ranks, so they often have good development skills but weak project management skills. They can give useful advice to other programmers about how a particular piece of code should be written or how one subsystem should interact with another. They can provide technical leadership, but they're not always good at recognizing and handling scheduling problems when something goes wrong.

For that reason, some larger projects divide the project manager's duties among two or more people. One project I worked on had a person dedicated to task tracking and making sure we kept to the schedule. She had training in project management but no programming experience. If something

started to slip, she immediately jumped all over the issue, figured out how much delay was required, asked about contingencies in case the task couldn't be finished, determined whether the delay would affect other tasks, and did all the nontechnical things a project manager must handle.

That person was called the "project manager," in contrast with the other project manager who was called the "project manager." It got a little confusing at times. Perhaps we should have called the task-tracking person the "developer babysitter" or the "border collie" because she gently guided us toward our goals by nipping at our heels. Often people call the other manager the "technical project manager"; although, that person may also handle nontechnical tasks such as interaction with customers and executives.

Meanwhile the "main" project manager was freed up to attack the problem from the development side. He could work with the developers to figure out what was wrong and how to fix it.

When I first encountered this set up, I thought it was kind of silly. Couldn't a single project manager handle both technical and tracking tasks? In our project, the separation actually made things easier. This may not be the right approach for every project, particularly small ones, but it was useful in our case.

If you are a project manager or want to become one, you should do a lot more reading about specific tools and techniques that are useful for keeping a project on track.

Before moving on to other topics, however, I want to cover a few more project management issues in greater detail. The next three sections describe PERT charts, the critical path method (CPM), and Gantt charts. PERT charts and CPM are generally used together but are separated here so that you can digest them in smaller pieces. Together these three tools can help you study the project's total duration, look for potential bottlenecks, and schedule the project's tasks.

However, you can't understand how tasks fit into a schedule unless you know how long those tasks will take, so the last sections about project management deal with predicting task lengths and with risk management.

PERT Charts

A *PERT chart* (PERT stands for Program Evaluation and Review Technique) is a graph that uses nodes (circles or boxes) and links (arrows) to show the precedence relationships among the tasks in a project. For example, if you're building a bunker for use during the upcoming zombie apocalypse, you need to build the outer defense walls before you can top them with razor wire.

PERT charts were invented in the 1950s by the United States Navy. They come in two flavors: activity on arrow (AOA), where arrows represent tasks and nodes represent milestones and activity on node (AON), where nodes represent tasks and arrows represent precedence relations. Activity on node diagrams are usually easier to build and interpret, so that's the kind described here.

To build an AON PERT chart, start by listing the tasks that must be performed, the tasks they must follow (their predecessors), and the time you expect each task to take. (You can also add best-case and worst-case times to each task if you want to perform more extensive analysis of the tasks and what happens when things go wrong.)

Note that you don't need to include every possible combination of predecessors. For example, suppose task C must come after task B, which must come after task A. In that case, task C must come after

task A, but you don't need to include that relationship in the table if you don't want to. The fact that task C must come after task B is enough to represent that relationship. However, you also don't need to remove every unnecessary relationship. Those extra relationships won't hurt anything.

If you like, you can add a Start task as a predecessor for any other tasks that don't have predecessors. Similarly, you can add a Finish task for any other tasks that don't have successors.

To make rearranging tasks easy, make an index card or sticky note for each task. (You can draw the chart on a piece of paper or with a drawing tool, but index cards and sticky notes make it easy to shuffle tasks around if necessary.) Include each task's name, predecessors, and expected time.

Then to build the chart, follow these steps:

1. Place the Start task in a Ready pile. Place the other tasks in a Pending pile.
2. Position the tasks in the Ready pile in a column to the right of any previously positioned tasks. (The first time through, the Ready pile only contains the Start task, so position it on the left side of your desk.)
3. Look through the tasks in the Pending pile and cross out the predecessors that you just positioned. (Initially that means you'll be crossing out the Start task.) If you cross out a card's last predecessor, move it to the Ready pile.
4. Return to step 2 and repeat until you have positioned the Finish task.

PUZZLING PREDECESSORS

If you don't move any tasks into the Ready pile during step 3, that means the tasks have a predecessor loop. For example, task A is task B's predecessor and task B is task A's predecessor.

For example, at my college, you needed to pay registration fees before you could get your student ID; you needed a student ID to get financial aid checks; and you needed financial aid checks to pay registration fees. (At least, you probably do if you need financial aid.) You needed to fill out extra paperwork to break out of the predecessor loop.

After you finish positioning all of the cards, draw arrows representing the predecessor relationships. (You may want to use a dry-erase marker so that you can get the arrows off your desk later.)

At this point, you have a chart showing the possible paths of execution for the tasks in the project.

EXAMPLE Building a PERT Chart

The steps for building a PERT chart are a bit confusing, so let's walk through an example that creates a PERT chart for a project that builds a bunker to protect you and your video games in case of a zombie apocalypse. (The U.S. Strategic Command actually developed a plan for fighting off a zombie apocalypse as part of a training exercise. You can read it at `i2.cdn.turner.com/cnn/2014/images/05/16/dod.zombie.apocalypse.plan.pdf`.)

Start by building a table that lists the tasks, their predecessors, and the times you expect them to take. Table 3-1 shows some of the tasks you would need to perform to build the bunker. To keep things simple, I've omitted a lot of details such as installing sewer lines, building forms for pouring concrete, and obtaining permits (assuming the planning officials haven't been eaten yet).

TABLE 3-1: Tasks for a Zombie Apocalypse Bunker

TASK	TIME (DAYS)	PREDECESSORS
A. Grade and pour foundation.	5	—
B. Build bunker exterior.	5	A
C. Finish interior.	3	B
D. Stock with supplies.	2	C
E. Install home theater system.	1	C
F. Build outer defense walls.	4	—
G. Install razor wire on roof and walls.	2	B, I
H. Install landmines (optional).	3	—
I. Install surveillance cameras.	2	B, F

After you've built the task table, create index cards for the tasks (or be prepared to draw them with a drawing tool). Figure 3-1 shows what the card for task I might look like.

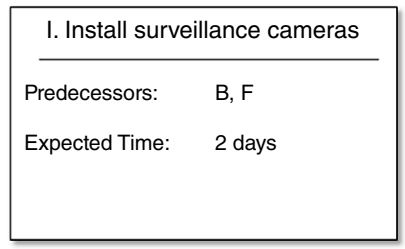


FIGURE 3-1: Each task's card should hold its name, duration, and predecessors. You'll fill in the total time later.

Next, start working through the four steps described earlier to arrange the cards. This is a lot easier to understand if you go to the trouble of creating index cards or sticky notes instead of trying to imagine what they would look like. Trust me. If you found the steps confusing, make the cards.

1. Place the Start task in a Ready pile. Place the other tasks in a Pending pile.

   Figure 3-2 shows the initial positions of the cards. (I've omitted the task names and abbreviated a bit to save space.)

2. Position the tasks in the Ready pile in a column to the right of any previously positioned tasks. (The first time through, the Ready pile contains only the Start task. Just position it on the left side of your desk.)

3. Look through the tasks in the Pending pile and cross out the predecessors that you just positioned. (Initially, that means you'll be crossing out the Start task.) If you cross out a card's last predecessor, move it to the Ready pile.

   Referring to Figure 3-2, you see that tasks A, F, and H have the Start task as predecessors. In fact, the Start task is the only predecessor for those tasks, so when you cross out the Start task, you move tasks A, F, and H into the Ready pile. Figure 3-3 shows the new arrangement.

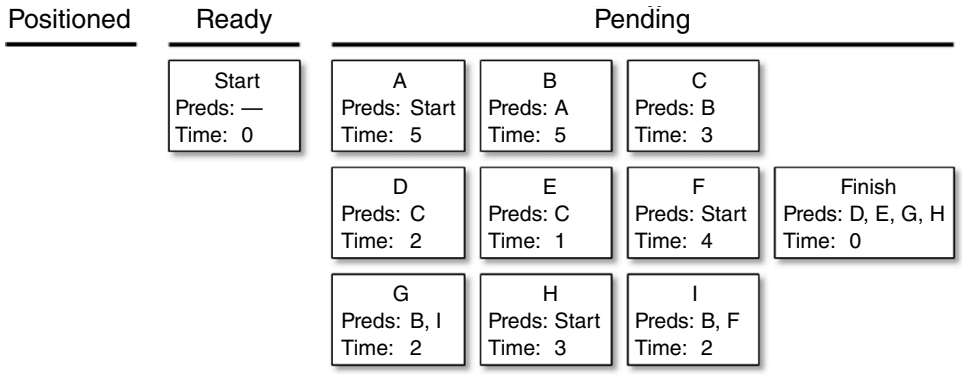


FIGURE 3-2: Initially only the Start task is in the Ready pile.

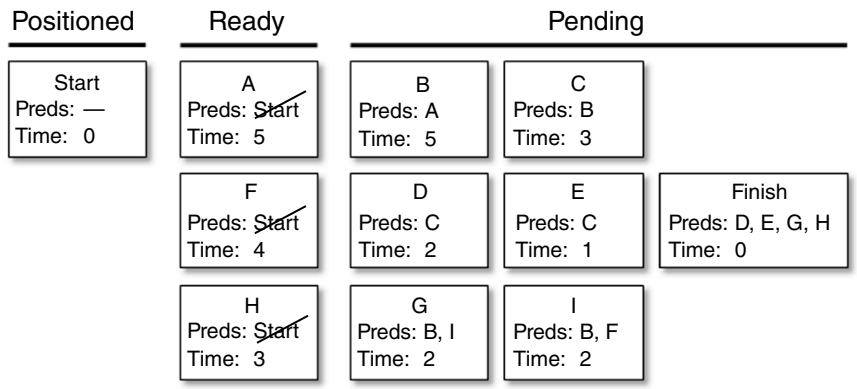


FIGURE 3-3: After one round, the Start task is positioned and tasks A, F, and H are in the Ready pile.

4. Return to step 2 and repeat until you have positioned the Finish task.

   To do that, position tasks A, F, and H because they're in the Ready pile. Then cross them out for any tasks that are still in the Pending pile. When you cross out those tasks, task B loses its last predecessor so move it into the Ready pile. Figure 3-4 shows the new arrangement.

5. Return to step 2 and repeat until you have positioned the Finish task.

   This time position task B and remove it from the remaining tasks' predecessor lists. After you cross task B off, tasks C and I have no more predecessors so move them to the Ready pile. Figure 3-5 shows the new arrangement.

   By now you probably have the hang of it. Position tasks C and I, and remove them from the Pending tasks' predecessor lists. That removes the last predecessors from tasks D, E, and G, so move them to the ready pile, as shown in Figure 3-6.

In the next round, position tasks D, E, and G, and move the Finish task to the Ready pile. Then one final round positions the Finish task.

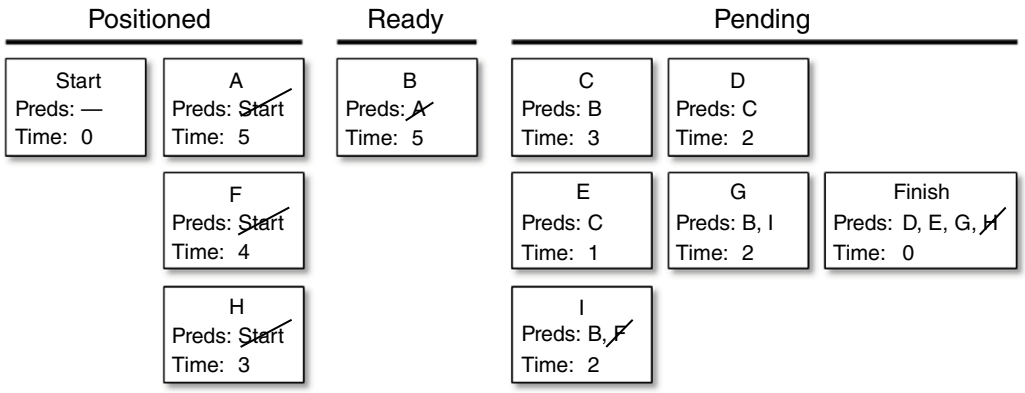


FIGURE 3-4: After two rounds, the Start task and tasks A, F, and H are positioned. Task B is in the Ready pile.

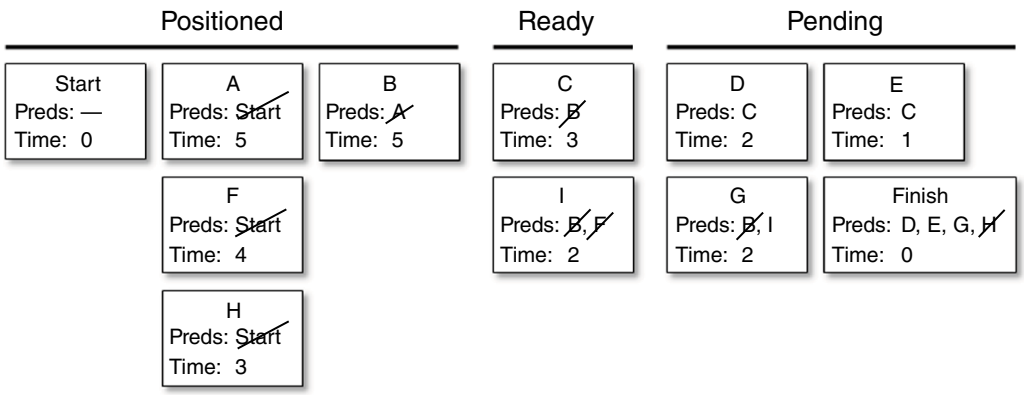


FIGURE 3-5: After three rounds, the Start task and tasks A, F, H, and B are positioned. Tasks C and I are in the Ready pile.

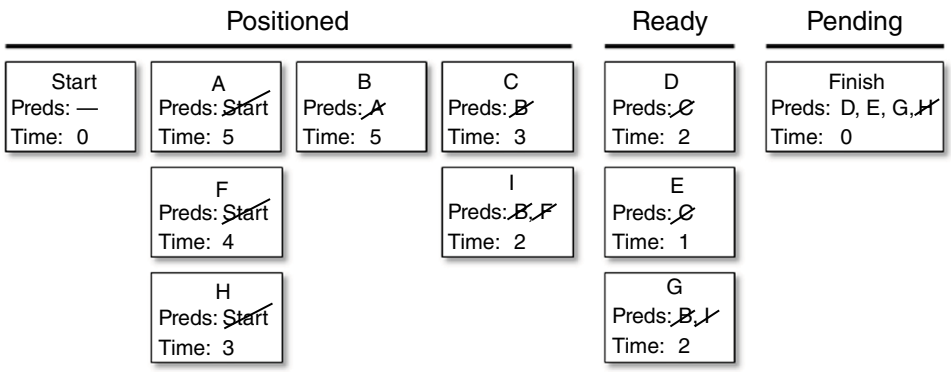


FIGURE 3-6: After four rounds, only the Finish task is still in the Pending pile.

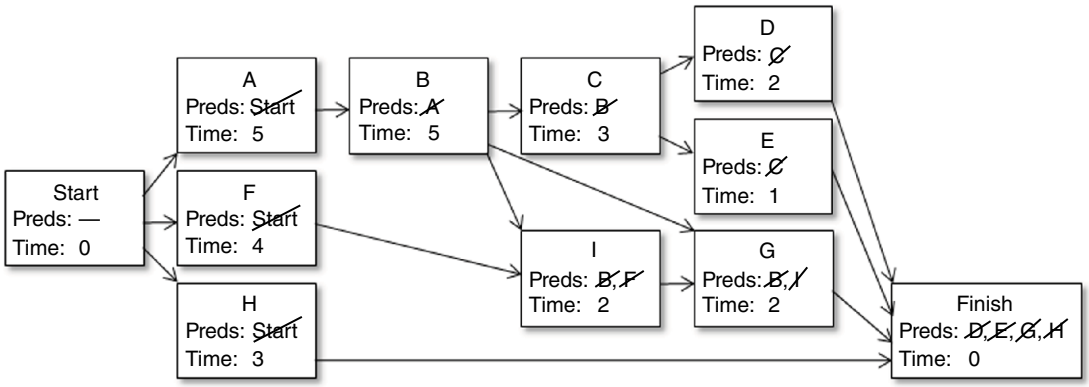


FIGURE 3-7: This PERT chart shows the paths of execution of the project's tasks.

Now draw arrows showing the predecessor relationships between the tasks. You may need to adjust the spacing and vertical alignment of the tasks to make the arrows look nice. Figure 3-7 shows the final result.

To check your work, you can verify that each task has one arrow entering it for each of its predecessors. For example, task G has two predecessors, so it should have two arrows entering it.

Critical Path Methods

PERT charts are often used with the critical path method, which was also invented in the 1950s. That method lets you find critical paths through the network formed by a PERT chart.

A *critical path* is a longest possible path through the network. (I say "a longest" instead of "the longest" because there may be more than one path with the same longest length.)

For example, refer to the PERT network shown in Figure 3-7. The path Start➢H➢Finish has a total time of 3 days. (No charge for the Start and Finish, plus 3 days for task H.)

Similarly, the path Start➢F➢I➢G➢Finish has a total time of 0 + 4 + 2 + 2 + 0 = 8 days.

With a little study of Figure 3-7 and some trial and error, you can determine that this network has a single longest path: Start➢A➢B➢C➢D➢ Finish with a total length of 0 + 5 + 5 + 3 + 2 + 0 = 15 days. Because that's the longest path, it is also the critical path.

If any task along the critical path is delayed, the project's final completion is also delayed. For example, if task C "Finish the interior" takes 5 days instead of 3 (perhaps you decided to add a nice bar with beer taps), then the whole project will take 17 days instead of 15.

For a simple project like this one, it's fairly easy to find the critical path. For projects containing hundreds or even thousands of tasks, this could be a lot harder. Fortunately, there's a relatively easy way to find critical paths.

Start at the left with the Start task. It takes no time to start, so label that task with the total time 0.

Now move to the right, one column at a time. For each task in the current column, set its total time equal to that task's time plus the largest total time for its predecessor tasks.

While you're at it, highlight the link that came from the predecessor with the greatest total cost. If more than one predecessor is tied for the largest total time, highlight them both.

When you're done, the Finish task will be labeled with the total time to complete the project (assuming nothing goes wrong, of course). You can follow the highlighted links back through the network to find the critical paths.

EXAMPLE Critical Paths

In this example, let's walk through the steps for adding total time and critical path information to the zombie apocalypse bunker project PERT chart shown in Figure 3-7.

Start by setting the total time for the Start task to 0.

Referring to Figure 3-7, you can see that the next column of tasks holds tasks A, F, and H, which have expected times 5, 4, and 3, respectively. Each has only Start as a predecessor, and that task has a total time 0 (we just labeled it), so each of these tasks' total time is the same as its own expected time. (So far, not too interesting.)

The next column holds only task B. It has an expected time of 5 and a single predecessor with time 5, so its total time is 5 + 5 = 10. Figure 3-8 shows the network at this point. The new total times and the selected links are highlighted in bold.

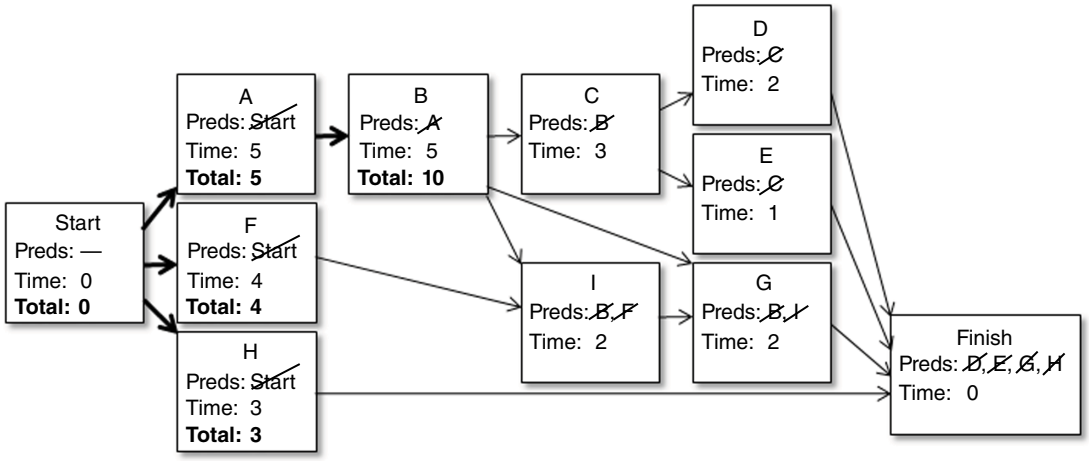


FIGURE 3-8: The total time for each task is its expected time plus the largest of its predecessors' total times.

Now things get a bit more interesting. The next column holds tasks C and I. Task C has an expected time of 3 and a single predecessor with a total time of 10, so its total time is 3 + 10 = 13.

Task I has an expected time of 2. It has two predecessors with total times of 10 and 4, so its total time is 2 plus the larger of 10 and 4 or 2 + 10 = 12. Figure 3-9 shows the updated network.

The next column holds tasks D, E, and G.

Task D has an expected time of 2. Its single predecessor, C, has a total time of 13, so task D's total time is 2 + 13 = 15.

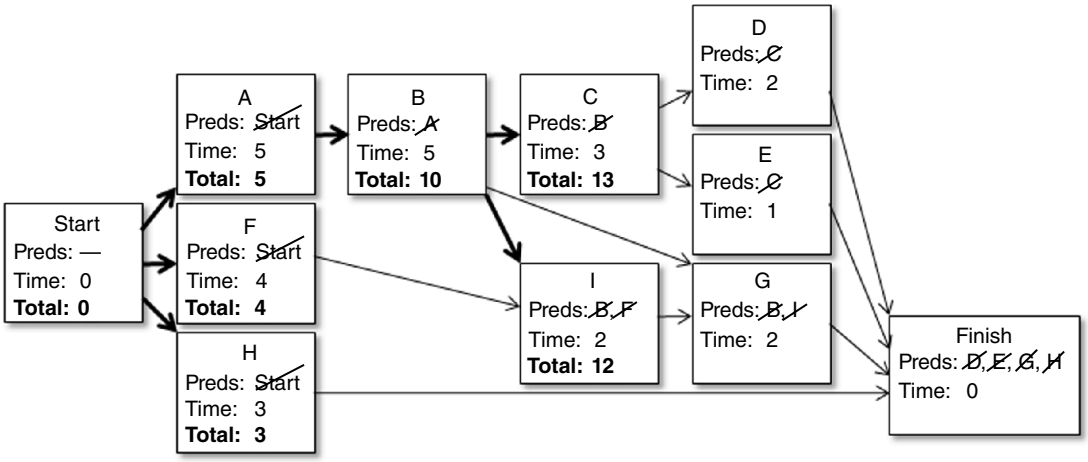


FIGURE 3-9: Task I's largest time predecessor is task B, so task I has a total time of 2 + 10 = 12.

Task E has an expected time of 1. It also has the predecessor C with the total time 13, so task E's total time is 1 + 13 = 14.

Task G has an expected time of 2. It has two predecessors: B with a total time of 10 and I with a total time of 12. That means task G's total time is 2 + 12 = 14.

The final column holds the Finish task. It has an expected time of 0, so its total time is the same as its predecessor with the largest total time. That's task D with a total time of 15. Figure 3-10 shows the final network.

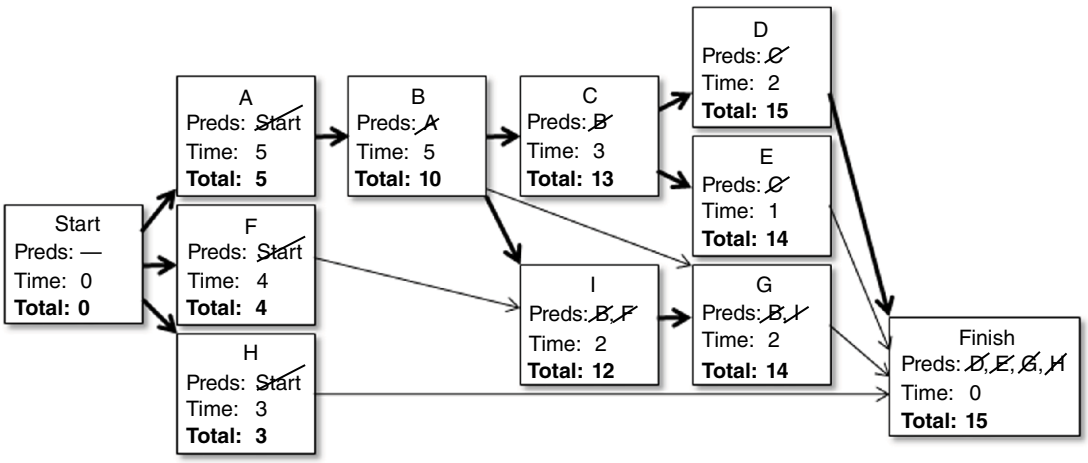


FIGURE 3-10: The complete zombie apocalypse bunker project has a total time of 15 days.

You can trace the bold arrows backward from the Finish to the Start in Figure 3-10 to find the critical path. Those tasks are (in their forward order) Start➢A➢B ➢C➢D➢Finish (as we found earlier).

In addition to showing you the critical path, the PERT network with total times can help you study the project for other possible problems. For example, Figure 3-10 holds two "almost critical paths." The paths through tasks E and G to the Finish task have total times of 14 days, which is only 1 day less than the true critical path. That means if any tasks along those paths are delayed by more than 1 day, the project's completion will be delayed.

The finished network also shows that Tasks F and H don't play a major role in the project's final completion time. Task F could stretch out for up to 10 days without changing the critical path. Task H could run even longer, lasting up to 15 days without impacting the finish date.

To look at this another way, that means you have some flexibility with tasks F and H. You can delay their start a bit if you want without changing the critical path. Sometimes, delaying a task can be useful to balance staffing levels. (After they finish building the bunker in task B, you may want to use the same masons to build the outer defense walls in task F.)

There may also be some reason to rearrange tasks slightly. For example, task H is a landmine installation. The whole project will probably be a lot safer if you delay that as long as possible so that people working on the project don't need to worry about stepping in the wrong places.

Gantt Charts

A *Gantt chart* is a kind of bar chart invented by Henry Gantt in the 1910s to show a schedule for a collection of related tasks. The fact that we're still using them more than 100 years later shows how useful they are for project scheduling.

A Gantt chart uses horizontal bars to represent task activities. The bars' lengths indicate the tasks' durations. The bars are placed horizontally on a calendar to show their start and stop times. Arrows show the relationships between tasks and their predecessors much as they do in a PERT chart.

Figure 3-11 shows a Gantt chart for the zombie apocalypse bunker project that I drew in Microsoft Excel. I've followed a common practice and repeated the task names on the right to make it easier to see which tasks start the arrows. Arrows lead from the end of each task to the beginning of successor tasks.

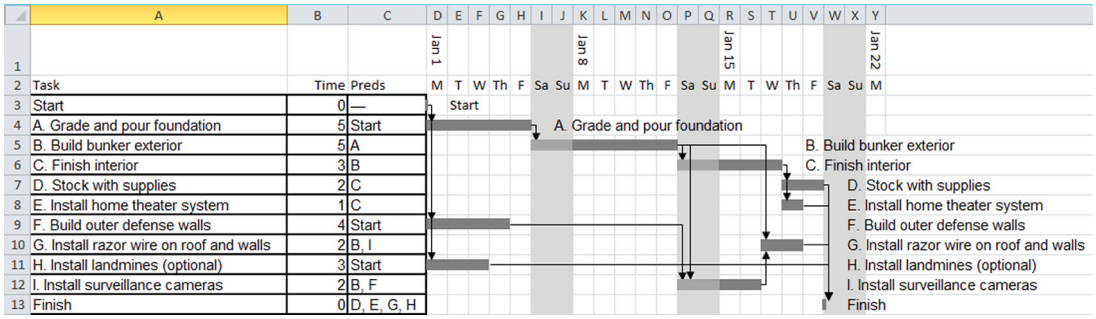


FIGURE 3-11: A Gantt chart shows task durations, start times, end times, and dependencies.

Notice that some of the tasks have been extended to cover the gaps created by weekends. (Figure 3-11 ignores holidays such as New Year's Day for simplicity, but in a real project you would need to account for them.) Also notice that the weekends have extended the project's total duration from 15 working days to 19 calendar days. (In case of a real zombie emergency, you might want to work through the weekends and holidays. I'm sure the zombies will!)

To build a Gantt chart, list the tasks, their durations, and their predecessors on the left, as shown in Figure 3-11.

Next, cut out a thin rectangle for each task. Give each rectangle a width that represents its duration. (For example, you could make each rectangle 1-inch wide per day.) Write the tasks' names on their rectangles.

Next, move from left to right through the columns in the PERT chart, placing each rectangle so that its left edge lines up with the right edge of its rightmost predecessor rectangle. For example, in Figure 3-11 the left edge of task G lines up with the right edge of task I.

If a rectangle includes a weekend, lengthen it so that it gets its required number of working days.

Finally, after you've positioned all the rectangles, add arrows to show the predecessor relationships.

Scheduling Software

The preceding sections explained how you can build PERT charts, find critical paths, and draw Gantt charts by hand. The process isn't too difficult, but the result isn't flexible. For example, suppose you decide to add a gas-powered generator and you want to run underground cables between it and the bunker before you pour the foundation.

Or suppose you start work and building the bunker takes longer than expected. In both of those cases, you need to shift some of the tasks farther to the right. Because I drew the schedule by hand, rearranging those tasks can be a hassle. The problem would be much worse for larger projects.

Fortunately, there are lots of project scheduling tools available for your computer. They make building schedules relatively easy and provide lots of extra features. For example, some enable you to click and drag to connect two tasks or to change a task's duration.

Some of those tools also enable you to define other kinds of relationships between tasks. For example, you might indicate that two tasks should start at the same time or that one task should start five days after another task starts.

If you need to manage a lot of project schedules or schedules with many tasks, you should try some of these tools to find one you like.

Predicting Times

PERT charts, critical path methods, and Gantt charts are great tools for figuring out how long a project will take, but they depend on your time estimates being accurate. If the times you assign for the tasks aren't reasonable, then those carefully built charts are nothing more than elaborate examples of GIGO (garbage in, garbage out).

One of the hardest parts of software engineering is predicting how long each task will take. One reason for this difficulty is that you rarely need to do *exactly* the same thing on multiple projects.

You may need to do something similar to something you did earlier, but the details are different enough to add some uncertainty. If a project includes a task that is *exactly* the same as one you've performed before, you can just copy the code you used before and you're done.

For example, suppose you're building an inventory application for a unicycle store, and you want to include screens that let the employees record daily timesheets. If you've build timesheet forms in a previous application, you can probably copy most or all the forms and code you wrote for the previous application and save a huge amount of time on that task.

Even if you need to make some fairly major changes, you can probably still skip a lot of the database design, form layout, and other pieces of this task that took up a lot of time when you built your first timesheet system.

Sometimes, you can take this idea even further and avoid building an entire project, either by reusing a previous project or by purchasing a commercial off-the-shelf (*COTS*) application.

COTS

CUSTOMER: I need to perform a lot of calculations, but they may change over time. Can you build something where I can enter values and equations in some sort of grid and make the program perform the calculations for me?

CONSULTANT: I could, but it would probably take a month or so and cost $20,000. What you should probably do is buy a COTS spreadsheet. It'll save you time and money and will probably be better in the long run.

CUSTOMER: Hmm. Okay. How about a program that helps me track task assignments for a long project? You know, to keep track of who's falling behind and how that will impact the final schedule?

CONSULTANT: Well, a basic program wouldn't be too hard. Maybe three weeks and $10,000 or $15,000. But you could just download some project management software. There are even free versions available if you don't need all the bells and whistles.

CUSTOMER: I see. Is there anything you *can* do for me?

CONSULTANT: I just saved you $30,000, didn't I? Ha ha.

CUSTOMER: Yes you did! Ha ha. You're fired.

The fact that you can reuse code (to some extent anyway) if you've performed the same task before means many software engineering tasks either have fairly short well-defined times, or you have little notion about how long they will take. In contrast, jobs that don't live inside cyberspace often include tasks that have well-defined durations even if they take a long time.

For example, suppose your company builds bee fences to keep elephants away from villages. You know from years of experience that it takes one person 1 day to build 50 feet of fence. If you have four employees and a customer wants a 400-foot fence, you can do some simple math to figure out how long it will take: 400 ÷ 50 ÷ 4 = 2 days.

If a new customer wants another 400-foot fence, you still know with reasonable certainty that it will take 2 days.

In contrast, suppose you want to build a bee fence design program. It will enable the user to enter some specifications and draw the fence on a map. The program will create a bill of materials, create purchase orders for the materials and either print them or transmit them to suppliers electronically, create a work schedule based on expected delivery dates, print (or transmit) an invoice for upfront costs, and generate a final invoice.

If you've never built this kind of application before, you probably don't know how long it will take to build. After you've built it, however, you won't need to build it again.

So if you assume a task's time estimate is either (1) short and well known or (2) long and highly uncertain, how can you create usable time estimates? Or are you doomed to rely on uninformed guesses? Fortunately, there are a few things you can do to minimize your risk even when you step into the great unknown.

Get Experience

One way to improve time estimates is to make the unknown known. If you can find someone who has done something similar to what you need to do, get that person to help. In smaller projects, you may be unable to pull people from other parts of your company to bring much needed experience to your team, but sometimes you can get them to help part time. They may give you time estimates that are better than random guesses, and they may give your team members some guidance about how to do the work.

Experience is even more important for long and difficult tasks. In a large project, it may be worthwhile to hire new experienced team members to tackle tricky tasks. I worked on one algorithmic project where we hired an algorithms specialist to help with maintenance. It was a good thing we did because he was the only one on the maintenance team who could understand how that part of the program worked.

Having people with previous experience can make or break a project. In fact, it's a software engineering best practice.

> **TIP** *Create a team that includes people who have done something similar before. This is particularly important for the project lead, who will give guidance to the other team members.*

Using experienced team members is the single best way to make time estimates reasonable.

Break Unknown Tasks into Simpler Pieces

Sometimes, you can break a complicated task into simple pieces that are easier to understand. In fact, that's basically what high-level and low-level designs are all about—breaking complicated tasks into simpler pieces.

For example, suppose the bee fence application needs an inventory component to track the materials your company has on hand and to order more material as needed. You may not know exactly how hard this is because you haven't done it before, but with some work (and possibly some advice from

someone who has done this sort of thing before), you can break the tasks into smaller pieces. Some of the things you'll need to do to build the inventory system include:

- Design an `Inventory` database table to store information about inventory items.
- Build a screen to let the user add and remove items from the `Inventory` table.
- Build an interface to let the program add and remove items from inventory as they are ordered and used in projects.
- Create an alert system to let someone know when inventory levels fall below a certain amount.

You may not know *exactly* how much time you'll need for each of these subtasks, but you can probably make better guesses than you could for the inventory subsystem as a whole.

> **TIP** *If you have access to people experienced with the task, have them review your breakdown before you finalize your time estimates. They may know from experience that you'll need to add a* `LeadTime` *field to the Inventory table or that creating an alert system takes a lot longer than you might expect. You'd probably discover those things as the project continued anyway, but learning this at the start will make your time estimates more accurate and may save you a lot of time and frustration trying to overcome problems that have been solved before.*

Breaking a complex task lets you convert a large unknown into several smaller pieces, which may individually be a bit less unpredictable.

Look for Similarities

Sometimes, tasks that you don't understand are at least somewhat similar to tasks that you have performed before. You may not have ordered live bees before, but you have ordered wire and fence posts, so you know at least a little about how to order supplies from distributors.

Obviously, there are some differences between bees and spools of wire, so you should expect to do some extra research before making your time estimates: Should you buy packaged bees, nucs, or established colonies? How early should you order the bees? They probably won't last as long in the warehouse as a pile of fence posts will.

As is the case in which you break large tasks into smaller ones, you should run your ideas past someone with experience if you can. They can tell you the things you missed and tell you where you may find unexpected problems.

Expect the Unexpected

Obviously, you can't predict every problem that comes along, but there are some delays that are reasonably predictable. For example, in any large project, some team members will become ill and miss some work time. They'll go on vacation and need time off for personal emergencies.

One way to handle this sort of "lost" time is to expand each task's time estimate by some amount. For example, adding 5 percent to each task's time allows for 2.6 weeks per year for vacation and sick leave.

One drawback to this approach is that people tend to use up any extra time scheduled for a task. For example, suppose a task should take 20 working days and you add an extra day to allow for lost time. If there are no problems with the task, you should finish it in 20 days and save the extra day for later in the project when you catch the plague and need to use it as sick leave. Unfortunately, most people will use up all 21 days and save nothing for later. Instead of allowing a 5-percent margin, you've basically just extended the project timeline by 5 percent.

Another approach is to add specific tasks to the project to represent lost time. If team members schedule their vacations in advance, you can include those explicitly. (Be sure not to let one team member volunteer for every "vacation time" task.)

You can also add tasks to represent sick time. Of course, you can't predict when people will get sick (with a few exceptions such as the days before and after long weekends), but you can add "sick time" tasks to the end of the schedule. Then when someone contracts a bad case of "Sunny Friday-itis," you can move the time from the "sick time" tasks to the tasks that are delayed.

Another kind of "lost time" problem occurs when your team is all geared up and raring to go but can't get anything done because of some other scheduling problem. The classic example is trying to get management approval during the holiday season. You have your project schedule worked out to the millisecond, but progress grinds to a halt because you need approval from the VP of Finance to order more highlighters and he's in Jamaica for two weeks. And don't expect your developers to be productive on August 20 if you order their computers on August 19. It's going to take some time to receive the computers, get the network running, test the e-mail system, and install *Call of Duty*.

You can avoid these kinds of problems by carefully planning for approvals, order lead times, and setup. In fact, while you're at it, you may as well make them tasks and put them in the schedule.

Track Progress

Even if you have previous experience with a type of task, break the task into smaller pieces, plan for "lost time," and allow a buffer for unexpected problems, sometimes things just take longer than you expect. It's extremely important to keep track of tasks as they progress and take action if one is not going according to plan.

For example, suppose a task was scheduled to take 20 days. After five days, you ask the developer assigned to that task how much is done and he says he's 25-percent complete and has 15 days of work remaining. In another week, the developer says he's 50-percent done and has 10 days of work remaining. So far so good, but after another week, the developer says he's 60-percent done (when he should be 75-percent finished).

Initially, it seemed like he was making good progress but as the task's completion date draws near, the developer realizes how much work is left to do. This is normal and not necessarily a cause for panic, but it does require attention. You need to dig deeper and find out if the developer can actually finish the task on time or if you need to adjust the schedule.

In reality the developer is just making the best guesses he can. If he hasn't performed a task like this one before, those guesses may not be perfect. In this example, the developer's first two estimates were probably off, so he had actually completed only 20 percent of the task after one week and 40 percent after two weeks. If that's the case, he probably needs another two weeks to finish the task instead of the one week that's scheduled. (Of course, that assumes the third estimate of 60 percent is correct, and it may not be.)

Many developers are naturally optimistic and assume they can make up lost time, but they're often wrong. Or they can make up the time but only by working ridiculously long hours. Working extra hours once in a while is okay, but developers who work extra hours too often eventually burn out. (Keeping a sustainable pace is one of the core principles behind agile development, which is discussed in Chapter 14, "RAD.")

At this point, you may want to add the extra week to the task and see what happens to the rest of the project's schedule.

80-PERCENT RIGHT, 50 PERCENT OF THE TIME

The whole schedule depends on time estimates that are uncertain at best. You make estimates for each task and, during development, the developers make estimates about how much work they have finished and how much work they have left to do.

It's hard to make estimates more accurate (that requires experience), but it's easy to make estimates worse. All you need to do is to yell at the developers, draw lines in the sand, talk about red lines and points of no return, brag about how you *don't* miss deadlines, and generally throw management-speak at the developers. If you make it clear that developers have to stay on track *at all costs*, their estimates will show that they *are* on track… right up to the point at which they miss their deadlines.

A much better approach is to encourage developers to give you estimates that are as truthful and accurate as possible. Over time you'll figure out who can make good estimates and who's always off by 15 percent. That improves your ability to plan and that greatly increases your chances of success.

If the developer can get the task back on schedule, that's great, but you should pay extra attention to that task to see if the latest 60 percent estimate is correct or if the task is really in more trouble than the developer thinks. The biggest mistake you can make is to ignore the problem and hope you can make up the time later. Unless you have a reason to believe you can catch up, you need to assume you'll fall farther behind. Working on a task that continues to slip week after week feels like you're trying to bail out a sinking lifeboat with a colander.

Possibly the second biggest mistake you can make is to pile extra developers on the task and assume they can reduce the time needed to finish it. As Fred Brooks said in his famous book *The Mythical Man-Month*, "adding manpower to a late software project makes it later." Adding someone with appropriate expertise to a task can sometimes help, but it takes time for new people to get up to speed on any task, so you shouldn't just throw more bodies at a task and hope that'll help. This feels like someone's thrown more people into your sinking lifeboat. You may like the company, but unless they have a working pump, their weight will just make you sink faster.

Risk Management

The preceding section talks about task-tracking and how you can react if a task starts to slip. Often you need to add extra time to the schedule and keep a close watch on that task. Sometimes, you can

add extra people to the task; although, bringing them up to speed may actually slow the task down if they don't bring particularly useful expertise to the job.

Risk management is more proactive. Instead of responding to problems after they occur, risk management identifies possible risks, determines their potential impacts, and studies possible work-arounds ahead of time.

For each task, you should determine:

- **Likelihood**—Do you know more or less how to perform this task? Or is this something you've never done before so it might hold unknown problems?
- **Severity**—Can the users live without this feature if the task proves difficult? Can you cancel this feature or push it into a future release?
- **Consequences**—Will problems with this task affect other tasks? If this task fails, will that cause other tasks to fail or make other tasks unnecessary?
- **Work-arounds**—Are there work-arounds? What other approaches could you take to solve this problem? For each work-around consider:
  - **Difficulty**—How hard will it be to implement this work-around? How long will it take? What are the chances that this work-around will work?
  - **Impact**—What affects do the work-arounds have on the project's usability? Is this going to make a lot of extra work for the users?
  - **Pros**—What are the work-arounds' advantages?
  - **Cons**—What are the work-arounds' disadvantages?

You can use your analysis to study how different kinds of problems will affect the schedule. For example, suppose a task is harder than you originally planned. You've used 5 of the 10 days allocated to the task but you haven't really made any progress. If that task's risk analysis includes a sure-fire work-around that provides an acceptable alternative and you're quite sure would take eight days to implement, you might want to switch to the work-around and take the 3-day schedule slip rather than following the original approach with its unknown duration.

EXAMPLE Example Risky Reorders

In this example, let's perform risk analysis on a reordering feature for the bee fence design application.

Suppose you want the bee fence application to automatically place orders for staples, envelopes, fence posts, and other supplies whenever inventory runs low. Unfortunately, you've never written code to do that before. This is a possible point of risk because you don't know how to do it, and it may be much harder to do than you think it is.

In this case, you might use the following notes to describe this task's risk:

- **Task**—Reorder inventory. (Reorder when inventory is low.)
- **Likelihood**—Medium. (We don't really know whether this will be a problem, but the likelihood is definitely not low.)

- **Severity**—High. (We need some way to reorder supplies or we'll be out of business!)
- **Consequences**—None. (Except, obviously, for the company going bankrupt and all the employees ending up on the street begging for spare change. By "None" I mean there are no other tasks that depend on this one working as originally planned.)
- **Work-around 1**—Send an e-mail to an administrator who then places the order manually.
  - **Difficulty**—Easy. I've done this before and it's not too hard. Estimated time: 3 days.
  - **Impact**—This change would make about 1 hour more of work for the administrator per month.
  - **Pros**—Simple. Keeps a person in the loop. (A programming bug can't make the administrator accidentally order 1 million fence posts or 12,000 miles of wire.)
  - **Cons**—Not automatic. The administrator needs to follow through. Will need some sort of backup when the administrator is out of the office.
- **Work-around 2**—Send a text message to an administrator who then places the order manually.
  - **Difficulty**—Easy. (Similar to Work-around 1).
  - **Impact**—Similar to Work-around 1.
  - **Pros**—Similar to Work-around 1. The administrator receives notification even if not at work. Could be added in addition to Work-around 1 for little extra work.
  - **Cons**—The administrator might forget to place the order, particularly if he receives the message while away from work.

After you've performed the risk analysis on the reorder inventory task, you can use it in your project planning. For example, you could allow 5 days to do this task. If you haven't made good progress in the first 2 days, you can drop back to Work-around 1 and push automatic reordering to the second release.

SUMMARY

As much as some programmers might like to deny it, management is an important part of software engineering. Executive management is essential for the project to succeed. Project management is critical for scheduling and tracking tasks to make sure the project moves toward completion instead of into a morass of side issues and never-ending tasks.

PERT charts, critical path methods, and Gantt charts can help a project manager keep things on track, but they won't do any good unless you have reasonable time estimates. Techniques such as using experienced team members, breaking large tasks into smaller pieces, and allowing for unexpected lost time can make time estimates more accurate.

Even if you use every conceivable time estimation trick, unexpected surprises can throw a monkey wrench into the works. Risk management lets you handle those sorts of unpredictable disasters

quickly and efficiently. If a task looks like it will be impossible or greatly delayed, you can switch to a work-around to stay on track and still produce something usable.

This chapter and the two previous ones provide background that you need before you move on to actually starting a new software project. The next chapter describes the first step in building a new application: requirements gathering.

EXERCISES

Okay, I admit the zombie apocalypse bunker project isn't software-related…*unless* you decide to write a 3-D computer game based on that concept! Sort of *World of Warcraft* meets *World War Z*. You could call it *World of Z-Craft*.

Table 3-2 summarizes some of the classes and modules you might need (and their unreasonably optimistic expected times) to develop players and zombies for the game. (The program would also need lots of other pieces not listed here to handle other parts of the game.)

TABLE 3-2: Classes and Modules for World of Z-Craft

TASK	TIME (DAYS)	PREDECESSORS
A. Robotic control module	5	—
B. Texture library	5	C
C. Texture editor	4	—
D. Character editor	6	A, G, I
E. Character animator	7	D
F. Artificial intelligence (for zombies)	7	—
G. Rendering engine	6	—
H. Humanoid base classes	3	—
I. Character classes	3	H
J. Zombie classes	3	H
K. Test environment	5	L
L. Test environment editor	6	C, G
M. Character library	9	B, E, I
N. Zombie library	15	B, J, O
O. Zombie editor	5	A, G, J
P. Zombie animator	6	O
Q. Character testing	4	K, M
R. Zombie testing	4	K, N

1. Draw a PERT chart for these tasks. Include the tasks' letters, predecessors, and expected times.

2. Use critical path methods to find the total expected time from the project's start for each task's completion. Find the critical path. What are the tasks on the critical path? What is the total expected duration of the project in working days?

3. How long is the second-shortest path in the PERT network you built for Exercise 2? What tasks lie along a second-longest path? By how much could the tasks on the path slip before impacting the project's total time?

4. Build a Gantt chart for the network you drew in Exercise 3. Start on Wednesday, January 1, 2020, and don't work on weekends or the following holidays:

HOLIDAY	DATE
New Year's Day	January 1
Martin Luther King Day	January 20
President's Day	February 17

   (These are U.S. holidays. If you live somewhere else, feel free to use your own holidays.)

   On what date do you expect the project to be finished?

5. Download a trial version of the project management tool of your choice and use it to enter the zombie apocalypse tasks. Does it agree with the end date you found in Exercise 4? (The Internet is crawling with useful project management tools, so you have lots of choices. The solution shown in Appendix A, "Solutions to Exercises," uses OpenProj. It's simple and you can download it for free at `OpenProj.org`.) What are the advantages and disadvantages of using the tool you selected over building a Gantt chart manually?

6. In addition to losing time from vacation and sick leave, projects can suffer from problems that just strike out of nowhere. Sort of a bad version of *deus ex machina*. For example, senior management could decide to switch your target platform from Windows desktop PCs to the latest smartwatch technology. Or a strike in the Far East could delay the shipment of your new servers. Or one of your developers might move to Iceland. How can you handle these sorts of completely unpredictable problems?

7. What techniques can you use to make accurate time estimates?

8. What are the two biggest mistakes you can make while tracking tasks?

WHAT YOU LEARNED IN THIS CHAPTER

- Executive support is critical for project success.
- A project manager schedules and tracks tasks, and keeps developers moving forward.
- PERT charts show precedence relationships among tasks.
- While building a PERT chart, if you can't find a task with no unsatisfied predecessors, the tasks contain a precedence loop and no schedule is possible.
- Critical path methods show the longest paths through a PERT network. If a task on one of those paths is delayed, the project's final completion is delayed.
- Gantt charts show task durations, start time, and end times.
- You can improve time estimates by using experience, breaking complex tasks into smaller tasks, and looking for similarities to previous tasks.
- You should plan for delays such as illness, vacation, and unexpected problems.
- Risk management lets you plan for problems so that you can react quickly when they occur.

4

Requirement Gathering

If you don't know where you are going, you'll end up someplace else.

—Yogi Berra

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Why requirements are important
- The characteristics of good requirements
- The MOSCOW method for prioritizing requirements
- Audience-oriented, FURPS, and FURPS+ methods for categorizing requirements
- Methods for gathering customer goals and turning them into requirements
- Brainstorming techniques
- Methods for recording requirements such as formal specifications, user stories, and prototypes

It's tempting to say that requirement gathering is the most important part of a software project. After all, if you get the requirements wrong, the resulting application won't solve the users' problems. You'll be like a tourist in Boston with a broken GPS. You may get somewhere interesting, but you probably won't get where you want to go.

Even though requirements are important for setting a project's direction, a project can fail at any other stage, too. If you build a flawed design, write bad code, fail to test properly, or even provide incorrect training materials, the project can still fail. If any one of the links in the development chain fails, the project will fail.

Let's just say that requirement gathering is the first link in the chain, so it's the first place where you can screw things up badly. Requirements *do* set the stage for everything that follows, so while you can argue over whether this is the most important step, it's definitely *an* important step.

This chapter explains what requirement gathering is and lists some typical requirements that are useful in many projects. It also describes some techniques you can use to gather requirements effectively.

REQUIREMENTS DEFINED

Requirements are the features that your application must provide. At the beginning of the project, you gather requirements from the customers to figure out what you need to build. Throughout development, you use the requirements to guide development and ensure that you're heading in the right direction. At the end of the project, you use the requirements to verify that the finished application actually does what it's supposed to do.

Depending on the project's scope and complexity, you might need only a few requirements, or you might need hundreds of pages of requirements. The number and type of requirements can also depend on the level of formality the customers want.

For example, if you're working on a casual in-house project, your boss may be satisfied with a few blanket requirements such as "find ways to improve order processing" or "write a tool to send spam to customers." As long as you create something vaguely useful, your project will probably be viewed as a success. (If not, you'll find out at your annual review.) As you'll see shortly, these sorts of vague requirements have some problems.

Large projects with higher stakes typically have far more requirements that are spelled out much more formally and in great detail. For example, if you're building an autopilot system for 747s or you're writing software to control pacemakers, your requirements must be unambiguous. You can't wait until the final weeks of testing to start thinking about whether "easy installation" means patients should change their own pacemaker parameters from a cell phone.

The following sections describe some of the properties that requirements should have to be useful.

Clear

Good requirements are clear, concise, and easy to understand. That means they can't be pumped full of management-speak, florid prose, and confusing jargon.

It is okay to use technical terms and abbreviations if they are defined somewhere or they are common knowledge in the project's domain. For example, when I worked at a phone company research lab, we often used terms like POTS (plain old telephone service), PBX (public branch exchange), NPA (numbering plan area, known to nontelephone people as an area code), and ISDN (integrated services digital network, or as some of us used to call it, "I still don't know"). The customers and development team members all knew those terms, so they were safe to use in the requirements.

To be clear, requirements cannot be vague or ill-defined. Each requirement must state in concrete, no-nonsense terms exactly what it requires.

For example, suppose you're working on a program to schedule appointments for utility repair people. (Those appointments that typically say, "We'll be there sometime between 6:00 a.m. and midnight during the next 2 weeks.") A requirement such as, "Improve appointment scheduling," is too vague to be useful. Does this mean you should tighten the appointment windows even if it means missing more appointments? Does it mean repair people should leave and make a new appointment if they can't finish a job within 1 hour? Or does it mean something crazy like letting customers tell you what times they can actually be home and then fitting appointments to those times?

A better requirement would be, "Reduce appointment start windows to no more than 2 hours while meeting 90 percent of the scheduled appointments."

Unambiguous

In addition to being clear and concrete, a requirement must be unambiguous. If the requirement is worded so that you can't tell what it requires, then you can't build a system to satisfy it. Although this may seem like an obvious feature of any good requirement, it's sometimes harder to guarantee than you might think.

For example, suppose you're building a street map application for inline skaters, and you have a requirement that says the program will, "Find the best route from a start location to a destination location." This can't be all that hard. After all, Google Maps, Yahoo Maps, MapQuest, Bing Maps, and other sites all do something like this.

But how do you define the "best" route? The shortest route? The route that uses only physically separated bike paths so that the user doesn't have to skate in the street? Or maybe the route that passes the most Starbucks locations?

Even if you decide the "best" route means the shortest one, what does that mean? The route that's the shortest in distance? Or the shortest in time? What if the route of least distance goes up a steep hill or down a set of stairs and that increases its time? (In this example, you might change the requirements to let the users decide how to pick the "best" route at run time.)

As you write requirements, do your best to make them unambiguous. Read them carefully to make sure you can't think of any way to interpret them other than the way you intend.

Then run them past some other people (particularly customers and end user representatives) to see if they agree with you.

A TIMELY JOKE

CUSTOMER: I need you to write a program to find customers that haven't paid their bills within 5 seconds.

DEVELOPER: Harsh! Most companies give their customers 30 days to pay their bills.

Consistent

A project's requirements must be consistent with each other. That means not only that they cannot contradict each other, but that they also don't provide so many constraints that the problem is unsolvable. Each requirement must also be self-consistent. (In other words, it must be possible to achieve.)

Consider again the earlier example of utility repair appointments. You might like to include the following two requirements:

- Reduce appointment start windows to no more than 2 hours.
- Meet 90 percent of the scheduled appointments.

It may be that you cannot satisfy these two requirements at the same time. (At least using only software. You might do it if you hire more repair people.)

In a complex project, it's not always obvious if a set of requirements is mutually consistent. Sometimes, any pair of requirements is satisfiable but larger combinations of requirements are not.

A common software engineering expression is, "Fast, good, cheap. Pick two." The idea is you can trade development speed, development quality, and cost, but you can't win in all three dimensions. Only three possible combinations work:

- Build something quickly with high quality and high cost.
- Build something quickly and inexpensively but with low quality.
- Build with high quality and low cost but over a long time.

Try to keep new requirements consistent with existing requirements. Or rewrite older requirements as necessary. When you finish gathering all the requirements, go through them again and look for inconsistencies.

Prioritized

When you start working on the project's schedule, it's likely you'll need to cut a few nice-to-haves from the design. You might like to include every feature but don't have the time or budget, so something's got to go.

At this point, you need to prioritize the requirements. If you've assigned costs (usually in terms of time to implement) and priorities to the requirements, then you can defer the high-cost, low-priority requirements until a later release.

Customers sometimes have trouble deciding which requirements they can live without. They'll argue, complain, and generally act like you're asking which of their children they want to feed to the dingoes. Unfortunately, unless they can come up with a big enough budget and timescale, they're going to need to make some sort of decision.

The exception occurs when you work on life-critical applications such as nuclear reactor cooling, air traffic control, and space shuttle flight software. In those types of applications, the customer may have a lot of "must have" requirements that you can't remove without compromising the applications' safety. You may remove cosmetic requirements like a space shuttle's automatic

turn-signal cancellation feature, but you're probably going to need to keep the fuel monitor and flight path calculator.

THE MOSCOW METHOD

MOSCOW is an acronym to help you remember a common system for prioritizing application features. The consonants in MOSCOW stand for the following:

M—Must. These are *required* features that must be included. They are necessary for the project to be considered a success.

S—Should. These are *important* features that should be included if possible. If there's a work-around and there's no room in the release 1 schedule, these may be deferred until release 2.

C—Could. These are *desirable* features that can be omitted if they won't fit in the schedule. They can be pushed back into release 2, but they're not as important as the "should" features, so they may not make it into release 2, either.

W—Won't. These are *completely optional* features that the customers have agreed will not be included in the current release. They may be included in a future release if time permits. (Or they may just be included in the requirements list to make a particularly loud and politically connected customer happy, and you have no intention of ever including these features.)

Let's face it. If a feature isn't a "must" or "should," then its chances of ever being implemented are slim. After this release has been used for a while, you'll probably receive tons of bug reports, requests for changes, and pleas for new features, so in the next release you still won't have time for the "could" and "won't" features.

(Unless you're one of these big software companies, who shall remain nameless, that thinks it needs to push a new version of its products out every 2 years to make customers buy something. Sometimes those products reach deep into the "could" and "won't" categories, and perhaps even the "why?" and "you must be joking!" categories.)

EXAMPLE ClassyDraw

For an example of using the MOSCOW method, consider a fictional drawing program named ClassyDraw. It's somewhat similar to MS Paint and allows you to draw line segments, ellipses, polygons, text, and other shapes. The big difference is that ClassyDraw represents each shape you draw as an object that you can later select, move, resize, modify, and delete.

Here's an initial requirement list:

1. Draw: line segments, sequences of line segments, splines, polygons, ellipses, circles, rectangles, rounded rectangles, stars, images, and other shapes.
2. Save and load files.

3. Protect the current drawing. For example, if the user tries to close the program while there are unsaved changes, prompt the user.
4. Let the user specify the line style and colors used to draw shapes.
5. Let the user specify the fill style and colors used to draw shapes.
6. Click to select an object.
7. Click and drag to select multiple objects.
8. Click or click and drag with the Shift key down to add objects to the current selection.
9. Click or click and drag with the Ctrl key down to toggle objects in and out of the current selection.
10. Click and drag the selected objects to move them.
11. Edit the selected objects' line and fill styles.
12. Delete the selected objects.
13. Select colors from a palette.
14. Place custom colors in a custom palette.
15. Support transparency.
16. Copy and paste the entire drawing, a rectangular selection, or an irregular selection as a bitmapped image.
17. Copy, cut, and paste the currently selected objects.
18. Allow the user to write scripts to add shapes to a drawing.
19. Let the user rearrange the palettes and toolbars.
20. Auto-save the current drawing periodically. If the program crashes, allow the user to reload the most recently saved version.
21. Auto-save the current drawing every time a change is made. If the program crashes, allow the user to reload the most recently saved version.
22. Provide online help.
23. Provide online tutorials.

Now you can use the MOSCOW method to prioritize these requirements.

Must. To identify the "must" requirements, examine each requirement and ask yourself: Could that requirement be omitted? Would the program be usable without that feature? Will users give the product 1-star reviews and say they wish they could give 0 stars? That the product would be overpriced if it were freeware?

The ClassyDraw application *must* be able to save and load files (2). You could build early test versions that couldn't, but it would be unacceptable to users.

Similarly the program must ensure the safety of the current drawing (3). The users would never forgive the program if it discarded a complicated drawing without any warning.

The program wouldn't be useful if it didn't draw, so the program must draw at least a few shapes (1). For starters, it could draw line segments, rectangles, and ellipses. You could add more shapes in later releases.

The program should probably allow the user to click objects to select them. Otherwise, the user may as well use MS Paint, so requirement 6 is a must. Of course, there's little point in selecting an object if you can't do anything with it, so the program must let the user at least move (10) and delete (12) the selected objects.

The "must" requirements include 1 (partial), 2, 3, 6, 10, and 12.

Should. To identify the "should" requirements, examine each of the remaining requirements and ask yourself, "Does that feature significantly enhance the product? If it were omitted, would users be constantly asking why it wasn't included? Is the feature common in other, similar applications? Will users give the product 2-star and 3-star reviews?"

Several requirements that are fairly standard for drawing applications didn't make the cut for the "must" category. (You could say they didn't pass muster.)

Most (if not all) of the other shapes in requirement 1 should be included in this group. When drawing new shapes, the user should also indicate the line and fill styles the new shapes should have (4, 5). That will require specifying colors, at least from a palette (13).

The click-and-drag selection technique (7) should be included, as should the ability to hold down the Shift or Ctrl key while making selections (8, 9).

Any decent application should have help (22) and documentation (23), so those should also be included.

The "should" requirements include 1 (remaining), 4, 5, 7, 8, 9, 13, 22, and 23.

Could. To identify the "could" requirements, examine each of the remaining requirements and ask yourself, "Would that requirement be useful to the users? Is it something special that other similar applications don't have? Will this help bump reviews up to 4 or 5 stars? Is this a feature that we should include at some point, just not in the first release?"

Another way to approach this category is to ask: Which features will we need in the long term? Which of the remaining features shouldn't be dumped in the trash heap labeled "won't"?

Most of the remaining requirements should probably not go in the "won't" pile. If they were that bad , they probably wouldn't have made it into the requirements list in the first place.

The "could" category should definitely include the ability to edit selected objects (11). This is another of the main reasons for allowing the user to select objects.

Support for custom colors (14) and transparency (15) would also be nice, if time permits. Cut, copy, and paste for images (16) and selected objects (17) would be useful, so they should be included.

The "could" requirements include 11, 14, 15, 16, and 17.

Won't. To identify the "won't" requirements, examine the remaining requirements and ask yourself, "Is this unnecessary, confusing, or just plain stupid? Will it be used only rarely? Does it add nothing useful to the application?" If you can't answer "yes" to those questions for a particular requirement, then you should think about moving that requirement into one of the other categories.

For this application, allowing users to write scripts (18) would be cool but probably rarely used. Letting the user rearrange palettes and toolbars (19) would be a nice touch, but isn't important.

Auto-saving (20, 21) is also a nice touch, but probably unnecessary. We can look at user requests and conduct surveys to see if this feature would be worth adding to a future release.

The "won't" requirements include 18, 19, 20, and 21.

After you've assigned each requirement to a category, go back through them and make sure you're happy with their assignments. If a requirement in the "could" category seems more important than one in the "should" category, switch them.

Also make sure every requirement is in some category and that every category contains some requirement. If every requirement is in the "must" category, then you may need to rethink your priorities (or your customer's priorities), or be sure you'll have enough time to get everything done.

Verifiable

Requirements must be verifiable. If you can't verify a requirement, how do you know whether you've met it?

Being verifiable means the requirements must be limited and precisely defined. They can't be open-ended statements such as, "Process more work orders per hour than are currently being processed." How many work orders is "more?" Technically, processing one more work order per hour is "more," but that probably won't satisfy your customer. What about 100? Or 1,000?

A better requirement would say, "Process at least 100 work orders per hour." It should be relatively easy to determine whether your program meets this requirement.

Even with this improved requirement, verification might be tricky because it relies on some assumptions that it doesn't define. For example, the requirement probably assumes you're processing work orders in the middle of a typical workday, not during a big clearance event, during peak ordering hours, or during a power outage.

An even better requirement might be, "Process at least 100 work orders per hour on average during a typical work day." You may want to refine the requirement a bit to try to say what a "typical work day" is, but this version should be good enough for most reasonable customers.

Words to Avoid

Some words are ambiguous or subjective, and adding them to a requirement can make the whole thing fuzzy and imprecise. The following list gives examples of words that may make requirements less exact.

- **Comparatives**—Words like faster, better, more, and shinier. How much faster? Define "better." How much more? These need to be quantified.
- **Imprecise adjectives**—Words like fast, robust, user-friendly, efficient, flexible, and glorious. These are just other forms of the comparatives. They look great in management reports, business cases, and marketing material, but they're too imprecise to use in requirements.

- **Vague commands**—Words like minimize, maximize, improve, and optimize. Unless you use these in a technical algorithmic sense (for example, if you optimize flow through a network), these are just fancy ways to say, "Do your best." Even in an algorithmic sense, these sorts of words are often applied to hard problems where exact solutions may not exist. In any case, you need to make the goals more concrete. Provide some numbers or other criteria you can use to determine whether a requirement has been met.

REQUIREMENT CATEGORIES

In general, requirements tell what an application is supposed to do. Good requirements share certain characteristics (they're clear, unambiguous, consistent, prioritized, and verifiable), but there are several kinds of requirements that are aimed at different audiences or that focus on different aspects of the application. For example, business requirements focus on a project's high-level objectives and functional requirements give the developers more detailed lists of goals to accomplish.

Assigning categories to your requirements isn't the point here. (Although there are two kinds of people in the world: those who like to group things into categories and those who don't. If you're one of the former, then you may need to do this for your own peace of mind.) The real point here is that you can use the categories as a checklist to make sure you've created requirements for the most important parts of the project. For example, if you look through the requirements and the reliability category is empty, you might consider adding some new requirements.

You can categorize requirements in several ways. The following sections describe four ways to categorize requirements.

Audience-Oriented Requirements

These categories focus on different audiences and the different points of view that each audience has. They use a somewhat business-oriented perspective to classify requirements according to the people who care the most about them.

For example, the corporate vice president of Plausible Deniability probably doesn't care too much about which button a call center clerk needs to press to launch a customer into a never-ending call tree as long as it works. In contrast, the clerk needs to know which button to press.

The following sections describe some of the more common business-oriented categories.

Business Requirements

Business requirements lay out the project's high-level goals. They explain what the customer hopes to achieve with the project.

Notice the word "hopes." Customers sometimes try to include all their hopes and dreams in the business requirements in addition to verifiable objectives. For example, they might say the project will "Increase profits by 25 percent" or "Increase demand and gain 10,000 new customers." Although those goals have numbers in them, they're probably outside the scope of what you can achieve through software engineering alone. They're more like marketing targets than project requirements. You can craft the best application ever put together, but someone still needs to use it properly to realize the new profits and customers.

Sometimes, those vague goals are unavoidable in business requirements, but if possible you should try to push them into the business case. The business case is a more marketing-style document that attempts to justify the project. Those often include graphs and charts showing projected costs, demand, sales figures, and other values that aren't known exactly in advance.

To think of this another way, I have no qualms about promising to write a system that can pull up a customer's records in less than 3 seconds or find the closest donut shop that's open at 2 a.m. (if you give me the data). But I wouldn't want to promise to improve morale in the Customer Complaints department by 15 percent. (What would that even mean?)

User Requirements

User requirements (which are also called *stakeholder requirements* by managers who like to use the word "stakeholder"), describe how the project will be used by the eventual end users. They often include things like sketches of forms, scripts that show the steps users will perform to accomplish specific tasks, use cases, and prototypes. (The sections "Use Cases" and "Prototypes" later in this chapter say more about the last two.)

Sometimes these requirements are very detailed, spelling out exactly what an application must do under different circumstances. Other times they specify *what* the user needs to accomplish but not necessarily *how* the application must accomplish it.

EXAMPLE Overly Specific Selections

In this example, you see how you can turn an overly specific requirement into one that's flexible without making it vague.

Suppose you're building a phone application that lets customers place orders at a sandwich and bagel shop called The Loxsmith. The program should let customers select the toppings they want on their bagels. They include lox (naturally), butter, cream cheese, gummy bears, and so on. Here's one way you could word this requirement:

> *The toppings form will display a list of toppings. The user can check boxes next to the toppings to add them to the bagel.*

That's a fine requirement. Clear, concise, verifiable. Everything you could want in a requirement. Unfortunately, it's also unnecessarily specific. It forces the designers and developers to use a specific technique to achieve the higher-level goal of letting the customer select toppings.

During testing, you might discover that The Loxsmith provides more than 200 toppings. In that case, the program won't be able to display a list of every topping at the same time. The user will need to scroll through the list, and that will make it hard for the customer to see what toppings are selected.

Here's a different version of the same requirement that doesn't restrict the developers as much.

> *The toppings form will allow the user to select the toppings put on the bagel.*

The difference is small but important. With this version, the developers can explore different methods for selecting toppings. If you have user-interface specialists on your team, they may create a variety of

possible solutions. For example, customers might drag and drop selections from a big scrollable list on the left onto a shorter list of selected items on the right. Then they could always see what toppings were selected. You might even display a cartoon picture of a bagel holding the user's four dozen selected toppings piled up like the Leaning Tower of Pisa.

Vague requirements are bad, but flexible requirements let you explore different options before you start writing code. To keep requirements as flexible as possible, try to make the requirements spell out the project's *needs* without mandating a particular approach.

Functional Requirements

Functional requirements are detailed statements of the project's desired capabilities. They're similar to the user requirements but they may also include things that the users won't see directly. For example, they might describe reports that the application produces, interfaces to other applications, and workflows that route orders from one user to another during processing.

These are things the application should do.

Note that some requirements could fall into multiple categories. For example, you could consider most user requirements to be functional requirements. They not only describe a task that will be performed by the user, but they also describe something that the application will do.

Nonfunctional Requirements

Nonfunctional requirements are statements about the quality of the application's behavior or constraints on how it produces a desired result. They specify things such as the application's performance, reliability, and security characteristics.

For example, a functional requirement would be, "Allow users to reserve a hovercraft online." A nonfunctional requirement would be, "The application must support 20 users simultaneously making reservations at any hour of the day."

Implementation Requirements

Implementation requirements are temporary features that are needed to transition to using the new system but that will be later discarded. For example, suppose you're designing an invoice-tracking system to replace an existing system. After you finish testing the system and are ready to use it full time, you need a method to copy any pending invoices from the old database into the new one. That method is an implementation requirement.

The tasks described in implementation requirements don't always involve programming. For example, you could hire a bunch of teenagers on summer break to retype the old invoices into the new system. (Although you'll probably get a quicker and more consistent result if you write a program to convert the data into the new format. The program won't get bored and stop coming to work when the next release of *Grand Theft Auto* comes out.)

Other implementation requirements include hiring new staff, buying new hardware, preparing training materials, and actually training the users to use the new system.

FURPS

FURPS is an acronym for this system's requirement categories: functionality, usability, reliability, performance, and scalability. It was developed by Hewlett-Packard (and later extended by adding a + at the end to get FURPS+).

The following list summarizes the FURPS categories:

- **Functionality**—What the application should do. These requirements describe the system's general features including what it does, interfaces with other systems, security, and so forth.
- **Usability**—What the program should look like. These requirements describe user-oriented features such as the application's general appearance, ease of use, navigation methods, and responsiveness.
- **Reliability**—How reliable the system should be. These requirements indicate such things as when the system should be available (12 hours per day from 7:00 a.m to 8:00 p.m.), how often it can fail (3 times per year for no more than 1 hour each time), and how accurate the system is (80 percent of the service calls must start within their predicted delivery windows).
- **Performance**—How efficient the system should be. These requirements describe such things as the application's speed, memory usage, disk usage, and database capacity.
- **Supportability**—How easy it is to support the application. These requirements include such things as how easy it will be to maintain the application, how easy it is to test the code, and how flexible the application is. (For example, the application might let users set parameters to determine how it behaves.)

FURPS+

FURPS was extended into FURPS+ to add a few requirements categories that software engineers thought were missing. The following list summarizes the new categories:

- **Design constraints**—These are constraints on the design that are driven by other factors such as the hardware platform, software platform, network characteristics, or database. For example, suppose you're building a financial application and you want an extremely reliable backup system. In that case, you might require the project to use a shadowed or mirrored database that stores every transaction off-site in case the main database crashes.
- **Implementation requirements**—These are constraints on the way the software is built. For example, you might require developers to meet the Capability Maturity Model Integration (CMMI) or ISO 9000 standards. (For more information on those, see `www.cmmifaq.info` and `www.iso.org/iso/iso_9000` respectively.)
- **Interface requirements**—These are constraints on the system's interfaces with other systems. They tell what other systems will exchange data with the one you're building. They describe things like the kinds of interactions that will take place, when they will occur, and the format of the data that will be exchanged.
- **Physical requirements**—These are constraints on the hardware and physical devices that the system will use. For example, they might require a minimum amount of processing power, a maximum amount of electrical power, easy portability (such as a tablet or smartphone), touch screens, or environmental features (must work in boiling acid).

EXAMPLE FURPS+ Checklist

In this example, we'll use FURPS+ to see if any requirements are missing for the The Loxsmith ordering application. Consider the following abbreviated list of requirements. The program should allow the user to:

> Start an order that might include multiple items.
>
> Select bagel type.
>
> Select toppings.
>
> Select sandwich bread.
>
> Select sandwich toppings.
>
> Select drinks.
>
> Select pickup time.
>
> Pay or decide to pay at pickup.

I've left out a lot of details from this list such as the specific bagel, bread, and topping types that are available, but at first glance, this seems like a reasonable set of requirements. It describes what the application should do but doesn't impose unnecessary constraints on how the developers should build it. It's a bit more vague than I would like (how do you *verify* that the user can select toppings?), but you can flesh that out. (In fact, I'll talk a bit about ways you can do that later in this chapter, particularly when I talk about use cases in the section "Use Cases.")

For this example, assume the requirements are spelled out in specific (but flexible) detail. Then use FURPS+ to see if there's anything important missing from this list. Spend a few minutes to decide in which FURPS+ category each of the requirements belongs.

Although the initial requirements all seem reasonable, they're all functionality requirements. They tell what the application should do but don't give much information about usability, reliability, performance, and other requirements that should belong to the other FURPS+ categories.

You might think that a requirements list containing only functionality requirements would be an unusual situation. However, left to their own devices, many programmers come up with exactly this sort of list. They focus on the work they are going to do and how it will look to the users. That's a good place to start the design, but in the background they're making a huge number of assumptions about things they take for granted.

For example, suppose you're a developer who writes Java applications running on Android tablets. In that case, you may think the previous list of requirements is just fine. Your version of the Eclipse Java development environment is up to date, you've installed the Android Software Development Kit (SDK), and you have "Eye of the Tiger" blasting on your headphones. You're ready to start cranking out code.

Unfortunately you're also making a ton of assumptions that may or may not sit well with the customer. In this example, you're assuming the application will be written in Java to run on Android tablets. What if the customer wants the application to run on an iPhone, Windows Phone, mobile-oriented web page, Google Glass, or some sort of smart wearable ankle bangle device? Or maybe all of the above?

Sometimes, you may not want any requirements in a particular category, but the fact that the preceding list contains *only* functionality requirements is a strong hint that we're doing something wrong. You

should at least think about every category and either (1) come up with some new requirements that belong there, or (2) write down why you don't think you need any requirements for that category.

So now look at the FURPS+ requirement categories:

Functionality—(What the program should do.) The initial list of requirements covers this category.

Usability—(What the program should look like.) You could add some requirements indicating how the user navigates from starting an order to picking sandwich and bagel ingredients. You could also provide details about login (should we create customer accounts?) and the checkout method. You should also specify that each form will display The Loxsmith logo.

Reliability—(How reliable the system should be.) Should the application be available only while The Loxsmith is open? Or should customers be able to pre-order a morning jalapeno popper bagel and double kopi luwak to pick up on the way in to work?

Performance—(How efficient the system should be.) How quickly should the application respond to customers (assuming they have a fast Internet connection)?

Supportability—(How easy should the system be to support?) The requirements should indicate that The Loxsmith employees can edit the information about the types of breads, bagels, toppings, and other items that are available. You might also want to add automated testing requirements, information about help available to customers, and any plans for future versions of the project.

Design—(Design constraints.) Here's where you would specify the target hardware and software platforms. For example, you might want the program to run on iPhones (code written with Xcode) and Windows Phones (code written in C#).

Implementation—(Constraints on the way the software is built.) You can specify software standards. For example, you might require pair programming or agile methods. (Those are described in Chapter 14, "RAD.")

Interface—(Interfaces with other systems.) Perhaps you want the application to call web services that use Simple Object Access Protocol (SOAP) to let other programs place sandwich orders. (Although it's not clear how many other companies will want an automated ordering interface to The Loxsmith, so perhaps this category will be intentionally left blank.)

Physical—(Hardware requirements.) For this application, the customers provide their own hardware (such as phones and tablets) so you don't need to specify those. You might want to specify the server hardware. Or you might want to lease space on an Internet service provider so that you don't need to buy your own hardware. (You should probably still study the available options so that you know how powerful they are and how much they cost.)

Using requirements categories as a checklist can help you notice if you are missing certain kinds of requirements. In this example, it helped identify a lot of requirements that might have been missed or hidden inside developer assumptions.

Common Requirements

The following list summarizes some specific requirements that arise in many applications.

- **Screens**—What screens are needed?
- **Menus**—What menus will the screens have?

- **Navigation**—How will the users navigate through different parts of the system? Will they click buttons, use menus, or click forward and backward arrows? Or some combination of those methods?
- **Work flow**—How does data (work orders, purchase requests, invoices, and other data) move through the system?
- **Login**—How is login information stored and validated? What are the password formats (such as, must require at least one letter and number) and rules (as in, passwords must be changed monthly)?
- **User types**—Are there different kinds of users such as order entry clerk, shipping clerk, supervisor, and admin? Do they need different privileges?
- **Audit tracking and history**—Does the system need to keep track of who made changes to the data? (For example, so you can see who changed a customer to premier status.)
- **Archiving**—Does the system need to archive older data to free up space in the database? Does it need to copy data into a data warehouse for analysis?
- **Configuration**—Should the application provide configuration screens that let the system administrators change the way the program works? For example, those screens might let system administrators edit product data, set shipping and handling prices, and set algorithm parameters. (If you don't build these sorts of screens, you'll have to make those changes for the customers later.)

GATHERING REQUIREMENTS

At this point you know what makes a good requirement (clear, unambiguous, consistent, prioritized, and verifiable). You also know how to categorize requirements using audience-oriented, FURPS, or FURPS+ methods. But how do you actually pry the requirements out of the customers?

The following sections describe several techniques you can use to gather and refine requirements.

Listen to Customers (and Users)

Sometimes, customers come equipped with fully developed requirements spelling out exactly what the application should do, how it should work, and what it should look like. More often they just have a problem that they want solved and a vague notion that a computer might somehow help.

Start by listening to the customers. Learn as much as you can about the problem they are trying to address and any ideas they may have about how the application might solve that problem. Initially, focus as much as possible on the problem, not on the customers' suggested solutions, so you can keep the requirements flexible.

If the customers insist on a particular feature that you think is unimportant, or if they request something that just seems strange, ask them why they want it. Sometimes, the requirement may be a random thought that isn't actually important, but sometimes the customers have a good reason that you just don't understand. Often the reason is so obvious to them that it doesn't occur to them to explain it until you ask. The customers probably know a lot more about their business than you do, and they may make assumptions about facts that are common knowledge to them but mysterious to you.

AN OFFER YOU CAN'T REFUSE

Suppose The Don's Waste Removal Service asks you to write an application that lets users plot out routes for garbage trucks. You're working through the list of requirements with the owner, Don, and he says, "A route that contains lots of left turns should be given no respect."

To most people, that may seem like a strange requirement. What has Don got against left turns?

Don's been working with garbage trucks for a long time so, like many people who do a lot of vehicle routing, he knows that trucks turning left spend more time waiting for cross traffic, so they burn more fuel. They are also more likely to be involved in accidents. (It always amazes me that people can fail to notice a 20-ton garbage truck stopped in front of them, but it happened in my neighborhood not long ago.) Penalizing routes that contain left turns (and U-turns) will save the company money.

Take lots of notes while you're listening to the customers. They sometimes mention these important but puzzling tidbits in passing. If a customer requirement seems odd, dig a bit deeper to find out what, if anything, is behind the request.

Use the Five Ws (and One H)

Sometimes customers have trouble articulating their needs. You can help by using the five Ws (who, what, when, where, and why) and one H (how).

Who

Ask who will be using the software and get to know as much as you can about those people. Find out if the users and the customers are the same and learn as much about the users as you can.

For example, if you're writing medical billing software, the users might be data entry operators who type in patient data all day. In contrast, your customers may be corporate executives. They may have worked their way up through the ranks (in which case they probably know everything about medical data entry down to the last billing code) or they may have followed a more business-school-oriented career path (in which case they may not know a W59.22 from a V95.43). (It's worth the time to look these up in your favorite browser.)

What

Figure out what the customers need the application to do. Focus on the goals as much as possible rather than the customers' ideas about how the solution should work. Sometimes, the customers have good ideas about what the application should look like, but you should try to keep your options open. Often the project members have a better idea than the customers of the kinds of things an application can do, so they may come up with better solutions if they focus on the goals.

(Of course, the customer is always right, at least until your paycheck is signed, so if the customer absolutely insists that the application must include a graphical slide rule instead of a calculator, chalk it up as an interesting exercise in graphics programming and make it happen.)

When

Find out when the application is needed. If the application will be rolled out in phases, find out which features are needed when.

When you have a good idea about what the project requires, use Gantt charts and the other techniques described in Chapter 3, "Project Management," to figure out how much time is actually needed. Then compare the customers' desired timeline to the required work schedule. If the two don't match, you need to talk to the customers about deferring some features to a later release.

Don't let the customers assume they can get everything on their time schedule just by "motivating you harder." In *Star Trek*, Scotty can squeeze eight weeks' worth of work into just two, but that rarely works in real-world software engineering. You're far more likely to watch helplessly as your best programmers jump ship before your project hits the rocky shoals of impossible deadlines.

Where

Find out where the application will be used. Will it be used on desktop computers in an air-conditioned office? Or will it be used on phones in a noisy subway?

Why

Ask why the customers need the application. Note that you don't need to be unnecessarily stupid. If the customers say, "We want to automate our parts ordering system so that we can build custom scooters more quickly," you don't need to respond with, "Why?" The customers just told you why.

Instead, use the "why" question to help clarify the customers' needs and see if it is real. Sometimes, customers don't have a well-thought-out reason for building a new system. They just think it will help but don't actually know why. (Or customers may have just received a new copy of *Management Buzzwords Monthly* and they're convinced they can crowdsource custom scooter design.)

Find out if there is a real reason to believe a new application will help. Is the problem really that ordering parts is inefficient? Or is the problem that each order requires a different set of parts that have a long shipping time? If streamlining the ordering process will cut the ordering time from 2 days to 1.5 days, while still leaving 4–6 weeks of shipping delay, then a new software application may not be the best place to spend your resources. (It might be better to maintain an inventory of slow-to-order parts such as wheel spinners and spoilers.)

How

The "What" section earlier in this chapter said you should focus on the goals rather than the customers' ideas about the solution. That's true, but you shouldn't completely ignore the customers' ideas. Sometimes, customers have good ideas, particularly if they relate to existing practices. If the users are used to doing something a certain way, you may reduce training time by making the application mimic that approach. Be sure to look outside the box for other solutions, but don't automatically think that software developers always make better decisions than the customers.

Study Users

Interviewing customers (and users) can get you a lot of information, but often customers (and users) won't tell you everything they do or need to do. They often take for granted details that they consider trivial but that may be important to the development team.

For example, suppose the users grind through long, tedious reports every day. The reports are so long, they often end the day in the middle of a report and need to continue working on it the next day. This may seem so obvious to the users that you don't discuss the issue.

A typical reporting application might require the users to log in every day, search for a particular report, and double-click it to open it. That could take a while (particularly if the user forgets which report it is). Fortunately, you know that users often start the day by reopening the last report of the previous day, so you can streamline the process. Instead of making users remember what report they last had open, the program can remember. You can then provide a button or menu item to immediately jump to that report.

By studying users as they work, you can learn more about what they need to do and how they currently do it. Then with your software-engineering perspective, you can look for solutions that might not occur to the users.

PRINTING PUZZLE

Watching users in their natural habitat often pays off. Many years ago, I was visiting a telephone company billing center in preparation for a project that automatically identified customers who hadn't paid their bills and so it could disconnect their service. We spent a week there studying the existing software systems and the users. It was interesting, but the reason I'm mentioning it now is a small comment made by one of the managers. In passing, she said something like, "I sure wish you could do something about the Overdue Accounts Report. Ha, ha."

That's the sort of comment that should make you dig deeper. What was this report and why was it a problem? It turned out that the existing software system printed out a list of every customer with an outstanding balance for every billing cycle. This was a *big* billing center serving approximately 15 million customers, so every two days (there were 15 billing cycles per month) the printer spit out a 3-foot tall pile of paper listing every customer in the cycle with an outstanding balance.

Balances ranged from a few cents to tens of thousands of dollars, and the big-balance customers were costing the company tons of money. Unfortunately, the printout listed the customers in some weird arrangement (sorted by customer ID or zodiac sign or something), so the billing people couldn't find the customers with the big balances.

What the customers didn't know (but we did) is that it's relatively easy to build a printer emulation program. It took approximately one week (mostly spent getting management approval) to write a program that pretended to be a printer, sucked up all the overdue account information, and sorted it by balance. It turned out that of

the thousands of pages of data produced every two days, the customers only needed the first two.

The moral of the story is, you need to pay attention to the customers' comments. They don't know what you can do with the computer, and you don't know their needs.

As you study the users, pay attention to how they do things. Look at the forms they fill out (paper or online). Figure out where they spend most of their time. Look for the tasks that go smoothly and those that don't. You can use that information to identify areas in which your project can help.

REFINING REQUIREMENTS

After you've talked to the customers and users, and watched the users at work, you should have a good understanding about the users' current operations and needs. (If you don't, ask more questions and watch the users some more until you do.)

Next, you need to use what you've learned to develop ideas for solving the user's problems. You need to distill the goals (what the customers need to do) into approaches (how the application will do it).

At a high level, the requirement, "Process customer records" is fine. It's also nice and flexible, so it allows you to explore many options for achieving that goal.

At some point, however, you need to turn the goals into something that you can actually build. You need to figure out how the users will select records to edit, what screens they will use, and how they will navigate between the screens. Those decisions will lead to requirements describing the forms, navigation techniques, and other features that the application must provide to let the users do their jobs.

NOTE *Moving from goals to requirements often forces you to make some design decisions. For example, you may need to specify form layouts (at least roughly) and the way work flows through the system.*

You might think of those as design tasks, but they're really part of requirements gathering. The following two chapters, which talk about design, deal with program design (how you structure the code) not user interface design and the other sorts of design described here.

The following two sections describe three approaches for converting goals into requirements.

Copy Existing Systems

If you're building a system to replace an existing system or a manual process, you can often use many of the behaviors of the existing system as requirements for the new one. If the old system sends customers e-mails on their birthdays, you can require that the new system does that,

too. If the users currently fill out a long paper form, you can require that the new system has a computerized form that looks similar—possibly with some tabs, scrolled windows, and other format changes to make the form look a bit better on a computer.

This approach has a few advantages. First, it's reasonably straightforward. It doesn't take an enormous amount of software engineering experience to dig through an existing application and write down what it does. (If you're lucky, you might even get the customers to do at least some of it so that you can focus on software design issues.)

This approach also makes it more likely that the requirements can actually be satisfied, at least to the extent the current system works. If an existing system does something, then you at least know it's possible.

Finally, this approach provides an unambiguous example of what you need to do. In the specification, you don't need to write out in excruciating detail exactly how the "Lazy Backup" screen works. Instead you can just say, "The Lazy Backup screen will work as it does in the existing system with the following changes: …."

Even though this approach is straightforward, it has some disadvantages. First, you probably wouldn't be building a new version of an existing system unless you planned to make some changes. Those changes aren't part of the original system, so there's no guarantee that they're even possible. They may also be incompatible with the original system. (Not all pieces of software play nicely together.)

A second problem with this approach is that users are often reluctant to give up even the tiniest features in an existing program. In the projects I've worked on, I've found that no matter how obscure and worthless a feature is, there's at least one user willing to fight to the death to preserve it. If the software has been in use for a long time, it may contain all sorts of odd quirks and peccadillos. You might like to streamline the new system by removing the feature that changes the program's background color to match the weather each day, but that's not always possible.

FOREVER FEATURES

I was once asked to help port part of an application to a new platform. The key piece of the application that the customer wanted to keep was fairly small, and the project manager estimated it would take a few hundred hours of work to get the job done.

When I dug through the original application, however, I found that it included more than 100 forms, each of which was moderately complicated. The system also included interfaces to a number of external databases and automated systems.

At this point, we went back to the customer and asked if they were willing to give up most of those 100+ forms and just keep the key tools we were trying to port.

By now you've probably guessed the punchline. The customer wouldn't give up any of the existing application's features. The project's estimated time jumped from a few hundred hours to several thousand hours, and the whole thing was scrapped.

There is some good news in this tale, however. We discovered the problem quickly during initial requirements gathering, so we hadn't wasted too much time before the project was canceled. It would have been much worse if we had started work only to have the requirements gradually expand to include everything in the original application. Then we would have wasted hundreds of hours of work before the project was canceled.

Using an existing system to generate requirements can be a big time-saver, as long as the development team and the customers all agree on which parts of the existing system will be included in the new one.

Clairvoyance

A lot more often than you might think, one or more people simply look at the project's goals, visualize a finished result, and start cranking out requirements. For example, the project lead might use gut feelings, common sense, tea leaves, tarot cards, and other arcane techniques to cobble together something that he thinks will work. If the project is large, pieces might be doled out to team leads so that they can work on their own pieces of the system, but the basic approach is the same: Someone sits down and starts churning out form designs, work flow models, login procedures, and descriptions of reports.

I'm actually being a bit unfair characterizing this approach as clairvoyance because it's actually quite effective in practice. Assuming the people writing the requirements understand the customers' needs and have previous experience, they often produce a good result. Ideally team leads are chosen for their experience and technical expertise (not because they're the boss's cousin), so they know what the computer can do and they can design a system that works.

This technique is particularly effective if the project lead has previously built a similar system. In that case, the lead already knows more or less what the application needs to do, which things will be easy and which will be hard, how much time everything requires, and which kinds of donuts motivate the programmers the best.

Having an experienced project lead greatly increases the chances that the requirements will include everything you need to make the project succeed. It also greatly increases the chances that the team will anticipate problems and handle them easily as development continues. In fact, this is such an important point, it's a best practice.

BEST PRACTICE: EXPERIENCED PROJECT LEADS

A project's chances for success are greatly improved if the project lead has previous experience with the same kind of project.

The same holds true for the other project members. Programmers with previous experience with the same kind of project will encounter fewer problems and meet their scheduled milestones more often.

Documenters who have written user manuals for similar applications will find writing manuals for the new project easier. Project managers with similar experience will know what tasks are likely to be difficult. Even customers with previous software engineering experience will be better at creating good requirements.

If you have access to design specialists such as user interface designers or human factors experts, get them to help. Any programmer can build forms, menus, and colorful labels, but some don't do a good job. A good user interface makes users productive. A bad one is frustrating and ineffective. (It's like trying to empty a bathtub with a teaspoon. You'll eventually succeed, but you'll spend the whole time thinking, "This is stupid. There has to be a better way!")

Brainstorm

Copying an existing application and clairvoyance are good techniques for generating requirements, but they share a common disadvantage: They are unlikely to lead you to new innovative solutions that might be better than the old ones. To find truly revolutionary solutions, you need to be more creative. One way to look for creative solutions is the group creativity exercise known as *brainstorming*.

You're probably somewhat familiar with brainstorming, at least in an informal setting, but there are several approaches that you can use under different circumstances.

The basic approach that most people think of as brainstorming is called the *Osborn method* because it was developed by Alex Faickney Osborn, an advertising executive who tried to develop new, creative problem-solving methods starting in 1939. Basically, he was tired of his employees failing to come up with new and innovative advertising campaigns. (As is the case with the Gantt charts described in Chapter 3, the fact that we're still using Osborn's techniques after all these years shows how useful they are.) Osborn's key observation is summed up nicely in his own words.

> *It is easier to tone down a wild idea than to think up a new one.*
>
> —Alex Faickney Osborn

Basically, the gist of the method is to gather as many ideas as possible, not worrying about their quality or practicality. After you assemble a large list of possible ideas, you examine them more closely to see which deserve further work.

To allow as many approaches as possible, you should try to get a diverse group of participants. In software engineering, that means the group should include customers, users, user interface designers, system architects, team leads, programmers, trainers, and anyone else who has an interest in the project. Get as many different viewpoints as you can. (Although in practice brainstorming becomes less effective if the group becomes larger than 10 or 12 people.)

To keep the ideas flowing, don't judge or critique any of the ideas. If you criticize someone's ideas, that person may shut down and stop contributing. Even a truly crazy idea can spark other ideas that may lead somewhere promising. Just write down every idea no matter how impractical it may seem. Even if an idea is impossible to implement using today's technology, it may be simple by next Wednesday.

(It wasn't that long ago that portable phones had the size, weight, and functionality of a brick. Now they're small enough to lose in the sofa cushions and have more computing power than NASA had when Neil Armstrong flubbed his "one small step" line on the moon.)

Osborn's method uses the following four rules:

1. **Focus on quantity.** Do everything you can to keep the ideas flowing. The more ideas you collect, the greater your chances of finding a really creative and revolutionary solution.
2. **Withhold criticism.** Criticism can make people stop contributing. Early criticism can also eliminate seemingly bad ideas that lead to better ideas.
3. **Encourage unusual ideas**. You can always "tone down a wild idea" but you may need to think way outside of the box to find really creative solutions.
4. **Combine and improve ideas.** Form new ideas by combining other ideas or using one idea to modify another.

Only after the flow of ideas is slowing to a trickle should you start evaluating the ideas to see what you've got. At that point, you can pick out the most promising ideas to develop further (possibly with more brainstorming).

Many people are familiar with Osborn's method (although they may not know its name), but there are also several other brainstorming techniques, some of which can be even more effective. The following list describes some of those techniques.

- **Popcorn**—(I think of this as the Mob technique.) People just speak out as ideas occur to them. This works fairly well with small groups of people who are comfortable with each other.
- **Subgroups**—Break the group into smaller subgroups (possibly in the same room) and have each group brainstorm. When the subgroups are finished, have the larger group discuss their best ideas. This works well if the main group is very large, if some people feel uncomfortable speaking in the larger group (the new developer in shorts and sandals may be afraid to speak out in front of the corporate vice president in a thousand dollar suit), or if one or two people are monopolizing the discussion.
- **Sticky notes**—Also called the nominal group technique (NGT). Participants write down their ideas on sticky notes, index cards, papyrus, or whatever. The ideas are collected, read to the group, and the group votes on each idea. The best ideas are developed further, possibly with other rounds of brainstorming.
- **Idea passing**—Participants sit in a circle. (I suppose you could use some other arrangement such as an ellipse, rectangle, or nonagon. As long as you have an ordering for the participants.) Each person writes down an idea and passes it to the next person. The participants add thoughts to the ideas they receive and pass them on to the next person. The ideas continue moving around the circle until everyone gets their original idea back. At this point, each idea should have been examined in great detail by the group. (Instead of a circle, nonagon, or whatever, you can also swap ideas randomly.)
- **Circulation list**—This is similar to idea passing except the ideas are passed via e-mail, envelope, or some other method outside of a single meeting. This can take a lot longer than idea passing but may be more convenient for busy participants.
- **Rule breaking**—List the rules that govern the way you achieve a task or goal. Then everyone tries to think of ways to break or circumvent those rules while still achieving the goal.

- **Individual**—Participants perform their own solitary brainstorming sessions. They can write (or speak) their trains of thought, use word association, draw mind maps (diagrams relating thoughts and ideas—search online for details), and any other technique they find useful. Some studies have shown that individual brainstorming may be more effective than group brainstorming.

The following list describes some tips that can make brainstorming more productive.

- Work in a comfortable room where everyone can feel at ease.
- Provide food and drinks. (I'll let you decide what kinds of drinks.)
- Start by recapping the users' current processes and the problems you are trying to solve.
- Use a clock to keep sessions short and lively. If you're using an iterative approach such as idea passing, keep the rounds short.
- Allow the group's attention to wander a bit, but keep the discussion more or less on topic. If you're designing a remote mining rig control system, then you probably don't need to be discussing Ouija boards or Monty Python quotes.
- However, a few jokes can keep people relaxed and help ideas flow, so a few Monty Python quotes may be okay.
- If you get stuck, restate the problem.
- Allow silent periods so that people have time to think about the problem and their ideas.
- Reverse the problem. For example, instead of trying to think of ways to build better blogging software, think of ways to build worse blogging software. (Obviously, don't actually do them.)
- Write ideas in slightly ambiguous ways and let people give their interpretations.
- At the end, summarize the best ideas and give everyone copies so that they can think about them later. Sometimes, a great idea pops into someone's head after the official brainstorming sessions are over.

Brainstorming is useful any time you want to find creative solutions to complex problems, not just during requirements gathering. You can use it to pick problems in your company that you might solve with a new software project. You can use it to design user interfaces, explore possible system architectures, create high-level designs, and plan interesting exercises for training classes. (You can even use brainstorming techniques outside of software engineering to decide where to go on your next vacation, reduce pollution in your city, or pick a school science fair project.)

Keep brainstorming in mind throughout the project as a technique you can use to attack difficult problems.

RECORDING REQUIREMENTS

After you decide what should be in the requirements, you need to write them down so that everyone can read them (and argue about whether they're correct). There are several ways you can record requirements so team members can refer to them throughout the project's lifetime.

Obviously, you can just write the requirements down as a sequence of commandments as in, "Thou shalt make the user change passwords on every full moon." There's a lot to be said for writing down requirements in simple English (or whatever your team's native language is). For starters, the team members already know that language and have been using it for many years.

You can still mess things up by writing requirements ambiguously or in hard-to-understand formats (such as limericks or haiku), but if you're reasonably careful, requirements written in ordinary language can be very effective.

The following sections describe some other methods for recording requirements.

UML

The Unified Modeling Language (UML) lets you specify how parts of the system should work. Despite its name, UML isn't a single unified language. Instead it uses several kinds of diagrams to represent different pieces of the system. Some of those represent program items such as classes. Others represent behaviors, such as the way objects interact with each other and the way data flows through the system.

I won't bash UML (it's too popular and I'm not famous enough to get away with it), but it does have some drawbacks. Most notably it's complicated. UML includes two main categories of diagrams that are divided into more than a dozen specific types, each with its own complex set of rules.

Specifying complex requirements with UML is only useful if everyone understands the UML. Unfortunately, many customers and users don't want to learn it. It's not that they couldn't. They just usually have better things to do with their time, like helping you understand their needs. (I did actually work on one project where the customers taught themselves how to use some types of UML diagrams so that they could specify parts of the system. It worked reasonably well, but it took a long time.)

I'll talk more about UML in the next chapter. For now during requirement gathering, you probably shouldn't rely heavily on UML unless your customers are already reasonably familiar with it. (For example, if you're writing a library for use by other programmers who already use UML.)

User Stories

> *Storytelling strikes me as a more powerful tool than quantification or measurement for what we do.*
>
> —Alan Cooper

A *user story* is exactly what you might think: a short story explaining how the system will let the user do something. For example, the following text is a story about a user searching a checkers database to find opponents:

> *The user enters his Harkness rating (optional), whether moves should be timed or untimed, and the variant (such as traditional, three-dimensional, upside-down, or Gliński). When the user clicks Search, the application displays a list of possible opponents that have compatible selections.*

Many developers write stories on index cards to encourage brevity. The scope of each story should also be limited so that no story should take too long to implement (no more than a week or two).

Notice that the story doesn't contain a lot of detail about things like whether the game variants are given in a list or set of radio buttons. The story lets you defer those decisions until later during design.

User stories should come with acceptance testing procedures that you can use at the end of development to decide whether the application satisfied the story.

User stories may seem low-tech, but they have some big advantages, not least of which is that people are already familiar with them. They are easy to write, easy to understand, and can cover just about any situation you can imagine. They can be simple or complex depending on the situation. Unlike UML, your customers, developers, managers, and other team members already know how to understand stories without any new training.

User stories give you a lot of expressiveness and flexibility without a lot of extra work. (In management speak, user stories allow you to leverage existing competencies to empower stakeholders.)

User stories do have some drawbacks. For example, you can easily write stories that are confusing, ambiguous, inconsistent with other stories, and unverifiable. Of course, that's true of any method of recording requirements.

Use Cases

A *use case* is a description of a series of interactions between actors. The actors can be users or parts of the application.

Often a use case has a larger scope than a user story. For example, a use case might explain how the application will allow a user to examine cardiac ultrasound data for a patient. That user might need to use many different screens to examine different kinds of recordings and measurements. Each of those subtasks could be described by a user story, but the larger job of examining all the data would be too big to describe on a single index card and would take longer to implement than a week or two.

Use cases also follow a template more often than user stories. A simple template might require a use case to have the following fields:

- **Title**—The name of the goal as in, "User Examines Cardiac Data." Usually, the title includes an action (examines) and the main actor (user).
- **Main success scenario**—A numbered sequence of steps describing the most normal variation of the scenario.
- **Extensions**—Sequences of steps describing other variations of the scenario. This may include cases such as when the user enters invalid data or the application can't handle a request. (For example, if the user searches for a nonexistent patient.)

Other templates include a lot more fields such as lists of stakeholders interested in the scenario, preconditions that must be met before the scenario begins, and success and failure variations.

Prototypes

A *prototype* is a mockup of some or all of the application. The idea is to give the customers a more intuitive hands-on feel for what the finished application will look like and how it will behave than you can get from text descriptions such as user stories and use cases.

A simple user interface prototype might display forms that contain labels, text boxes, and buttons showing what the finished application will look like. In a *nonfunctional prototype*, the buttons, menus, and other controls on the forms wouldn't actually do anything. They would just sit there and look pretty.

A *functional prototype* (or *working prototype*) looks and acts as much like the finished application will but it's allowed to cheat. It may do something that looks like it works, but it may be incomplete and it probably won't use the same methods that the final application will use. It might use less efficient algorithms, load data from a text file instead of a database, or display random messages instead of getting them from another system. It might even use hard-coded fake data.

For example, the prototype might let you enter search criteria on a form. When you clicked the Search button, the prototype would ignore your search criteria and display a prefilled form showing fake results. This gives the customers a good idea about how the final application will work but it doesn't require you to write all the code.

There are a couple of things you can do with a prototype after it's built. First, you can use it to define and refine the requirements. You can show it to the customers and, based on their feedback, you can modify it to better fit their needs.

After you've fine-tuned the prototype so that it represents the customers' requirements as closely as possible, you can leave it alone. You can continue to refer to it if there's a question about what the application should look like or how it should work, but you start over from scratch when building the application. This kind of prototype is called a *throwaway prototype*.

Alternatively, you can start replacing the prototype code and fake data with production-quality code and real data. Over time, you can evolve the prototype into increasingly functional versions until eventually it becomes the finished application. This kind of prototype is sometimes called an *evolutionary prototype*. This approach is used by some of the iterative approaches described in Chapter 13.

SURVIVAL OF THE LAZIEST

You need to be careful if you use an evolutionary prototype. While throwing together an initial version to show the customers what the final application will do, developers can (and should) take shortcuts to get things done as quickly as possible. That can result in code that's sloppy, riddled with bugs, and hard to maintain.

As long as the prototype works, that's fine. The prototype is only supposed to give you an idea about how the program will work, so it doesn't need to be as maintainable as the finished application in the long run.

That's fine if you're using the prototype only to define requirements, but if you try to evolve the prototype into a production application, you need to be sure to go back and remove all the shortcuts and rewrite the code properly. If you don't remove all the prototype code, you'll certainly pay the price later in increased bug fixes and maintenance.

Requirements Specification

How formally you need to write up the requirements depends on your project. If you're building a simple tool to rename the files on your own computer in bulk, a simple description may be enough. If you're writing software to fill out legal forms for a law firm, you probably need to be much more formal. (And you might want to hire a different law firm to review your contract.)

If you search the Internet, you can find several templates for requirement specifications. These typically list major categories of requirements such as user documentation, user interface design, and interfaces with other systems.

For example, Villanova University has an example template in Word format at `tinyurl.com/obqhatt`. The North Carolina Enterprise Project Management Office has another one at `tinyurl.com/n7ttqfh`. (These are really long URLs so I used tinyurl to shorten them.)

VALIDATION AND VERIFICATION

After you record the requirements (with whatever methods you prefer), you still need to validate them and later verify them. The two terms validation and verification are sometimes used interchangeably. Here are the definitions I use. (I think these are the most common interpretations.)

Requirement validation is the process of making sure that the requirements say the right things. Someone, often the customers or users, need to work through all the requirements and make sure that they: (1) Describe things the application should do. (2) Describe *everything* the application should do.

Requirement verification is the process of checking that the finished application actually satisfies the requirements.

VALIDATION VERSUS VERIFICATION

Another way to think of this is

Validation—Are we doing the right things?

Verification—Are we doing the things right?

Those two statements are glib, but it's hard to remember which is which. Perhaps a better way to remember the difference is that "validation" comes before "verification" alphabetically and validation comes before verification in a software project.

CHANGING REQUIREMENTS

In many projects, requirements evolve over time. As work proceeds, you may discover that something you thought would be easy is hard. Or you may stumble across a technique that lets you add a high-value feature with little extra work.

Often changes are driven by the customers. After they start to see working pieces of the application, they may think of other items that they hadn't thought of before.

Depending on the kind of project, you may accommodate some changes, as long as they don't get out of hand. You can help control the number of changes by creating a *change control board*. Customers (and others) can submit change requests to this board (which might actually be a single person) for approval. The board decides whether a change should be implemented or deferred to a later release.

The development methods described in Chapters 13 and 14 are particularly good at dealing with changing requirements because they tend to build an application in small steps with frequent opportunities for refinement. If you add new features in a mini-project every two weeks, it's easy to add new requirements into the next phase. There's still a danger of never finishing the project, however, if the change requests keep trickling in.

SUMMARY

Requirements gathering may not be *the most* important stage of a project, but it certainly is *an* important stage. It sets the direction for future development. If you get the requirements wrong, you may develop something but there's no guarantee that it will be useful.

Good requirements must satisfy some basic requirements of their own. For example, they must be clear and consistent. Having hundreds of requirements won't do you any good if no one can understand what they mean or if they contradict each other.

Some developers group requirements into categories. For example, you can use audience-oriented categories, FURPS, or FURPS+ to organize requirements. Categorizing requirements alone doesn't help you define the project, but you can use the categories as a checklist to make sure you haven't forgotten anything obvious. (They also make it easier to understand other software engineers at parties when they say, "This party has good functional requirements but the nonfunctionals could use some work!")

There are several ways you can gather requirements. Obviously, you should talk with the customers and, if possible, the users. You can use the five Ws and one H to help guide the conversation. Studying the users as they currently perform their jobs is often instructive. It can help clarify the project's goals, and occasionally you may discover simple things you can add to the project that will make the users' jobs a whole lot easier.

After you understand the customers' needs, you must refine those needs into requirements. Three techniques that can help include: copying an existing system, using previous experience to just write them down, and brainstorming. Brainstorming is often more work but can sometimes lead to creative solutions that you might not have discovered otherwise.

Finally, after you know what the requirements are, you need to record them so everyone can refer to them as the project continues. Some ways you can record requirements include formal written specifications, UML diagrams, user stories, use cases, and prototypes.

Before you move on to the next phase of development, you should validate the requirements to ensure that they actually meet the customers' needs. (Later, near the end of the project, you'll also need to verify that the project has met the requirements.)

If you think this seems like a lot of work before the project "actually" begins, you're right. However, it's critical to the project's eventual success. Without sound requirements, how will you know what

to build? Unless the requirements are clear and verifiable, how will you know if you've achieved your goals?

After you gather, record, and validate the requirements, you're ready to move on to the next stage of development: high-level design. You may have already incorporated some design decisions into the requirements. For example, you might have made some user interface decisions or picked a system architecture.

The next chapter explains some of the high-level design decisions you might need to make, whether in the requirements phase or during a separate high-level design step. It also provides some guidance on how to make those decisions.

EXERCISES

1. List five characteristics of good requirements.
2. What does MOSCOW stand for?
3. Suppose you want to build a program called TimeShifter to upload and download files at scheduled times while you're on vacation. The following list shows some of the application's requirements.
   a. Allow users to monitor uploads/downloads while away from the office.
   b. Let the user specify website log-in parameters such as an Internet address, a port, a username, and a password.
   c. Let the user specify upload/download parameters such as number of retries if there's a problem.
   d. Let the user select an Internet location, a local file, and a time to perform the upload/download.
   e. Let the user schedule uploads/downloads at any time.
   f. Allow uploads/downloads to run at any time.
   g. Make uploads/downloads transfer at least 8 Mbps.
   h. Run uploads/downloads sequentially. Two cannot run at the same time.
   i. If an upload/download is scheduled for a time when another is in progress, it waits until the other one finishes.
   j. Perform scheduled uploads/downloads.
   k. Keep a log of all attempted uploads/downloads and whether they succeeded.
   l. Let the user empty the log.
   m. Display reports of upload/download attempts.
   n. Let the user view the log reports on a remote device such as a phone.

o. Send an e-mail to an administrator if an upload/download fails more than its maximum retry number of times.

p. Send a text message to an administrator if an upload/download fails more than its maximum retry number of times.

For this exercise, list the audience-oriented categories for each requirement. Are there requirements in each category?

4. Repeat Exercise 3 using the FURPS requirement categories.

5. What are the five Ws and one H?

6. List three techniques for gathering requirements from customers and users.

7. Explain why brainstorming can be useful in defining requirements.

8. List the four rules of the Osborn method.

9. Figure 4-1 shows the design for a simple hangman game that will run on smartphones. When you click the New Game button, the program picks a random mystery word from a large list and starts a new game. Then if you click a letter, either the letter is filled in where it appears in the mystery word, or a new piece of Mr. Bones's skeleton appears. In either case, the letter you clicked is grayed out so that you don't pick it again. If you guess all the letters in the mystery word, the game displays a message that says, "Congratulations, you won!" If you build Mr. Bones's complete skeleton, a message says, "Sorry, you lost."

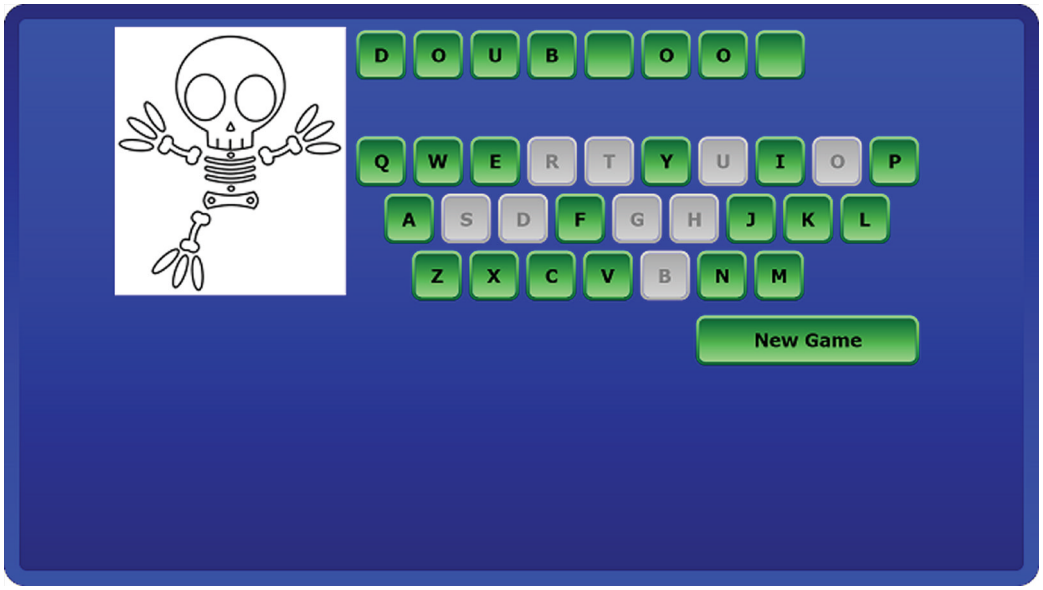


FIGURE 4-1: The Mr. Bones application is a hangman word game for Windows Phone.

Brainstorm this application and see if you can think of ways you might change it. Use the MOSCOW method to prioritize your changes.

10. (Instructors) Have the class brainstorm ideas to address a fairly difficult issue (such as reversing global warming, ending global hunger, or making politicians honor their campaign promises). If time permits, try a couple different brainstorming variations such as popcorn, subgroups, and individual. Discuss what went well and what didn't.

WHAT YOU LEARNED IN THIS CHAPTER

- Requirements are important to a project because they set the project's goals and direction.
- Requirements must be clear, unambiguous, consistent, prioritized, and verifiable.
- The MOSCOW method provides one way to prioritize requirements.
- FURPS stands for Functionality, Usability, Reliability, Performance, and Supportability.
- FURPS+ also adds design constraints, implementation requirements, interface requirements, and physical requirements.
- You can gather requirements by talking to customers and users, watching users at work, and studying existing systems.
- You can convert goals into requirements by copying existing systems and methods, using previous experience to write them down, and brainstorming.
- You can record requirements in written specifications, UML diagrams, user stories, use cases, and prototypes.
- Requirements may change over time. That's okay as long as it happens in a controlled manner.
- Requirement validation is the process of checking that the requirements meet the customers' needs.
- Requirement verification is the process of checking that the finished project satisfies the requirements.

5

High-Level Design

Design is not just what it looks like and feels like. Design is how it works.

—Steve Jobs

Design is easy. All you do is stare at the screen until drops of blood form on your forehead.

—Marty Neumeier

WHAT YOU WILL LEARN IN THIS CHAPTER:

- The purpose of high-level design
- How a good design lets you get more work done in less time
- Specific things you should include in a high-level design
- Common software architectures you can use to structure an application
- How UML lets you specify system objects and interactions

High-level design provides a view of the system at an abstract level. It shows how the major pieces of the finished application will fit together and interact with each other.

A high-level design should also specify assumptions about the environment in which the finished application will run. For example, it should describe the hardware and software you will use to develop the application, and the hardware that will eventually run the program.

The high-level design does not focus on the details of how the pieces of the application will work. Those details can be worked out later during low-level design and implementation.

Before you start learning about specific items that should be part of the high-level design, you should understand the purpose of a high-level design and how it can help you build an application.

THE BIG PICTURE

You can view software development as a process that chops up the system into smaller and smaller pieces until the pieces are small enough to implement. Using that viewpoint, high-level design is the first step in the chopping up process.

The goal is to divide the system into chunks that are self-contained enough that you could give them to separate teams to implement.

PARALLEL IMPLEMENTATION

Suppose you're building a relatively simple application to record the results of Twister games for a championship. It needs to store the names of the players in each match, the date and time they played, and the order in which they fell over during play.

You might break this application into two large pieces: the database and the user interface. You could then assign those two pieces to different groups of developers to implement in parallel.

(You'll see in the rest of this chapter that there are actually a lot of other pieces you might want to specify even for this simple application.)

There are a lot of variations on this basic theme. On a small project, for example, the project's pieces might be small enough that they can be handled by individual developers instead of teams.

In a large project, the initial pieces might be so big that the teams will want to create their own medium-level designs that break them into smaller chunks before trying to write any code. This can also happen if a piece of the project turns out to be harder than you had expected. In that case, you may want to break it into smaller pieces and assign them to different people.

ADDING PEOPLE

Breaking an existing task into smaller pieces is one of the few ways you can sometimes add people to a project and speed up development.

Adding new people to the same old tasks usually doesn't help and often actually slows development as the new people get up to speed and get in each other's way. (It can feel like you're in a leaky lifeboat with a single bucket and more people are climbing aboard. You may enjoy the company, but their extra weight will make you sink faster.)

However, if you can break a large task into smaller pieces and assign them to different people, you may speed things up a bit. The new people still need time come up to speed, so this won't always help, but at least people won't trip over each other trying to perform the same tasks.

In some projects, you may want to assign multiple pieces of the project to a single team, particularly if the pieces are closely related. For example, if the pieces pass a lot of data back and forth, it will be helpful if the people building those pieces work closely together. (Multitier architectures, which

are described in the "Client/Server" section later in this chapter, can help minimize this sort of interaction.)

Another situation in which this kind of close cooperation is useful is when several pieces of the application all work with the same data structure or with the same database tables. Placing the data structure or tables under the control of a single team may make it easier to keep the related pieces synchronized.

WHAT TO SPECIFY

The stages of a software engineering project often blur together, and that's as true for high-level design as it is for any other part of development. For example, suppose you're building an application to run on the Windows phone platform. In that case, the fact that your hardware platform is Windows phones should probably be in the requirements. (Although you may want to add extra details to the high-level design, such as the models of phones that you will test.)

Exactly what you should specify in the high-level design varies somewhat, but some things are constant for most projects. The following sections describe some of the most common items you might want to specify in the high-level design.

Security

The first thing you see when you start most applications is a login screen. That's the first *obvious* sign of the application's security, but it's actually not the first piece. Before you even log in to the application, you need to log in to the computer.

Your high-level design should sketch out all the application's security needs. Those needs may include the following:

- **Operating system security**—This includes the type of login procedures, password expiration policies, and password standards. (Those annoying rules that say your password must include at least one letter, one number, one special character like # or %, and three Egyptian hieroglyphs.)
- **Application security**—Some applications may rely on the operating system's security and not provide their own. Others may use the operating system's security to make the user reenter the same username and password. Still others may use a separate application username and password. Application security also means providing the right level of access to different users. For example, some users might not be allowed access to every part of the system. (I'll say more about this in the section "User Access" later in the chapter.)
- **Data security**—You need to make sure your customer's credit card information doesn't fall into the hands of Eastern European hackers.
- **Network security**—Even if your application and data are secure, cyber banditos might steal your data from the network.
- **Physical security**—Many software engineers overlook physical security. Your application won't do much good if the laptop it runs on is stolen from an unlocked office.

All these forms of security interact with each other, sometimes in non-obvious ways. For example, if you reset passwords too often, users will pick passwords that are easier to remember and possibly easier for hackers to guess. You could add your name to the month number (Rod1 for January, Rod2 for February, and so forth), but those would be easy to guess. If you make the password rules too strict (requiring two characters from each row of the keyboard), users may write their passwords down where they are easy to find.

Physical security also applies to passwords. I've seen large customer service environments in which users often needed manager approval for certain kinds of common operations. In fact, those overrides were so common that the manager didn't have time to handle them and get any other work done. The solution they adopted was to write the manager's username and password on a whiteboard at the front of the room so that everyone could use it to perform their own overrides.

The password was insecure, so any hacker who got into the room could do just about anything with the system. (Fortunately, the room had no windows and was difficult to get into without the right badge and passwords.)

This also meant that any user could impersonate the manager and do just about anything. If that's the case, why bother having user permissions?

If you need to make 50 exceptions per day, then they're not actually exceptions. The solution would have been to not require manager approval for such a common task. Then the manager could have kept her password private and used overrides only for truly important stuff.

Hardware

Back in the old days when programmers worked by candlelight on treadle-powered computers, hardware options were limited. You pretty much wrote computers for large mainframes or desktop computers. You had your pick of a few desktop vendors, and you could pick Windows or Macintosh operating systems, but that was about it.

These days you have a lot more choices and you need to specify the ones that you'll be using. You can build systems to run on mainframes (yes, they still exist), desktops, laptops, tablets, and phones. Mini-computers act sort of as a mini-mainframe that can serve a handful of users. Personal Digital Assistants (PDAs) are small computers that are basically miniature tablets.

Wearable devices include such gadgets as computers strapped to the wearer's wrist (sort of like a PDA with a wrist strap and possibly extra keys and buttons), wristbands, bracelets, watches, eyeglasses, and headsets.

Additional hardware that you need to specify might include the following:

- Printers
- Network components (cables, modems, gateways, and routers)
- Servers (database servers, web servers, and application servers)
- Specialized instruments (scales, microscopes, programmable signs, and GPS units)
- Audio and video hardware (webcams, headsets, and VOIP)

With all the available options (and undoubtedly many more on the way), you need to specify the hardware that will run your application. Sometimes, this will be relatively straightforward. For example, your application might run on a laptop or in a web page that could run on any web-enabled hardware. Other times the hardware specification might include multiple devices connected via the Internet, text messages, a custom network, or by some other method.

EXAMPLE Selecting a Hardware Platform

Suppose you're building an application to manage the fleet of dog washing vehicles run by The Pampered Poodle Emergency Dog Washing Service. When a customer calls in to tell you Fifi ran afoul of a skunk, you dispatch an emergency dog-washer to the scene.

In this case, your drivers might access the system over cell phones. A desktop computer back at the office would hold the database and provide a user interface to let you do everything else the business needs such as logging customer calls, dispatching drivers, printing invoices, tracking payments, and ordering doggy shampoo.

For this application, you would specify the kind of phones the drivers will use (such as Windows, iOS, or Android), the model of the computer used to hold the database and business parts of the application, and the type of network connectivity the application will use. (Perhaps the database desktop serves data on the Internet and the phones download data from there.)

Another strategy would be to have the desktop serve information to the drivers as web pages. Then the drivers could use any web-enabled device (smartphone, tablet, Google Glass) to view their assignments.

User Interface

During high-level design, you can sketch out the user interface, at least at a high level. For example, you can indicate the main methods for navigating through the application.

Older-style desktop applications use forms with menus that display other forms. Often the user can display many forms at the same time and switch between them by clicking with the mouse (or touching if the hardware has a touch screen).

In contrast, newer tablet-style applications tend to use a single window (that typically covers the entire tablet, or whatever hardware you're using) and buttons or arrows to navigate. When you click a button, a new window appears and fills the device. Sometimes a Back button lets you move back to the previous window.

Whichever navigational model you pick, you can specify the forms or windows that the application will include. You can then verify that they allow the user to perform the tasks defined in the requirements. In particular, you should walk through the user stories and use cases and make sure you've included all the forms needed to handle them.

In addition to the application's basic navigational style, the high-level user interface design can describe special features such as clickable maps, important tables, or methods for specifying system settings (such as sliders, scrollbars, or text boxes).

This part of the design can also address general appearance issues such as color schemes, company logo placement, and form skins.

FOLLOW EXISTING PRACTICES

Most users have a lot of experience with previous applications, and those applications follow certain standardized patterns. For example, desktop applications typically have menus that you access from a form's title bar. The menus drop down below and submenus cascade to the right. That's the way Windows applications have been handling menus for decades and users are familiar with how they work.

If your application sticks to a similar pattern, users will feel comfortable with the application with little extra training. They already know how to use menus, so they won't have any trouble using yours. Instead they can concentrate on learning how to use the more interesting pieces of your system.

Now suppose your application changes this kind of standard interaction. Perhaps you access the menus by clicking a little icon on the right edge of the toolbar and then menus cascade out to the left instead of the right. Or perhaps there are no menus, just panels filled with icons you can click to open new forms. In that case, users will need to learn how to use your new system. That will at least lead to some unnecessary confusion, and it might create a lot of annoyance for the users.

(I use one tool in particular, which I won't name, that for some reason thinks it knows a better way to handle menus, toolbars, and toolboxes. It's frustrating, incredibly annoying, and sometimes leads to major outbreaks of swearing.)

Unless you have a good reason to change the way most applications already work, stick with what the users already know.

You don't need to specify every label and text box for every form during high-level user interface design. You can handle that during low-level design and implementation. (Often the controls you need follow from the database design anyway, so you can sometimes save some work if you do the database design first. Some tools can even use a database design to build the first version of the forms for you.)

Internal Interfaces

When you chop the program into pieces, you should specify how the pieces will interact. Then the teams assigned to the pieces can work separately without needing constant coordination.

It's important that the high-level design specifies these internal interactions clearly and unambiguously so that the teams can work as independently as possible. If two teams that need to interact don't agree on how that interaction should occur, they can waste a huge amount of time. They may waste time squabbling about which approach is better. They will also waste time if one team needs to change the interface and that forces the other team to change its interface, too. The problem increases dramatically if more than two teams need to interact through the same interface.

It's worth spending some extra time to define these sorts of internal interfaces carefully before developers start writing code. Unfortunately, you may not be able to define the interfaces before writing at least some code. In that case, you may need to insulate two project teams by defining a temporary interface. After the teams have written enough code to know what information they need to exchange, they can define the final interface.

DEFERRED INTERFACES

I worked on one project where two teams needed to pass a bunch of information back and forth. Of course, at the beginning of the project, neither team had written any code to work with the other team, so neither team could call the other. We also weren't sure what data the two teams would need to pass, so we couldn't specify the interface with certainty.

To get both teams working quickly, the high-level design specified a text file format that the teams could use to load test data. Instead of calling each other's code, the teams could read data from a test data file. They were also free to modify the formats of their files as their needs evolved.

After several months of work, the two teams had written code to process the data and their needs were better defined. At that point, they agreed on a format for passing data and switched from loading data from data files to actually calling each other's code.

It would have been more efficient to have defined the perfect interface at the beginning during high-level design, but that wasn't an option. Using text files to act as temporary interfaces allowed both teams to work independently.

(The multitier design described in the "Architecture" section later in this chapter does something similar.)

External Interfaces

Many applications must interact with external systems. For example, suppose you're building a program that assigns crews for a large chartered fishing company. The application needs to assign a captain, first mate, and cook for each trip. Your program needs to interact with the existing employee database to get information about crew members. (You don't want to assign a boat three cooks and no captain.) You might also need to interact with a sales program that lets salespeople book fishing trips.

In a way, external interfaces are often easier to specify than internal ones because you usually don't have control over both ends of the interface. If your application needs to interact with an existing system, then that system already has interface requirements that you must meet.

Conversely, if you want future systems to interface with yours, you can probably specify whatever interface makes sense to you. Systems developed later need to meet your requirements. (Try to make your interface simple and flexible so that you don't get flooded with change requests.)

Architecture

An application's architecture describes how its pieces fit together at a high level. Developers use a lot of "standard" types of architectures. Many of these address particular characteristics of the problem being solved.

For example, rule-base systems are often used to handle complex situations in which solving a particular problem can be reduced to following a set of rules. Some troubleshooting systems use this approach. You call in because your computer can't connect to the Internet, and a customer rep from some distant time zone asks you a sequence of questions to try to diagnose the problem. The rep reads a question off a computer screen, you answer, and the rep clicks the corresponding button to get to the next question. Rules inside the rep's diagnostic system decide which question to give you next.

Other architectures attempt to simplify development by reducing the interactions among the pieces of the system. For example, a component-based architecture tries to make each piece of the system as separate as possible so that different teams of developers can work on them separately.

The following sections describe some of the most common architectures.

Monolithic

In a *monolithic architecture*, a single program does everything. It displays the user interface, accesses data, processes customer orders, prints invoices, launches missiles, and does whatever else the application needs to do.

This architecture has some significant drawbacks. In particular, the pieces of the system are tied closely together, so it doesn't give you a lot of flexibility. For example, suppose the application stores customer address data and you later need to change the address format. (Perhaps you add a field to hold suite numbers.) Then you also need to change every piece of code that uses the address. This may not be too hard, but it means the programmers working on related pieces of code must stop what they're doing and deal with the change before they can get back to their current tasks. (The multitier architectures described in the next section handle this better, allowing the different teams of developers to work more independently.)

A monolithic architecture also requires that you understand how all the pieces of the system fit together from the beginning of the project. If you get any of the details wrong, the tight coupling between the pieces of the system makes fixing them later difficult.

Monolithic architectures do have some advantages. Because everything is built into a single program, there's no need for complicated communication across networks. That means you don't need to write and debug communication routines; you don't need to worry about the network going down; and you don't need to worry about network security. (Well, you still need to worry about some hacker sneaking in through your network and attacking your machines, but at least you don't need to encrypt messages sent between different parts of the application.)

Monolithic architectures are also useful for small applications where a single programmer or team is working on the code.

Client/Server

A *client/server architecture* separates pieces of the system that need to use a particular function (clients) from parts of the system that provide those functions (servers). That decouples the client and server pieces of the system so that developers can work on them separately.

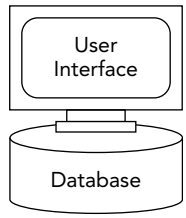


FIGURE 5-1: An application can directly hold its own data.

For example, many applications rely on a database to hold information about customers, products, orders, and employees. The application needs to display that information in some sort of user interface. One way to do that would be to integrate the database directly into the application. Figure 5-1 shows this situation schematically.

One problem with this design is that multiple users cannot use the same data. You can fix that problem by moving to a *two-tier architecture* where a client (the user interface) is separated from the server (the database). Figure 5-2 shows this design. The clients and server communicate through some network such as a local area network (LAN), wide area network (WAN), or the Internet.

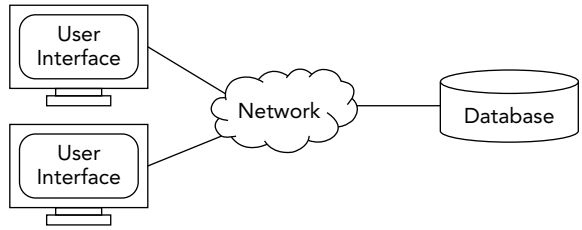


FIGURE 5-2: In a two-tier architecture, the client is separate from the server.

In this example, the client is the user interface (two instances of the same program) and the server is a database, but that need not be the case. For example, the client could be a program that makes automatic stock purchases, and the server could be a program that scours the Internet for information about companies and their stocks.

The two-tier architecture makes it easier to support multiple clients with the same server, but it ties clients and servers relatively closely together. The clients must know what format the server uses, and if you change the way the server presents its data, you need to change the client to match. That may not always be a big problem, but it can mean a lot of extra work, particularly in the beginning of a project when the client's and server's needs aren't completely known.

You can help to increase the separation between the clients and server if you introduce another layer between the two to create the *three-tier architecture*, as shown in Figure 5-3.

In Figure 5-3, the middle tier is separated from the clients and the server by networks. The database runs on one computer, the middle tier runs on a second computer, and the instances of the client run on still other computers. This isn't the only way in which the pieces of the system can communicate. For example, in many applications the middle tier runs on the same computer as the database.

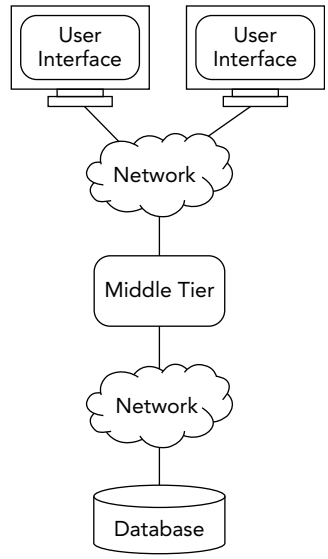


FIGURE 5-3: A three-tier architecture separates clients and servers with a middle tier.

In a three-tier architecture, the middle tier provides insulation between the clients and server. In this example, it provides an interface that can map data between the format provided by the server and the format needed by the client. If you need to change the way the server stores data, you need to update only the middle tier so that it translates the new format into the version expected by the client.

Conversely, if the client's data needs change, you can modify the middle tier to insert fake data until you have a chance to update the server to provide the actual data.

The separation provided by the middle tier lets different teams work on the client and server without interfering with each other too much.

In addition to providing separation, a middle tier can perform other actions that make the data easier to use by the client and server. For example, suppose the client needs to display some sort of aggregate data. Perhaps Martha's Musical Mechanisms needs to display the total number of carillons sold by each employee for each of the last 12 quarters. In that case, the server could store the raw sales data, and the middle tier could aggregate the data before sending it to the client.

TIER TERMINOLOGY

Sometimes, the client tier is called the *presentation tier* (because it presents information to the user); the middle tier is called the *logic tier* (because it contains business logic such as aggregating data for the presentation tier); and the client tier is called the *data tier* (particularly if all it does is provide data).

You can define other *multitier architectures* (or *N-tier architectures*) that use more than three tiers if that would be helpful. For example, a data tier might store the data, a second tier might calculate aggregates and perform other calculations on the data, a third tier might use artificial intelligence techniques to make recommendations based on the second tier's data, and a fourth tier would be a presentation tier that lets users see the results.

BEST PRACTICE

Multitier architectures are a best practice, largely because of the separation they provide between the client and server layers. Most applications don't use more than three tiers.

Component-Based

In *component-based software engineering* (*CBSE*), you regard the system as a collection of loosely coupled components that provide services for each other. For example, suppose you're writing a system to schedule employee work shifts. The user interface could dig through the database to see what hours are available and what hours an employee can work, but that would tie the user interface closely to the database's structure.

An alternative would be to have the user interface ask components for that information, as shown in Figure 5-4. (UML provides a more complex diagram for services that is described in the section "UML" later in this chapter.)

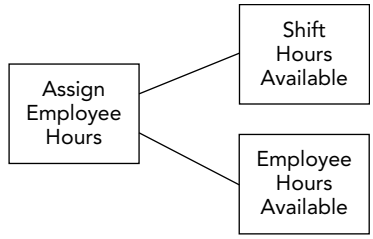


FIGURE 5-4: In a component-based architecture, components help decouple pieces of code.

The Assign Employee Hours user interface component would use the Shift Hours Available component to find out what hours were not yet assigned. It would use the Employee Hours Available component to find out what hours an employee has available. After assigning new hours to the employee, it would update the other two components so that they know about the new assignment.

A component-based architecture decouples the pieces of code much as a multitier architecture does, but the pieces are all contained within the same executable program, so they communicate directly instead of across a network.

Service-Oriented

A *service-oriented architecture* (*SOA*) is similar to a component-based architecture except the pieces are implemented as services. A *service* is a self-contained program that runs on its own and provides some kind of service for its clients.

Sometimes, services are implemented as *web services*. Those are simply programs that satisfy certain standards, so they are easy to invoke over the Internet.

DEFINING SOA

Some big software vendors such as IBM and Oracle also define *Service Component Architecture* (*SCA*). This is basically a set of specifications for SOA defined by those companies.

Data-Centric

Data-centric or *database-centric architectures* come in a variety of flavors that all use data in some central way. The following list summarizes some typical data-centric designs:

- Storing data in a relational database system. This is so common that it's easy to think of as a simple technique for use in other architectures rather than an architecture of its own.
- Using tables instead of hard-wired code to control the application. Some artificial intelligence applications such as rule-based systems use this approach.
- Using stored procedures inside the database to perform calculations and implement business logic. This can be a lot like putting a middle tier inside the database.

Event-Driven

In an *event-driven architecture* (*EDA*), various parts of the system respond to events as they occur. For example, as a customer order for robot parts moves through its life cycle, different pieces of the system might respond at different times. When the order is created, a fulfillment module might

notice and print a list of the desired parts and an address label. When the order has been shipped, an invoicing module might notice and print an invoice. When the customer hasn't paid the invoice for 30 days, an enforcement module might notice and send RoboCop to investigate.

Rule-Based

A *rule-based architecture* uses a collection of rules to decide what to do next. These systems are sometimes called *expert systems* or *knowledge-based systems*.

The troubleshooting system described earlier in this chapter uses a rule-based approach.

Rule-based systems work well if you can identify the rules necessary to get the job done. Sometimes, you can build good rules even for complicated systems; although that can be a lot of work.

Rule-based systems don't work well if the problem is poorly defined so you can't figure out what rules to use. They also have trouble handling unexpected situations.

ROTTEN RULES

For several years I had a fairly odd network connection leading directly to my phone company's central office. One day it didn't work, so I called tech support, and the service rep started working through his troubleshooting rules. Unfortunately, the phone company hadn't offered my type of service for several years, so the rules didn't cover it.

Eventually, the rep reached a rule that asked me to unplug my modem and reconnect it. I explained that the modem was in the central office and that unplugging anything on my end would also disconnect my phone. The rules didn't give him any other options, so he insisted. I unplugged my cable and predictably the phone call dropped.

I called back, got a different rep who was a little better at thinking outside of the rules, and we discovered (as I had suspected) that the problem was at the central office.

Rule-based systems are great for handling common simple scenarios, but when they encounter anything unexpected they're quite useless. For that reason, you should always give the user a way to handle special situations manually.

Distributed

In a *distributed architecture*, different parts of the application run on different processors and may run at the same time. The processors could be on different computers scattered across the network, or they could be different cores on a single computer. (Most modern computers have multiple cores that can execute code at the same time.)

Service-oriented and multitier architectures are often distributed, with different parts of the system running on different computers. Component-oriented architectures may also be distributed, with different components running on different cores on the same computer.

In general, distributed applications can be extremely confusing and hard to debug. For example, suppose you're writing an application that sells office supplies such as staples, paper

clips, and demotivational posters. You sell to companies that might have several authorized purchasers.

Now suppose your application uses the following steps to add the cost of a new purchase to a customer's outstanding balance:

1. Get customer balance from database.
2. Add new amount to balance.
3. Save new balance in database.

This seems straightforward until you think about what happens if two people make purchases at almost the same time with a distributed application. Suppose a customer has an outstanding balance of $100. One purchaser buys $50 worth of sticky notes while another purchaser is buying a $10 trash can labeled "suggestions." Now suppose the application executes the two purchasers' steps in the order shown in Table 5-1.

TABLE 5-1: Office Supply Purchasing Sequence

PURCHASER 1	PURCHASER 2
Get balance. ($100)	
	Get balance. ($100)
Add to balance. ($150)	
	Add to balance. ($110)
Save new balance. ($150)	
	Save new balance. ($110)

In Table 5-1, time increases downward so Purchaser 1 gets the account balance first and then Purchaser 2 gets the account balance.

Next Purchaser 1 adds $50 to his balance to get $150, and then Purchaser 2 adds $10 to his balance to get $110.

Purchaser 1 then saves his new balance of $150 into the database. Finally Purchaser 2 saves his balance of $110 into the database, writing over the $150-balance that Purchaser 1 just saved. In the end, instead of holding a balance of $160 ($100 + $50 + $10), the database holds a balance of $110.

In distributed computing, this is called a *race condition*. The two processes are racing to see which one saves its balance first. Whichever one saves its balance second "wins." (Although you lose.)

A distributed architecture can improve performance as long as you don't run afoul of race conditions and other potential problems.

Mix and Match

An application doesn't need to stick with a single architecture. Different pieces of the application might use different design approaches. For example, you might create a distributed service-oriented

application. Some of the larger services might use a component-based approach to break their code into decoupled pieces. Other services might use a multitier approach to separate their features from the data storage layer. (Combining different architectures can also sound impressive at cocktail parties. "Yes, we decided to go with an event-driven multitier approach using rule-based distributed components.")

CLASSYDRAW ARCHITECTURE

Suppose you want to pick an architecture for the ClassyDraw application described in Chapter 4. (Recall that this is a drawing program somewhat similar to MS Paint except it lets you select and manipulate drawing objects.) One way to do that is to think about each of the standard architectures and decide whether it would make sense to use while building the program.

1. **Monolithic**—This is basically the default if none of the more elaborate architectures apply. We'll come back to this one later.
2. **Client/server, multitier**—ClassyDraw stores drawings in files, not a database, so client/server and multitier architectures aren't needed. (You could store drawings in a database if you wanted to, perhaps for an architectural firm or some other use where there would be some benefit. For a simple drawing application, it would be overkill.)
3. **Component-based**—You could think of different pieces of the application as components providing services to each other. For example, you could think of a "rectangle component" that draws a rectangle. For this simple application, it's probably just as easy to think of a `Rectangle` class that draws a rectangle, so I'm not going to think of this as a component-based approach.
4. **Service-oriented**—This is even less applicable than the component-based approach. Spreading the application across multiple computers connected via web services (or some other kind of service) wouldn't help a simple drawing application.
5. **Data-centric**—The user defines the drawings, so there's no data around which to organize the program. (Although a more specialized program, perhaps a drafting program for an architectural firm or an aerospace design program, might interact with data in a meaningful way.)
6. **Event-driven**—The user interface will be event-driven. For example, the user selects a tool and then clicks and drags to create a new shape.
7. **Rule-based**—There are no rules that the user must follow to make a drawing, so this program isn't rule-based.
8. **Distributed**—This program doesn't perform extensive calculations, so distributing pieces across multiple CPUs or cores probably wouldn't help.

Because none of the more exotic architectures applied (such as multitier or service-oriented), this application can have a simple monolithic architecture with an event-driven user interface.

Reports

Almost any nontrivial software project can use some kinds of reports. Business applications might include reports that deal with customers (who's buying, who has unpaid bills, where customers live), products (inventory, pricing, what's selling well), and users (which employees are selling a lot, employee work schedules).

Even relatively simple applications can sometimes benefit from reports. For example, suppose you're writing a simple shareware game that users will download from the Internet and install on their phones. The users won't want reports (except perhaps a list of their high scores), but you may want to add some reporting. You could make the game upload information such as where the users are, when they use the game, how often they play, what parts of the game take a long time, and so forth. You can then use that data to generate reports to help you refine the game and improve your marketing.

AD HOC REPORTING

A large application might have dozens or even hundreds of reports. Often customers can give you lists of existing reports that they use now and that they want in the new system. They may also think of some new reports that take advantage of the new system's features.

However, as development progresses, customers inevitably think of more reports as they learn more about the system. They'll probably even think of extra reports after you've completely finished development.

Adding dozens of new reports throughout the development cycle can be a burden to the developers. One way to reduce report proliferation is to forbid it. Just don't allow the customers to request new reports. Or you could allow new reports but require that they go through some sort of approval process so you don't get too many requests.

Another approach is to allow the users to create their own reports. If the application uses a SQL database, it's not too hard to buy or build a reporting tool that lets users type in queries and see the results. I've worked on projects where the customers used this capability to design dozens of new reports without creating extra work for the developers.

If you use this technique, however, you may need to restrict access to it so the users don't see confidential data. For example, a typical order entry clerk probably shouldn't be able to generate a list of employee salaries.

Some SQL statements can also damage the database. For example, the SQL `DROP TABLE` statement can remove a table from the database, destroying all its data. Make sure the ad hoc reporting tool is only usable by trusted users or that it won't allow those kinds of dangerous commands.

As is the case with high-level user interface design, you don't need to specify every detail for every report here. Try to decide which reports you'll need and leave the details for low-level design and implementation.

Other Outputs

In addition to normal reports, you should consider other kinds of outputs that the application might create. The application could generate printouts (of reports and other things), web pages, data files, image files, audio (to speakers or to audio files), video, output to special devices (such as electronic signs), e-mail, or text messages (which is as easy as sending an e-mail to the right address). It could even send messages to pagers, if you can find any that aren't in museums yet.

> **TIP** *Text (or pager) messages are a good way to tell operators that something is going wrong with the application. For example, if an order processing application is stuck and jobs are piling up in a queue, the application can send a message to a manager, who can then try to figure out what's wrong.*

Database

Database design is an important part of most applications. The first part of database design is to decide what kind of database the program will need. You need to specify whether the application will store data in text files, XML files, a full-fledged relational database, or something more exotic such as a temporal database or object store. Even a program that doesn't use any database still needs to store data, perhaps inside the program within arrays, lists, or some other data structure.

If you decide to use an external database (in other words, more than data that's built into the code), you should specify the database product that you will use. Many applications store their data in relational databases such as Access, SQL Server, Oracle, or MySQL. (There are dozens if not hundreds of others.)

If you use a relational database, you can sketch out the tables it contains and their relationships during high-level design. Later you can provide more details such as the specific fields in each table and the fields that make up the keys linking the tables.

DEFINING CLASSES

Often the tables in the database correspond to classes that you need to build in the code. At this point, it makes sense to write down any important classes you define. Those might include fairly obvious classes such as `Employee`, `Customer`, `Order`, `WorkAssignment`, and `Report`.

You'll have a chance to refine those classes and add others during low-level design and implementation. For example, you might create subclasses that add refinement to the basic high-level classes. You could create subclasses of the `Customer` class such as `PreferredCustomer`, `CorporateCustomer`, and `ImpulseBuyer`.

Use good database design practices to ensure that the database is properly normalized. Database design and normalization is too big a topic to cover in this book. (For an introduction to database design, see my book *Beginning Database Design Solutions*, Wiley, 2008.) Although

I don't have room to cover those topics in depth, I'll say more about normalization in the next chapter.

Meanwhile there are three common database-specific issues that you should address during high-level design: audit trails, user access, and database maintenance.

Audit Trails

An *audit trail* keeps track of each user who modifies (and in some applications views) a specific record. Later, management can use the audit trails to see which employee gave a customer a 120-percent discount. Auditing can be as simple as creating a history table that records a user's name, a link to the record that was modified, and the date when the change occurred. Some database products can even create audit trails for you.

A fancier version might store copies of the original data in each table when its data is modified. For example, suppose a user changes a customer's billing data to show the customer paid in full. Instead of updating the customer's record, the program would mark the existing (unpaid) record as outdated. It would then copy the old record, update it to show the customer's new balance, and add the date of the change and the user's name. Some applications also provide space for the users to add a note explaining why they gave the customer a $12,000-credit on the purchase of a box of cereal.

Later, you can compare the customer's records over time to build an audit trail that re-creates the exact sequence of changes made for that customer. (Of course, that means you need to add a way for the application to display the audit trail, and that means more work.)

> **NOTE** *Some businesses have rules or government regulations that require them to delete old data including audit trails.*

Many applications don't need auditing. If you write an online multiplayer rock-paper-scissors game, you probably don't need an extensive record of who picked paper in a match two months ago. You also may not need to add auditing to programs written for internal company use, and other programs that don't involve money, confidential records, or other data that might be tempting to misuse. In cases like those, you can simplify the application by skipping audit trails.

User Access

Many applications also need to provide different levels of access to different kinds of data. For example, a fulfillment clerk (who throws porcelain dishes into a crate for shipping) probably doesn't need to see the customer's billing information, and only managers need to see the other employees' salary information.

One way to handle user access is to build a table listing the users and the privileges they should be given. The program can then disable or remove the buttons and menu items that a particular user shouldn't be allowed to use.

Many databases can also restrict access to tables or even specific columns in tables. For example, you might be able to allow all users to view the `Name`, `Office`, and `PhoneNumber` fields in the `Employees` table without letting them see the `Salary` field.

Database Maintenance

A database is like a hall closet: Over time it gets disorganized and full of random junk like string, chipped vases, and unmatched socks. Every now and then, you need to reorganize so that you can find things efficiently.

If you use audit trails and the records require a lot of changes, the database will start to fill up with old versions of records that have been modified. Even if you don't use audit trails, over time the database can become cluttered with outdated records. You probably don't need to keep the records of a customer's gum purchase three years ago.

In that case, you may want to move some of the older data to long-term storage to keep the main database lean and responsive. Depending on the application, you may also need to design a way to retrieve the old data if you decide you want it back later.

You can move the older data into a *data warehouse*, a secondary database that holds older data for analysis. In some applications, you may want to analyze the data and store modified or aggregated forms in the warehouse instead of keeping every outdated record.

You may even want to discard the old data if you're sure you'll never need it again.

Removing old data from a database can help keep it responsive, but a lot of changes to the data can make the database's indexes inefficient and that can hurt performance. For that reason, you may need to periodically re-index key tables or run database tuning software to restore peak performance. In large, high-reliability applications, you might need to perform these sorts of tasks during off-peak hours such as between midnight and 2 a.m.

Finally, you should design a database backup and recovery scheme. In a low-priority application, that might involve copying a data file to a DVD every now and then. More typically, it means copying the database every night and saving the copy for a few days or a week. For high-reliability systems, it may mean buying a special-purpose database that automatically shadows every change made to any database record on multiple computers. (One telephone company project I worked on even required the computers to be in different locations so that they wouldn't all fail if a computer room was flooded or wiped out by a tornado.)

These kinds of database maintenance activities don't necessarily require programming, but they're all part of the price you pay for using big databases, so you need to plan for them.

Configuration Data

I mentioned earlier that you can save yourself a lot of time if you let users define their own ad hoc queries. Similarly, you can reduce your workload if you provide configuration screens so that users can fine-tune the application without making you write new code. Store parameters to algorithms, key amounts, and important durations in the database or in configuration files.

For example, suppose your application generates late payment notices if a customer has owed at least $50 for more than 30 days. If you make the values $50 and 30 days part of the configuration, you won't need to change the code when the company decides to allow a 5-day grace period and start pestering customers only after 35 days.

Make sure that only the right users can modify the parameters. In many applications, only managers should change these values.

Data Flows and States

Many applications use data that flows among different processes. For example, a customer order might start in an Order Creation process, move to Order Assembly (where items are gathered for shipping), and then go to Shipping (for actual shipment). Data may flow from Shipping to a final Billing process that sends an invoice to the customer via e-mail. Figure 5-5 shows one way you might diagram this data flow.

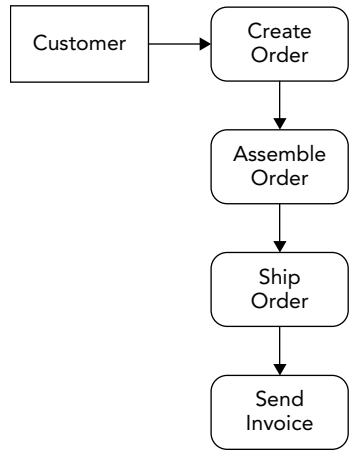


FIGURE 5-5: A data flow diagram shows how data such as a customer order flows through various processes.

You can also think of a piece of data such as a customer order as moving through a sequence of states. The states often correspond to the processes in the related data flow. For this example, a customer order might move through the states Created, Assembled, Shipped, and Billed.

Not all data flows and state transitions are as simple as this one. Sometimes events can make the data take different paths through the system. Figure 5-6 shows a state transition diagram for a customer order. The rounded rectangles represent states. Text next to the arrows indicates events that drive transitions. For example, if the customer hasn't paid an invoice 30 days after the order enters the Billed state, the system sends a second invoice to the customer and moves the order to the late state.

These kinds of diagrams help describe the system and the way processes interact with the data.

Training

Although it may not be time to start writing training materials, it's never too early to think about them. The details of the system will probably change a lot between high-level design and final installation, but you can at least think about how you want training to work. You can decide whether you want users to attend courses taught by instructors, read printed manuals, watch instructional videos, or browse documentation online.

Trainers may create content that discusses the application's high-level purpose, but you have to fill in most of the details later as the project develops.

UML

As mentioned in Chapter 4, "Requirement Gathering," the Unified Modeling Language (UML) isn't actually a single unified language. Instead it defines several kinds of diagrams that you can use to represent different pieces of the system.

The Object Management Group (OMG, yes, as in "OMG how did they get such an awesome acronym before anyone else got it?") is an international not-for-profit organization that defines modeling standards including UML. (You can learn more about OMG and UML at `www.uml.org`.)

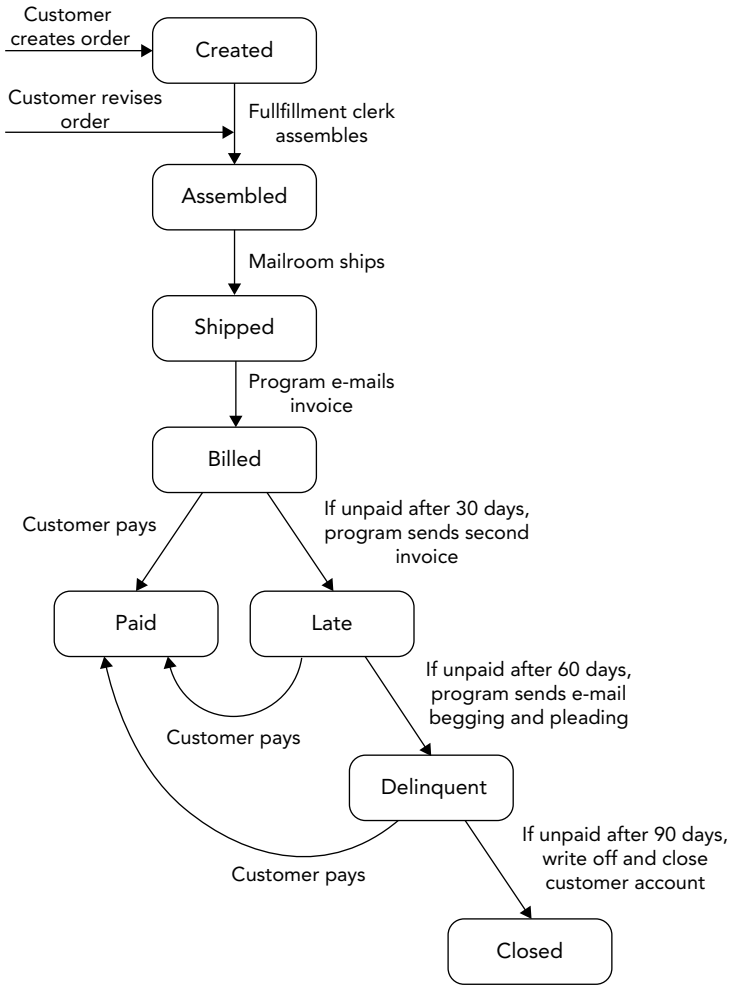


FIGURE 5-6: A data flow diagram shows how data such as a customer order flows through various processes.

UML 2.0 defines 13 diagram types divided into three categories (and one subcategory) as shown in the following list:

- Diagram
  - Structure Diagram
    - Class Diagram
    - Composite Structure Diagram
    - Component Diagram
    - Deployment Diagram

- Object Diagram
- Package Diagram
- Profile Diagram

- Behavior Diagram
  - Activity Diagram
  - Use Case Diagram
  - State Machine Diagram
  - Interaction Diagram
    - Sequence Diagram
    - Communication Diagram
    - Interaction Overview Diagram
    - Timing Diagram

Many of these are rather complicated so I won't describe them all in excruciating detail here. Instead the following sections give overviews of the types of diagrams in each category and provide a bit more detail about some of the most commonly used diagrams.

Structure Diagrams

A *structure diagram* describes things that will be in the system you are designing. For example, the class diagram (one type of structure diagram) shows relationships among the classes that will represent objects in the system such as inventory items, vehicles, expense reports, and coffee requisition forms.

OBJECTS AND CLASSES

I'll say a bit more about classes and class diagrams shortly, but briefly a *class* defines a type (or class) of items, and an *object* is an instance of the class. Often classes and objects correspond closely to real-world objects.

For example, a program might define a `Student` class to represent students. The class would define properties that all students share such as `Name`, `Grade`, and `HomeRoom`.

A specific instance of the `Student` class would be an object that represents a particular student, such as Rufus T. Firefly. For that object, the `Name` property would be set to "Rufus T. Firefly," `Grade` might be 12, and `HomeRoom` might be "11-B."

The following list summarizes UML's structure diagrams:

- Class Diagram—Describes the classes that make up the system, their properties and methods, and their relationships.
- Object Diagram—Focuses on a particular set of objects and their relationships at a specific time.

- Component Diagram—Shows how components are combined to form larger parts of the system.
- Composite Structure Diagram—Shows a class's internal structure and the collaborations that the class allows.
- Package Diagram—Describes relationships among the packages that make up a system. For example, if one package in the system uses features provided by another package, then the diagram would show the first "importing" the second.
- Deployment Diagram—Describes the deployment of *artifacts* (files, scripts, executables, and the like) on *nodes* (hardware devices or execution environments that can execute artifacts).

The most basic of the structure diagrams is the class diagram. In a class diagram, a class is represented by a rectangle. The class's name goes at the top, is centered, and is in bold. Two sections below the name give the class's properties and methods. (A *method* is a routine that makes an object do something. For example, the `Student` class might have a `DoAssignment` method that makes the `Student` object work through a specific class assignment.) Figure 5-7 shows a simple diagram for the `Student` class.

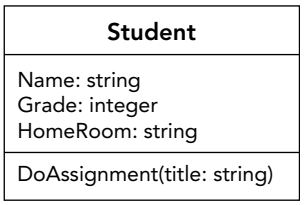


FIGURE 5-7: A class diagram describes the properties and methods of classes.

Some people add annotations to class representations to give you more detail. Most class diagrams include the data types of properties and parameters passed into methods, as shown in Figure 5-7. You can also add the symbols shown in Table 5-2 to the left of a class member to show its visibility within the project.

TABLE 5-2: Class Diagram Visibility Symbols

SYMBOL	MEANING	EXPLANATION
+	Public	The member is visible to all code in the application.
–	Private	The member is visible only to code inside the class.
#	Protected	The member is visible only to code inside the class and any derived classes.
~	Package	The member is visible only to code inside the same package.

Class diagrams also often show relationships among classes. Lines connect classes that are related to each other. A variety of line styles, symbols, arrowheads, and annotations give more information about the kinds of relationships.

The simplest way to use relationships is to draw an arrow indicating the direction of the relationship and label the arrow with the relationship's name. For example, in a school registration application, you might draw an arrow from the `Student` class to the `Course` class to indicate that a `Student` is associated with the `Courses` that student is taking. You could label that arrow "is taking."

At the line's endpoints, you can add symbols to indicate how many objects are involved in the relationship. Table 5-3 shows symbols you can add to the ends of a relationship.

TABLE 5-3: Class Diagram Multiplicity Indicators

SYMBOLS	MEANING
1	Exactly 1
0..1	0 or 1
0..*	Any number (0 or more)
*	Any number (0 or more)
1..*	1 or more

The class diagram in Figure 5-8 shows the "is taking" relationship between the `Student` and `Course` classes. In that relationship, 1 `Student` object corresponds to 1 or more `Course` objects.

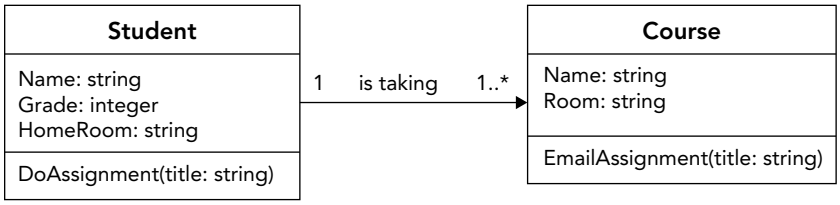


FIGURE 5-8: The relationship in this class diagram indicates that 1 Student takes 1 or more Courses.

Another important type of class diagram relationship is inheritance. In object-oriented programming, one class can inherit the properties and methods of another. For example, an honors student is a type of student. To model that in an object-oriented program, you could define an `HonorsStudent` class that inherits from the `Student` class. The `HonorsStudent` class automatically gets any properties and methods defined by the `Student` class (`Name`, `Grade`, `HomeRoom`, and `DoAssignment`). You can also add new properties and methods if you like. Perhaps you want to add a `GPA` property to the `HonorsStudent` class.

In a class diagram, you indicate inheritance by using a hollow arrowhead pointing from the child class to the parent class. Figure 5-9 shows that the `HonorsStudent` class inherits from the `Student` class.

Class diagrams for complicated applications can become cluttered and hard to read if you put everything in a single huge diagram. To reduce clutter, developers often draw multiple class diagrams showing parts of the system. In particular, they often make separate diagrams to show inheritance and other relationships.

For information about more elaborate types of class diagrams, search the Internet in general or the OMG website `www.omg.org` in particular.

Behavior Diagrams

UML defines three kinds of basic *behavior diagrams*: activity diagrams, use case diagrams, and state machine diagrams. The following sections provide brief descriptions of these kinds of diagrams and give a few simple examples.

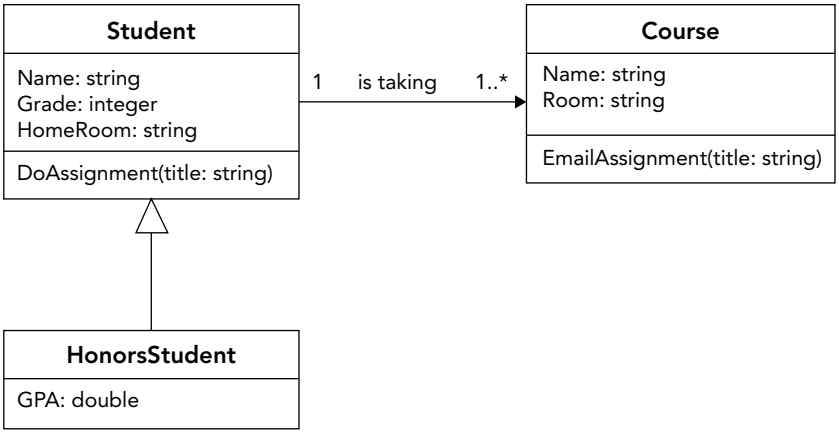


FIGURE 5-9: A class diagram indicates inheritance with a hollow arrowhead.

Activity Diagrams

An *activity diagram* represents work flows for activities. They include several kinds of symbols connected with arrows to show the direction of the work flow. Table 5-4 summarizes the symbols.

TABLE 5-4: Activity Diagram Symbols

SYMBOL	REPRESENTS
Rounded rectangle	An action or task
Diamond	A decision
Thick bar	The start or end of concurrent activities
Black circle	The start
Circled black circle	The end

Figure 5-10 shows a simple activity diagram for baking cookies.

The first thick bar starts three parallel activities: Start oven, mix dry ingredients, and mix wet ingredients. If you have assistant cookie chefs (perhaps your children, if you have any), those steps can all proceed at the same time in parallel.

When the three parallel activities all are done, the work flow resumes after the second thick bar. The next step is to combine all the ingredients.

A test then checks the batter's consistency. If the batter is too sticky, you add more flour and recheck the consistency. You repeat that loop until the batter has the right consistency.

When the batter is just right, you roll out the cookies, wait until the oven is ready (if it isn't already), and bake the cookies for eight minutes.

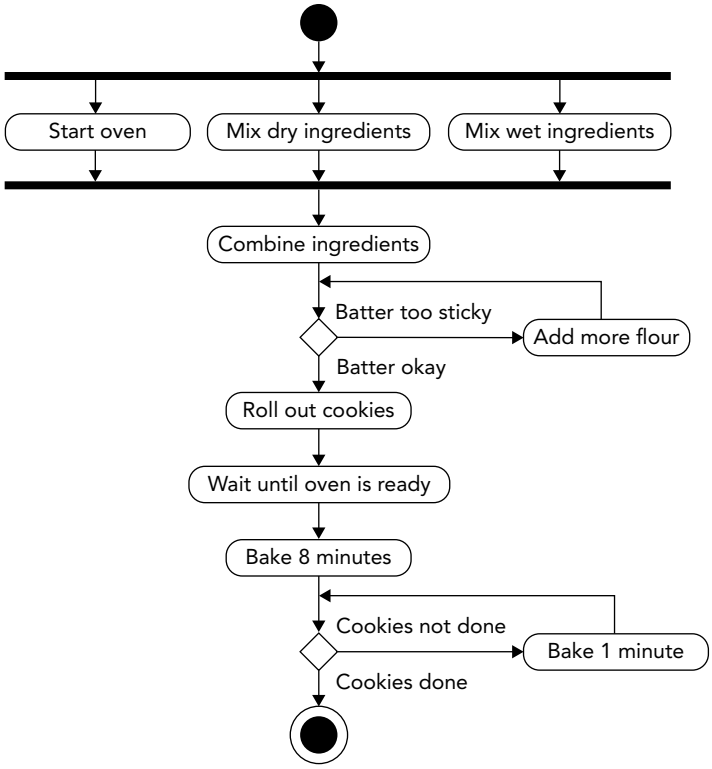


FIGURE 5-10: An activity diagram is a bit like a flowchart showing how work flows.

After eight minutes, you check the cookies. If the cookies aren't done, you bake them for one more minute. You continue checking and baking for one more minute as long as the cookies are not done.

When the cookies are done, you enter the stopping state indicated by the circled black circle.

Use Case Diagram

A *use case diagram* represents a user's interaction with the system. Use case diagrams show stick figures representing actors (someone or something that performs a task) connected to tasks represented by ellipses.

To provide more detail, you can use arrows to join subtasks to tasks. Use the annotation `<<include>>` to mean the task includes the subtask. (It can't take place without the subtask.)

If a subtask might occur only under some circumstances, connect it to the main task and add the annotation `<<extend>>`. If you like, you can add a note indicating when the extension occurs. (Usually both `<<include>>` and `<<extend>>` arrows are dashed.)

Figure 5-11 shows a simple online shopping use case diagram. The customer actor performs the "Search site for products" activity. If he finds something he likes, he also performs the "Buy products" extension. To buy products, the customer must log in to the site, so the "Buy products" activity includes the "Log on to site" activity.

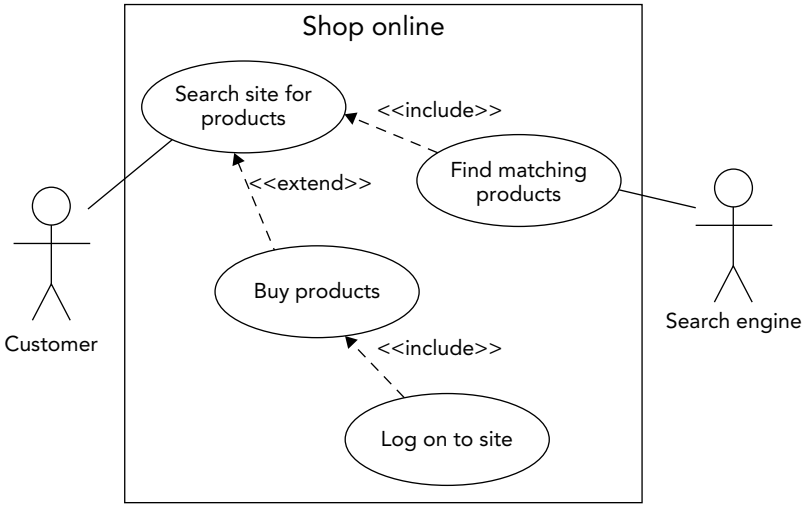


FIGURE 5-11: A use case diagram shows actors and the tasks they perform (possibly with subtasks and extensions).

The website's search engine also participates in the "Search site for products" activity. When the customer starts a search, the engine performs the "Find matching products" activity. The "Search" activity cannot work without the "Find" activity, so the "Find" activity is included in the "Search" activity.

State Machine Diagram

A *state machine diagram* shows the states through which an object passes in response to various events. States are represented by rounded rectangles. Arrows indicate transitions from one state to another. Sometimes annotations on the arrows indicate what causes a transition.

A black circle represents the starting state and a circled black circle indicates the stopping state.

Figure 5-12 shows a simple state machine diagram for a program that reads a floating point number (as in –17.32) followed by the Enter key.

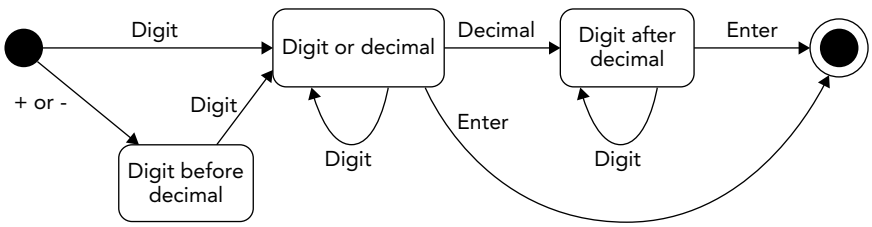


FIGURE 5-12: This state machine diagram represents reading a floating point number.

The program starts and can read a digit, +, or –. (If it reads any other character, the machine fails and the program would need to take some action, such as displaying an error message.) If it reads a +, or –, the machine moves to the state "Digit before decimal."

From that state, the user must enter a digit, at which point the machine moves into state "Digit or decimal." The machine also reaches this state if the user initially enters a digit instead of a +, or –.

Now if the user enters another digit, the machine remains in the "Digit or decimal" state. When the user enters a decimal point, it moves to the "Digit after decimal" state. If the user presses the Enter key, the machine moves to its stopping state. (That happens if the user enters a whole number such as 37.)

The machine remains in the "Digit after decimal" state as long as the user types a digit. When the user presses the Enter key, the machine moves to its stopping state.

Interaction Diagrams

Interaction diagrams are a subset of activity diagrams. They include sequence diagrams, communication diagrams, timing diagrams, and interaction overview diagrams. The following sections provide brief descriptions of these kinds of diagrams and give a few simple examples.

Sequence Diagram

A *sequence diagram* shows how objects collaborate in a particular scenario. It represents the collaboration as a sequence of messages.

Objects participating in the collaboration are represented as rectangles or sometimes as stick figures for actors. They are labeled with a name or class. If the label includes both a name and class, they are separated by a colon.

Below each of the participants is a vertical dashed line called a *lifeline*. The lifeline basically represents the participant sitting there waiting for something to happen.

An *execution specification* (called an *execution* or informally an *activation*) represents a participant doing something. In the diagram, these are represented as gray or white rectangles drawn on top of the lifeline. You can draw overlapping rectangles to represent overlapping executions.

Labeled arrows with solid arrowheads represent synchronous messages. Arrows with open arrowheads represent asynchronous messages. Finally, dashed arrows with open arrowheads represent return messages sent in reply to a calling message.

Figure 5-13 shows a customer, a clerk, and the `Movie` class interacting to print a ticket for a movie. The customer walks up to the ticket window and requests the movie from the clerk. The clerk uses a computer to ask the `Movie` class whether tickets are available for the desired show. The `Movie` class responds.

Notice that the `Movie` class's response is asynchronous. The class fires off a response and doesn't wait for any kind of reply. Instead it goes back to twiddling its electronic thumbs, waiting for some other request.

If the class's response is `false`, the interaction ends. (This scenario covers only the customer successfully buying a ticket.) If the response is `true`, control returns to the clerk, who uses the computer to ask the `Movie` class to select a seat. This causes another execution to run on the `Movie` class's lifeline.

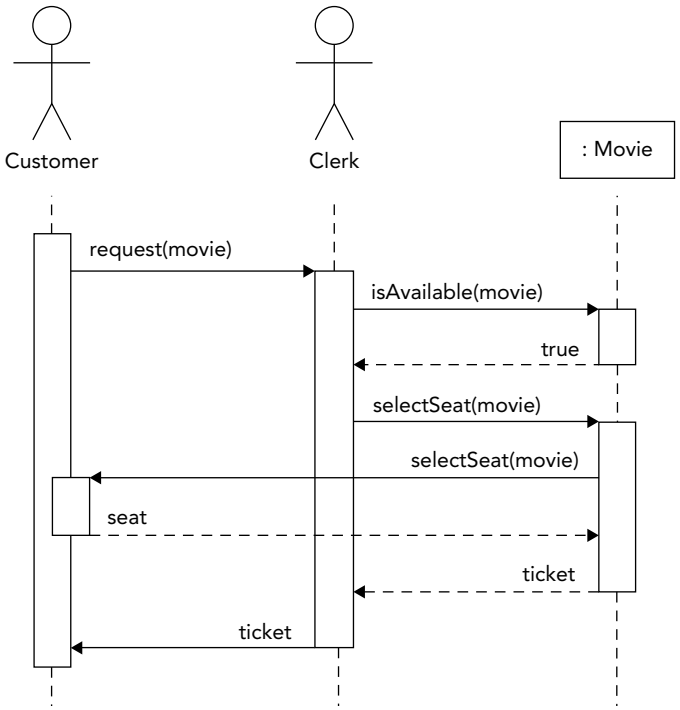


FIGURE 5-13: A sequence diagram shows the timing of messages between collaborating objects.

The `Movie` class in turn asks the customer to pick a seat from those that are available. The customer is still waiting for the initial request to finish, so this is an overlapping execution for the customer.

After the customer picks a seat, the `Movie` class issues a ticket to the clerk. The clerk then prints the ticket and hands it to the customer.

The point of this diagram is to show the interactions that occur between the participants and the order in which they occur. If you think the diagram is confusing, feel free to add some text describing the process.

Communication Diagram

Like a sequence diagram, a *communication diagram* shows communication among objects during some sort of collaboration. The difference is the sequence diagram focuses on the sequence of messages, but the communication diagram focuses more on the objects involved in the collaboration.

The diagram uses lines to connect objects that collaborate during an interaction. Labeled arrows indicate messages between objects. The messages are numbered that so you can follow the sequence of messages.

Figure 5-14 shows a communication diagram for the movie ticket buying-scenario that was shown in Figure 5-13.

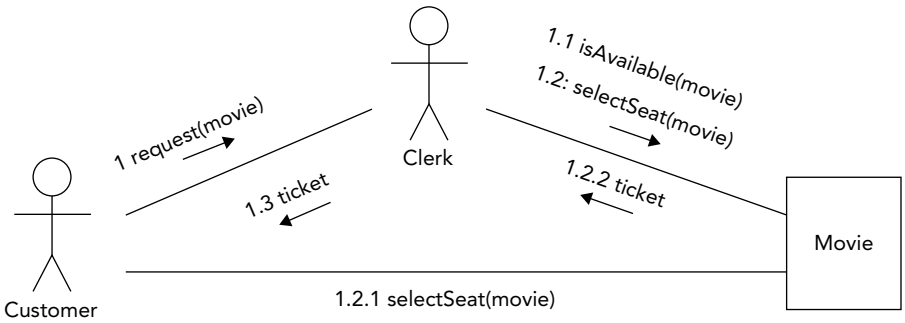


FIGURE 5-14: A communication diagram emphasizes the objects participating in a collaboration.

Following is the sequence of messages in Figure 5-14:

- **1:** The customer asks the clerk for a movie ticket.
- **1.1:** The clerk asks the `Movie` class if a seat is available.
- **1.2:** The clerk asks the `Movie` class to select a seat.
- **1.2.1:** The `Movie` class asks the user to pick a seat.
- **1.2.2:** The `Movie` class sends the clerk a ticket for the selected seat.
- **1.3:** The clerk prints the ticket and hands it to the customer.

The exact timing of the messages and some of the details (such as return messages) are not represented well in the communication diagram. Those details are better represented by a sequence diagram.

Timing Diagram

A *timing diagram* shows one or more objects' changes in state over time. A timing diagram looks a lot like a sequence diagram turned sideways, so time increases from left to right. These diagrams can be useful for giving a sense of how long different parts of a scenario will take.

More elaborate versions of the timing diagram show multiple participants stacked above each other with arrows showing how messages pass between the participants.

Interaction Overview Diagram

An *interaction overview diagram* is basically an activity diagram where the nodes can be frames that contain other kinds of diagrams. Those nodes can contain sequence, communication, timing, and other interaction overview diagrams. This lets you show more detail for nodes that represent complicated tasks.

SUMMARY

High-level design sets the stage for later software development. It deals with the grand decisions such as:

- What hardware platform will you use?
- What type of database will you use?
- What other systems will interact with this one?
- What reports can you make the users define so you don't have to do all the work?

After you settle these and other high-level questions, the stage is set for development. However, you're still not quite ready to start slapping together code to implement the features described in the requirements. Before you start churning out code, you need to create low-level designs to flesh out the classes, modules, interfaces, and other pieces of the application that you identified during high-level design. The low-level design will give you a detailed picture of exactly what code you need to write so you can begin programming.

The next chapter covers low-level design. It explains how you can refine the database design to ensure the database is robust and flexible. It also describes the kinds of information you need to add to the high-level design before you can start putting 0s and 1s together to make the final program.

EXERCISES

1. What's the difference between a component-based architecture and a service-oriented architecture?
2. Suppose you're building a phone application that lets you play tic-tac-toe against a simple computer opponent. It will display high scores stored on the phone, not in an external database. Which architectures would be most appropriate and why?
3. Repeat question 2 for a chess program running on a desktop, laptop, or tablet computer.
4. Repeat question 3 assuming the chess program lets two users play against each other over an Internet connection.
5. What kinds of reports would the game programs described in Exercises 2, 3, and 4 require?
6. What kind of database structure and maintenance should the ClassyDraw application use?
7. What kind of configuration information should the ClassyDraw application use?
8. Draw a state machine diagram to let a program read floating point numbers in scientific notation as in + 37 or –12.3e + 17 (which means $-12.3 \times 10^{+17}$). Allow both E and e for the exponent symbol.

WHAT YOU LEARNED IN THIS CHAPTER

- High-level design is the first step in breaking an application into pieces that are small enough to implement.
- Decoupling tasks allows different teams to work on them simultaneously.
- Some of the things you should specify in a high-level design include:
  - Security (operating system, application, data, network, and physical)
  - Operating system (Windows, iOS, or Linux)
  - Hardware platform (desktop, laptop, tablet, phone, or mainframe)
  - Other hardware (networks, printers, programmable signs, pagers, audio, or video)
  - User interface style (navigational techniques, menus, screens, or forms)
  - Internal interfaces
  - External interfaces
  - Architecture (monolithic, client-server, multitier, component-based, service-oriented, data-centric, event driven, rule-based, or distributed)
  - Reports (application usage, customer purchases, inventory, work schedules, productivity, or ad hoc)
  - Other outputs (printouts, web pages, data files, images, audio, video, e-mail, or text messages)
  - Database (database platform, major tables and their relationships, auditing, user access, maintenance, backup, and data warehousing)
  - Top-level classes (`Customer`, `Employee`, and `Order`)
  - Configuration data (algorithm parameters, due dates, expiration dates, and durations)
  - Data flows
  - Training
- UML diagrams lets you specify the objects in the system (including external agents such as users and external systems) and how they interact.
- The main categories of UML diagrams are structure diagrams and behavior diagrams (which includes the subcategory interaction diagrams).

6

Low-Level Design

We try to solve the problem by rushing through the design process so that enough time is left at the end of the project to uncover the errors that were made because we rushed through the design process.

—Glenford Myers

WHAT YOU WILL LEARN IN THIS CHAPTER:

- How to use generalization and refinement to build inheritance hierarchies
- Warning signs of bad inheritance hierarchies
- How to use composition to build new classes without inheritance
- How normalization protects databases from anomalies
- Rules for first, second, and third normal forms

High-level design paints an application's structure in broad strokes. It identifies the system's general environment (hardware, operating system, network, and so on) and architecture (such as monolithic, client/server, and service-oriented). It identifies the system's major components such as reporting modules, databases, and top-level classes. It should also sketch out how the pieces of the system will interact.

Low-level design fills in some of the gaps to provide extra detail that's necessary before developers can start writing code. It gives more specific guidance for how the parts of the system will work and how they will work together. It refines the definitions of the database, the major classes, and the internal and external interfaces.

High-level design focuses on *what*. Low-level design begins to focus on *how*.

As an analogy, if you were building a highway system, high-level design would determine what cities (and perhaps what parts of those cities) would be connected by highways. The low-level design would indicate exactly where the highways would be placed, where the ramps would be, and what elementary schools would be surrounded by four-lane traffic circles.

The border between high-level and low-level design is often rather fuzzy. Typically, after a piece of the system is added to the high-level design, team members continue working on that piece to develop its low-level design. Particularly on a large project, some people will be working on high-level designs while others work on low-level designs. Developers may even start implementing parts of the system that have been adequately defined.

In a way, you can describe low-level design as high-level design for micro-managers. You extend the high-level design by providing more and more detail until everything is specified precisely enough to start implementation.

However, refining a high-level design isn't necessarily easy. You may know generally what you need in the database (customer data and stuff), but unless you refine that knowledge into a good detailed database design, you may run into all sorts of problems later. The data may become inconsistent, the program might lose critical information, and finding data may be slow. Different database designs can make the difference between finding the data you need in seconds, hours, or not at all.

The following sections describe some of the most important concepts you should keep in mind during low-level design. They explain how to refine an object model to identify the application's classes, how to use stepwise refinement to provide additional detail for a task, and how to design a database that is flexible and robust.

OO DESIGN

The high-level design should have identified the major types of classes that the application will use. Now it's time to refine that design to identify the specific classes that program will need. The new classes should include definitions of the properties, methods, and events they will provide for the application to use.

A QUICK OO PRIMER

In object-oriented (OO) development, classes define the general properties and behaviors for a set of objects. An *instance* of a class is an object with the class's type.

For example, you could define an `Author` class to represent authors. An instance of the class might represent the specific author William Shakespeare. After you define the `Author` class, you could create any number of instances of that class to represent different authors.

Classes define three main items: properties, methods, and events.

A *property* is something that helps define an object. For example, the `Author` class might have `FirstName` and `LastName` properties to identify the specific author an instance represents. It might have other properties such as `DateOfBirth`, `DateOfDeath`, and `WrittenWorks`.

A *method* is a piece of code that makes an object do something. The `Author` class might have a `Search` method that searches an object's `WrittenWorks` values for a work that contains a certain word. It might also have methods to print a formatted list of the author's works, or to search online for places to buy one of the author's works.

An *event* is something that occurs to tell the program that something interesting has happened. An object *raises* an event when appropriate to let the program take some action. For example, an `Author` object might raise a `Birthday` event to tell the program that today is the author's birthday. (That would be hard for Shakespeare because no one knows exactly he was born.) When the program creates an `Author` object, that object would raise the `Birthday` event if it were the author's birthday. It would also raise that event if the object already existed and the clock ticked over past midnight so that it became the author's birthday.

After you design a class, you can use it like a cookie cutter to make as many instances of the class as you like. Each instance has the same properties, methods, and events; although, the properties can have different values in different instances.

Object-oriented development involves lots of other details, but this should be enough to get you through the following discussion. If you want more information about object-oriented programming, look for a book on the subject, either in general or for your favorite programming language.

Also look for books on design patterns. An object-oriented *design pattern* is an arrangement of classes that performs some common and useful task. For example, the model-view-controller (MVC) pattern breaks a user interface interaction into three pieces: a model object that represents some data, view objects that display a view of the data to the user, and controller objects that control the model, possibly allowing the user to manipulate the data. Design patterns can be useful in designing the classes that make up an application, but they're outside the scope of this book.

The following sections explain how you can define the classes that an application will use.

Identifying Classes

The previous chapter tells you that you should identify the main classes that the application will use, but it doesn't tell you how to do that. One way to pick classes is to look for nouns in a description of the application's features.

For example, suppose you're writing an application called FreeWheeler Automatic Driver (FAD) that automatically drives cars. Now consider the sentence, "The program drives the car to the selected destination." That sentence contains three nouns: program, car, and destination.

The program probably doesn't need to directly manipulate itself, so it's unlikely that you'll need a `Program` class. It will almost certainly need to work with cars and destinations, so you probably do need `Car` and `Destination` classes.

When you're studying possible classes, think about what sorts of information the class needs (properties), what sorts of things it needs to do (methods), and whether it needs to notify the program of changing circumstances (events). For this example, the `Car` class is going to be fully loaded, providing all sorts of properties (such as `CurrentSpeed`, `CurrentDirection`, and `FuelLevel`), methods (such as `Accelerate`, `Decelerate`, `ActivateTurnSignal`, and `HonkHorn`), and events (such as `DriverPressedStart`, `FuelLevelLow`, and `CollisionImminent`).

The `Destination` class is probably a lot simpler because it basically just represents a specific location. In fact, it may be that the application needs only a single instance of this class to record the current destination.

Making only a single instance of a class is a warning sign that perhaps the class isn't necessary. The fact that the `Destination` class doesn't do anything or change on its own (so it doesn't provide methods or events) is another indication that you might not need that class. In this example, you could store the destination information in a couple variables holding latitude and longitude.

Note that the class definitions depend heavily on how you will use the objects. For example, you could define a `Passenger` class to represent people riding in the car. A passenger has all sorts of interesting information such as `Name`, `Address`, `Age`, and `CreditScore`. However, the FreeWheeler program doesn't need to know any of that information. It might not even need to know if the car contains any passengers. (Although it probably needs to have a driver, at least until automated cars become so good they can travel on their own.)

Building Inheritance Hierarchies

After you define the application's main classes, you need to add more detail to represent variations on those classes. For example, FreeWheeler is going to need a `Car` class to represent the vehicle it's driving, but different vehicles have different characteristics. A 106-horsepower Toyota Yaris handles differently than a 460-horsepower Chevrolet Corvette. It would be bad if the program told the Yaris to pull out in front of a speeding tractor trailer, assuming it could go from 0 to 60 miles per hour in 3.7 seconds.

You can capture the differences between related classes by *deriving* a *child class* from a *parent class*. In this example, you might derive the `Yaris` and `Corvette` child classes from the `Car` parent class.

Child classes automatically inherit the properties, methods, and events defined by the parent class. For example, the `Car` class might define methods such as `SetParkingBrake`, `TurnLeft`, and `DeployDragChute`. Because `Corvette` inherits from the `Car` class, a `Corvette` object automatically knows how to perform those methods.

This is one important way object-oriented programming languages achieve code reuse. You write code once in the parent class and any child classes use that same code without you rewriting it.

The fact that `Corvette` inherits from `Car` also means that a `Corvette` is a kind of `Car`. Intuitively, that makes sense. In real life, a Corvette is a car, so it should do anything that any other car can do.

Because an instance of a child class also belongs to the parent class, the program should be able to treat the object as if it were of the parent class if that would be helpful. In this example, that means a program should be able to treat a `Corvette` object as either a `Corvette` or as a more generic `Car`. For instance, the program could create an array of `Car` objects and fill it with instances of the `Corvette`, `Yaris`, `VolkswagenBeatle`, or `DeLorean` classes. The program should be able to treat all those objects as if they were `Car`s without knowing their true classes. The capability to treat objects as if they were actually from a different class is called *polymorphism*.

You can derive multiple classes from a single parent class. For example, you could derive `Corvette`, `Edsel`, and `Pinto` all from the `Car` class.

Conversely, most object-oriented programming languages do not allow *multiple inheritance*, so a class can have at most a single parent class. Because classes can have at most one parent but any number of children, the relationships between classes form a tree-like *inheritance hierarchy*.

There are a lot of ways you can modify basic inheritance relationships. For example, a child class can add properties, methods, and events (which together are called *members*) that are not available in the parent class. A child class can also replace a parent class member with a new version.

In some languages the child class can even define a new version of a member that applies when the program refers to an object by using the child class but not when it refers to it with a variable that has the parent class's type. For example, you might give the `Car` class a `ParallelPark` method that carefully backs the car into a parking space. The `Corvette` class might define a new version that locks up the brakes and slides the car into the space sideways as if James Bond were driving. Now if the program defines a variable of type `Car` that refers to a `Corvette` object and invokes its `ParallelPark` method, you get the first version. If the program defines a second variable of type `Corvette` that refers to the same object and invokes its `ParallelPark` method, you get the second version.

The details of how you define classes, build inheritance hierarchies, and add or modify their members depend on the language you use, so those things aren't covered in this book. Before moving on to other topics, however, you should know about the two main ways for building inheritance hierarchies: refinement and generalization.

Refinement

Refinement is the process of breaking a parent class into multiple subclasses to capture some difference between objects in the class. When I derived the `Corvette`, `Edsel`, and `Pinto` classes from the `Car` class, that was refinement.

One danger to refinement is *overrefinement*, which happens when you refine a class hierarchy unnecessarily, making too many classes that make programming more complicated and confusing. People are naturally good at categorizing objects. It takes only a few seconds of thought to break cars into the classes shown in Figure 6-1. The open arrowheads point from child classes to their parent classes.

With a bit more work, you can grow this hierarchy until it is truly enormous. There are a couple hundred models of car on the roads in the United States alone. You could refine most of those models with different options such as different engine sizes, radios, speakers, alloy wheels, spoilers, and seat warmers. You could add still more subclasses to represent different colors.

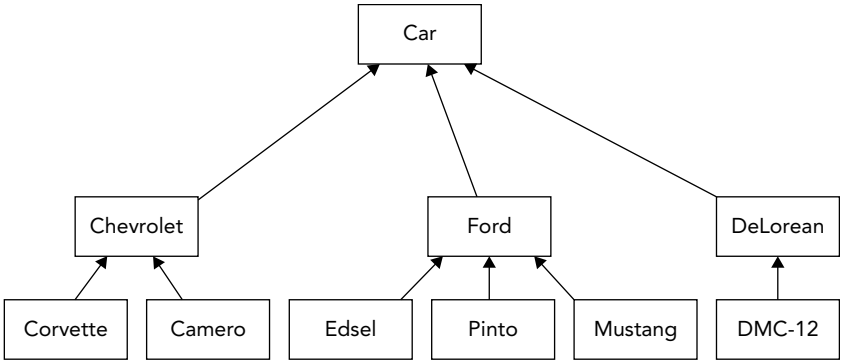


FIGURE 6-1: People are naturally good at building inheritance hierarchies.

The resulting hierarchy would contain many thousands (possibly millions) of classes. Obviously, a hierarchy that large wouldn't be useful. There's no way you could write enough code to actually use each of the classes, and if you're not going to use a class, why build it?

There are two main problems here. First, the classes are capturing data that isn't relevant to the application. The FreeWheeler application doesn't care what color a car is or whether it has a CD changer. It only cares about the car's driving characteristics: mileage, maximum acceleration, turn radius, and so forth. The hierarchy in Figure 6-1 doesn't capture any of that information.

RISKY REFINEMENT

Even if the program cares about certain differences between objects, that doesn't mean those differences would make a good inheritance hierarchy. For example, suppose you're writing a car sales application. Customers often want to shop for cars first by make, then by model, and then by option packages and other features. In that case, the customer's search strategy looks a lot like Figure 6-1.

Unfortunately, if you use those values to build the inheritance hierarchy, you get a monstrously huge hierarchy. Even though the program cares a lot about those differences, they're better handled as properties rather than subclassing. It's easy enough for a program to search a database for specific property values such as make or model without storing the data in a hierarchical format.

The second problem with this hierarchy is that the differences between cars could easily be represented by properties instead of by different classes. The differences identified so far actually are just different values for the same properties. For example, Chevrolet, Ford, and DeLorean are all just different values for a `Make` property. You could eliminate that whole level of the hierarchy by simply adding a `Make` property to the `Car` class.

Similarly, a car's model (Corvette, Edsel, and Mustang) is just a name for a specific type of car. You may have some expectations based on the name (you probably think a Corvette is faster than a Pinto), but to the FreeWheeler program, those are just labels.

You can avoid these kinds of hierarchy problems if you focus on behavioral differences between the different kinds of objects instead of looking at differences in properties.

For example, what are the behavioral differences between a Corvette and a Pinto? The Corvette accelerates quicker, but both cars *can* accelerate, just at different rates. They still have the same acceleration behavior, so you can represent that difference as an `Acceleration` property in the `Car` class.

For an example where there is a behavioral difference, consider transmission type. To accelerate a car with automatic transmission to freeway speeds, you simply stomp on the gas pedal until the car is going fast enough. Bringing a manual transmission car up to speed is much more complicated, requiring you to use the gas pedal, the clutch, and the gear shift. Both kinds of vehicles accelerate, but the details about how they do it are different.

In object-oriented terms, the `Car` class might have an `Accelerate` method that makes the car accelerate. The `Automatic` and `Manual` subclasses would provide different implementations of the `Accelerate` method that handle the appropriate details.

Figure 6-2 shows a revised inheritance hierarchy. The first section under a class's name lists its properties (just `Acceleration` in this example). A subclass does not repeat items that it inherits without modification from its parent class. In this example, the `Automatic` and `Manual` classes inherit the `Acceleration` property.

The second section below a class's name shows methods (`Accelerate` in this example). The method is italicized in the `Car` class to indicate that it is not implemented there and must be overridden in the child classes.

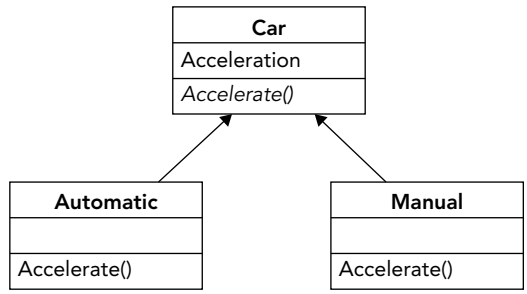


FIGURE 6-2: This hierarchy focuses on behavioral differences between classes.

Generalization

Refinement starts with a single class and creates child classes to represent differences between objects. Generalization does the opposite: It starts with several classes and creates a parent for them to represent common features.

For example, consider the ClassyDraw application in the examples in Chapter 4, "Requirement Gathering," and Chapter 5, "High-Level Design." This program is a drawing application somewhat similar to MS Paint, except it allows you to manipulate drawn objects. It enables you to select an object, drag it into a new position, stretch it, move it to the top or bottom of the stacking order, delete it, copy and paste it, and so forth.

The program represents drawn objects as (you guessed it) objects, so it needs classes such as `Rectangle`, `Ellipse`, `Polygon`, `Text`, `Line`, `Star`, and `Hypotrochoid`.

These classes draw different shapes, but they also have a lot in common. They all let you click their object to select it, move the object to the top or bottom of the drawing order, move the object, and so forth.

Because all those objects share these features, it makes sense to create a parent class that defines them. The program can build a big array or list to hold all the drawing objects represented by the parent class and then use polymorphism to invoke the common methods as necessary.

For a concrete example, suppose the user clicks part of a drawing to select a drawn object. Classes such as `Rectangle` and `Ellipse` use different techniques to decide whether you clicked their objects, but they both need a method to do that. You could call this method `ObjectIsAt` and make it return true if the object is at a specific clicked location. The parent class, which I'll call `Drawable`, can define the `ObjectIsAt` method. The child classes would then provide their own implementations.

Figure 6-3 shows the drawing class inheritance hierarchy.

Just as you can go overboard with refinement to build an inheritance hierarchy containing thousands of car classes, you can also get carried away with generalization. For example, suppose you're building a pet store inventory application. You define a `Customer` class and an `Employee` class. They share some properties such as `Name`, `Address`, and `ZodiacSign`, so you generalize them by making a `Person` class to hold the common properties.

Next, you define various pet classes such as `Dog`, `Cat`, `Gerbil`, and `Capybara`. You generalize them to make a `Pet` class.

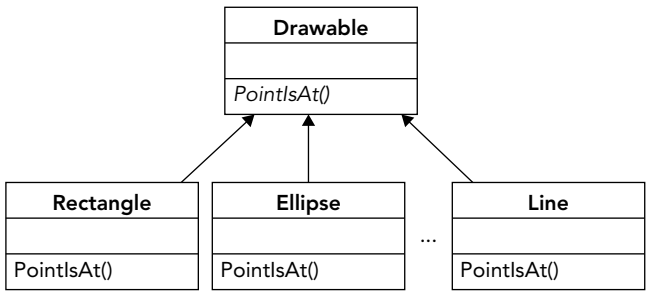


FIGURE 6-3: Generalization creates the Drawable parent class.

In a fit of inspiration (possibly assisted by whatever you were drinking), you realize that people and pets are all animals! So you make an `Animal` class to be a parent class for `Person` and `Pet`. They can even share some properties such as `Name`.

Logically, this makes sense. People and pets really are animals (as long as your pet store doesn't sell pet rocks or stuffed toys). However, it's unlikely that the program will ever take advantage of this fact. It's hard to imagine the program building an array or list containing both employees and birds and then treating them in a uniform way. In all likelihood, the program will treat people and pets in different ways, so they don't need to be merged into a single inheritance hierarchy.

Hierarchy Warning Signs

The following list gives some questions you can ask yourself when trying to decide if you have an effective inheritance hierarchy.

- Is it tall and thin? In general, tall, thin inheritance hierarchies are more confusing than shorter ones. Tall hierarchies make it hard for developers to remember which class to use under different circumstances. How tall an inheritance hierarchy can be depends on your application, but if it contains more than three or four levels, you should make sure you really need them all.
- Do you have a huge number of classes? Suppose your car sales application needs to track make, model, year, color, engine, wheel size, and motorized cup holders. If you try to use

classes to represent every possible combination, you'll get a combinatorial explosion and thousands of classes. If you have more than a dozen or so classes, see if you can replace some with simple properties.

- Does a class have only a single subclass? If so, then you can probably remove it and move whatever it was trying to represent into the subclass.
- If there a class at the bottom of the hierarchy that is never instantiated? If the `Car` hierarchy has a `HalfTrack` class and the program never makes an instance of that class, then you probably don't need the `HalfTrack` class.
- Do the classes all make common sense? If the `Car` hierarchy contains a `Helicopter` class, there's probably something wrong. Either the class doesn't belong there or you should rename some classes so things make sense. (Perhaps you need a `Vehicle` class?)
- Do classes represent differences in a property's value rather than in behavior or the presence of properties? A simple sales program might not need separate classes to represent notebooks and three-hole punches because they're both simple products that you sell one at a time. You might want a separate class for more expensive objects like computers because they might have a `Warranty` property that notebooks and hole punches probably don't have.

Object Composition

Inheritance is one way you can reuse code. A child class inherits all of the code defined by its parent class, so you don't need to write it again. Another way to reuse code is *object composition*, a technique that uses existing classes to build more complex classes.

For example, suppose you define a `Person` class that has `FirstName`, `LastName`, `Address`, and `Phone` properties. Now you want to make a `Company` class that should include information about a contact person.

You could make the `Company` class inherit from the `Person` class so it would inherit the `FirstName`, `LastName`, `Address`, and `Phone` properties. That would give you places to store the contact person's information, but it doesn't make intuitive sense. A company is not a kind of person (despite certain Supreme Court rulings), so `Company` should not inherit from `Person`.

A better approach is to give the `Company` class a new property of type `Person` called `ContactPerson`. Now the `Company` class gets the benefit of the code defined by the `Person` class without the illogic and possible confusion of inheriting from `Person`.

This approach also lets you place more than one `Person` object inside the `Company` class. For example, if you decide the `Company` class also needs to store information about a billing contact and a shipping contact, you can add more `Person` objects to the class. You couldn't do that with inheritance.

DATABASE DESIGN

There are many different kinds of databases that you can use to build an application. For example, specialized kinds of databases store hierarchical data, documents, graphs and networks, key/value pairs, and objects. However, the most popular kind of databases are relational databases.

DATABASE RANKINGS

To see the top database engines ranked by popularity, go to `db-engines.com/en/ranking`. It's a pretty interesting list.

Relational databases are simple, easy to use, and provide a good set of tools for searching, combining data from different tables, sorting results, and otherwise rearranging data.

Like object-oriented design, database design is too big a topic to squeeze into a tiny portion of this book. However, there is room here to cover a few of the most important concepts of database design. You can find a book on database design for more complete information. (For example, see my book *Beginning Database Design Solutions*, Wrox, 2008.)

The following section briefly explains what a relational database is. The sections after that explain the first three forms of database normalization and why they are important.

Relational Databases

Before you learn about database normalization, you need to at least know the basics of relational databases.

A *relational database* stores related data in *tables*. Each table holds *records* that contain pieces of data that are related. Sometimes records are called *tuples* to emphasize that they contain a set of related values.

The pieces of data in each record are called *fields*. Each field has a name and a data type. All the values in different records for a particular field have that data type.

Figure 6-4 shows a small `Customer` table holding five records. The table's fields are `CustomerId`, `FirstName`, `LastName`, `Street`, `City`, `State`, and `Zip`. Because the representation shown in Figure 6-4 lays out the data in rows and columns, records are often called *rows* and fields are often called *columns*.

CustomerId	FirstName	LastName	Street	City	State	Zip
1028	Veronica	Jenson	176 Bradley Ave	Abend	AZ	87351
2918	Kirk	Wood	61 Beech St	Bugsville	CT	04514
7910	Lila	Rowe	8391 Cedar Ct	Cobblestone	SC	35245
3198	Deirdre	Lemon	2819 Dent Dr	Dove	DE	29183
5002	Alicia	Hayes	298 Elf Ln	Eagle	CO	83726

FIGURE 6-4: A table's records are often called rows and its fields are often called columns.

The "relational" part of the term "relational database" comes from relationships defined between the database's tables. For example, consider the `Orders` table shown in Figure 6-5. The `Customers` table's `CustomerId` field and the `Orders` table's `CustomerId` field form a relationship between the two tables. To find a particular customer's orders, you can look up that customer's `CustomerId` in the `Customers` table in Figure 6-4, and then find the corresponding `Orders` records.

CustomerId	OrderId	DateOrdered	DateFilled	DateShipped
1028	1298	4/1/2015	4/4/2015	4/4/2015
2918	1982	4/1/2015	4/3/2015	4/4/2015
3198	2917	4/2/2015	4/7/2015	4/9/2015
1028	9201	4/5/2015	4/6/2015	4/9/2015
1028	3010	4/9/2015	4/13/2015	4/14/2015

FIGURE 6-5: The Customers table's CustomerId column provides a link to the Orders table's CustomerID column.

One particularly useful kind of relationship is a foreign key relationship. A *foreign key* is a set of one or more fields in one table with values that uniquely define a record in another table.

For example, in the `Orders` table shown in Figure 6-5, the `CustomerId` field uniquely identifies a record in the `Customers` table. In other words, it tells you which customer placed the order. There may be multiple records in the `Orders` table with the same `CustomerId` (a single customer can place multiple orders), but there can be only one record in the `Customers` table that has a particular `CustomerId` value.

The table containing the foreign key is often called the *child table*, and the table that contains the uniquely identified record is often called the *parent table*. In this example, the `Orders` table is the child table, and the `Customers` table is the parent table.

LOOKUP TABLES

A *lookup table* is a table that contains values just to use as foreign keys.

For example, you could make a `States` table that lists the states that are allowed by the application. If your company has customers only in New England, the table might contain the values Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island.

The `Customers` table would be a child table connected to the `States` table with a foreign key. That would prevent a user from adding a new customer in a state that wasn't allowed.

In addition to validating user inputs, lookup tables allow the users to configure the application. If you let users modify the `States` table, they can add new records when they decide to work with customers in new states.

Building a relational database is easy, but unless you design the database properly, you may encounter unexpected problems. Those problems may be that:

- Duplicate data can waste space and make updating values slow.
- You may be unable to delete one piece of data without also deleting another unrelated piece of data.

- An otherwise unnecessary piece of data may need to exist so that you can represent some other data.
- The database may not allow multiple values when you need them.

The database-speak euphemism for these kinds of problems is *anomalies*.

Database normalization is a process of rearranging a database to put it into a standard (normal) form that prevents these kinds of anomalies. There are seven levels of database normalization that deal with increasingly obscure kinds of anomalies. The following sections describe the first three levels of normalization, which handle the worst kinds of database problems.

First Normal Form

First normal form (*1NF*) basically says the table can be placed meaningfully in a relational database. It means the table has a sensible, down-to-earth structure like the kind your grandma used to make.

Relational database products tend to enforce most of the 1NF rules automatically, so if you don't do anything too weird, your database will be in 1NF with little extra work.

The official requirements for a table to be in 1NF are:

1. Each column must have a unique name.
2. The order of the rows and columns doesn't matter.
3. Each column must have a single data type.
4. No two rows can contain identical values.
5. Each column must contain a single value.
6. Columns cannot contain repeating groups.

To see how you might be tricked into breaking these rules, suppose you're a weapons instructor at a fantasy adventure camp. You teach kids how to whack each other safely with foam swords and the like. Now consider the signup sheet shown in Table 6-1.

TABLE 6-1: Weapons Training Signup Sheet

NAME	WEAPON	WEAPON
Shelly Silva	Broadsword	
Louis Christenson	Bow	
Lee Hall	Katana	
Sharon Simmons	Broadsword	Bow
Felipe Vega	Broadsword	Katana
Louis Christenson	Bow	
Kate Ballard	Everything	

Here campers list their names and weapons for which they want training. You'll call them in for instruction on a first-come-first-served basis.

This signup sheet violates the 1NF rules in several ways.

It violates Rule 1 because it contains two columns named `Weapon`. The idea is that a camper might want help with more than one weapon. That makes sense on a signup sheet but won't work in a relational database.

It violates Rule 2 because the order of the rows indicates the order in which the campers signed up and the order in which you'll tutor them. In other words, the ordering of the rows is important. (The order of the columns might also be important if you assume the first `Weapon` column holds the camper's primary weapon.)

It violates Rule 3 because Kate Ballard didn't enter the name of a weapon in the first weapon column. Ideally, that column's data type would be `Weapon` and campers would just enter a weapon's name, not a general comment such as "Everything."

It violates Rule 4 because Louis Christenson signed up twice for tutoring with the bow. (I guess he wants to get *really* good with the bow.)

The signup sheet doesn't violate Rule 5, but that's mostly due to luck. There's nothing (except common sense) to stop campers from entering multiple weapons in each `Weapon` column, and that would violate Rule 5.

Here's how you can put this signup sheet into 1NF.

Rule 1—The signup sheet has two columns named `Weapon`. You can fix that by changing their names to `Weapon1` and `Weapon2`. (That violates Rule 6, but we'll fix that later.)

Rule 2—The order of the rows in the signup sheet determines the order in which you'll call campers for their tutorials, so the ordering of rows is important. To fix this problem, add a new field that stores the ordering data explicitly. One way to do that would be to add an `Order` field, as shown in Table 6-2.

TABLE 6-2: Ordered Signup Sheet

ORDER	NAME	WEAPON1	WEAPON2
1	Shelly Silva	Broadsword	
2	Louis Christenson	Bow	
3	Lee Hall	Katana	
4	Sharon Simmons	Broadsword	Bow
5	Felipe Vega	Broadsword	Katana
6	Louis Christenson	Bow	
7	Kate Ballard	Everything	

An alternative that might be more useful would be to add a `Time` field instead of an `Order` field, as shown in Table 6-3. That preserves the original ordering and gives extra information that the campers can use to schedule their days.

TABLE 6-3: Signup Sheet with Times

TIME	NAME	WEAPON1	WEAPON2
9:00	Shelly Silva	Broadsword	
9:30	Louis Christenson	Bow	
10:00	Lee Hall	Katana	
10:30	Sharon Simmons	Broadsword	Bow
11:00	Felipe Vega	Broadsword	Katana
11:30	Louis Christenson	Bow	
12:00	Kate Ballard	Everything	

Rule 3—In Table 6-3, the `Weapon1` column holds two kinds of values: the name of a weapon or "Everything" (for Kate Ballard).

Depending on the application, there are several approaches you could take to fix this kind of problem. You could split a column into two columns, each containing a single data type. Alternatively, you could move the data into separate tables linked to the original record by a key.

In this example, I'll replace the value "Everything" with multiple records that list all the possible weapon values. The result is shown in Table 6-4.

TABLE 6-4: Signup Sheet with Explicitly Listed Weapons

TIME	NAME	WEAPON1	WEAPON2
9:00	Shelly Silva	Broadsword	
9:30	Louis Christenson	Bow	
10:00	Lee Hall	Katana	
10:30	Sharon Simmons	Broadsword	Bow
11:00	Felipe Vega	Broadsword	Katana
11:30	Louis Christenson	Bow	
12:00	Kate Ballard	Broadsword	
12:00	Kate Ballard	Bow	
12:00	Kate Ballard	Katana	

Rule 4—The current design doesn't contain any duplicate rows, so it satisfies Rule 4.

Rule 5—Right now each column contains a single value, so the current design satisfies Rule 5. (The original signup sheet would have broken this rule if it had used a single `Weapons` column instead of using two separate columns and people had written in lists of the weapons they wanted to study.)

Rule 6—This rule says a table cannot contain repeating groups. That means you can't have two columns that represent the same thing. This means a bit more than two columns don't have the same *data type*. Tables often have multiple columns with the same data types but with different meanings. For example, the `Camper` table might have `HomePhone` and `CellPhone` fields. Both of them would hold phone numbers, but they represent different *kinds* of phone numbers.

In the current design, the `Weapon1` and `Weapon2` columns hold the same type and kind of data, so they form a repeating group.

ROTTEN REPETITION

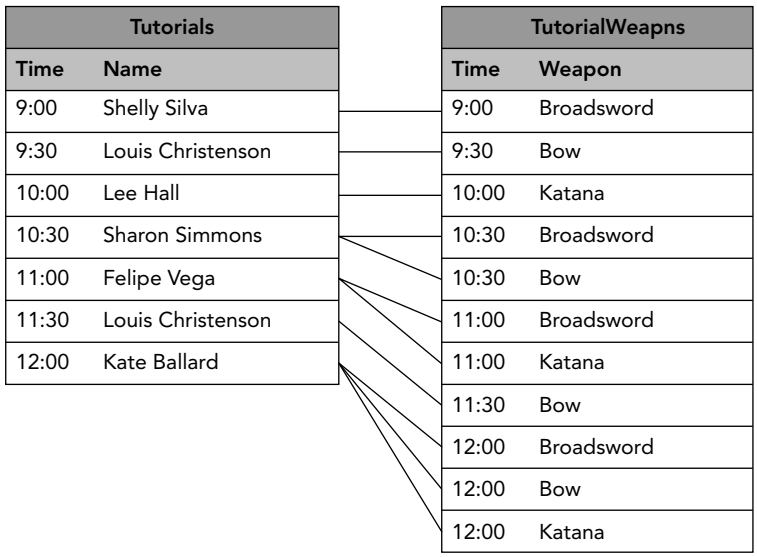
In general, adding a number to field names to differentiate them is a bad idea. If the program doesn't need to differentiate between the two values, then adding a number to their names just creates a repeating group.

The only time this makes sense is if the two fields contain similar items that truly have different meanings to the application. For example, suppose a space shuttle requires two pilots: one to be the primary pilot and one to be the backup in case the primary pilot is abducted by aliens. In that case, you could name the fields that store their names `Pilot1` and `Pilot2` because there really is a difference between them.

Usually in cases like this, you can give the fields more descriptive names such as `Pilot` and `Copilot`.

Another way to look at this is to ask yourself whether the record "Sharon Simmons, Broadsword, Bow" and the rearranged record "Sharon Simmons, Bow, Broadsword" would have the same meaning. If the two have the same meaning even if you switch the values of the two fields, then those fields form a repeating group.

The way to fix this problem is to pull the repeated data out into a new table. Use fields in the original table to link to the new one. Figure 6-6 shows the new design. Here the `Tutorials` and `TutorialWeapons` tables are linked by their `Time` fields.



Tutorials

Time	Name
9:00	Shelly Silva
9:30	Louis Christenson
10:00	Lee Hall
10:30	Sharon Simmons
11:00	Felipe Vega
11:30	Louis Christenson
12:00	Kate Ballard

TutorialWeapns

Time	Weapon
9:00	Broadsword
9:30	Bow
10:00	Katana
10:30	Broadsword
10:30	Bow
11:00	Broadsword
11:00	Katana
11:30	Bow
12:00	Broadsword
12:00	Bow
12:00	Katana

FIGURE 6-6: This design is in first 1NF. Lines connect related records.

Second Normal Form

A table is in *second normal form* (*2NF*) if it satisfies these rules:

1. It is in 1NF.
2. All non-key fields depend on all key fields.

Without getting two technical, a *key* is a set of one or more fields that uniquely identifies a record. Any table in 1NF must have a key because 1NF Rule 4 says, "No two rows can contain identical values." That means there must be a way to pick fields to guarantee uniqueness, even if the key must include every field.

For an example of a table that is not in 2NF, suppose you want to schedule games for campers at the fantasy adventure camp. Table 6-5 lists the scheduled games.

TABLE 6-5: Camp Games Schedule

TIME	GAME	DURATION	MAXIMUMPLAYERS
1:00	*Goblin Launch*	60 mins	8
1:00	*Water Wizzards*	120 mins	6
2:00	*Panic at the Picnic*	90 mins	12
2:00	*Goblin Launch*	60 mins	8
3:00	*Capture the Castle*	120 mins	100
3:00	*Water Wizzards*	120 mins	6
4:00	*Middle Earth Hold'em Poker*	90 mins	10
5:00	*Capture the Castle*	120 mins	100

The table's primary key is `Time+Game`. It cannot have two instances of the same game at the same time (because you don't have enough equipment or counselors), so the combination of `Time+Game` uniquely identifies the rows.

You should quickly review the 1NF rules and convince yourself that this table is in 1NF. In case you haven't memorized them yet, the 1NF rules are:

1. Each column must have a unique name.
2. The order of the rows and columns doesn't matter.
3. Each column must have a single data type.
4. No two rows can contain identical values.
5. Each column must contain a single value.
6. Columns cannot contain repeating groups.

Even though this table is in 1NF, it suffers from the following anomalies:

- **Update anomalies—**If you modify the `Duration` or `MaximumPlayers` value in one row, other rows containing the same game will be out of sync.

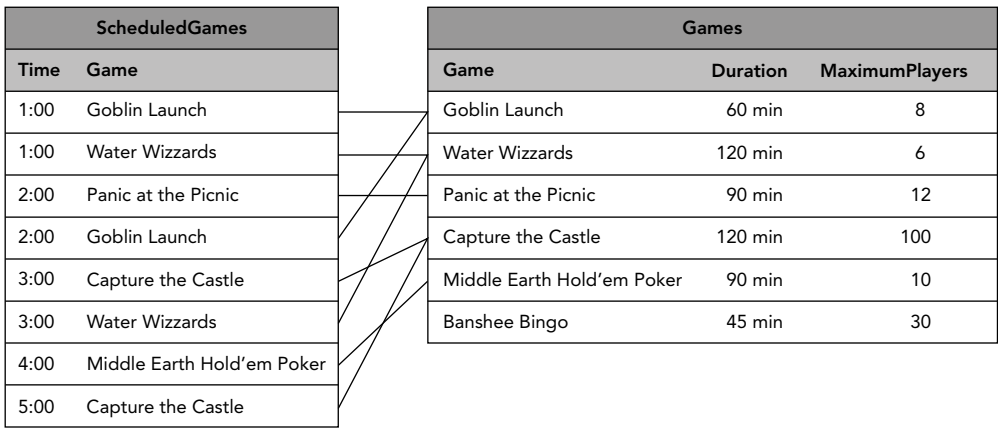
- **Deletion anomalies**—Suppose you want to cancel the *Middle Earth Hold'em Poker* game at 4:00, so you delete that record. Then you've lost all the information about that game. You no longer know that it takes 90 minutes and has a maximum of 10 players.
- **Insertion anomalies**—You cannot add information about a new game without scheduling it for play. For example, suppose *Banshee Bingo* takes 45 minutes and has a maximum of 30 players. You can't add that information to the database without scheduling a game.

The problem with this table is that it's trying to do too much. It's trying to store information about both games (duration and maximum players) and the schedule.

The reason it breaks the 2NF rules is that some non-key fields do not depend on *all* the key fields. Recall that this table's key fields are `Time` and `Game`. A game's duration and maximum number of players depends only on the `Game` and not on the `Time`. For example, *Water Wizzards* lasts for 120 minutes whether you play at 1:00, 4:00, or midnight.

To fix this table, move the data that doesn't depend on the *entire* key into a new table. Use the key fields that the data does depend on to link to the original table.

Figure 6-7 shows the new design. Here the `ScheduledGames` table holds schedule information and the `Games` table holds information specific to the games.



ScheduledGames

Time	Game
1:00	Goblin Launch
1:00	Water Wizzards
2:00	Panic at the Picnic
2:00	Goblin Launch
3:00	Capture the Castle
3:00	Water Wizzards
4:00	Middle Earth Hold'em Poker
5:00	Capture the Castle

Games

Game	Duration	MaximumPlayers
Goblin Launch	60 min	8
Water Wizzards	120 min	6
Panic at the Picnic	90 min	12
Capture the Castle	120 min	100
Middle Earth Hold'em Poker	90 min	10
Banshee Bingo	45 min	30

FIGURE 6-7: Moving the data that doesn't depend on *all* the table's key fields puts this table in 2NF.

Third Normal Form

A table is in *third normal form* (*3NF*) if:

1. It is in 2NF.
2. It contains no transitive dependencies.

A *transitive dependency* is when a non-key field's value depends on another non-key field's value.

For example, suppose the fantasy adventure camp has a library. (So campers have something to read after they get injured playing the games.) Posted in the library is the following list of the counselors' favorite books, as shown in Table 6-6.

TABLE 6-6: Counselors' Favorite Books

COUNSELOR	FAVORITEBOOK	AUTHOR	PAGES
Becky	*Dealing with Dragons*	Patricia Wrede	240
Charlotte	*The Last Dragonslayer*	Jasper Fforde	306
J.C.	*Gil's All Fright Diner*	A. Lee Martinez	288
Jon	*The Last Dragonslayer*	Jasper Fforde	306
Luke	*The Color of Magic*	Terry Pratchett	288
Noah	*Dealing with Dragons*	Patricia Wrede	240
Rod	*Equal Rites*	Terry Pratchett	272
Wendy	*The Lord of the Rings Trilogy*	J.R.R. Tolkein	1178

This table's key is the `Counselor` field.

If you run through the 1NF rules, you'll see that this table is in 1NF.

The table has only a single key field, so a non-key field cannot depend on only *some* of the key fields. That means the table is also in 2NF.

When posted on the wall of the library, this list is fine. Inside a database, however, it suffers from the following anomalies:

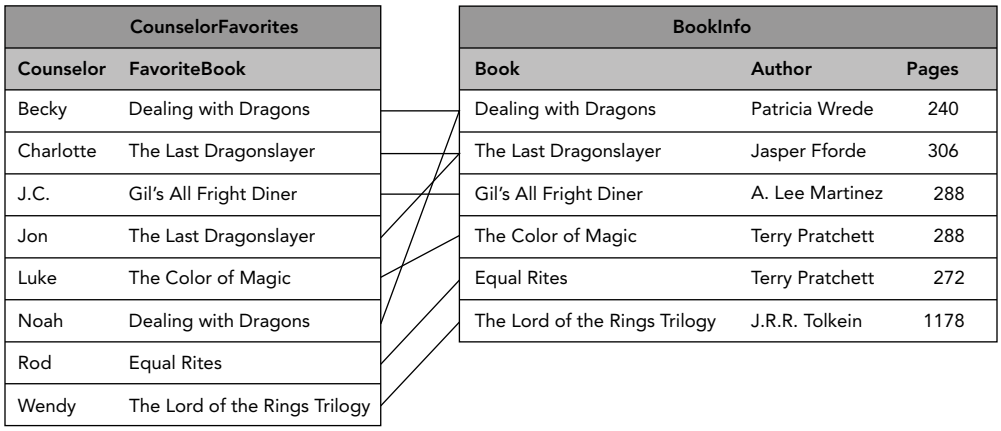
- **Update anomalies—**If you change the `Pages` value for Becky's row (*Dealing with Dragons*), it will be inconsistent with Noah's row (also *Dealing with Dragons*). Also if Luke changes his favorite book to *Majestrum: A Tale of Hengis Hapthorn*, the table loses the data it has about *The Color of Magic*.
- **Deletion anomalies—**If J.C. quits being a counselor to become a professional wrestler and you remove his record from the table, you lose the information about *Gil's All Fright Diner*.
- **Insertion anomalies—**You cannot add information about a new book unless it's someone's favorite. Conversely, you can't add information about a person unless he declares a favorite book.

The problem is that some non-key fields depend on other non-key fields. In this example, the `Author` and `Pages` fields depend on the `FavoriteBook` field. For example, any record with `FavoriteBook` *The Last Dragonslayer* has `Author` Jasper Fforde and `Pages` 306 no matter whose favorite it is.

DIAGNOSING DEPENDENCIES

A major hint that there is a transitive dependency in this table is that there are lots of duplicate values in different columns. Another way to think about this is that there are "tuples" of data (`FavoriteBook+Author+Pages`) that go together.

You can fix this problem by keeping only enough information to identify the dependent data and moving the rest of those fields into a new table. In this example, you would keep the `FavoriteBook` field in the original table and move its dependent values `Author` and `Pages` into a new table. Figure 6-8 shows the new design.



CounselorFavorites	
Counselor	**FavoriteBook**
Becky	Dealing with Dragons
Charlotte	The Last Dragonslayer
J.C.	Gil's All Fright Diner
Jon	The Last Dragonslayer
Luke	The Color of Magic
Noah	Dealing with Dragons
Rod	Equal Rites
Wendy	The Lord of the Rings Trilogy

BookInfo		
Book	**Author**	**Pages**
Dealing with Dragons	Patricia Wrede	240
The Last Dragonslayer	Jasper Fforde	306
Gil's All Fright Diner	A. Lee Martinez	288
The Color of Magic	Terry Pratchett	288
Equal Rites	Terry Pratchett	272
The Lord of the Rings Trilogy	J.R.R. Tolkein	1178

FIGURE 6-8: Moving non-key fields that depend on other non-key fields into a separate table puts this table in 3NF.

Higher Levels of Normalization

Higher levels of normalization include Boyce-Codd normal form (BCNF), fourth normal form (4NF), fifth normal form (5NF), and Domain/Key Normal Form (DKNF). Some of these later levels of normalization are fairly technical and confusing, so I won't cover them here. See a book on database design for details.

Many database designs stop at 3NF because it handles most kinds of database anomalies without a huge amount of effort. In fact, with a little practice, you can design database tables in 3NF from the beginning, so you don't need to spend several steps normalizing them.

More complete levels of normalization can also lead to confusing database designs that may make using the database harder and less intuitive, possibly giving rise to extra bugs and sometimes reduced performance.

One particular compromise that is often useful is to intentionally leave some data denormalized for performance reasons. A classic example is in ZIP codes. ZIP codes and street addresses are related, so if you know a street address, you can look up the corresponding ZIP code. For example, the ZIP code for 1 Main St., Boston, MA is 02129-3786.

Ideally, normalization would tell you to store only the street address and then use it to look up the ZIP code as needed. Unfortunately, these relationships aren't as simple as, "All Main St. addresses in Boston have the ZIP code 02129-3786." ZIP codes depend on which part of the street contains the address and sometimes even which side of the street the address is on. That means you can't build a table to perform a simple lookup.

You could build a much more complicated table to find an address's ZIP code, perhaps with some confusing code. Or you might use some sort of web service provided by the United States Postal Service.

Usually, however, developers just include the ZIP code as a separate field in the address. That means there's a lot of "unnecessary" duplication, but it doesn't take up much extra room and it makes looking up addresses much easier.

LOADS OF CODES

Addresses and postal codes are also related outside of the United States. For example, the postal code for 1 Main St., Dungiven, Londonderry England is BT47 4PG, and the postal code for 1 Main St., Vancouver, BC, Canada is V6A 3Y5. You can use various postal websites to look up codes for different addresses in different countries.

In theory, you could look up the postal codes for any address. In practice, it's a lot easier to just include them in the address data.

SUMMARY

Low-level design fills in some of the gaps left by high-level design to provide extra guidance to developers before they start writing code. It provides the level of detail necessary for programmers to start writing code, or at least for them to start building classes and to finish defining interfaces. Low-level design moves the high-level focus from *what* to a lower level focus on *how*.

Like most of the topics covered in this book, low-level design is a huge subject. There's no way to cover every possible approach to low-level design in a single chapter. However, this chapter does provide an introduction to two important facets of low-level design: object-oriented design and database design.

Object-oriented design determines what classes the application uses. Database design determines what tables the database contains and how they are related. Object-oriented design and database design aren't all you need to do to ensure success, but poor designs almost always lead to failure.

The boundary between high-level and low-level design is rather arbitrary. Low-level design tasks are similar to high-level design tasks but with a greater level of detail. In fact, the same kinds of tasks can slip into the next step in software engineering: development.

The next chapter provides an introduction to software development. It explains some general methods you can use to organize development. It also describes a few useful techniques you can use to reduce the number of bugs that are introduced during development.

EXERCISES

1. Consider the `ClassyDraw` classes `Line`, `Rectangle`, `Ellipse`, `Star`, and `Text`. What properties do these classes all share? What properties do they not share? Are there any properties shared by some classes and not others? Where should the shared and nonshared properties be implemented?
2. Draw an inheritance diagram showing the properties you identified for Exercise 1. (Create parent classes as needed, and don't forget the `Drawable` class at the top.)

3. The following list gives the properties of several business-oriented classes.

   - `Customer`—`Name`, `Phone`, `Address`, `BillingAddress`, `CustomerId`
   - `Hourly`—`Name`, `Phone`, `Address`, `EmployeeId`, `HourlyRate`
   - `Manager`—`Name`, `Phone`, `Address`, `EmployeeId`, `Office`, `Salary`, `Boss`, `Employees`
   - `Salaried`—`Name`, `Phone`, `Address`, `EmployeeId`, `Office`, `Salary`, `Boss`
   - `Supplier`—`Name`, `Phone`, `Address`, `Products`, `SupplierId`
   - `VicePresident`—`Name`, `Phone`, `Address`, `EmployeeId`, `Office`, `Salary`, `Managers`

   Assuming a `Supplier` is someone who supplies products for your business, draw an inheritance diagram showing the relationships among these classes. (Hint: Add extra classes if necessary.)

4. How would the inheritance hierarchy you drew for Exercise 3 change if you decide to add the `Boss` property to the `Hourly` class?

5. How would the inheritance hierarchy you drew for Exercise 3 change if `Supplier` represents a business instead of a person?

6. Suppose your company has many managerial types such as department manager, project manager, and division manager. You also have multiple levels of vice president, some of whom report to other manager types. How could you combine the `Salaried`, `Manager`, and `VicePresident` types you used in Exercise 3? Draw the new inheritance hierarchy.

7. If a table includes a ZIP code with every address, what 1NF, 2NF, and 3NF rules does the table break?

8. What data anomalies can result from including postal codes in address data? How bad are they? How can you mitigate the problems?

9. In the United States Postal Service's ZIP+4 system, ZIP codes can include 4 extra digits as in 20500-0002. Suppose you store address data with a single `Zip` field that has room for 10 characters. Some addresses include only a 5-digit ZIP code and others include a ZIP+4 code. Does that violate any of the 1NF, 2NF, or 3NF rules? Should you do anything about it?

10. Do telephone area codes face issues similar to those involving ZIP codes?

11. Suppose you're writing an application to record times for dragon boat races and consider the table shown in Figure 6-9. Assume the table's key is `Heat`. What 1NF, 2NF, and 3NF rules does this design violate?

12. How could you fix the table shown in Figure 6-9?

Distance	Heat	Time	Team	Team	Winner	Time	Time
500	1	9:00	Buddhist Temple	Wicked Wind	Buddhist Temple	2:55.372	2:57.391
500	2	9:20	Rainbow Energy	Rising Typhoon	Rising Typhoon	3:10.201	3:01.791
1000	3	9:40	Math Dragons	Supermarines	Math Dragons	5:52.029	6:23.552
1000	4	10:00	Flux Lake Tritons	Elf Power	Elf Power	6:08.480	6:59.717

FIGURE 6-9: This table records dragon boat race results.

WHAT YOU LEARNED IN THIS CHAPTER

- A class defines the properties, methods, and events provided by instances of the class.
- Nouns in the project description make good candidates for classes.
- Inheritance provides code reuse.
- Polymorphism lets a program treat an object as if it had a parent class's type.
- In refinement, you add details to a general class to define subclasses.
- In generalization, you extract common features from two or more classes to define a parent class.
- Inheritance hierarchy warning signs include:
  - The hierarchy is tall and thin.
  - The hierarchy contains a large number of classes.
  - A class has a single subclass.
  - A class at the bottom of the hierarchy is never instantiated.
  - The classes don't make common sense.
  - Classes represent differences in property values, not different properties themselves or different behaviors.
- Composition provides code reuse. It also lets you include multiple copies of a type of object inside a class, something inheritance doesn't do.
- Relational databases contain tables that hold records (or rows). The records in a table all have the same fields (or columns).
- A foreign key forms a relationship between the values in a parent table and the values in a child table. The child table's fields must contain values that are present in the parent table.
- A lookup table is a foreign key parent table that simply defines values that are allowed in other tables.
- Normalization protects a database from data anomalies.
- 1NF rules:
  1. Each column must have a unique name.
  2. The order of the rows and columns doesn't matter.
  3. Each column must have a single data type.
  4. No two rows can contain identical values.
  5. Each column must contain a single value.
  6. Columns cannot contain repeating groups.

- 2NF rules:
  1. It is in 1NF.
  2. All non-key fields depend on all key fields.
- 3NF rules:
  1. It is in 2NF.
  2. It contains no transitive dependencies. (No non-key fields depend on other non-key fields.)

7

Development

A good programmer is someone who always looks both ways before crossing a one-way street.

—Doug Linder

Always code as if the guy who ends up maintaining your code will be a violent psychopath who knows where you live.

—Martin Golding

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Tools that are useful to programmers
- How to decide which algorithms are better than others
- How to use top-down design to turn designs into code
- Programming tips that can make code easier to debug and maintain

To many programmers, development is the heart of software engineering. It's where fingers hit the keyboard and churn out the actual program code of the system. Without development, there is no application.

As is the case with other stages of software development, the edges of development are a bit blurry. Low-level design may identify the classes that a program will need, but it may not spell out every method that the classes must provide and it might provide few details about how those methods work. That means the development stage must still include some design work as developers figure out how to build the classes.

Similarly, the next stage of software engineering, testing, often begins before development is completely finished. In fact, it's best to test software early and often. It's widely known that bugs are easiest to find and fix if they're detected soon after they're created, so if possible you should test every method you write as soon as it's finished (sometimes even before it's finished).

Most developers write programs because they like to write code. (I know I do. For me, solving a tricky programming problem is like solving a difficult Sudoku puzzle. I get a great feeling of satisfaction from crunching a bunch of numbers and having a beautiful fractal or a three-dimensional game pop out.) Over the years, programmers have collectively spent a huge amount of time programming, fixing bugs in their code, and thinking of ways to avoid similar bugs in the future. That has generated a huge number of books about programming style and techniques for avoiding, detecting, and fixing bugs.

This chapter provides an introduction to some of the techniques that I've found most useful over the years. It begins by describing some tools and general problem-solving approaches that you can use to turn the description of a method into code. It then explains some specific techniques that you can use to make your code easier to debug and maintain.

If you're not a programmer, for example, if you're a project manager or a customer, you may not need to memorize every one of these rules and apply them to your daily life. However, it's still worth your time to read them so that you'll know what's involved in writing good code (and so you'll understand what the programmers are complaining about).

USE THE RIGHT TOOLS

Including overhead (office space, computer hardware, network hardware, Internet service provider, vacation, sick time, a well-stocked soda machine, and so forth), employing a programmer can easily cost more than $100,000 per year. Still I have seen managers refuse to spend a few hundred bucks for proper programming tools. I've seen projects end the year with thousands of dollars left over for hardware expenses, but not a nickel for software tools.

When you're spending $50 per hour on each employee, you don't have to save much of their time to make a little extra expense worthwhile. You don't need to go crazy and spend thousands of dollars to buy everyone a high-end video recording package (unless that's what your business does), but you should spend a little money to make sure your team has all the tools it needs.

The following sections describe some of the development tools that every programmer should have.

Hardware

Few things are as frustrating as trying to write software on inadequate hardware. Programmers need fast computers with lots of memory and disk space. A programmer with an underpowered computer or insufficient memory takes longer to do everything.

Even worse, waiting for slow compilations breaks the programmer's train of thought. To write bug-free (or at least minimally buggy) code, a programmer must stay focused on a method's design until it has been completely written. Breaking the writing process into dozens of chunks separated by several minutes of thumb twiddling (or more likely, trips to the water cooler) breaks the programmer's

train of thought, so he needs to re-create an understanding of the code each time. If each new understanding doesn't match the previous ones, the result is far more likely to contain bugs.

THE TORTOISE AND THE SLOTH

I once worked on an application using a slow development environment. I would add the next feature to the code, press the Compile button, and wander off for five or six minutes to wait for the compilation to finish. It was just too frustrating to sit there staring at the screen while the compiler slowly dribbled out periods to tell me that it was working and not dead.

Meanwhile my business partner was stuck on another project but with a similar development cycle. We spent a lot of time in the hallway talking about vacations.

After about a month of that, I got a new development environment that had a lot fewer features but that was much faster. It let me reproduce everything I had done in the previous month in just two days. As you can probably guess, I never used the other environment again.

Make sure the programmers have all the hardware resources they need to do their jobs quickly and effectively. If that means buying more memory, disk space, or even new computers, do it. It's insane to waste hundreds of hours a year of a programmer's time to save a few hundred dollars. (Although I've known managers who did exactly that. In fact, I've known managers who wouldn't pay for new hardware for their programmers, but who needed the absolute top-of-the line computers for themselves so that they could fill out expense reports and answer e-mail.)

There are two drawbacks to buying the programmers everything they need. First, some programmers will go overboard and buy all sorts of fun toys that they don't actually need. Most programmers don't need a USB controlled NERF rocket launcher or a Darth Vader USB hub. If you have the money, you might let some of those purchases slide in the interests of morale. Otherwise, you might want to check the product SKUs on the purchase requisitions you're signing. (I've known people to try to requisition Dalmatian puppies and cars, mostly as jokes. Those were caught, but I know of one lab that managed to buy a hot tub one piece at a time. They got in a whole lot of… well…hot water.)

The second and far more important drawback to giving developers everything they want is that they sometimes forget that their users may not have such nice equipment. I've used applications that were blazingly fast on the developers' computer but that were painfully slow for the users. Modern computers are fast enough and cheap enough that this isn't the problem it used to be in the "old days" two or three years ago, but you should always test applications with hardware that is similar to whatever your end users will be stuck with.

Network

I've known development groups that didn't allow access to external networks. I can understand why that might be necessary if you're designing a new *Minecraft* mod and are worried that foreign

hackers will steal your plans and sell them to terrorists, but if it's at all possible, you should allow programmers to have free access to the Internet. Often a quick search can find a solution to a programming problem that would otherwise take hours to solve.

For example, when I'm working on a tricky project, I often use my own websites (`www.csharphelper.com` and `www.vb-helper.com`) to look up specific techniques. My sites are particularly useful to me because they hold solutions to lots of problems I've encountered in the past and because I know more or less what they contain. I also often find solutions on Wikipedia (`www.wikipedia.org`) and I find a lot of mathematical solutions on Wolfram MathWorld (`mathworld.wolfram.com`). And, of course, I often use a search engine to look for other solutions.

You should gently encourage staff members not to spend their whole day playing *Cookie Clicker* or in chat rooms arguing about who is better, Kirk or Picard, but try to provide a fast Internet connection and the freedom to use it.

Development Environment

This is the absolute minimum necessary to make programming possible. It at least includes the compiler or interpreter that translates program code into something the computer can execute.

An *integrated development environment* (*IDE*) such as Eclipse (mostly for Java, although plug-ins let you write in other languages such as C++ or Ruby) or Visual Studio (for Visual C#, Visual Basic, Visual C++, JavaScript, and F#) can also include much more. Depending on the version you have installed, they can include debuggers, code profilers, class visualization tools, auto-completion when typing code, context-sensitive help, team integration tools, and more.

Note that you don't always need the fanciest development environment possible. For example, Visual Studio comes in many different versions, ranging from the free "express" edition designed for individual users, to the "professional" and "ultimate" editions designed for large project teams, which cost a whole lot (MSRP, prices in U.S. dollars). The more expensive versions include tools and resources that are most useful for larger projects so, if you're writing a small application by yourself, you may do just as well with the free express edition.

Similarly, Eclipse comes in a variety of IDEs with a lot of different plug-ins to meet the needs of different kinds of users. For example, Eclipse for Testers is designed for testers. (Well, duh.) If you're not doing a lot of testing, you may want to use a different version.

WHO KNOWS

Most mature development environments include remarkably powerful tools for writing code. They're so effective for a very good reason: the programmers who wrote them know what you need to write programs. In contrast, programmers may not know a lot about court reporting software, medical diagnostics, or cabinet design. However, if programmers know anything, they know what features make development environments effective. There will always be some variation, and you may need to pay extra to get the best features, but there are some amazingly powerful tools out there if you're willing to learn how to use them.

Source Code Control

If your development environment doesn't include source code control, a separate system is essential. Chapter 2, "Before the Beginning," explains that a documentation management system is important for letting you track the many documents that make up a project. Source code control is even more important for program code where changing a single character can reduce a working program to a worthless pile of gibberish.

A good source code management system enables you to go back through past versions of the software and see exactly what changes were made and when. If a program stops working, you can pull out old versions of the code to see which changes broke the program. After you know exactly what changes were made between the last working version and the first broken one, you can figure out which changes caused the bug and you can fix them.

Source code control programs also prevent multiple programmers from tripping over each other as they try to modify the same code at the same time.

Profilers

Profilers let you determine what parts of the program use the most time, memory, files, or other resources. These can save you a huge amount of time when you're trying to tune an application's performance. (I'll say more about this in the section "Defer Optimization" later in this chapter.)

You may not need to buy every programmer a profiler. Typically, a small part of a program's code determines its overall performance, so you usually don't need to study every line's performance extensively. Still it's important to have profilers available when they are needed.

Static Analysis Tools

Profilers monitor a program as it executes to see how it works. Static analysis tools study code without executing it. They tend to focus on the code's style. For example, they can measure how interconnected different pieces of code are or how complex a piece of code is. They can also calculate statistics that may indicate code quality and maintainability such as the number of comments per line of code and average the number of lines of code per method.

Testing Tools

Testing tools, particularly automated tools, can make testing a whole lot faster, easier, and more reliable. I'll talk more about testing tools in the next chapter (which covers testing). For now, just be aware that every programmer must perform at least some testing, so everyone should have access to testing tools.

Source Code Formatters

Some development environments do a better job of formatting code than others. For example, some environments automatically indent source code to show how code is nested in `if-then` statements and loops. That formatting makes code easier to read and understand. That in turn reduces the number of bugs in the code and makes finding and fixing bugs easier.

Other development environments don't provide much in the way of formatting. If you're using that kind of environment, a separate code formatter can standardize indentation, align and reformat comments, break code so it fits on a printout, enforce some code standards, and more.

(Your team will need to decide on the level of code uniformity you want to enforce. Too much standardization can be annoying to developers, but left to their own devices, a few programmers will produce such free-spirited results that their code looks more like an E.E. Cummings poem than professional software.)

Refactoring Tools

The term *refactoring* is programmer-speak for "rearranging code to make it easier to understand, more maintainable, or generally better." Some refactoring tools (which may be built into the IDE) let you do things like easily define new classes or methods, or extract a chunk of code into a new method.

Refactoring tools can be particularly useful if you're managing existing code (as opposed to writing new code).

Training

This is another category where some managers are penny-wise and pound-foolish. Training makes programmers more effective and keeps them happy. A few thousand dollars spent on training can greatly improve performance and help you retain your staff.

Online video training courses and books are often less effective than in-person training, but they're also a lot less expensive and they let you study whenever you have the time. If a $50 book gives you a single new tip, then it's probably worth it.

You do need to be a little selective, however. If you buy too many books, you won't have time to read them all.

SELECTING ALGORITHMS

After low-level design is mostly complete (and you have all your tools in place), you should have a good sense of what classes you need and the tasks those classes need to perform. The next step is writing the code to perform those tasks.

For more complicated problems, the first step is researching possible algorithms. An *algorithm* is like a recipe for solving a hard programming problem. In the decades since computers were invented, many efficient algorithms have been developed to solve problems such as the following:

- Sorting and arranging pieces of data
- Quickly locating items in databases
- Finding optimal paths through street, power, communication, or other networks
- Designing networks to provide necessary capacity and redundancy to prevent single points of failure

- Encrypting and decrypting data
- Picking optimal investment strategies
- Finding least cost construction and production strategies
- Many, many more

For complicated problems like these, the difference between a good algorithm and a bad one can make the difference between finding a good solution in seconds, hours, days, or not at all.

Fortunately, these sorts of algorithms have been extensively studied for years, so you usually don't need to write your own from scratch. You can use the Internet and algorithm books to look for an approach that fits your problem. (For example, see my introductory book *Essential Algorithms: A Practical Approach to Computer Algorithms*, Wiley, 2013.)

You'll probably still need to do some work plugging the algorithm into your application, but there's no need for you to reinvent everything from scratch. However, even if you don't need to build an algorithm from the ground up, you should know some of the characteristics that make an algorithm a good choice for you. The following sections describe some of those characteristics.

Effective

Obviously, an algorithm won't do you much good if it doesn't solve your particular problem. An algorithm that finds critical paths through a PERT chart (remember those from Chapter 3, "Project Management"?) won't help you much with calculating the ideal maintenance schedule for a fleet of trucks. You need to pick the right algorithm for the job.

If an algorithm doesn't meet your needs exactly, look for an algorithm that does. If you can find something that only comes close but doesn't *quite* fit your situation, ask yourself whether the algorithm's result is good enough or if you can adjust your requirements a bit to make the available algorithm usable.

If you can't find an algorithm that fits your problem, and you can't adjust your problem to fit the available algorithms, then you may need to write your own algorithm or modify an existing one. Complicated algorithms often include some of the most highly studied and optimized code you will ever encounter, so modifying them can be difficult. (That difficulty can also make it a fun challenge, but complicated algorithms should probably come with a sticker that says, "Modify at your own risk.")

If you do need to write your own algorithm or modify an existing one, be sure to perform extra testing to make sure it works correctly.

Efficient

The best algorithm in the world won't do you much good if it takes seven years to build the daily production schedule or if it requires the users to have 3 petabytes (1 million gigabytes) of memory on their cell phones. To be useful, an algorithm must satisfy your speed, memory, disk space, and other requirements.

This is one of the reasons Chapter 4 said requirements must be verifiable. If you don't know ahead of time how quickly the program must find a result, how can you know whether the algorithm you've selected is fast enough?

Note that some algorithms may be efficient enough for one purpose but not for another. For example, suppose you and your friend discover a pirate treasure. Each piece of treasure has a different value, and you want to divide the treasure as equally as possible. (In the algorithm literature, this is called the "partition problem"; although, I like to call it the "booty division problem").

One algorithm for solving this problem is to simply try every possible division of the spoils and see which combination gives you the best result. For example, if there are three pieces of treasure labeled A, B, and C, then there are only eight possible ways to divide the treasure. Table 7-1 shows the possible combinations.

TABLE 7-1: Possible Divisions of 3 Items

YOU	FRIEND
A, B, C	—
A, B	C
A, C	B
B, C	A
A	B, C
B	A, C
C	A, B
—	A, B, C

Notice that for every possible division there is another division with the items swapped between you and your friend. For example, in one division you get items A and B, and your friend gets item C. In the swapped division, your friend gets items A and B, and you get item C. Both of the matching divisions are equally even, so you can cut the number of possibilities you need to consider in half if you ignore one of each pair of divisions. One way to do that is to arbitrarily assign item A to you. Those sorts of tricks are what make algorithms fun!

That algorithm works well for small problems, but if the number of treasures is large, the algorithm will take too long. If there are N items, then there are 2^N possible ways to divide the treasure. (2^{N-1} possible ways if you arbitrarily give yourself the first item.)

For large values of N, the value 2^N can be large, for example, if you find a big treasure with 50 items, $2^N \approx 1.1 \times 10^{15}$. If you had a computer that could examine 1 million possible treasure divisions per second, it would take you almost 36 years to examine all the possibilities.

If you do find a larger treasure, you can't use the simple "try every possible solution" approach. In that case, you need to try a different algorithm.

In fact, this is known to be a provably difficult problem, and there are no known algorithms that can solve it exactly for large problem sizes. For large N, you need to turn to *heuristics*—algorithms that give good solutions but that don't guarantee to give you the best solution possible.

For example, one heuristic would be to assign items randomly to you and your friend. The odds of you randomly guessing a perfect solution would be very small, but this method would be so fast you could perform several million or possibly even a billion trials and pick the best result you stumble across. (I think this is how countries set their economic policies. They make a bunch of random changes and, if any of them seem to work, they claim that was the plan all along.)

Another heuristic would be to give the next item to whichever of you currently has the smaller total value. For 50 items, that would require only 50 steps so it would be incredibly fast. The odds of you blundering across a perfect solution would still be fairly small; although the result would often be better than purely random guessing.

As this example shows, you need to understand how an algorithm will perform for your problem before you decide to use it. *Big O notation* is a system for studying the limiting behavior of algorithms as the size of the problem grows large. Search the Internet for "big O notation" or read an algorithms book (like the one I mentioned earlier) for more information on big O notation and algorithm complexity.

> **NOTE** *I can think of three other ways to divide the treasure perfectly evenly, and they don't even require a computer. First, donate the treasure to a museum. Second, auction off the treasure and split the proceeds. Finally, give it all to me and let me worry about it!*

Predictable

Some algorithms produce nice, predictable results every time they run. For example, if you search a list of numbers, you can find the largest one every time.

Other algorithms may be less predictable. The heuristics described in the previous section can't always find a perfect division of treasure. In fact, a perfect division may be impossible. (Suppose you have four treasures with values 10, 10, 20, and 30.) For the booty division problem, you can't even tell whether a perfect division of the spoils is *possible* without finding one.

Some algorithms may not produce the same results every time you run them. If you use the random heuristic described in the previous section several times, you'll probably get different answers each time. In that case, it may be hard to tell if the algorithm is working correctly.

It's also nice to know that an algorithm eventually finishes. It's a lot easier to tell that something's wrong when an algorithm takes twice as long to finish as you expect. Algorithms such as the random guessing heuristic can run indefinitely if you let them. In cases like that, you need to simply build in a cutoff that stops the algorithm after some set amount of time and takes the best solution found so far.

STOPPING CRITERIA

Actually, there are several ways you can stop an algorithm that might otherwise run indefinitely. For example, you might run until you find a solution of a particular quality. For the booty division problem, you might run until the algorithm finds a solution in which the two piles of treasure have values differing by no more than 10 percent. Of course, you'd still need to stop searching after some time period, just in case you can't find a solution that meets that criterion.

You can also save the best solution found after some time period and let the algorithm continue running in the background to look for better solutions. The application has a solution at all times, but it may gradually improve over time.

Although some algorithms such as this heuristic are inherently unpredictable, you should favor predictable algorithms if possible. It's much easier to debug a broken algorithm if you can reliably reproduce incorrect results whenever you need them.

Simple

Ideally an algorithm, like any other piece of code, should be elegantly simple. Simple code is easy to understand and easy to debug. It's easier to modify (if you decide to peel off the "Modify at your own risk" sticker) and it's easier to understand how the algorithm's performance varies for different inputs.

Some remarkably clever algorithms are also extremely simple, whereas others are a lot more involved. If you have a choice between a simple algorithm and a complex one that does the same job, pick the simple one.

Prepackaged

If you can find an algorithm that is implemented inside your programming language or in a library, use it. There's no need to write, test, debug, and maintain your own code if someone else can do it for you.

Prepackaged algorithms also tend to be more thoroughly studied and tested than anything you have time to write. A software vendor may spend hundreds of person-hours testing code that you would probably write, test, and shove out the door in a few hours. Its results may not always be better than yours, but if there is a problem you can ask the vendor to fix it instead of spending more time on it yourself.

Sometimes, libraries can also give you better performance. A library vendor may write more highly optimized code than you can. For example, its sorting routine might be written in assembly language whereas your version would be written in a higher-level language such as C++, C#, or Java.

In the end it may turn out that a prepackaged solution won't work for you either because it doesn't have the features you need or because your specific problem allows you to greatly improve the performance. However, it's always worth looking for an easier solution.

TOP-DOWN DESIGN

If you can't find an algorithm to handle your situation, you need to write some code of your own. Even if you do find an algorithm that can be useful, you'll probably need to write some code to prepare for the algorithm and to process the results. So how do you get from a big, intimidating task like "design optimal routes for 300 delivery vehicles" or "schedule the classes for 1,200 middle-school students" to actual working code?

One useful approach is *top-down design*, also called *stepwise refinement*. In top-down design, you start with a high-level statement of a problem, and you break the problem down into more detailed pieces.

Next, you examine the pieces and break any that are too big into smaller pieces. You continue breaking pieces into smaller pieces until you have a detailed list of the steps you need to perform to solve the original problem.

As you break a task into smaller pieces, you should be on the lookout for opportunities to save some work. If you notice that you're performing some chore more than once (perhaps while describing multiple main tasks), you should think about pulling that chore out and putting it in a separate method. Then all the tasks can use the same method. That not only lets you skip writing the same code a bunch of times, it also lets you invest extra time testing and debugging the common code while still saving time overall.

If the main task's description becomes too long, you should break it into shorter connected tasks. For example, suppose you need to write a method that searches a customer database for people who might be interested in golf equipment sales. You identify several dozen tests that identify likely prospects: people who earn more than $50,000 per year, people who live near golf courses, country club members, people who wear plaid shorts and sandals with spikes, and so forth.

If the list of tests is too long, it will be hard to read the full list of steps required to perform the original task. In that case, you should pull the tests out, place them in a new task described on a separate sheet of paper (or possibly several), and refer to the new task as a subtask of the original.

For example, suppose the original method is called `PromoteSales`. Originally, its description might look like this:

`PromoteSale()`

1. Identify customers who are likely to buy items on sale and send them e-mails, flyers, or text messages as appropriate.

Now add some detail.

`PromoteSale()`

1. For each customer:
    A. If the customer is likely to buy:
        i. Send e-mail, flyer, or text message depending on the customer's preferences

Step A "If the customer is likely to buy" will be pretty long, so create a new `IsCustomerLikelyToBuy` method. Similarly, step i will be fairly complicated, so create a new `SendSaleInfo` method. Now the main task looks like the following.

`PromoteSale()`

1. For each customer:
   A. If `IsCustomerIsLikelyToBuy()`
      i. `SendSaleInfo()`

At this point, you need to write the `IsCustomerLikelyToBuy` and `SendSaleInfo` methods. Here's the `IsCustomerLikelyToBuy` method.

`IsCustomerLikelyToBuy()`

1. If (customer earns more than $50,000) return `true`.
2. If (customer lives within 1 mile of a golf course) return `true`.
3. If (customer is a country club member) return `true`.
4. If (customer wears plaid shorts and sandals with spikes) return `true`.

   …

   73. If (none of the earlier was satisfied) return `false`.

Here's the `SendSaleInfo` method.

`SendSaleInfo()`

1. If (customer prefers e-mail) send e-mail message.
2. If (customer prefers snail-mail) send flyer.
3. If (customer prefers text messages) send text message.

You can add other contact methods such as voicemail, telegraph, or carrier pigeon if appropriate.

This version of the `SendSaleInfo` method may also need some elaboration to explain how to determine which contact method the customer prefers.

`SendSaleInfo()`

1. Use the customer's `CustomerId` to look up the customer in the database's `Customers` table.
2. Get the customer's `PreferredContactMethod` value from the database record.
3. If (customer prefers e-mail) send e-mail message.
4. If (customer prefers snail-mail) send flyer.
5. If (customer prefers text messages) send text message.

Continue performing rounds of refinement, providing more detail for any steps that aren't painfully obvious, until the instructions are so detailed a fifth-grader could follow them.

At that point, sit down and write the code. If you've reached a sufficient level of detail, translating your instructions into code should be a mostly mechanical process.

INSUFFICIENT DETAIL

Some developers stop refining their code design when they think the list of instructions is enough to get them started but before it provides a painful level of detail. For example, many developers wouldn't bother to spell out how to look up the customer in the database and get the customer's `PreferredContactMethod` value.

That's probably okay in this example, at least if you're an experienced developer. That kind of design shortcut can lead to problems, however, if a step turns out to be harder than you originally thought it would be.

It can be disastrous if you turn the instructions over to someone else who doesn't have your background and some steps are harder for that person than they would be for you. (I've worked on projects where the team lead gave a junior developer instructions that were obvious to the lead but mystifying to the developer. Rather than asking for help, the developer flailed about for weeks without making any progress.)

PROGRAMMING TIPS AND TRICKS

Top-down design gives you a way to turn a task statement into code, but there are still a lot of tricks you can use to make writing code faster and easier. Other tips make it easier to test code, debug it when a problem surfaces, and maintain the code in the long term.

The following sections describe some of my favorite tips for writing good code.

Be Alert

Writing good code can be difficult. To know if you're writing the code correctly, you need to completely understand what you're trying to do, what the code actually does, and what could go wrong. You need to know in what situations the code might execute and how those situations could mess up your carefully laid plan. You need to ask yourself, what if an important file is locked, a needed value isn't found in a parameter table, or if a user can't remember his password.

Keeping everything straight can be quite a challenge. You can make your life a little easier if you write code only while you're wide awake and alert.

Most people have certain times of day when they're most alert. Some people are natural morning people and work best in the morning. Others work better in the afternoon. Some programmers do their best work after midnight when the rest of the world is asleep.

Figure out when your most effective hours are and plan to write code then. Fill out progress reports and timesheets during less productive hours.

Write for People, Not the Computer

Probably the most important tip in this chapter is to write code for people, not for computers. The computer doesn't care whether you use meaningful names for variables, indent your code nicely, use comments, or spell words correctly. It doesn't care how clever you are, and it doesn't care if your code produces a correct result.

In fact, the computer doesn't even read your code. Depending on your programming language and development environment, your code must be translated one, two, or more times before the computer can read it. All the computer wants to see is a string of 0s and 1s. If you were really writing code for the computer's benefit, your code would look like this:

```
10000000 00000000 00000000 00000000 00001110 00011111 10111010 00001110 00000000
10110100 00001001 11001101 00100001 10111000 00000001 01001100 11001101 00100001
01010100 01101000 01101001 01110011 00100000 01110000 01110010 01101111 01100111
01110010 01100001 01101101 00100000 01100011 01100001 01101110 01101110 01101111
01110100 00100000 01100010 01100101 00100000 01110010 01110101 01101110 00100000
01101001 01101110 00100000 01000100 01001111 01010011 00100000 01101101 ...
```

The reason you write code in some higher-level programming language is that 0s and 1s are confusing for you. It would be incredibly difficult to remember the strings of 0s and 1s needed to represent different programming commands. (Although I know someone who used to have a computer's boot sequence memorized in binary so that he could toggle it in using switches when the computer needed to be restarted!)

Using a higher-level language lets you tell the computer what to do in a way that *you* can understand. Later, when your application is doing something wrong, it lets you trace through the execution to see what the computer is doing and why.

Debugging and maintaining code is far more difficult and time-consuming than writing code in the first place. The main reason is because you know what you are trying to do when you write code. Later when you're called upon to debug it, you might not remember exactly what the code is supposed to do. That makes it harder to identify the difference between what the code is supposed to do and what it actually does, so it's harder to fix.

Fixing a bug also has a much higher chance of adding a new bug than writing new code does, and for the same reason. When you're debugging, you don't have as clear an understanding of what the code is supposed to do. That makes it much easier to change the code in a way that breaks it.

To make debugging and maintaining code easier, you need to write code that is clear and easy to understand. Hopefully, whoever is eventually forced to track down a bug in your code won't be a violent psychopath, but you can make that person's job a lot easier if you remember it's that person you're writing for, not the computer.

IT COULD BE YOU!

Always remember that the person debugging your code a year from now could be you! After enough time has passed, there's no way you'll remember exactly how the code was supposed to work. When you're writing the code initially, it may seem obvious, but a year or two later you'll only have whatever clues you left for yourself in the code to go by.

You can make your job easier by writing code that's clear and lucid, or you can learn to hate the younger you.

When you write code, remember that you're writing it for a possible future human reader (who might be you) and not for the computer.

Comment First

There are a few things that most programmers instinctively avoid because they don't feel like they're part of writing code. One of those is writing comments.

Many programmers write the bare minimum of comments they think they can get away with and then rush off to write more code. This is so common, in fact, that it has its own movement: just barely good enough (JBGE). The idea is that writing lots of comments is a waste of time. Besides, comments are usually wrong anyway, so rather than spending more time rewriting and fixing them, you should just write better code.

You can read my rant about JBGE in the section "Code Documentation" in Chapter 2. In this section, I want to talk about why comments need to be revised so often.

Many programmers use one of two models for writing comments. The first approach is to write comments as you code. You write a loop and then put a comment on top of it. Later you realize that the loop isn't quite right, so you change it and then update the comment. A bit later you realize that the loop still isn't right, so you change it again and revise the comment once more. After 37 rounds of revisions, you've either spent a huge amount of time updating the comment, or you've given up (thinking you'll revise the comment later) and the comment is hopelessly disconnected from the final code.

The second strategy is to write all the code without comments. When you're finished with your 37 revisions, you go back and insert the bare minimum number of comments that you think you can get away with without getting yelled at by the lead developer. (The lead developer does the same thing, so he doesn't care all that much about comments anyway.)

In both of these scenarios, the problem isn't that you have too many comments. The real problem is that you're trying to write comments to explain what the code *does* and not what it *should do*. When you tweak the code, you change what it does, so you need to update the comment. That creates a lot of work and that makes programmers reluctant to write comments.

If the code is well-written, the future reader will read the code to see what it actually does. What that person needs is comments to explain what the program is supposed to do. Then debugging becomes an exercise in determining where the program isn't doing what it's supposed to be doing.

One way to write comments that explain what the program is supposed to be doing is to write the comments first. That lets you focus on the intent of the code and not get distracted by whatever code is sitting actually there in front of you.

It also means you don't need to revise the comment a dozen times. The code itself might change a dozen times, but the *intent* of the code better not! If it does, then you didn't do enough planning in the high-level and low-level design phases.

For example, consider the following C# code. (If you don't know C# or some similar language like C++ or Java, just focus on the comments.)

```
// Loop through the items in the "items" array.
for (int i = 0; i < items.Length - 1; i++)
{
    // Pick a random spot j in the array.
    int j = rand.Next(i, items.Length);
    // Save item i in a temporary variable.
    int temp = items[i];
    // Copy j into i.
    items[i] = items[j];
    // Copy temp into position k.
    items[j] = temp;
}
```

The comments in this code explain what the code is doing, but they're mostly redundant. For example, the first comment explains exactly what the line of code that follows it does: through the array. That's certainly true, but any programmer who can't figure that out by looking at the looping statement itself probably shouldn't be debugging anyone's code.

Similarly, the other comments are just English versions of the programming statements that follow. The comment `Copy j into i` is even a bit cryptic, and the comment `Copy temp into position k` contains a typo, presumably because the code's author changed the name of a variable and forgot to update the comment.

From a stylistic point of view, the comments are also distracting. They break up the visual flow and make the code look cluttered and busy.

Now that you've read the code, ask yourself, "What does it do?" Well yeah, it loops through the array, moves values into a temporary variable, and then moves them back into the array, but why? Does it accomplish what it was supposed to do? It's kind of hard to tell because the comments don't actually tell you what the code is supposed to do.

Now consider the following version of the code:

```
// Randomize the array.
// For each spot in the array, pick a random item and swap it into that spot.
for (int i = 0; i < items.Length - 1; i++)
{
    int j = rand.Next(i, items.Length);
    int temp = items[i];
    items[i] = items[j];
    items[j] = temp;
}
```

In this version, the comments tell you what the code is supposed to do, not what it actually does. The first comment gives the code's goal. The second comment tells how the code does it.

After you read the comments, you can read the code to see if it does what it's supposed to do. If you think there's a bug, you can step through the code in the debugger to see if it works as advertised.

This code is less cluttered and easier to read. It doesn't contain redundant comments that are just English versions of the code statements. These comments also don't need to be revised if the developer had to modify the code while writing it.

The best part of the comment-first approach is that the comments pop out for free if you use top-down code design. In the top-down method, you repeatedly break pieces of code into smaller and smaller pieces until you reach the point where a trained monkey could implement the code.

At that point, put whatever comment characters are appropriate for your language in front of the steps you've created (`//` for C#, C++, or Java; `'` for Visual Basic; `*` for COBOL, and so forth), and drop them into the source code. Now fill in the code between the comments.

If your top-down design goes to a level of extreme detail, you may need to pull back a bit on the level of commenting. There's nothing wrong with the design going all the way to the level of explicitly giving the `if-then` statements you need to execute to perform a particular test, but that level of detail isn't necessary in the comments. Only include the comments that tell what the code is supposed to do and not the ones that repeat the actual code.

You may also need to add a few summary comments, particularly if your development team has rules for things like standard class and method headers, but most of the commenting work should be done.

You may also need to add a few comments to code that is particularly obscure and confusing. Remember, you might be debugging this code in a year or two.

Write Self-Documenting Code

In addition to writing good comments, you can make the code easier to read if you make the code self-documenting. Use descriptive names for classes, methods, properties, variables, and anything else you possibly can.

One exception to this rule is looping variables. Programmers often loop through a set of values and they use looping variables with catchy names like `i` or `j`. That's such a common practice that any programmer should be able to figure out what the variable means even though it doesn't have a descriptive name.

That doesn't mean you should avoid descriptive names if they make sense. If you're looping through the rows and columns of a matrix, you can name the looping variables `row` and `column`. Similarly, if you're looping through the pixels in an image, you can name the looping variables `x` and `y`. Those names give the reader just a little more information and make it easier to keep track of what the code is doing.

You can also make your code easier to understand if you don't use magic numbers. (A *magic number* is a value that just appears in the code with no explanation. For example, it might represent

an error code or database connection status.) Instead of using a magic number, use a named constant that has the same value.

Better still, if your language supports enumerated types, use them. They also give names to magic numbers and some development environments can use them to enforce type rules. For example, suppose you create an enumerated type named `MealSizes` that defines the values `Large`, `ExtraLarge`, and `Colossal`. Internally, the program might represent those values as 0, 1, and 2, but your code can use the textual values. If you define a variable `selected_size`, then your code can't give it the value 4 because that isn't an allowed value. (Actually, in many programs you can weasel around that check and force the variable to have the value 4. That would defeat the purpose of the enumerated type, so don't do it!)

Keep It Small

Write code in small pieces. Long pieces of code are harder to read. They require you to keep more information in your head at one time. They also require you to remember what was going on at the beginning of the code when you're reading statements much later.

For example, suppose a piece of code loops through a set of customers. For each customer, it loops through the customer's orders. For each order, it loops through the order's items. Finally, for each item it loops through price points for that item. At some point later in the code, you'll come to statements that end each of those loops. For example, in C#, C++, or Java you'll come to a } character. If the code is short, you can look up a few lines to figure out which loop is ending. If the loops started a few hundred lines earlier, it may be hard to decide which loop is ending.

You may also eventually come across code like the following.

```
                }
            }
        }
    }
```

There's nothing here to tell you which loops are ending.

THIS IS THE END

If a closing brace } is far from its corresponding opening brace {, you can make the code easier to understand by adding a comment after it explaining which loop is ending. For example, the following statement shows how you might end a `for` loop that's looping through the X coordinates of an image.

```
} // Next x
```

If you prefer more laconic comments, you could simply use `// x`.

I know some programmers loathe this style of comment, but if the start and end of a loop are far apart, this can be helpful.

I think many of the programmers who hate this kind of comment do so because they are forced to use it for *every* closing brace. You should use it only when it helps, not make an annoying rule that drives programmers crazy.

If a piece of code becomes too long, break it into smaller pieces. Exactly how long is "too long" varies depending on what you're doing. Many developers used to break up methods that didn't fit on a one-page printout. A more recent tree-friendly rule of thumb is to break up a method if it won't fit on your computer's screen all at one time. (This may be why no one programs on smartphones. You'd have thousands of 10-line methods.)

AVOIDING BREAKUPS

Some complicated algorithms may be confusing enough that it's hard to keep everything they do in mind all at once, but splitting them can ruin performance. Or there may be no good place to split them because all the pieces are interrelated. In those cases, you may be stuck with a long chunk of code.

Sometimes, a little extra documentation can act as a roadmap to help you keep track of what the code is doing. (This should be documentation in a separate file, not just more comments, which would make the code even longer.)

You can also refer to external documentation inside the comments. For example, if your code uses Newton's method for finding the roots of a polynomial, don't embed a five-page essay in the comments. Instead add the following comment to the code and move on to something more productive.

```
// Use Newton's method to find the equation's roots. See:
// http://en.wikipedia.org/wiki/Newton's_method
```

In general, if it's hard to keep everything a method does in mind all at once, consider splitting it apart.

Stay Focused

Each class should represent a single concept that's intuitively easy to understand. If you can't describe a class in a single sentence, then it's probably trying to do too much, and you should consider splitting it into several related classes.

For example, suppose you're writing an application to schedule seminars for a conference and to let people sign up for them. You probably shouldn't have a single class to represent attendees and presenters. Attendees and presenters may have a lot in common (they both have names, addresses, phone numbers, and e-mail addresses), but conceptually they are very different. Instead of creating a single `AttendeeOrPresenter` class to represent both kinds of person, make separate `Attendee` and `Presenter` classes. You can make them inherit from a common `Person` parent class, so you don't have to write the same name and address code twice, but making one mega-class will only confuse other developers. (Besides, the name `AttendeeOrPresenter` sounds wishy-washy.)

Just as a class should represent a single intuitive concept, a method should have a single clear purpose. Don't write methods that perform multiple unrelated tasks. Don't write a method called `PrintSalesReportAndFetchStockPrices`. The name might be nicely descriptive, but it's also cumbersome, so it's a hint that the method might not have a single clear purpose.

One of my favorite examples of this was the `Line` method in earlier versions of Visual Basic. As you can probably guess, that method drew a line on a form or picture box. What's not obvious from the name is that it could also draw a box if you added the parameter `B` to the method call. I'm sure there was some implementation reason why this method drew boxes as well as lines, but seriously? A method named `Line` should draw lines not boxes.

Even if two tasks are related, it's often better to put them in separate methods so that you can invoke them separately if necessary.

Avoid Side Effects

A *side effect* is an unexpected result of a method call. For example, suppose you write a `ValidateLogin` method that checks a username and password in the database to see if the combination is valid. Oh, and by the way, it also leaves the application connected to the database. Leaving the database open is a side effect that isn't obvious from the name of the `ValidateLogin` method.

Side effects prevent a programmer from completely understanding what the application is doing. Because understanding the code is critical to producing high-quality results, avoid writing methods with side effects.

Sometimes, a method may need to perform some action that is secondary to its main purpose, such as opening the database before checking a username/password pair. There are several ways you can remove the hidden side effects.

First, you can make the side effect explicit in the method's name. For example, you could call this method `OpenDatabaseAndLogin`. That's not an ideal solution because the method isn't performing one well-focused task, but it's better than having unexpected side effects. (Any time you have "And" or "Or" in a method name, you may be trying to make the method do too much.)

Second, the `ValidateLogin` method could close the database before it returns. That removes the hidden side effect; although it may reduce performance because you may want the database to be open for use by other methods.

Third, you could move the database opening code into a new method called `OpenDatabase`. The program would need to call `OpenDatabase` separately before it called `ValidateLogin`, but the process would be easy to understand.

Fourth, you could create an `OpenDatabase` method as before and make that method keep track of whether the database was already open. If the database is open, the method wouldn't open it again. Then you could make every method that needs the database (including `ValidateLogin`) call `OpenDatabase`. Methods such as `ValidateLogin` would encapsulate the call to `OpenDatabase` so you wouldn't need to think about it when you called `ValidateLogin`. There's still some extra work going on behind the scenes that you may not know about, but with this approach you don't need to keep track of whether the database is open or closed.

It may take a little extra work to remove side effects from a method, but it's worth it to make the code that calls the method easier to understand.

Validate Results

Murphy's law states, "Anything that can go wrong will go wrong." By that logic, you should always assume that your calculations will fail. Maybe not every single time, but sooner or later they will produce incorrect results.

Sometimes, the input data will be wrong. It may be missing or come in an incorrect format. Other times your calculations will be flawed. Values may not be correctly calculated or the results may be formatted incorrectly.

To catch these problems as soon as possible, you should add validation code to your methods. The validation code should look for trouble all over the place. It should examine the input data to make sure it's correct, and it should verify that the result your code produces is right. It can even verify that calculations are proceeding correctly in the middle of the calculation.

The main tool for validating code is the assertion. An *assertion* is a statement about the program and its data that is supposed to be true. If it isn't, the assertion throws an exception to tell you that something is wrong.

EXCEPTIONAL TERMINOLOGY

The term *exception* is programmer-speak for an unexpected error caused by the code. Exceptions can be caused by all sorts of situations such as trying to open a file that doesn't exist, trying to open a file that is locked by another program, performing an arithmetic calculation that divides by zero, using up all the computer's memory, or trying to use an object that doesn't exist.

When an exception occurs, the program's execution is interrupted. If you have an error handler in place, it can examine the exception information to figure out what went wrong and it can try to fix things. For example, it might tell the user to close the application that has a file locked and then it could try to open the file again.

If no error handler is ready to catch the exception, the program crashes.

For example, suppose you're writing a method to list customer orders sorted by their total cost. When the method starts, you could assert that the list contains at least two orders. You could also loop through the list and assert that every order has a total cost greater than zero.

After you sort the list, you could loop through the orders to verify that the cost of each order is at least as large as the cost of the one before it.

One type of assertion that can sometimes be useful is an invariant. An *invariant* is a state of the program and its data that should remain unchanged over some period of time.

For example, suppose you're working on a work scheduling application that defines an `Employee` class. You might decide that all `Employee` objects must always have at least 40 hours of work in any given week. (Although some of those hours might be coded as vacation.)

Here the invariant condition is that the `Employee` object must have at least 40 hours of worked assigned to it. You could add assertions to the object's properties and methods to periodically verify that the invariant is still true. (Ideally, the class would provide only a few public properties and methods that could change the `Employee`'s work schedule and those would verify the invariant, at least before and after they do their work.)

TIMELY ASSERTIONS

Most programming languages have a method for conditional compilation. By setting a variable or flipping a switch, you can indicate that certain parts of the code shouldn't be compiled into the executable result. For example, the following code shows some validation code in C#.

```
#if DEBUG_1
    // Validate the sorted order data.
    ...
#endif
```

The code between the `#if` and `#endif` directives is compiled only if the debugging symbol `DEBUG_1` is defined. If that symbol isn't defined, then the validation code is ignored by the compiler.

You can use techniques such as this one to add tons of validation code to the application. While you are testing and debugging the application, you can define the symbol `DEBUG_1` (and any other debugging symbols) so the testing code is compiled. When you're ready to release the program, you can remove the debugging symbols so that the program runs faster for the customers.

Later, if you discover a bug, you can redefine the debugging symbols to restore the testing code to hunt for the bug.

Some languages such as C# also have built-in conditional compilation for assertions. For example, the following statement asserts that an order's `TotalCost` value is greater than 0.

```
Debug.Assert(order.TotalCost > 0);
```

The compiler automatically includes this statement in debug builds and removes it from release builds.

Assertions and other validation code can make it easy to find bugs right after they are written when they're easest to fix. Unfortunately, it's hard to believe the code you just wrote isn't perfect. After all, you just spent hours slaving over a hot keyboard, pounding away with no breaks (maybe just one to refresh your coffee). The code is still fresh in your mind, so you know exactly how it works (or at least how you *think* it works). Obviously, there isn't bug in it or you would have already fixed it!

That thinking makes it hard for most programmers to write validation code. They just assume it isn't necessary.

However, bugs do occur, so obviously they must be lurking in some of the code that was just written. If only you could convince programmers to add validation code to their methods, you might catch the bugs before they become established.

One way to encourage programmers to write validation code is to have them write it before writing the rest of a method's code. (This is similar to the way you can often get better comments if you write them before you write the code.) Writing the validation code first ensures that it happens.

This also has the advantage that you probably don't yet know exactly how the final code will work. You don't have it all in your head whispering seductively, "You did a great job writing me. There's really no need to validate the results." You also don't have preconceptions about how the code works, so you won't be influenced in how you write the validation code. You can look for incorrect results without making assumptions about where errors are impossible.

Practice Offensive Programming

The idea behind *defensive programming* is to make code work no matter what kind of garbage is passed into it for data. The code should work and produce some kind of result no matter what.

For example, consider the following `Factorial` function written in C#. (In case you don't remember, the factorial of a number N is written N! and equals $1 \times 2 \times 3 \times \ldots \times N$.)

```
public int Factorial(int number)
{
    int result = 1;
    for (int i = 2; i <= number; i++) result *= i;
    return result;
}
```

This code initializes the variable `result` to the value 1. It then multiplies that value by 2, 3, 4, and so on up to the number passed into the method as a parameter. It then returns `result`.

This code works well in most cases. The code even works for strange values of the input parameter `number`. For example, if `number` is 0 or 1, the method sets `result` to 1, the loop does nothing, and the method returns the value 1. That happens to be correct because by definition 0! = 1 and 1! = 1.

If the parameter `number` is negative, the code also sets `result` to 1, the loop does nothing, and the method returns 1.

In fact, due to a quirk in the way C# handles integer overflow, this method even returns a value if `number` is really large. If `number` is 100, the loop causes `result` to overflow. The program sets `result` equal to 0, ignores the overflow, and continues merrily crunching away. When it's finished, it returns the value 0.

This is traditional defensive programming in action. No matter what value you pass into the method, it continues running. It may not always return a meaningful result, but it doesn't crash either.

Unfortunately this approach also hides errors. If the program is trying to calculate 100!, it's probably doing something wrong. At a minimum, it probably doesn't want to get the value 0.

A better approach is to make the `Factorial` method throw a temper tantrum if its input is invalid. That way you know something is wrong and you can fix it. I call this, *offensive programming*. If something offends the code, it makes a big deal out of it.

The following code shows an offensive version of the `Factorial` method:

```
public int Factorial(int number)
{
    Debug.Assert(number >= 0);
    checked
    {
        int result = 1;
        for (int i = 2; i <= number; i++) result *= i;
        return result;
    }
}
```

The code begins with an assertion that verifies that the input parameter is at least 0.

The method includes the rest of its code in a `checked` block. The `checked` keyword tells C# to not ignore integer overflow and throw an exception instead. That takes care of cases in which the input parameter is too big.

If the program passes the new version of the Factorial function an invalid parameter, you'll know about it right away so you can fix it.

Use Exceptions

When a method has a problem, there are a couple ways to tell the program that something's wrong. Two of the most common methods are throwing an exception and passing an error code back to the calling code.

For example, the `Factorial` method shown in the previous section throws an exception if there's an error. The call to `Debug.Assert` throws an exception if its condition is `false`. The `checked` block throws an exception if the calculations cause integer overflow.

As mentioned earlier in this chapter, an exception interrupts the program's execution and forces the code to take action. If you don't have any error handling code in place, the program crashes. That means a lazy programmer can't ignore a possible exception. If a method such as `Factorial` might throw an exception, the code must be prepared to handle it somehow.

In contrast, suppose the `Factorial` method indicated an error by returning an error code. For example, when passed the number –300, it might return the value –1. The factorial of a number is never negative, so the value –1 would indicate there is a problem.

The trouble with this approach is the program could ignore the error code. In that case, the program might end up displaying the bogus value –1 to the user or using that value in some other calculation. The result will be gibberish that is at best unhelpful and at worst misleading and confusing.

In general it's better to throw an exception to indicate an error instead of returning an error code. That way the program can't ignore a potentially confusing situation.

Write Exception Handers First

Now that you're using assertions and exceptions to indicate errors, the code that calls your method needs to use exception handling to deal with those exceptions.

Unfortunately, error handlers are a bit like comments in the sense that many programmers find them boring and don't like to write them. They're also a bit like validation code because it's easy to assume that they're not necessary because you *know* the code works.

One way to create better error handlers is to follow the same strategy you can use when writing comments and validation code: Do it first. When you start writing a method, paste in all the comments that you got from top-down design, add code to validate the inputs and verify the outputs, and then wrap error handling code around the whole thing.

First, make the error handling code look for exceptions that you expect to happen occasionally and that you can do something about (like trying to open a locked file).

Next, add code that looks for other expected exceptions about which you can't do anything except complain to the user. That code should restate any exceptions in terms the user can understand. For example, instead of telling the user, "Arithmetic operation resulted in an overflow," you can present a more meaningful message like, "All orders must include at least 1 item."

Don't Repeat Code

If you find that you're writing the same (or nearly the same) piece of code more than once, consider moving it into a separate method that you can call from multiple places. That obviously saves you the time needed to write the code more than once. More important, it lets you debug and maintain the code in a single place.

Later if you need to modify the code for some reason, you need to make the change only in one method. If the code were duplicated, you would need to update it in every place it occurred. If you forgot to update it in one place, the different copies of the code would be out of synch and that can lead to some extremely confusing bugs. (Yes, I speak from experience here.)

Defer Optimization

One of my favorite rules of programming is:

> *First make it work. Then make it faster if necessary.*

Highly optimized code can be a lot of fun to write, but it can also be very confusing. That means it takes longer to write and test. It's also harder to read, so it's harder to debug and fix if there is a problem.

Meanwhile, even the least optimized code is usually fast enough to get the job done. If you're displaying a list of 10 choices to the user, it doesn't matter if it takes 10 or 12 milliseconds to display. The user is going to stare at the choices for 3 or 4 seconds anyway, so it's not worth spending a lot of extra programming effort to shave 0.05 percent off the total time.

To program as efficiently as possible, write code in the most straightforward way you can, even if it's not the fastest way you can imagine. After you get the code working, you can decide whether it is so slow that it requires optimization.

OPTIMIZATION OVERLOAD

I've never worked on a project that failed because the code was too slow. I've worked on a couple projects that were initially too slow and we rewrote their performance bottlenecks to bring them up to an acceptable speed. It really wasn't all that hard.

In contrast, I've worked on a couple projects that failed because their design was too complicated. People spent so much time trying to optimize the design and come up with the most efficient approach possible that the code was too complicated to implement and debug.

I'll say it again: First make it work. Then make it faster if necessary.

If you do discover that the program isn't running fast enough, take some time to determine where performance improvements will give you the most benefit.

Typically 80 percent of a program's time is spent in 10 percent of the code. (Or 90 percent is spent in 10 percent of the code, or something. The idea is, the program spends most of its time executing a small fraction of the code.) Time you spend optimizing the 80 percent that's already fast enough is time that would be better spent on the slow 20 percent. (Frankly, you'd be better off just wasting that time by talking around the water cooler eating donuts. Time you spend messing about inside the 80 percent of the code that's already working fine can only make that code more confusing and harder to debug and maintain over time.)

Before you start ripping the code apart, use a profiler to see exactly where the problem code is. Then attack only the problem and not the whole program. (So you don't mess up the rest of the code with friendly fire.)

PROFILERS PROFILED

In case you haven't used one, a *profiler* is a program that monitors the progress of a program while it runs to identify the parts that are slow, that use the most memory, or that otherwise might be bottlenecks. Different profilers work in different ways. For example, some add code (called *instrumentation*) to your program to record the number of times every method is called and the amount of time the program spends in each method.

Profilers are *very* handy for tracking performance problems. I worked on one program that was taking approximately 20 minutes to load its data when it started. The project manager refused to buy a profiler ("real programmers don't need them") and had a number of theories about where in the data processing algorithms the bottlenecks were.

I snuck off into my office and installed a profiler for a 30-day free trial. Within a few hours, I had discovered that the problem wasn't in the main algorithms at all. The problem was actually in some fairly trivial string-processing code. Basically, the

program was going back to a database hundreds of times to re-fetch values that it had already loaded. I built a simple table to keep track of the values that had already been fetched and cut the program's startup time from 20 minutes to under 4.

If I hadn't used the profiler, I would probably have wasted a week or two and only shaved a minute or so off of the startup time. (After the fact the project lead admitted that, okay, perhaps a profiler was a good idea after all.)

Before you start optimizing code, make sure it works properly. Then if you do find that performance is insufficient, carefully analyze the problem (using a profiler if you can) so that you don't waste time optimizing code that is already fast enough.

SUMMARY

Most programmers love to program, but they can't do a good job without the proper tools. If you don't have the right hardware, software, and network support, writing good code is slow and frustrating. That leads to distraction and more bugs. Writing good code also requires debugging, testing, and profiling tools. Depending on the development environment, you may also need code formatting and refactoring tools.

Before you starting writing code, make sure you have the tools you need to do so effectively. If you don't write code, make sure those who do get the tools they need.

Even if you're using all the proper tools, writing good code isn't guaranteed. There are dozens or perhaps hundreds of tips and tricks you can use to make your code safer. This chapter describes a few of my favorites. By using those techniques, you can make your programs more reliable, easier to debug, and easier to modify in the future.

Unfortunately, even the best program can still contain bugs. In fact, it's common in software engineering to assume that every nontrivial program contains some bugs. The only questions are, "How many bugs?" and "How often will the bugs affect the users?"

Testing lets you find and fix as many bugs as possible. If you test a program effectively, you can eventually reduce the number and severity of the remaining bugs so that the program is still usable. (Just as if you squash enough cockroaches, the rest eventually learn to hide better.)

The next chapter explains software testing. It describes techniques you can use to find bugs and estimate the number of bugs that remain in an application.

EXERCISES

1. The greatest common divisor (GCD) of two integers is the largest integer that evenly divides them both. For example, the GCD of 84 and 36 is 12 because 12 is the largest integer that evenly divides both 84 and 36. You can learn more about the GCD and the Euclidean algorithm, which you can find at `en.wikipedia.org/wiki/Euclidean_algorithm`.

Knowing that background, what's wrong with the comments in the following code? Rewrite the comments so that they are more effective. (Don't worry about the code if you can't understand it. Just focus on the comments.) (Hint: It should take you only a few seconds to fix these comments. Don't make a career out of it.)

```
// Use Euclid's algorithm to calculate the GCD.
private long GCD(long a, long b)
{
    // Get the absolute value of a and b.
    a = Math.Abs(a);
    b = Math.Abs(b);

    // Repeat until we're done.
    for (; ; )
    {
        // Set remainder to the remainder of a / b.
        long remainder = a % b;
        // If remainder is 0, we're done. Return b.
        if (remainder == 0) return b;
        // Set a = b and b = remainder.
        a = b;
        b = remainder;
    };
}
```

2. Why might you end up with the bad comments shown in the previous code?

3. How could you add validation code to the method shown in Exercise 1? (If you don't know how to write the validation code in C#, just indicate where it should be and what it should do.)

4. How could you apply offensive programming to the modified code you wrote for Exercise 3?

5. Should you add error handling to the modified code you wrote for Exercise 4?

6. The following code shows one way to swap the values in two integers `a` and `b`. The ^ operator takes the "exclusive or" (XOR) of the two values. The comments to the right explain how this method works.

```
// Swap a and b.     Let A and B be the original values.
b = a ^ b;        // b = A ^ B
a = a ^ b;        // a = A ^ (A ^ B) = (A ^ A) ^ B = B
b = a ^ b;        // b = B ^ (A ^ B) = (B ^ B) ^ A = A
```

This is a clever piece of code. It lets you swap two values without needing to waste memory for a temporary variable. So why isn't it good code? Write an improved version.

7. Using top-down design, write the highest level of instructions that you would use to tell someone how to drive your car to the nearest supermarket. (Keep it at a very high level.) List any assumptions you make.

WHAT YOU LEARNED IN THIS CHAPTER

- Use the right tools:
  - Fast development hardware and a fast Internet connection
  - A good development environment and source code formatters (if necessary)
  - Source code control
  - Profilers and static analysis tools
  - Testing and refactoring tools
  - Training
- Select algorithms that are effective, efficient, predictable, simple and (if possible) prepackaged.
- Use top-down design to fill in code details.
- Programming tips:
  - Program when you're most alert.
  - Write code for people, not for the computer.
  - Write comments, validation code, and exception handlers before you start writing the actual code.
  - Use descriptive names, named constants, and enumerated types.
  - Break long methods into manageable pieces.
  - Make each class represent a single concept that's intuitively easy to understand.
  - Keep methods tightly focused on a single task and without side effects.
  - Program offensively to expose bugs as quickly as possible.
  - Signal problems with exceptions instead of error codes.
  - If you're writing the same piece of code for a second time, extract it into a method that you can call repeatedly.
  - Only optimize after you sure it's necessary. Then use a profiler to find the code that actually needs optimization.

8

Testing

Testing is the process of comparing the invisible to the ambiguous, so as to avoid the unthinkable happening to the anonymous.

—James Bach

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Goals of testing
- Reasons why you might not want to remove a bug
- How to prioritize bugs
- Kinds of tests and testing techniques
- Good testing habits
- Methods for estimating number of bugs

It's a software engineering axiom that all nontrivial programs contain bugs. Actually, it's such an important point that it deserves to be put in its own note and explained with an example.

> **NOTE** *All Nontrivial Programs Contain Bugs*

For example, Windows 2000 was said by some to contain a whopping 63,000+ known bugs when it was shipped. Microsoft quickly retorted that this number didn't actually

count bugs. It included feature requests, notes asking developers to make something work better or more efficiently than it already did, clarification requests, and other nonbug issues. The *true* bugs, Microsoft explained, were mostly minor issues that wouldn't seriously hurt users.

No matter how you count them, Windows 2000 contained a *lot* of "undesirable features" ranging from changes that should probably have been made to indisputable bugs.

You might think that's the result of shoddy workmanship, but no project of that size could possibly have shipped without any bugs. The industry average number of bugs per thousand lines of code (kilo lines of code or *KLOC*) is typically estimated at about 15 to 50. When you consider that Windows 2000 contained more than 29 million lines of code, it's a miracle it works at all. Even assuming 10 bugs per KLOC, Windows 2000 should contain approximately 290,000 bugs. Suddenly 63,000 bugs is starting to look good, isn't it?

NASA's Goddard Space Flight Center, which takes bugs *very* seriously because a mistake in its code could cost lives and hundreds of millions of dollars, is said to have reduced its number of bugs to less than 0.1 per KLOC. Even if Microsoft could afford to follow Goddard's practices (and getting the number of bugs per KLOC down to that level is *very* expensive), Windows 2000 would still contain 2,900 bugs.

I don't know about you, but if I encountered 2,900 bugs on a daily basis, I'd toss my computer out a window and start using a typewriter.

BIGGER AND BETTER?

Windows 8 is rumored to contain between 30 and 80 million lines of code, so clearly Microsoft isn't reducing its bug count by shrinking its operating system, but don't think this is just Microsoft's problem. The Firefox browser contains approximately 10 million lines of code, the Linux operating system contains more than 50 million, Mac OS X Tiger has approximately 85 million, and Facebook has approximately 60 million. It takes a lot of code to include something to annoy everyone!

You can see an interesting chart showing the size of some big applications at `www.makeuseof.com/tag/million-lines-code-lot`.

Given that any nontrivial program contains bugs, what can you do about it? Are you doomed to suffer the slings and arrows of outraged customers? Or should you just throw in the towel and open a florist's shop instead of writing software?

Even though you can't wipe out every bug, you can catch the ones that will be most irritating to users. You can reduce the number of high-profile bugs to the point where users see them only rarely. If your program uses a good design, it should also recover from bugs gracefully so that the program doesn't crash.

This chapter explains testing techniques you can use to flush out the majority of the most annoying bugs. It explains kinds of tests you should run and when to run them. It also explains how to estimate the number of bugs in the system so that you have some idea of whether you're getting closer to your goal of eliminating the high-profile bugs.

TESTING GOALS

Ideally you would sit down, write code that perfectly satisfies the requirements, and you'd be done. Unfortunately that rarely happens. More often than not, the first attempt at the software satisfies some but not all the requirements. It may also incorrectly handle situations that weren't specified in the requirements. For example, the code may not work in every possible situation.

That's where testing comes in. Testing lets you study a piece of code to see whether it meets the requirements and whether it works correctly under all circumstances. (Usually, the second goal means a method works properly with any set of inputs.)

To get a complete picture of how a piece of code performs, you can carry out several different kinds of tests using a variety of techniques. Sections later in this chapter describe some of the most important of those. Before you get to them, however, it's worth knowing that it's not always worth removing every single bug from a program. Instead the goal is often to reduce the number bugs and their frequency of occurrence so that users can get their jobs done with a minimum of annoyance.

REASONS BUGS NEVER DIE

Simply put, a *bug* is a flaw in a program that causes it to produce an incorrect result or to behave unexpectedly. Bugs are generally evil (although occasionally they make games more fun), but it's not always worth your effort to try to remove every bug. Removing some bugs is just more trouble than it's worth. The following sections describe some reasons why software developers don't remove every bug from their applications.

Diminishing Returns

Finding the first few bugs in a newly written piece of software is relatively easy (and therefore cheap). After a few months of testing, finding bugs may become extremely difficult. At some point, finding the next bug would cost you more than you'll ever earn by selling the software.

Deadlines

In a just and fair world, software would be released when it was ready. In the real world, however, companies are often driven by deadlines imposed by management, competition, or a marketing department.

You might delay a release to fix high-profile bugs, but if the remaining bugs aren't too bad, you might be forced to release before you would like.

Consequences

Sometimes a bug fix might have undesirable consequences. For example, suppose you're building a drawing application and the tool that draws spirals isn't saving the spirals' colors correctly. You could fix it, but that would require changing the format of the saved picture files. That would force the users to convert their data files, and that would make them storm your office with torches and pitchforks.

In this example, it might be better to leave the spiral-saving code unfixed for now and include a fix in the next major release. Users expect some pain in major releases, so you might get away with it then. (But just in case, you should make sure the escape helicopter is fueled and ready to go.)

It's Too Soon

If you just released a version of a program, it may be too soon to give the users a new patch to fix a minor bug. Users won't like you if you release new bug fixes every 3 days. As a rule of thumb:

- If a bug is a security flaw, release a patch immediately, even if you just released a patch yesterday. (If you did release a patch yesterday, you better be sure the new patch fixes things correctly! Your reputation is at stake.) Include a note explaining how wonderful you are for protecting the users' valuable data.
- If a bug makes users swear at your program more than once a day, release a patch as soon as possible (as often as monthly). Include a profuse apology.
- If a bug is annoying enough to make users smirk at your program occasionally, fix it in a minor release (as often as twice a year). Include a huge fanfare about how great you are for looking after the users' needs.
- If a bug is just a nice-to-have new feature or a performance improvement, fix it in the next major release (at most once per year). Explain how responsive you are and that the users' needs are your number one concern.

Too many releases will annoy users, so you need to weigh the benefit of any bug patch against the inconvenience.

Usefulness

Sometimes users come to rely on a particular bug to do something sneaky that you didn't intend them to do. They won't thank you if you remove their favorite feature, even if it started out as a bug.

> *Any sufficiently advanced bug is indistinguishable from a feature.*
>
> —Bruce Brown

If the users have adopted a bug and are using it in their favor, formalize it and add it to the application's requirements. You may extend its behavior to give the users an even better feature and take credit for it.

Obsolescence

Over time, some features may become less useful. Eventually they may go away entirely. In that case, it may be better to just let the feature die rather than spending a lot of time fixing it.

For example, if an operating system has a bug in a floppy drive controller that limits its performance, it may be just as well to ignore it. Floppy drives are rare these days, so the bug probably won't inconvenience too many users. (In fact, some computers are shipping without CD or DVD drives these days. As long as your network and USB devices work, you may cut back on maintenance of your CD drivers. Of course, you still need to use a USB CD drive, at least for now.)

It's Not a Bug

Sometimes users think a feature is a bug when actually they just don't understand what the program is supposed to do. (It seems like Facebook has perfected this problem. It moves its security settings around and users complain that their cat pictures are visible to everyone in the world.)

This is really a problem of user education. Sometimes the documentation isn't correct and sometimes it's missing entirely. Sometimes the user isn't willing to read all the way through both paragraphs of documentation and see that the feature is clearly described.

If the documentation is incomplete or unclear, this is a "documentation bug" that you can fix the next time you release a new version of the documentation.

DOCUMENTATION DELETED

Back in the old days, when you bought a piece of software, you also got a nice, fat book explaining how to use it. Some particularly long user manuals came as a set of ring binders with pages that you could replace when the vendor sent you manual updates.

These days most application documentation comes electronically in text files, PDF files, or online help applications. That allows vendors to update the documentation any time it is necessary. (See the earlier section "It's Too Soon." The same ideas apply to documentation as well as software. Your customers won't thank you for sending them daily documentation updates.)

You can greatly decrease this problem by using a good user interface design. If the application groups features logically so users can find them easily, the users won't complain that a feature is missing when it isn't. If features are named clearly so it's obvious what they do, users won't complain that a feature doesn't do what they think it's supposed to do.

It Never Ends

If you try to fix every bug, you'll never release anything.

This is similar a problem you may have when buying a new computer. If you just wait another couple months, something faster will come out for the same price. If you do buy a nice, shiny, new machine, something better instantly goes on sale. At some point, you just need to pry open your

wallet, buy something, and get on with your life. (It also helps to avoid looking at advertisements afterwards, so you don't see the faster machines going on sale.)

Similarly at some point you need to stop testing, cross your fingers, and publish your application. It's almost guaranteed to be imperfect, but hopefully it's better than nothing.

It's Better Than Nothing

As the previous section mentions, your application may not be perfect, but hopefully it's better than nothing. In some cases, it may be so much better than nothing that it's worth releasing the application even though it's seriously flawed.

This is particularly true if your application is for in-house use. If you're writing a tool for your fellow employees to use, they may be willing to put up with some rough edges to get their jobs done more easily.

THE TOOLSMITH

If a software project is large enough, it may be worth having a dedicated toolsmith. A *toolsmith* is someone whose job is to build tools for use by others on the project. A tool might count the lines of code in the project's modules, rearrange the controls on a form in top-down/left-to-right order, search customer data for patterns, build a random test database, or just about anything else that makes the other team members' lives easier.

I spent a large chunk of time on one project writing a form handler that let the other developers arrange labels and text boxes on forms. On another project I built a tool that helped developers define complex menu hierarchies more easily. (The development environment we were using back then was bad at both designing forms and building menus.)

The programs written by a toolsmith are often somewhat unfinished. They may contain bugs and may require their users to follow certain paths or risk falling into untested parts of the program. Still, if the tool is useful enough, it's worth living with a few quirks.

The reason you can get away with less-than-perfect applications in-house is that future sales don't depend on the program working perfectly. Outside customers might refuse to buy later releases of the program and may flame you in online discussion groups, but your coworkers are stuck with you.

Fixing Bugs Is Dangerous

When you fix a bug, there's a chance that you'll fix it incorrectly, so your work doesn't actually help. There's also a chance that you'll introduce one or more new bugs when you fix a bug.

In fact, you're significantly more likely to add a bug to a program when you're fixing a code than when you're writing new code from scratch. When you write new code, you (hopefully) understand what you want the code to do and how it should work. When you're fixing code sometime later, you don't have the same level of understanding.

To reduce the problem, you need to study the code thoroughly to try to regain the understanding you originally had. Hopefully, you were paying attention in Chapter 7, "Development," when I said you should write code for people not the computer. If you did, then it will be much easier for you to figure out what the broken piece of code is trying to do.

Finally, whether you fix the bug correctly, other pieces of code may rely on the buggy behavior. When you change the code, you may break other pieces of code that were (at least apparently) working before.

Which Bugs to Fix

There may be some good reasons not to fix every bug, but in general bugs are bad, so you should remove as many of them as possible. So how do you decide which bugs to fix and which to put in the "fix later" category?

To decide which bugs you should fix, you should use a simple cost/benefit analysis to prioritize them. For each bug, you should evaluate the following factors.

- **Severity**—How painful is the bug for the users? How much work, time, money, or other resources are lost?
- **Work-arounds**—Are there work-arounds?
- **Frequency**—How often does the bug occur?
- **Difficulty**—How hard would it be to fix the bug? (Of course, this is just a guess.)
- **Riskiness**—How risky would it be to fix the bug? If the bug is in particularly complex code, fixing it may introduce new bugs.

After you evaluate all the bugs, you can assign them priorities. Note that you may want the priorities to change over time. If your next release is a long time away, you can focus on the most severe bugs without work-arounds. If your time is limited, you can focus on the least risky bugs so that you don't break anything else before the next release.

LEVELS OF TESTING

Bugs are easiest to fix if you catch them as soon as possible. After a bug has been in the code for a while, you forget how the code is supposed to work. That means you'll need to spend extra time studying the code so that you don't break anything. The longer the bug has been around, the greater the chances are that other pieces of code rely on the buggy behavior, so the longer you wait the more things you may have to fix.

In order to catch bugs as soon as possible, you can use several levels of testing. These range from tightly focused unit testing that examines the smallest possible pieces of code, to system and acceptance testing that exercises the system as a whole.

Unit Testing

A *unit test* verifies the correctness of a specific piece of code. As soon as you finish writing a piece of code, you should test it. Test it as thoroughly as possible because it will get harder to fix later.

LITTLE TESTS AND BIG TESTS

It's much easier to test a lot of little pieces of code rather than one big piece. Combining many pieces of code can lead to a combinatorial explosion of the number of paths through the code that you need to test.

For example, suppose you have a piece of code that performs 10 `if-then` tests. Depending on a set of values, the code takes one branch or another at each of the 10 decision points.

To follow every possible path through the code, you need to test every possible combination of branches. For 10 branches with 2 paths each, that's 2^{10} = 1,024 possibilities. If you don't check them all, you may have a combination that doesn't work.

Even if you do check them all, there's a chance that there's a bug in one of them, and you just got unlucky and didn't notice it. You should still at least touch every possible path. (If you don't walk down a path in a forest, you won't notice the snake sitting in the middle of it.)

Now suppose you break the big piece of code into 10 pieces, each containing a single `if-then` test. If you test the pieces separately, you need only two test cases for each, making a total of 20 test cases.

This is a somewhat simplistic example, but breaking big chunks of code into simpler pieces makes them much easier to test and debug.

Usually unit tests apply to methods. You write a method and then test it. If you can, you may even want to test parts of methods. That lets you catch bugs minutes or even seconds after they hatch, while they're still weak and easy to kill.

If you're using an object-oriented programming language, be sure to test code that doesn't act like a normal method. For example, be sure to test constructors (which execute when you make a new object), destructors (which execute when you destroy an object), and property accessors (which execute when the program gets or sets a property's value).

Because unit tests are your first chance to catch bugs, they're extremely important. Unfortunately, it's also easy for programmers to assume the code they just wrote works. After all, if it didn't work, you would have fixed it!

Chapter 7 said that you can write more effective validation code if you write it before you write the routine it protects. The same applies here. You can often do a better job on a method's unit tests if you write them before you write the method. That way you won't know what assumptions the code makes, so you won't make the same assumptions when you write the tests.

You may also want to add more test cases after you write the code, so you can look for situations that the code might not handle correctly. The "Testing Techniques" section discusses some of the kinds of tests you may want to write.

Typically, a test is another piece of code that invokes the code you are trying to test and then validates the result. For example, suppose you're writing a method that organizes Pokémon card decks. It groups the cards by evolution chain (cards that are related) and then sorts the chains by their total smart ratings (average of attack, defense, special attack, and special defense). A unit test might generate a deck containing 100 random cards, pass them into the method, and validate the sorted result. The test method could repeat the random deck test a few hundred times to make sure the sorting method works for different random decks.

Other tests may perform user actions such as opening forms, clicking on buttons, or clicking and dragging on a window to see what happens.

After you write the tests and use them to verify that your new code works, you should save the test code for later use. Sometimes, you may want to incorporate some or all the unit tests in regression testing (described in the next section).

You also need the tests again if you discover a bug in this code. You may think the unit tests are enough to flush out every bug so there won't be any in the future, but that's not the case. Bugs eventually appear. If you've saved all your unit tests, you won't need to write them again for the routine that went wrong. You also won't need to rewrite them if there's no bug but you need to modify the code.

Of course, writing a bunch of tests can clutter up your artistically formatted code. Depending on your programming environment, you may avoid that by moving the test code into separate modules. You can also use conditional compilation to avoid compiling the test code in release builds so it doesn't make the final executable bigger.

Integration Testing

After you write a chunk of code and use unit tests to verify that it works (or seems to work), it's time to integrate it into the existing codebase. An *integration test* verifies that the new method works and plays well with others. It checks that existing code calls the new method correctly, and that the new method can call other methods correctly.

Integration typically focuses on the new code and other pieces of code that interact with it, but it should also spend some time verifying that the new code didn't mess up anything that seems unrelated.

For example, suppose you're building a program to help you design duct tape projects (things like duct tape wallets, flowers, suits of armor, and prom dresses). You just wrote a new method to build parts lists giving the amount and kinds of duct tape you need for a particular project.

The new method passes its unit tests with flying colors, so you integrate it into the existing codebase. In integration tests, the main program can call the method successfully, and the new method can call existing code to do things like fetch duct tape roll lengths and prices.

Everything seems fine until you try to use the program to order new duct online. Suddenly that part of the program is no longer working. That duct tape ordering module may seem completely unrelated to the parts list method, but somehow it's not.

For example, the parts list code might open the pricing database and accidentally leave a price record locked. You might not notice this during unit testing and integration testing, but the tape ordering part of the program won't work if that record is locked.

To discover this kind of bug, you use regression testing. In *regression testing*, you test the program's entire functionality to see if anything changed when you added new code to the project. These tests look for ways the program may have "regressed" to a less useful version with missing or damaged features.

Ideally, when you finish unit testing a piece of code, you would then perform integration testing to make sure it fits in where it should and that it didn't break anything obvious. Then you perform regression testing to see if it broke something non-obvious.

Unfortunately, performing regression testing on a large project can take a lot of time, so developers often postpone regression testing until a significant amount of code has been added or modified. Then they run the regression tests. Of course, at that point there may be a lot of bugs and it may be hard to figure out which change caused which bug. Some of the "new" code may also not be all that new, so some of the bugs may be a bit older and therefore harder to fix.

To fix bugs as quickly as possible, you need to perform regression testing as often as possible.

Automated Testing

You might not have time to run through every test every day. After all, you need time to do other things like write new code, perform code reviews, and eat donuts at staff meetings. However, a good automated testing system may do it for you. Automated testing tools let you define tests and the results they should produce. Some of them let you record and replay keyboard events and mouse movements so that a test can interact with your program's user interface.

After running a test, the testing tool can compare the results it got with expected results. Some tools can even compare images to see if a result is correct.

For example, to test a drawing program, you might record your actions as you draw, resize, and color a polygon. Later the testing tool would repeat the steps you took and see if the resulting picture matched the one you got when you did it interactively.

Some testing tools can run *load tests* that simulate a lot of users all running simultaneously to measure performance. For example, load tests can tell if too many users trying to access the same database will cause problems in your final release.

A good testing tool should let you schedule tests so that you can run regression testing every night after the developers all go home. (Or you could start the tests running before you leave for the night.)

When you come in the next morning, you can check the tests to see if there are any newly discovered problems that you should fix before you begin writing new code.

OUTSOURCING TESTS

One annoying feature of outsourcing is that there's no good time for the clients and suppliers to meet. If it's during the middle of the work day here, it's the middle of the night there or vice versa. (I suppose that wouldn't be a problem if you're working in San Jose and outsourcing to Los Angeles, but I don't think that's typical.)

A friend of mine used the time difference to his advantage. His software development team would write code during the day. They would perform their unit and integration tests, and then ship their code to testers in India before they left for the day.

When the Indian testers arrived in the morning, the new code would be waiting for them. They would run the regression tests and send the results back to the developers, who would see them first thing the next day. (Or maybe first thing on the same day. It depends on how you look at time zones.)

The result was a lot like what you would get from an automated testing tool, but humans have a lot more flexibility than automated tools, so they can follow much more complicated instructions.

Component Interface Testing

Component interface testing studies the interactions between components. This is a bit like regression testing in the sense that both examine the application as a whole to look for trouble, but component interface testing focuses on component interactions.

A common strategy for component interface testing is to think of the interactions between components as one component sending a message (a request or a response) to another. You can then make each component record its interactions (plus a timestamp) in a file. To test the component interfaces, you exercise the system and then review the timeline of recorded events to see if everything makes sense.

THE BIG PICTURE

I've done some work with a company that processes photographs taken at popular tourist destinations such as amusement parks and sporting events. The photographers take your picture and upload it to a local computer.

Components in the application perform several processing steps such as moving the picture into a (huge) database, turning the pictures right side up (sometimes the photographers hold their cameras sideways), and creating smaller thumbnail images.

For debugging purposes, the components can write messages with timestamps into a log file so that you can see what's going on and so that you can tell if one of the components it stuck. This company processes tens of thousands of photographs every day, so if a process gets stuck for a few hours, hundreds or thousands of customers can't buy pictures of themselves standing beside their favorite theme park mascots.

Because the company processes so many images, the log files can grow extremely quickly. Depending on the level of information recorded, the logs can grow by megabytes per hour.

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To prevent the log files from eventually gobbling up all the disk space on the planet, the components were written so that they check systemwide settings when they start to decide how much information to record. If something's going wrong, you change the settings and restart a component. (To make that possible, they're also good at picking up where they left off when you restart them.) After a few minutes, you check the log files to see what's wrong and you fix the problem. When you're done, you change the settings back to allow little or no logging, and restart again.

The ability to quickly change the amount of information recorded without recompiling has been extremely useful in keeping the process running smoothly.

Planning ahead of time for component interface testing can also help with the application's design. Thinking in terms of loggable messages passed between components helps keep the components decoupled and gives them a clearer separation. That makes them easier to implement and test separately.

System Testing

As you may guess from its name, *system testing* is an end-to-end run-through of the whole system. Ideally, a system test exercises every part of the system to discover as many bugs as possible.

A thorough system test may need to explore many possible paths of interaction with the application. Unfortunately, even simple programs usually contain a practically unlimited number of possible paths of interaction.

For example, suppose you're writing a program to keep track of dirt characteristics for hikaru dorodango (dirt polishing) enthusiasts, things like color, amount available, and grain size. Also suppose the program includes only a login screen and a single form that uses a grid to display dirt information. Then you would need to try each of the following operations:

- Start the program and click Cancel on the login screen.
- Start the program, enter invalid login, click OK, verify that you get an error message, and finally click Cancel to close the login screen.
- Start the program, enter invalid login, click OK, verify that you get an error message, enter valid login information, and click OK. Verify that you can log in.
- Log in, view saved information, and close the program. Log in again and verify that the information is unchanged.
- Log in, add new dirt information, and close the program. Login in again and verify that the information was saved.
- Log in, edit some dirt information, and close the program. Login in again and verify that the changes were saved.
- Log in, delete a dirt information entry, and close the program. Login in again and verify that the changes were saved.

You need all those tests for just two screens, neither of which can do much. (Even then, I've seen a lot of applications where those tests wouldn't be good enough. For example, some programs won't save changes in a grid control unless you move the cursor to another cell after changing a cell's data.)

For more complicated applications, the number of combinations can be enormous. In the end, you'll probably have to test the most common and most important scenarios, and leave some combinations untested.

Acceptance Testing

The goal of *acceptance testing* is to determine whether the finished application meets the customers' requirements. Normally, a user or other customer representative sits down with the application and runs through all the user cases you identified during the requirements gathering phase to make sure everything works as advertised.

Remember that the requirements may have changed after the requirements phase. In that case, you obviously verify that the application satisfies the revised requirements.

Acceptance testing is usually straightforward; although, depending on the number of use cases, it can take a long time. A fairly simple application might need only a few use cases. (The hikaru dorodango example described in the preceding section might need only a few to check that you can log in, view, add, edit, and delete data.) A large, complex application with detailed needs might have dozens or hundreds of use cases. In that case it might take days or even weeks to go through them all.

One mistake developers sometimes make is waiting until the application is finished before starting acceptance testing. You do need to perform acceptance testing then, but if that's the first time the customer sees the application, there may be problems. Customers may decide that their interpretation of a use case is different from yours. Or they may decide that what they need is different from what they thought they needed during requirements gathering.

In those cases, you're much better off if you do a quick run-through of each use case as soon as the application can handle it. Then if you need to change the requirements, you can do it while there's still some time left in the development schedule and not at the end of the project when all of the programmers have scheduled overseas vacations.

Other Testing Categories

Unit test, integration test, component interface test, and system test categorize tests based on their scale with unit test being at the smallest scale and system test including the entire application. An acceptance test differs from a system test in the point of view of the tester: A system tester is typically a developer, whereas an acceptance tester is a customer representative.

The following list summarizes other categories of testing that differ in their scope, focus, or point of view.

- **Accessibility test**—Tests the application for accessibility by those with visual, hearing, or other impairments.
- **Alpha test**—First round testing by selected customers or independent testers. Alpha tests usually uncover lots of bugs and defects, so they generally aren't open to a huge number of users because that might ruin your reputation for building good software.

- **Beta test**—Second round testing after alpha test. Generally, you shouldn't give users beta versions until the application is quite solid or you might damage your reputation for building good software. Sometimes, beta tests are used as a sneaky form of a limited trial to build excitement for a new release in the user community.
- **Compatibility test**—Focuses on compatibility with different environments such as computers running older operating system versions. Also checks compatibility with older versions of the application's files, databases, and other saved data.
- **Destructive test**—Makes the application fail so that you can study its behavior when the worst happens. (Obviously, if you have good backups, you won't actually destroy the code. You'll destroy the application's performance.)
- **Functional test**—Deals with features the application provides. These are generally listed in the requirements.
- **Installation test**—Makes sure you can successfully install the system on a fresh computer.
- **Internationalization test**—Tests the application on computers localized for different parts of the world. This should be carried out by people who are natives of the locales.
- **Nonfunctional test**—Studies application characteristics that aren't related to specific functions the users will perform. For example, these tests might check performance under a heavy user load, with limited memory, or with missing network connections. These often identify minimal requirements.
- **Performance test**—Studies the application's performance under various conditions such as normal usage, heavy user load, limited resources (such as disk space), and time of day. Records metrics such as the number of records processed per hour under different conditions.
- **Security test**—Studies the application's security. This includes security of the login process, communications, and data.
- **Usability test**—Determines whether the user interface is intuitive and easy to use.

TESTING TECHNIQUES

The previous sections described some different levels of testing (unit, integration, component, system, and acceptance) and alluded to some methods for testing (try out every combination of actions that you can think of), but they didn't explain specific techniques for performing actual tests.

In particular, they didn't discuss generating data for tests. For example, suppose a method organizes Pokémon card decks as described earlier. You can test it by generating a random deck and seeing if the method organizes it correctly, but how do you know it will work with *every* possible deck?

The following sections describe some approaches to designing tests to find as many bugs as possible.

Exhaustive Testing

In some cases, you may be able to test a method with every possible input. For example, suppose you write a tic-tac-toe (noughts-and-crosses) program and one method is in charge of picking the

best move from a current board position. You could test the method by passing it a board position, seeing what move it picks, and then verifying that there are no better moves that it could have chosen instead.

There are only 9! = 362,880 possible board arrangements, so you could pass the method every possible combination of moves to see what it does. (In fact, many of the board arrangements are impossible. For example, you can't have three Os on the top row and three Xs on the middle row in the same game. That means there are fewer than 9! possible arrangements to test.)

This sort of exhaustive testing conclusively proves that a method works correctly under all circumstances, so it's the best you can possibly do. Unfortunately, most methods take too many combinations of input parameters for you to exhaustively try them all.

For a ridiculously simple example where an exhaustive test is impossible, suppose you write a `Maximum` method that compares two 32-bit integers and returns the one that's larger. Each of the two inputs can take roughly 4.3×10^9 values (between –2,147,483,648 and 2,147,483,647), so there are approximately 1.8×10^{19} possible combinations. Even if you had a computer that could call the method and verify its results 1 billion times per second, it would take more than 570 years to check every combination.

Because most methods take too many possible inputs, exhaustive testing won't work most of the time. In those cases, you need to turn to one of the following methods.

Black-Box Testing

In *black-box testing*, you pretend the method is a black box that you can't peek inside. You know what it is supposed to do, but you have no idea how it works. You then throw all sorts of inputs at the method to see what it does.

You can start black-box testing by sending it a bunch of random inputs. Remember that you need to perform these tests only occasionally, not every time the program runs, so you can test a *lot* of random values. For example, you might throw a few million random pairs of values at the `Maximum` method described in the previous section. It doesn't matter if it takes the test a few minutes to finish.

Even if you don't know how the method works, you can try to guess values that might mess it up. Typically, those involve special values like 0 for numbers and blank for strings. They may also include the largest and smallest possible values. For strings that might mean a string that's all blanks or all ~ characters.

Sometimes, you can trip up a method that expects to process names by using strings containing numbers or special characters such as &#%!$ (which looks like a cartoon character swearing).

Some methods don't work well if their inputs include a lot of duplicates, so try that. For example, quicksort is one of the fastest sorting algorithms usually, but it gives terrible performance if the items it is sorting all have the same value. (Consult an algorithms book or search for quicksort online if you want to see the details.)

If a method takes a variable number of inputs, make sure it can handle 0 inputs and a really large number of inputs. If it takes an array or list as a parameter, see what it does if the array or list is empty or missing.

Finally, look at boundary values. If a method expects a floating point parameter between 0.0 and 1.0, make sure it can handle those two values.

White-Box Testing

In *white-box testing*, you get to know how the method does its work. You then use your extra knowledge to design tests to try to make the method crash and burn.

White-box testing has the advantage that you know how the method works, so you can try to pick particularly difficult test cases. Unfortunately it has the disadvantage that you know how the method works, so you might skip some test cases that you assume work.

For example, you might know that a method would be confused by zero-length strings. But you knew that when you wrote the code, so you handled it. The problem is, you may not have handled it correctly. If you handled everything correctly, then there wouldn't be any bugs and you wouldn't need testing at all.

Use white-box testing to create tests you know will be troublesome, but don't skip tests that you "know" the method can handle.

Gray-Box Testing

Gray-box testing is a combination of white-box and black-box testing. Here you know some but not all the internals of the method you are testing. Your partial knowledge of the method lets you design specific tests to attack it.

For example, suppose a method examines test score data to find students that might need extra tutoring help. You don't know all the details, but you do know that it uses the quicksort algorithm to sort the students by their grades. In that case, you might want to see what the method does if every student has the same grade because that might mess up quicksort. (Because you don't know what else is going on inside the method, you also need to write a bunch of black-box styles tests.)

BLACK-BOX AND WHITE-BOX TESTING

With black-box testing, if you truly don't know how a method works, then it's harder to assume it handles specific cases correctly. Unfortunately with black-box testing, you don't know where to look for weaknesses.

White-box testing lets you specifically attack a method's weaknesses, but as mentioned a couple of times (both in this chapter and in Chapter 7) it's easy for programmers to assume their code works. (That's the biggest drawback of white-box testing.) That can make them skip some test cases that might uncover a bug.

You can get the best of both worlds by combining black-box and white-box testing. One way to do that is to have two different people test a method. The programmer who wrote it can build some white-box tests, and someone else can design some black-box tests.

Many software projects have designated testers who do nothing but try their hardest to destroy their colleagues' code. Sometimes their attitude can be a bit adversarial, but the results can be remarkable if team members don't take things too seriously. (There's a great short article about IBM's Black Team at `www.t3.org/tangledwebs/07/tw0706.html`.)

Another approach that can give some of the same benefits is to have developers write black-box tests before they write a method's code. (Okay, these might really be more like "dark-gray-box" tests because a developer might have some idea about how he will write the method. You can probably do even better if you have one person write the black-box tests and then have another write the code.) Then after the method is written, its author can create white-box tests to go with it.

TESTING HABITS

Just as there are good programming habits, there are also good testing habits. These habits make testing more effective so you're more likely to find bugs quickly and relatively painlessly. They also make it less likely that new bugs will appear when you fix a bug.

The following sections describe some testing habits that can make you a better tester.

Test and Debug When Alert

In Chapter 7, I said that you should write code when you're most alert. That helps you understand the code better so that it reduces the chances of you writing incorrect code and adding bugs to the application.

Similarly, you should test and debug when you're alert. Then when something goes wrong, you'll be more likely to understand what the program is supposed to be doing, what it is actually doing, and how to fix it. Debugging while tired is a good way to add new bugs to the program.

(DWT stands for "driving while texting" and is illegal in most U.S. states. DWT can also stand for "debugging while tired," and it should be illegal, too.)

One nice thing about automated tests is that they don't get tired. You may be exhausted after a long day of coding, but a testing tool can exercise the application while you catch up on your sleep. Then in the morning you can start refreshed chasing any bugs that were found.

Test Your Own Code

Before you check your code in and claim it's ready for prime time, test it yourself. This is the last chance you have to find your own bugs before someone else does. Save yourself some embarrassment and do your own work. If you make someone else do it for you, they may decide to rub your nose in it for days or weeks to come.

Stories abound that tell of programmers who don't test their code before checking it into the project. One of my friends who was a project manager hung a toy skunk outside the door of the developer

who broke the weekly build. It stayed there until someone else broke a build. One time the skunk stayed outside my friend's door for more than a month, so no one was immune to the skunk. (That sort of thing can be amusing, but only if everyone takes it with good humor. Some people couldn't handle that sort of thing.)

Another group I heard of had a programmer whose name happened to be Fred. Pretty much every week Fred managed to break the build, so the other programmers would spend several hours "de-fredding" the code.

Lots of larger projects have that "one guy" who messes up the project build. Don't be that guy.

Have Someone Else Test Your Code

It's important to test your own code, but you're too close to your code to be objective. You have assumptions about how it works that unconsciously influence the tests you perform. To find as many bugs as possible, you also need someone with a fresh perspective to test it.

Even if you're Super Programmer (faster than a speeding binary search, more powerful than a linked list, and able to leap tall b-trees with a single bound), you're going to make mistakes every now and then. You've spent a lot of time and effort on your code, so when someone gently points out your mistakes, it's easy to become defensive. Your feelings are hurt. You feel personally attacked. You pull into yourself like a spurned teenager and start playing emo music on your earphones. (In the worst case, you retreat into your fortress of solitude and become a super-villain.)

In fact, all that actually happened is that someone else found a mistake that anyone could have made. They didn't cause the mistake; it was already sitting there waiting to pounce during a demo for the company president. (And I've seen that happen! A lot!) You should be grateful that the bug was caught before it escaped into a released product where it could embarrass your whole programming team.

Mistakes happen all the time, particularly in software development. It's important to thank the tester for pointing out this flaw, fix it, and move on with no hard feelings.

The ability to take this kind of criticism can be such an important factor in software engineering that Gerald Weinberg coined the term "egoless programming" in his book *The Psychology of Computer Programming*. Even though he wrote that book way back in 1971, the term is still important in programming today. (The latest edition of his book is *The Psychology of Computer Programming: Silver Anniversary Edition*, Dorset House, 1998).

THE RULES OF EGOLESS PROGRAMMING

Here's a summary of Gerald Weinberg's Ten Commandments of Egoless Programming:

1. **Understand and accept that you will make mistakes.** Everyone makes mistakes. (Even me after 30+ years of programming experience.) Try to avoid mistakes, but realize that they will occur anyway. No one else programs without any mistakes, so why should you?

2. **You are not your code.** Just because you wrote a piece of flawed code, that doesn't make you a bad person. Don't take the bug home with you and ruin your weekend obsessing over it. Be glad the bug was found when it was. (And wish it had been found sooner!)

3. **No matter how much "karate" you know, someone else will always know more.** Even the greatest programmers of all time sometimes learn from others. And chances are, some of the people around you have more experience, at least in some facets of programming. Learn what Yoda has to offer.

4. **Don't rewrite code without consultation.** By all means fix bugs, but don't rewrite sections of code without consulting with your team. Bulk rewrites should be performed only for good reasons (like replacing a buggy section of code or rearranging code so that it can be broken up into separate methods), not because you don't like someone's indentation or variable names. If it ain't broke, don't fix it.

5. **Treat people who know less than you with respect, deference, and patience.** Even you started out as a programming novice. You made simple mistakes, did things the hard way because you didn't know better, and asked naive questions (if you were smart enough to ask questions). Be patient and don't reinforce the stereotype that good programmers are all prima donnas. (Also see #3. You may know more than someone, but not everyone.)

   One of the lessons I've learned over the years is that good ideas sometimes lie behind bad code. A piece of code that you think is weird may be trying to address an issue that isn't obvious. Stay humble and find out what the programmer was trying to do. Then decide if there's a better way to deal with the issue.

6. **The only constant in the world is change.** After a while, programmers tend to become comfortable with what they know. Unfortunately, change happens anyway whether you like it or not. Embrace change and see if it can work in your favor.

   (I worked on one project with about 25 programmers and around 100,000 lines of object-oriented code. Unfortunately the project manager said flat out that he "didn't get object-oriented code." He learned to program before object-oriented languages were invented and he didn't see the point. That made him practically useless in any technical discussion.)

   At the same time, don't discard something just because something new has come along. Like programmers, techniques that stand the test of time do so because they're useful.

7. **The only true authority stems from knowledge, not from position.** Don't use your position (as lead developer, senior architect, or even corporate vice president) to force your point of view down others' throats. Base your decisions on facts and let the facts speak for you.

continues

(continued)

8. **Fight for what you believe, but gracefully accept defeat.** Programming tasks rarely have a single unambiguous solution. There's *always* more than one way to tackle a problem. If the group doesn't decide to take your approach, don't worry about it. If the result is good enough, then it's good enough.

   Later if it turns out you were right and the approach taken wasn't good enough, don't rub it in. That attitude makes it harder for the group to make good decisions in the future. (Besides, some day you'll be on the wrong side of a decision and your coworkers will be slow to forget the time you acted all high and mighty.)

9. **Don't be "the guy in the room."** Sometimes you may need to close your office door and bang out some code, but don't go into hibernation and emerge only briefly to restock your Twinkie and NOQ energy drink supply. Stay engaged with the other developers so you can collaborate with them effectively.

10. **Critique code instead of people—be kind to the coder, not to the code.** This can be as simple as a subtle wording change. Instead of saying, "What were you thinking you utter moron?" you could say, "It looks like this variable isn't being initialized before it's passed into this routine." Okay, that example is a bit extreme, but you get the idea. Make comments that refer to what the code is doing not to the person who wrote it.

    Comments should also be positive if possible and focus on improving the code instead of dwelling on pointing out what's wrong. Instead of, "This variable isn't being initialized," you could say, "We should probably initialize this variable." (Notice how that comment also treats the code as group property instead of one person's mistake? It's good to help developers think of it as a joint project and not a collection of code owned by specific people.)

Fix Your Own Bugs

When you fix a bug, it's important to understand the code as completely as possible. If you wrote a piece of code, you probably have a greater understanding of it than your fellow programmers do. That makes you the logical person to fix it. Anyone else will need to spend more time coming up to speed on what the code is supposed to do and how it works.

If someone else fixes your code and does it wrong, your code looks bad. It may not be your fault (well, ultimately it was because you made the initial mistake), but you're the one who gets credit for the new bug. You may end up having to fix your own problem and the new one.

Besides, if you made a mistake, it may be useful to fix it yourself so that you can learn how to avoid that mistake in the future.

Think Before You Change

It's common to see beginning programmers randomly changing code around hoping one of the changes will make a bug go away. (Sadly, you sometimes also see those sorts of random changes in experienced programmers.)

I won't say this is the *worst* way to debug code but only because I'm sure someone out there can come up with an even more terrible method. However, this is certainly an extremely bad way to fix software. If you're making random changes, you're not paying attention to what the changes are doing. If a change makes a bug disappear, you don't really know if it fixed the bug or just hid it. You don't know if the change added a new bug (or several). You also missed out on an opportunity to learn something so you won't make the same mistake in the future.

CARD COUNTING

In college I had a roommate whose professor made everyone work with punched cards. (If you don't know what those are, see `en.wikipedia.org/wiki/Punched_card`.) It took several minutes to an hour to get the Computer Center to run a deck of cards, and the professor's theory was that using cards instead of typing code into the computer interactively would discourage people from trying to fix a program by trial-and-error.

Of course, what students did was make four or five copies of their decks (which could contain several hundred cards each) so they could make four or five random changes per session. It just goes to show how clever people can be at being stupid.

Don't Believe in Magic

Suppose you've spent hours chasing a bug. You've made some test changes and the bug has gone away. It's remarkable how many developers stop at that point, pat themselves on the back, and call it a job well done.

Unless you know why the changes you made fixed the bug, you can't assume the bug is really gone. Sometimes you've just hidden it. Or perhaps it went away for completely unrelated reasons, like your order processing center in New York just shut down for the evening and stopped sending you new orders.

Before you cross a bug off of your To Do list, make sure you understand exactly what changes you made and why they worked. (Also ask yourself if the changes will have bad consequences.)

See What Changed

If you're debugging new code, you can't check an older version to see what changed, but if you're chasing a bug in code that has been recently modified (perhaps due to a bug fix), see what's changed. Sometimes the difference makes the bug pop out and saves you hours of work.

Fix Bugs, Not Symptoms

Sometimes developers focus so closely on the code that they don't see the bigger picture. They find a line of code that contains a bug and fix it without considering whether there's a larger issue.

For example, suppose you're writing a method that calculates registration prices for a bull riding competition. Unfortunately, the method is giving senior citizen discounts to people who don't deserve them. (People over 85 get $3 off, but the program is giving them to younger contestants, too.)

You step through the code for a few problem customers, and you discover the bug is in the following calculation:

```
age = current_year - birth_year
```

It turns out some people have entered their birthdates in the format mm/dd/yy. For example, assuming it's 2015, someone born in 2005 who enters her age as 4/1/05 will have a calculated age of 2015 – 05 = 2010. With an age of more than 2,000 years, she's certainly old enough for the discount.

One way to fix this would be to check the customer's birthdate and, if the year doesn't contain four digits, not offer the discount. You might anger a few 104-year-olds, but at least you won't have parents accusing you of encouraging 12-year-olds to ride bulls.

This fix works (sort of), but it doesn't address the real problem: Customers are entering their birthdates in the wrong format. A better solution would be to modify the user interface to require customers to enter their birthdates in the required format. (You could also add some assertions to look for a valid format to make sure this sort of bug doesn't reappear later.)

Look at the entire context of the code that contains a bug and ask yourself whether you're fixing a bug or a symptom of something bigger. Make sure you understand the whole problem before you act.

Test Your Tests

If you write a bunch of tests for a method and those tests don't find any bugs, how do you know they're working? Perhaps the tests are flawed and they don't detect errors correctly.

After you write your tests, add a few bugs to the code you're testing and make sure the tests catch them. (Basically you need to test the tests.)

HOW TO FIX A BUG

Obviously, when you fix a bug you need to modify the code, but there are a few other actions you should also take.

First, ask yourself how you could prevent a similar bug in the future. What techniques could you use in your code? What tests could you run to detect the bug sooner?

Second, ask yourself if a similar bug could be lurking somewhere else. You just went to a lot of trouble isolating this bug. If other pieces of code contain a similar problem, it will be easier if you

find them now instead of waiting for them to break something else. Do a search of the rest of the project's code to see if you can find this bug's cousins.

Third, look for bugs hidden behind this one. Sometimes, the symptoms of one bug mask the symptoms of another. For example, suppose you write a method that flags customers who have unpaid balances greater than $50.00. You write a second method that sends e-mails to those customers to nag them. Unfortunately, a missing decimal point in the first method makes it find customers with balances greater than $5,000. Because you don't have any customers with such large balances, you never discover that the second method is sending e-mails to the wrong addresses. (This is sort of like asking a mechanic to fix your car's starter when you don't realize the engine is also missing.)

Fourth, examine the code's method and look for other possibly unrelated bugs. Bugs tend to travel in swarms. A piece of code may be extra complicated, poorly organized, or cluttered with badly conceived patches to previous bugs. Whatever the reason, some pieces of code are just buggier than others. When you fix a bug, look around for others. If you find a nest of bugs, ask whether you should refactor it to make it more maintainable.

Finally, make sure your fix doesn't introduce a new bug. The chances of a line of modified code containing a bug are much higher than those for an original line of code. (That combined with the fact that bugs tend to swarm means some piece of code can actually sprout bugs faster than you can fix them. It's like playing a particularly annoying game of whack-a-mole.) Take extra care to try to not cause more problems than you solve. Then thoroughly test your changes to make sure they worked and that they didn't break anything.

ESTIMATING NUMBER OF BUGS

One of the unfortunate facts about bugs is that you can never tell when they're all gone. As Edsger W. Dijkstra put it, "Testing shows the presence, not the absence of bugs." You can run tests as long as you like, but you can never be sure you've found every bug.

Similarly you can't know the number of bugs lurking in a project. (If you could, then you could just keep testing until that number reached zero.) Fortunately, there are some techniques you can use to estimate the number of bugs remaining in a program. They have some serious drawbacks, but at least they're better than nothing. (They also give you some actual, if not necessarily verifiable, numbers to report at management presentations to prove that you're doing something useful now that programming is winding down.)

Tracking Bugs Found

One method for estimating bugs is to track the number of bugs found over time. Typically, when testing gets started in a serious way, this number increases. After the testers have uncovered the most obvious bugs, the number levels off. Hopefully, the number of bugs found eventually declines. If you plot the number of bugs found per day, the graph should look more or less like the one in Figure 8-1.

When you're working out near the "getting close to zero" part of the graph, you have some reason to believe that you've found most of the bugs.

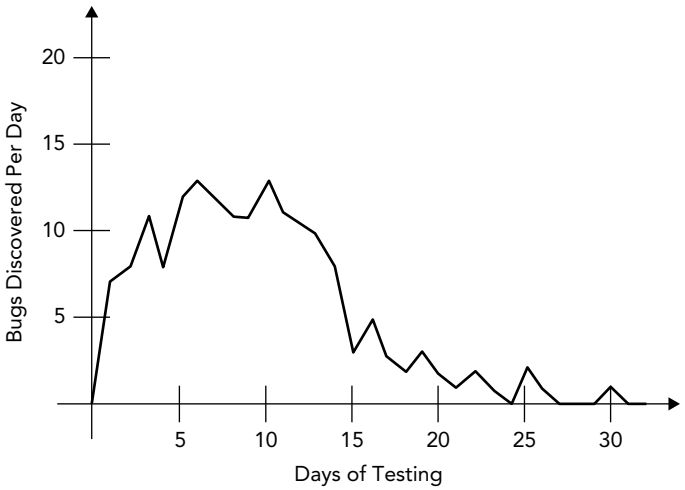


FIGURE 8-1: When you're in the "getting close to zero" part of the graph, you may be running out of bugs.

This approach is easy, intuitive, and doesn't require a lot of extra work (beyond finding the bugs, which you need to do anyway), so it's a good start. (Graphs are also good in management presentations. You can make them colorful and people can pretend to understand them.)

Unfortunately, this approach has a couple of problems. First, it tends to track the easiest bugs to find. After 4 weeks of testing, you may have found 80 percent of the easy bugs but only 5 percent of the tricky bugs. The graph declines because you're running out of easy-to-find bugs, but there may still be plenty of sneakier bugs lying in wait.

Similarly, this kind of estimate assumes your test coverage is equally good on all parts of the project. If you've neglected part of the application or failed to look for a particular kind of bug (for example, invalid customer data), there may be a whole slew of bugs remaining that you don't know about. Sometimes, you can see this effect when you add a new test to your automated test suite and suddenly a whole bunch of new bugs appear.

CODE COVERAGE

Some testing tools can measure *code coverage*, the lines of code that are executed during a demonstration or a suite of tests. They can tell you how many times a particular piece of code has been exercised.

You should use code coverage tools to make sure that every part of the system is visited at least once by the tests. Executing a line of code doesn't guarantee that you've found any bug in that line. However, if you don't execute a chunk of code, you're guaranteed not to find any bugs hiding there.

Seeding

Another approach for estimating bugs is to "seed" the code with bugs. Simply scatter some bugs throughout the application.

Run your tests and see how many of the artificial bugs you find. If the unintentional bugs are about as good at hiding as the bugs you planted, you should be able to estimate the number of bugs remaining.

For example, suppose you insert 40 bugs in the code and your tests find 34 of them. That 85-percent success rate implies that you may have found 85 percent of the real bugs. If you've found 135 real bugs so far, then there may have originally been approximately $135 \div 0.85 \approx 159$ bugs. That means there are about $159 - 135 = 24$ bugs remaining.

The previous approach (tracking found bugs) assumes the bugs you've found are representative of the bugs as a whole. The seeding approach makes a similar assumption. It assumes the artificial bugs can accurately represent the true bugs.

Unfortunately, it's a lot easier to create simple bugs by tweaking a line of code here and there than it is to create complex bugs that involve interactions between several methods in different modules. That means the seeding method can greatly underestimate the number of complicated and subtle bugs.

The Lincoln Index

Consider the following word problem.

> *Suppose you have two testers Lisa and Ramon. After they bash away at the application for a while, Lisa finds 15 bugs and Ramon finds 13. Of the bugs, they find 5 in common. In total, how many bugs does the application contain?*

The correct answer in this case is, "Wait, I thought this was a software engineering book, not a mathematics text. You didn't say I was going to have to solve word problems!"

Of course you don't really know how many bugs are in the application, but the Lincoln index gives you a guess. In this example, the Lincoln index is $15 \times 13 \div 5 = 39$.

More generally, if two testers find E_1 and E_2 errors respectively, of which S are in common, then the Lincoln index is given by the following equation:

$$L = \frac{E_1 \times E_2}{S}$$

Like all the other bug estimation techniques, this one isn't perfect. It relies on the assumption that the testers have an equal chance to find any particular bug, and that's probably not true. Both testers are most likely to find the easiest bugs, so the value S is probably larger than it would be if finding bugs was completely random. That means the Lincoln index probably underestimates the true number of bugs.

Another way the Lincoln index can break down is if Lisa and Ramon have similar testing styles. In that case, their common style may tend to lead them to find the same bugs. Again the value S would be larger than it would if bugs were found randomly, and the Lincoln index would be smaller than it should be.

> **NOTE** *The Lincoln index was described by Frederick Charles Lincoln in 1930, long before the invention of modern computers. He was an ornithologist who used the method to estimate the number of birds in a given area based on the number of birds counted by different observers. For more information about the Lincoln index, see* `en.wikipedia.org/wiki/Lincoln_index`.

HOW DOES THE LINCOLN INDEX WORK?

Suppose the two testers have probabilities P_1 and P_2 of finding any given bug and assume the application contains B bugs. Then you would expect them to find $E_1 = P_1 \times B$ and $E_2 = P_2 \times B$ bugs, respectively.

The chance of a particular bug being found by *both* testers would be $P_1 \times P_2$, so you would expect them to find $S = P_1 \times P_2 \times B$ bugs in common.

Plugging those values into the formula for the Lincoln index gives

$E_1 =$

$$L = \frac{E_1 \times E_2}{S}$$

$$= \frac{(P_1 \times B)\,(P_2 \times B)}{P_1 \times P_2 \times B}$$

When you get through canceling, all that's left is B. That means you should expect the Lincoln index to be about the same as B, the total number of bugs.

SUMMARY

If all programs contain bugs, you may be tempted to throw your hands up in the air, walk away from your software engineering job, and open a bakery. Even though you generally cannot remove every bug from a program, you can usually remove enough bugs that the remaining ones don't appear too often and don't inconvenience users too much.

The key to finding bugs so that you can remove them is testing. By constantly testing code at small, medium, and large scales, you can find bugs as soon as possible and make removing them easier. Continue testing until bug estimation techniques indicate that you may have caught most of the important bugs.

When your testing efforts aren't finding much to fix, it's time to start deployment. The next chapter describes typical deployment tasks and some of the things you should do to make deployment easier.

EXERCISES

1. Two integers are *relatively prime* (or *coprime*) if they have no common factors other than 1. For example, 21 = 3 × 7 and 35 = 5 × 7 are *not* relatively prime because they are both divisible by 7. By definition –1 and 1 are relatively prime to every integer, and they are the only numbers relatively prime to 0.

   Suppose you've written an efficient `IsRelativelyPrime` method that takes two integers between –1 million and 1 million as parameters and returns `true` if they are relatively prime. Use either your favorite programming language or pseudocode (English that sort of looks like code) to write a method that tests the `IsRelativelyPrime` method. (Hint: You may find it useful to write another method that also tests two integers to see if they are relatively prime.)

2. What changes do you need to make to the `IsRelativelyPrime` method to test all the testing code? In other words, what do you need to do to test the testing code?

3. What testing techniques did you use to write the test method in Exercise 1? (Exhaustive, black-box, white-box, or gray-box?) Which ones *could* you use and under what circumstances?

4. What limitations do the tests you wrote for Exercise 1 have? Would a particular testing technique help?

5. The following code shows a C# version of the `AreRelativelyPrime` method and the `GCD` method it calls.

```
// Return true if a and b are relatively prime.
private bool AreRelativelyPrime(int a, int b)
{
    // Only 1 and -1 are relatively prime to 0.
    if (a == 0) return ((b == 1) || (b == -1));
    if (b == 0) return ((a == 1) || (a == -1));

    int gcd = GCD(a, b);
    return ((gcd == 1) || (gcd == -1));
}

// Use Euclid's algorithm to calculate the
// greatest common divisor (GCD) of two numbers.
// See http://en.wikipedia.org/wiki/Euclidean_algorithm
private int GCD(int a, int b)
{
    a = Math.Abs(a);
    b = Math.Abs(b);

    // If a or b is 0, return the other value.
    if (a == 0) return b;
    if (b == 0) return a;

    for (; ; )
    {
```

```
        int remainder = a % b;
        if (remainder == 0) return b;
        a = b;
        b = remainder;
    };
}
```

The `AreRelativelyPrime` method checks whether either value is 0. Only –1 and 1 are relatively prime to 0, so if `a` or `b` is 0, the method returns `true` only if the other value is –1 or 1.

The code then calls the `GCD` method to get the greatest common divisor of `a` and `b`. If the greatest common divisor is –1 or 1, the values are relatively prime, so the method returns `true`. Otherwise, the method returns `false`.

Now that you know how the method works, implement it and your testing code in your favorite programming language. Did you find any bugs in your initial version of the method or in the testing code? Did you get any benefit from the testing code?

6. Write an exhaustive test for the `AreRelativelyPrime` method in pseudocode. What are the benefits and drawbacks to this version?

7. Write a version of the program you wrote for Exercise 5 that uses an exhaustive test. How large can you make the range of values (to the nearest powers of 10) and still finish testing in under 10 seconds? Approximately how long would it take to test with the range –1 million to 1 million?

8. Does all this this seem like a lot of work?

9. Exhaustive testing actually falls into one of the categories black-box, white-box, or gray-box. Which one is it and why?

10. The section "The Lincoln Index" describes an application where Lisa found 15 bugs, Ramon found 13 bugs, and they found 5 in common. The Lincoln index estimates that the application might contain approximately 39 bugs in total. After you fix all of the bugs that Lisa and Ramon found, how many are left?

11. Suppose you have three testers: Alice, Bob, and Carmen. You assign numbers to the bugs so the testers find the sets of bugs {1, 2, 3, 4, 5}, {2, 5, 6, 7}, and {1, 2, 8, 9, 10}. How can you use the Lincoln index to estimate the total number of bugs? How many bugs are still at large?

12. What happens to the Lincoln estimate if the two testers don't find any bugs in common? What does it mean? Can you get a "lower bound" estimate of the number of bugs?

13. What happens to the Lincoln estimate if the two testers find *only* bugs in common? What does it mean?

14. The Lincoln index has a statistical bias, so some people prefer to use the Seber estimator:

$$Bugs = \frac{(E_1 + 1) \times (E_2 + 1)}{(S + 1)} - 1$$

Repeat Exercise 10 with the Seber estimator. How does it compare to the Lincoln index estimate?

15. Suppose two testers find 7 and 5 bugs respectively but none in common. Repeat Exercise 12 with the Seber estimator.

16. Suppose two testers find only the same bugs. Repeat Exercise 13 with the Seber estimator.

▶ WHAT YOU LEARNED IN THIS CHAPTER

- Goals of testing
- Reasons not to remove a bug (diminishing returns, deadlines, it's too soon since the last release, the bug is useful, the code will soon be obsolete, it's a feature not a bug, at some point you need to release something, the program is already worth using, fixing bugs is dangerous)
- How to decide which bugs to fix (severity, work-arounds, frequency, difficulty, riskiness)
- Levels of testing (unit, integration, component interface, system, acceptance)
- Uses for automated testing
- Testing categories (accessibility, alpha, beta, compatibility, destructive, functional, installation, internationalization, non-functional, performance, security, usability)
- Testing techniques (exhaustive, black-box, white-box, gray-box)
- Good testing habits (test when alert, test your own code, have someone else test your code, use egoless programming, fix your own bugs, think before you change, don't believe in magic, see what changed, fix bugs not symptoms)
- How to fix a bug (How can you prevent similar bugs in the future? Could the bug be elsewhere? Look for bugs hidden by this bug. Look for unrelated bugs. Make sure your fix doesn't introduce another bug.)
- Methods for estimating number of bugs (tracking, seeding, Lincoln index, Seber estimator)

9

Deployment

Plans are nothing; planning is everything.

—Dwight D. Eisenhower

WHAT YOU WILL LEARN IN THIS CHAPTER:

- What you should put in a deployment plan
- Why you need a rollback plan
- Cutover strategies
- Common deployment tasks
- Common deployment mistakes

After you've built the next blockbuster first-person shooter, financial projection tool, or Goat Simulator, it's time for deployment. *Deployment* is the process of putting the finished application in the users' hands and basking in their adulation.

At least in theory. In reality deployment can be a nightmare unrivaled by any step in the software engineering process. It can be the stage when you discover that the program that worked perfectly in testing scenarios is a total failure in the real world. It can be the point when you realize that all your months or years of labor slaving over an overclocked CPU has been for naught. It can be when you and your coworkers learn how many resumes per hour the laser printer down the hall can produce.

Fortunately, the reality usually falls somewhere between the user adulation and nightmare scenarios. Most things work, more or less, with a few notable exceptions that give you interesting stories to tell later at the wrap party. (In the words of Captain Jack Sparrow in *Pirates of the Caribbean: Dead Man's Chest*, "Complications arose, ensued, were overcome.")

IMPLEMENTATION AND INSTALLATION

In addition to the term "deployment," some people use the terms *implementation*, *installation*, and *release*. In this context, they all mean basically the same thing; although they may show slight differences in the speaker's background.

Programmers tend to think of "implementation" as writing code to do something. (As in, "Did you implement the user validation module yet?") "Installation" sounds more humdrum than the other terms. You call an electrician or a plumber to install something. Besides, "deployment" sounds more dynamic. You don't "install" or "implement" troops into a field of battle.

Software developers do occasionally talk about releasing programs into the wild.

This chapter describes the deployment phase of a software engineering project. It explains deployment scope and lists some of the things you should consider in a deployment plan.

SCOPE

A project's scope can range from a small tool you wrote for your own use, to in-house business software that will be used by hundreds or thousands of users. Some of the largest projects (things like operating systems, browsers, and game console games) might have millions of users.

In addition to the number of users, scope includes the size of the application. It includes the amount of data involved, the number of external systems that are affected, and the sheer quantity of code (all of which could fail).

As you can probably guess, larger deployments provide more opportunities for mistakes. Big projects have more pieces that can go wrong. They also provide more combinations of little things that can add up to big problems.

For those reasons, small deployments are usually the smoothest. If you write an application for your own use and it doesn't work, you've only inconvenienced yourself and you have no one else to blame. If you roll out a new version of an operating system to millions of customers and then immediately discover you need to send out a security fix, you lose credibility. (Yes, that scenario happens all the time.)

Before you begin deployment planning, you should consider the scope of the deployment and plan accordingly. How much pain will failure during deployment cause? How much of that pain will come back to haunt you? If a failure will inconvenience a lot of users, or make the users unable to help their customers, you should spend extra time writing the best deployment plan possible. The next section explains in general what you need to put into a deployment plan.

THE PLAN

If everything went according to plan, you could write down a simple list of steps to follow and then work through them with guaranteed success. Unfortunately, the real world rarely works that way. Something always goes wrong. Perhaps not everything, but something.

When the inevitable emergency occurs, how well you recover depends largely on how thoroughly you planned for unexpected situations. If you have a backup plan ready to go, you may work around the problem and keep moving forward. If you don't have a backup plan, you may need to stop the deployment and try again later.

Even stopping a deployment can be difficult and dangerous if you don't plan for it. After you drive over a cliff, it's a little late to say, "Oh wait. I forgot something. Let's try this tomorrow."

To start deployment planning, list the steps that you hope to follow. Describe each step in detail as it is supposed to work.

Next, for every step, list the ways that step could fail. Then describe the actions that you will take if one of those failures occurs. Describe work-arounds or alternative approaches that you could use.

This part of planning can be extremely hard. It's not always easy to think of work-arounds for every possible disaster. Sometimes it may not even be possible.

For example, suppose your application requires 40 new networked computers with 8 GB of memory. What will you do if the network doesn't work? Or if the computers don't arrive from the manufacturer? Or if the manufacturer sends you eight computers with 40 GB of memory? In those cases, you may be unable to continue the deployment in any meaningful way. You may think your software installation is bulletproof, but hardware issues bring deployment to a screeching halt before it gets started. In that case, the "solution" to those problems might be to delay the deployment and fix the problems (or die trying).

For a slightly less obvious example, suppose your computers arrive on schedule and they work just fine, but there's something wrong with the network and you're not getting the bandwidth you should so the users can only process four or five jobs per day instead of the normal 15 to 20. You *could* move the users onto the new system anyway, but that would cause unnecessary pain and suffering (and you'll get your fair share). At this point, it would be better to postpone the deployment for a day or two, figure out what's wrong with the network, and start over.

After you've worked through all the plan's desired steps and anticipated as many problems as possible, write a rollback plan that lets you undo everything you've done. Be sure you can restore any other applications that you've updated and any data that you've converted for the new system.

Unfortunately, rolling back some of those sorts of changes can be difficult. For example, suppose your new application will run on a new operating system. If something goes wrong, restoring the older operating system can be a huge pain.

There are a few things you can do to make such a major restoration possible. For example, you can make complete images of the computers you're updating so that you can put them back exactly as you found them if necessary.

At some point, the pain of retreat is greater than the pain of moving forward. Some call that the *point of no return*. People often underestimate how painful moving forward can be, however, so it's good to delay the point of no return as much as possible. It's one thing to say, "We'll just press onward and let the users deal with any problems that crop up." It's another thing entirely to face management when the database fails and the users are reduced to writing customer orders on pieces of paper.

Often the action that determines the point of no return is moving users to the new system. You can set up networks, install new printers, and spray your company logo on new computers, but until

people are using the new application, it's relatively easy to go back. The next section discusses the process of moving people to the new application.

CUTOVER

Cutover is the process of moving users to the new application. There are several ways you can manage cutover. For some applications, you can just post the new version on the Internet and let users grab it. For other projects, you may be able to e-mail a new version to users, or you may be able to just install the new system on users' computers.

More interesting deployments require that you do a bunch of set up (upgrading operating systems, converting data into new formats, and installing coffee machines) before you can move users to the new system.

During the setup time, the users may be unable to do their jobs. To minimize disruption, it's important that the whole process go as smoothly as possible. The following sections describe four ways you can make life easier for all concerned: staged deployment, gradual cutover, incremental deployment, and parallel testing.

Staged Deployment

If you can't reduce the impact of catastrophic failures, you can sometimes reduce their likelihood by using staged deployment. In *staged deployment*, you build a *staging area*, a fully functional environment where you can practice deployment until you've worked out all the kinks.

After you have the installation working smoothly, you can test the new application in an environment that's more realistic than the one used by the developers. You can use the staging area to find and fix a few final bugs before you inflict them on the users.

If you can, use power users to help do the testing. They'll know what problems the other users are most likely to encounter. (Users can also break a system in ways no programmer or tester can.) Staged testing will also give them a preview of what's coming. Hopefully, they'll like what they see and tell the other users how wonderful their future lives will soon become.

When you're fairly certain that everything is ready for prime time, you sneak in at night and perform the actual deployment on the user's computers, like Santa leaving presents in children's stockings. Hopefully you leave presents and not a lump of coal. (You don't really have to sneak in at night, but many companies do basically that. They have IT personnel upgrade the users' computers at night or over the weekend to minimize disruption.)

You still need a deployment plan in case something unexpected goes wrong. Just because everything works flawlessly in the staging environment doesn't mean it will on the users' machines. However, staging should have reduced the number of major problems you encounter.

Gradual Cutover

In *gradual cutover*, you install the new application for some users while other users continue working with their existing system. You move one user to the new application and thoroughly test it.

When you're sure everything is working well, you move a second user to the new system. When that user is up and running, you install a third user, then a fourth, and so on until everyone is running the new application.

The advantage to this approach is that you don't destroy every user's productivity if something goes wrong. The first few guinea pigs may suffer a bit, but the others will continue with business as usual until you work out any tangles in the installation procedure. Hopefully, you'll stumble across most of the unexpected problems with the first couple of users, and deployment will be effortless for most of the others.

One big drawback to this approach is that the system is schizophrenic during deployment. Some users are using one system while others are doing something different. Depending on the application, that can be hard to manage. You may need to write extra tools to keep the two groups logically separated, or you may need to impose temporary rules of operation on the users.

For example, suppose you're building version 2.0 of your AdventureTrek program, an application that lets customers make reservations for adventure treks such as BASE jumping off of national monuments, kayaking over waterfalls, and hang gliding over active volcanos. Unfortunately, the new version uses an updated database format to accommodate your latest offering: wing-walking on jets.

Now consider what happens when you move a user to the new system. The database is full of records in the old format. Either the 2.0 user must work with the old records, or the system must route the old records to users that are still on version 1.0. After the 2.0 user creates some new records, the system must route those records only to that user because the others can't read a version 2.0 record.

Eventually you'll move all the users to the new version and, at that point, no one will work with the older records. Obviously you need to convert the older records into the new format at some time. Of course, once you do, people using version 1.0 won't be able to do anything, so you'll need to switch them all over to version 2.0 right away.

Figure 9-1 shows a Gantt chart that gives one possible schedule for migrating all 20 users to the new version.

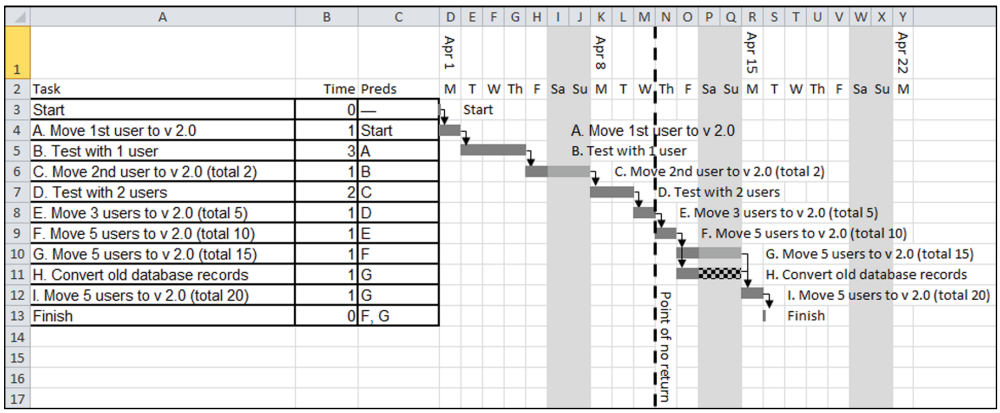


FIGURE 9-1: This schedule takes 11 work days to migrate all 20 users to AdventureTrek 2.0.

The schedule starts by moving one user to the new version. Pick one of the power users for this so that user can help exercise the new version thoroughly. The schedule then calls for three days of testing with this user on the new version.

Next, the schedule moves a second user to version 2.0. Testing continues for two more days with just two users on the new version.

If everything is going smoothly after this point, the schedule starts moving groups of users to the new version. It moves three more users to the new version, making a total of five. The next day it moves five more users, and it moves five again on the following day.

At this point (Friday, April 12), 15 users are using version 2.0, five users are using version 1.0, and the database contains a mix of old and new record formats.

If you move the last users to the new version, then no one will be able to work with the older records, so it's time to convert the database.

Depending on the volume of business in the application, you may need to convert the database before cutover is finished. For example, if the old records require a *lot* of maintenance, then five users on the old version may not be enough. In that case, you might want to convert the data after 10 users are on the version 2.0.

Now the schedule upgrades the final five users and converts the old data in the database. Because database conversions often take longer than expected, the schedule places the conversion on a Friday, so the database developers can work over the weekend if necessary. The extra time is represented in the Gantt chart by a checkerboard pattern to indicate that it might not be necessary.

> **NOTE** *Working the occasional Friday night and weekend is the price many software developers pay for keeping the users productive, but don't abuse them. If you make developers work too many evenings and weekends, their work-related productivity will drop and their resume-polishing productivity will soar.*

Incremental Deployment

In *incremental deployment*, you release the new system's features to the users gradually. First, you install one tool (possibly using staged deployment or gradual cutover to ease the pain). After the users are used to the new tool, you give them the next tool.

This method doesn't work well with large monolithic applications because you usually can't install just part of such a system. (Imagine building a new air traffic control system and installing only the part that lets planes take off. You'd have to program really fast to get the landing parts of the application in place before anyone runs out of fuel.)

This method often works nicely with the iterated development approaches described in Chapters 13 and 14. There programmers build one feature at a time and, when a feature is ready, it's released to the users.

Parallel Testing

Depending on how complicated the new system is, you might want to run in parallel for a while to shake the bugs out. For example, if you have enough users, you could have a handful of them start using the new system in parallel with the old one. They would use the new system to do their jobs just as if the new system were fully deployed.

Meanwhile another set of users would continue using the old system. The old system is the one that actually counts. The new one is used only to see what would happen if it were already installed.

After a few days, weeks, or however long it takes to give you enough confidence in the new system, you start migrating the other users to the new system. You can ease the process by using staged deployment and gradual cutover if you like.

DEPLOYMENT TASKS

The tasks you need to perform for a successful deployment depend on the application you're installing. A simple program like FileZilla (a really nice, free FTP program) just installs a new version of itself and you're ready to go. If you're building a customer support center from scratch, you've got a lot more work to do.

The following list itemizes some of the things you might need to deal with for a large deployment.

- **Physical environment**—These are physical things that the users need such as cubicles or offices, desks, chairs, power, lighting, telephones (possibly including headsets), and motivational posters (such as waterfalls, soaring eagles, and cats hanging from clotheslines). Plus everything that goes into any work environment such as restrooms, coffee machines, and supply closets (where employees can steal staples and rubber cement).
- **Hardware**—This includes network hardware (such as cables, fiber, switches, routers, and gateways), printers, scanners, CD or DVD burners, backup hardware, disk farms, database hardware, external hard drives, call routers, and, of course, the users' computers.
- **Documentation**—This can include some combination of physical and online documentation. It might include training materials, user manuals, help guides, and cheat sheets listing common commands.
- **Training**—If the application is complicated or very different from what users currently have installed, you may need to train the users. For larger installations, developers may have to train the trainers (either professional instructors or power users) who will then train the users.
- **Database**—Most nontrivial applications include some sort of database. Depending on the database, you may need to install database software on one or more central database servers and on the users' computers. You may also want extra hardware and software to provide extra data security features such as backups, shadowing, and mirroring.
- **Other people's software**—This is software that you didn't write. It includes systems that interact with your application (purchasing systems, web services, file management tools, cloud services, and printing and scanning tools) and other software that users need to be

productive (e-mail, chat, browsers, search engines, trouble-shooting databases, and word processors). Plus, of course, the operating system.

- **Your software**—This is the application you've built. It includes the application itself, plus any extra tools you've created. It also includes monitoring and testing tools that let you make sure the application is working correctly.

Of course, your project's needs will vary. You may not need telephone headsets and you may need extra motivational posters.

DEPLOYMENT MISTAKES

The basic steps for successful deployment are (1) make a plan, (2) anticipate mistakes, and (3) work through the plan overcoming obstacles as they arise. If something goes wrong and you don't have an easy fix, rollback whatever you've done, study the problem, and try again later. You can reduce the inconvenience for users by using staged deployment, gradual cutover, incremental deployment, and parallel testing.

If you do a good job of following those steps, you should eventually get even the most complicated application up and running. Occasionally, however, a deployment fails so spectacularly that nothing can save it. Or the deployment finishes, but with all the fun and carnival atmosphere of a root canal.

The following list summarizes some of the easiest ways to torpedo an otherwise viable project:

- **Assume everything will work**—This may seem like a rookie's mistake, but many people assume their deployment plan will just magically work. Maybe you'll get lucky and that will be true, but you should probably assume it won't.
- **Have no rollback plan**—Rolling a deployment back can be a real hassle, but it's usually better than living with whatever damage you do during a failed deployment.
- **Allow insufficient time**—If everything goes smoothly, you won't need much time, but when something goes wrong, all bets are off. A deployment that should take hours could take days or even weeks. Allow extra time for unexpected problems. Then hedge your bets by scheduling the end of deployment on a Friday so that you can work into the weekend if the plan goes off the rails.
- **Don't know when to surrender**—It's easy to work around one or two small issues that don't play out as expected, but how do you know when to stop? If you keep pushing through (or around) little issues (and sometimes big ones), eventually all the compromises add up to give you a terrible result. (Like a beginning poker player with a pair of threes being gradually sucked into a huge pot.) Define conditions under which you'll fold and try again later. For example, you might quit after 4 hours or after three things go wrong. Or you might use a point system with 1 point for a trivial change, 2 points for a small work-around, and 5 points if you can't get something to work. When you get to 5 points, quit for the day.
- **Skip staging**—Staging can be time-consuming and expensive, particularly if you need to install new hardware and software. However, for a complicated deployment, staging is crucial. It lets you work out all the deployment glitches so that you don't need to completely trash the users' computers.

- **Install lots of updates all at once**—It's tempting to install a lot of updates at the same time so that you don't need to inconvenience the users repeatedly. Unfortunately, the more things you try to do at once, the more likely it is you'll run into problems. Limit the number of things you try to deploy all at once. Save the rest for a later deployment.
- **Use an unstable environment**—Have you ever used a computer where the scanning software works (sometimes), the print queues seem to get stuck randomly, and your video editing software sometimes won't import certain kinds of files? If the tools you use don't work together consistently, then you have other problems you should fix before you start a new deployment. Sometimes finding the right combination of tools that can work together can be challenging. Adding a new application will only make things worse.
- **Set an early point of no return**—If you explicitly set a point of no return, you don't need to figure out how to roll back any changes after that point. Unfortunately, you don't always know how bad things might get near the end of the deployment. The last installation task could be a total disaster that takes you days to figure out. You should set the point of no return as late as possible in the deployment schedule so that you can retreat whenever necessary. Even better, don't have a point of no return!

There's a common theme to these methods for failure. They all assume things will go well. Perhaps this is more of the unbounded optimism that makes programmer's fail to test their code. You just wrote the deployment plan and you didn't see anything wrong with it. If you had, you would have fixed it. The logical conclusion is that everything will work perfectly. That means you don't need a rollback plan, sufficient time, surrender conditions, staging, and a late point of no return.

Assume you will have problems. If you also assume that some of those problems may be big, you'll be ready in case you need to cancel the deployment and start over. If you prepare for the worst, the worst that will happen is you'll be pleasantly surprised when things go well.

SUMMARY

The basic strategy for successful deployment is straightforward. Make a plan that anticipates as many problems as possible, and then follow the plan. If big unexpected problems occur, roll back any changes you've made and try again later.

There are still a few details to take care of. For example, you need to know when to abandon a deployment attempt and try again another day. (He who quits and runs away, lives to deploy another day.) You can also use cutover strategies to make things easier.

As long as you make a plan and realize that some things will almost certainly go wrong, you should do okay and eventually get the application up and running. After that (and perhaps a celebratory team dinner at a nice restaurant), the application moves into maintenance. During this phase, your application serves its intended purpose (drawing electronic schematics, tracking orders, posting pictures of cats, or whatever), and the users send you comments, suggestions, change requests, and bug reports. (And once in a great while, a "thank you" that makes the whole thing seem worthwhile.)

At this point in your project, you've finished initial development. You gathered requirements, created high- and low-level designs, written tons of code, tested the code (and fixed some bugs), and deployed the application to the users. You're probably more than ready for a break. All you

want to do is run off to Disneyland, Aruba, or wherever you consider the happiest place on Earth. Unfortunately, there are a few things you need to take care of before you disappear in addition to arranging for a pet sitter. The next chapter describes tasks that you should perform at the end of a project before all the developers go their separate ways.

EXERCISES

1. Suppose you've written a small tool for your own use that catalogues your collection of pogs. You're planning your third upgrade and you need to revamp the database design. Which cutover strategy should you use?

2. Suppose you're writing an application that includes a lot of separate tools. One creates work orders, a second assigns jobs to employees, a third lets employees edit jobs to close them out, and so forth. Which cutover strategies could you use when deploying a new version of this application?

3. Suppose the application described in Exercise 2 uses a database. Each of the pieces needs to use the database and you need to change the database structure for the new deployment. Does that change your answer to Exercise 2?

4. Suppose you're writing a large application with thousands of users scattered around different parts of your company. Which cutover strategy would you use?

5. Suppose you're building a new MMO (massively multi-player online game) and you expect to have tens of thousands of users. (Your business plan says within the next 18 months.) Users will download and install your program. What cutover strategy should you use?

6. President Eisenhower was big on planning. If you Google around a bit, you can find several quotes by Eisenhower extolling the virtues of planning (including the quote at the beginning of this chapter). Here's another quote from his remarks at the National Defense Executive Reserve Conference on November 14, 1957.

   > *I tell this story to illustrate the truth of the statement I heard long ago in the Army: Plans are worthless, but planning is everything. There is a very great distinction because when you are planning for an emergency you must start with this one thing: the very definition of "emergency" is that it is unexpected, therefore it is not going to happen the way you are planning.*

   If emergencies don't happen the way you're planning, then why make a plan in the first place? Does this apply to deployment plans?

7. Suppose you just released a version 3.0 of your popular shareware program Fractal Frenzy, which lets users draw fractals, zoom in and save coordinates, make movies zooming in and out, and generally make cool pictures. Unfortunately, the day after the release, you discover a bug that prevents users from saving coordinates so that they can't return to saved pieces of a fractal. What should you do? Tell people right away? Wait until there's a fix? Wait until the next release?

8. Suppose you're the manager of the Internal Software Development department at a medical device manufacturer. One of your projects, Test Track, records quality test results for the devices your company makes. Depending on the device, testers record between a few dozen and several hundred test measurements per week. Your software lets testers perform data analysis to see whether the products are up to scratch.

   Unfortunately, you just learned about a bug that makes the product occasionally examine the wrong device's data. About once a month, for no obvious reason, a tester requests data on one device but gets results about a different device. Repeating the query once or twice seems to get the right results.

   What should you do? Should you rush out an emergency patch? Wait until the next major update? Ignore the problem and hope it will go away?

WHAT YOU LEARNED IN THIS CHAPTER

- A project's scope influences how thoroughly a plan must anticipate every possible problem.
- A deployment plan should include the steps needed for deployment, possible places where things can go wrong, and work-arounds for them.
- You should be able to roll back any changes you make if a deployment becomes stuck.
- The point of no return is where it would be more painful to roll back a failing deployment than to press ahead. (If you have a good rollback strategy, then you don't need a point of no return.)
- Three cutover strategies are staged deployment, gradual cutover, and incremental deployment. Parallel testing can also help as a prelude to full deployment with one of the three strategies.
- Deployment tasks may include:
  - Physical environment
  - Hardware
  - Documentation
  - Training
  - Database
  - Other people's software
  - Your software
- Common mistakes during deployment include:
  - Assuming everything will work
  - Having no rollback plan
  - Allowing insufficient time
  - Not knowing when to surrender
  - Skipping staging
  - Installing a lot of updates at once
  - Using an unstable environment
  - Setting an early point of no return

10

Metrics

You can't control what you can't measure.

—Tom DeMarco

Measuring programming progress by lines of code is like measuring aircraft building progress by weight.

—Bill Gates

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Grouping defects by importance or task
- Using Ishikawa diagrams to discover root causes of problems
- Defining and using attributes, metrics, and indicators
- Understanding the difference between process and project metrics
- Using size and function point normalization to compare projects with different sizes and complexities

At this point, you've finished the project. Congratulations! Some of your team members are probably itching to move on to whatever comes next, whether they plan to continue maintaining this project, start a new one, or leave to achieve that lifelong ambition of becoming a barista.

However, you should do a few more things before the team scatters to the four corners of the IT industry. Chief among those is a discussion of the recently completed project to determine what you can learn from your recent experiences. You need to analyze the project to see what went well, what went badly, and how you can encourage the first and discourage the second in the future. To do that, you need to find ways to measure the project. (Exactly how do you measure the project's "wonderfulness?")

This chapter describes tasks that you should perform after initial development is over. It discusses methods you can use to analyze defects (which include change requests, bugs, and other vermin) so that you can try to anticipate and minimize similar defects in the future. It also explains metrics that you can use to measure the project's characteristics and how you can use those metrics when you work on future projects.

METICULOUS METRICS

Like most software engineering tasks, gathering metrics doesn't happen only in one place (in this case, at the end of the project). It's easier to gather metrics throughout the project rather than waiting until the end. For example, you should keep track of the project's status (lines of code written, bugs fixed, milestones missed, and so forth) as you go along. I've put metrics in this chapter because at the end of a project you can look back with a new perspective and see how it all unfolded.

WRAP PARTY

You've finished the project! That's no small feat, so you should do something as a team to celebrate. Have a party, company picnic, trip to an amusement park, or some other wrap-up activity. At least have lunch together and joke about all the times the customers altered the specifications, changed their minds about what hardware to use, and asked why you were using C++ instead of COBOL. Let the healing begin.

Note that the wrap party cannot be just another project meeting but with cupcakes, balloons, and "I Survived Project Ennui" T-shirts. Feel free to gossip about company politics, argue about whether the corporate vision statement makes sense if you read it backward, and speculate about whether upper management will be indicted for insider trading. Don't discuss outstanding bugs, analyze metrics, or turn the party into a group performance review. Do that some other time.

It's obvious that a software organization can't succeed unless its customers are satisfied, but it also can't function unless its employees are happy. A wrap activity helps bring closure to the project and makes people feel like they accomplished something.

DEFECT ANALYSIS

At a philosophical level, any time an application doesn't do what it's supposed to, you can consider it a bug. For example, when you first start a project, it doesn't do anything. Unless that's its desired behavior, you could think of that as a bug. (If that *is* the desired behavior, let me know because I've already written that application.)

Some development methodologies actually come pretty close to that point of view.

- Task: Create a new Add Customer form.
- Bug: It doesn't let you enter a customer name.
- Change: Add a Customer label and text box.

- Bug: It doesn't let you enter a customer address.
- Change: Add an Address label and address text boxes.
- Bug: There's no OK button.
- And so forth.

However, when you're thinking about bugs with an eye toward preventing them in the future, it's helpful to differentiate among different ways the program isn't working correctly.

Kinds of Bugs

At the highest level, you can group all incorrect features into *defects*. You can then categorize defects into *bugs* (code that was written incorrectly) and *changes*. (The code is doing what the specification said to do, but the specification was wrong.)

Note that it may not be anyone's fault that the specification was wrong. For example, the customers' needs may have changed since the project started. Or the environment may have changed, as when a new operating system is installed or management decides everything must move to the cloud. (Hopefully they know what the cloud is.)

The following sections describe several other ways you can categorize defects.

Discoverer

One important way to group defects is by who reported them. Bugs that are found and fixed by programmers are often invisible to the customers. The customers never need to know all the dirty little secrets that went into building the final application.

In contrast, changes that are requested by customers are obviously visible to the customers. Generally you should satisfy as many change requests as possible, as long as they don't mess up the schedule. (They give you brownie points you can spend later to resist the customers' efforts to shorten the schedule.)

The worst combination is a bug that is discovered by the customers. If a bug gets to the customers, it must have snuck past code reviews, unit tests, and integration tests. They're somewhat embarrassing and reduce the customers' confidence in your team's ability to produce a high-quality application. (They also reduce your brownie points.)

For each defect, ask three questions:

- How could you have avoided the defect in the first place?
- How could you have detected the defect sooner?
- For customer-discovered defects, how could you have found the defect before the customers did?

Severity

This categorization is quite obvious. Assign a severity to each defect and focus on those that are most severe. You can use a 1 to 10 scale (or 1 to 100 scale, or whatever) if you like, but you probably don't need that level of detail. Usually, you can simply assign each defect the severity Low, Medium, or High.

Focus on the high severity defects, and for each one ask how you could have avoided it, how you could have detected it sooner, and (for customer-discovered defects) how you could have found it before the customers did. (Do these questions seem familiar?)

Time Created

You can further categorize defects by when they were created. Defects tend to snowball, so those created earlier in the project usually have greater consequences than those created later. For example, a defect added during high-level design has a lot more potential to cause pandemonium than a defect added in the last module written.

By now you can probably guess what I'm going to say next. Focus on the defects that were created earliest because they can cause the most damage. For each defect, ask how you could have avoided it, how you could have detected it sooner, and (for customer-discovered defects) how you could have found it before the customers did.

Age at Fix

Defects are like cancer: The longer they go undetected, the greater the potential consequences. Group defects by the length of time they existed before they were detected and fixed. Focus on those that remained in hiding the longest and ask the usual three questions.

Task Type

Another way to categorize defects is by the type of task you were trying to accomplish when it was created. By the type of task I don't mean "trying to write a `for` loop" or "writing a vibrant and profound sentence for the specification." I mean things like Specification, High-Level Design, User Interface Design, or Database Code.

The types of tasks you should use will depend on the project. For example, if you're writing a finance application that will run on desktop systems, then you probably don't need a Phone Interface category.

Some typical task categories include the following:

- Specification
- Design
  - High-Level
  - Security
  - User Interface
  - External Interface
  - Database
  - Algorithm
  - Input/Output
- Programming
  - Tools
  - Security

    - User Interface
    - External Interface
    - Database
    - Algorithm
    - Input/Output
- Documentation
- Hardware

The previous methods for categorizing defects focus on what's most important. The errors discovered by users, have high severity, were created early, and that remained undiscovered for a long time tend to have the greatest impact, so they're important. After you identify them, you can ask the three questions to see how you can avoid the same problems in future projects.

In contrast, task categories don't identify the most important defects. Instead they try to group defects by common causes. Defects that were added while performing similar tasks may have similar causes and (hopefully) similar solutions.

For example, suppose you discover that a lot of defects originated in the specification. In that case, many of them may have a common cause such as not paying attention to the customer, not studying the user's current process enough, or unrealistic customer requests. In that case, you may be able to fix a whole bunch of defects in future projects by addressing a single issue. Perhaps if you spend a bit more time running through use cases with the customers before you finalize the specification, you can avoid some of these defects.

Ishikawa Diagrams

To figure out in which category a defect belongs, ask what task was being performed when the defect was created. For example, suppose you discover a defect on the login screen. The code incorrectly validates the user's name and password. Password validation is a security feature, so this task might fall into the Programming/Security category.

Often, however, a defect is the end of a sequence of events that was started by some primordial mistake. In this example, suppose the code does exactly what the security design said it should. In that case, the error is actually in Design/Security, not in the code.

It's also possible that this defect has an even more distant cause. Perhaps the security design correctly reflected what was described by the specification. In that case, the error is in the specification, not the design or the code.

Perhaps the specification, design, and code are all correct, and the error is in the database. Or worst of all, perhaps two or more pieces of the puzzle contain errors that combine to create the defect. (On television crime shows, a single murder leads to all the confusing clues. Imagine how much more confusing things would be if multiple crimes occurred at the same spot and muddled each other's clues.) In this example, there could be problems with any combination of the login code, the database code, the database design, the database itself, the database specification, or the security specification.

Sometimes discovering the root the root cause of a defect can be challenging. One tool that can help is the *Ishikawa diagram* (named after Kaoru Ishikawa). These are also called *fishbone diagrams* because they look sort of like a fish skeleton. (And *Fishikawa diagrams* are an amusing blend of the two names. For your Word of the Day, look up "portmanteau" in the dictionary and ignore the definitions that deal with luggage.) They're also called *cause and effect diagrams*, but a name that prosaic won't impress anyone at IT cocktail parties.

QUALITY CONTROL

Kaoru Ishikawa used these diagrams in the late 1960s to manage quality in the Kawasaki shipyards. They've been used extensively in quality management for industrial processes.

This is another one of those tools like PERT charts and Gantt charts (see Chapter 3, "Project Management") that are so useful for managing projects in general that they've been around far longer than software engineering has. (When the first colonists land on Tau Ceti e, they'll probably use a PERT chart to order the tasks they need to perform, a Gantt chart to schedule them, and an Ishikawa diagram to figure out why the sunscreen was left behind on the kitchen counter on Earth.)

To make an Ishikawa diagram, write the name of the defect you're trying to analyze (Incorrect Username/Password Validation) on the right of a sheet of paper. (This is the head of the fish.)

Next draw a horizontal arrow pointing to the defect name from left to right. (This is the fish's backbone.)

Now think of possible causes and contributing factors for the defect. Represent them with angled arrows leading into the spine. (These are the fish's ribs.) Label each arrow with the cause you identified.

For each of the fish's ribs, think about causes and contributing factors for that rib. Add them, again with labeled arrows. Continue adding contributing factors to each of the factors you've already listed until you run out of ideas. (I confess I haven't seen a fish with this type of skeleton. Maybe you can find them in Lake Karachay, the world's foremost duping site for radioactive waste.)

Figure 10-1 shows a sample Ishikawa diagram (although many people would omit the fishy outline).

The exact format of the diagram doesn't matter too much and there are several variations in style. The only things that are really consistent among most diagrams are

- The effect or outcome is on the right.
- There's a backbone.
- Arrows (or lines) lead from causes to intermediate causes or effects.
- Arrows (or lines) are labeled.

It doesn't matter whether you use lines or arrows, and sometimes they may point from right to left if that makes them fit in the diagram better.

Figure 10-2 shows another version of the previous diagram with a different style.

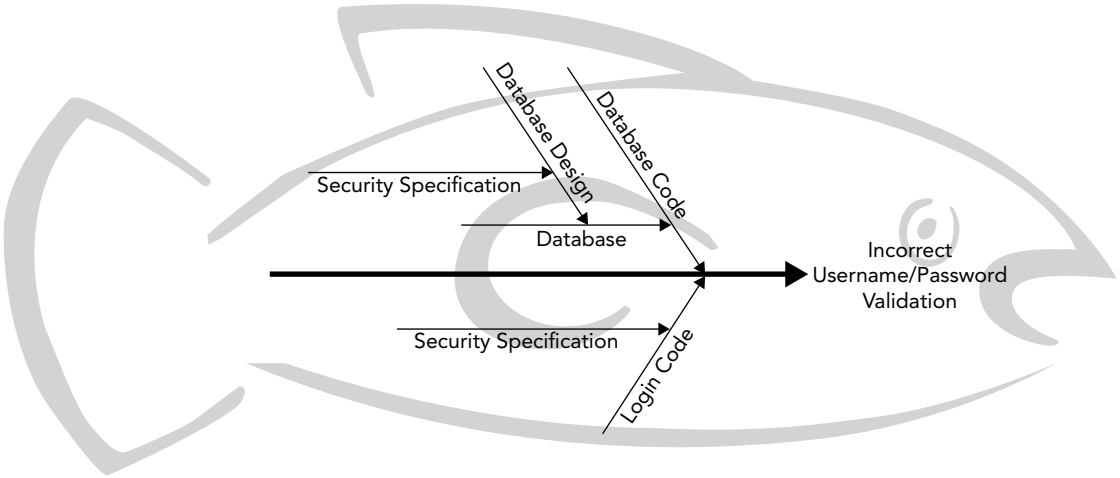


FIGURE 10-1: An Ishikawa (or fishbone) diagram shows causes leading to effects.

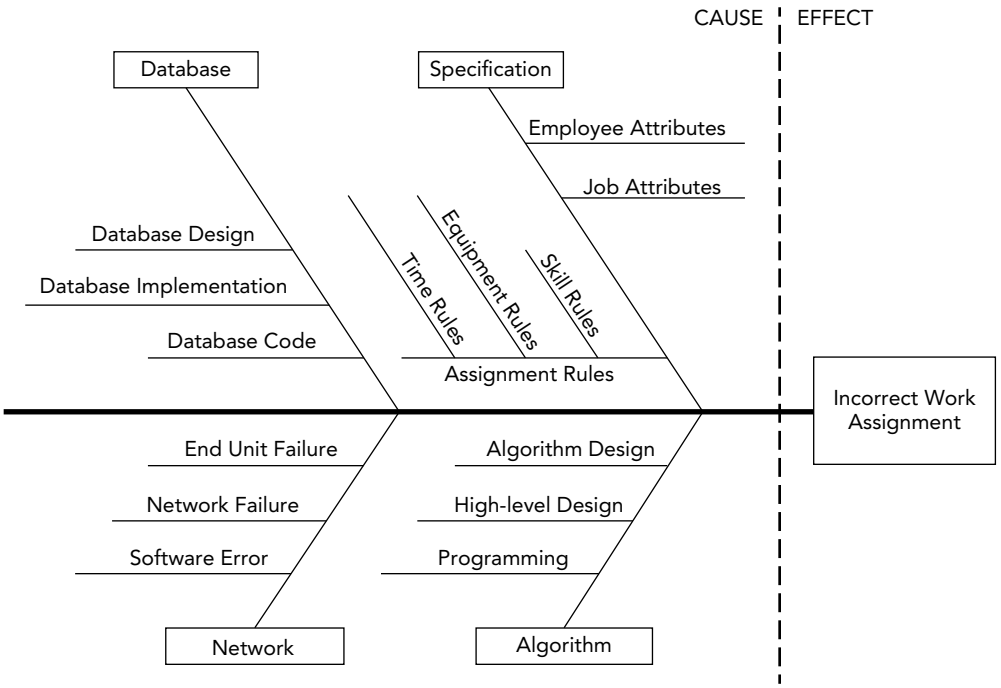


FIGURE 10-2: The exact format of an Ishikawa diagram doesn't matter as long as you can tell what causes lead to what other causes and effects.

After you build an Ishikawa diagram for a defect, take a close look at each of the possible causes and decide which ones actually helped cause the defect. Highlight causes that did play a role and cross out those that didn't. If you're not sure about a cause, study it further, possibly adding contributing causes to it.

When you're finished, you should have discovered the root causes of the defect. You can then ask the three magic questions about the defect.

You should also use the diagram to group the defect's causes. In Figure 10-2, for example, you might find that all the problems lay in the Specification rib. In that case, you should look more closely at your specification process to see if there's something you could do to make the specification more reliable in future projects.

SOFTWARE METRICS

The defect analysis techniques described in the previous sections are more or less qualitative. They help you characterize defects based on their discoverer, severity, and age at time of removal.

In contrast, software metrics give you quantitative measurements of a project. Before you learn what kinds of metrics you can analyze, you should know a few metric-related terms.

An *attribute* is something you can measure. It could be the number of lines of code, the number of defects, or the number of times the word "mess" appears in code comments.

A *metric* is a value that you use to study some aspect of a project. Sometimes a metric is the same as an attribute. For example, you might get useful information about a project from the number of bug reports you have received. Often metrics are calculated values. For example, you may want to look at bug reports per week or bug reports per line of code instead of just the total number of bug reports.

After you have metrics, you study them to see if any of them are good *indicators* of the project's future. For example, consider the metric "comments per thousand lines of code (KLOC)." If comments per KLOC is 3, that may be an indicator that the project will be hard to maintain.

You can then do two things with your indicators. First, you can use them to predict the future of your current project. For example, if you've been fixing 10 defects per week for the last 2 weeks, and you hope to clear your list of 875 defects before the initial release in just under a month, then you could be in trouble.

The second thing you can do with indicators is make strategy improvements for future projects. For example, if this project did fall into the "3 comments per KLOC" category, then you might want to change your code review process to gently encourage programmers to add a few more comments. (And to make sure they're meaningful and not just statements such as `Add 1 to num_orders`.)

SIMILAR SITUATIONS

Metrics and indicators sometimes apply only to similar projects. For example, your programmers may crank out an average of 50 lines of code per day over the course of a three-month Visual Basic desktop project. That doesn't necessarily mean they can produce the same amount of code over a two-year firmware project for a particular phone.

Metrics and indicators will be most useful for projects that are most similar. They may still be useful for other projects, but you should keep an eye on how well they are predicting a new project's future so that you can adjust your expectations if necessary.

To summarize:

- Measure relevant attributes.
- Use the attributes to derive meaningful metrics.
- Use metrics to create indicators.
- Use indicators to predict the project's future.
- Use indicators to make process improvements.

Now that you have a little background in software metrics, the following sections give some additional details.

COMMON COMPLAINTS

Aside from the project manager, software engineers often resist tracking metrics. Team members may feel that collecting metrics is hard and time-consuming. They may say they spend all their time measuring and counting instead of working. And besides, metrics are subjective and don't prove anything.

Some people also think metrics will be used against them to measure how productive (or unproductive) they are.

Metrics are sometimes a bit subjective and ambiguous, but any measurements are better than nothing. (Exploring a vast cavern with a book of matches isn't as good as using floodlights, but it's better than wandering in the dark bumping into walls and falling down pits.)

You should try to explain to the team members that metrics really are useful. Try to keep the extra work to a minimum and assure people that they are used to guide the project and not to determine who writes the most documentation or lines of code. It's easy to write a lot of badly written code, so punishing someone who writes less code but with higher quality doesn't make sense anyway.

The following sections explain more precisely what attributes might make good metrics, what you can use metrics for, and how you can normalize metrics so they are meaningful for projects of different sizes.

Qualities of Good Attributes and Metrics

You can measure many attributes of a software engineering project. You can measure the number of lines of code, the customers' satisfaction level, the hours the team members spent playing *Bouncing Balls*, the font used in the specification, or the team's total number of trips to the coffee pot.

Of course, some of those attributes are hard to measure (such as customer satisfaction) and others are irrelevant. The following list gives characteristics that good attributes and metrics should ideally have.

- **Simple**—The easier the attribute is to understand, the better.
- **Measureable**—To be useful, you must measure the attribute.
- **Relevant**—If an attribute doesn't lead to a useful indicator, there's no point measuring it.
- **Objective**—It's easier to get meaningful results from objective data rather than subjective opinions. The number of bugs is objective. The application's "warmth and coziness" is not.
- **Easily obtainable**—You don't want to realize the team members' fears by making them spend so much time gathering tracking data that they can't work on the actual project. Gathering attribute data should not be a huge burden.

Sometimes it's impossible to satisfy all these requirements. In particular, some important attributes can be hard to measure. For example, customer satisfaction is extremely important, but it can be hard to quantify.

For attributes such as this one, which are important but hard to measure, you may need to use indirect measurements. For example, you can send out customer satisfaction surveys and track the number of change requests you receive.

Using Metrics

Metrics have several possible uses. You can use them to

- Minimize a schedule.
- Reduce the number of defects.
- Predict the number of defects that will arise.
- Make defect removal easier and faster.
- Assess ongoing quality.
- Improve finished results.
- Improve maintenance.
- Make sure a project is on schedule.
- Detect risks such as schedule slip, excessive bugs, or features that won't work and adjust staffing and work effort to address them.

As I mentioned in the previous section's tip, metrics and indicators work best for projects similar to those during which you gathered your metric data. Two projects that use different development methodologies, programming languages, or user environments may not always produce the same results. That means you need to use some common sense when you use indicators to try to predict a project's future.

However, it's probably a bigger mistake to completely ignore what an indicator is telling you. Suppose in previous projects you've noticed that a low number of pages of program documentation gave you lots of bugs. Just because your current project is using a different programming language, that doesn't mean this indicator is wrong. If the programmers are producing fewer pages of documentation but the bug rate remains low, try to figure out why.

It could be that the new language is more self-documenting. (Previous projects used assembly language but this one's using Visual Basic.)

It could be you have a really good programming team on this project. In that case, you'll probably need that extra documentation for long-term maintenance when these programmers all wander off to new projects.

It could also be the case that the programmers have been working through the easy stuff first and work will become much harder later. In that case, you need to be sure the amount of documentation picks up as the difficulty level increases.

Don't ignore what your metrics are saying. If they contradict the facts, learn why so that you know whether you need to adjust the metrics or the project.

TIPS FOR USING INDICATORS

You can use indicators to provide regular feedback to the team. If it looks like some part of the project is wandering away from the practices suggested by your indicators, gently nudge the project back on course.

Don't think of indicators just as harbingers of doom. (Abandon hope all ye who stray from the required number of use cases per form.) Think of them as signposts pointing in the right direction. If you get lost, use them to guide the project back to the correct path. (It may sound like MBA doublespeak, but use them as opportunities for improvement not reasons for despair.)

Don't use metrics and indicators to appraise individuals or the team as a whole. If you yell and scream at team members because they're messing up your indicators, they'll stop giving you accurate metric data. You can suggest that someone spend more time working through use cases during requirements gathering, but if you threaten them, they're just as likely to tell you they're doing the work when they aren't.

For similar reasons, make sure people aren't hideously overworked. If team members don't have time for all their assigned tasks, they'll dump the ones they consider the lowest priority. Usually that includes tracking metrics.

Finally, don't get stuck obsessing over a single metric. If you're not spending much time on code reviews and your indicator says you should be seeing a lot of bugs, but the bugs aren't there, then perhaps this isn't a problem after all. By all means try to figure out why things are going so smoothly, but don't create a problem where one doesn't already exist.

Metrics and indicators are often grouped into two categories depending on how you use them: process metrics and project metrics. The following sections describe those categories.

Process Metrics

Process metrics are designed to measure your organization's development process. You collect them over a long time period for many projects, and then use them to fine-tune the way you do software engineering.

For example, suppose you collect data over a series of projects and you draw the graph in Figure 10-3 showing hours of code review per KLOC versus number of bugs per KLOC.

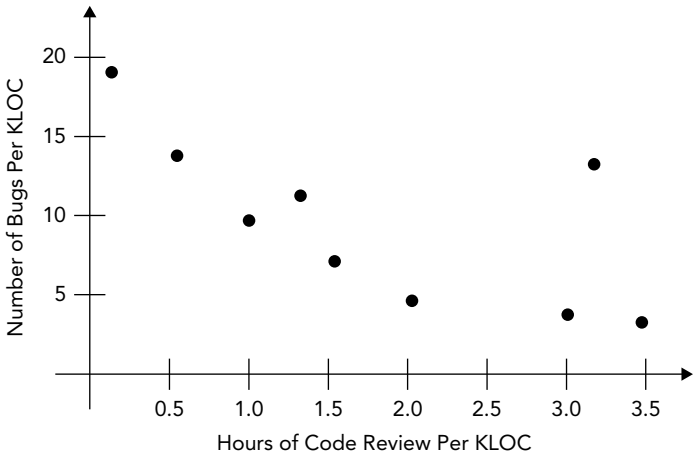


FIGURE 10-3: This graph shows the relationship between hours of code review and bugs per KLOC.

Looking at the graph in Figure 10-3, you might decide that you want to try to spend 1.5 to 2 hours of code review per KLOC in future projects. That seems to let you find most of the bugs that you would catch even if you used a lot more time on reviews. (I'd also want to dig deeper to figure out why the second project from the right had so many bugs despite the relatively large investment in code reviews. Was it a different kind of project? Was it particularly large or small? Was it run by an inexperienced technical lead?)

Project Metrics

Project metrics (which are sometimes called *product metrics* because they are about a specific software product) are intended to measure and track the current project. They let you use past performance to predict future results. Based on your predictions, you can adjust your strategy to improve those results.

You can also use project metrics to set goals. For example, suppose you have three customer representatives on your team writing use cases. Over the last week, they each managed to write an average of 10 use cases per day. You want to have 10 to 20 (call it an average of 15) use cases for the project's more complicated forms, and you have 20 complicated forms to go.

If the numbers hold true (and they may not), you need to write $20 \times 15 = 300$ more use cases. At a rate of 30 use cases per day (10 for each of the three customer representatives), you should finish in about $300 \div 30 = 10$ days. You can make that a goal: Finish writing the use cases in the next two weeks.

Things to Measure

The things you can measure on a software project are practically limitless. Fortunately, you need to track only a few metrics to get a good sense of how a project is progressing.

At a high level there are two kinds of metrics you should track: inputs and outputs. Inputs are the things you spend on the project. The following list describes some input metrics.

Cost—Money spent on the project for hardware, software, development tools, networking services, paper, training, and so forth. (For business purposes, you may also want to track salaries and overhead, but they're not as directly related to the project's performance. In contrast, if you're not spending anything on development tools, you're probably not getting the best result for your efforts.)

Effort—This is the amount of work being put into the project. It is usually measured in person-hours. Effort is relatively easy to measure.

Defect rates—The number of defects discovered over time. Defect rates are also fairly easy to measure.

Lines of code (LOC)—The number of lines of code produced per day. You might think this would be easy to measure, but it's actually kind of hard to decide what to count as a line of code. For example, do you count comments and blank lines? What about statements that are split across multiple lines? All those things pump up the line count without adding anything extra as far as the computer is concerned, but they also make the code easier to read and understand, so you should encourage programmers to use them appropriately.

Some development organizations treat a command split across multiple lines as a single line of code. Some ignore comments and blank lines. Others count blank lines up to 25 percent of the total code and ignore any blank lines over 25 percent.

It doesn't matter too much which approach you take as long as your rules are consistent across projects and the programmers don't try to game the system. (If you count comments and judge programmers on the number of lines of code they produce, you may get files with dozens of comments per actual line of code.)

Pages of documentation—There are several kinds of documentation that you might want to track. Project documentation (such as the specification and design documents) are important because they ensure that everyone is working toward a common vision. If you don't have enough of this kind of documentation, different team members may end up working at cross-purposes, resulting in extra defects and difficult long-term maintenance.

User documentation is obviously important to the end users. If you have too little, the users won't figure out how to use your program.

User documentation also reflects the complexity of the application. If you need a lot of documentation to explain the program, that may mean the design is overly complicated, and that may also indicate a lot of future defects and maintenance problems.

You can measure all those attributes fairly directly. (At least if you can decide what to measure for LOC.) Some other attributes are harder to measure directly. They're either hard to quantify or they're subjective. The following list describes some of those items and how you might try to measure them.

- **Functionality**—How well does the application do what it is supposed to do? How well does it let the users do their jobs? This is quite subjective, but you can measure things such as the numbers of help requests, change requests, and user complaints.
- **Quality**—Do the users think of this as a high-quality application? Is it relatively bug-free? Again, this is subjective, but you can track user complaints to get some idea. You can also do user surveys. (You know, those annoying surveys that ask you how likely you are to recommend a product to your friends.)
- **Complexity**—How complex is the project? This is hard to measure directly. The amount of project documentation gives you a hint about the project's complexity. Lots of documentation may indicate a complex project that needs a lot of explaining. (Or it may just indicate you have a team member who loves to write.)

  There are a lot of other ways to estimate complexity. You can count the `if-then` statements in the code because they determine the number of paths through the code. You could also count the number of loops or other complicated code features such as recursion and particular data structures. Unfortunately, making all those counts is a fair amount of extra work.

  Function points provide another method for estimating a project's complexity. The section "Function Point Metrics" later in this chapter explains them in detail.
- **Efficiency**—How efficient is the application? In rare cases, you can calculate the theoretical maximum efficiency possible and compare the application to that. For example, you might determine that a routing program finds solutions within 15 percent of the optimal routes. In general, however, this is hard to measure.

  You can compare the users' performance to their performance before they started using your application, but you won't know if there could be an even better way to do things. (Of course, if the users were more productive before they started using your application, you might need to either write a second version or update your resume.)
- **Reliability**—How reliable is the application? This one is a little easier to measure. You can keep track of the number of times the program crashes or produces an incorrect result.
- **Maintainability**—How easy will it be to maintain the application in the long term? You can get some notion of how hard maintenance will be by looking at other metrics such as the amount and quality of the project documentation, the number of comments, and the code complexity, but usually you won't really know how maintainable the project is until you've been maintaining it for a while.

One problem with all metrics is that they're hard to apply to projects of different sizes. Studies have shown that projects of different sizes have different characteristics. For example, in larger projects team members spend more time coordinating activities than they do in smaller projects. That means they may be unable to write and debug as much code per day.

One way to make metrics a bit more meaningful for different project sizes is to *normalize* them by performing some calculation on them to account for possible differences in project size. There

are two general approaches for normalizing metrics: size normalization and function point normalization. The following two sections describe those two approaches.

Size Normalization

Suppose you measure the number of developers, total time, effort (in person-months), LOC, and number of bugs for projects Ruction and Fracas. Table 10-1 shows the results.

TABLE 10-1: Attributes for Projects Ruction and Fracas

	PROJECT RUCTION	PROJECT FRACAS
Developers	3	7
Time (months)	1	24
Effort (pm)	$3 \times 1 = 3$	$7 \times 24 = 168$
LOC	1,210	75,930
Bugs	6	462

In which project were the developers more productive? Which project contained buggier code? Just looking at the numbers in the table, it's hard to tell. Project Fracas includes a *lot* more code, but it also took a lot more effort. Project Ruction contained far fewer bugs, but it also contained much less code.

In *size-oriented normalization*, you divide an attribute's value by the project's size to get some sort of value per unit of size. Assuming everything about two projects is similar except for their sizes (a big assumption), the normalized metrics should be comparable.

For this example, you could divide total lines of code by the effort it took to produce the code. Similarly, you could divide the number of bugs by the total number of lines of code. Table 10-2 shows the normalized values.

TABLE 10-2: Normalized Metrics for Projects Ructino and Fracas

	PROJECT RUCTION	PROJECT FRACAS
LOC / pm	$1{,}210 \div 3 = 403$	$75{,}930 \div 168 = 452$
Bugs / KLOC	$6 \div 1.21 = 4.96$	$462 \div 75.93 = 6.08$

The normalized values show that project Fracas was more productive in terms of lines of code for the effort (452 versus 403 LOC per person-month), but project Ruction had less buggy code (4.96 versus 6.08 bugs per KLOC).

The following list gives some of the measurements of size that you can use to normalize values.

- Number of team members
- Effort (person-months)
- KLOC or LOC

- Cost (dollars, euros, doubloons, or whatever)
- Pages of documentation
- Number of bugs
- Number of defects
- Time (days, months, years)

Divide an attribute value by the value that makes the most sense. For example, bugs are a feature of code, so you should probably divide the number of bugs by LOC or KLOC, instead of the number of team members or effort. Similarly lines of code are produced over time by team members, so you should probably divide LOC by number of team members and number of months (which is the same as dividing by person-months).

Other combinations, such as dividing number of bugs by the number of team members, can also have meaning hidden inside them, but they're harder to interpret.

Size-oriented metrics have a big advantage that they're usually easy to calculate. It's easy to count the number of lines of code (assuming you can agree on how to count comments and blank lines) and it's easy to count the number of person-months spent on the project, so it's easy to calculate LOC / effort. These metrics also have the advantage that a lot of project modeling applications use them as inputs.

These metrics also have a few disadvantages. One problem with normalized metrics is that you can't actually use them to predict the future unless you can already predict the future. For example, LOC / effort lets you predict how long it takes to build a project, but only if you can predict how many lines of code you need to write.

For a concrete example, suppose you know from past experience that your team can produce approximately 400 LOC / pm. If you're about to start project Rhubarb and you think it will require roughly 11,000 lines of code, then you can predict that it will take approximately $11{,}000 \div 400 = 27.5$ person-months of effort. The catch is you need to know that the project will need 11,000 lines of code.

GUESSING THE UNGUESSABLE

Although you can't know how many lines of code you are going to need ahead of time, you can make some educated guesses based on past experience. You should at least take a stab at the worst case, best case, and average case of past scenarios. Then you can take a weighted average of the three (perhaps giving them weights 1, 1, and 3, respectively) to make an "expected scenario."

Feel free to fudge things a bit to take into account any extra information you may have. For example, if a new project is fairly complicated and very different from past projects, you may want to change the weighting factors a bit to give the worst case a bit more pull.

(If you majored in Divinatory Statistics in college, feel free to calculate σ, μ, ρ, and any other Greek letters that you think will help you to better predict the most likely outcome.)

Another problem with size-oriented metrics is that they're language-dependent. The same program may require 1,700 lines of code if you write it in assembly but only 750 lines if you write it in Java.

These metrics also penalize programs that use short but elegant solutions. Project Harmony might do the same thing as project Fracas but using half as many lines of code written in the same amount of time. If the result is better designed and more elegant, then it might be better code even though it looks like the Harmony team was one-half as productive.

Function Point Normalization

The real problem with size-oriented normalization is that it's tied to a particular implementation of an application, not to the application's inherent complexity. *Function-point* (*FP*) normalization tries to fix that by calculating a FP number to represent the application's complexity. You then divide various attributes such as lines of code or number of bugs by the FP value to get a normalized result.

> **ANOTHER BLAST FROM THE PAST** *Function point analysis was developed in the 1970s by Allan J. Albrecht in an attempt to measure application complexity without counting lines of code. Like Ishikawa diagrams, function points are useful enough that they've stuck around.*

Function points measure a project from the user's point of view so they count what the application does, not how it does it. Because they are measured from the user's point of view, they should be hardware-independent and software-independent. An application should do the same things whether you build it in C++ on a Linux desktop system, in Java on an Android device, or in COBOL on a mainframe.

There are many different variations on function points that use various measures of the application's behavior to represent its complexity. For example, different versions count the number of forms, external inputs, event triggers, and so forth. This section describes a version that is reasonably easy to calculate and that seems to be fairly common.

I'll describe the calculation details shortly. First, here's an overview of the process.

1. Count five specific *function point metrics* that include such things as the number of inputs and the number of outputs.
2. Multiply each of those values by a *complexity factor* to indicate how complicated each activity is. Add up the results to get a *raw FP* value.
3. Calculate a series of *complexity adjustment factors* that take into account the importance of general features of the application. (For example, how important is the transaction rate to the application?) Add the complexity adjustment factors to get the *complexity adjustment value* (*CAV*).
4. Take a weighted average of the raw FP and the CAV and voilà! You get the final FP value.

Don't worry if this seems complicated. It requires a lot of steps, but each of the steps is quite simple. The following sections describe the four main steps in greater detail and show an example calculation.

Count Function Point Metrics

In this step, you estimate the number of the following items.

Inputs—The number of times data moves into the application and updates the application's internal data. This includes inputs the user enters on screens and inputs from other applications and external files. An example would be a New Student form that lets the user enter student ID, name, address, phone, and other information in the application's database.

Outputs—The number of times outputs move out of the application. This includes outputs displayed to the user as well as outputs sent to external systems or external files. An example would be producing a Delinquent Account report that lists accounts with outstanding balances. The report could be printed, sent to an external file, or sent to another program for processing.

Inquiries—The number of times the application performs a query/response action. This is different from an input followed by an output because it doesn't update the application's internal data. For example, the user might enter a customer ID and the application would display that customer's information, but it wouldn't update the database.

Internal Files—The number of internal logical files used by the application. This includes things such as configuration files, data files, and database tables.

External Files—The number of files that the application uses that are maintained by some other program. For example, the application might use an inventory database that is maintained by a separate inventory tracking program.

The next step is to multiply the number of each kind of item by its complexity.

Multiply by Complexity Factors

As you count these metrics, you should estimate the complexity of each. For example, consider as an input a New Student form that lets the user enter information about a new student. Suppose the form contains 15 text boxes. You may decide that means this input has medium complexity.

COMPLEXITY CONUNDRUM

Different FP techniques use different methods for deciding whether a piece of the system has low, medium, or high complexity. Some look at factors such as the number of internal tables and the number of data values involved in an action. For example, an Order Creation form might create records in three tables and include 20 fields where you enter data.

In this chapter, I'll just assume you can use your intuition to assign complexity values because that's a lot simpler. The exact formula you use doesn't matter too much as long as you're consistent across projects.

If you want to compare the FP values of your applications to those of programs written by other groups, then you need to use one of the more precisely defined methods for determining complexity. (For an example, see the tables at `http://www.softwaremetrics.com/fpafund.htm`.)

			Complexity			
Category	**Number**		**Low**	**Medium**	**High**	**Result**
Inputs	_____	×	3	4	6	= _____
Outputs	_____	×	4	5	7	= _____
Inquiries	_____	×	3	4	6	= _____
Internal Files	_____	×	7	10	15	= _____
External Files	_____	×	5	7	10	= _____
					Total (raw FP)	_____

FIGURE 10-4: Use this table to calculate raw FP.

After you calculate a complexity value for each of the items you're counting, use them to get a sense of the overall complexity for each of the metric categories. For example, if you have two low, five medium, and one high complexity inputs, then the inputs as a whole have medium complexity.

Now multiply the number in each metric category by the appropriate values shown in Figure 10-4.

Figure 10-5 shows a sample raw function point calculation. For example, this application has 10 inputs with a relatively high complexity. In the first line of the calculation, the number of inputs 10 is multiplied by the high complexity factor 6 to give the result 60.

			Complexity			
Category	**Number**		**Low**	**Medium**	**High**	**Result**
Inputs	10	×	3	4	(6)	= 60
Outputs	5	×	(4)	5	7	= 20
Inquiries	4	×	3	(4)	6	= 16
Internal Files	23	×	(7)	10	15	= 161
External Files	2	×	(5)	7	10	= 10
					Total (raw FP)	**267**

FIGURE 10-5: In this example, the application's raw FP value is 267.

The next step is to apply complexity adjustment factors.

Calculate Complexity Adjustment Value

The function point metrics look at particular facets of the application. The complexity adjustment factors include a series of indicators designed to measure the complexity of the application as a whole.

C-A-V IS NOT FOR ME

Some developers use the raw FP and don't bother with the CAV. The two main reasons are that some cost estimation tools take the raw FP as an input and that the CAV plays too big a role in the final FP calculation. The web page `http://alvinalexander.com/FunctionPoints/node29.shtml` has more information about this issue (although it uses some different terminology).

To calculate the complexity adjustment factors, consider each of the following items.

1. Data communication
2. Distributed data processing
3. Performance
4. Heavily used configuration
5. Transaction rate
6. Online data entry
7. End user efficiency
8. Online update
9. Complex processing
10. Reusability
11. Installation ease
12. Operational ease
13. Multiple sites
14. Facilitate change

Rate the importance of each of the 14 factors according to Table 10-3.

TABLE 10-3: CAV Ratings

IMPORTANCE	RATING
Irrelevant	0
Minor	1
Moderate	2
Average	3
Significant	4
Essential	5

After you make these decisions, simply add the complexity adjustment factors to get the complexity adjustment value.

Table 10-4 shows a sample complexity adjustment calculation.

TABLE 10-4: Sample CAV Ratings

FACTOR	RATING
Data communication	2
Distributed data processing	4
Performance	5
Heavily used configuration	2
Transaction rate	3
Online data entry	5
End user efficiency	5
Online update	1
Complex processing	1
Reusability	0
Installation ease	4
Operational ease	5
Multiple sites	5
Facilitate change	1
Total (CAV)	**42**

The final step is to use the raw FP and the CAV to calculate the adjusted FP value.

Calculate Adjusted FP

To calculate the final FP, simply use the following formula.

$FP = (\text{raw FP}) \times (0.65 + 0.01 \times \text{CAV})$

For example, the calculation in Figure 10-5 got a raw FP of 267. The CAV in the preceding section was 32. For those values, the final FP result is:

$FP = (267) \times (0.65 + 0.01 \times 42) = 285.69$

SUMMARY

Metrics enable you to characterize and track projects. Process metrics let you compare multiple projects over a long period of time to see if you can improve your development process. For example, if one project has fewer bugs per line of code than the others, you can study that project to see why it is different and try to reproduce those results in future projects.

Project metrics enables you to make predictions about a project that is still underway. For example, if a project isn't producing enough lines of code for where it is in its schedule, you can look for ways to increase productivity. Without metrics, it's often hard to tell when a project is going off course until it's too late to do anything about it.

Size normalization enables you to compare projects of different sizes. Function point normalization enables you to compare projects of different sizes and complexities. Comparisons are always better if the projects are similar, but those two techniques enable you to get at least some meaningful information from projects with some differences.

This chapter focused mostly on lines of code and bugs, but the same techniques apply to every output from software engineering. You can use metrics to track the specifications, use cases, design documents, change requests, and number of donuts eaten. If any numbers wander away from what's normal, you can dig deeper to see if there's a problem you can correct or perhaps an unexpected benefit you can exploit in the future.

Tracking bugs is a good way to estimate the application's maintainability. If the code is buggy, then maintaining it will probably be hard. The next chapter focuses on maintenance. It explains what the team's role is during the maintenance phase and describes some of the directions the project can take after its initial release.

EXERCISES

1. Suppose a project has a `States` table that lists the states where the customer does business. A search dialog lets the user select one of the states from a drop-down list to select accounts from the selected state. Some of the use cases call for the states to be set to Maine, Vermont, New Hampshire, and Massachusetts, but during tests New Hampshire doesn't appear in the drop-down list.

   Draw an Ishikawa diagram showing possible causes for this problem. What steps would you take to try to find the root cause of the problem?

2. Compare size normalization and FP normalization. When would you use one or the other?

3. Are there times when you could use both size normalization and FP normalization to compare two projects?

4. Assume a project has a raw FP score of 500. What are the largest and smallest final FP values the project might have? How would it achieve those values?

5. Give an example where project A has more bugs than project B but seems to be in better shape according to size normalization. Assuming the projects are in roughly the same development stage, what else do you need to know to decide whether project A will finish before project B?

6. For the example you made for Exercise 5, what else do you need to know to estimate when the two projects will finish flushing out all their bugs?

7. Calculate an FP value for Microsoft WordPad.

8. Calculate an FP value for Microsoft Word.

9. Judging from your experience solving Exercises 7 and 8, how consistent do you think FP values will be when different people perform the calculations? (Compare your solutions to my solutions in Appendix A, "Solutions to Exercises," if you like.) What could you do to improve consistency?

10. What do your solutions to Exercises 7 and 8 tell you about Microsoft WordPad and Microsoft Word? Does that result agree with what you would expect?

11. Which do you think is better, size normalization or function point normalization?

12. Table 10-5 shows the number of programmers that worked on four projects.

TABLE 10-5: Number of Programmers

PROJECT	# PROGRAMMERS
Unicorn	10
Pegasus	8
Griffin	12
Jackalope	7

Table 10-6 shows the cumulative numbers of lines of code written and bugs discovered during each week of active coding for the four projects. For example, by the end of week 3, project Griffin contained 5,141 lines of code and 62 known bugs.

TABLE 10-6: Lines of Code and Bugs

	UNICORN		PEGASUS		GRIFFIN		JACKALOPE	
WEEK	LOC	BUGS	LOC	BUGS	LOC	BUGS	LOC	BUGS
1	1,107	0	542	0	450	3	126	5
2	2,349	2	1,374	12	2,392	17	1,201	27
3	3,482	7	2,759	37	5,141	62	3,515	60
4	4,272	30	4,680	61	6,008	102	5,176	72
5	6,009	72	6,012	89	7,817	156		88
6	7,522	110		104	9,750	160		
7	9,759	156				175		
8	11,895	207						
9		273						

The final bug numbers for each project include bugs found after initial programming stopped.

Assuming these projects have roughly similar complexity, how can you meaningfully compare the programmers' productivity and bug rates at the ends of the projects? What do your calculations show? Can you think of any places to look for process improvements?

13. Suppose you're tracking a new project (project Hydra) that you expect to include approximately 7,000 lines of code. Assuming its progress is similar to the progress of the projects described in Exercise 12, how many person-weeks should this project's programming phase take? How many bugs do you expect to find?

14. Seeing the results of Exercise 13, you decide you can finish the programming for project Hydra in nine weeks with five developers. Table 10-7 shows the project's actual progress after week 3.

TABLE 10-7: PROJECT HYDRA PROGRESS

WEEK	LOC	BUGS
1	370	0
2	693	2
3	969	12
4	1,251	24

Should you be concerned?

WHAT YOU LEARNED IN THIS CHAPTER

- You can rate a defect's importance by discoverer, severity, time created, and age at fix.
- Group defects by task (specification, design, programming, hardware, and so forth) to look for common causes.
- An Ishikawa diagram can help you find the root causes of a defect.
- Attributes are things you can measure; metrics are values you can use to evaluate a project; and indicators give indications of a project's state and future.
- Attributes→metrics→indicators→projections and process improvements.
- Software metrics let you characterize, track, and predict a project's characteristics such as defects, bugs, and lines of code written.
- Process metrics are used to improve your development process in the long run. Project (or product) metrics are used to track and predict the current project's progress.
- Size-normalized metrics enable you to compare projects of different sizes but similar complexities. These metrics are values divided by a measure of the project's size. For example, "bugs per KLOC" or "pages of documentation per person."
- Function points enable you to estimate a project's complexity.
- Function point normalization enables you to compare projects of different sizes and complexities. Values are divided by the project's FP value to give metrics such as "KLOC per FP" or "bugs per FP."

11

Maintenance

Troutman's Second Programming Postulate: The most harmful error will not be discovered until a program has been in production for at least six months.

—Anonymous

All programming is maintenance programming, because you are rarely writing original code.

—Dave Thomas

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Why maintenance is a major percentage of total project cost
- The four categories of maintenance tasks
- What the "second system" and "third time's a charm" effects are
- How to know when you should rewrite code to make it more maintainable
- Bug tracking states

So you finished the initial release of your application and held wrap-up meetings to make your team members better software engineers. Congratulations! On most projects, a fair number of those people will now wander off to do other things. Some will join new projects and start the whole process all over again. Others may take new roles on other projects. For example, a programmer may become a team lead or a team lead may become a project manager. Still others may leave to satisfy their life-long dreams of becoming lobster fishermen.

Hopefully, a few team members will remain as the project moves into the maintenance phase. Having some original team members during maintenance helps provide continuity for the project so that its original vision isn't lost.

CHANGE FOR THE WORSE

On one project I worked on, the maintenance crew took over and made all sorts of changes to improve the application. Then the users spent weeks forcing them to put things back the way they were. If more of the maintenance group had been around from the beginning, they would have understood the application better and been more hesitant to make those changes in the first place.

Some programmers dislike maintenance programming because they find it boring. It can be a lot of fun to write an application that finds the shortest route that visits all the ice cream stores in your town for a bicycle ice cream crawl. It's less fun to debug your application when you discover it is telling people to bike on the highway. It can be downright painful to dive into someone else's rat's nest of kludges, hacks, and bug fixes to make major changes.

Maintenance may not always be a lot of fun, but it's important because maintenance is often relatively expensive. (In management-speak, maintenance accounts for a large percentage of *total cost of ownership* or *TCO*.) Often maintenance accounts for 75 percent of a project's total cost.

This chapter describes the tasks that make up software maintenance. It explains why maintenance is expensive and methods you can use to reduce maintenance costs.

MAINTENANCE COSTS

You may wonder why maintenance is such a large percentage of a project's total cost. One reason is that applications often live far longer than they were originally intended. A typical business application might be in use years or even decades after it was written. Most businesses are stingy, so writing a new program to replace an old one that still works is rarely an option. (Even if the existing application is so old it measures lengths in cubits and lets you click a sundial to select times.) I worked on one application 30 years ago that is still in use today, even though the company that owns the code has been bought at least twice since then.

For further proof that applications often exceed their life expectancies by decades, consider the Y2K problem. Programs written as far back as the 1950s and 1960s stored dates as 2-digit numbers to save space. For example, the year 1978 was stored as '78. That worked pretty well until after the year 2000 when dates became ambiguous. For example, if you're working for a hospital in 2005 and one of your patients was born in '03, should you schedule a pediatric appointment or a geriatric appointment? I doubt many programmers in 1960 imagined their code would still be in use 40 years later.

Contrary to the predictions of the pundits on the Y2K apocalypse lecture circuit, planes didn't fall from the sky like leaves in autumn; missiles didn't decide they were past their expiration dates and explode; and streets didn't boil with lava. Still, retired BASIC and COBOL programmers from around the world briefly hung up their fishing rods to help the $300 to $600 billion effort to fix this single problem. That's a lot of money to keep decades-old software running. (I'm not sure what will happen when the Y3K problem hits and there are no COBOL programmers left.)

The moral is, you should pretend you're carving your code in stone to last for the ages. Chances are it'll last longer than you expect.

A second important reason why maintenance costs often dwarf initial development costs is that it's much easier to write fresh code than it is to modify old code. To safely modify old code, you need to spend time studying it. Because you didn't just write the code, it's not fresh in your mind. If you don't dig into the code and make sure you understand how it works, you're just as likely to add bugs to the code as remove them.

After you make your changes, you need to test them to verify that they work. You also need to thoroughly test the rest of the application to make sure your changes didn't break anything.

You can reduce maintenance costs by doing a good job when you write the initial code. For example, develop simple but flexible designs, use good programming practices, insert comments to make the code easy to read, and provide documentation so future generations of maintenance programmers can figure out what you were thinking when you wrote the code.

TASK CATEGORIES

At a high level, the tasks that go into long-term maintenance are roughly the same as those that go into initial development. You gather requirements, make designs, write some code, test the code, and deploy a new version. Although the tasks are similar, the focus is different. During maintenance, you tend to spend more time on bug fixes and feature enhancements than on writing completely new code.

Generally maintenance tasks are grouped into the following four categories:

- **Perfective**—Improving existing features and adding new ones
- **Adaptive**—Modifying the application to meet changes in the application's environment
- **Corrective**—Fixing bugs
- **Preventive**—Restructuring the code to make it more maintainable

The relative effort spent on each of these categories depends on the project. For example, in a relatively small phone app with a short lifespan, you might focus most of your energy on building a new version (perfective) and not worry about making the current version compatible with future phone operating systems (adaptive). For a larger project that you plan to use within your company for many years, you might spend a lot more effort on bug fixes (corrective).

For a typical large application, the relative effort spent on each of the categories (out of the 75 percent of the project's total cost represented by maintenance) might be:

- **Perfective**—50 percent
- **Adaptive**—25 percent
- **Corrective**—20 percent
- **Preventive**—5 percent

The following sections describe these categories in more detail.

Perfective Tasks

For many applications, particularly large ones with long lifespans, this is often the biggest part of maintenance. If you've done a good job building the initial application, the users may like it, but they still want tweaks, adjustments, and improvements. (Although this doesn't include bug fixes, which are tweaks of a different sort. I'll talk about those in the "Corrective" section a bit later in this chapter.)

Sometimes, the specification didn't represent exactly what the users need to do. Maybe the specification didn't explain the user's needs correctly. (Although you should have caught that earlier when the customers reviewed the specifications.) Or maybe the users didn't quite understand what they would need to do after the application was in place.

Sometimes, the tools you built let the users think of ways to do things that they hadn't before. Often the users don't know exactly what's possible until they see the program and have a chance to work with it for a while. They know how they're doing their jobs now, but sometimes no one actually knows how they will do their jobs with your new tools.

Users may also want completely new features that weren't in the original specification. They may have been left out of the first release to save time. Sometimes, it's another example of the "we didn't know this was possible until now" scenario.

Even you and your fellow developers can think of improvements and modifications based on the users' experiences. After you watch the users bashing away on your application, you may discover whole new uncharted areas of new opportunities that the users can't see because they don't have your software engineering background.

THE BIG PICTURE

One of the first big projects I worked on was a dispatching system for telephone repair people. You entered information about jobs and employees, and the system assigned employees to appropriate jobs.

The program included a map that showed all the employees and their jobs on a street map. It didn't help the work assignment code, but we stuck it in anyway, mostly because it had a high "gee whiz" factor for executive presentations (and because it was fun to program).

After the users had been experimenting with the system for a while during parallel testing, we noticed that the dispatchers used a map screen a lot more than we expected. In fact, they used it all the time. We asked them why and they said it was the only place in the system where they could see a list of every employee in the system. We had all sorts of screens that let them look at a particular employee, an employee's assignments, jobs that had not been assigned, and so forth, but no place where they could see every employee's data at the same time.

So we added a screen to do that. (They still used the map screen a lot. I think they just liked it. It also let them see if the employees were all assigned to jobs that happened to be near the same restaurant around lunchtime. That really reduced productivity.)

The tasks that fall into the perfective category tend to be one of two sorts: feature improvements and new features.

Feature Improvements

Feature improvements involve modifying existing code, so in some ways they're similar to bug fixes. That means you should be aware of the same issues when you handle them.

You need to carefully study the existing code so that you're sure you understand what it does and how it works. You need to plan the modifications you're going to make. Don't just start ripping out old code and typing in new. When you're reasonably certain that your changes won't break things you can make your modifications.

Remember that changing old code is more likely to introduce bugs than writing new code, so you need to test your changes thoroughly. The users probably won't like your modification if it doesn't work or it breaks something else.

New Features

Adding new features to an application is a lot like writing code for the initial application, so you should follow the same steps:

1. Make a specification explaining what you will do.
2. Get the users to sign off on the specification so that they agree that you're doing the right thing.
3. Create high-level and low-level designs.
4. Write the code.
5. Test, test, and test. (And save the tests in case you need to run them again later.)
6. Use good practices (such as staging and gradual cutover) to deploy the new version of the program.

Adding new features is almost like running a completely new mini-project.

If there are enough changes or the changes are big enough (for example, they require restructuring the program's class hierarchy or architecture), you may want to create a new major version of the application.

A new version is basically a whole new project. Start over from scratch and follow all the steps described up to this part of the book. You can probably take a lot of shortcuts because of your experience with the first version of the program. For example, you may reuse most of the high-level design you wrote for the previous version.

The Second System Effect

In his book *The Mythical Man-Month* (Addison-Wesley, 1975), Frederick Brooks says, "…plan to throw one away; you will anyhow." The notion is that you will learn a lot about the system you need to build when you build it. After you're finished, you'll discover that you could have done a lot of things better, so you throw the first version away and write a new one.

Some developers have suggested that you could crank out a hasty version of the application, throw it away, and then build the real application. Perhaps then you can learn what you need to know without spending all the effort needed to build a "real" first version. (That's sort of what prototyping is.)

Of course if you *plan* to throw away the first version, you may do such a poor job of it that you don't learn the things you need to know to build the good second version. You may use so many sloppy shortcuts that you don't get any practice using the "real" techniques you'll need to build a solid second version.

That leads to the corollary, "If you plan to throw one away, plan to throw two away." If you don't learn anything from the "quick and dirty" first version, your second version is basically just a delayed first version. (By the process of mathematical induction, that means you should plan to throw them all away.)

In the 1995 edition of his book, Brooks retracted his initial assertion, saying it was too simplistic and implicitly assumes you're using the waterfall model of development. (You'll learn more about models of development in Chapters 12 through 14.)

Still, Brooks's notion of a "second system effect" has some merit. The first time you build a system, you don't know everything you'll need to do. You don't necessarily have perfect specifications, and you don't know how to implement the features that are specified correctly. You don't know how the pieces fit together. Sometimes, you may not even know what the pieces are.

When you build the second system, you know a lot more about what you can do and how things need to work. Unfortunately, that sometimes leads developers to throw in every conceivable cool feature (plus the kitchen sink) to make the application the best software solution ever created by programmer-kind. As a result, the second version is confusing, hard to use, bloated, and generally inefficient.

Finally, in the third version (if you have any customers left), you can build the application that you should have built in the first place. At this point, you're a Master Craftsman at software development, programming in general, and your application in particular. You know what the application should do and (just as important) what is should *not* do. You know which user interface features work and which don't. You know what pieces are necessary and how they all fit together. You have become one with the development environment and are perfectly positioned to build the best system possible.

THIRD TIME'S A CHARM

The third version of an application is often the first version that's really useful. In fact, it's so common that many users wait until the third version before they buy a product. (I've done that several times.)

To prevent users from waiting (and depriving them of much-needed revenue and customer-assisted debugging), some software companies give the first release of a product the version number 3.0, hoping users will buy it. Occasionally, you can find an application version 3.0, but there was never a version 1.0 or 2.0.

It doesn't always have to work like that. You can struggle against fate and make a real difference, but it takes some effort. To avoid building one or more throwaway versions, you need to carefully follow these steps.

1. Gather requirements, write a specification, and thoroughly validate it with the users.
2. Make high-level designs that provide a framework for development. It should keep pieces loosely coupled and provide enough flexibility to do what you need it to do.
3. Create low-level designs that indicate how to create the features you need.
4. Write code while following good programming practices so that you don't end up with a tangled web of mysterious and uncommented code.
5. Test thoroughly to flush out bugs as quickly as possible.
6. Use good deployment techniques (such as staging and gradual cutover).

In other words, follow all the normal steps of software development.

Having developers who are experienced with the type of application you build can also help reduce the "second system" and "third time's a charm" effects. If they've already built their first (and possibly second) versions, you can build more useful versions.

Iterative and RAD development models use other techniques to try to keep development moving toward a useable application. (You'll learn more about them in Chapters 13 and 14.)

Adaptive Tasks

Adaptive tasks help keep the application usable when the things around it change. If the users' hardware, operating system (OS), database, other tools (such as spreadsheets or reporting tools), network security, or other pieces of the users' environment change, it could break your application, so you have to fix it.

Unfortunately, the tools on which your application relies may also be interrelated, so changes to one may affect the others. For example, suppose your application uses a graphics toolkit that uses a particular database. Now the operating system changes so the toolkit no longer works. You upgrade the toolkit so that it's compatible with the new operating system, but the new version of the toolkit isn't compatible with the current version of the database it needs. Unfortunately, the database vendor hasn't finished building a version that's compatible with the new version of the operating system, so you're stuck.

There's no combination of your application, the graphics toolkit, and the database that can run on the new operating system. You can tell the users that it's not your fault, but they still can't process orders, so customers can't get their electric roller skates (or whatever).

To make matters worse, the same scenario can arise if any one of the tools you use is updated. For example, if a new version of the graphics toolkit is released, it may break your application. If a new version of the database appears, it may break the graphics toolkit. Then you're stuck waiting for the graphics vendor to update its toolkit before you can even see if the changes will break your application.

You can take a couple approaches to make these scenarios less likely. First, you can minimize the use of external tools. If you don't use a graphics toolkit, you don't have to worry about a new version breaking your application. If a new version of the operating system breaks your application, at least you have only your own code to fix. You don't need to wait weeks or months for all your tool vendors to revise their products until a workable combination is possible.

Second, you can just ignore new releases of operating systems, databases, toolkits, and any other external tools that you use. I knew one company that had a single computer that ran a program to control a robotic assembly line. Unfortunately, a vendor discontinued support for the programming language used to write the program. After the next operating system release, programs written in that language would no longer be supported. In some later operating system version, the program would stop working completely.

As if that weren't bad enough, new computer hardware wouldn't support the older version of the operating system needed by the program. (Just try to buy a modern computer running Windows 3.11 or OS/2.) Eventually, the computer running the program would die, and the assembly line would be offline for good.

The company could rewrite the application in a new language, but that would be a lot work (in other words, expensive). Besides, the program did what the company wanted and didn't need any new features.

To solve the problem cheaply, the company bought some inexpensive computers, installed the current operating system on them, and added the assembly line program. Now when the computer controlling the assembly line dies, the company pulls another computer from the closet and the assembly line is back up and running. (Although the company is sort of stuck in the 1009s. Eventually that program is going to need to be rewritten.)

Ignoring upgrades worked for that company, but it's a strategy that's getting harder to follow. These days many products install new releases automatically, so it's harder to avoid having some product upgrade itself and break something.

Some companies fight that problem by explicitly prohibiting any upgrades. When a new version of the operating system or some other important piece of the environment is available, the IT department loads the latest version of everything on an isolated computer and tests it. If everything works, the new configuration is rolled out to the users' computers. (Remember staging from Chapter 9, "Deployment"?)

This tight control over the users' computers often seems arbitrary and totalitarian to the users. (Why can't I install the latest version of Othello on my computer?) But you can understand what they're trying to accomplish.

Corrective Tasks

Corrective tasks are simply bug fixes. You've probably been making them since you started development, if not sooner. If you think of mistakes in the specification, designs, documentation, and other pieces of the program as bugs (and you should), then you've been fixing bugs since the project started. (If you extend that a bit to the world outside of work, then you've been fixing bugs since the day you were born. For example, being unable to walk and talk is a bug that takes a newborn about two years to fix.)

You probably already know in general how to fix a bug. Find it, study the code so that you're sure you understand it, fix the bug, test, and release a new version of the application with the bug fixed.

There are several ways this process can go wrong. Perhaps the most obvious way is if you fix the bug incorrectly and don't notice during your tests. In that case, you can add an additional step at the end: file another bug report describing the mistake you made fixing the original bug.

One of the worst ways to fail to fix a bug is to lose track of it. At least if you fix a bug incorrectly you have some record of the original bug. If you lose track of a bug, there's little chance that it will ever be fixed (unless a user reports it again). What may be just one of dozens or hundreds of bugs to you, might be really important to some user patiently waiting for you to fix it.

To avoid losing bugs, you need a bug tracking system. There are several kinds of bug tracking systems you can use.

INCIDENTALLY

Some companies don't like the term "bug" (maybe they're insectophobic), so they call these things "incidents." They may also include change and enhancement requests in the incident category, possibly so that they can deemphasize the number of bugs. (Sure we have 3,000 incidents, but lots of them are change requests.)

For really small projects, you can simply keep track of bugs in a spreadsheet. That works well if you don't have too many bugs but doesn't work as well if you have many developers who need to update the spreadsheet at the same time.

You can store bug information in a directory hierarchy. You would create a text file describing each bug and then move them from directory to directory to group them by status. For example, the `Bugs/New` directory (or `Bugs\New` if you have a Windows accent) would contain new bugs that have not yet been examined by the project team. The `Bugs/Assigned/Rod` directory would contain bugs assigned to me.

You can store bug information in a database. That works well, but building the database and tools to work with it can be a lot of work. If you're not a database developer who thinks of this as a fun exercise to crank out over the weekend while your friends are off waterskiing, you might want to use a prebuilt bug tracker instead.

Finally, you can use a prebuilt bug tracking application. There are a lot of bug tracking applications available ranging in price from $0 to a $1,000 or so per month. (The expensive ones are designed for *really* big projects with up to a few thousand users.)

Whichever method you use, you can assign a *state* to each bug to keep track of its status within the system. The following list describes typical states that a bug tracking system might use:

- **New**—The bug has just arrived and has not yet been assigned to anyone.
- **Assigned**—The bug has been assigned to someone to fix.

- **Reproduced**—The bug has been reproduced by a team member. The bug's description includes instructions for reproducing the bug. (It is sometimes called "verified.")
- **Cannot Reproduce**—A team member has examined the program and can't make the bug occur. Often a "we can't reproduce the bug" message is sent back to the customer and the bug is closed. (As a user, this is my least favorite status because I know the vendor will never fix this bug. Often it seems like they didn't try very hard to reproduce it.)
- **Pending**—A request for more information has been sent to the customer who reported the bug. Sometimes, this state is used before Cannot Reproduce.
- **Fixed**—The bug has been fixed but not tested yet. (This is sometimes called "resolved.")
- **Tested**—The fix has been thoroughly tested and the bug is verified as gone.
- **Deferred**—The bug should not be fixed, or at least not yet. For example, you might want to fix it in the next major release because fixing it now would be too hard.
- **Closed**—The bug has been either fixed, deferred, or otherwise abandoned (see the Cannot Reproduce status), and no further action will be taken on it. (This is sometimes called "resolved.")
- **Reopened**—The bug reappeared after being closed. The bug should probably be treated as if it were a new bug. Although there may be some benefit to reassigning it to the person who originally worked on it, because that person may know more about the code containing the bug. (And it seems like a fitting punishment.)

Bug tracking applications typically come with an assortment of features. For example, they may produce reports showing bugs in various states, bugs cleared over a period of time, and bugs assigned to a particular developer. Some can notify developers via e-mail or some other method when bugs are assigned to them.

Some systems can automatically move bugs from one state to another. For example, when a new bug report appears, the system might assign it to a developer chosen from a list of those who are allowed to fix bugs. It would assign the bug to that person and change the bug's status to Assigned.

Another approach would be to have the system send the bug to a manager and ask the manager to assign the bug to a developer.

Some systems also allow you to indicate who is allowed to make certain transitions. For example, if you have separate bug fixers and testers, you could allow the fixers to move a bug from Assigned to Fixed, and the testers would move the bug from Fixed to Tested (or send it back to Reproduced if the tests fail).

MY FAVORITE BUG

My favorite bug of all time appeared in a large application we developed for internal company use. One of its forms let the user enter search criteria to build a list of matching jobs. The user could then scroll through the list and double-click on jobs to get more information.

During testing, one of our power users reported that this form occasionally made the application crash. She didn't know why and could not reproduce the crash reliably, but it happened about once per day.

We performed dozens of test queries, opened multiple detail screens, resized the form, and did everything we could think of to test the program, but we couldn't make the crash happen even once.

Finally, we both flew to Tampa (she from Fort Wayne, I from Boston) so I could watch her crash the program. For about half an hour, she built lists, clicked buttons, rearranged panels, and resized the form. Just as she was starting to doubt her own sanity, the program crashed. It took me about another half an hour to figure out how to reproduce the crash.

It turned out that the form contained a splitter that you could use to make one panel smaller (holding search criteria) and another larger (holding query results). There was a bug in the splitter control we were using that made it crash if you made one of the panels exactly 1 pixel tall. It was pretty hard to do. If the panel was 2 pixels tall, everything was fine. You had to be resizing the panels more or less randomly and release the mouse at just the right instant.

When I could reproduce the problem, it didn't take long to figure out what was happening and how to fix it. I added a quick test in the code to ensure that the panels were never less than 2 pixels tall and everything worked fine.

The point of this story (aside from showing off my ninja debugging skills) is that users are rarely crazy. If you can't reproduce a bug, that doesn't mean it isn't there. It is almost surely there, you just can't find it.

So if you can't instantly reproduce a bug, dig a bit deeper. By all means ask for more information, but don't be surprised if the user doesn't have any more information for you. Then dig even deeper. If you close the bug now, it'll come back to haunt you like the last Easter egg that you didn't find until June—and with the associated smell.

One final twist to an already complicated situation is priority. Some bugs are more important than others. If one bug makes the application crash every day or two and a second bug is a typographical error in the Swedish version of the program, the first bug probably deserves higher priority. (Although a typo may be easy to fix, so you might want to bang it out to boost your productivity stats.)

Preventive Tasks

Preventive tasks involve restructuring the code to make it easier to debug and maintain in the future. The fancy "impress them at cocktail parties" word for rewriting code to improve it is *refactoring*.

If you've been paying the least bit of attention, you know that modifying code is more likely to introduce new bugs than writing new code is. If that's true, then why would you ever mess around inside working code? That would be like asking a mechanic with questionable skills to rebuild your

brand new car's engine. It will be expensive, might not make things any better, and might make them a whole lot worse.

If you look back at the "Task Categories" section earlier in this chapter, you'll see that typically only approximately 5 percent of a project's maintenance cost is spent on preventive tasks. That number is low largely because of the risk involved with modifying working code. (Companies also usually have a strong "if it ain't broke, don't fix it" bias, which is completely justified here.)

WHAT'S PREVENTIVE?

The discussion of preventive maintenance doesn't include adaptive tasks (modifying or adding features) or corrective tasks (fixing bugs). Those often require some revision of the existing code. For example, you might need to rewrite a piece of code to add a new feature to the program. If you make the fewest changes possible, that doesn't count as preventive maintenance.

I'm also not counting rewriting a piece of code right after you wrote it to make it more elegant and flexible. That's part of the initial programming and, yes, you should do it. Code is often pretty rough the first time around, and you can often make it more efficient, easier to modify, and easier to understand if you rewrite it right away. After you write a piece of new code, look it over (by yourself or in a code review) and see if you can improve it before moving on.

This section focuses on changes you make to the code before you need to modify it to make it easier to deal with later.

Despite the dangers, there are several reasons why you might want to refactor code, and a few reasons not to. The following sections describe some of the most important of those reasons.

Clarification

If a piece of code is confusing, you should add comments to it explaining how it works. You should do that as you're writing the code or immediately after you finish writing it, while the code is still fresh in your mind. Later, when people need to read the code (including you after you've forgotten how it works), they have a chance of understanding how the code works.

Unfortunately, many programmers don't include enough (or any) comments. Sometimes, they think the code is obvious because it's still fresh in their minds. Sometimes, they get pulled away for more urgent tasks before they get around to writing comments and documentation. Sometimes, they're just plain lazy. In those cases, it may be worth adding comments to particularly confusing pieces of code.

It's often not worth the effort to add comments to random pieces of code. To write good comments, you need to spend a lot of time studying the code carefully so that you're sure you understand how it works. If you don't know what the code is doing, you may insert misleading comments and they can do more harm than good.

For that reason, I recommend that you add comments to code only when you need to modify it. That gives you extra incentive to study the code carefully (or your modifications won't work). You'll also need to test your changes to verify that they work, and that helps verify your understanding.

No matter how thoroughly you study the code, however, there's still a chance that you don't really get it, so your new comments should always be regarded with a bit of suspicion. Keep the following quote in mind.

> *Don't get suckered in by the comments—they can be terribly misleading. Debug only code.*
>
> —Dave Storer

That doesn't mean comments are completely useless, but they aren't always correct. That's particularly true for comments added long after the code was written.

Code Reuse

Sometimes when you're modifying code you realize you've done something similar before. Instead of repeating yourself, it may make more sense to extract the common code into a new class or method that you can call from multiple locations. Then when you need to do the same thing a third, fourth, or fifth time, you won't need to write the same code all over again.

Saving you the trouble of writing repeated code is nice, but the real benefit here is in maintaining the duplicated code. Suppose you have the same (or similar) piece of code repeated in several places. What happens if you find a bug in that code? Or if you just decide to change the way the code works? Perhaps you decide to store values in meters instead of feet or you store some data in a database instead of a file.

In those cases, you need to modify the code in exactly the same way in every place that it occurs throughout the program. If you miss any of the occurrences or make one of them incorrectly, the code will be inconsistent. The resulting bugs can be extremely hard to find. (I know that from firsthand experience.)

Making changes consistently is even harder if the pieces of code are similar but not exactly the same because it makes it harder to find the related pieces of code.

The *DRY* (don't repeat yourself) *principle* says you should extract common code any time you repeat yourself.

THERE'S NO SUCH THINGS AS 2

One of my mottos is, "There's no such thing as 2." You can write a piece of code once. If you write it a second time, how do you know you won't then need to write it a third or a fourth time?

The same idea holds for user interface design. A customer record can hold a single emergency contact phone number, but if users decide they want to allow a second, how do you know they won't then ask for a third, fourth, and fifth?

Start by assuming users can have only one emergency contact number. As soon as users want to add a second, assume the customer might have any number of phone numbers. That way you can modify the user interface once instead of several times.

Improved Flexibility

Sometimes, when you modify a piece of code, you realize the code isn't as flexible as you'd like. It was written in a way that made sense at the time, but that prevents you from easily making the changes you now need to make. If you need to make only a single change, you can simply make the change, test it, fix anything you've broken, and move on to the next item on your to-do list.

However, suppose you're going to make similar changes in the future. In that case, it may be worth spending a little extra time now to clean up the code so that it's easier to make those changes later. (This is a new version of "Fool me once, shame on you. Fool me twice, shame on me.")

For a concrete example, suppose you've written a perfectly good application that lets the user control the lights in a high-rise office building. It lets you turn individual lights on and off so that you can use the building as a 35-story pixel display. After the first release, the customers decide they want a tool that lets them display the company logo. Unfortunately, you didn't plan for that, so adding it is a bit of a hassle.

If you were paying attention when the preceding section talked about the DRY principle and "there's no such thing as 2," you can probably guess where this story is headed. After you write this tool, the customers are probably going to want another one. They'll want new tools to draw letters, words, and simple pictures. (They probably won't ask for scrolling messages and animation just yet because the lights don't turn on and off fast enough to make those work very well.)

You could just write the logo tool, but it would probably be worthwhile to spend a little extra time to refactor the code a bit to make building these sorts of tools easier. It'll cost you more time now, but will save time down the road. More important, it will make the code cleaner, so you'll be less likely to introduce bugs when you write new tools later.

Bug Swarms

As mentioned in Chapter 8, "Testing," bugs tend to travel in swarms. What that means is some methods, modules, or classes tend to be buggier than others. That can happen for several reasons. Perhaps that chunk of code is exceptionally complicated or confusing. Perhaps it wasn't thought out well in advance during high-level and low-level design. Perhaps the code was modified several times so its original elegant design has been shredded into confetti. Perhaps the code was written by a beginning programmer who hadn't learned about `for` loops yet.

However they form, bug swarms are dangerous. A piece of code has produced a lot of bugs in the past and is likely to continue spawning bugs in the future. At some point, it's better to step back, study the code so that you understand what it's supposed to do, and rewrite it from scratch.

This can be risky. Buggy as it is, the code probably does more or less what it's supposed to do, so there's a chance you'll replace ugly but working code with elegant but broken code.

That means you should perform at least a quick cost-benefit analysis to decide whether it's worth the risk. For example, if you've wasted two or three hours per week for the last few months fixing bugs in a 30-line method, it's probably worth rewriting that method. In contrast, it's less clear whether you should completely rewrite a `Customer` class that contains 7,000+ lines of code just to chase a couple bugs that you haven't been able to reproduce.

My rule of thumb is, if I'm sick and tired of fixing bugs in a particular piece of code, then it's time to consider rewriting it.

Bad Programming Practices

Fixing bad programming practices is both a good reason and a bad reason to refactor code. It's a good reason because the result can be code that is easier to understand, test, debug, and modify. It's a bad reason because, in theory at least, you shouldn't have any bad programming practices in your code.

Ideally after you write a piece of code, you should review it (either yourself or in a formal code review) and make sure you've followed good programming practices. Still, sometimes bad code slips into a project.

Even if the code starts out good, it can be modified and remodified until it no longer follows good programming practices. Over time a method that was initially short, elegant, and tightly-focused can morph into an incomprehensible jungle of loops, branches, and unrelated tests.

For example, suppose you write a nice, short, tightly focused method that takes a student ID as a parameter and fetches that student's data from a database. A few days later, the method's requirements change to make it select only students that are currently enrolled in classes. You modify the code to add that check. No big deal. A week after that, someone else wants to search for students by name instead of student ID, so you add a student name parameter and modify the code accordingly. After a few other changes, the method that once was straightforward is a confusing mess. You used to be able to view all of the code on a single screen, but now it contains hundreds of lines of code with `if-then` statements spanning several pages, so you have to scroll back and forth to figure out what's happening.

At that point, you should probably rewrite the method to restore its original tight focus. You should break this frankenmethod into several separate methods, each of which performs a single, unambiguous task. The result will be more methods and probably a larger total number of lines of code, but the methods will each be easier to understand, use correctly, debug, and maintain.

The following list shows some of the bad programming practices that you should avoid initially and that might indicate a class, method, or other piece of code could benefit from refactoring:

- The code is too long.
- The code is duplicated.
- A loop is too long.
- Loops are nested too deeply.
- It doesn't do much.
- It's never used.
- It has a vague or unfocused purpose.
- It performs more than one task.
- It takes a lot of parameters.

If you see code that has changed over time to include some of these symptoms of bad code, consider refactoring.

Individual Bugs

Finding an individual bug is not a good reason to rewrite code. If you find a single bug in a method, just fix it and move on. One bug does not make a swarm. There's no reason to rip a good piece of code apart and risk breaking something just because it contains a single bug.

Now if you discover another bug in the same piece of code next week and a third bug the week after that (and you didn't add them while fixing the first bug), then you should think about rewriting the code to clean it up.

Not Invented Here

This is the worst reason for rewriting code, but it's also probably the most common. When some programmers see someone else's code, it doesn't look quite right. The structure is wrong, the names of the variables are misleading (it should use `num_students` instead of `student_count`), the comments don't use proper grammar, and the indentation is off. Terrible code! Who wrote this gibberish?

The problem isn't actually the code; it's that the second programmer didn't write it. Everyone thinks their approach, naming convention, commenting style, and everything else is the best. If you weren't using the best possible techniques for writing code, you'd do things differently. Thinking you need to rewrite a piece of code just because someone else wrote it is called the *not invented here syndrome* (*NIHS*).

When you're in school, assignments tend to have a single correct answer. In contrast, in the real programming world there's *never* a single correct answer. There are always several (perhaps hundreds) of different ways to accomplish the same thing. Some ways may be better than others (searching a database by using an index is a lot faster than pulling up random records hoping to get the one you want), but there are usually lots of ways that are good enough to get the job done.

When you see a piece of strange code, you shouldn't ask yourself whether it's the correct solution or the best solution. Instead you should ask whether it satisfies the criteria that mean it should be rewritten. Just because it's not the solution you would have chosen doesn't mean it needs to be changed.

That leads to one of my favorite mottos (which I learned the hard way).

> *If it's good enough, it's good enough.*

If the code works correctly, is fast enough to satisfy your needs, and doesn't contain a swarm of bugs, leave it alone.

TASK EXECUTION

Whether you need to modify existing code for perfective, adaptive, corrective, or preventive reasons, you need to follow roughly the same steps to make useful changes without adding new bugs. At a high level, the steps you follow are roughly the same as those that go into initial development:

- Requirement gathering
- High-level design

- Low-level design
- Development
- Testing
- Deployment

For smaller maintenance tasks, you can probably abbreviate or skip some of those steps. For example, if you need to change only a single line of code to fix a bug, your requirement gathering probably just includes the statement, "Fix the bug." You also probably don't need to spend a lot of time on high-level or low-level design, and you may defer deployment until the application's next major release.

You should never skimp on testing, though.

After you make your changes, you need to perform maintenance on your maintenance. (New features you add may contain bugs or need future modification. Any bugs you fix may be fixed incorrectly and need further repair. Of course, those bug fixes may need fixes, which need more fixes, and so on until you wonder if you're trapped in the movie *Inception*. You better keep your chess piece or spinning top handy.)

Some maintenance tasks may be similar to regular development tasks, but their relative frequency often changes. In an application for internal use that does a good enough job already, the focus may be on bug fixing instead of feature improvements and enhancements. That's also often the case with first releases of consumer applications. No one is going to buy version 2.0 if the customers universally hate version 1.0 for its bugginess.

If you sell your application online and need a continuing stream of revenue to keep the creditors at bay, you may decide to focus more on creating new and improved features for a new release. (Of course, you still need to fix any bugs. See the last sentence in the preceding paragraph.)

SUMMARY

Maintenance is somewhat similar to normal development. You still need to perform roughly the same tasks (requirement gathering, high-level design, low-level design, write code, test, and deploy the results). Sometimes the focus is slightly different (you'll probably spend more time fixing bugs than writing new code) and you might skimp on some of the steps (you probably won't need an extensive high-level design to fix a one-line bug), but the basic approach is similar. Testing is particularly important so that you don't introduce too many new bugs when you fix old ones.

This chapter finishes the introduction to basic software engineering tasks. All software development projects include the basic tasks in one form or another with varying amounts of emphasis.

The chapters in the next part of the book describe different models of software development. For now, you can think of them as different ways to arrange the basic development steps. For example, iterative models use the same steps but repeated many times to try to keep the project moving toward a usable result.

EXERCISES

1. Suppose your programming team writes an application with 10,000 lines of code. During testing, you decide that the team generates roughly 20 bugs per KLOC (kilo-lines of code) for new code. (That's probably a bit on the low side for a typical development team, but I'll give you the benefit of the doubt.) During bug fixing, you discover they generate about twice that many bugs when they modify older code. How many lines of code will the team actually generate including original code, fixes, fixes to fixes, and so forth?

2. After you write the lines of code you predicted in your answer to Exercise 1, are you done with maintenance?

3. Consider your answer to Exercise 1. Suppose the number of lines of code the team members can write for different kinds of code is given in the following table.

CODE TYPE	LINES PER DAY
New code	20
Fix a bug	4
Fix a bug fix	2
Fix a fixed bug fix	1

   How many person-days will it take to write all the code?

4. If you have two team members, approximately how many months will the project described in Exercise 3 take? (Yes, I'm totally cheating here. You can look back on a project and calculate the number of lines of code per day you wrote, but you generally can't use imaginary productivity numbers to predict a project's duration.) What if you have five team members? 10? 111?

5. Draw a flowchart showing how a bug report might move through the states New, Assigned, Reproduced, Cannot Reproduce, Fixed, Tested, and Closed. Allow the bug to move into Pending if it cannot be reproduced.

   Label the connecting arrows with the tasks that lead to the new state. For example, label the arrow leading from New to Assigned "Assign." Require approval before moving a bug into the Closed state.

6. From which states could a bug move into the states Pending, Deferred, or Reopened?

7. Why might you want to move a bug from the Closed state to the Deferred state?

8. What are the total (approximate) percentages of cost spent on each of the four maintenance categories over the life of an application?

9. Place the following situations in their correct maintenance task categories (perfective, adaptive, corrective, or preventive).

   a. Change the `SaveSnapshot` method because it isn't saving files in BMP format correctly.

   b. Change the `SaveSnapshot` method so that it can also save files in PNG format.

   c. Change the main program to restore the settings in use when the previous session ended.

   d. Add comments to a 200-line method that currently has the single comment `CodeNinja was here 4/1/2003`.

   e. Write documentation to clarify a module's low-level design.

   f. Remove the `PremiumCustomer` class because it isn't used.

   g. Add icons to display on the new operating system's startup page.

   h. Rewrite a method because the program grew so large the old version wasn't fast enough.

   i. Rewrite a method because it uses an unnecessarily complicated algorithm.

   j. Rewrite a 15-line method because it contained seven known bugs (now fixed).

   k. Rewrite a 715-line method to make it smaller.

   l. Rewrite a complicated method to see how it works. Then tuck the new code away for future reference but don't replace the original code in the application.

   m. Rewrite the logging method to use cloud services to store data instead of storing data locally.

   n. Rewrite the login screen to deal with the company's new firewall.

   o. Change the Order List screen to let the user sort orders on any field.

10. In which of the following situations should you consider rewriting a piece of code (preventive maintenance)? If you can't tell from just the description, what else would you need to know before deciding?

    a. A method is 412 lines long.

    b. A method is 10 lines long but very confusing.

    c. A method uses `for`, `while`, and `for-each` loops nested 12 levels deep.

    d. At one point the code makes a series of method calls 37 levels deep.

e. A method violates the team's variable naming conventions.

f. A method draws a rectangle, line, or ellipse depending on its parameters.

g. It takes 43 seconds to log in to the application.

h. You've just discovered the fifth bug in a 40-line method.

i. Roughly once per day, the program crashes and loses any work the user hasn't already saved.

j. When the user tries to close the application, it crashes. Otherwise it seems to work just fine.

k. A coworker (definitely not you) fixed a bug in a method, but you later discovered that the bug fix caused another bug. The coworker fixed it again, but that also caused another bug.

l. A coworker fixed a bug in a method and that caused another bug. A different coworker fixed that bug, but the fix lead to yet another bug. A third coworker fixes the latest bug and (you guessed it) caused another bug.

m. Roughly once per day, the program crashes, but the user can easily restart it without losing any work.

WHAT YOU LEARNED IN THIS CHAPTER

- Maintenance is *expensive*, sometimes accounting for up to 75 percent of a project's total cost.
- One reason why maintenance is expensive is that applications often live far longer than expected.
- Maintenance tasks can be divided into four categories:
  - Perfective tasks improve, modify, or add features to a project.
  - Adaptive tasks modify an application to work with changing conditions in the environment such as a new operating system version or changes to external interfaces.
  - Corrective tasks are bug fixes.
  - Preventive tasks (refactoring) modify the code to make it easier to maintain in the future.
- Sometimes developers learn what they need to do to build a system while making the first version, so the second version is the first good one (the second system effect).
- Sometimes a system's second version is bloated and full of unnecessary bells and whistles, so the third version is the first good one (the third time's a charm effect).
- Bugs typically travel through some of the following states: New, Assigned, Reproduced, Cannot Reproduce, Pending, Fixed, Tested, Deferred, Closed, and Reopened.
- You don't always need to refactor code, even if it doesn't follow good programming guidelines. (If it ain't broke, don't fix it.)
- To perform maintenance tasks successfully, you need to follow the normal software engineering steps: requirement gathering, high-level design, low-level design, development, testing, and deployment. (Although you can often abbreviate some of those steps. You probably don't need extensive high-level design to fix a one-line bug.)

PART II
Process Models

- **CHAPTER 12:** Predictive Models
- **CHAPTER 13:** Iterative Models
- **CHAPTER 14:** RAD

12

Predictive Models

The best way to predict your future is to create it.

—Abraham Lincoln

Prediction is very difficult, especially if it's about the future.

—Niels Bohr

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Predictive models, when they are useful, and when they probably won't work
- The waterfall, waterfall with feedback, and sashimi models
- Incremental waterfall variations
- V-model and the software development life cycle

The chapters before this one describe specific tasks that you must perform for any software engineering project. In every project, you need requirements, design, testing, deployment, and maintenance. Up to this point, I've sort of implied that you'll follow those steps more or less in order one at a time. (Although I've hinted several times that steps may overlap.)

Exactly how you handle those tasks can vary depending on the scope of the project. For a large traditional project, the specification might include hundreds of pages of text, charts, diagrams, and use cases. For a small project that you're writing for your own use, the specification might be all in your head, and you might "write" it while walking the dog or singing in the shower.

The "large traditional" approach and the "for my own use" approach are two models of software development. The chapters in this part of the book describe some typical software development models in a bit more detail.

This chapter describes some predictive development models. The section "Predictive and Adaptive" later in this chapter explains what a predictive model is.

MODEL APPROACHES

Over the years, software engineers have developed a *lot* of different development models, each with its own adherents who will fight to the death to prove their model is best. I have two theories about why there are so many different models.

First, developers may just be trying to come up with the coolest names and acronyms. Names like Scrum and sashimi, and acronyms like RAD and LSD support this theory. And extreme programming sounds like an obvious prelude to energy drink product placement ads. (Imagine a programmer jumping off a cliff in a wingsuit with a laptop and a sports drink.)

My second (and I admit more likely) theory is that a huge number of people have spent an enormous amount of time (person-millennia if not person-eons) on software engineering. During that time, some very smart people noticed that there were problems with the methods they were using. Development wandered off on the wrong path, programmers didn't test their code, or the project took so long that by the time it was finished the customers' needs had changed.

Some of those smart people took the time to study their problems and came up with different approaches to try to address those problems. The resulting development models tend to emphasize one part of development or another. For example, agile methods allow a project's goals to change over time to track changing customer needs. Test-driven development forces programmers to write tests for their code. Extreme programming uses "pair programming" to ensure that every piece of code goes through a kind of code review.

There is a lot of overlap among the different models. For example, many developers noticed that customer requirements sometimes change, so there are a lot of agile methods that all try to address that issue.

Each model has its own philosophy, set of rules, and lists of important principles. Acolytes of a particular model may claim that you're not following The One True Path if you're skipping one of the model's steps. (If you don't serve sprinkle donuts on Wednesdays, then you're not really using Crumb!)

They can think that if they like, but I take a slightly less-restrictive approach. In practice what actually matters is whether you produce high-quality software reasonably close to on time and within your budget. A lot of development models use clever techniques to make development more likely to produce a good result. Sometimes, it may be useful to borrow a technique from one model and add it to another.

Still, there's some benefit to picking a model and trying to follow its rules. That at least gives you some guidelines you can follow. (It also helps with seating arrangements at dinner parties. Placing a staunch waterfall supporter next to an extreme programmer could be dangerous!)

PREREQUISITES

Before you start using a particular model, you need to be sure everyone on the team is on board. Everyone needs to agree on what the rules are and what procedures you will use to make sure the rules are followed. At first, some of the techniques the models use (such as daily 15-minute meetings or pair programming) can seem strange or downright awkward. Unless everyone commits to the model, you're going to have trouble getting the most out of it.

PREDICTIVE AND ADAPTIVE

One way to categorize development models is by the way they handle requirements. In a *predictive development model*, you predict in advance what needs to be done and then you go out and do it. You use the requirements to design the system, and you use the design as a blueprint to write the code. You test the code, have customers sign off saying it really does what the specification says it should, and then pop the champagne.

As an analogy, you build a brick wall with a predictive model. Based on past experience, you know exactly how long it will take to build a wall of the desired size. You can easily calculate how many bricks you'll need. Then you can order the bricks, schedule some masons, and get the job done.

Unfortunately, it's often hard to predict exactly what a software application needs to do and how you should build it ahead of time. Sometimes, particularly if you're working with new technology, you just don't know what the program should do. Sometimes, if you're unfamiliar with a particular programming technique, your design doesn't work. And sometimes changing business situations mean what you thought the customers needed at the beginning isn't what they need at the end.

An *adaptive development model* enables you to change the project's goals if necessary during development. Instead of picking a design at the outset and doggedly plodding toward it even when the design is no longer relevant, an adaptive model lets you periodically reevaluate and decide whether you need to change direction.

That doesn't mean you can't predict the final requirements if your Ouija board lets you. You can start with a good idea of what the final application should look like. The adaptive model just gives you chances to fine-tune the project if necessary.

For an analogy for an adaptive model, consider a typical TV detective show. It starts with a murder. (Your goal is to find the killer.) You know some of the things you need to do (interview witnesses, check cell phone records, whip off your sunglasses and squint meaningfully into the distance, say pithy things by the coffee machine), but you don't know exactly where the case will lead. You follow the first clue, and it leads to a second, which leads to a third, and so forth. Each time you find a new clue, you update the direction of the investigation.

Admittedly, the detective show is an extreme example in which you have no real idea what's going on until the last few minutes of the show when the hero tricks the villain into confessing during a tape-recorded phone conversation. In an adaptive software project, you usually know more or less what you need to build, but you can change direction if necessary.

You might think that an adaptive model is always better than a predictive one, but there are cases in which a predictive model works quite well. For example, predictive models work well when the

project is relatively small; you know exactly what you need to do, and the timescale is short enough that the requirements won't change during development.

Success and Failure Indicators

The following list describes some indicators that mean a predictive project may be successful.

- **User involvement**—If the users help define the requirements, they're more likely to be correct.
- **Clear vision**—If the customers and developers have the same clear vision about the project's goals, development will stay on track.
- **Limited size**—A small size helps the customers and team members see the whole picture all at once. Requirements won't have time to change.
- **Experienced team**—Experienced team members are less likely to design something they can't build. They also won't wander off writing code that doesn't work out. (Of course, an experienced team is helpful for any project.)
- **Realistic**—If the users ask for a telepathic user interface, a guess-what-I-want-to-do module, and the ability to predict tomorrow's lotto numbers, they're going to be disappointed.
- **Established technology**—If you stick to technology that you've used before, you'll understand how to use it correctly.

Of course, each of those success indicators can also be a failure indicator. If users aren't involved, the vision is unclear, or you're using untried technology, the project is more likely to fail.

The following list describes a few other things that might indicate a predictive project won't succeed:

- **Incomplete requirements**—In a predictive project, if the requirements don't say you should do something, it won't get done.
- **Unclear requirements**—If the customers and developers don't all have the same vision of what the application should do, you'll have trouble satisfying everyone.
- **Changing requirements**—The requirements are like railroad tracks: After they're set, changing course is difficult.
- **No resources**—Even if you have clear requirements and a perfect design, a single programmer can't write a 10,000-line program in a week.

Before you launch a predictive project, make sure these and other omens are favorable.

Advantages and Disadvantages

Adaptive models can handle the most reasonable of those problems (no model will let a single user write a 10,000-line program in a week), but there are still some advantages to predictive models. The following list summarizes some of the greatest benefits.

- **Predictability**—If everything goes according to plan (and you sort of have to make that assumption if you're going to use a predictive model), then you know exactly when different

stages will occur. In particular, you know when you'll be finished and how much effort (aka money) you'll need.

- **Stability**—Because the requirements are "set in stone" at the beginning of the project, the customers know exactly what they are getting. That's particularly important for life-critical systems such as systems that control medical devices, automobiles, and airplanes.
- **Cost-savings**—If the design is clear and correct, you won't waste time following development paths that turn out to be dead ends.
- **Detailed design**—If you design everything correctly up front, then you shouldn't need to waste time making a lot of decisions during later development. You just follow the plan. That makes programming faster (and therefore cheaper).
- **Less refactoring**—Adaptive projects tend to require refactoring. A programmer writes some code. Sometime later, the requirements change and the code needs to be modified. The result may need to be refactored to make it more efficient or to satisfy code standards. These problems don't occur as often in predictive projects.
- **Fix bugs early**—If the requirements and design are correct and complete, then you won't have to fix any bugs they would have caused later. Because it's easier to fix bugs early on, that saves you more time.
- **Better documentation**—Some of the adaptive models deemphasize documentation to the point where there is very little (if any). Predictive models require a lot of documentation before programming starts, so you at least have some documentation. That makes it easier to move new people into the project because they can read the documentation to get up to speed. (You'll still need to keep an eye on the programmers if you want comments in the code.)
- **Easy maintenance**—Because you can consider the application from a broader perspective, you can create a more elegant design that's more consistent and easier to maintain.

Even if everything works perfectly, a predictive project still has some disadvantages.

- **Inflexible**—Just because you *thought* the requirements wouldn't change, that doesn't mean they won't. If they do, accommodating them can be hard. (Basically, a predictive model is a gamble that requirements won't change too much.) That lack of flexibility also means you can't take advantage of new opportunities. If someone invents a new easier way to display sales reports, you won't be able to take advantage of it.
- **Later initial release**—Many adaptive models enable you to give the users a program as soon as it does something useful. With a predictive model, the users don't get anything until development is finished.
- **Big Design Up Front (BDUF)**—You need to define everything up front. You can't start development until you know everything you're going to need to do. You can't start development until you understand all the nooks and crannies of the application. That may mean some team members are stuffing the suggestion box or playing mahjong while others are still working on requirements.

The most "pure" predictive models assume that each stage of development is finished completely and correctly before the next stage begins. (I'll describe some models that bend that assumption later in this chapter.) In particular, you can't start cranking out code until the requirements and designs are finished. For that reason, these models are sometimes called *Big Design Up Front* (*BDUF*) models.

For example, a typical waterfall model project might spend 20–40 percent of its time on requirements and design, 30–40 percent of its time on programming, and the rest of its time on testing and deployment. If you don't spend a lot of time on the design, then the requirements and design won't be clear and correct, and you don't get the predictive model benefits.

One of the biggest ideas of BDUF projects is that the time spent on design up-front saves you time later in the project. You don't get that it you skimp on the early project's phases.

There's still a lot of argument about whether all these benefits are real. Adaptive model fans argue that they save more time and money because predictive projects often produce an unusable result. That's probably true, but to be fair you need to compare times when the models work. Obviously, a working adaptive project is better than a broken predictive one.

That's enough discussion about predictive models in general. The next chapter says more about the advantages and disadvantages of adaptive models. Meanwhile the rest of this chapter describes some particular predictive models.

WATERFALL

Waterfall is the plain vanilla of the predictive model world. It assumes that you finish each step completely and thoroughly before you move on to the next step. Figure 12-1 shows the quintessential picture of the waterfall model. Imagine water cascading from one step to the next.

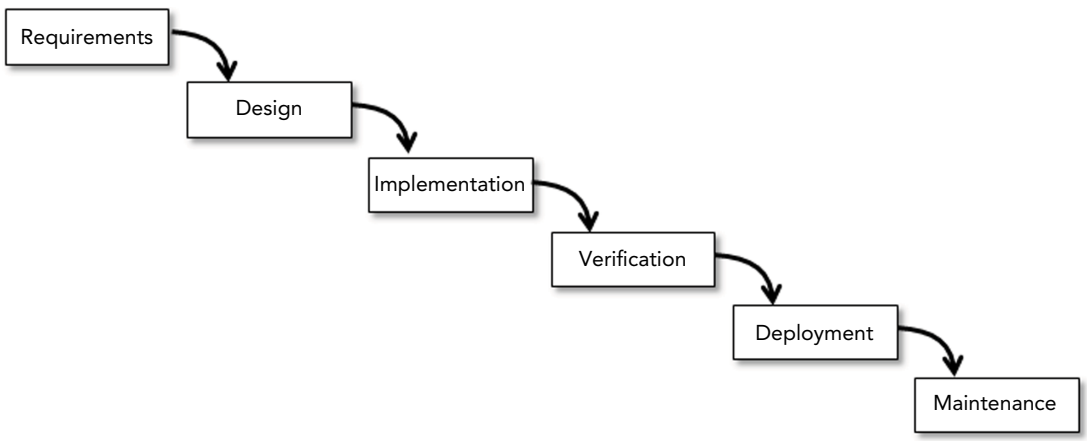


FIGURE 12-1: In the waterfall model, each step follows the one before in a strict order.

The waterfall analogy is actually fairly clever. The water represents information and the stages act like buckets. When one bucket is full (you've finished filling it up with information), the information floods from that bucket into the next so that it can direct the following task.

The waterfall model can work reasonably well if all the following assumptions are satisfied:

- The requirements are precisely known in advance.
- The requirements include no unresolved high-risk items.
- The requirements won't change much during development.
- The team has previous experience with similar projects so that they know what's involved in building the application.
- There's enough time to do everything sequentially.

You can add additional steps or split steps to give more detail if you like. For example, you could break Verification into Testing and Validation, or you could break Design into High-Level Design and Low-Level Design.

You can also elaborate on a step. For example, you could break Design into User Interface Design, High-Level Design, Low-Level Design, and possibly other pieces.

Few developers use the pure waterfall model these days, but some of its variations are quite useful.

WATERFALL WITH FEEDBACK

If you assume that you can carry out each step perfectly (and nothing changes during development), then the waterfall model leads to inevitable success. Unfortunately, it's hard to perform every step of development perfectly. Because the model doesn't allow you to go back to earlier steps, if you fail at any step, all the later steps will be wrong. For example, if the requirements are wrong, the development team plods along anyway, headed in the wrong direction like a cabbie trying to navigate in Singapore with a street map of London.

The *waterfall with feedback* variation enables you to move backward from one step to the previous step. (Like a salmon leaping up a fish ladder.) Figure 12-2 shows this model.

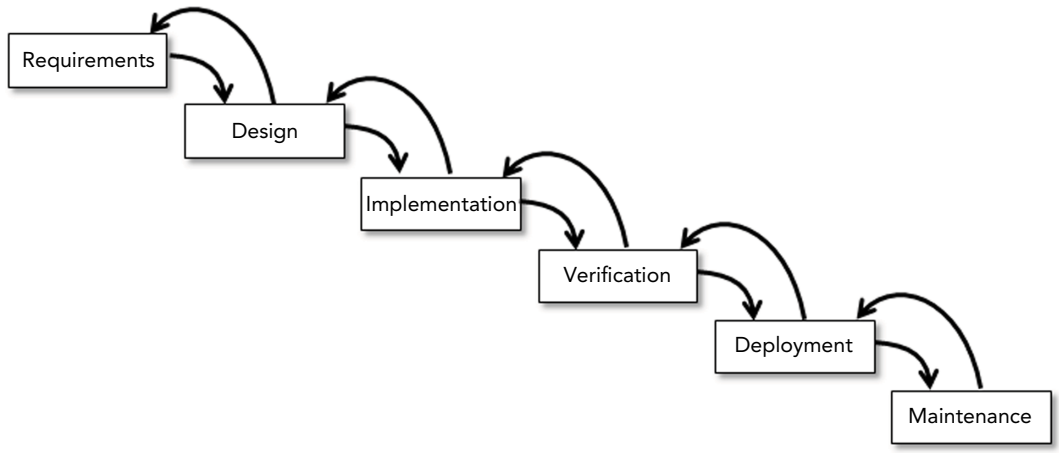


FIGURE 12-2: In the waterfall with feedback model, you can go back to the previous step.

Now if you're working on design and you discover that there was a problem in the requirements, you can briefly go back to the requirements and fix them.

The farther you have to go back up the cascade, the harder it is. For example, if you're working on implementation and discover a problem in the requirements, it's hard to skip back up two steps to fix the problem.

It's also less meaningful to move back up the cascade for the later steps. For example, if you find a problem during maintenance, then you should probably treat it as a maintenance task instead of moving back into the deployment stage.

Because moving back up the cascade is hard, you still need to be good at making predictions. You can fix some mistakes, but the goal is still to complete each step completely and effectively before moving on.

SASHIMI

Sashimi (also called *sashimi waterfall* and *waterfall with overlapping phases*) is similar to the waterfall model except the steps are allowed to overlap. (Much as the thin slices of fish overlap in the Japanese dish sashimi.) Figure 12-3 shows the stages of a sashimi project.

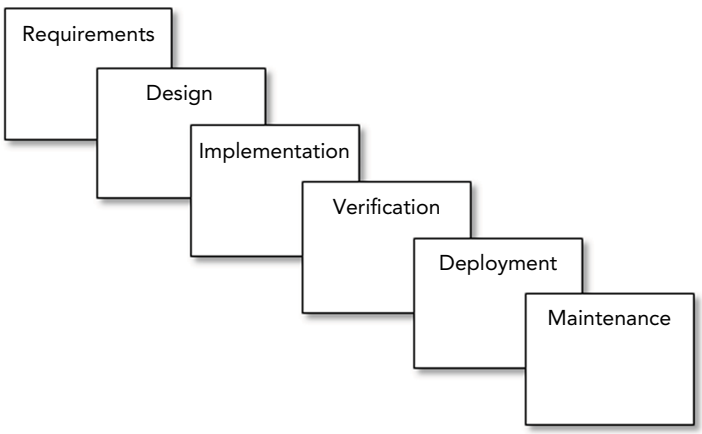


FIGURE 12-3: In the sashimi model, development phases overlap.

In a project's first phase, some requirements will be defined while you're still working on others. At that point, some of the team members can start designing the defined features while others continue working on the remaining requirements.

A bit later, the design for some parts of the application will be more or less finished but the design for other parts of the system won't be. At that point, some developers can start writing code for the designed parts of the system while others continue working on the rest of the design tasks, and possibly even on remaining requirements.

Similarly other parts of the development process might overlap, although there are probably limits. For example, you may want to delay deployment until the application is tested and verified.

You can even allow greater overlap between project phases. For example, you could have people working on requirements, design, implementation, and testing all at the same time.

There are several advantages to allowing stages to overlap. First, it means people with different skills can focus on their specialties without waiting for others. For example, a database designer can start laying out tables and indexes even if the user interface requirements aren't finished. This kind of overlap keeps the team members more productive.

A second advantage is that it lets you perform a *spike* or *deep dive* into a particular topic to learn more about it. For example, suppose you're working on requirements and the customers ask if you can incorporate an EEG headset into the program to let you control the application with your thoughts. You haven't done that before, so you assign some team members to give it a try. They quickly design and implement a prototype to see what would be involved and to let the users see what it would look like. At that point, you have people working on requirements, design, and implementation all at the same time. Based on what you learn from the prototype, you can refine the requirements.

A third advantage to overlapping phases is it lets later phases modify earlier phases. If you discover during design that the requirements are impossible or need alterations, you can make the necessary changes.

To avoid unnecessary work, you may want to encourage team members not to get too far ahead (unless they're performing an exploratory spike). That way if you need to change the requirements, you won't need to discard or rewrite a lot of code.

INCREMENTAL WATERFALL

The *incremental waterfall* model (also called the *multi-waterfall* model) uses a series of separate waterfall cascades. Each cascade ends with the delivery of a usable application called an *increment*. Each increment includes more features than the previous one, so you're building the final application incrementally. (Hence the name "incremental waterfall.")

Figure 12-4 shows the stages in an incremental waterfall project.

During each increment, you'll get a better understanding of what the final application should look like. You'll learn what did and didn't work well in the previous increment. The users will also probably give you a long laundry list of new features they want added. All of that helps you prepare for the next increment.

Notice in Figure 12-4 that the different increments overlap in the time dimension. If you understand what you need to do in the next iteration, you don't need to wait until the current iteration is completely finished before you start writing new requirements documents. Of course, if you start the next increment before the users have had a chance to work with the current one, you won't get as much feedback from them.

You can use any of the waterfall variations for each of the increments. For example, you could use a series of waterfalls with feedback or a sashimi series, as shown in Figure 12-5.

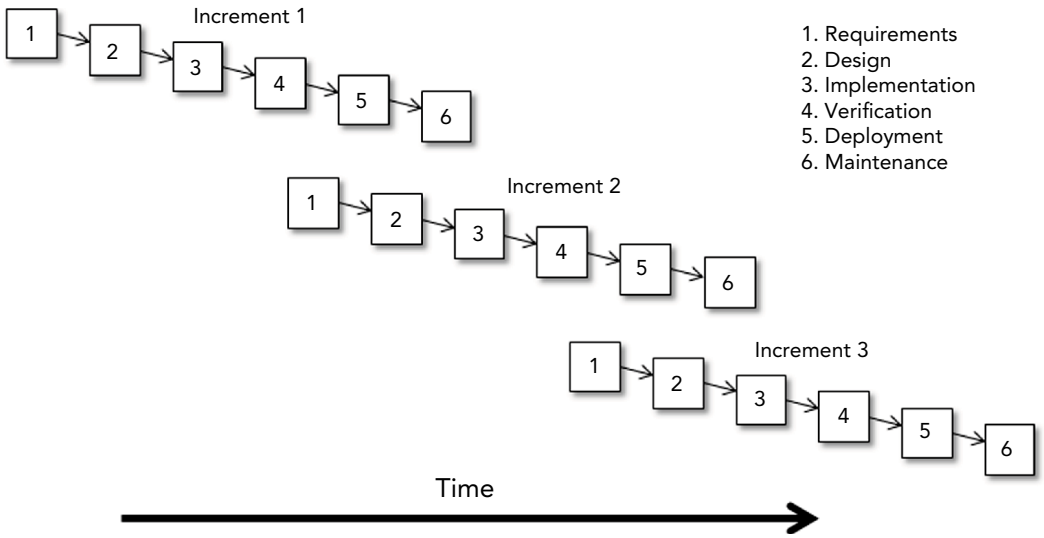


FIGURE 12-4: In the incremental waterfall model, a series of waterfall cascades provide an increasing level of functionality.

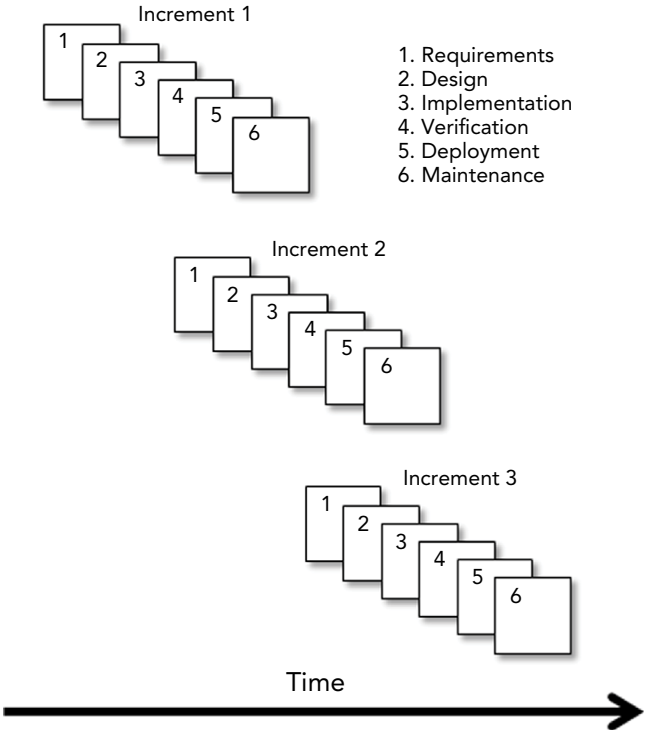


FIGURE 12-5: This incremental waterfall project uses a series of sashimi waterfalls.

Figure 12-4 and Figure 12-5 show projects that use three increments, but you can use as many as you like. In fact, for an application with a long useful life, you could use an open-ended series of increments. You would just keep adding new increments whenever you wanted to make a new version of the application to add new features.

REFACTORING REQUIRED

Sometimes, programs that grow incrementally become strange creatures with illogical interfaces, inconsistent mechanisms, and code as strange as anything H.P. Lovecraft could have written (if he'd been a programmer). I've worked with programs that had been used and modified for decades, and it was nearly impossible to make any significant changes without breaking something.

At some point, you may need to slip in a refactoring increment to clean house. That increment might add little or no new functionality, but it will let you move forward with future increments more efficiently.

The incremental waterfall model is actually somewhat adaptive because it lets you reevaluate your direction at the start of each increment, but I've included it in this chapter for three reasons. First, this is a waterfall variation, so I want to put it with the other waterfall models.

Second, it's not all *that* adaptive. You can change direction when you start a new increment, but within each increment the model runs predictively. You can make only small changes allowed by whichever particular waterfall model you use for the increments (waterfall with feedback or sashimi).

The fact that you're building on a previous increment also gives the project some inertia that limits the amount of change you can add to the next release. For example, you can add, remove, and tweak features in a new increment, but you probably shouldn't radically change the user interface. That would be more like a completely new project rather than an incremental change to the ongoing series.

Finally, increments tend to run over a longer scale than the stages in most adaptive models. For example, a long-running project might use a new increment every year or two. That gives the users a nice, steady, predictable release schedule. In contrast, some adaptive models produce new builds of an application every month or even every week. You probably wouldn't release all of those builds to the users, but the pace is definitely more frenetic. The incremental waterfall model is somewhat adaptive, but usually over long timescales.

V-MODEL

V-model is basically a waterfall that's been bent into a V shape, as shown in Figure 12-6.

The tasks on the left side of the V break the application down from its highest conceptual level into more and more detailed tasks. This process of breaking the application down into pieces that you can implement is called *decomposition*.

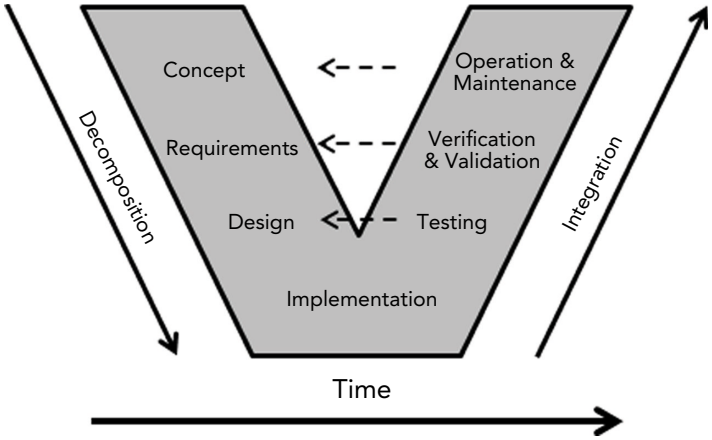


FIGURE 12-6: In V-model, each of the tasks on the left corresponds to a task on the right.

The tasks on the right side of the V consider the finished application at greater and greater levels of abstraction. At the lowest level, testing verifies that the code works. At the next level, verification confirms that the application satisfies the requirements, and validation confirms that the application meets the customers' needs. This process of working back up to the conceptual top of the application is called *integration*.

Each of the tasks on the left corresponds to a task on the right with a similar level of abstraction. At the highest level, the initial concept corresponds to operation and maintenance. At the next level, the requirements correspond quite directly to verification and validation. Testing confirms that the design worked. (Like the cheese, implementation stands alone, so it doesn't correspond to another task.)

SYSTEMS DEVELOPMENT LIFE CYCLE

The *software development life cycle* (*SDLC*), which is also called the *application development life cycle*, is exactly what it sounds like. It covers all the tasks that go into a software engineering project from start to finish: requirements, design, implementation, and so forth. This is similar to the waterfall model (actually the waterfall model is one version of SDLC), but I want to present two new ideas here.

First, check out Figure 12-7. This figure emphasizes that the end of one project can feed directly into the next project in a never-ending circle of life. (Cue *The Lion King* music.) The incremental waterfall model is basically just a series of SDLCs flattened out and possibly with some overlap, so one project starts before the previous one is completely finished. (Actually, the picture is a lot like a complete metamorphic life-cycle diagram. The application goes through the stages: egg, larva, pupa, and adult.)

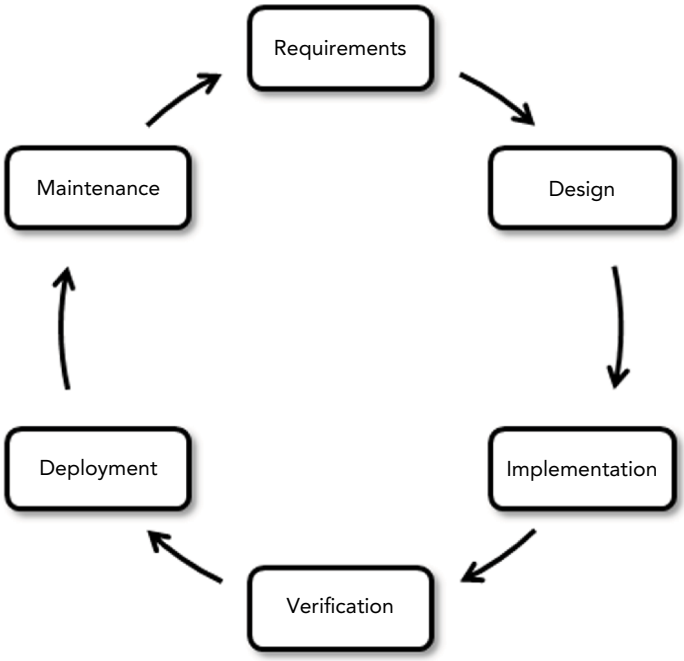


FIGURE 12-7: In the software development life cycle, project phases feed into each other in a potentially infinite loop.

The second new idea is that you can break down the basic steps in a lot more detail if you like. (You should for bigger projects, at least.) The following list describes tasks that are commonly represented as part of the SDLC. Some of them are even broken down into subtasks. (I would have included them all in Figure 12-7, but I would have had to use a 2-point font and you would have needed a microscope to read everything.)

- **Initiation**—An initiator (often a customer, executive champion, or software manager looking for something to charge on his time card) comes up with the initial idea.
- **Concept development**—The initiator, usually with help from others who might be interested in the project, explores the concept to see if it's worthwhile and to evaluate possible alternatives. This step includes an initial project definition, a feasibility analysis, a cost-benefit analysis, and a risk analysis.

  You can make "go/no go" decisions at any step in the project, but the decision you make at this point is a big one. After concept development, you should have enough information to make an informed decision. After this point, it gets harder and more expensive to cancel the project as it starts to staff up and gain momentum. (Sometimes, careers are tied to the success of big projects, and anyone in that position will tenaciously resist any attempt to end the project after it gets rolling. They'll cling desperately to the sinking project like a barnacle stuck to the Titanic.)

- **Preliminary planning**—A project manager (PM) and technical lead are assigned to the project, and they start planning. If it's a big project, the project might be broken into teams and team leads would be assigned. All these leaders make preliminary plans to estimate necessary resources such as staffing, computers, network, development tools, and microwave popcorn.

  This is when the leaders gather the tools they'll need to track and manage the project, tools such as those described in Chapter 2, "Before the Beginning," and Chapter 3, "Project Management," for document tracking, building PERT and Gantt charts, and tracking tasks. The technical managers also decide on the development model, programming language, development environment, coding tools, and code conventions (if those things aren't already specified by the company).

  If it hasn't already, the team starts gathering metrics so the project manager can keep an eye on the project to make sure it remains headed in the right direction.

- **Requirements analysis**—The team studies the user's needs and creates requirement documents. Those may include text, pictures, use cases, prototypes, and long-winded descriptions of business rules. It may also include UML diagrams showing application structure, user behavior, and anything else that helps the users understand what the team will be building. (See Chapter 4, "Requirement Gathering.")

  The team also builds technical requirements that let the developers know what they need to build.

- **High-level design**—The team creates high-level designs that specify major subsystems, data flow, database needs, and the rest of the application's high-level structure. (See Chapter 5, "High-Level Design.")

- **Low-level design**—The team creates low-level designs that explain how to build the application's pieces. The designs provide enough detail that a second-shelf programmer would have a chance of building the right thing. (See Chapter 6, "Low-Level Design.")

- **Development**—The team writes the program code. They follow good programming practices. They perform unit tests, regression tests, and system tests. They fix the bugs that inevitably appear and handle any change requests that are approved by the change committee. The team also prepares user documentation and training materials. (See Chapter 7, "Development," and Chapter 8, "Testing.")

- **Acceptance testing**—The customers finally get a chance to take the application for a test drive in its (almost) final form. Traditionally, the application breaks at this point when the users do something completely reasonable that the developers never thought about. After a few bug fixes and perhaps a small change or two, the customers agree that the application satisfies the requirements. (Acceptance testing can be in the staging environment that will be used to prepare for rollout in the next phase.)

- **Deployment**—The team rolls out the application. (See Chapter 9, "Deployment.")

- **Maintenance**—The application allows the users to do their jobs better than ever before, and everyone lives happily ever after (aside from the inescapable bug fixes and change requests). (See Chapter 11, "Maintenance.")

The team continues to track the application's usefulness throughout its lifetime to determine whether it needs repair, enhancement, or replacement with a new version or with something completely different.

Keep in mind that even an application that's working perfectly needs periodic maintenance and upgrades. Every two years or so a new version of the operating system will appear, and many companies will require that all applications be upgraded to the new version. Also roughly two years after you install the application, computer power will have doubled. Eventually, the application will seem so slow compared to the users' home computers, laptops, tablets, phones, phablets, and other gizmos, they'll want new hardware. And don't forget new monitors. Eventually, everyone will want 32" Ultra HD 4 K monitors (or possibly 8 K or 16 K, although I've seen the 4 K televisions, and they may have a higher resolution than real life). You may think users can live with their existing hardware, but have you noticed how few of them are still using 1980s era CRTs, even though they were as indestructible as battleships? When Ultra HD 4 K monitors become reasonably common, everyone is going to want one.

Eventually, the maintenance team needs to figure out how to upgrade the application to the latest hardware and operating system, and how to dispose of the old hardware. (If the hardware isn't too out of date, see if any of your neighborhood schools want a donation.)

CERTAIN DESTRUCTION

Some companies have security policies that indicate how to dispose of old hardware, so any data it contains can't be scraped off by cyber criminals. I knew of one company working on high-security government projects that had a special policy for decommissioning disk drives. Erasing the disk or passing it through a strong magnetic field wasn't good enough. A field technician had to come to the site, take the drive apart, and manually remove the platters so they could be physically shredded. The process cost about $5,000 per drive. (Then I think the pieces were sprinkled with holy water and buried under a crossroad.)

- **Review**—The team uses metrics (which hopefully they remembered to gather throughout the project) to assess the project and decide whether the development process can be improved in the future. (See Chapter 10, "Metrics.")
- **Disposal**—Eventually, the application's usefulness comes to an end. (Or perhaps not, as the Y2K problem proved.) During this stage, the cleanup crew plans the application's removal and possibly its replacement by something else. They need to decide what data needs to be archived and how to protect it so that a hacker can't break in and steal sensitive data.

Like the waterfall model and other purely predictive models, the unadulterated SDLC probably isn't used by many developers these days. It's still useful occasionally, basically in the same situations in which the waterfall model and its variants are useful. It's also an important term to know during those late-night programming jam sessions at conferences.

SUMMARY

Predictive models are useful primarily because they give a lot of structure to a project. For many customers, it's nice to have a fully developed plan that you can follow throughout the project's lifetime. A predictive project makes scheduling simpler, includes documentation that makes it easier to add new people to the project, and can cost less (if everything goes according to plan).

Predictive models have some advantages, but they also have some big disadvantages. Probably the biggest problem with predictive models is that they don't handle change well. In today's constantly changing business world, projects often have fuzzy, incomplete, or changing requirements. Even the best predictive project can fail if it results in a powerful application that doesn't fit the customers' needs when it's finished.

The next chapter describes adaptive development models that handle those kinds of uncertainty better than predictive models do. They allow you to reassess the customers' needs and the project's status to change direction if necessary.

EXERCISES

1. Indicate which of the following tasks would be better handled predictively or adaptively and briefly say why.
   a. Building a pedestrian bridge over a river
   b. Following a series of clues in a scavenger hunt
   c. Making a scavenger hunt for others to follow
   d. Planning a picnic
   e. Planning a picnic in Seattle
   f. Planning a major motion picture
   g. Teaching an introductory programming course
   h. Finding a specific restaurant while visiting an unfamiliar city before 1990
   i. Finding a specific restaurant while visiting an unfamiliar city with a GPS
   j. Finding a specific restaurant while visiting an unfamiliar city in a few years when cars drive themselves and are plugged into a smart street network

2. Briefly explain why each of the following projects might be risky predictive projects.
   a. The Federal Aviation Administration (FAA) wants you to rewrite the U.S. air traffic control system.
   b. A small archery supply store wants you to write some sales software, but the two partners can't agree on exactly what it should do.

c. Your customer wants you and your team of five intrepid developers to write a word processing application as powerful as Microsoft Word in the next three months. (At double your normal rates!)

d. A real estate developer wants to build an application that helps design large housing developments. (Your team just finished building a vacation costing application.)

e. Your customer dumped a 10-page software specification on your desk and then left on a 3-week vacation.

f. Your customer wants to build a 3-D printing application that lets you make buildings out of concrete. (Really, search the Internet for "3-D printer castle Andrey Rudenko" to see what one bored contractor did with this idea in his spare time.)

3. Under what circumstances would a predictive model cost less in time and effort than an adaptive model? Under what circumstances would it cost more?

4. How does waterfall with feedback differ from sashimi?

5. How many increments could you use in an incremental waterfall project?

6. Explain how each of the V-model decomposition tasks correspond to the integration tasks. (For example, why does Requirements correspond to Verification and Validation?)

WHAT YOU LEARNED IN THIS CHAPTER

- Predictive development models:
  - Anticipate the work to be done, schedule it, and then do it.
  - Work well for short projects where you know in advance everything that you'll need to do.
  - Work poorly if requirements are uncertain or change during the project.
  - Can be cheaper than adaptive models if everything goes according to plan but can be much more expensive if you need to make extensive changes.
- Adaptive models:
  - Give you opportunities to change direction.
  - Work well with changing or uncertain requirements.
- In a waterfall model, one phase "pours into" the next. The phases are done in order one after another.
- In a waterfall with feedback, one phase can feed back into the previous phase to make corrections.
- In the sashimi model, multiple phases can overlap. Some developers can be working on one phase while others move ahead to other phases.
- The incremental waterfall model uses a series of waterfalls. Each waterfall produces an *increment*, a new version of the application that is incrementally improved over the previous version.
- V-model shows the correspondence between *integration* tasks and *decomposition* tasks.
- The software development life cycle includes all the tasks that go into a predictive development model.

13

Iterative Models

When to use iterative development? You should use iterative development only on projects that you want to succeed.

—Martin Fowler

Control is for beginners.

—Deborah Mills-Scofield

Iteration is truly the mother of invention.

—Mary Brodie

WHAT YOU WILL LEARN IN THIS CHAPTER:

- Differences between predictive, iterative, incremental, and agile approaches
- Benefits of prototyping and kinds of prototypes
- Spiral, Unified Process (plus variations), and Cleanroom development models

Predictive software development has some big advantages. It's predictable, encourages a lot of up-front design (hence the nickname big design up front or BDUF), and gives a certain inevitability to a project.

Unfortunately, that inevitably can lead to either success or failure. If the design is correct and everything stays on track, the project is like a luxury train coasting majestically into Grand Central Station. However, if something goes wrong, the project is more like a train engulfed in flames and speeding toward a dynamited bridge.

In recent years, software organizations have spent a lot of effort developing techniques that help keep projects headed in the right direction. Lumping all those models and techniques together would make for a bloated chapter, so I decided to split them up a bit.

This chapter discusses one of the techniques that is easiest to apply to any other development model: iteration. In an iterative model, you build the final application incrementally. You start with a minimally working program and then add pieces to it, making it better and better, until you decide the application is as good as it can be (or at least good enough).

I actually snuck a little iteration into the preceding chapter with the incremental waterfall model. This chapter focuses on other iterative variations. The next chapter introduces a bunch of other techniques and approaches that can help keep software engineering efforts on track.

ITERATIVE VERSUS PREDICTIVE

The problem with predictive models is that they are ill-suited to handle unexpected change. They can deal with small changes (such as customers deciding they want combo boxes instead of list boxes on their forms), but they don't handle big changes well (such as customers deciding they want 20 extra reports that are all viewable on a desktop computer, tablet, or smartphone).

Predictive projects spend a lot of effort at the beginning figuring out exactly what they will do. After you gather requirements and commit to a schedule, it's hard to change course. In theory you could stop the project at any point and head in a new direction. In practice that rarely happens. Changing direction in a big way would essentially mean starting over. You would have to go through the requirements and design phases again. You would also have to abandon all the work you did in those phases the first time around. If the changes are big enough, this is practically the same as declaring the project a failure (no one wants to do that) and starting a new one.

Even if you manage to point the project in a new direction, there's no guarantee that you won't need to do it all over again. Actually, because your customers have already shown that they're willing to put you through all that pain and inconvenience, further changes seem if anything more likely.

One of the biggest reasons why those changes are so painful is the size of the commitment you've made. If you're three years into a five-year schedule, you've already invested a lot of effort in the project and you have a lot to lose. But what if you were only three months into a five-month plan? Scrapping the work-to-date and starting over would still be annoying, but it would be much less painful. (You might even get to keep your job.)

Predictive models also don't handle fuzzy requirements well. Unless you nail down the requirements precisely at the beginning of the project, it's impossible to create a solid schedule. How can you plan to build something with unknown requirements? (Imagine what would happen if you went to a real estate developer and said, "We want to build a new shopping mall. We don't know exactly where it will be or what it will look like, but start building it and we'll work out the details later.")

Iterative models address those problems by building the application incrementally. They start by building the smallest program that is reasonably useful. Then they use a series of *increments* to add more features to the program until it's finished (if it is ever finished).

Because each increment has a relatively small duration (compared to a predictive project), you're committed to a smaller amount of work. If you decide that the project is heading in the wrong direction, you need to stop only the most recent increment and start a new one instead of canceling the whole project and starting over.

Better still, because you can reorient the project before each new increment, you're less likely to need to cancel anything.

You may have trouble foreseeing the direction a predictive project should take four years from now. It's much easier to guess where you should be headed four months from now. Even if you decide that you need to adjust course, you can probably finish the current iteration and make the adjustments in the next one.

Iterative models also handle fuzzy requirements reasonably well. If you're unsure of some of the application's requirements, you can start building the parts you do understand and figure out the rest later. Sometimes, you'll learn things building the first part of the system that will make the rest of the requirements clear. Other times the requirements clarify themselves over time.

The preceding chapter described an iterative waterfall model that uses a series of waterfall-style projects to incrementally refine an application. Figure 13-1 shows the stages in an iterative waterfall project.

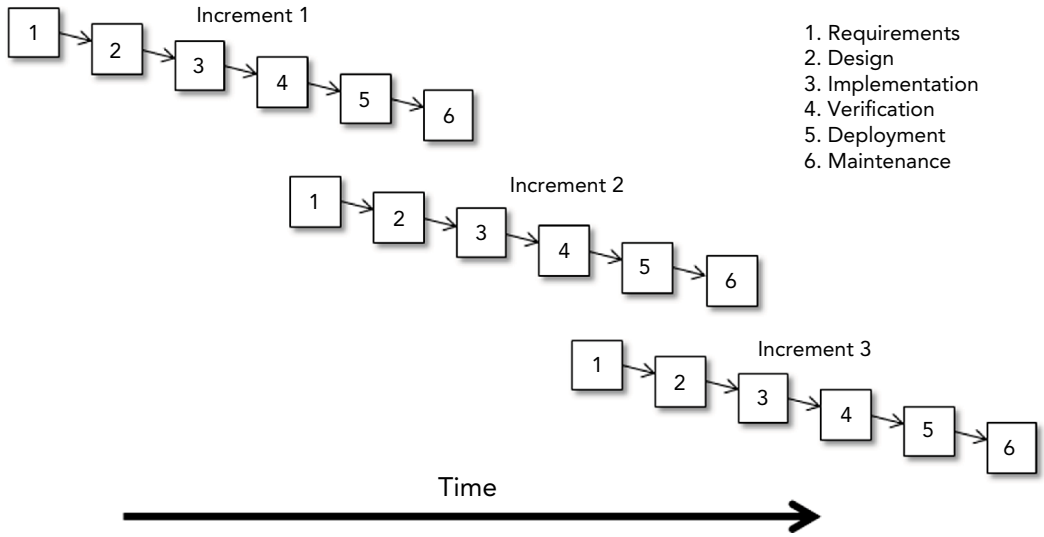


FIGURE 13-1: Iterative models use a series of development efforts to incrementally refine an application.

Other models also use iterative approaches. Many of the models described in the next chapter use iterative techniques to help stay on the right track.

You can even use iterative methods for just one part of a project. For example, you can use iterative prototyping to refine a project's requirements. After that, you could use waterfall, sashimi, or some other model to finish development.

The following sections describe some common iterative techniques that you can use to improve a project's chance of success.

ITERATIVE VERSUS INCREMENTAL

Normally, you think of an iterative project as running through several cycles, each of which provides an incremental improvement over the preceding version. Technically, however, that's not necessarily the case, so an iterative project might not be incremental.

For example, suppose in version 1 of a project you produce a usable application, but its code doesn't follow good programming standards. In version 2 you rewrite the code to make the project more maintainable. Version 2 doesn't add any new features to the application, so in some sense you might not think of it as an incremental improvement over version 1. The process is iterative but not incremental.

Karl Scotland provides an interesting perspective on this issue at `availagility.co.uk/2009/12/22/fidelity-the-lost-dimension-of-the-iron-triangle`. He argues that the difference between iterative and incremental development is clear if you consider the fidelity of a project's features. By *fidelity* he means the completeness of the feature. For example, a low-fidelity real-estate search screen might let you search for houses by price. A high-fidelity version would let you search by price, square feet, number of bedrooms, number of bathrooms, availability of high-speed Internet, and distance to the nearest ice cream store. (Karl explicitly avoids the term "quality" for this because he doesn't want to get into an argument about releasing low-quality code. All the code is assumed to be high quality. It's just some versions of a feature might do more than others.)

Now suppose you're working on a project that provides three features. Here's how you might use fidelity to describe different development approaches:

- **Predictive**—Provides all three features at the same time with full fidelity.
- **Iterative**—Initially provides all three features at a low (but usable) fidelity. Later iterations provide higher and higher fidelity until all the features are provided with full fidelity.
- **Incremental**—Initially provides the fewest possible features for a usable application, but all the features present are provided with full fidelity. Later versions add more features, always at full fidelity.
- **Agile**—Initially provides the fewest possible features at low fidelity. Later versions improve the fidelity of existing features and add new features. Eventually all the features are provided at full fidelity. (The next chapter says more about agile development models.)

Figure 13-2 shows a representation of these approaches. The rectangles represent the application's features. In the predictive model, the users don't receive any program until the application is completely finished. The iterative model starts with low-fidelity versions of every feature and then improves them over time. The incremental model starts with nothing and then adds new features with full fidelity. Finally, the agile model starts with some features of low fidelity and over time improves fidelity and adds more features.

All four of those approaches end with an application that includes all the features at full fidelity. It's the routes they take to get to their final solutions that differ.

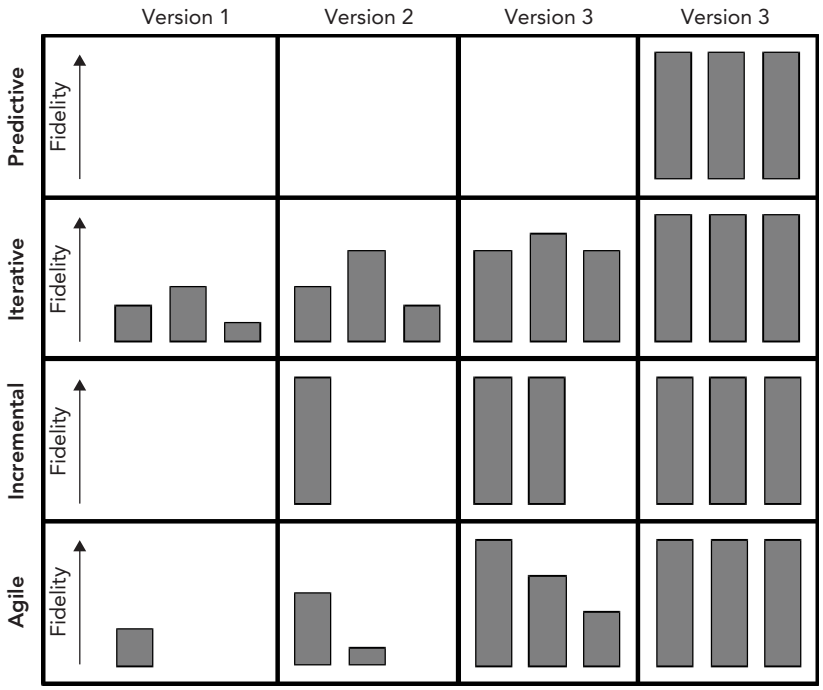


FIGURE 13-2: Different development approaches add features and increase fidelity in different ways.

The difference is somewhat pedantic, but it's probably worth knowing just so you're not confused when a senior executive starts throwing around terms he doesn't really understand.

PROTOTYPES

The section "Prototypes" in Chapter 4 briefly described prototypes. This section provides some additional details and focuses on how prototypes can be useful in iterative development.

A *prototype* is a simplified model that demonstrates some behavior that you want to study. Typically, a software prototype is a program that mimics part of the application you want to build.

Two important facts about prototypes are that they don't need to work the same way the final application will, and they don't need to implement all the features of the final application. They just give you a glimpse of a piece of the final application.

For example, suppose you're building a product ordering system. You enter some parameters such as a date range or a customer ID number, and click a List button to make the system display a list of matching orders. You can then double-click to view an order's details. From the order detail, you can click links to jump to detailed information about the items in the order or to see the customer's contact information.

During the requirements gathering phase, you might build a prototype to let the customers see what the finished application will look like. When you click the List button, the prototype displays a

predefined list of orders. When you double-click an order, the prototype doesn't display information for that order. Instead it displays information about a preselected order. Finally, if you click a link on the order, you can see information about the preselected customer.

This prototype doesn't work exactly the same way the finished application will work. If it did, it would be the actual application and not just a prototype. However, it lets the customers see what the application will look like. It lets them click some buttons and links so that they can try out the program's method for interacting with users.

After the customers experiment with the prototype, they can give you feedback to help refine the requirements. For example, when they see the order list, they may think of other fields they want to display. After they try double-clicking to open an order's detail information, they may decide they would rather check boxes next to one or more orders and then click a Detail button to open detail pages for all the selected orders. When they view a customer's information, they may decide they want a quick way to see that customer's order history.

Although software prototypes are often programs, you can make other kind of prototypes using less sophisticated techniques. For example, you might mock up some screens using pieces of paper to show customers what the application will look like as they navigate through the system. (A slightly more high-tech version might use a PowerPoint slide show instead of pieces of paper.) If an application includes special hardware, such as a fingerprint scanner, you could tape a cardboard version onto a laptop to show customers what it will look like.

Sometimes, prototypes don't even have a user interface. For example, suppose you're writing a billing application that will process customer charges to generate invoices. You could write a prototype that fetches a particular customer's data, calculates outstanding charges, and prints an invoice. That would let programmers study how the data processing code works before they try to do the same thing for the entire customer database.

HORIZONTAL AND VERTICAL PROTOTYPES

A *horizontal prototype* is one that demonstrates a lot of the application's features but with little depth. For example, the prototype described earlier that lets a user pretend to navigate through customer orders is a horizontal prototype. Horizontal prototypes are often user interface prototypes that let customers see what the finished application will look like.

In contrast, a *vertical prototype* is one that has little breadth but great depth. The example described earlier that has no user interface and generates an invoice for a single customer is a vertical prototype.

The following sections explain some additional details about prototypes.

Types of Prototypes

There are several ways you can use a prototype. Chapter 4 mentioned two important types of prototypes: throwaway prototypes and evolutionary prototypes. In a throwaway prototype, you use

the prototype to study some aspect of the system and then you throw it away and write code from scratch.

In an evolutionary prototype, the prototype demonstrates some of the application's features. As the project progresses, you refine those features and add new ones until the prototype morphs into the finished application.

A third kind of prototyping is incremental prototyping. In *incremental prototyping*, you build a collection of prototypes of that separately demonstrate the finished application's features. You then combine the prototypes (or at least their code) to build the finished application. As is the case with an evolutionary prototype, the prototype code becomes part of the final application, so you need to use good programming techniques for all the prototypes. That means coding is slower than it is with a throwaway prototype. Because the pieces of the system are built from separate prototypes, it may be easier for different programmers or teams to work on the pieces at the same time. That may let you finish the combined application sooner—although, you do need to allow time to integrate the pieces.

Pros and Cons

The following list summarizes prototyping's main benefits:

- **Improved requirements**—Prototypes allow customers to see what the finished application will look like. That lets them provide feedback to modify the requirements early in the project. Often customers can spot problems and request changes earlier so the finished result is more useful to users.
- **Common vision**—Prototypes let the customers and developers see the same preview of the finished application, so they are more likely to have a common vision of what the application should do and what it should look like.
- **Better design**—Prototypes (particularly vertical prototypes) let the developers quickly explore specific pieces of the application to learn what they involve. Prototypes also let developers test different approaches to see which one is best. The developers can use what they learn from the prototypes to improve the design and make the final code more elegant and robust.

Programming, like the rest of life, follows the rule of TANSTAAFL: There ain't no such thing as a free lunch. Prototyping comes with some disadvantages to go with its advantages:

- **Narrowing vision**—People tend to focus on a prototype's specific approach rather than on the problem it addresses. When you show customers (and developers) a prototype, they'll be less likely to think about other solutions that might do a better job.

  To avoid this problem, either don't build a prototype until you've considered possible alternatives, or build several prototypes to choose from.
- **Customer impatience**—A good prototype can make customers think that the finished application is just around the corner. They'll say things like, "The prototype looks good. Can't you just add a little error handling and a few extra features and call it done?"

  To avoid this, make sure customers realize that the prototype isn't anywhere close to the finished application. It's like a realistically painted cruise ship made out of papier-mâché. It may look ready to set sail, but you wouldn't want to put it in the ocean and climb aboard.

- **Schedule pressure**—This goes with the preceding issue. If customers see a prototype that they think is mostly done, they may not understand that you need another year to finish and may pressure you to shorten the schedule.

  To avoid this problem, the project manager, executive champion, and other management types need to manage customer expectations so that they know what will be ready and when.

- **Raised expectations**—Sometimes, a prototype may demonstrate features that won't be included in the application. For example, those features might turn out to be too hard. Sometimes, features are included to assess their value to users, and the features are dropped if they don't have enough benefit. Other times a feature may be present just to show a possible future direction. In those cases, users may be disappointed when their favorite features are missing from the finished application. This can be a particular problem with projects that release a series of versions of the application and someone's pet feature isn't included in release 1.0.

  To avoid this, make sure customers understand which features will be included and when.

- **Attachment to code**—Sometimes, developers become attached to the prototype's code. That can make them follow the methods used by that code (or even reuse the code wholesale) even if a better design exists. This can be a particularly bad problem with throwaway prototypes where the initial code might have low quality.

  To avoid this, make sure developers understand that the code should change if a better design is available. Hold design reviews and code reviews to make sure no one is stuck following a prototype approach if there's a better alternative.

- **Never-ending prototypes**—Throwaway prototypes are supposed to be built relatively quickly to provide fast feedback. Sometimes, developers spend far too much time refining a prototype to make it look better and include more features that aren't actually necessary.

  To avoid this, make sure the prototype doesn't include any more than is necessary to give customers a feel for how the program will work. Don't waste time making the prototype more flexible than necessary. Do the least amount of work you can get away with. For example, a prototype rarely needs to use a database. Usually you can just hard-wire data into the program to get a feel for how the final program will look. If customers decide they need to see more, they can say so.

Prototypes are great for helping you decide on the direction you should take. They can help define the user interface and other features, make sure customers and developers are on the same page, and let developers explore different solutions.

SPIRAL

The spiral model (not to be confused with a "death spiral" or "circling the drain") was first described in 1986 by Barry Boehm. He describes it as a "process model generator." It uses a risk-driven approach to help project teams decide on what development approach to take for various parts of the project. For example, if you don't understand all the requirements, then you might use an iterative approach for developing them.

The general spiral approach shown in Figure 13-3 consists of four basic phases.

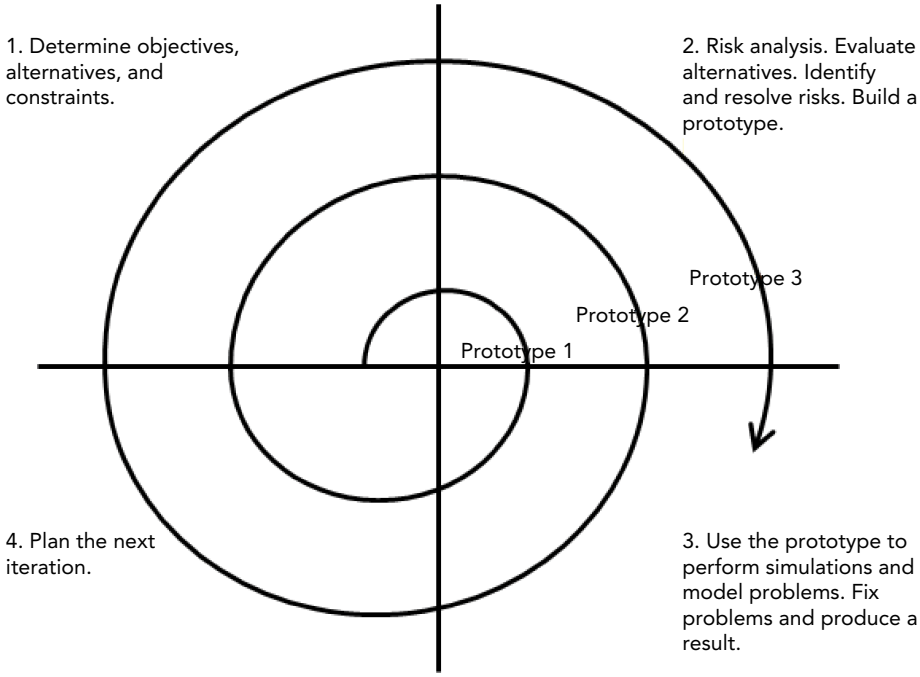


FIGURE 13-3: The spiral process uses four phases.

In the first phase (which some call the planning phase), you determine the objectives of the current cycle. You define any alternatives and constraints on the objectives.

In the second phase (which some call the risk analysis phase), you perform a risk analysis to determine what the biggest risk factors are that could prevent you from achieving this cycle's objectives. You resolve the risks and build a prototype to achieve your objectives. (Note that this may not be a program. For example, if the goal of the current cycle is to build requirements, then this will be a set of prototype requirements.)

In the third phase (which some call the engineering phase), you use the prototype you just built to evaluate your solution. You perform simulations and model specific problems to see if you're on the right track. (For example, you might run through a bunch of operational scenarios to see if your prototype requirements can handle them.) You use what you learn to achieve the original objectives. After this phase, you should have something concrete to show for your efforts.

In the fourth phase (which some call the evaluation phase), you evaluate your progress so far and make sure the project's major stakeholders agree that the solution you came up with is correct and that the project should continue. If they decide you've made a mistake, you run another lap around the spiral to fix whatever problems remain. (You identify the missed objectives, evaluate alternatives, identify and resolve risks, and produce another prototype.) After you're sure you're on the right track, you plan the next trip around the spiral.

For a concrete example, consider Figure 13-4. The first trip around the spiral builds the project requirements. The team examines alternatives, identifies the largest risks (perhaps the customers' performance requirements are unclear), resolves the risks, and builds a prototype set of requirements. Team members then use the prototype to analyze the requirements and verify that they are correct. At that point, the verified requirements become the actual requirements.

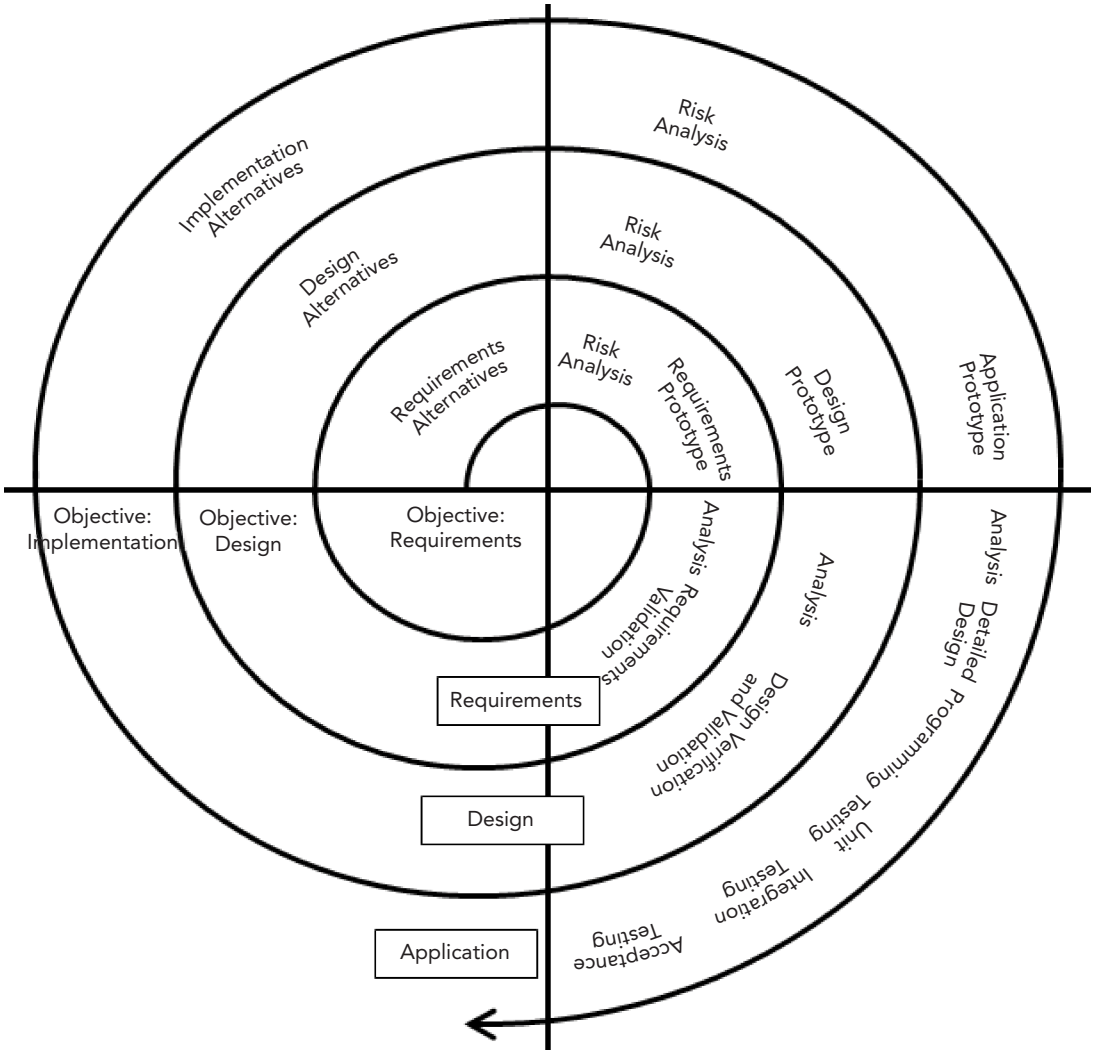


FIGURE 13-4: In this project, the major risks were requirements, design, and implementation.

The next trip around the spiral builds the application design. The team evaluates design alternatives, identifies and resolves the major risks, and builds a prototype design. Team members analyze the design and verify that it makes sense. The prototype design then becomes the design.

The final trip around the spiral drives the application's implementation. The team evaluates implementation alternatives (although they're probably used to a particular development approach already). They identify risks (perhaps previous projects have had maintenance issues) and resolve them (they decide to have more code reviews). The team then builds an operational prototype that shows how the program will work. They use the prototype to verify that everything is on track, and then they actually build the application. In this cycle, the implementation steps are broken down into detailed design, programming, unit testing, integration testing, and acceptance testing.

This example doesn't include every cycle that you might want to perform. For example, you might want to make separate user interface design or database design cycles.

Clarifications

Since he initially described the spiral approach, Boehm has made several clarifications mostly to correct mistakes people made interpreting the method. Those clarifications include the following:

- This is not simply a series of waterfall models drawn in a spiral and executed one after another to form an incremental approach. In fact, you could use multiple spirals to build different versions of an application.
- The activities need not follow a single spiral sequence. For example, you could spin the user interface design and database design off into completely separate spirals that both feed into an overall project cycle.
- You can add items, remove items, or perform items in different orders in a specific spiral model as needed. The activities you need to perform depend on the project.

Boehm further defined six characteristics that spiral development cycles should follow:

1. Define tasks concurrently. There's no need to perform everything sequentially.
2. Perform the following four tasks in each cycle. (Basically they are goals of the four phases.)
    a. Consider the goals of all stakeholders.
    b. Identify and evaluate alternative approaches for satisfying the stakeholders' goals.
    c. Identify and resolve risks in the selected approach.
    d. Make sure the stakeholders agree that the results of the current cycle are correct. Get the stakeholders' approval to continue the project into the next cycle.
3. Use risk to determine the level of effort. For example, perform enough code reviews to minimize the risk of buggy code, but don't perform so many reviews that you risk finishing late.
4. Use risk to determine the level of detail. For example, put enough work into the requirements to minimize the risk of the application not satisfying the customers, but don't over-specify requirements to the point where they restrict the developers' flexibility.
5. Use anchor milestones. Boehm later added the following anchor milestones to track the project's progress.

a. **Life Cycle Objectives (LCO)**—When the stakeholders agree that the project's technical and management approach is defined enough to satisfy all the stakeholders' goals, then it has reached its LCO milestone.

b. **Life Cycle Architecture (LCA)**—When the stakeholders agree that the project's approach can satisfy the goals and all significant risks have been eliminated or mitigated, then it has reached its LCA milestone.

c. **Initial Operational Capability (IOC)**—When there has been sufficient preparation to satisfy everyone's goals, then the project has reached its IOC milestone and should be installed. The preparations include everything needed to make the project a success. For example, the application is ready and tested, the user site is set up, the users have been trained, and the maintenance programmers are ready to take over.

6. Focus on the system and its life cycle rather than on short-term issues such as writing an initial design or writing code. This is intended to help you focus on the big picture.

Pros and Cons

The spiral approach is considered one of the most useful and flexible development approaches. The following list summarizes some of its main advantages:

- Its spiral structure gives stakeholders a lot of points for review and making "go" or "no-go" decisions.
- It emphasizes risk analysis. If you identify and resolve risks correctly, it should lead to eventual success.
- It can accommodate change reasonably well. Simply make any necessary changes and then run through a cycle to identify and resolve any risks they create.
- Estimates such as time and effort required become more accurate over time as cycles are finished and risks are removed from the project.

The following list summarizes some of the spiral approach's biggest disadvantages:

- It's complicated.
- Because it's complicated, it often requires more resources than simpler approaches.
- Risk analysis can be difficult.
- The complication isn't always worth the effort, particularly for low-risk projects.
- Stakeholders must have the time and skills needed to review the project periodically to make sure each cycle is completed satisfactorily.
- Time and effort estimates become more accurate as cycles are finished, but initially those estimates may not be good.
- It doesn't work well with small projects. You could end up spending more time on risk analysis than you'd need to build the entire application with a simpler approach.

For those reasons, the spiral approach is most useful with large high-risk projects and projects with uncertain or changeable requirements.

UNIFIED PROCESS

Despite its name, the *Unified Process* (*UP*) isn't actually a process. Instead it's an iterative and incremental development framework that you can customize to fit your business and projects.

The Unified Process approach is divided into the following four phases:

- **Inception**—During this phase you come up with the project's idea. (Or as in the movie, someone else comes up with the project's idea and makes you think it's yours.) This should be a short phase where you provide a business case, identify risks, provide an initial schedule, and sketch out the project's general goals. It should not include detailed requirements that might restrict the developers.
- **Elaboration**—During this phase you create the project requirements. You build use cases, architectural diagrams, and class hierarchies. You need to specify the system, but you still don't want to restrict developers with unnecessarily detailed requirements. The main goals are to identify and address risks so that the project doesn't fail later. Normally, this phase is divided into several iterations with the first addressing the most important risks.
- **Construction**—During this phase you write, test, and debug the code. This phase is divided into several iterations, each of which ends with a tested, high-quality working executable program that you can release to the users. The iterations implement the most important features first.
- **Transition**—During this phase you transfer the project to customers and the long-term maintenance team. Based on feedback from users, you might make changes and refinements and then release a new version, so this phase can include several iterations. This phase includes all the usual transitioning tasks such as staging, building the user environment (computers, networks, coffee machines, and so forth), user documentation, and user training.

You can add more phases if you like. For example, you might add the following two phases to model the application's life cycle after transition:

- **Production**—During this phase users use the application. The normal Unified Process assumes that the development team doesn't continue producing new versions of the application during this phase.
- **Disposal**—During this phase you remove the application and move users to a replacement system. If you're building the replacement, then this phase overlaps with the new project's transition phase.

Figure 13-5 shows the relative sizes of the Unified Process phases. A rectangle's height represents the resources (mostly the number of people in the development team) required for that phase. A rectangle's width represents the amount of time spent on that phase.

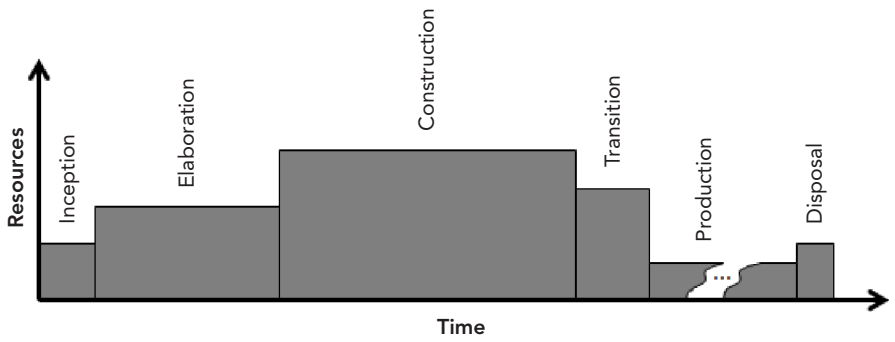


FIGURE 13-5: In the Unified Process, construction takes more time and effort than the other phases.

Figure 13-6 shows the relative amounts of different kinds of work during the project's phases and the iterations within those phases. For example, implementation work (programming) is relatively light during inception and elaboration, picks up during the construction iterations, and then tapers off during transition.

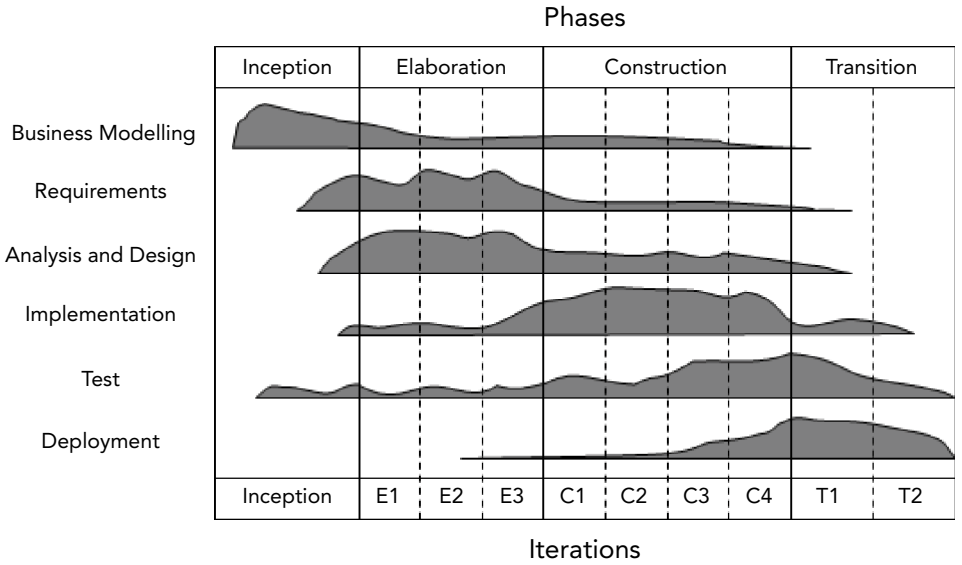


FIGURE 13-6: In the Unified Process, the amounts of different kinds of work grow and shrink during different project phases.

The project shown in Figure 13-6 had three elaboration iterations, four construction iterations, and two transition phases.

Pros and Cons

The following list summarizes some of the main advantages of the Unified Process approach:

- The iterative approach to the elaboration, construction, and transition phases enables you to incrementally define the requirements and assemble the application.

- The elaboration iterations focus on risks and risk mitigation to improve the project's chance of success.
- It can accommodate different development models flexibly. For example, you could use a series of waterfalls or an agile approach to the construction phase.
- The inception and elaboration phases generate a lot of documentation that can help new developers join the team later.
- It can enable incremental releases if wanted.

Some of the Unified Process approach's disadvantages are similar to those of the spiral approach. The following list summarizes some of the biggest Unified Process disadvantages:

- It's complicated (although not quite as confusing as the spiral approach).
- Because it's complicated, it often requires more resources than simpler approaches.
- Risk analysis can be difficult.
- The complication isn't always worth the effort, particularly for low-risk projects.
- It doesn't work well with small projects. You could end up spending more time on inception and elaboration than you'd need to build the entire application with a simpler approach.

Like the spiral approach, the Unified Process approach is most useful with large high-risk projects and projects with uncertain or changeable requirements.

Rational Unified Process

The *Rational Unified Process* (*RUP*) is IBM's version of the Unified Process. It uses the same four basic phases defined by UP: inception, elaboration, construction, and transition.

It also uses the same standard engineering disciplines (on the left in Figure 13-6): business modeling, requirements, analysis and design, implementation, test, and deployment. It also adds three "supporting disciplines": configuration and change management, project management, and environment. (Environment refers to customizing the process for the development organization and the current project.)

The main advantages to RUP over UP are the tools provided by IBM that make using the process easier. Those tools include artifact templates, document production and sharing, change request tracking, visual modeling, performance profiling, and more.

ARTIFACTUALLY

In RUP an *artifact* is a final or intermediate result that is produced by the project. The RUP includes documents (such as design documents and deployment plans), models (such as use cases and design models), and model elements (pieces of models such as classes or subsystems).

As you might expect, the advantages and disadvantages of RUP are similar to those for UP.

There are several variations on UP and RUP. For example, the *Open Unified Process* (*OpenUP*) is a tool that makes using the Unified Process easier. To make OpenUP more accessible to its target

audience (smallish projects with 3–6 team members working on projects lasting 3–6 months), it omits most of the optional features provided by RUP, so it's easier to use.

OpenUP is part of the open source Eclipse Process Framework. For more information on OpenUP, see `epf.eclipse.org/wikis/openup`. For more information on the Eclipse Process Framework, see `www.eclipse.org/epf`.

The *Agile Unified Process* (*AUP*) is another simplified version of RUP. It brings agile methods such as test-driven development and agile modeling to UP. In 2012, AUP was superseded by *Disciplined Agile Delivery* (*DAD*, not to be confused with your father).

DAD has a structure that's somewhat similar to UP. In particular, it has the three phases: inception, construction, and transition. (Elaboration is divided between inception and construction.) DAD also borrows many techniques from different agile development approaches such as Scrum, Extreme Programming, Kanban, and others. I won't say any more about DAD until the next chapter, after you've learned more about those agile approaches.

CLEANROOM

The Cleanroom model emphasizes defect prevention rather than defect removal. The idea is to build the application in steps that are carefully monitored and tested to prevent anything bad from entering into the application. (The name is inspired by the way a manufacturing clean room prevents dust and other gunk from getting into the manufacturing process.)

The following list summarizes Cleanroom's basic principles:

- **Formal methods**—Code is produced using formal mathematical methods that help ensure that the code satisfies the design models. Code reviews also help verify that the code correctly implements the required behavior.
- **Statistical quality control**—Code is produced incrementally. Each increment's quality is measured to ensure that the project is making acceptable progress.
- **Statistical testing**—Testing uses statistical experiments to estimate the application quality. (This requires some serious statistical analysis so that you can estimate not only the application's quality but so that you can also calculate a level of confidence for that estimate.)

Unfortunately, the mathematics needed to do the statistical analysis is quite intimidating. I like math more than most people (my C# Helper website `www.csharphelper.com` is littered with mathematical examples for C# developers) but even I hesitate when faced with statistical testing models. Some of them are seriously complicated and confusing.

Still, the basic ideas behind Cleanroom are excellent. First, if you don't let bad code sneak into the application, then you won't need to fix it later.

Second, if you evaluate the quality of the application after every iteration, you can track how effective your development effort is. You can also fine-tune development if the number of defects increases in a particular iteration.

Even if you don't have the tools or expertise to follow the Cleanroom process in every detail, it's worth borrowing those two principles.

SUMMARY

Iterated development is one technique for trying to keep a software engineering project on track. It lets you periodically review your progress to ensure that the application is heading toward a result that satisfies the requirements. It also lets you refine and correct the requirements over time if necessary.

Prototyping lets you study pieces of an application so that you can make adjustments. Models such as spiral and Unified Process (and its variants) use iteration to help the development and requirements eventually meet. Some of those models also place an emphasis on risk management to reduce the chances of the project failing.

In addition to keeping a project heading in the right direction, iterative and incremental methods allow you to release partial implementations of the application if they are useful. The next chapter describes other techniques that let you give the users partial functionality as soon as possible.

EXERCISES

1. Suppose your customer wants an application with 10 features and insists that the application is completely useless unless all 10 are implemented with full fidelity. Would there be any benefit to iterative, incremental, or agile approaches?
2. Explain why a throwaway prototype inherently uses an agile approach.
3. How does an incremental prototype differ from an incremental project? What would you need to do to use an incremental prototype in an incremental project?
4. Can you use an evolutionary prototype in a predictive project (such as waterfall)?
5. Can you use an incremental prototype in a predictive project?
6. Look at the project shown in Figure 13-6. Why might the deployment tasks start during the elaboration phase instead of at the beginning of the transition phase? What deployment tasks might you be performing during elaboration? What tasks might you be performing during construction?
7. Look at the project shown in Figure 13-6. The testing tasks begin in the inception phase before the implementation tasks start. What are you testing during inception if there isn't any code yet?
8. Look at the project shown in Figure 13-6. What kinds of code are the team members writing during the elaboration phase? What kinds of tests are they performing during that phase?
9. Add a new row to the bottom of Figure 13-6 that shows the amount of customer interaction required during different phases of development for an in-house project.

10. Draw a diagram showing how the phases of the waterfall model match up with those of Unified Process. What are the main differences?

11. Indicate whether the following items describe the predictive, iterative, incremental, or agile approaches.

    a. Features are released as soon as they are useful. Over time, existing features are improved and new features are added.

    b. Features are released one at a time with full fidelity.

    c. All the application's features are released at the same time with full fidelity.

    d. Every feature is released quickly with low fidelity and then improved over time.

12. Which approach (predictive, iterative, incremental, or agile) gets a working program to users the soonest? Latest? What can you say about the timing of the other two approaches?

13. Suppose you're a real estate developer building a neighborhood containing 100 houses. How would each of the predictive, iterative, incremental, and agile approaches correspond to home sales? Assume the "features" of the project are the houses and "releasing a feature" means allowing people to move into a home. Which of the approaches could work? Which approach do developers actually use?

14. Suppose you're a different real estate developer who specializes in more interesting projects. This time you're building an amusement park. How would each of the predictive, iterative, incremental, and agile approaches correspond to opening the park? The "features" of the project are the rides, snack shops, and games of "chance" (which actually leave little to chance). "Releasing a feature" means allowing people to ride on a ride, buy greasy food at high prices, or use darts to try to pop balloons that seem to be made of Kevlar. Which of the approaches could work?

WHAT YOU LEARNED IN THIS CHAPTER

- Predictive approaches make one big release when everything is done.
- Iterative approaches release every feature with low fidelity and then improve fidelity over time.
- Incremental approaches release features as they are finished with high fidelity.
- Agile approaches combine iterative and incremental approaches. They release features when they are usable. Over time they improve existing features and add new ones.
- A prototype is a simplified model that lets you study the behavior of some part of an application.
- Horizontal prototypes have breadth but little depth. They are typically used to study user interfaces and show customers what the application will look like.
- Vertical prototypes have little breadth and great depth. They are typically used to study architecture and programming issues.
- You don't reuse the code in a throwaway prototype.
- Over time an evolutionary prototype is refined and improved until it becomes the finished application.
- In incremental prototyping, you build separate prototypes of the application's features and then combine them to form the finished application.
- The spiral model uses a sequence of repeating phases (planning, risk analysis, engineering, and evaluation) to identify and neutralize project risks.
- Unified Process is an iterative and incremental approach that uses the phases' inception, elaboration, construction, and transition. The last three phases are iterative.
- Rational Unified Process is IBM's version of Unified Process. Other versions include OpenUP, Agile Unified Process, and Disciplined Agile Delivery.
- Cleanroom uses formal methods, statistical quality control, and statistical testing to prevent defects from entering an application's code. Its two principles, "Don't let bad code into the application," and "Evaluate the quality of the application after each iteration," are worth using in any development approach.
- You shouldn't ride roller coasters that don't have full fidelity.

14

RAD

The problem with quick and dirty, as some people have said, is that the dirty remains long after the quick has been forgotten.

—Steve McConnell

Excellent firms don't believe in excellence–only in constant improvement and constant change.

—Tom Peters

WHAT YOU WILL LEARN IN THIS CHAPTER

- General RAD principles
- Agile methods
- James Martin RAD, XP, Scrum, Lean, Crystal, FDD, AUP, DAD, DSDM, and Kanban
- Principles, roles, and values that are common to several RAD development approaches

When you boil down software engineering to its most fundamental level, its goals are simply to produce useful software as quickly as possible.

All the software development models described so far focus on the first of those goals: producing useful applications. They try to ensure that the result meets the specifications and that the specifications actually specify something useful. Iterative models such as iterated waterfall and Unified Process even allow you to change the project's course of direction in case it wanders off track or the requirements change over time.

Techniques such as prototyping help ensure that the specification gives the customer a result that is useful. Models such as Unified Process emphasize risk management to ensure that the development effort succeeds. All the models spend at least some effort encouraging good programming techniques so that the result is robust and maintainable.

None of the models described so far actually focus on the second goal of software engineering: producing software quickly. That's not to say those models encourage a lackadaisical approach. None of them say developers should sit around doing nothing. (Although I've met a few developers who would have done more for their projects if they *had* done nothing.) Many models help you track tasks so that you can quickly decide if a task is falling behind and jeopardizing the project's schedule.

However, the models discussed so far don't focus on increasing development speed. They implicitly do things to limit the number of bugs, which can save you time in the long run, but they don't provide techniques for accelerating development.

This chapter describes *rapid application development* (*RAD*) models. These models incorporate some of the best features of the models described in the preceding chapters, plus new features that help developers give useful results to the end user quickly.

RAD VERSUS RAD

James Martin, one of the pioneers of RAD in the 1980s, described a specific development methodology in his book *Rapid Application Development* (Macmillan, 1991). Later the terms rapid application development and RAD expanded to include a variety of other models that favor rapid development, so there's sometimes confusion about the two uses of the term.

This chapter uses *rapid application development* and *RAD* to mean the more general genre of models. *James Martin RAD* means his specific model.

Some tools also bill themselves as RAD tools. Some of them do provide a framework that you can use to follow a particular RAD development model. Others are merely tools that you can use to do things rapidly. For example, rapid prototyping tools can help you build user interface prototypes relatively quickly and easily. Those tools can be useful in a RAD project, but they don't give you a RAD project.

To see the difference, ask yourself whether you could apply a tool to a non-RAD project. For example, could you use a prototyping tool in a waterfall project? Sure. Could you use James Martin RAD in a waterfall project? Not really.

Similarly, some development environments claim to be RAD environments. For example, some people consider the Visual Studio development environment to be a RAD tool. It certainly lets you build programs rapidly and you can easily use it in a RAD project, but it isn't inherently RADish, and you could easily use it in a waterfall project. (In fact, I've done that many times.)

The techniques used by RAD models push developers to generate as much high-quality code as possible as quickly as possible. Some of the techniques may seem a bit strange. They may seem even stranger if you have experience with software engineering, depending on which development models you've used before.

Some of the methods may seem counterintuitive or some sort of "touchy-feely" new age nonsense focused more on the developers than on the code. Remember that the code is written for the programmers, not for the computer. The computer can read any gibberish you dump into the compiler. Code must be written for people if you want them to read, understand, debug, modify, and maintain it. That means it's essential to keep the developers happy and productive.

RAD PRINCIPLES

One of the driving forces behind RAD is the idea that things always change. As Heraclitus said, "The only thing that is constant is change." He didn't mention software requirements because he lived roughly between 535 BC and 475 BC, but if he had known about software engineering, he probably would have pointed out that requirements change often.

Sometimes, at the end of a project, the customers realize that the requirements didn't accurately describe their needs. Even though the application satisfies the requirements, it doesn't satisfy their needs.

Other times the customers' needs change during the project's development. The company's goals, competition, or customer desires change, so by the time the application is ready, no one wants it.

Those facts lead to an obvious problem with big design upfront (BDUF) models: by the time an application is finished, it doesn't satisfy the customers' needs. Iterative models help keep a project on track, but they have their limits. If you perform a new iteration every year or so, you could wander far off track before you realize you're heading in the wrong direction.

RAD methods take iterative ideas to the extreme. Instead of using iterations lasting a year or two, their iterations last a month, a week, or even less. Some RAD techniques also apply iteration to everything, not just to programming. They apply iteration to requirement gathering, requirement validation, and design.

The following list summarizes some of the most common techniques used in RAD development models:

- Small teams (approximately one-half a dozen people or fewer). That leads to projects of limited scope. (Six people probably can't write a million-line application in a year.)
- Requirement gathering through focus groups, workshops, facilitated meetings, prototyping, and brainstorming.
- Requirement validation through iterated prototypes, use cases, and constant customer testing of designs.
- Repeated customer testing of designs as they evolve.
- Constant integration and testing of new code into the application.
- Informal reviews and communication among team members.
- Short iterations lasting between a few months and as little as a week.

- Deferring complicated features for later releases. Doing just enough work to get the job done.
- *Timeboxing*, which is RADspeak for setting a tight delivery schedule for producing something, usually the next iteration of the application. The scope can change (for example, you might defer a feature to the next iteration), but the completion date for the iteration cannot.

ITERATION 0

Agile models sort of assume the project begins in the middle. The project starts and you're immediately zipping through iterations producing high-quality increments for the customers.

In practice, projects generally need some startup time to put things in place for later development. During that period, you'll set up the team's hardware, install the development environment, and find out which local restaurants provide late night delivery.

You'll also meet the customers and find out generally what the project is about. You'll probably build different kinds of models describing the system you're going to build, gather requirements, and do everything else that needs to be done before you actually start iterations.

You can think of those activities as a separate stage before the project starts if you like (or if that lets you claim those tasks shouldn't count toward your budget), but some developers call those startup-oriented boot-strapping kinds of activities *iteration 0*.

While you're performing those startup tasks, you're not delivering value to the customer, so agile projects generally try to keep iteration 0 as short as possible. These tasks are important, but the sooner you start iteration 1, the sooner you can deliver something to the customers. So keep iteration 0 simple.

As with all software engineering approaches, RAD models have their share of advantages and disadvantages. The following list shows some general RAD advantages:

- More accurate requirements. The customers can adjust the requirements as needed during the project.
- The ability to track changing requirements. If requirements must change (within reason), the project can start tracking the new requirements in the next iteration.
- Frequent customer feedback and involvement. In addition to helping keep the project on track, this keeps the users engaged with the project.
- Reduced development time. If everything goes smoothly, you don't spend as much time writing requirements in excessive detail.
- Encourages code reuse. One of the key RAD ideas is to do whatever it takes to get the current iteration done. If an existing piece of code does what you need it to do (or even almost what you need it to do), timeboxing encourages you to use that code instead of writing something new.

- Possible early releases with limited functionality.
- Constant testing promotes high-quality code and eases integration issues.
- Risk mitigation. Before each iteration, you can look for potential risks and handle them.
- Greater chance of success. BDUF projects sometimes spend a lot of time following an incorrect path before discovering they're heading in the wrong direction and they need to be radically redone or even canceled. Frequent increments allow RAD projects to detect and correct problems quickly before they become insurmountable.

The following list summarizes some general RAD disadvantages.

- Resistance to change. It can be hard to get existing software engineering groups to adopt new RAD models, particularly given how odd some of their techniques can seem. (A nineteenth-century blacksmith's apprentice would be more comfortable with pair programming than many BDUF programmers.)
- Doesn't handle large systems well. Big systems require a lot of effort, and that usually means a lot of people. The communication overhead alone makes it hard to run large projects in a RAD model. (If you can partition the project into nicely disconnected pieces, you may have a chance.)
- Requires more skilled team members. Every team member does not need to be a programming Obi Wan Kenobi, but small RAD teams can't include too many complete beginners.
- Requires access to scarce resources. Frequent customer interaction is essential to keep the project on track. Often that interaction must be with customers who are experts in their fields, and those people tend to be in high demand.
- Adds extra overhead if the requirements are known completely and correctly in advance.
- Less managerial control. Many managers have trouble allowing a project to head off in its own ever-changing direction. (If you think of the project as a hunting pack chasing a fox wherever it leads, a manager may wonder what happens if the pack scents a rabbit.)
- Sometimes results in a less than optimal design. (See the following text.)
- Unpredictability. Some customers just want to know how much and how long, and they really aren't interested in shaping the application throughout its development.

A RAD project's small iterations occasionally lead to a suboptimal design. Sometimes, the best design is too big to implement in a single iteration, so a RAD approach won't get there incrementally.

As an analogy, consider the International Space Station (ISS). Because it was built from pieces that had to squeeze into a rocket, it was constructed incrementally over many years involving more than 115 space flights and 180 spacewalks. It's amazingly complicated and a remarkable feat of engineering, but I can't help thinking it would be different if it hadn't been built incrementally. Perhaps something more like the torus-shaped Elysium habitat from the movie of the same name. (And what would Apple have designed if they'd been given the job? I'm sure it would have been elegantly beautiful, cost five times as much, and been called the iStation or perhaps iISS.)

JAMES MARTIN RAD

James Martin's original RAD model uses the following four phases.

- **Requirements planning**—During this phase, the users, executive champion, management, team leaders, and other stakeholders agree on the project's general goals and requirements. The requirements should be specified in a general way so that they don't restrict later development unnecessarily. When the stakeholders agree on the requirements and the project receives approval to continue, the user design phase begins.
- **User design**—The users and team members work together to convert the requirements into a workable design. They use techniques such as focus groups, workshops, prototyping, and brainstorming to come up with a workable design.
- **Construction**—The developers go to work building the application. The users continue to review the pieces of the application as the developers build them to make corrections and suggestions for improvements.
- **Cutover**—The developers deliver the finished application to the users. (You can use the usual cutover strategies such as staged delivery, gradual cutover, or incremental deployment.)

The user design and construction phases overlap with the users constantly providing adjustments to the developers in a sort of continuous feedback loop. The project iterates the user design and construction phases as needed. When the application has met all the requirements, it is delivered to the users.

Figure 14-1 shows the way a James Martin RAD project moves through its four phases.

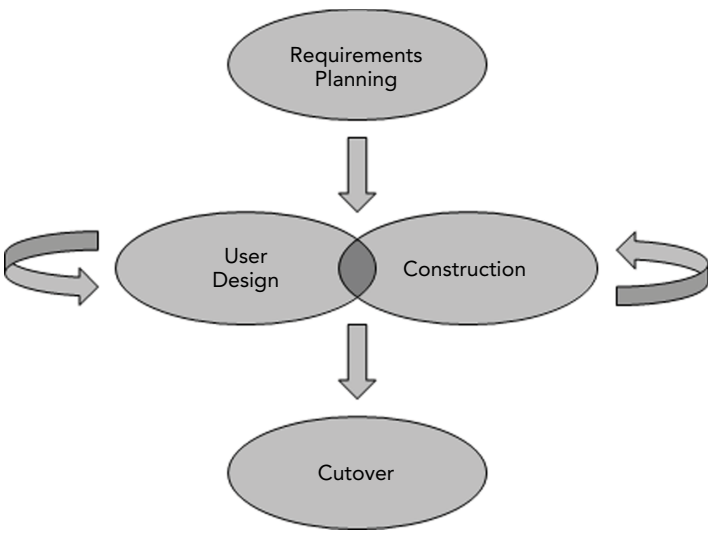


FIGURE 14-1: In James Martin RAD, the user design and construction phases iterate until the application meets its requirements.

AGILE

Agile development is more a set of guidelines than an actual development model. It includes a set of principles that its founders believe can help with any development effort. Because it's a set of guidelines, there are many ways you can interpret its rules. For example, people often say a particular method is "an agile technique" because it attempts to address one or more of the guidelines.

In 2001 a group of developers got together at Snowbird resort in Utah to talk about lightweight alternatives to BDUF methodologies such as waterfall and Spiral. After their discussions (and I suspect a lot of skiing), they published the *Manifesto for Agile Software Development*. The following text shows the manifesto (which you can also read at `agilemanifesto.org`):

> *We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:*
>
> ***Individuals and interactions*** *over processes and tools*
>
> ***Working software*** *over comprehensive documentation*
>
> ***Customer collaboration*** *over contract negotiation*
>
> ***Responding to change*** *over following a plan*
>
> *That is, while there is value in the items on the right, we value the items on the left more.*
>
> | | | |
> |---|---|---|
> | *Kent Beck* | *James Grenning* | *Robert C. Martin* |
> | *Mike Beedle* | *Jim Highsmith* | *Steve Mellor* |
> | *Arie van Bennekum* | *Andrew Hunt* | *Ken Schwaber* |
> | *Alistair Cockburn* | *Ron Jeffries* | *Jeff Sutherland* |
> | *Ward Cunningham* | *Jon Kern* | *Dave Thomas* |
> | *Martin Fowler* | *Brian Marick* | |
>
> *© 2001, the above authors*
> *this declaration may be freely copied in any form, but only in its entirety through this notice.*

Some of the original authors later formed the nonprofit Agile Alliance (`www.agilealliance.org`) to promote agile development ideas.

Like any good manifesto, this one's values are general enough to apply to just about any situation. Of course, that also makes them flexible enough to use in support of all sorts of arguments that may not make sense.

For example, the value "Working software over comprehensive documentation" is sometimes used to justify providing little or no documentation. ("But the *Agile Manifesto* says I don't have to write any documentation!" See my tirade about just-barely-good-enough documentation in the section "Code Documentation" in Chapter 2, "Before the Beginning.")

The manifesto's site and the Agile Alliance site provide some elaboration to make it a bit easier to understand exactly what the authors had in mind. For example, the following paragraph by

Jim Highsmith from the manifesto history page (`agilemanifesto.org/history.html`) clarifies some of the authors' ideas:

> *The Agile movement is not anti-methodology, in fact, many of us want to restore credibility to the word methodology. We want to restore a balance. We embrace modeling, but not in order to file some diagram in a dusty corporate repository. We embrace documentation, but not hundreds of pages of never-maintained and rarely-used tomes. We plan, but recognize the limits of planning in a turbulent environment. Those who would brand proponents of XP or Scrum or any of the other Agile Methodologies as "hackers" are ignorant of both the methodologies and the original definition of the term hacker.*

From this paragraph and the manifesto, you can take a couple of useful tidbits of information.

- Agile is not a methodology. You can use it to enhance methodologies.
- Modeling is okay but not just for the sake of crossing off some item required by management.
- Documentation is great but not hundreds of pages that will never be used. (So you probably shouldn't pay documenters by the number of pounds of documentation they generate.)
- Planning is good, but be aware that plans don't always work out in a changing environment.
- Some of the authors were tired of being called hackers.

In addition to the manifesto itself, the manifesto's website lists the following 12 guiding principles (at `www.agilemanifesto.org/principles.html`).

1. *Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.*
2. *Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.*
3. *Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.*
4. *Business people and developers must work together daily throughout the project.*
5. *Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.*
6. *The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.*
7. *Working software is the primary measure of progress.*
8. *Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.*
9. *Continuous attention to technical excellence and good design enhances agility.*

10. *Simplicity—the art of maximizing the amount of work not done—is essential.*
11. *The best architectures, requirements, and designs emerge from self-organizing teams.*
12. *At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.*

Most of these are reasonably self-explanatory, so they don't need further explanation, although I will say a bit about self-organizing teams shortly.

Notice that the agile values and principles don't actually tell you how to implement them. For example, the second principle says you should welcome changing requirements, but it doesn't say whether you should do that with Sashimi, James Martin RAD, or some other approach. You could even use an incremental waterfall; although accommodating change late in the development process would be harder. Methodologies such as Scrum and Extreme Programming, which are described later in this chapter, were designed with the agile values and principles in mind, so they generally do a good job of following them.

WHAT'S AGILE ENOUGH?

The fact that you can apply the agile values and principles to different development models makes them useful in a lot of situations. Unfortunately, it also can make it difficult to decide whether a particular development approach is "agile enough."

Suppose you're at a job interview and your prospective boss asks, "Have you ever worked on an agile project?" If you've used Scrum, Kanban, or one of the other well-known agile methods, then you can safely say "yes."

If you've used James Martin RAD, which by my reckoning gets a grade of B on the agile scale, then it's probably safe to say "yes" and then add a few words of explanation.

If you added only a few agile techniques such as pair programming and test-driven development (described later in this chapter) to a waterfall project, then you should probably say, "No but…" and then explain exactly what you did. It's better to leave the interviewer thinking, "Well, he didn't use an agile model, but he understands some of the agile techniques," instead of, "The fool thinks waterfall is agile! Next applicant!"

Self-Organizing Teams

The eleventh agile principle touts the wonders of self-organizing teams. So what is a self-organizing team and how can you organize one (so to speak)?

A self-organizing team is one that has the flexibility and authority to find its own methods for achieving its goals. Teams with different levels of authority may also set their own goals, track their progress, and even pick the team members.

STORMING THE RIDGE

For an example of a self-managing team, imagine a common scene in war movies. The platoon's advance is stymied by enemy fire and the sergeant yells, "Johnson, I need you and two 'volunteers' to take out that machine gun nest!" The sergeant doesn't care how the job gets done or who does it as long as the problem is eliminated.

Johnson might pick his two closest buddies and run screaming up the hill, firing from the hip, only to be gunned down just as he drops a satchel charge into the enemy emplacement. Or he and his comrades might lob a few RPGs over the ridge until they get lucky and hit the target. Or he might say, "Sarge, let's retreat a mile or two and call in an airstrike." It's up to Johnson and his two unfortunate friends to come up with a solution. (As the most dramatic, the first solution would probably be the one picked by the movie's director.)

For comparison, the opposite of a self-organizing team is a micromanaged team where the manager tells everyone else exactly what to do and when. (For more information on micromanagement, read some *Dilbert* cartoons.)

The members of a self-organizing team are motivated so they take on work without waiting for it to be assigned. They take responsibility for their work and track their own progress. If problems arise, they aren't afraid to ask for help either inside or outside of the team.

The increased sense of ownership the members feel often makes them more enthusiastic and effective at finding good solutions to problems. Ideally, they'll attack any problem that stands in their way eagerly and relentlessly. In practice, you may need to draw straws to see who gets stuck with that one messy chore no one wants, but most of the time the team members can divide up the work in a way that makes everyone more or less happy.

The members communicate as a team to ensure that the group is working toward its goals (which may be set outside of the team, at least at a high level). To communicate effectively, the team members must feel safe. They need to trust each other to use feedback constructively. One way to help make that kind of trust possible is to adopt the rules of egoless programming described in the section "Have Someone Else Test Your Code" in Chapter 8, "Testing."

TRUST ME

If you don't think this kind of trust is essential, try this experiment. Hold a meeting and ask for ideas about some company issue—how to improve the cafeteria food, keep the lunch room clean, chase the geese off the lawns, whatever. The instant someone offers a suggestion, shout them down and tell them how stupid their idea is. Then see if you can get any suggestions out of the others.

Actually you should probably skip that experiment. You may never gain everyone's trust. Although it's amazing how many annual company meetings I attended that had more or less that format. People would make suggestions and then upper management would explain why it was a bad idea and dodge any questions.

Unfortunately, self-organizing teams don't always arise spontaneously. Even if you assemble a group of competent, motivated people and tell them to organize themselves, you'll probably need to keep an eye on them. Instead of guiding them like a traditional manager would, you can encourage them to take the initiative and then offer support when they need it. Hopefully, they'll eventually leave you behind and start running the show on their own.

For some more information on self-organizing teams, search the Internet. Following are two articles that can get you started:

- "What Are Self-Organizing Teams?" at `www.infoq.com/articles/what-are-self-organising-teams`
- "Self-Organizing Teams: What and How" at `https://www.scrumalliance.org/community/articles/2013/january/self-organizing-teams-what-and-how`

Agile Techniques

Although the agile manifesto doesn't tell you how to implement the values and principles, there are several techniques that are fairly common to most agile methods. The following sections describe some of those techniques.

Communication

Agile projects use frequent (sometimes practically continuous) customer communication to keep the project on track. The customers examine the most recent iteration and then offer corrections, suggestions, and change requests. The developers adjust the next iteration accordingly.

Unfortunately, if every customer is talking constantly to every developer, no one has time to get anything done. To improve efficiency, most methods appoint a primary customer representative who becomes the main point of contact between the customers and the developers.

Sometimes, the development team also has a primary contact, often the project manager or technical lead. If the customer contact and developer contact have the authority to make decisions for their respective groups, they can handle most of the communications and leave everyone else free to perform their other duties.

CUSTOMER MANAGEMENT

I was once on one project that started to have a communication avalanche near the end of the development phase. The customers were excited and eager to see what was happening, so they started calling the developers to get progress reports. At one point, every developer could expect one or two calls every day and we were losing about 10 developer-hours per day.

At that point the project manager made some new rules. At 3:00 p.m. each day, he held a conference call to update any customers who wanted to hear about the project's status. Then he would answer any questions they had.

continues

(continued)

We didn't really need a single customer contact at that point because the project was settling down into its final form, so communication was mostly one-way from the team to the customers. That approach may not work on every project, but it worked well for that one.

Many methods use one or more big boards to display the project's current status. The boards are placed where everyone can see them frequently, so everyone knows exactly where the project stands at all times. (Some people call this board the *information radiator* or just the *big board*.)

Some development models use frequent meetings to make it easier for the developers to communicate. For example, in Scrum the team meets every day in a "daily standup" where everyone reviews what they did since the last meeting, what they plan to do before the next meeting, and what might stand in their way. Because there are so many meetings, they must start on time and be short to avoid wasting a lot of precious developer time.

Incremental Development

Agile projects are iterative and incremental. The iterations are relatively short, with durations of a week to a couple months. Iterations are timeboxed to keep the project moving briskly along.

Each iteration incorporates every development step, including requirements analysis, design, programming, testing, and verification. An iteration is basically a mini-project all by itself.

CROSS-FUNCTIONAL TEAMS

It's also helpful if every team member has a good understanding of every part of the iteration process. In other words, everyone should understand requirement analysis, design, programming, testing, and the rest. That way anyone can spot a problem with any piece of the development process and fix it.

If every member of the team understands all the development functions, the team is called *cross-functional*.

Because each iteration is thoroughly tested, bugs are caught as quickly as possible. That makes them easier to fix because they're most likely to be in the current iteration's code. It also means the code has high quality, so you don't need to waste time fixing old bugs in later iterations.

The goal of each iteration is to have a fully tested application that has high enough quality that you could release it to users. You may not want to actually do that, however, if the iteration doesn't add enough new features to the project. It's often better to save up the changes and make fewer bigger releases every few months rather than bombarding the users with a new version every week. For example, Table 14-1 shows a possible build schedule for a three-month project.

TABLE 14-1: Release Schedule for a Three Month Project

WEEK	BUILD TYPE	VERSION
1	Test	0.1
2	Test	0.2
3	Test	0.3
4	Test	0.4
5	Release	1.0
6	Test	1.1
7	Test	1.2
8	Release	2.0
9	Test	2.1
10	Test	2.2
11	Test	2.3
12	Release	3.0

Every week the developers build, test, and debug the application. The builds made at the end of weeks 5, 8, and 12 are released to the customers. Note that you don't necessarily need to decide which builds will be released when you start the project. You can just wait until the application has enough new and useful features to justify a new release.

The test builds are *point releases*, so the application's minor version number increases by 1. In the release builds, the application's major version number increases by 1.

VERSION SCHEMES

Different development environments have different version numbering schemes. For example, Visual Studio breaks version information into four pieces. Version 1.2.3.4 means major version 1, minor version 2, build 3, and revision 4.

You can use those fields to give meaning to an application's versions. For example, you could use the fields for the following purposes:

- **Major**—This represents a new major release with significant new features. Major releases come out once or twice a year.
- **Minor**—All nonmajor releases are minor releases.

continues

(continued)

- **Build**—Each weekly build gets a new build number.
- **Revision**—Builds that are not final weekly builds get a new revision number.

For example, suppose you released version 3.0.0.0 last month, and version 3.1.0.0 last week. During this week's testing, you make builds 3.1.0.1 through 3.1.0.13. After you get a final weekly build properly tested and debugged, you rename it 3.1.1.0.

After each iteration, the customers (or customer representatives) review the build to see if the project is still heading in the right direction. Then they can provide feedback.

The most critical type of feedback is a "go/no go" decision. If the project has been hopelessly derailed, it may be best to cancel it and move on, possibly to a new project that takes a different approach.

In some sense, deciding to cancel a project is similar to deciding whether to fold in poker. The goal in poker isn't to build the best possible hand. The goal is actually to decide as quickly as possible whether you're going to beat the other players' hands. If you don't think you can win, you should fold as quickly as possible before you put too much money in the pot.

Similarly, if a software project won't succeed, it's better to decide that as early as possible so that you can cancel it before you waste a lot of time and resources on it.

(Bluffing isn't supposed to be part of the metaphor. In poker, you can try to convince the other players that you have a winning hand even though you don't, hoping they'll all fold and leave you the pot. In software development, you generally shouldn't try to keep a dying project alive, but I have seen managers keep a project alive long enough to jump to another project and dump the zombie project on someone else.)

Focus on Quality

I've said it before but I'll say it again (and probably again until you're sick of hearing about it): In agile projects, all development must have high quality. Because of the fast iteration cycle, developers don't have time to spend chasing down bugs that entered the code months ago.

It's much better to take a little extra time to write good, solid code than it is to rush through the programming and have to fix it later—and then fix the fixes—and then fix *those* fixes. As Lewis Carroll wrote, "The hurrier I go, the behinder I get."

Programming takes up a large percentage of an agile project's time, so agile methodologies have developed many techniques for making it easier and faster to write solid code. The section "Incremental Development" earlier in this chapter explained how rapid iteration helps lead to high-quality code. Other agile techniques that improve code quality include unit and integration testing, pair programming, and test-driven development. (I'll say more about pair programming in the next section. I'll say more about test-driven development in the section "Test-Driven and Test-First Development" later in this chapter.)

XP

Extreme Programming (*XP*) isn't called extreme because you do it while hang gliding, ice climbing, or base jumping. It's called extreme because it takes normal programming practices to extreme levels.

For example, consider code reviews. Traditional programming models use periodic code reviews to improve code quality. Every week or so, some or all the developers get together to walk through someone's code to look for problems and possible improvements. Code reviews also let you determine whether the code satisfies its design requirements. Code reviews are a good practice, but they have a couple of drawbacks (even if everyone programs egolessly).

For one thing, code reviews can take a lot of time. If everyone on the team spends a couple hours every week in code reviews, that's time they aren't writing code. To save time, code reviews often cover only a small fraction of the code. The team members can apply the ideas and techniques discussed during a review to other pieces of code, but it would be better if every piece of code were reviewed.

Another drawback to traditional code reviews is that they aren't held right after the code is written. If you hold reviews weekly, some of the code could be a week old by the time it's reviewed. That's better than not reviewing the code at all, but the code isn't completely fresh in the programmer's mind.

You can improve code reviews by examining more of the code and doing it closer to the time it was written. Instead of reviewing 20 percent of the new code weekly, what if you could review 40 percent of the code twice a week? Or 75 percent of the code every other day? Taking this idea to the extreme, what if you could review every single comment and line of code as it was being written when the digital ink wasn't even dry? Sounds ridiculous, doesn't it?

Actually, that's just what the Extreme Programming technique of pair programming does. In *pair programming*, two (or possibly even three) programmers sit in front of the same monitor and work on a piece of code together. One of them (called the *driver* or *pilot*) controls the keyboard. As he types, the driver keeps up a steady monologue explaining what he's doing. Or more properly, the monologue explains what the driver *thinks* he's doing.

One benefit of the stream-of-consciousness monologue is that it slows the driver down and forces him to think about his own code. Often when I've taught programming classes, simply making students explain what their code is doing is enough for them to find their own mistakes.

The second programmer of the pair (called the *observer*, *navigator*, or *pointer*) watches and reviews each line of code as it is typed. The observer makes sure the code makes sense and does what the driver thinks it does. The observer can also think about possible improvements or future changes. Basically, the observer performs an extreme, real-time, line-by-line code review. The two programmers switch roles frequently so they both stay fresh.

In practice, pair programming has been shown to have several advantages. It improves quality, largely because the code is constantly reviewed by two programmers with slightly different points of view. Pair programming takes more time (in person-hours), but it more than compensates by reducing the number of bugs. The programmers are more confident in their code, learn to communicate more easily, and share knowledge constantly so that they can learn new skills. Most programmers even find pair programming more fun.

PAIR PROGRAMMING PROBLEMS

Earlier in this chapter, I said that one disadvantage to RAD techniques is resistance to change. It's often hard to get people to adopt new techniques, and pair programming is a good example.

Programmers who have worked alone often find it hard to switch to pair programming. It feels unnatural having someone constantly looking over your shoulder. Some programmers eventually get used to it, but it may be a tough transition.

Pair programming is also sometimes used by management as an excuse for removing the developers' personal space. Anyone who does more than performing simple implementation tasks sometimes needs somewhere quiet to sit and think without interruption. (And I don't mean the library.) They need an office where they can shut out the world and focus on complex problems. If developers spend all their time in shared offices or large group areas, they won't find the best solutions to tough problems.

Communication is important but not to the point of distraction.

XP Roles

Many agile models define specific roles for the people participating in the project. The following list summarizes the most common XP roles:

- **Customer**—Defines the requirements, verifies that the application meets the users' needs, and provides frequent feedback to keep development on track. Sometimes, several customers may be involved, but on a daily basis, a single on-site customer usually plays the main customer role.
- **Tracker**—Monitors the team members' progress and provides useful metrics.
- **Programmer**—Defines the application's architecture and writes the code.
- **Coach**—Helps the team work effectively, self-organize, and use good XP practices.
- **Tester**—Helps the customer write and perform acceptance tests for use cases; looks for missing requirements and holes in the design.
- **Administrator**—Sets up and maintains the team members' computers, network, and development tools.

Exactly which roles are used on different projects varies somewhat. For example, some teams add extra roles such as a doomsayer who looks for trouble and a manager who goes to meetings and generally acts as an interface between the team and the outside world.

Some of these roles can also be combined. For example, the administrator is usually also a programmer, and the manager might also be the tracker.

Some combinations of roles should not be allowed. For example, a programmer probably shouldn't be combined with the customer, tester, or tracker.

XP Values

Like agile, XP has a collection of values and principles. Following are the values:

- **Communication**—The requirements must be communicated from the customers to the developers so that everyone acquires a common vision of the system's goals. Communication is aided by simple designs, extensive collaboration, frequent interaction, shared metaphors, and regular feedback.
- **Simplicity**—XP encourages simple designs. The application should start with the simplest possible approach, and then more features are added later only if necessary. Sometimes, this approach is referred to as "you ain't gonna need it" (YAGNI, pronounced YAG-nee).
- **Feedback**—Frequent unit and integration tests provide feedback about the code's quality. Customers give feedback through periodic reviews (every couple weeks) about the application's direction and usability. The developers give feedback to customers about how difficult and time-consuming changes will be. Finally, pair programmers give each other feedback on their designs and code constantly.
- **Courage**—Developers must have the courage to:
  - Start with simple solutions even when they know of more complicated approaches. (Solve the problems of today, not those of tomorrow.)
  - Refactor code when necessary.
  - Throw away code when necessary.
  - Provide feedback.
- **Respect**—This value was added in the second edition of the book *Extreme Programming Explained: Embrace Change* by Kent Beck and Cynthia Andres (Addison-Wesley, 2004). This includes respect for others as well as self-respect. Team members respect the project by striving for higher quality and never committing code to the project that will break the build. They respect others and consider their feedback.

XP Practices

XP projects use an assortment of practices to satisfy the XP values. There are some variations in the specific practices used by different XP projects, but they all have more or less the same flavor. The following list gives some of the most common of those practices:

- Have a customer on site.
- Play the planning game.
- Use standup meetings.
- Make frequent small releases.
- Use intuitive metaphors.
- Keep designs simple.
- Defer optimization.

- Refactor when necessary.
- Give everyone ownership of the code.
- Use coding standards.
- Promote generalization.
- Use pair programming.
- Test constantly.
- Integrate continuously.
- Work sustainably.
- Use test-driven and test-first development.

The following sections provide more detail about those practices.

Have a Customer On Site

If possible, keep a customer on site so that the developers can ask questions whenever necessary. Ideally, that customer should have the authority to make decisions so that work can keep moving without waiting for management approval. (You don't want to try to get three levels of management to sign off on a design change during the winter holiday season! You may as well go home until the middle of January.)

Give the customer an office, cubicle, futon, or whatever work space is appropriate for your environment. Make sure the customer feels like a team member and not an interloper trespassing on your territory.

Play the Planning Game

The *planning game* has two parts: release planning and iteration planning.

During release planning, the team focuses on the next customer release. To do that (and to make the process more like a game and less like work), user stories are written on cards. The team shuffles the cards around and tries to determine how many of the cards can be implemented in time for the next customer release.

Developers ensure that the time estimates for the stories are reasonable. Customers help decide which stories are most important. Together the developers and customers create a release plan that is realistic and that gives the customers the functionality they need most as quickly as possible.

You need to create a realistic release plan. Sometimes, the customers may pressure the developers to reduce the time allowed for crucial tasks. The developers need to resist to ensure that the final plan is sensible. An unrealistic release plan will only cause headaches for everyone later.

The second part of the planning game is iteration planning. At the beginning of each iteration (usually every 1 to 3 weeks), the team gets together to develop a plan for that iteration. The team selects user stories from the current release plan, starting with the most important outstanding stories.

The iteration plan should also include any items from the previous iterations that haven't passed their acceptance tests. For example, if the customers decide they want a particular feature changed, that change goes in the current iteration plan.

After the team has picked the most critical tasks to add to the next iteration, the developers pick the tasks they will perform (in good self-organizing fashion). Each developer estimates the amount of time needed for the tasks he picked. (Note that different people may need different amounts of time for the same tasks.) Ideally, each task should take no more than one to three days.

SPIKE IT

In XP, a *spike* or *spike solution* is a quick throwaway prototype used to explore a solution to a particular problem. You can use a spike to study a possible approach to see if it will work, to compare different approaches, or to make a better estimate of how difficult a task will be to reduce planning risk. If you're unsure about how to do something or how long something will take, spike it.

The team can adjust the tasks to give the iteration a reasonably short length. If the task estimates make the iteration too short, you can add a few more tasks from the release plan. If the iteration seems too long, you can defer a few tasks until the next iteration. You can also break a task into smaller subtasks if necessary to achieve the right iteration length.

Use Standup Meetings

Start each day with a *standup meeting*, a brief meeting that lasts 15 minutes or less. All team members (including the onsite customer) must attend the standup meeting and briefly tell what they did since the last meeting, what they hope to achieve before the next meeting, and any problems they foresee in getting that work done.

The meeting is called a *standup* meeting because typically the participants remain standing to encourage brevity. If you have a five-person team and you want to hold the meeting to 15 minutes, everyone needs to stay focused. (You do the math.)

You can hold the meeting in front of the Big Board and refer to it if necessary. You may also want to hold the meeting first thing in the morning while everyone is fresh and before people get deeply involved in their tasks. (Of course, people may have different ideas about what "first thing in the morning" means and not everyone is fresh at 8:00 a.m. Use some self-organized negotiation.)

ADDING VARIETY

If weather permits, try occasionally turning a standup meeting into a short walk outside (as long as you don't need to refer to the Big Board). You can adjust the duration and speed of the walk according to the team members' physical condition and enthusiasm.

Standup meetings have the nice side effect of keeping developers focused on their tasks. If you tell everyone you're going to design the vehicle inventory tables today, you either need to do it or tomorrow you'll need to admit to everyone that you didn't.

The standup meeting removes the need for most other meetings, but you can have others if you need to address a particular problem. For those meetings, only the people directly involved should attend, so the rest of the team can keep working on their tasks.

As any effective manager can tell you, you should try to keep all meetings focused and on track. A meeting should have a purpose other than running out the clock until quitting time.

Make Frequent Small Releases

Ideally, each release should have a relatively short timeframe so that you can give the customers useful software as soon as possible. This also lets you get frequent feedback from the customers. The longer it is between releases, the farther off course the project can wander before it's corrected.

You can think of each release as checking a roadmap. If you don't check the map often enough, then your trip from Indiana to Mississippi might take you through North Carolina.

Frequent iterations also force you to perform integration tests so that you can flush out bugs sooner.

Use Intuitive Metaphors

If possible, use easy-to-understand metaphors to describe the system. If the customers and developers share a common metaphor, they are more likely to share a common vision of the application.

For example, many websites use a shopping cart metaphor. Just telling visitors they have a shopping cart lets them make several reasonable assumptions. For example, they know they can add things to the cart, remove things from the cart, and go to the checkout area to buy whatever is in the cart at the time. Other common programming metaphors include the waste basket, desktop, file, and document. If you can describe your system with an intuitive metaphor, it will be easier for the users to learn.

Keep Designs Simple

Use the simplest design that can handle the immediate task. If you have to, you can modify the design later to satisfy later needs. If you make the design overly complicated now, you may end up wasting a lot of time building flexibility that you never use.

Defer Optimization

This is a hard rule for many developers to accept. You spend years in school learning the most efficient ways to store data, sort numbers, and search databases. Now you're told to throw all that away and ignore optimization.

Unfortunately, highly optimized code is often complicated, confusing, hard to debug, and even harder to modify later. Combine that with the fact that few software engineering projects fail due to slow performance, and it's clear that you shouldn't optimize code unless it's absolutely necessary.

Most code doesn't actually need to be all that fast. Modern computers, memory, databases, networks, and other pieces that make up a system are so fast that they spend most of their time sitting around twiddling their electronic thumbs waiting for the user to do something anyway. Does it really matter whether a screen pops up in 10 milliseconds or 2 milliseconds if it then takes the user one-half a second to notice it's even there? Probably not.

In most projects, a relatively small amount of the code (as low as 5 or 10 percent) determines the overall speed of the application. Start with no optimization. Later if the performance is unacceptable (and *only* if it's unacceptable), use a code profiler to figure out which parts of the code are wasting the users' time and optimize only those pieces of code.

I have seen several projects fail because they didn't work. I've never worked on a project that failed because it worked correctly but too slowly.

I worked on one project that was so slow a user could make a single change to a sales model and then wait 20 minutes for the analysis to update. The user would review the results, make another change, and then wait another 20 minutes. The company continued using the application for years despite its amazingly bad performance!

First make the application work. Then make it work faster only if absolutely necessary.

Refactor When Necessary

Because you're keeping the design simple, you'll sometimes need to rework old code to make it do new things. Don't be afraid to refactor when necessary.

This is one of the places where you may lose time over a BDUF project. If a BDUF design is correct, you can start by implementing the final design. XP tells you to use the simplest possible design to handle your current needs and then refactor it later if necessary, so you sort of sneak up on the final design. The refactoring takes extra time that the BDUF project doesn't spend (at least in theory).

GETTING A JUMP ON REFACTORING

I'm not a big fan of being intentionally stupid. (That's why I seldom listen to politicians' speeches.) The idea behind the "start simple and refactor if necessary" approach is that *most of the time* you'll avoid doing unnecessary work and you'll need to refactor only occasionally.

If you're absolutely positive that you're going to need some other design feature at a later point, you should at least write the code so that it'll be easier to refactor later. In particular, the observer can tell the driver to insert comments in the code indicating where that refactoring might occur.

Better still, move the feature that will later require refactoring into the current iteration. Then the simplest design possible will not require refactoring later.

Give Everyone Ownership of the Code

The team should have the sense that everyone owns all the code so anyone can change any piece of code as necessary. In a self-organizing team, you have the power to modify all the code if you need to.

However, there's sometimes an advantage to having a particular person work on a piece of code. For example, it might be better if the senior algorithms expert works on the tricky algorithm that forms the heart of your application instead of letting the high school summer intern mess up the code. That shouldn't be a problem because the algorithm guru will probably pick that task during the planning game.

In general, however, no one should need to wait for someone else to work on a particular piece of code.

CODE COORDINATION

Use document and code management systems to ensure that only one team member works on a particular document or piece of code at any given time. You want everyone to be able to modify any piece of code, but not at the same time.

Use Coding Standards

To make it easier for every team member to modify any piece of code, the team should adopt coding standards and conventions. If all the code uses a consistent style, it's easier for anyone to read, understand, and modify.

Promote Generalization

Encourage team members to learn about every piece of the system. Ideally, everyone should know as much as possible about every nook and cranny in the application. That helps with the preceding goal of allowing anyone to work on any piece of code. It also lets all the team members acquire new skills and become more valuable team members. Some day you may want to offer the summer intern a permanent job.

Again on the theme of not being intentionally stupid, if your team includes a Ph.D. in algorithms research, the other team members may have some trouble following all the details about how your MMO's differential intelligence swarming algorithm makes the zombies chase the players. That doesn't mean you shouldn't try. You may not figure it all out, but you can probably learn something.

For more typical programming tasks, such as database design, user interface creation, and integration with external systems, everyone should at least pick up the basics.

Use Pair Programming

This gives you constant code reviews. See the earlier description of pair programming for details.

Test Constantly

Test thoroughly, test everything, test often. Even if a piece of code passes all its tests in one iteration, keep testing it in future iterations. You may not find a mistake in *that* piece of code, but its tests may uncover a problem in some other related piece of code.

Automate as much of the testing as possible so it's easier to run the tests. Tests that are easy to run are more likely to be run and run more frequently.

When you find a bug, add a new test that would detect the bug sooner in that code and in other pieces of code if possible. Add it to the test suite so that you can catch similar bugs in the future.

Test, test, test!

Integrate Continuously

The entire application should be rebuilt, integrated, and tested as frequently as possible to flush out bugs. Many teams rebuild and test the system weekly or even every night. If the testing is automated, you can kick it off before you turn out the lights on your way out the door and then review the test log first thing in the morning.

That doesn't mean developers will never have unfinished code lying around. If a task will take three days, it won't be ready for two nightly builds. In cases like that, you should keep your new code in your own separate directory and add it to the project's main code repository only after you have it finished and thoroughly tested so that you don't break the project's build.

You can make integration testing a bit easier if you dedicate a computer to just that purpose. None of the developers should use it for day-to-day programming chores, so it doesn't become cluttered with the developers' unfinished novels, fantasy football playoff brackets, and pictures of cats using poor grammar. You may even want a separate staging computer where you can prepare for release deliveries.

Having a dedicated integration computer also ensures that only one programming pair can integrate at a time, so pairs don't trip over each other.

Work Sustainably

This doesn't mean you should use computers made only from bamboo and powered by solar panels. (Although that would be very cool!) It means you need to set a working pace that all the team members can keep up indefinitely. Short release and iteration cycles provide a lot of benefits, but you should keep them short by not including too much in each cycle, not by making the developers work 60-hour weeks.

Encourage (by force if necessary) developers to work only 40-hour weeks and discourage overtime.

Pushing the team to meet arbitrarily shortened deadlines leads to burnout, crankiness, and employee turnover. Rested developers are more enthusiastic and productive.

Use Test-Driven and Test-First Development

In *test-driven development* (*TDD*), you start with a piece of code, which might initially be empty or a stub that doesn't do anything. You then pick a function that the code should perform and you write a test that would verify that the function worked properly if the code did it.

Next, you see if it passes the test. Normally, the code fails because you haven't yet given it any code to perform the function you're testing. If the code does somehow pass the test, then it was a crummy test because the code doesn't perform the function yet! In that case, write another test and try again until the code fails.

After the code fails, write new code to perform the function. Add the simplest piece of code that can satisfy the test and nothing extra. Don't anticipate future functions by writing code to handle them, too. You'll get to that later.

Now run the new test(s) plus any previous tests that you wrote for earlier functions. If all goes well, the code passes all the tests this time. If the code fails, fix the code and try again until it passes all the tests.

When the code passes all the tests, refactor if necessary to clean up the code and move to the next function. Because each incremental piece of code you added satisfies only the current test and does nothing more, you'll often need to refactor to integrate the separate pieces into a maintainable section of code.

Figure 14-2 shows the TDD process in a flowchart.

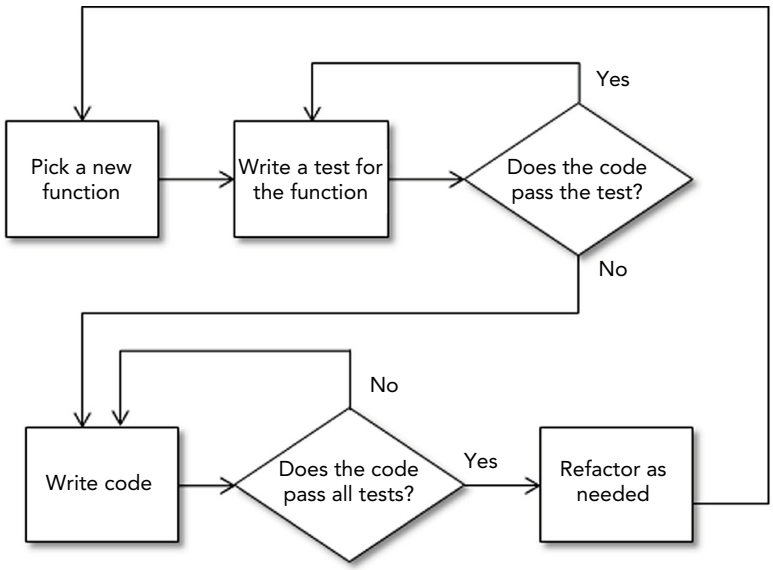


FIGURE 14-2: In test-driven development, you write a test for each function before you write the code to perform the function.

Test-first development is closely related to test-driven development. In *test-first development* (*TFD*), you write all the unit tests for a piece of code before you write the code. You then write all the code. You can add more tests if you think of them while you're writing the code. After you write the code, run the tests and fix the code if it doesn't pass.

IS TDD TFD?

Some developers use test-first development to mean any method where you write tests before you write code. By that definition, test-driven development is one kind of test-first development. I prefer the "write all the unit tests first" definition.

The difference is that in TDD you sneak up on the finished code a bit at a time in the smallest possible steps. In TFD you write all the tests at once and then you write all the code at once.

The main advantage to TFD is that it enables you write the unit tests before your brain is contaminated with knowledge about how the code works. That means you're more likely to build

tests that look for correct and incorrect *results* instead of testing to see if the code works the way you *think* it does. After all, the code may work the way you think it does and still not do the right thing.

SCRUM

Scrum was named after a procedure in rugby that the teams use to put the ball back into play after an accidental rule violation such as the ball going out of bounds. The players huddle together in a big interlocked mob, and then someone throws the ball under the players' legs. The players try to hook the ball out with their feet and take possession of it.

I actually think it's a strange word to use for a software development method. In rugby both teams are locked in the scrum and fighting against each other for control of the ball, which is hardly a model for the kinds of cooperation you'd like in a software development team. Perhaps it's the way something useful pops out of a big chaotic pile of people pushing against each other that reminds people of software engineering.

Scrum Roles

The members of a Scrum team play three roles.

- **Product owner**—Represents the customers, users, and other stakeholders. The product owner writes user stories to describe the project's goals and then prioritizes them. The resulting prioritized list of wanted features is called the *product backlog*. (I've always thought "backlog" was a somewhat harsh term implying you're already behind and playing catch-up. Starting a project with a huge backlog feels kind of like being born owing back taxes.)

  As the liaison between the development team and the stakeholders, the product owner has the following duties.

  - Defines the requirements and verifies that the product meets those requirements
  - Sets requirement priorities; helps determine which requirements make it into the next iteration given resource constraints
  - Keeps the stakeholders posted on the project's status; demonstrates the product to the stakeholders
  - Plans and announces releases
  - Provides a point of contact between the stakeholders and developers

  The product owner generally shouldn't modify an iteration while it is underway; although, he can make changes in the next iteration and can cancel an iteration if necessary (for example, if the product owner decides the biggest goal of the sprint is obsolete).

- **Team member**—These are the self-organized cross-functional team members who build the application. During each iteration, each team member helps handle all the typical tasks you need to write a decent piece of software (analysis, design, program, test, document, and so forth).
- **Scrum Master**—The Scrum Master acts as a remover of obstacles for the team. This person also ensures that the team follows good Scrum practices, challenges the team to improve,

and sometimes leads meetings. Typically, a Scrum Master isn't a project manager because the team is self-organizing, so it guides itself. Some even say that adding a project manager to a Scrum project makes things harder. (Note that most Scrum Masters don't like being called Scrum Bags; although some might be okay with the title Scrum Lord.)

Notice how homogenous most of the team members are. The product owner and Scrum Master are different, but everyone else is part of the same egalitarian team, sharing duties and guiding themselves in a good self-organizing manner.

Scrum Sprints

A Scrum project creates a series of timeboxed incremental iterations, which are usually called *sprints*. In traditional Scrum, a sprint is 30 days long; although some people prefer shorter sprints of one, two, or three weeks.

The result of each sprint is a fully tested and approved piece of software, which is sometimes called a *potentially shippable increment* (*PSI*). You could actually deploy a PSI to the users; although, you may want to wait and release a version of the application only when there are enough new features to justify the inconvenience to the users.

Before each sprint begins, the team holds a *sprint planning meeting*. Typically, that meeting is timeboxed to four hours so that it doesn't take up too much time.

During that meeting, the product owner decides which user stories should be selected for the upcoming sprint. The goal is to provide the greatest benefit to the users in each iteration, so the most useful items should be selected. Fixes for any outstanding bugs should also be included.

The developers can ask for clarification and point out any potential problems. When the meeting is done, the selected items are moved from the product backlog into the *sprint backlog*. The product owner is then usually asked to disappear (but stay close in case of questions) while the developers break the user stories into tasks.

After the sprint's goals and tasks have been defined, the developers roll up their sleeves, divide up the tasks, and really get to work. They analyze the tasks, design solutions, write code, and test.

During the sprint, the team holds a quick 10–15 minute *daily scrum* (sometimes called a "standup," although "scrum" seems more scrummy) where each developer answers the Three Questions of Agile Development:

- What did you do since the last scrum?
- What do you hope to accomplish before the next scrum?
- What obstacles do you see in your way?

If a developer sees looming obstacles, the Scrum Master looks into them (to earn the coveted title Remover of Obstacles.)

After all the work is done, the sprint ends with a *sprint review meeting*. The development team presents the current PSI to the product owner, who checks the results against the items that were originally selected for the sprint to make sure the sprint's goals have been met. If the application can't handle even part of any of the user stories, the product owner can flag that story as unfinished.

After the sprint review meeting, the Scrum Master and the development team hold a *retrospective meeting* where they discuss the recent sprint. Here they discuss the three big questions about any development method and particularly any iterative method:

- What went well and how can we make it happen again?
- What went poorly and how can we avoid that in the future?
- How can we improve the next sprint?

Planning Poker

In Scrum, *planning poker* (also called *Scrum poker*) is a game you can play to decide how much work a particular task might be. Each team member gets a deck of cards with values based roughly on the Fibonacci sequence. In that sequence, each number is the sum of the two previous numbers: 0, 1, 1, 2, 3, 5, 8, 13, 21, etc.

The cards used for the planning game are modified somewhat, but the idea is that task lengths typically follow a distribution similar to the numbers in the Fibonacci sequence.

What that means is that fine distinctions between the durations of large tasks aren't very meaningful. For example, the difference between a one-hour task and a two-hour task is quite large, but the difference between a 21-hour task and a 22-hour task isn't. The difference is still one hour, but the uncertainty in estimating the task's duration is likely to be more than an hour anyway, so you can't really tell which of the two large tasks is harder.

Some teams use actual playing cards and give each player an ace, 2, 3, 5, 8, and king, where the king represents a task too big or too complicated to talk about presently.

You can also make your own decks or buy commercially available decks. Some decks use the values 0, 1, 2, 3, 5, 8, 13, 21, 34, 55, and 89. Others use qualitative values such as extra-small, small, medium, large, and extra-large.

Other decks use 0, ½, 1, 2, 3, 5, 8, 13, 20, 40, and 100. Those are similar to the Fibonacci numbers with some rounding to make them a bit more palatable. (It's more intuitive to tell the customers that a feature will take a nice round 40-hour week instead of 34 hours because a value such as 34 implies an unrealistic level of certainty.)

Some decks also include a question mark card to indicate that an item will take an unknown amount of time, and a coffee cup card to indicate that you need a break.

After everyone has a card deck, the game begins. The meeting moderator, who normally doesn't play the game, reads a user story and then leads a brief discussion of restrictions, risks, and assumptions. (Some teams use an egg timer to ensure that the team doesn't spend too much time on any single story.)

The players select cards from their decks and place them face-down on the table. When everyone is ready, they turn their cards over simultaneously.

Having the players turn their cards over at the same time helps prevent *anchoring*, a phenomenon in which early decisions anchor later decisions. For example, suppose you're trying to decide whether you want to assign a task a 2 or 3, but then another team member plays a 34. You might decide that

you grossly underestimated the task and decide to bump up to an 8. Playing your cards at the same time gets more honest estimates from everyone.

After everyone plays a card, the people with the highest and lowest estimates are given a *soapbox* to explain why they feel their estimate is correct. Who knows? The guy who played a 34 when everyone else played 2 or 3 might know something that everyone else doesn't.

After the soapboxing, you gather up your cards and do it again. You repeat the process until the group reaches a consensus for that item. Write down the number of points for that story (called its number of *story points*) and move on to the next item.

When you're done, you'll have a list showing estimates of the difficulty of all of the project's user stories.

Burndown

Scrum uses burndown charts to measure progress. A *burndown chart* shows the amount of work remaining plotted over time. A *sprint burndown chart* shows the amount of work for a sprint. A *product burndown chart* (also called a *release burndown chart*) shows the amount of work remaining for the whole project.

You can measure the amount of work in story points, expected number of hours of work, or any other measurement you find useful. You can let the chart's X-axis show the date or, for a project burndown chart, the sprint number.

Figure 14-3 shows a product burndown chart. When you know the total amount of work and the project's planned duration, you can calculate an ideal burndown by assuming you can do the same amount of work in every sprint.

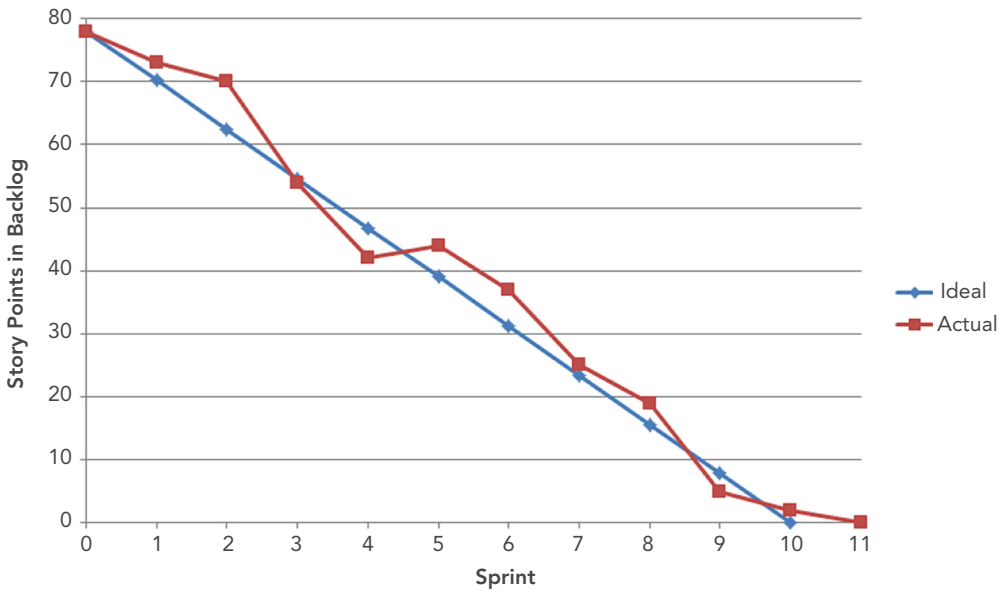


FIGURE 14-3: A project burndown chart shows the amount of work remaining for each sprint.

BOOK BURNDOWN

Sometimes, I use a chart similar to the one in Figure 14-3 to track my progress while writing a book. I plot the average number of pages I need to have written for each day plus the number of actual pages I've written. That lets me see at any point whether I'm on schedule or falling behind. Unless I keep a careful track constantly, it's easy to fall far behind, and then catching up can be hard.

In practice, rather than telling me how far behind I am, the chart usually shows me how far ahead I am. That lets me decide how much goofing off I can do (things like maintaining the C# Helper website `www.csharphelper.com`, making audio training lessons, answering e-mail, eating, and sleeping).

As the project continues, some sprints will be more productive than others, so the actual progress won't follow the ideal burndown exactly. You can use the burndown charts (which should be posted on the project's big board so that everyone can see them) to decide if the project is getting too far off of its targets.

In Figure 14-3, the project started a bit slowly but caught up to the ideal burndown and even pulled ahead after sprints 3 and 4. During sprint 5, the project lost ground, either because new goals were added to the project backlog or because some tasks turned out to be harder than expected. The project caught up again during sprint 9 but then slowed down a bit and finished one sprint later than planned.

Velocity

A project's *velocity* represents the amount of work the team can perform during a sprint. To calculate the velocity during a sprint, simply add up the number of features the sprint delivered. To calculate the number of features, you can use story points, backlog items, or any other measure that you find useful.

For example, suppose your team implements 12 story points during a sprint. Then the velocity during that sprint is 12.

Usually, after a few sprints the team's velocity becomes relatively stable and you can use it to estimate how much work future sprints can accomplish. However, there are a couple of reasons why velocity might fluctuate. For example, Scrum teams are usually fairly small (somewhere around three to nine people), so adding or removing a single person can make a big difference. Removing one person from a four-person project means losing 25 percent of your staff. Because the sprints are relatively short, you may even see this effect if a single developer takes a week's vacation or is sick for a few days.

Velocity will also vary if you change the length of the sprints; for example, switching from four weeks to two weeks.

Because Scrum focuses on project management and not developmental details, you can combine it with other development methodologies. For example, you can use Scrum to set up the iterations used in an XP project.

LEAN

Lean Software Development (also called simply *Lean* or *LSD*) isn't a much-needed attempt to help programmers lose weight. (Actually, all agile methods should help by maintaining a sustainable pace, so programmers have time to get some exercise instead of sitting in front of their keyboards all day. Whether they decide to actually go out and get that exercise instead of going home to watch YouTube videos is their decision.)

Instead, Lean is an application of principles learned in lean manufacturing to software engineering. The idea behind Lean is to keep the application as lean and fat-free as possible. Nothing should go into the application that isn't there for a good reason.

Like Scrum, Lean focuses on managing iterations of development. Lean focuses more closely on gathering the right requirements and ensuring that only essential ingredients get into each iteration.

Lean Principles

Like some other agile methods, Lean defines a set of guiding principles.

- **Eliminate waste**—Anything that doesn't contribute directly to the project should be regarded as waste and eliminated. That may include such items as:
  - Unclear requirements. (Clarify or eliminate them.)
  - Unnecessary features and code. (Don't make the code unnecessarily flexible.)
  - Unnecessary repetition. (Some ways to avoid repetition include refactoring to make methods that perform common tasks, automating testing, and keeping records so that you don't need to make the same decisions twice.)
  - Unnecessary meetings and bureaucracy. (It's every developer's dream to eliminate those!)

  If something doesn't add to customer value, leave it out. If you can leave something out and still achieve the project's goals, leave it out.
- **Respect the team**—Give the team the respect and authority it needs to work effectively. Help the team self-organize.
- **Defer commitment**—Don't make decisions until you know enough to make them intelligently. If you can't make a decision on a feature, design, or other element without making a lot of assumptions, defer the feature until a later iteration. Don't start building grand designs until the customers know what they need. Explore alternatives before deciding on which approach to use.
- **Deliver quickly**—Use frequent short iterations to deliver value to the customers as quickly as possible.
- **Build knowledge**—Learn as much as possible. Use prototypes and other methods to learn requirements. Use early testing to learn about bugs before they're hard to find. Use short iterations to ensure that development is on the right track.

- **Build quality in**—Validate assumptions throughout the project. If an old assumption no longer applies, discard it. If new assumptions arise, add them. Ensure the project has an integrated, consistent feel. Refactor if the code loses its integrity and becomes hard to maintain and modify.
- **See the whole**—The team should be cross-functional so everyone can work on every step of development (analysis, design, programming, and so forth). Everyone should see the big picture, and spot and fix problems in any part of the system. No one should think of a problem as someone else's problem. If the project has a problem, everyone has a problem.

Like Scrum, Lean focuses on project management and not developmental details. That means you can combine it with other development methodologies. For example, you can use Lean ideas to set the goals for an XP project's iterations.

CRYSTAL

Crystal isn't actually a development model. Instead it's a family of development methodologies developed by Alistair Cockburn in the 1990s that all have the word "Crystal" in their names. The rest of each method's name is a color that indicates a project's size. For example, Crystal Clear (the most popular color) is intended for small projects.

The following list shows the Crystal method names and the numbers of developers they generally support:

- Crystal Clear (1–6)
- Crystal Yellow (7–20)
- Crystal Orange (21–40)
- Crystal Orange Web (21–40)
- Crystal Red (41–80)
- Crystal Maroon (81–200)
- Crystal Diamond (201–500)
- Crystal Sapphire (501–1,000)

The project's criticality is gauged by the types of items that are at risk:

- Comfort
- Discretionary money
- Essential money
- Life

For example, a game would have comfort criticality and a nuclear power plant control system would have life criticality.

Figure 14-4 shows the possible combinations of the two dimensions: color and criticality.

	Clear 1-6	Yellow 7-20	Orange 21-40	Red 41-80	Maroon 81-200	Diamond 201-500	Sapphire 501-1,000
Comfort	C6	C20	C40	C80	C200	C500	C1000
Discretionary Money	D6	D20	D40	D80	D200	D500	D1000
Essential Money	E6	E20	E40	E80	E200	E500	E1000
Life	L6	L20	L40	L80	L200	L500	L1000

FIGURE 14-4: Crystal defines a matrix of color and criticality combinations.

The values in the table's body show an abbreviation that tells you a project's criticality and size. For example, a project involving discretionary money with 35 project members would be a D35 (Orange) project.

WHERE'S CRYSTAL ORANGE WEB?

Crystal Orange Web was a special case designed by Alistair Cockburn to produce a continuing stream of applications for public use in an E50 project. (Yes, I know the table would make that a Red project, but Cockburn decided to call it Orange.) The Orange Web model doesn't seem to have been used much, but Cockburn believes it may have some value because many businesses seem to be headed toward this sort of never-ending development cycle.

All the Crystal methods have the following seven common features.

- **Frequent iterations**—Frequent iterations result in releases. In critical projects, only some of the releases might be delivered to the users; although the customers can view the others to provide feedback.
- **Constant feedback**—The team meets regularly to discuss development and ways it can be improved. The team also meets with customers to keep the project on track.
- **Constant communication**—Team members should be located at the same location so that they can communicate easily and frequently. For small projects, they should ideally be in the same room (which the developers will probably give an amusing name such as The Pit, The Clubhouse, or The Thunderdome).
- **Safety**—Crystal projects define three kinds of safety. First, team members can express their opinions safely without fear of blame. Second, the project should be safe in the sense that it should finish on time and within budget. Third, you need to consider the project's criticality (comfort, discretionary money, essential money, and life). That kind of safety is more crucial in medical and flight software than it is in an online game.
- **Focus**—Team members should be given enough time to focus on their key items without interruptions such as phone calls, meetings, or requests to help the boss set up a printer.

(The Crystal rules say developers should be guaranteed at least two uninterrupted hours per day, and that they should remain with a project for at least two days before being moved to another project—although both of those seem minimal to me.) The focus of the project should also be clearly stated so that everyone knows exactly what the goals are. The project leader should prioritize tasks so that team members know what their highest priority tasks are.

- **Easy access to expert users**—The developers should be able to talk to the expert users to ask questions and request feedback. The Crystal rules say the expert should be available to meet at least two hours per week and be available for phone calls.
- **Testing support**—The team's environment should include automated testing and continuous integration to spot problems quickly. It should also include code management so that problematic code can be isolated and replaced with an earlier working version if necessary.

A key assumption in the Crystal family is that larger projects need more formalization to keep the developers organized. In a small four-developer Crystal Clear project, you can usually get away with a verbal understanding of the customers' needs, informal developer meetings, and a cross-functional team where everyone pitches in on everything.

That approach won't work with a 150-developer Crystal Maroon project. For such a large project, you'll need to add extra management tools such as a project hierarchy with multiple teams, more specialized roles (such as team leaders, a project manager, and testers), and progress tracking.

You also need to adjust the amount of control the project uses depending on its criticality. For example, a Crystal Clear online game project could have fairly flexible requirements and play testing. In contrast, a similarly sized life-critical project would need formal requirements, extensive testing, and rigorous verification.

However, given that different projects need different amounts of management and different levels of formality, the Crystal philosophy is that you should pick the minimal combination that can still do the job.

> *Everything should be made as simple as possible, but not simpler.*
>
> —Albert Einstein

Crystal's lightest colors are the most studied and used, so they're the ones described in the following sections.

Crystal Clear

Crystal Clear is a relatively relaxed and easy-going approach. You can probably get some idea of the general Crystal Clear ambiance from the following Cockburn quote:

> *The difference between Crystal Clear and Extreme Programming is that XP is much more disciplined, Crystal Clear is much more tolerant, even sloppy-looking. I would say XP is more productive, Crystal Clear more likely to get followed.*
>
> —Alistair Cockburn

One way to differentiate the Crystal methods is to look at the team member roles that are required. Crystal Clear requires only three roles.

- **Sponsor**—The person for whom the software is developed and who will ultimately sign off on the finished application.
- **Senior designer**—Someone who knows how to design the software and make any necessary technical decisions.
- **Programmer**—Someone who can write the code.

A project can have more than one person in each role (usually in the programmer role). Any other roles (such as project manager, tester, database administrator, or caterer) are played by the team members. For example, some or all the programmers could share the testing role, and the senior designer might also cater team meetings by buying donuts.

Because this is a relatively small project, the team can informally discuss the project's goals and keep them in mind fairly easily. The team may write use cases to ensure that specific goals are met.

Crystal Clear projects are expected to deliver production releases every two or three months, possibly with shorter nonreleased development iterations.

The main measure of progress is released software.

Crystal Yellow

With 7 to 20 team members, Crystal Yellow projects are slightly bigger than Crystal Clear projects. Because the team is a bit bigger, the project needs slightly more management.

For example, it's probably impractical to have 20 developers all work in the same room and constantly interrupt each other. It would also be hard (although perhaps not impossible) for everyone to work cross-functionally on every aspect of the application. (It would also be impossible to get 20 developers to agree on the same radio station to play in their shared workspace.)

To ease coordination for the larger group, a Crystal Yellow project might adopt the following practices.

- **Easy communication**—Even if the team isn't all squeezed into the same room, they still need to communicate easily.
- **Code ownership**—Teams could each own an area of the project. This lets each team focus on its own piece so that they don't need to know everything about everything. (Each team might work in a single room to improve its internal communication.)
- **Feedback**—End users provide frequent feedback. This reduces the need for detailed requirements.
- **Automated testing**—This is always a good idea, but with multiple teams working on the same project, it's even more important.
- **Mission statement**—This helps give everyone the same vision of the project. (This doesn't need to be a vacuous management-speak statement like, "Manifest box-externalized criteria

going forward to leverage end-of-play synergy and maximize stakeholder competencies." It should be a clear, verifiable statement.)

- **More formal increments**—Iterations should be timeboxed to a month and begin with a list of the features that will be included. The team still doesn't necessarily need to release the result of every increment.

The team still uses relatively informal communication to avoid extensive requirement documentation and to keep everyone headed in the same direction. (For those with a management-speech impediment, you could say "rowing in the same direction.")

Crystal Orange

Crystal Orange projects have 21 to 40 team members and typically last one to two years. They require even more management support to prevent people from tripping over each other.

These projects may add some of the following new roles:

- **Business analyst**—A domain expert to help define the application's purpose and provide feedback during development.
- **Project manager**—You *might* handle tracking for a Crystal Yellow project without a dedicated project manager, but a Crystal Orange project needs someone dedicated to tracking the project's progress.
- **Architect**—Someone to focus on the application's overall high-level design.
- **Team leader**—The project is broken into areas that are assigned to separate teams. Hopefully, they'll be self-organizing, but usually each team needs someone with a bit more experience to guide the team and to act as the team's point of contact with the rest of the project.

Projects this large may require specialized skills, so the team might include other specialists as needed. For example, it might include a requirements gatherer, database designer, user interface designer, mentor, toolsmith, technical writer, system manager, or tester. (It's unlikely that a project could get by with one business analyst, one project manager, one architect, and 37 programmers.)

The following tasks add more formality to the project to help keep it on track.

- **Requirements**—Smaller Crystal projects may not need requirements documents, but a project this size has too many details to handle informally.
- **Tracking**—The project manager (with help from everyone else) tracks tasks, progress, milestones, and potential risks. The project manager should produce status reports so everyone (including the customers) can see how the project is progressing.
- **Release schedule**—The schedule should indicate when production releases occur and (tentatively at first) what they contain.
- **Object models**—The architect needs to do something to justify the title.
- **Code reviews**—Designs and code need more formal review. This is a bigger project so design and code problems can cause a lot more trouble and be much harder to fix later.

- **Acceptance testing**—The customers should provide a more formal level of acceptance than is required by smaller projects.
- **Delivery**—These are more formal, so you should use good release techniques such as staged delivery and incremental rollout. Delivery may require user setup, documentation, and training.

By now I'm sure you get the idea. The "harder" members of the Crystal family require more formality and management overhead. The informal approach used by a four-person Crystal Clear project just won't work with a 40-person Crystal Orange project.

Projects larger than Crystal Orange seem to be rare (I haven't heard of any) but would require even more overhead, planning, and tracking if they were to get anything done (other than generating an avalanche of unread e-mail). Such large projects might need to split into teams composed of subteams, possibly with their own feature teams or working groups.

I shudder to think what a Crystal Sapphire project would be like. Even if you had seven teams with seven subteams of 10 developers, each would still get you only to Diamond size. You'd have to rent a convention center to hold a whole-project meeting. You might have easy communication locally, but you could spend years working on a 1,000 person project and not even meet everyone, much less communicate freely with them all.

Those giant Crystal projects seem to be as common as politicians voting themselves pay cuts, so I won't speculate about what they would look like.

FEATURE-DRIVEN DEVELOPMENT

Feature-Driven Development (*FDD*) is another iterative and incremental development model. Unlike most of the other agile models, FDD was created to work with large teams. (Originally, Jeff De Luca designed FDD to meet his needs on a 15-month, 50 person project in 1997.)

Where other models use risk, customer value, waste, or some other theme to guide development, FDD focuses on application features. At a high level, an FDD project builds a list of wanted features and then iteratively adds those features to the application until every feature has been added.

A more detailed view of FDD involves several roles, five phases, and milestones to ensure the iterations run smoothly. The following sections describe those pieces of FDD.

FDD Roles

FDD defines six main roles and a bunch of secondary roles. The following list summarizes the primary roles.

- **Project manager**—This is the project's administrative leader. The project manager tracks the project's progress, budget, and other resources. She handles all the administrative nonsense that companies typically try to inflict on employees so that the team can work effectively.
- **Chief architect**—This person is responsible for the project's overall programmatic design. The chief architect doesn't write the design but instead helps the team come up with a design cooperatively.

- **Development manager**—This person manages day-to-day development activities. The development manager resolves conflicts, makes sure the development teams have the resources they need, and referees if the chief programmers have disagreements they can't resolve.
- **Chief programmers**—These are experienced developers who are familiar with all the functions of development (design, analysis, coding, and so on). They lead teams of programmers who work on a set of assigned programming tasks. The chiefs help their teams solve design problems, and they resolve any issues that get in the way of their teams.
- **Class owner**—In many agile models, the code is jointly owned by the entire development team, so any member can modify anyone else's code. In contrast, FDD assigns ownership of each class to a specific developer. If a feature requires changes to several classes, the class owners get together to form a *feature team* that works to make the needed changes. The members of the feature team work closely together in a sort of many-headed pair programming group.
- **Domain expert**—These are customers, users, executive champions, and others who know about the project domain and how the finished application should work. They are the source of information for the developers. They are sometimes called *Subject Matter Experts* (*SMEs*).

The following list briefly describes secondary roles that an FDD project may have (mostly in larger projects).

- **Build engineer**—Sets up and controls the build process. This may include source code control.
- **Deployer**—Handles deployment. This may include tasks such as staging, setting up the users' environment, and converting old data into new formats.
- **Domain manager**—Leads the domain experts and provides a single point of contact to resolve domain issues.
- **Language guru** or **language lawyer**—Someone who is an expert in the programming language, technology, and other arcane items used by the team. Other developers can go to this person for help if necessary.
- **Release manager**—Gathers information from the chief programmers to track the project's progress.
- **System administrator**—Maintains the team's computers and network.
- **Technical writer**—Writes online and printed documentation and training materials.
- **Internaler**—Runs internal scripts to look for trouble. Verifies that the application meets the requirements.
- **Toolsmith**—Creates tools for the other developers.

Smaller projects may not need some of these roles. Often one person can play multiple roles. For example, an "ordinary" developer could also be the language guru or toolsmith.

FDD Phases

FDD projects move through five phases. The first three occur at the start of the project (during iteration 0, if you like that term) and the last two phases are repeated iteratively until the application is complete.

The following sections describe the five FDD phases.

Develop a Model

When the project starts, the team builds an object model for the application. To some, this may smell suspiciously like big design upfront. In FDD, however, the model is built quickly and iteratively with the assistance of *domain experts* (also called *Subject Matter Experts* or *SME*s).

The model's goal is to give the customers and the development team a common vision of the application's scope and goals. It should help everyone understand the domain's key concepts, interactions with other systems, potential problems, and ways the application will be used.

At this point, the model paints a broad picture, focusing on the application's breadth. Later it will be refined iteratively to provide the detail needed to actually implement the project's features.

Build a Feature List

The next step is to build a list of the features that make up the application. FDD technically defines a feature as an *action/result/object* triple where the *action* generates the *result* related to the *object*.

For example, a feature might be "calculate the customer's outstanding balance." Here the action is "calculate," the result is "outstanding balance," and the object is "the customer."

To help with large projects, FDD organizes the feature into a three-level hierarchy with the levels corresponding to areas, activities, and features.

The top-level groups the features by domain area. For example, an order-processing system might have the areas Order Tracking, Inventory, Billing, and Reporting.

The areas are divided into activities that represent things the user might need to do. For example, Order Tracking might be divided into the activities Create Order, View Order, Modify Order, Delete Order, and so on.

The activities are divided into features. These are the atomic operations that make up the activities expressed in FDD's action/result/object style. For example, the following list shows some of the features you might include for the Create Order activity:

- Find customer record (find/record/customer)
- Create new customer record (create/record/customer)
- Check order items' inventory availability (check/availability/item)
- Calculate order subtotal (calculate/subtotal/order)
- Calculate order shipping (calculate/shipping/order)
- Set order status to pending (set/status pending/order)

Converting the object model into a feature list is mostly mechanical (although it can take a while for a large project). The resulting hierarchy is called the *feature list*. (It may not be as snappy a name as "backlog," but at least it's descriptive.)

Plan by Feature

During this phase, the planning team prioritizes the features and builds an initial schedule. Groups of related features are assigned to the chief programmers and become their teams' feature lists.

Because FDD uses class ownership, the features assigned to a team also assign the classes that provide those features to the team. For example, if you assign a bunch of customer-related features to a team, then you'll probably want to assign the `Customer` class to that team. In that case, it also makes sense to assign the other `Customer` class features to the team.

In that way the object model helps group the features. Usually, the resulting groups are quite natural and intuitive, at least for features that are visible to the users. More esoteric features used internally by the application such as database tools, external interfaces, and scheduling systems may have little intuitive meaning to anyone other than the developers. In those cases, you can still use the object model to group related features.

Design by Feature

In this phase, the chief programmer selects a collection of features to be implemented in the next two-week iteration. For each selected feature, the chief programmer gathers the owners of the classes that will be involved into a feature team.

If the chief programmer thinks it's necessary, a domain expert can perform a *domain walkthrough* to review the feature. The expert can describe the feature's intent, requirements, side effects, data needs, and anything else that can help the feature team understand what the feature should do.

Next, the feature team (with guidance from the chief programmer as needed) creates sequence diagrams representing the feature. (Look at the "Sequence Diagram" section in Chapter 5, "High-Level Design," if you don't remember what those are.)

The class owners then write method prologues. A *method prologue* is a description of a method that includes its purpose, input and output parameters, return type, possible exceptions (ways the method can fail), and assumptions.

During the design phase, the feature team hopefully adds new details to the project's classes. The chief programmer updates the project's object model to show the new detail. (Remember the "Develop a Model" phase created only an initial model without a lot of detail. This phase fills out the model.)

Finally, the chief programmer holds a *design inspection* to make sure the new feature design didn't omit anything. The inspection can involve the feature team and possibly other project members, depending on what the chief programmer thinks would be most effective. For example, if someone outside of the feature team has experience doing something similar, it might be wise to include that person in the inspection.

When this phase is finished, the result is a *design package* that includes:

- A description of the package
- Sequence diagrams showing how the features will work

- Alternatives (if any)
- Updated object models
- Method prologues

The result is sort of like the start of a big design upfront project, but on a smaller scale. It may seem like a lot of overly formal work just to plan the implementation of a single feature, but the goal is for the chief programmer to prepare the other team members to move forward into the next phase with a good chance of success. All this setup is particularly necessary if the project is large and includes developers with varying degrees of skill and experience.

Build by Feature

Armed with the completed design packages, the class owners build the methods that implement the iteration's selected features. The new code is unit tested and run through a code inspection (held by the chief programmer). If everything looks good, the code is promoted to the project's build.

Figure 14-5 shows the relationships among the FDD project's five phases at a high level.

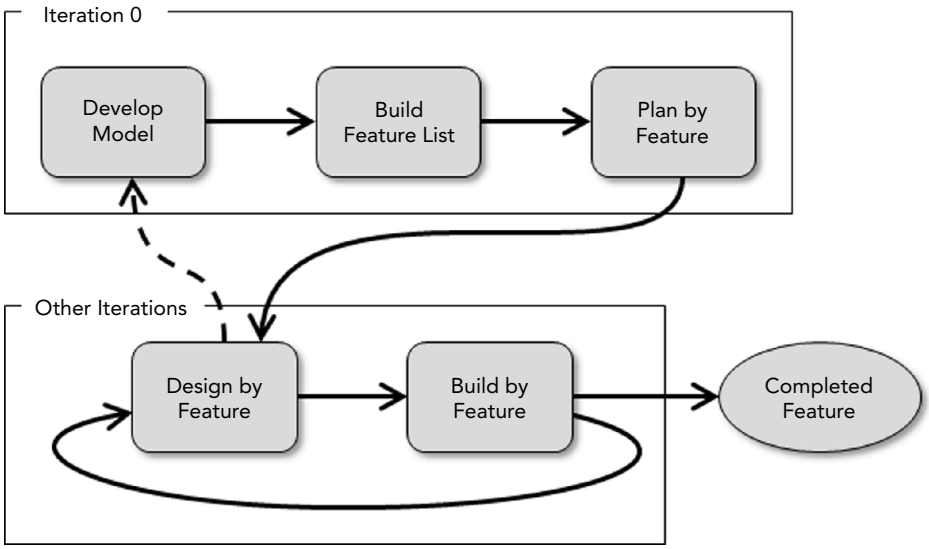


FIGURE 14-5: In FDD, the last two phases repeat for each feature iteration. The Design by Feature phase feeds changes back to the object model.

FDD Iteration Milestones

In an FDD project, the features must be implemented in no more than two weeks, so they are necessarily fairly small. Although the iterations are quick, they include a fair number of tasks.

To keep track of everything that's going on during an iteration, FDD defines six milestones. Table 14-2 shows the six milestones and the completion percentage each represents.

TABLE 14-2: FDD Milestones

PHASE	MILESTONE	PERCENTAGE
Design by Feature	Domain Walkthrough	1%
	Design	40%
	Design Inspection	3%
Build by Feature	Code	45%
	Code Inspection	10%
	Promote to Build	1%

For example, after the domain walkthrough (which is optional), design, and design inspection, an iteration is considered 1 + 40 + 3 = 44% complete.

Notice that the percentages give almost one-half of the iteration's credit to the Design by Feature phase. This reflects the importance of design, particularly for large projects with developers of varying skills. As mentioned earlier, the chief programmer (who is more experienced) uses the design phase to set up the team members for success during the build phase.

AGILE UNIFIED PROCESS

The *Agile Unified Process* (*AUP*) is an agile version of the Unified Process (UP) described in Chapter 13, "Iterative Models." Scott Ambler, who led the development of AUP (and who has written several books about agile development and UP), describes AUP as "serial in the large" and "iterative in the small."

By "serial in the large," he means AUP sequentially follows the normal four phases of the Unified Process: inception, elaboration, construction, and transition. By "iterative in the small," he means that AUP performs each of those phases iteratively.

Throughout its lifespan, the project involves the following seven disciplines:

- **Model**—Attempts to understand the problem being addressed, its restrictions and assumptions, and possible solutions. The result should be a model of a solution.
- **Implementation**—Converts the model into an executable program. It also includes basic testing such as unit testing. (You haven't finished implementation if your code doesn't work.)
- **Test**—Involves more testing to find bugs. It also validates the implementation to ensure that it satisfies the requirements. It may include normal validation tests such as user validation in a staging area.
- **Deployment**—Delivers the result. This may include any of the usual deployment tasks such as setting up the users' work environment, training, and actual installation.
- **Configuration management**—Manages the items produced by the project such as requirement documents, designs, and, of course, source code. It not only tracks versions of

those artifacts, but it also controls changes to them (so that one annoying customer can't make 20 changes to the requirements every day before breakfast).

- **Project management**—Guides the rest of the project. It includes identifying and mitigating risks, assigning tasks, tracking progress, and interacting with forces outside of the project team (and panicking when the team misses milestones).
- **Environment**—Supports the project by making sure the team has everything it needs such as hardware, software, training, manuals, caffeine, and administrative support. (It's well known that many developers who can type 74 words of code per minute can't write a simple business letter.)

Usually all these disciplines are going on simultaneously in varying amounts. For example, early on, the model discipline plays a major role while the deployment discipline is almost nonexistent. Figure 14-6 shows the general idea.

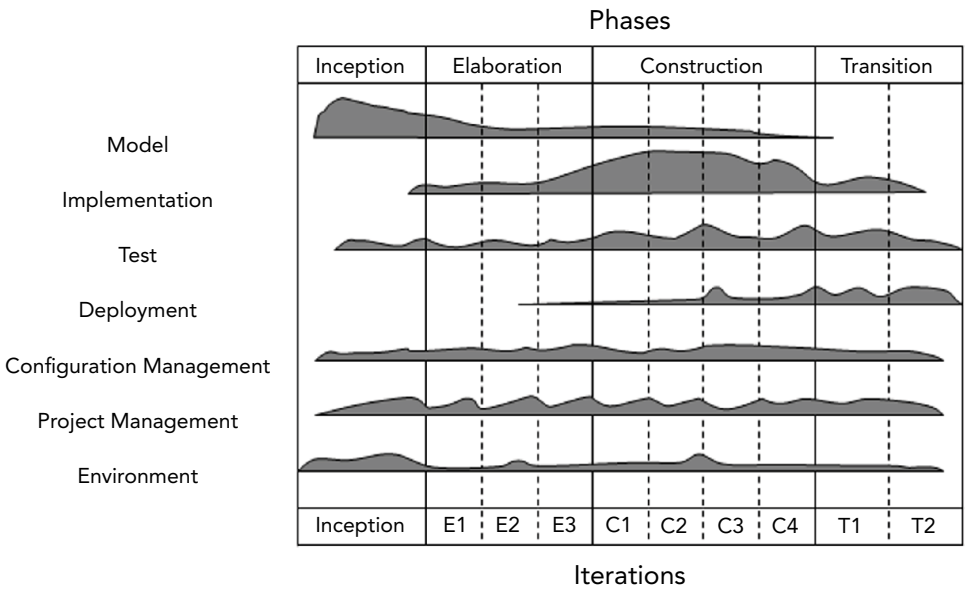


FIGURE 14-6: All the seven AUD disciplines occur simultaneously in different amounts.

If you were paying attention when you read about UP in Chapter 13, this should be familiar. One big difference is that UP is designed to produce a single release. In contrast, AUP can produce many agile releases. Typically, an AUP project will have many more iterations that are shorter than those used in UP.

Usually, most of the iterations end with a development build that isn't released to the users. (Although, it may be placed on a demo computer for the users to play with.) Only some of the iterations end in production builds that are deployed.

For example, Table 14-3 shows a possible AUP release schedule. The internal builds are iterations that aren't released to the users.

TABLE 14-3: AUP Project Release Schedule

ITERATION	BUILD TYPE	VERSION
1	Development	0.1
2	Development	0.2
3	Development	0.3
4	**Production**	1.0
5	Development	1.1
6	Development	1.2
7	Development	1.3
8	Development	1.4
9	**Production**	2.0
10	Development	2.1
11	Development	2.2
12	Development	2.3
13	Development	2.4
14	Development	2.5
15	**Production**	3.0

In a particular project, you might have more or fewer development builds for every production build. You'll have to weigh the features provided by a new release to the inconvenience to the users.

In 2012, Scott Ambler stopped work on AUP in favor of DAD, which is described in the next section.

DISCIPLINED AGILE DELIVERY

In the words of its inventor Scott Ambler, "The *Disciplined Agile Delivery* (*DAD*) decision process framework is a people-first, learning-oriented hybrid agile approach to IT solution delivery. It has a risk-value delivery life cycle, is goal-driven, is enterprise aware, and is scalable." (Any description that contains so many management-speak terms must be good!)

By now, most of those terms should be familiar to you and you can probably guess what they mean. The following section briefly describes the key pieces of that description.

DAD Principles

Here's a brief summary of the key terms in Scott Ambler's definition of DAD.

- **People-first**—In the DAD philosophy, the interactions among people play a critical role in the project's success. The DAD roles described shortly help define how people interact. DAD also uses typical agile ideas about allowing the team members to express themselves freely without fear of censorship or retribution.
- **Learning-oriented**—Throughout the project the team members should learn from each other to improve their cross-functionality. They should also constantly review their development practices and improve them if possible.
- **Hybrid**—DAD is based on Scrum but also takes ideas from Extreme Programming, Unified Process, Kanban, Lean, and others.
- **Agile**—Like most agile methodologies, DAD uses iterated development and delivers "consumable solutions" as they are ready. DAD encompasses the entire delivery life cycle (unlike some agile methods that focus mostly on development); although it doesn't actually require you to use a particular life cycle model, so you can keep your options open for some of the details.
- **Risk-value delivery life cycle**—During the inception phase, the team identifies risks. The team addresses risks throughout the project.
- **Goal-driven**—During each iteration, the highest priority requirements are pulled into the goals for that iteration.
- **Enterprise aware**—DAD emphasizes several levels of awareness (individual, team, enterprise, and community) that developers should keep in mind as they work. Enterprise awareness encourages the team to consider the business's overall goals and strategy. It also allows the team to identify similar work being performed within the business and look for ways to collaborate.
- **Scalable**—DAD's goal-driven approach makes it easier to scale than some approaches.

The following section describes the roles defined by DAD.

DAD Roles

One of DAD's key principles is "people first." To help define the interactions among team members, DAD defines 10 roles: five primary and five secondary.

Four of the primary roles (product owner, team lead, team member, and architecture owner) are considered team roles. The fifth primary role is stakeholder.

The secondary roles are specialist, domain expert, technical expert, integrator, and independent tester. The following list shows the roles' descriptions grouped by their categories:

- **Primary Roles:**
  - **Stakeholder**—Someone who will be affected by the project. (Users, managers, the executive who staked her career on the project, and so forth.)

- **Team Roles:**
  - **Product owner**—The point of contact on the team who represents the stakeholders. This person has authority to make decisions for the stakeholders.
  - **Architecture owner**—Makes architectural decisions for the team.
  - **Team lead**—The agile coach. (No, not someone good at running obstacle courses. Someone with experience at DAD projects.) This person helps the team improve its processes during development, ensures that the team has any needed resources, and generally helps keep things moving.
  - **Team member**—A cross-functional developer who focuses on analysis, design, programming, testing, and all the other typical development tasks.
- **Secondary Roles:**
  - **Domain expert**—Provides additional detailed knowledge of the user domain in addition to the expertise provided by the product owner.
  - **Technical expert**—An expert in a particular technical area such as database design, mobile platforms, or cloud storage.
  - **Integrator**—Helps integrate the pieces of the system. Helps to integrate the application with other external systems.
  - **Independent tester**—The developers perform most of the testing, but for a particularly complicated or critical application, you may want independent testers.
  - **Specialist**—Someone who specializes in a particular part of development such as user interface design or human factor research.

DAD Phases

DAD uses three big phases taken from UP. (Not surprising given that Scott Ambler developed UP.) Those phases are inception, construction, and transition. The UP elaboration phase is divided between inception and construction in DAD.

The inception phase is similar to the one used by UP. Here, you figure out the project's main goals, develop a common vision, build a business case, and beg for funding. You also identify risks, create an initial design, and make an initial schedule.

In addition to tasks similar to those used by the UP inception phase, you also consider the new project in the enterprise environment. You make sure the project is aligned with the larger business goals, and you look for similar work being done elsewhere in the company.

During the construction phase, you use iterated development to produce potentially consumable solutions. (Something you wouldn't be embarrassed to give to the customers.) The early iterations should test the application's architecture so that you don't run into nasty surprises later.

The project also has a few higher-level goals throughout the construction phase. The team members should learn from each other to improve their skills. They should identify and remove risks, focus on quality (so ongoing testing is a must), look for ways to improve the development process, and use customer feedback to track changing goals.

The transition phase is fairly standard. You ensure that the application is usable and that it meets the customers' goals. Then you deliver the application using good deployment techniques such as staged delivery or incremental cutover.

DYNAMIC SYSTEMS DEVELOPMENT METHOD

Dynamic Systems Development Method (*DSDM*) is an agile framework managed by the DSDM Consortium (`www.dsdm.org`). It is one of the heavier agile methodologies. It also has one of the longest and most "management-friendly" names, and has one of the most unpronounceable abbreviations. (If you really want to pronounce DSDM, I recommend the pronunciation DIZ-dim so that it rhymes with "wisdom.") All those facts may be the result of the method being invented by people with a business perspective instead of a software development background.

DSDM was originally invented in an attempt to bring some business discipline to the relatively untamed RAD wilderness. It attempts to bring a higher-level project focus to sit above other RAD models such as Scrum.

The following sections describe the DSDM phases, principles, and participant roles.

DSDM Phases

DSDM uses the three phases (with various substages and steps) described in the following list:

- **Pre-project**—These are things that need to happen before the project can even start. They include identifying possible projects, getting executive approval and commitment, and receiving funding.
- **Project life cycle**—This is where the application is actually built. DSDM defines four stages within this phase.
  - **Study**—This includes a feasibility study (to determine whether the project is possible) and a business study (to decide whether the project is worth the expense). During these studies, facts are usually gathered through facilitated workshops. Requirements are prioritized using the MOSCOW method. (See the "Prioritized" section in Chapter 4, "Requirement Gathering.")
  - **Functional modeling**—Here the team builds one or more working prototypes and models to describe the pieces of the system. This phase uses four steps that are repeated as often as necessary: identify a prototype, make a plan, create the prototype, and review the prototype. The team uses feedback from these cycles to iteratively improve the prototypes and models. The result is used to refine and prioritize the requirements.
  - **Design and build**—In this stage, the team integrates the models built in the preceding stage to form a single prototype that satisfies all the requirements. This stage includes four steps that are similar to those used in the preceding stage: Identify the features of the prototype, make a plan, create the prototype, and review the prototype. Those steps are repeated as often as necessary until the prototype evolves into the final working system. This stage also includes creating user documentation.
  - **Implementation**—This is where the team deploys the system. Like the other life cycle stages, it too includes four steps: Seek user approval and guidelines, train users,

implement, and review business results. If the review shows that the system meets the requirements, the project leaves the life cycle phase and moves into post-project.

- **Post-project**—This phase includes typical maintenance tasks such as bug fixes and making changes.

Figure 14-7 shows the normal flow for the project life cycle phase. The arrows show the normal sequence of events; although the project can move between any of the functional model, design and build, and implementation stages if necessary. For example, if the design and build stage uncovers a fundamental problem, the project could move back to the functional model stage.

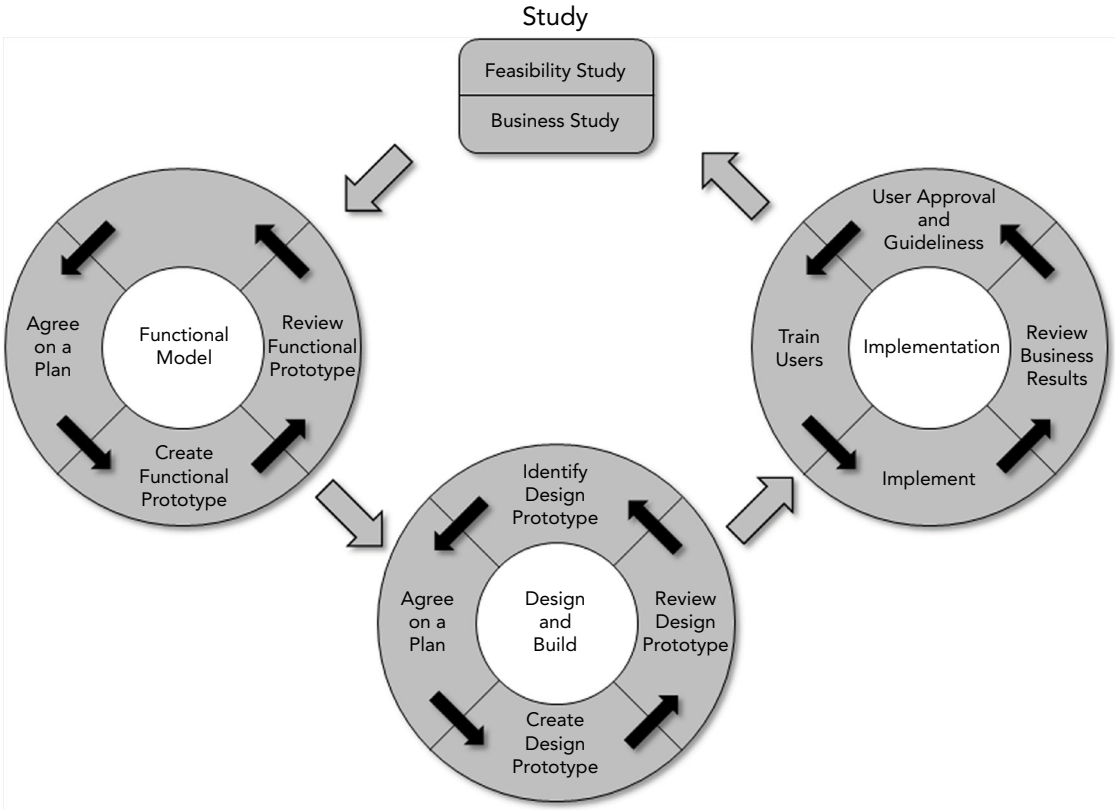


FIGURE 14-7: The DSDM life cycle includes the four stages: study, functional model, design and build, and implementation.

DSDM Principles

Like many RAD development models, DSDM has a set of guiding principles. Those principles are described in the following list.

- **Active user involvement**—Users must be involved to provide guidance and feedback.
- **Team empowerment**—The team must have the authority to make design decisions throughout development. Users can request changes to correct decisions in later iterations

if necessary. (That doesn't mean developers should blindly make arbitrary decisions all over the place. Active user involvement means users can ask for guidance whenever they need it.)

- **Frequent delivery**—Frequent delivery moves the project toward its final form.
- **Meeting business needs**—The main criterion for acceptance is delivery of software that satisfies business needs (which should be in the requirements).
- **Iterative and incremental**—These provide quicker delivery and feedback. (Without these, it would be harder to think of DSDM as agile.)
- **Reversible changes**—All the changes made during the project life cycle should be reversible. (This makes good source code control essential.)
- **Constant testing**—Constant testing uncovers bugs quickly and gives the code higher quality.
- **Collaboration and cooperation**—All the stakeholders need to work together throughout the project.
- **Requirements are refined**—Initially, the requirements are written at a high level without a lot of encumbering details. Details are worked out during development.
- **The 80/20 rule**—It is assumed that 80 percent of the project's features can be satisfied in 20 percent of the total time you would need to finish the project. The project focuses on that 80 percent to provide the most features as quickly as possible. The remaining 20 percent of the features are left for later releases.

DSDM Roles

Like other RAD models, DSDM defines a set of roles for the team members. (I think the first things you need to do when you invent a new methodology are to create a set of principles and a set of roles.) The following list describes the roles:

- **Executive sponsor**—The executive champion who protects the project from outside interference. This person should have the authority to provide funds and has ultimate decision-making power.
- **Visionary**—The person who has a clear vision of what the application should be, particularly early on when the requirements are fuzzy. This person also tracks the project to make sure it is converging on the vision.
- **Ambassador user**—Acts as a liaison between the users and the developers. Provides the users with project updates and provides the developers with user feedback.
- **Technical coordinator**—Manages the project's overall design and architecture. Monitors the project's technical quality.
- **Developer**—Writes and tests the code.
- **Tester**—Tests the code to uncover bugs. Verifies that the code meets the requirements.
- **Project manager**—Does all the usual project manager things such as tracking deadlines to make sure teams stay within their timeboxes.

DSDM projects may also define many secondary roles depending on the size of the project and the number of interested stakeholders. Those roles may include the following:

- **Advisor user**—Any user who brings a useful viewpoint to the project.
- **Architect**—Specializes in developing the application architecture.
- **Business advisor**—Provides business knowledge to the developers. For example, this person may help ensure that the project satisfies business rules, company policies, and regulatory requirements.
- **Business ambassador**—Provides business information from the viewpoint of the users.
- **Business analyst**—Provides day-to-day business focus for the development team. Helps ensure that the daily decisions made by the developers support the project's business goals.
- **Business visionary**—The person who holds a clear vision of the application's business role, particularly early in the process when that role isn't clearly written down. Ensures that the project's requirements help meet the business goals.
- **DSDM coach**—Helps the project team use the DSDM methodology properly.
- **Quality manager**—Ensures the application's quality. Tracks bug reports, testing, reviews, and other techniques used to improve quality. Uses statistical methods to estimate quality. Defines the project's quality procedures (such as testing review guidelines).
- **Scribe**—Keeps records of requirements, agreements, assumptions, and other key facts discovered at workshops.
- **Senior developer**—A software engineering ninja that other developers can call when they need help.
- **System integrator**—Builds and tests the interfaces between the application and other applications.
- **Team lead**—Leads a team of developers.
- **Workshop facilitator**—Plans, runs, and encourages participation at workshops. (This may sound like a silly role, but in the meetings I've had with facilitators, they've been surprisingly useful. They basically did the corny everyone-get-to-know-each-other thing, got some conversation started, and then got out of the way.)

KANBAN

Kanban (which is Japanese for "signboard" or "billboard") is a *just-in-time* (*JIT*) production methodology for controlling logistics in a production chain. The basic idea is to use cards (not coincidentally called *kanban*s) on each station in the chain to represent the inventory of parts at that station. When that station runs out of parts, its kanban is sent to the supplier to indicate a need for more.

Basically the kanban acts as a message saying, "This station needs more parts." The kanban "pulls" new parts from the supplier as needed. In practice there are a few variations on Kanban. For example, you could keep a small backup bucket of parts to use while you're waiting for new parts.

For another example, some books of checks contain a sheet inserted near the end of the book that says, "Reorder checks now." That's basically a Kanban-style warning that you are about to run out of checks and that you should reorder. You still have a few checks to go, just in case you need to write more checks before you get the new supply. (Of course, these days you can make all your payments electronically or with credit cards. I think the occasional tax payment is just about all I still use checks for.)

For a final example (which you probably have seen, even if you don't have a checking account so the previous example was confusing), you can think of the little "out of gas" symbol next to your car's gas gauge as a Kanban-style warning that you're about to run out of gas. When it lights up, you still have some gas (otherwise, it would be hard to drive to the gas station to get more), but you should refuel soon.

In a production environment, kanbans make it easy to track parts inventory and supply, so you can optimize the process. For example, you can discover exactly how many M12 torq-set screws you use per month, so you can preorder accordingly.

In software engineering, Kanban is a translation of the production Kanban into a software development environment. At this point, you would probably expect to see a list of principles, practices, and roles, and you'd be mostly right. The following sections describe Kanban principles and practices, although Kanban doesn't define roles. (Shocking, I know!)

Kanban Principles

Like many agile methodologies, Kanban has a set of heartwarming guiding principles designed to create a healthy and productive workplace. Of the four basic principles, three are aimed directly at the fact that Kanban may initially seem weird to development organizations. They help make moving to Kanban practices as simple and unobtrusive as possible. (If you're lucky, you can sneak in some of the Kanban practices without upper-management noticing.)

The following list describes the Kanban principles.

- **Start with current practices**—Kanban doesn't explicitly mandate every part of the development process, so you can work it into whatever system you're using now.
- **Seek incremental change**—Add Kanban principles to your current practices gradually. If you try to jump to Kanban all at once, you may face resistance to change. (I've seen people fight tooth and nail against a change to the day on which timecards were processed. Imagine the fuss you could get if you told people they had to switch from their venerated waterfall model to something agile!)
- **Respect the current process**—Your current system probably has some benefits, so you shouldn't just throw it away even if you can. Keep your current roles and responsibilities. (I told you Kanban didn't define any roles.) Over time you can let those roles morph (in a self-organizing way, of course).
- **Encourage leadership in everyone**—Like many other agile models, Kanban encourages everyone to take ownership of the project and their duties. Don't wait for someone else to decide to tackle a task or fix a bug. Show some leadership and do it yourself.

Kanban Practices

Although Kanban is intended to sift gently down over your existing practices, it does define some practices.

- **Visualize workflow**—Kanban enables you to visualize the work you are doing today in the context of other tasks. This encourages free communication and collaboration among the team members.
- **Limit** *work in progress (**WIP**)*—The JIT nature of production-line Kanban means the production chain holds as little inventory as possible. In software engineering, Kanban limits the amount of work that is being done at any moment. In contrast, you might pull too much or too little work into a Scrum sprint. By reducing multitasking, Kanban removes the inherent penalty for task switching and makes developers more productive.
- **Enhance flow**—When you finish one task, you pull the next-highest priority item from the backlog. (This is similar to the way a production-line kanban "pulls" new inventory from a supplier.) Instead of using sprints that involve planning, design, estimating, and testing of a set of features, you perform those same steps for each individual feature when you get to it.

In general, Kanban works a lot like Scrum. The biggest difference (aside from Kanban's lack of predefined roles) is that Scrum works in sprints and Kanban works continuously one feature at a time.

Recall that at the beginning of a new Scrum sprint, the sprint planning meeting pulls an assortment of high-priority items from the project backlog into the sprint backlog. The sprint (which is typically 30 days) works through its backlog to produce a potentially shippable increment. When the project includes enough new features to be worth the hassle, it is delivered to the users.

In contrast, Kanban developers pull the highest priority item from the project backlog one at a time whenever they finish a task. (This is a good opportunity for everyone to demonstrate the fourth principle and show some leadership.) It's a bit like having a Scrum project where every item is in its own sprint. That lets Kanban deliver increments more often (when it's worthwhile). It also makes Kanban extremely responsive to rapidly changing user priorities.

Kanban Board

The Kanban board is one of the more unique Kanban features. The board is a form of big board or information radiator that shows all the project's tasks and their current statuses.

The board can have many forms. The simplest might have only three columns labeled To Do, In Progress, and Done. As tasks move from one status to another, you move sticky notes, cards, or whatever you're using to represent the tasks from one column to the next.

To get a more detailed view of exactly where the tasks are, Kanban boards for software projects typically use more columns. For example, you could use the columns Backlog, Ready, Coding, Testing, Approval, and Done. Feel free to change the names and add or remove columns if you like. You can even group the columns, as shown in Figure 14-8.

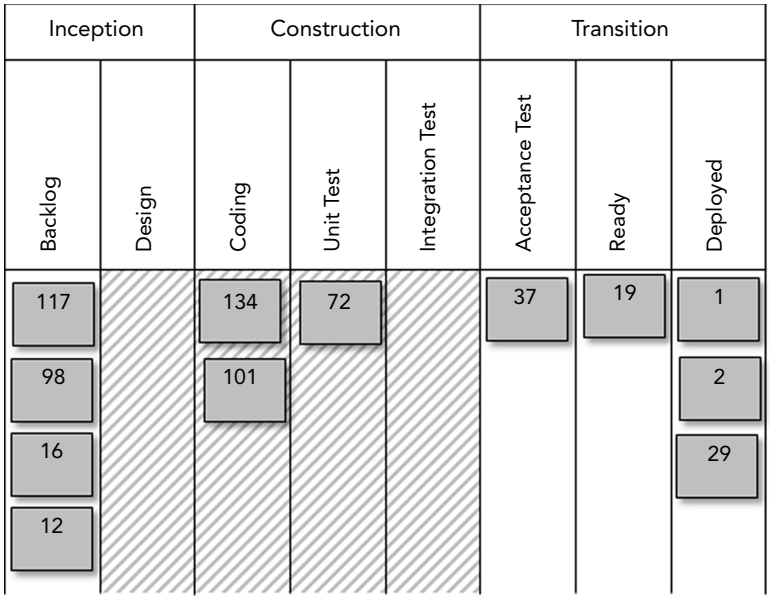


FIGURE 14-8: The Kanban board lets everyone see the status of the project's tasks at a glance.

I filled the Design, Coding, Unit Test, and Integration Test columns with a hatch pattern to indicate that they are WIP columns. Remember that one of the Kanban practices is to limit the WIP. If there are too many cards in the WIP columns, there may be a problem. For example, if the project has four team members but 27 cards in the WIP columns, the developers might be taking on too many tasks to focus on them properly.

The cards shown in Figure 14-8 are too small to hold much information, so they just show task numbers. In practice the cards might also include information such as the title of the task, a brief description, and the person working on the task.

Some Kanban boards use rows in the "in progress" columns to show who's working on which tasks. For example, the tasks in the top row might be owned by Alice, those in the second row might be owned by Bob, and so forth.

Tasks in the non-WIP columns wouldn't belong to anyone. For example, tasks in the Backlog column are waiting for someone to pick them. Tasks in the Acceptance Test column are waiting for the users to verify that they meet the requirements. (At least in my imaginary project—the person who performs acceptance testing might vary depending on your development model.)

On a large project, you'll probably need to use a computerized board. That seems more fitting for a software engineering effort; although, it would make it a bit harder to grasp the project's status at a glance as you walk by. (Plus I think there's something kind of fun about posting sticky notes on a whiteboard. Maybe it's just me.)

A computerized board can handle a huge number of tasks (it would also be hard to fit 1,237 sticky notes in the Backlog column at the start of a large project), could automatically keep the tasks sorted by priority, and could provide hyperlinks to let you easily get more information about the tasks.

There are many variations on the Kanban board, each tailored to suit a particular development team's practices. It's interesting to search the Internet for images of Kanban boards and see some of the alternatives.

SUMMARY

As long as it is, this chapter merely touched on a few of the more common RAD methodologies. If you want more information about any of them, you should search the Internet or buy a book about them. A lot of them have books that explain exactly how their original versions work.

There are also dozens (if not hundreds) of other methodologies. Some methods descended from others, and there are even methods built as mashups of other methods. For example, DAD (which descended from AUP, which descended from RUP, which descended from UP) includes elements of Scrum, XP, UP, Kanban, Lean, and other methodologies that aren't described in this chapter.

Each one of those methodologies has countless variations, adaptations, and customizations used by different development teams. That may make it hard to understand the "official" version of a particular methodology, but that kind of customization lies at the heart of agile development. Different agile methods may use different approaches, but they all ask you to constantly look for ways to improve your project and the development process. Because no two projects are exactly alike, it makes sense that no two development models would be exactly alike, either. If you haven't made any modifications to the development model, then you're probably not doing it right.

If you're thinking about joining a development team, hopefully this chapter and the previous ones will help you understand in general what your potential new teammates mean when they say they use waterfall, Cleanroom, Crystal Orange, or Kanban. At least you'll know enough to ask the right questions to learn more about their customizations and additions.

EXERCISES

1. Suppose you're working for Stodgy Megacorp, an old-fashioned company that calls employees "assets," puts Suggestion Box labels on its wastebaskets, and uses a classic one-pass waterfall model for software development. Which of the four agile values does that model violate?
2. Which of the 12 agile principles does Stodgy Megacorp's waterfall model violate?
3. Given your answers to Exercises 1 and 2, should you forget the waterfall model as a possible approach to software engineering?
4. Which of the four agile values does James Martin RAD satisfy?
5. Which of the 12 agile principles does James Martin RAD satisfy?

6. Explain why Scrum velocity isn't quite the same as the difference between the amount of work in the project backlog before and after a sprint. When will velocity equal that difference?

7. You can directly measure the amount of person-hours spent on a sprint, but story points are just a guess. Why might it be more useful to calculate velocity in story points per sprint instead of actual work performed per sprint even though you're using guesses instead of facts?

8. If your story points measure the estimated number of days for each user story (instead of using another metric such as small, medium, and large), what does it mean if the number of actual person-days spent on sprints is consistently lower than the number of story points assigned to the sprints? What if actual days is higher than story points? In those cases, do you need to revise your story point estimates?

9. Is maximizing a Scrum project's velocity the most important goal? Why or why not?

10. The term "lean software development" was introduced by Mary Poppendieck and Tom Poppendieck in their book *Lean Software Development* (Addison-Wesley Professional, 2003). In that book, they use the slogan, "Think big, act small, fail fast; learn rapidly." Briefly explain what each of those phrases means.

11. Which of the following scenarios is similar to Kanban in a production line setting? Why or why not?

    a. The last few feet of a cash register tape have red edges.

    b. The same situation as Exercise 11a, except on a self-service register.

    c. When your light bulb burns out, you replace it with a bulb stored in the closet.

    d. The same situation as Exercise 11c, except when you take a bulb from the closet you see how many bulbs are left. If there are no more bulbs, you write "Light Bulbs" on your shopping list.

    e. When your pen runs out of ink, it stops working.

WHAT YOU LEARNED IN THIS CHAPTER

- RAD techniques include:
  - Small teams
  - Requirement gathering through focus groups and workshops
  - Requirement validation through prototypes, use cases, and customer testing
  - Repeated customer testing
  - Constant integration and testing
  - Testing, testing, and more testing
  - Informal reviews and communication
  - Short iterations
  - Deferring complicated features to later releases
  - Timeboxing
- RAD advantages include:
  - More accurate requirements
  - Ability to handle changes
  - Frequent customer involvement encourages engagement
  - Reduced development time and early releases
  - Code reuse
  - Constant testing leads to high-quality code
  - Risk mitigation
  - Greater chance of success
- RAD disadvantages include:
  - Resistance to change
  - Doesn't work well with large systems
  - Requires skilled team members
  - Requires access to scarce resources such as expert users
  - Adds extra overhead
  - Less managerial control
  - May give a less-than-optimal design
  - Unpredictable

- The Agile Manifesto defines four rules to make an agile-friendly environment:
  - Individuals and interactions over processes and tools
  - Working software over comprehensive documentation
  - Customer collaboration over contract negotiation
  - Responding to change over following a plan
- Agile techniques include:
  - Provide early and continuous delivery
  - Welcome changing requirements
  - Have developers and stakeholders work closely together
  - Use motivated team members
  - Convey information with conversations
  - Measure progress by working software
  - Use sustainable development
  - Pay continuous attention to excellence
  - Keep things as simple as possible
  - Use self-organizing teams
  - Reflect on the development process and improve it
  - Deliver incremental and evolutionary results
- Different agile methods use the same techniques organized in different ways:
- Extreme Programming practices include:
  - Customer on site
  - Planning game
  - Standup meetings
  - Frequent small releases
  - Intuitive metaphors
  - Simple designs
  - Deferred optimization
  - Refactoring
  - Shared code ownership
  - Coding standards
  - Promoting generalization

  - Pair programming
  - Constant testing
  - Constant integration
  - Sustainable pace
  - Test-driven and test-first development
- James Martin RAD uses four phases: requirements planning, user design, construction, and cutover.
- Scrum uses short sprints to produce potentially shippable increments. A backlog contains the prioritized tasks that need to be accomplished. Planning poker helps estimate task difficulty. Burndown charts show how many tasks are completed over time. Velocity indicates how many story points the team completes per sprint.
- Lean focuses on waste and removes everything wasteful.
- The Crystal methods address projects of different sizes. Crystal colors include Clear, Yellow, Orange, Orange Web, Red, Maroon, Diamond, and Sapphire. Criticality is measured as comfort, discretionary money, essential money, and life. Larger projects require more formality. More critical projects require more control and testing.
- Feature-Driven Development focuses on features. It uses five phases. The first three phases (develop a model, build a feature list, and plan by feature) occur in iteration 0. The remaining two phases (design by feature, and build by feature) occur repeatedly in other iterations.
- Agile Unified Process is an agile version of Unified Process. It is serial in the large (it follows the four phases of UP: inception, elaboration, construction, and transition), and iterative in the small (it performs those phases iteratively). Throughout the project, different disciplines occur in different amounts.
- To summarize Disciplined Agile Delivery, Scott Ambler says, "The Disciplined Agile Delivery (DAD) decision process framework is a people-first, learning-oriented hybrid agile approach to IT solution delivery. It has a risk-value delivery lifecycle, is goal-driven, is enterprise aware, and is scalable." It uses the AUP phases' inception, construction, and transition.
- Dynamic Systems Development Method adds more business controls to an agile process. Its major phases are pre-project, project life cycle, and post-project. Project life cycle includes study, functional modeling, design and build, and implementation.
- Kanban in a production chain uses kanban cards to "pull" new inventory when a parts station is empty (or running low). Kanban software development uses cards on a Kanban board to show the states the tasks are in. When a developer finishes a task, he pulls the highest priority task from the project backlog. Kanban limits the amount of work in progress.

APPENDIX

Solutions to Exercises

Some of the exercises in this book have many possible solutions. For example, Exercise 4-7 asks you to think of ways to modify the Mr. Bones application. With a little creativity, you could probably come up with hundreds of possible modifications, so your answer probably won't match mine.

In ambiguous cases like that one, look over the solution to see if it makes sense to you. If it doesn't, you might want to review the material in the corresponding chapter. (Or you might like to e-mail me and ask, "What on earth were you thinking?")

You can also start a discussion on the book's P2P forum about any of these solutions. Sometimes, those kinds of discussions are fascinating.

CHAPTER 1

1. The basic tasks that all software engineering projects must handle are:
    1. Requirements Gathering
    2. High-Level Design
    3. Low-Level Design
    4. Development
    5. Testing
    6. Deployment
    7. Maintenance
    8. Wrap-up

2. The following list gives a one sentence description of each of the tasks listed for Exercise 1.
   a. **Requirements Gathering**—Learn the customer's wants and needs.
   b. **High-Level Design**—Describe the major pieces of the application and how they interact.
   c. **Low-Level Design**—Provide more detail about how to build the pieces of the application so that the programmers can actually implement them.
   d. **Development**—Write code to implement the application.
   e. **Testing**—Use the application under different circumstances to try to detect any flaws or bugs.
   f. **Deployment**—Roll out the application to the users.
   g. **Maintenance**—Implement bug fixes, additions, enhancements, and future versions of the program.
   h. **Wrap-up**—Evaluate the project's history to determine what went right and what went wrong so that you can repeat the good things and avoid the bad things in future projects.
3. The reason the tasks don't stand out is that this kind of project is small and fast, so many of the tasks occur only in my head.

   Steps 1 through 3 (customer sends me a request, I reply saying what I think the customer wants, and the customer confirms) are clearly requirements gathering.

   Step 4 (I crank out a quick example program) combines high-level design, low-level design, development, and testing all in one step. For most small questions, I do these all in my head. For larger questions, I sometimes need to pull out paper and pencil and scribble out a bit of design before I start coding. (Coding without proper design is a bad habit. I get away with it only for small examples.)

   Step 5 (I e-mail the example to the customer) is deployment.

   Step 6 (the customer examining the example) is also part of deployment, which includes normal operation of the program. If the customer asks more questions, that's essentially revising the requirements.

   Step 7 (I answer the new questions) is maintenance because the customer is asking for changes to the original example. Usually in practice the first example is either good enough or almost good enough, so there's not much else to do.

   The one missing task here is wrap-up. The first several times I built this sort of quick example for a customer, I learned from the experience and adjusted the way things worked in the future. Probably the most important thing I learned was the level of detail the customers need. These customers are smart and like to do their own work so that they can learn new techniques, so over time I learned to make the examples a lot less detailed. The customer just wants the basic techniques and can fill in things such as error handling, big user interfaces, and documentation. Making less complete examples saves me time and them money.

4. First, the bug fix may be incorrect. Second, the fix may break other code that depended on the original buggy behavior. Third, the fix might change some correct behavior to a new correct behavior, but another piece of code might depend on the original behavior.
5. Here are some of the things you might need during deployment:
   - New computers for the back-end database
   - New network
   - New computers for the users
   - User training
   - On-site support while the users get to know the new system
   - Parallel operations while some users get to know the new system and other users keep using the old system
   - Special data maintenance chores to keep the old and new databases synchronized
   - Bug fixes
   - Unexpected tasks

CHAPTER 2

1. Seven features that a document management system should provide are the ability to:
   - Share documents.
   - Prevent multiple users from changing a document at the same time.
   - Fetch the latest version of a document.
   - Fetch earlier versions of a document.
   - Search documents for keywords.
   - See the changes made to a document.
   - Compare two versions of a document to see their differences.
2. This is an exercise, not a question, so just follow the instructions. Figure A-1 shows the document I created for this exercise. The deletion is lined-out in red and the insertion is underlined in blue. (You can't see the colors in this book, but you should see them in your file.) You can experiment with the other change tools such as the Accept and Reject drop-downs if you like.
3. The Compare tool produces a result that looks a lot like the change tracking tool. It doesn't know who made the changes or when, so in that sense it's not as good as the change tracking tool. It also doesn't know the document's complete change history. For example, if you add a word and later remove it, the Compare tool doesn't know that word ever existed.

   The Compare tool is useful, however, if you have multiple versions of a document that doesn't contain change tracking information.

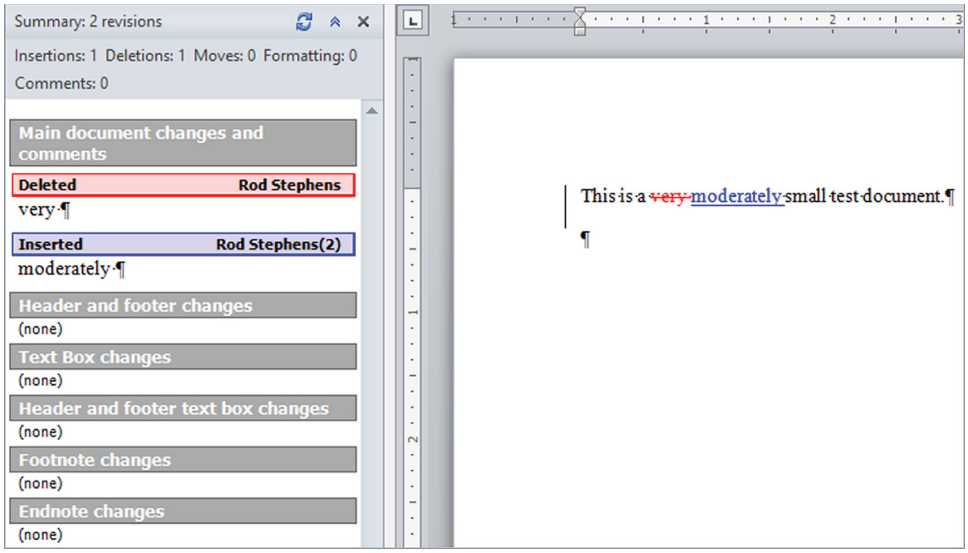


FIGURE A-1: Microsoft Word has revision-tracking tools that let you see who has modified a document and when.

4. This is another exercise, not a question, so follow the instructions and you should be alright. Figure A-2 shows a Google Docs file I created for this exercise.

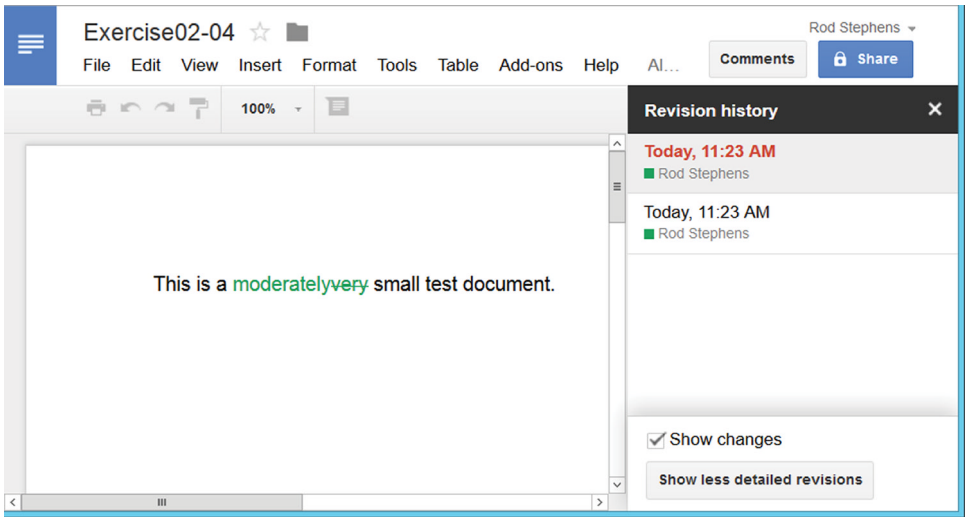


FIGURE A-2: Google Docs also has revision-tracking tools that let you see who has modified a document and when.

5. JBGE stands for Just Barely Good Enough. It's the philosophy that you shouldn't write any more code documentation or comments than absolutely necessary.

CHAPTER 3

1. Figure A-3 shows one possible PERT chart for part of the zombie apocalypse software project.

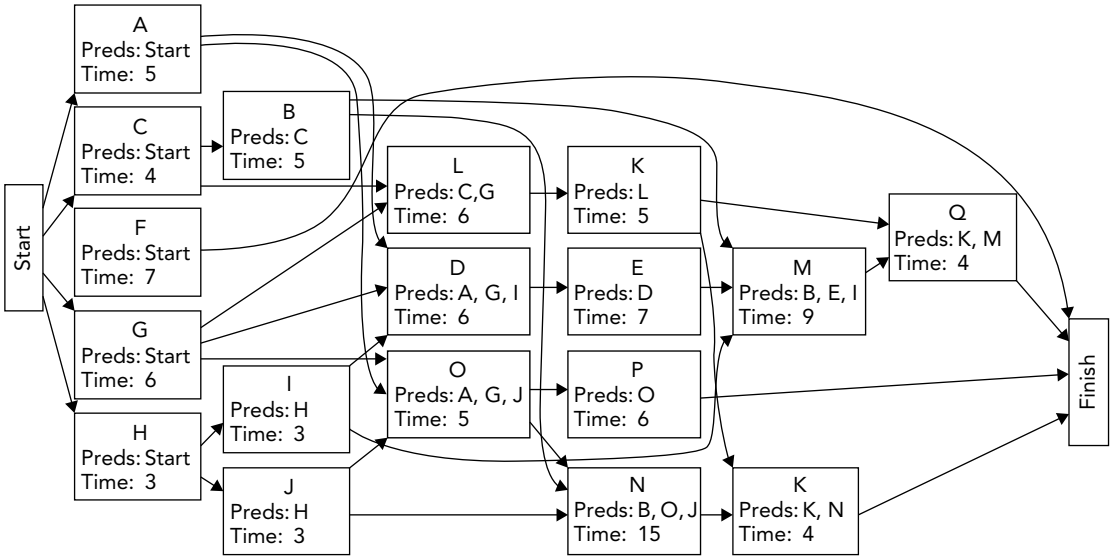


FIGURE A-3: This PERT chart includes tasks needed to build a small part of a 3-D zombie apocalypse game.

2. Figure A-4 shows a PERT network with its critical path highlighted with bold, black arrows for the zombie apocalypse software project. Bold gray arrows show the greatest cost paths into each node.

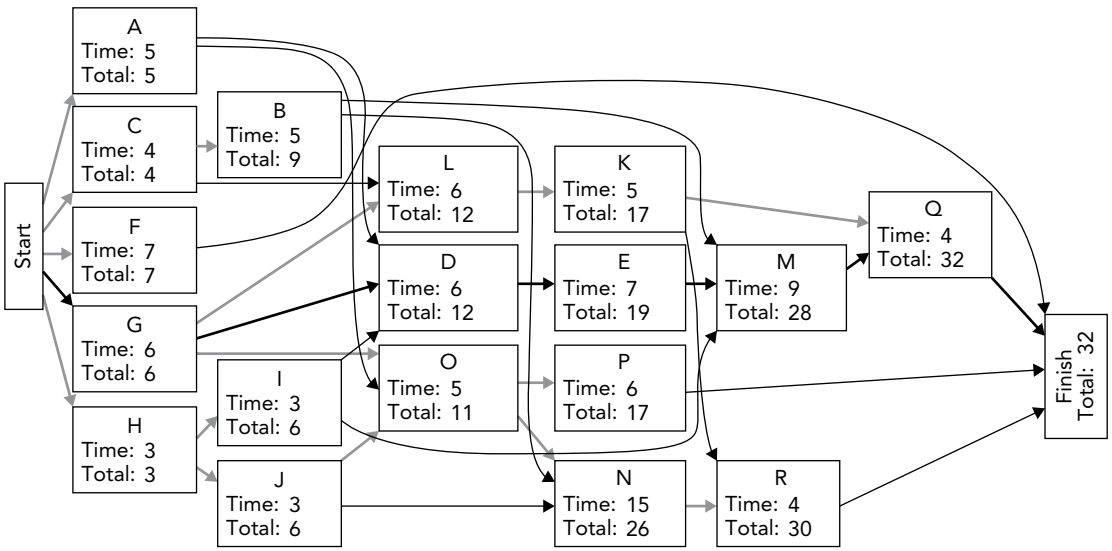


FIGURE A-4: The critical path for this piece of the zombie apocalypse game includes tasks G, D, E, M, and Q.

The critical path passes through the tasks G, D, E, M, and Q and has a total expected length of 32 working days.

3. The PERT network shown in Figure A-4 has two second-shortest paths: G ➢ O ➢ N ➢ R and H ➢ J ➢ O ➢ N ➢ R. They both have a length of 30 days. The tasks on those paths could slip up to 2 days before changing the project's total expected time.

4. Figure A-5 shows a Gantt chart for the PERT network referred to in Figure A-4. According to Figure A-5, this part of the game should be finished in the evening of February 18.

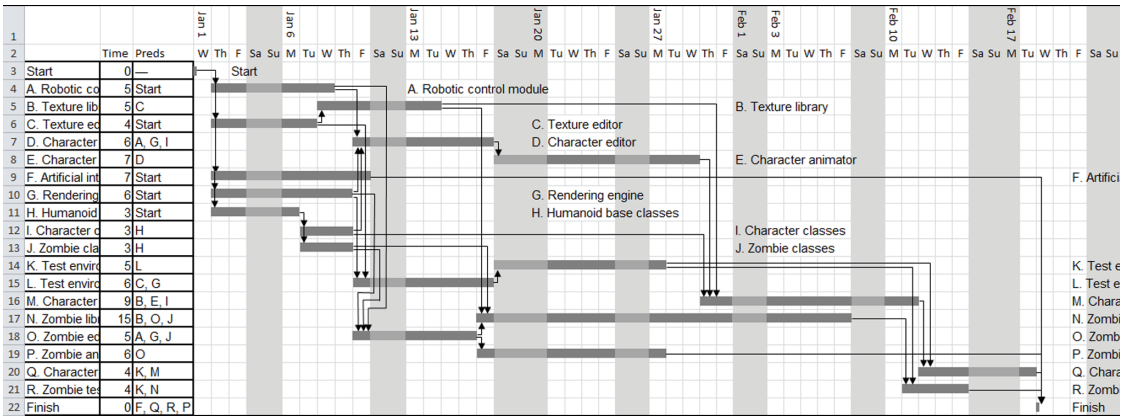


FIGURE A-5: This Gantt chart shows this piece of the zombie apocalypse game finished at the end of the day February 18.

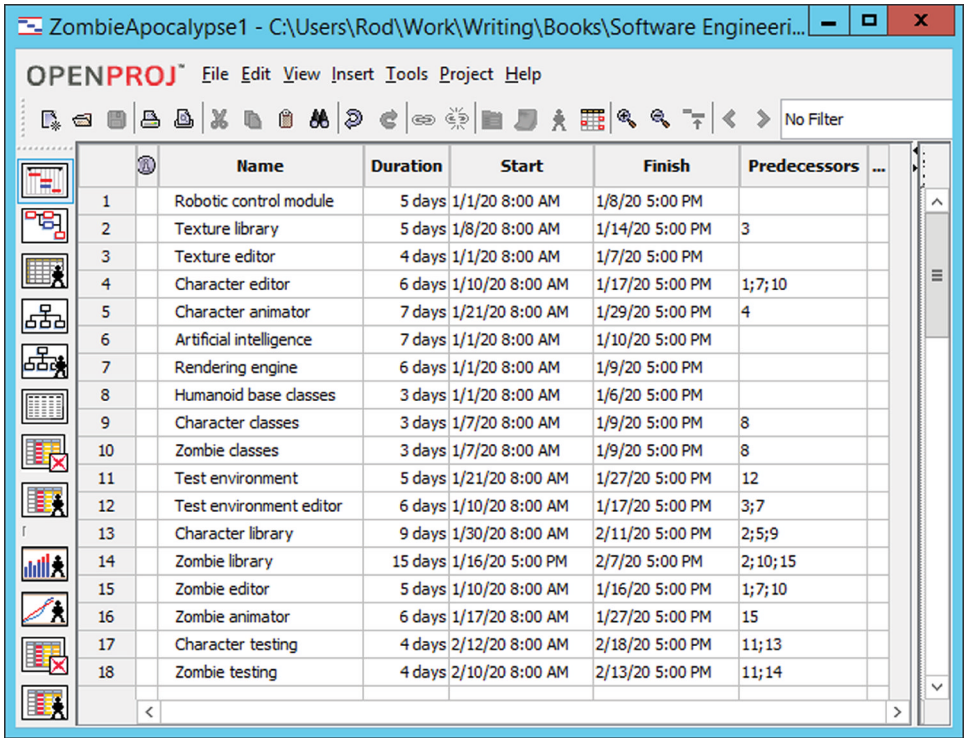
5. Figure A-6 shows OpenProj displaying the tasks for the zombie apocalypse project. You enter the task data in this worksheet area.

   To get OpenProj to build a correct schedule, you need to mark the dates January 1, January 20, and February 17 as holidays. To do that, select Tools Change ➢ Working Calendar. Select each date and click its Non-working time option. Figure A-7 shows the resulting Gantt chart in OpenProj.

   OpenProj has the disadvantage that it isn't quite as flexible as a Gantt chart you draw by hand. For example, when you draw a chart by hand, you can adjust the arrows to make everything fit exactly the way you want.

   However, OpenProj and other project management tools have the huge advantages that they are simple and they give you far fewer chances to make mistakes. They may also provide other features such as work assignment tracking. For those reasons, you should use some sort of tool if you plan to manage a lot of projects or projects with many tasks.

6. You can treat *deus ex machina* problems the same way you handle unexpected sick leave. Add tasks at the end of the schedule to account for completely unexpected problems. When one of these problems does occur, insert its lost time into the schedule.



	Name	Duration	Start	Finish	Predecessors
1	Robotic control module	5 days	1/1/20 8:00 AM	1/8/20 5:00 PM	
2	Texture library	5 days	1/8/20 8:00 AM	1/14/20 5:00 PM	3
3	Texture editor	4 days	1/1/20 8:00 AM	1/7/20 5:00 PM	
4	Character editor	6 days	1/10/20 8:00 AM	1/17/20 5:00 PM	1;7;10
5	Character animator	7 days	1/21/20 8:00 AM	1/29/20 5:00 PM	4
6	Artificial intelligence	7 days	1/1/20 8:00 AM	1/10/20 5:00 PM	
7	Rendering engine	6 days	1/1/20 8:00 AM	1/9/20 5:00 PM	
8	Humanoid base classes	3 days	1/1/20 8:00 AM	1/6/20 5:00 PM	
9	Character classes	3 days	1/7/20 8:00 AM	1/9/20 5:00 PM	8
10	Zombie classes	3 days	1/7/20 8:00 AM	1/9/20 5:00 PM	8
11	Test environment	5 days	1/21/20 8:00 AM	1/27/20 5:00 PM	12
12	Test environment editor	6 days	1/10/20 8:00 AM	1/17/20 5:00 PM	3;7
13	Character library	9 days	1/30/20 8:00 AM	2/11/20 5:00 PM	2;5;9
14	Zombie library	15 days	1/16/20 5:00 PM	2/7/20 5:00 PM	2;10;15
15	Zombie editor	5 days	1/10/20 8:00 AM	1/16/20 5:00 PM	1;7;10
16	Zombie animator	6 days	1/17/20 8:00 AM	1/27/20 5:00 PM	15
17	Character testing	4 days	2/12/20 8:00 AM	2/18/20 5:00 PM	11;13
18	Zombie testing	4 days	2/10/20 8:00 AM	2/13/20 5:00 PM	11;14

FIGURE A-6: Enter the task data into OpenProj's worksheet area.

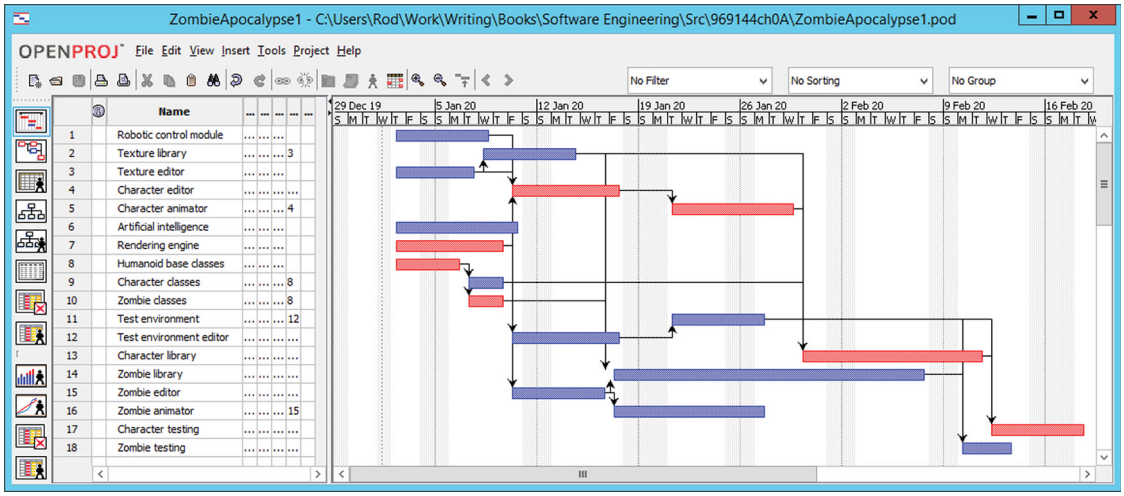


FIGURE A-7: OpenProj uses the task data to generate a Gantt chart.

7. Techniques that help you make accurate time estimates include:
   - Gaining experience in this type of task
   - Breaking large tasks into smaller pieces
   - Looking for similarities with tasks you have performed before
   - Allowing for unexpected delays such as time lost to sickness, vacation, and completely unpredictable causes
   - Planning for tasks with lead times such as management approvals and ordering times
   - Asking for advice and assistance from people with experience
8. The biggest mistake you can make while tracking tasks is not taking action when a task slips. At a minimum, you need to pay closer attention to the task so that you can take action if it's in trouble.

   The second biggest mistake is piling more people on the task and assuming they can cut the total time. Unless the new people have particularly useful expertise, bringing them up to speed may make the task take even longer.

CHAPTER 4

1. Five characteristics of good requirements are clear (easy to understand), unambiguous, consistent, prioritized, and verifiable.
2. MOSCOW stands for Must (must be included), Should (should be included if possible), Could (could be included if we have the resources), and Won't (won't be included).
3. The following lists show the TimeShifter requirements with their audience-oriented categories shown in parentheses. (B = Business, U = User, F = Functional, N = Nonfunctional, and I = Implementation.)
   a. Allow users to monitor uploads/downloads while away from the office. (B)
   b. Let the user specify website log-in parameters such as an Internet address, a port, a username, and a password. (U, F)
   c. Let the user specify upload/download parameters such as number of retries if there's a problem. (U, F)
   d. Let the user select an Internet location, a local file, and a time to perform the upload/download. (U, F)
   e. Let the user schedule uploads/downloads at any time. (N)
   f. Allow uploads/downloads to run at any time. (N)
   g. Make uploads/downloads transfer at least 8 Mbps. (N)
   h. Run uploads/downloads sequentially. Two cannot run at the same time. (N)
   i. If an upload/download is scheduled for a time when another is in progress, the new task waits until the other one finishes. (N)

j. Perform scheduled uploads/downloads. (F)

k. Keep a log of all attempted uploads/downloads and whether they succeeded. (F)

l. Let the user empty the log. (U, F)

m. Display reports of upload/download attempts. (U, F)

n. Let the user view the log reports on a remote device such as a phone. (U, F)

o. Send an e-mail to an administrator if an upload/download fails more than its maximum retry number of times. (U, F)

p. Send a text message to an administrator if an upload/download fails more than its maximum retry number of times. (U, F)

All the categories include at least one requirement except for implementation requirements, which is empty. You might need to buy new hardware or network bandwidth to support the application, but you're presumably performing uploads and downloads now, so you may already have everything you need. In that case, there are no implementation requirements.

4. The following lists show the TimeShifter requirements with their FURPS categories shown in parentheses. (F = Functionality, U = Usability, R = Reliability, P = Performance, and S = Supportability.)

The listed requirements don't say much about what the application should look like, so I stretched the usability category a bit to include requirements that describe user tasks, even though they don't say much about how those tasks will be accomplished.

a. Allow users to monitor uploads/downloads while away from the office. (F)

b. Let the user specify website log-in parameters such as an Internet address, a port, a username, and a password. (F, U, S)

c. Let the user specify upload/download parameters such as number of retries if there's a problem. (F, U, S)

d. Let the user select an Internet location, a local file, and a time to perform the upload/download. (F, U, S)

e. Let the user schedule uploads/downloads at any time. (R)

f. Allow uploads/downloads to run at any time. (R)

g. Make uploads/downloads should transfer at least 8 Mbps. (P)

h. Run uploads/downloads sequentially. Two cannot run at the same time. (F)

i. If an upload/download is scheduled for a time when another is in progress, the new task waits until the other one finishes. (F)

j. Perform scheduled uploads/downloads. (F)

k. Keep a log of all attempted uploads/downloads and whether they succeeded. (F)

l. Let the user empty the log. (F, U, S)

m. Display reports of upload/download attempts. (F, U)

n. Let the user view the log reports on a remote device such as a phone. (F, U)

o. Send an e-mail to an administrator if an upload/download fails more than its maximum retry number of times. (F, U, S)

p. Send a text message to an administrator if an upload/download fails more than its maximum retry number of times. (F, U, S)

All the FURPS categories include at least one requirement.

5. The five W's and one H are who, what, when, where, why, and how.

6. Three specific techniques for gathering requirements include:

   - Listen to customers and users.
   - Use the five W's and one H (who, what, when, where, why, and how).
   - Study users. Watch them at work. Study current practices.

7. Brainstorming lets you search for creative and novel solutions to problems.

8. Alex Osborn's four rules are:

   a. Focus on quantity.

   b. Withhold criticism.

   c. Encourage unusual ideas.

   d. Combine and improve ideas.

9. Here are some changes that you could make to the Mr. Bones application. (Your results are likely to differ.) The letters in parentheses indicate their MOSCOW priorities.

   - **Advertising (M)**—A phone application typically costs money to install or displays advertising. Currently, the program does neither. It could be modified to display advertising.
   - **Scoring (S)**—Right now you either win or lose. The program could be changed to calculate a score.
   - **Score keeping (S)**—If the program calculates scores, it could keep track of them so that the user can try to beat the previous best score.
   - **Multiple high scores (S)**—If the program tracks high scores, it could be modified to track high scores for multiple users.
   - **Different fonts (C)**—The program could allow users to pick different fonts. (This could be useful if the buttons are too small for users to touch on a phone.)
   - **Quick win (C)**—The program could allow the user to type a guess for the whole word to get extra points. (For example, if you have filled in **A_A_E_T_C**, you might guess ANAPESTIC all at once.)
   - **Multiple skill levels (C)**—The program could allow users to pick a skill level. An algorithm would use word length and the letters in a word to estimate difficulty.

- **Different backgrounds (C)**—The program could let the users pick different backgrounds (in addition to the shaded background).
- **Different pictures (C)**—The program could let the users pick different pictures (in addition to the cartoonish skeleton).
- **Random pictures (C)**—The program could display random pictures (in addition to the cartoonish skeleton).
- **Animated win (C)**—When the user wins, the program could display an animation.
- **Animated loss (C)**—When the user loses, the program could animate the finished skeleton (or other picture).
- **Report high score (W)**—The program could let users report their high scores to a central database so that other users can view them on a web page.
- **Animated pictures (W)**—The program could display animated pictures that wave, wink, roll their eyes, and so on.
- **Word difficulty tracking (W)**—The program could track the number of incorrect guesses for each word to determine its difficulty. It would periodically report values to a central database for distribution during later updates.
- **Different letter selection mechanisms (W)**—The program could allow users to pick letters in different ways. For example, by dragging and dropping letters into specific positions.
- **Time limits (W)**—The program could display a countdown. Each correct guess would increase the time available.

10. Your results may vary.

CHAPTER 5

1. A component-based architecture regards pieces of the system as loosely coupled components that provide services for each other. A service-oriented architecture is similar except the pieces are implemented as services, often running on separate computers communicating across a network. The two are similar, but the pieces are more separated in a service-oriented architecture.
2. This is a simple, self-contained application so no remote services or database is required. That means client-server, multitier, component-based, and service-oriented architectures are probably overkill. You could use them internally within the phone, but a simple computer opponent probably isn't complicated enough to make them necessary.

   For this application, a monolithic architecture would probably work well because it's a relatively small, self-contained application.

   A data-centric approach also works well in this example. For tic-tac-toe in particular, it's easy to build tables of moves and the best responses, so it will probably use some data-centric or rule-based techniques.

The user interface will be event-driven, at least in terms of responding to user events. You could also make the computer opponent raise events when it makes moves, so you might make that part of the system event-driven, too. However, for this simple application that's probably not necessary.

Finally, you could use distributed components to make different processes explore different sequences of moves simultaneously, but again tic-tac-toe just isn't that complicated an application, so it's probably not necessary.

In conclusion, this application would probably be easiest to build as a simple monolithic rule-based (data-centric) application.

3. A chess program is similar in many ways to a tic-tac-toe program, so its architecture can be similar. Like the tic-tac-toe program, the chess program won't need to interact with remote processes. Chess programs also use tables of typical moves and precalculated responses, so this application will still have rule-based (data-centric) pieces.

   Because searching for optimal moves is so difficult in chess, this program could include distributed pieces running on different cores simultaneously. That would make this a monolithic rule-based (data-centric) application with distributed pieces.

4. This scenario may seem a lot more complicated than the previous one, but it's not too bad. The user interface is basically the same. The only changes are: (1) The program needs to exchange information with another instance of the program across the Internet, and (2) There's no computer opponent.

   Removing the computer opponent means the program doesn't need distributed pieces.

   You could use web services to allow two programs to communicate over the Internet. That would make the application a monolithic rule-based (data-centric) service-oriented application.

5. The games described in Exercises 2 and 3 are self-contained. They could produce reports on high scores stored on the local hardware (phone, laptop, and so on). They could also keep track of high scores reported by users from all over the Internet. (Although that would add Internet access to the program's requirements and require a lot of work that would otherwise be unnecessary, so you might want to skip this at least for the first release.)

   Those programs might also produce reports on the automated opponent such as its difficulty level and how far down the game tree it searches. Usage reports might be handy for marketing purposes, but you should allow the users to disable them.

   The two-player game used in Exercise 4 could provide reports showing the user's results versus other players. Those reports could include information about the other players such as their ranking (either using standard chess rankings or rankings determined by this program). It could also provide leaderboards and challenge ladders to help users interact with each other.

6. The ClassyDraw application can store each drawing in a separate file, so it doesn't need much of a database. Operating system tools can let the user manage files. For example, they let the user delete old files and make backup copies of files.

The program could create a temporary file while the user is editing a drawing. Then if the program crashes or is ended prematurely, it could ask the user if it should restore the temporary file the next time it starts.

7. At first you might think ClassyDraw wouldn't need configuration information, but it has a few pieces of configurable data. For example, it should keep track of its current directory. Many similar programs use the last directory they used to load or save a file as their current directory, so that information is stored implicitly and not in a configuration screen.

   The program could also keep track of defaults such as its initial color palette, drawing size, and object characteristics. (When the user draws a new circle, what color and line style should it use?) You could use whatever settings were used for the most recently created object (that's the way MS Paint does it), or you could let the user tell the program to use a particular object as a template for future objects. (That's the way Microsoft Word's drawing canvas does it.)

8. Figure A-8 shows a state machine diagram for reading a floating point value in scientific notation.

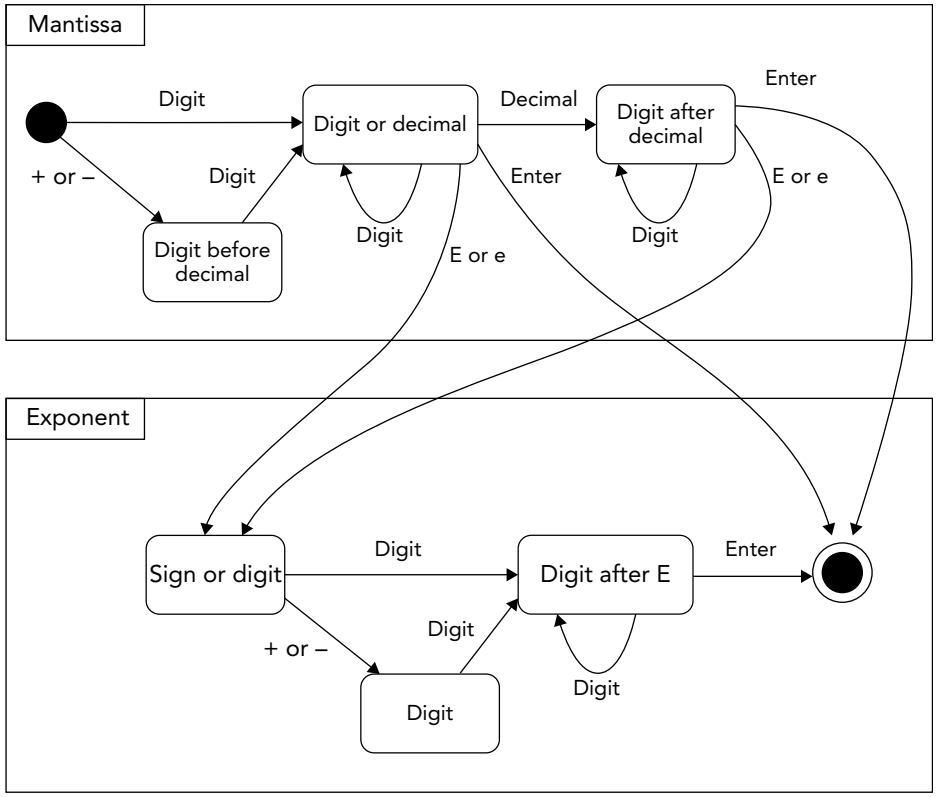


FIGURE A-8: This state machine diagram shows how a program could read a floating point number in scientific notation as in –12.3e + 17.

CHAPTER 6

1. Those classes all represent things that are drawn, so they share properties needed for drawing. Those include foreground color and background color. All the classes can also define their drawing position by storing an upper-left corner, a width, and a height.

   Some classes need extra data to draw their particular type of shape, and the classes won't share that data. For example, the `Text` class needs font information and the string to draw. The `Star` class needs to know how many points to give the star.

   Some properties can be shared by some classes and not others. `Rectangle`, `Ellipse`, and `Star` can be filled, so they need a fill color. The classes that draw lines (`Line`, `Rectangle`, `Ellipse`, and `Star`) also need line properties (such as line thickness and dash style).

   Table A-1 summarizes the shared, partially shared, and nonshared properties.

TABLE A-1: Properties Shared by ClassyDraw Classes

PROPERTY	USED BY
`ForeColor`	All
`BackColor`	All
`UpperLeft`	All
`Width`	All
`Height`	All
`Font`	`Text`
`String`	`Text`
`NumPoints`	`Star`
`FillColor`	`Rectangle`, `Ellipse`, `Star`
`LineThickness`	`Rectangle`, `Ellipse`, `Star`, `Line`
`DashStyle`	`Rectangle`, `Ellipse`, `Star`, `Line`

2. Figure A-9 shows an inheritance hierarchy for the properties listed for Exercise 1.
3. Figure A-10 shows the inheritance diagram.
4. You could simply move the `Boss` property from the `Salaried` class to the `Employee` class. The structure of the hierarchy wouldn't change.

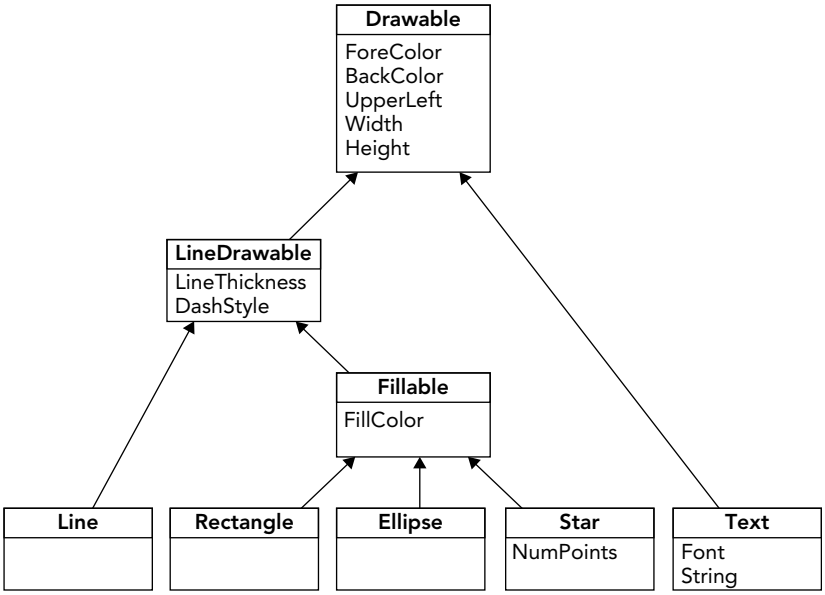


FIGURE A-9: This inheritance hierarchy represents shape classes in the ClassyDraw application.

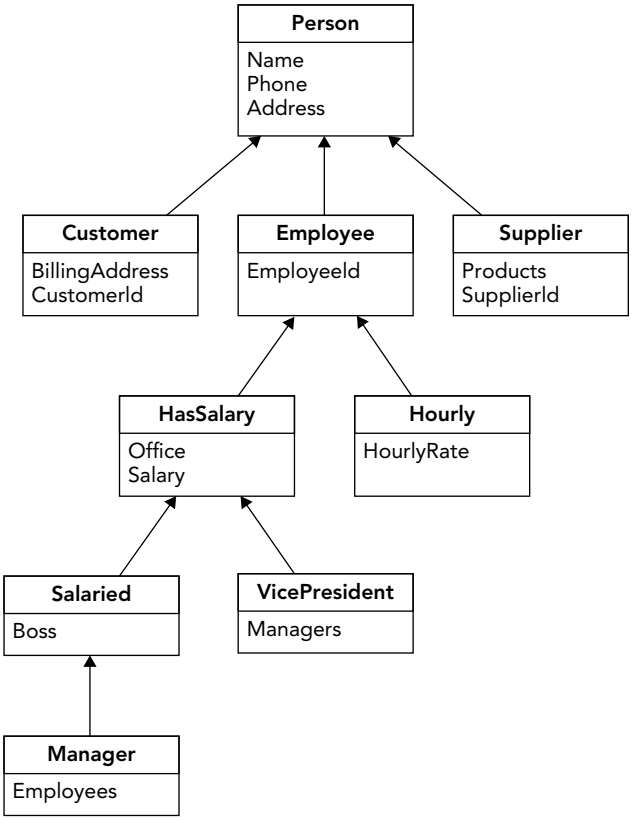


FIGURE A-10: This inheritance hierarchy represents business classes.

5. If `Supplier` represents a business instead of a person, it doesn't make sense to have it inherit from a `Person` class, even though it does need the properties provided by `Person`.

   If you want to store information for a company contact person, a better approach would be to use composition to make the `Company` class include a `ContactPerson` property of type `Person`.

   If you just want to store the company's name, phone number, and address without associating it with a contact person, then you could rename the `Person` class to something that applies to both people and companies. For example, you might call it `HasAddress`. That would be less intuitive than using composition, however.

6. To represent all the managerial types, you could give the `Salaried` class the properties `Office`, `Salary`, `Boss`, and `Employees`. The `Boss` property would not be filled in for top-level vice presidents who don't report to anyone. The `Employees` property would be empty for bottom-level employees who are not managers of anything.

   Figure A-11 shows the new inheritance hierarchy.

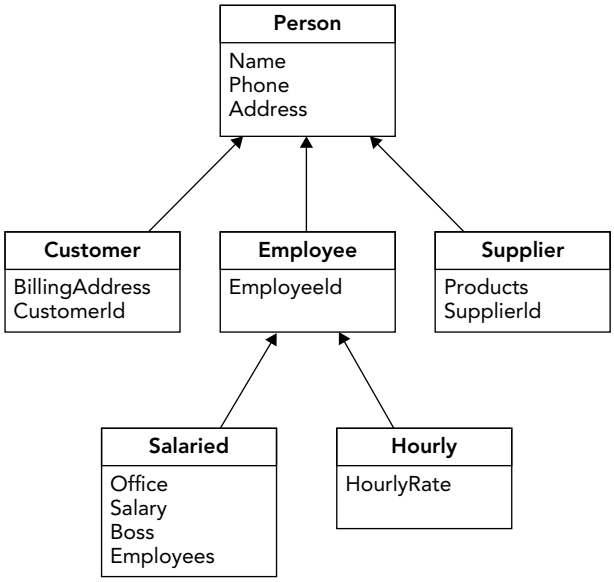


FIGURE A-11: This inheritance hierarchy represents business classes.

7. Storing ZIP codes in this way violates the 3NF rule, "It contains no transitive dependencies," because a non-key field (ZIP code) depends on other non-key fields (the entire address).

8. Including postal codes in address data leads to insertion, update, and deletion anomalies.

   - **Insertion anomalies**—You cannot store information about a postal code unless there is an address that uses it. This is usually no big deal because you generally don't need to do anything with a postal code unless it is part of some address.

- **Update anomalies**—There are several ways this could be a problem:
  - If you change one record's postal code, it could become inconsistent with other neighboring addresses. For example, if you change the ZIP code for 1 Main St, Boston, MA to 92123, then it won't match the ZIP code for 2 Main St, Boston, MA. Then again, that may be correct, so you probably shouldn't update any other ZIP codes.
  - A bigger problem would be if the Postal Service changes a ZIP code to a new value. Then you need to update all the records with the old ZIP code. This might be time-consuming if the database is big, but it shouldn't be too hard to treat it as a one-time conversion.
  - Probably the worst case scenario is when the Postal Service splits a ZIP code into two or more new ones. In that case, you'd need to check every address in the original ZIP code and figure out its new one. In some applications, it might be better to just invalidate the ZIP codes (for example, set them to 00000) and make users enter their new values the next time they place an order.
- **Deletion anomalies**—If you delete the last record with a particular ZIP code, you lose any information about that ZIP code. As is the case with insertion anomalies, this probably isn't a big deal because you don't do anything with the ZIP code information itself.

Even though you probably shouldn't make a separate table to hold ZIP code information, it may still be worth making a lookup table that lists the allowed ZIP codes. If your customers have only a handful of ZIP codes, a lookup table can catch data entry typos.

9. You could think of this as breaking the 1NF rule, "Each column must have a single data type," or "Each column must contain a single value." That would be true only if you think of the pieces of the ZIP code as separate values with their own meaning. Most applications treat the two possible pieces of a ZIP code as a single value, so putting them in the same field is okay.

   The field still breaks the 3NF rule, "It contains no transitive dependencies," as described in the solution to Exercise 7.

   It's probably not worth any extra effort to handle this field differently. Just make the program validate the field that so the user doesn't enter bogus values such as "20500-12" or "1924-12920."

10. Once upon a time, area codes mapped fairly closely to geographic areas, so if you had an address, you could figure out the corresponding area code. These days when you move, you can keep your old cell phone number, so you can't rely on any relationship between area code and address. In fact, you could have two phones at the same address with just about any area codes.

    I don't know enough about non-U.S. phone numbering plans to know if there is any relationship between address and parts of non-U.S. phone numbers, but my guess is cell phones have made any such relationship obsolete.

The only part of a phone number that I know you can store separately to improve normalization is country code. For example, the code for the United States is +1, the code for the United Kingdom is +44, and the code for Svalbard is +47 79. That means you could move the country code into a separate table and look up the values you need based on an address. That's a lot of work for little benefit (it seems unlikely that the country codes will change), so it's probably better to store country codes as part of phone numbers. (If you need them at all. If you don't have customers outside of your country, then you probably don't need to store country codes.)

11. This table design violates the following normalization rules:

    - 1NF rules:
        a. Each column must have a unique name. (There are multiple `Team` and `Time` columns.)
        b. The order of the rows and columns doesn't matter. (The order of the `Team` and `Time` columns matters.)
        c. Columns cannot contain repeating groups. (The `Team` and `Time` columns are repeating groups.)
    - 2NF rules:
        a. It is in 1NF.
        b. All non-key fields depend on all key fields. (`Winner` depends on the two `Time` fields, not on the `Heat` field. In other words, you can deduce `Winner` without knowing `Heat`.)
    - 3NF rules:
        a. It is in 2NF.
        b. It contains no transitive dependencies. (`Winner` depends on the non-key `Team` and `Time` fields.)

12. You could satisfy the rules about nonrepeating column names and the columns ordering not mattering by renaming the `Team` and `Time` fields to be `Team1`, `Team2`, `Time1`, and `Time2`, but that would still leave the table holding repeating groups.

    Note that the first `Time` field holds the heat's starting time. That is a different kind of value than the other `Time` fields, so it doesn't form a repeating group. Renaming it to `StartTime` would fix its name.

    To solve the problem, you should create a new `Heats` table to hold heat numbers, distances, and start times. Then create a second `HeatParticipants` table to hold information about the teams that participated in each heat. Figure A-12 shows the new design.

    Notice that the new design doesn't have a `Winner` field in either table. You can deduce a heat's winner by fetching the data for the two participating teams and comparing their times.

Heats		
Heat	Distance	StartTime
1	500	9:00
2	500	9:20
3	1000	9:40
4	1000	10:00

HeatParticipants		
Heat	Team	Time
1	Buddhist Temple	2:55.372
1	Wicked Wind	2:57.391
2	Rainbow Energy	3:10.201
2	Rising Typhoon	3:01.791
3	Math Dragons	5:52.029
3	Supermarines	6:23.552
4	Flux Lake Tritons	6:08.480
4	Elf Power	6:59.717

FIGURE A-12: These tables hold information about dragon boat races.

CHAPTER 7

1. The problem with the original GCD code's comments is that they just say what the code does and not why it does it. They don't add anything that isn't obvious from the code itself. For example, the following three lines leave you with the feeling of, "Well, duh!"

```
// Get the absolute value of a and b.
a = Math.Abs(a);
b = Math.Abs(b);
```

This algorithm is short but tricky to understand. You could include a big explanation of how it works, but that would clutter the code and make it harder to read. Besides, there's already a perfectly good description of the algorithm online.

The following code shows a version with much better comments:

```
// Use Euclid's algorithm to calculate the GCD.
// See en.wikipedia.org/wiki/Euclidean_algorithm.
private long GCD(long a, long b)
{
    a = Math.Abs(a);
    b = Math.Abs(b);

    for (; ; )
    {
        long remainder = a % b;
        if (remainder == 0) return b;
        a = b;
        b = remainder;
    };
}
```

All you need is the reference to the URL where you can find a description of the algorithm.

2. There are two likely reasons why the original GCD code ended up with bad comments. First, the programmer may have taken a top-down design to its logical conclusion where the code is described in excruciating detail. That's good programming practice, but it

can result in these kinds of redundant comments because each comment describes a code statement.

When using top-down design to generate comments, you need to stop one step before the actual code. In this example, the last step before writing out the code would be here:

- Use Euclid's algorithm to calculate the GCD.
    - See `en.wikipedia.org/wiki/Euclidean_algorithm`.

The second way this kind of comment sometimes occurs is if the programmer added the comments after writing the code. After the code is written, it's easy to just say what each line of code does and not why it is doing it. (It's sort of like a third-grade book report. You tend to get a repetition of the story and not the deeper insights you might get from a professional book reviewer.)

3. The parameters `a` and `b` should be greater than 0. (Actually, the algorithm works if `a` is 0, but that's a weird case that probably indicates an error in the calling code, so we'll flag that as an error.)

   If you verify that the values are greater than 0, then you can remove the calls to `Math.Abs` that convert `a` and `b` into their absolute values.

   The method can also verify that the return value actually divides both the `a` and `b` evenly. It should, but this is a good chance to check for bugs.

   The following code shows the revised GCD method. The validation code is highlighted:

```
// Use Euclid's algorithm to calculate the GCD.
// See en.wikipedia.org/wiki/Euclidean_algorithm.
private long GCD(long a, long b)
{
    // Verify that a and b are greater than 0.
    Debug.Assert(a > 0);
    Debug.Assert(b > 0);

    // Save the original values for later validation.
    long original_a = a;
    long original_b = b;

    for (; ; )
    {
        long remainder = a % b;
        if (remainder == 0)
        {
            // Verify that the result evenly divides the original values.
            Debug.Assert(original_a % b == 0);
            Debug.Assert(original_b % b == 0);

            return b;
        }
        a = b;
        b = remainder;
    };
}
```

You could also check that the result is the *smallest* even divisor of `a` and `b`. That's a bit trickier and more time-consuming, so you can include it in a conditional compilation block to make it easy to remove from release versions of the program.

The following snippet shows the new version of the code that validates the result with the new lines of code highlighted. That code is included in the compilation only if the symbol `DEBUG_1` is defined:

```
    if (remainder == 0)
    {
        // Verify that the result evenly divides the original values.
        Debug.Assert(original_a % b == 0);
        Debug.Assert(original_b % b == 0);

#if DEBUG_1
        // Verify that there are no larger common divisors.
        long max_value = Math.Min(original_a, original_b);
        for (long test_value = b + 1; test_value <= max_value; test_value++)
    {

            Debug.Assert(
                (original_a % test_value != 0) ||
                (original_b % test_value != 0));
        }
#endif

        return b;
    }
```

The new loop runs from the result plus 1 to the minimum of the original `a` and `b` values. It asserts that the values in that range do not evenly divide both `a` and `b` because any value that did would be a larger common divisor than the one found by the method.

4. The validation code written for Exercise 3 is already fairly offensive. It validates the inputs and the result, and the `Debug.Assert` method throws an exception if there is a problem.

5. You could add error handling code to the GCD method, but you actually want the calling code to handle any errors. As it is, if the code throws any exceptions, they are passed up to the calling code so that they can be handled there. That means you don't need to add error handling code here.

6. This isn't good code *because* it's clever. That makes it harder to understand (most people take a while to figure out how this swap works) and, remember, you should be writing code for people to understand, not for the computer's convenience.

   For all its obscurity, this code doesn't buy you much. It saves you from allocating a 4- or 8-byte temporary variable, but if one more variable is going to ruin your program's performance, your application has some serious problems.

   The following code shows a version that's much easier to understand:

```
// Swap a and b.
long temp = a;
a = b;
b = temp;
```

7. Your answer will be different from mine, but here's how to get to *my* nearest supermarket, to give you an idea of the level of detail required.

   a. Find the car.
   b. Open the car.
   c. Start the car.
   d. Back out of the parking space.
   e. Turn to the left (as you look at the parking space). Drive out of the parking lot to the cross street.
   f. Turn left. Drive until the street ends.
   g. Turn right. Drive to the stop sign.
   h. Turn left. Drive to the first stoplight.
   i. Turn right. Drive until you see the supermarket.
   j. Turn into the supermarket parking lot.
   k. Find an empty parking space and park in it.
   l. Stop the car and get out.
   m. Go buy Twinkies and Red Bull.

   This description makes the assumptions:

   a. The car is parked head-first (which should be true for my car).
   b. You properly adjust the seat and mirrors when you enter the car.
   c. There's gas in the car. (Another reasonable assumption.)
   d. You know how to drive a manual transmission. (I bet you didn't see that one coming!)
   e. There's nothing behind the car when you pull out.
   f. You can safely drive when instructed. No cars, people, dogs, trees, or other objects jump in the way.
   g. You know how to shift gears as needed.
   h. There are empty parking spaces in the supermarket parking lot.
   i. The supermarket is open.

   The lesson here is that even the most mundane chores can involve a huge number of steps, each of which can rely on a lot of assumptions. When broken down, some of the steps can also lead to a lot of smaller steps. For example, it takes a lot of instructions to explain how to start a car that has manual transmission if you don't know how to do it, particularly if you assume anything could go wrong.

CHAPTER 8

1. To test a method, you need a way to verify that the results it returns are correct. Sometimes, that's easiest if you write another method that performs the same

calculation in a different way. Then you can pass inputs to both methods and verify that they agree.

For this example, I wrote a `Validate _ AreRelativelyPrime` method that uses an inefficient algorithm for determining whether two values are relatively prime. The following C# code shows the method. (If you don't know C#, just read the description that follows the code.)

```
// Return true if a and b are relatively prime.
// This is a test method that is less efficient than
// AreRelativelyPrime and is used only to validate that method.
private bool Validate_AreRelativelyPrime(int a, int b)
{
    // Use positive values.
    a = Math.Abs(a);
    b = Math.Abs(b);

    // If either value is 1, return true.
    if ((a == 1) || (b == 1)) return true;

    // If either value is 0, return false.
    // (Only 1 and -1 are relatively prime to 0.)
    if ((a == 0) || (b == 0)) return false;

    // Loop from 2 to the smaller of a and b looking for factors.
    int min = Math.Min(a, b);
    for (int factor = 2; factor <= min; factor++)
    {
        if ((a % factor == 0) && (b % factor == 0)) return false;
    }
    return true;
}
```

This code first converts `a` and `b` into positive values. Then if either value is 1, it returns `true` because 1 and –1 are relatively prime to every number.

Next if `a` or `b` is 0, the method returns `false` because only 1 and –1 are relatively prime to 0 and the code already checked whether `a` or `b` is 1.

The code then makes the value `factor` loop from 2 to the smaller of `a` and `b`. The code takes the values `a` and `b` modulus `factor` to see if `factor` divides evenly into `a` and `b`. (The modulus is the remainder after division. For example, 14 % of 5 is 4 because 14 divided by 5 is 2 with a remainder of 4. If `a % factor` is 0, then `factor` divides into `a` evenly so `factor` is a factor of `a`.)

If `factor` divides into both `a` and `b` evenly, then `a` and `b` are not relatively prime so the method returns `false`.

Finally, if none of the values of `factor` divide into both `a` and `b`, then the numbers are relatively prime so the method returns `true`.

Having written the `Validate _ AreRelativelyPrime` method, you can use it to test the original `AreRelativelyPrime` method. I wrote a C# method named `Test _ AreRelativelyPrime` to perform a series of tests. The method is quite long (and unless you speak C# or a related

language, it would probably be confusing), so I won't repeat it here. The following text shows the tests that the method performs in pseudocode:

```
For 1,000 trials, pick random a and b and:
    Assert AreRelativelyPrime(a, b) =
        Validate_AreRelativelyPrime(a, b)

For 1,000 trials, pick random a and:
    Assert AreRelativelyPrime(a, a) =
        Validate_AreRelativelyPrime(a, a)

For 1,000 trials, pick random a and:
    Assert AreRelativelyPrime(a, 1) relatively prime
    Assert AreRelativelyPrime(a, -1) relatively prime
    Assert AreRelativelyPrime(1, a) relatively prime
    Assert AreRelativelyPrime(-1, a) relatively prime

For 1,000 trials, pick random a (not 1 or -1) and:
    Assert AreRelativelyPrime(a, 0) relatively prime
    Assert AreRelativelyPrime(0, a) relatively prime

For 1,000 trials, pick random a and:
    Assert AreRelativelyPrime(a, -1,000,000) =
        Validate_AreRelativelyPrime(a, -1,000,000)
    Assert AreRelativelyPrime(a, 1,000,000) =
        Validate_AreRelativelyPrime(a, 1,000,000)
    Assert AreRelativelyPrime(-1,000,000, a) =
        Validate_AreRelativelyPrime(-1,000,000, a)
    Assert AreRelativelyPrime(1,000,000, a) =
        Validate_AreRelativelyPrime(1,000,000, a)

Assert AreRelativelyPrime(-1,000,000, -1,000,000) =
    Validate_AreRelativelyPrime(-1,000,000, -1,000,000)
Assert AreRelativelyPrime(1,000,000, 1,000,000) =
    Validate_AreRelativelyPrime(1,000,000, 1,000,000)
Assert AreRelativelyPrime(-1,000,000, 1,000,000) =
    Validate_AreRelativelyPrime(-1,000,000, 1,000,000)
Assert AreRelativelyPrime(1,000,000, -1,000,000) =
    Validate_AreRelativelyPrime(1,000,000, -1,000,000)
```

This code verifies the method's results for pairs of random values, pairs of identical numbers, 1, –1, 0, and the smallest and largest values supported by the `AreRelativelyPrime` method –1 million and 1 million.

2. The testing code checks a lot of special cases, so you need to insert a lot of bugs into the `AreRelativelyPrime` method to test each special case. I added the following code to break each of the tests:

```
#if TEST_TESTS
    if (a == -1000000) return true;
    if (a == 1000000) return true;
    if (a == b) return true;
    if (a == 1) return false;
    if (b == 1) return false;
```

```
    if (a == -1) return false;
    if (b == -1) return false;
    if (a == 0) return true;
    if (b == 0) return true;
#endif
```

This code made the method return incorrect answers for each of the tests so the testing code could catch the errors. Note that the method didn't always return an incorrect answer. For example, the first statement says –1,000 is relatively prime to the number `a`. That's correct for some values of `a` but not for all values. Because the testing method runs 1,000 trials of most tests, it better find a number for which this is wrong and it better detect that error.

Notice that the code is enclosed in an `#if…#endif` conditional compilation block. That lets me easily disable the test-breaking code without removing it so that I can turn it on again later if I need to. (Actually, after you test the testing code, you can probably remove this. You probably won't need it again and it clutters up the original method.)

3. Because the statement of Exercise 1 doesn't say how the `AreRelativelyPrime` method works, this must be a black-box test.

   If I told you how the `AreRelativelyPrime` method works, you could write white-box and gray-box tests for it.

   You could try to perform an exhaustive test, but with allowed values ranging from –1 million and 1 million, there would be $(1{,}000{,}000 - -1{,}000{,}000 + 1)^2 = 2{,}000{,}001^2 \approx 4$ trillion pairs of values to test, which is probably too many. If the allowed values ranged from –1,000 to 1,000, you would have only approximately 1 million pairs to test, so this would be possible.

4. The tests I wrote for Exercise 1 use the `Validate_AreRelativelyPrime` method to test the `AreRelativelyPrime` method. Because we don't know how the `AreRelativelyPrime` method works, there's a chance that the two methods use the same technique. In that case, we might be using an incorrect method to validate another incorrect method, so they could be both wrong in the same way.

   If you knew how the `AreRelativelyPrime` method works, then you could write white-box tests that you know use a different method for determining whether two integers are relatively prime. That would increase your certainty that the tests work.

5. You can download an example C# program at `www.csharphelper.com/examples/howto_test_isrelativelyprime.zip`.

   When I wrote this program, I did find some problems in the `AreRelativelyPrime` method. The initial version didn't have restrictions on the values `a` and `b`, and the method had trouble handling the maximum and minimum possible integer values. That inspired me to restrict the allowed values. Testing often leads to restrictions such as this one.

   Other than that, the `AreRelativelyPrime` method worked well. It took a bit of effort to get the `Validate _ AreRelativelyPrime` method and the test-breaking code to work exactly as I wanted. It wasn't really hard, but it did force me to think carefully about the weird values –1, 0, and 1. That's another benefit of writing tests: It makes you think harder about special cases that might trip up the application.

6. The following text shows an exhaustive test for the `AreRelativelyPrime` method in pseudocode:

```
For a = -1,000,000 to 1,000,000
    For b = -1,000,000 to 1,000,000
        Assert AreRelativelyPrime(a, b) =
            Validate_AreRelativelyPrime(a, b)
```

   This version is much simpler than the previous test code. It also checks every possible combination, so it's guaranteed to flush out any bugs (as long as the `Validate _ AreRelativelyPrime` method is correct).

   It has the big drawback that it's slow, so it can handle only relatively limited ranges of values.

7. You can download an exhaustive version of the program at `www.csharphelper.com/examples/howto_test_isrelativelyprime2.zip`.

   On my computer, this program can handle the range –1,000 to 1,000 (approximately 4 million pairs) in roughly 9 seconds. The range –1 million to 1 million includes approximately 1 million times as many pairs, so it should take approximately 9 million seconds or around 104 days.

8. Yes, this is a lot of work. That's the price you pay for some assurance that the code works as advertised. Fortunately, most of the work is reasonably straightforward.

9. Exhaustive tests are black-box tests because they don't rely on knowledge of what's going on inside the method they are testing.

10. Lisa found 15 – 5 = 10 bugs that Ramon didn't, plus the 5 in common. Ramon found 13 – 5 = 8 bugs of his own, plus the 5 in common. That means:

$$\begin{aligned}[\text{Total found}] &= [\text{Lisa only}] + [\text{Ramon only}] + [\text{Common}] \\ &= 10 + 8 + 5 \\ &= 23\end{aligned}$$

    That means the number of remaining bugs is roughly 39 – 23 = 16. (Of course, this assumes you don't add any new bugs while fixing the ones that have been found.)

11. You can use each pair of testers to calculate three different Lincoln indexes.

    - Alice/Bob: $5 \times 4 \div 2 = 10$
    - Alice/Carmen: $5 \times 5 \div 2 = 12.5$
    - Bob/Carmen: $4 \times 5 \div 1 = 20$

    You could take an average of the three to get a rough estimate of $(10 + 12.5 + 20) \div 3 \approx 14$ bugs. Alternatively, you could assume the worst and plan for 20 bugs. In either case, you should continue to track the number of bugs found, so you can revise your estimate when you have more information.

12. If the testers don't find any bugs in common, then the equation for the Lincoln index divides by 0, giving you an infinite result. What this means is you have no clue about how many bugs there are.

    You can get a sort of lower bound for the number of bugs by pretending the testers found 1 bug in common. For example, if the testers found 5 and 6 bugs, respectively, then the lower bound index would be $(5 \times 6) \div 1 = 30$ bugs.

13. If the testers find only bugs in common, then the equation for the Lincoln index gives ($E_1 \times E_1$) ÷ E_1 = E_1 bugs, so the result assumes they have found every bug. That seems unlikely, particularly if the testers have found only a few bugs so far.

14. Here $E_1 = 15$, $E_2 = 13$, and $S = 5$, so the Seber estimator is:

$$\begin{aligned} Bugs &= \frac{(15 + 1) \times (13 + 1)}{(5 + 1)} - 1 \\ &= \frac{16 \times 14}{6} - 1 \\ &\approx 36 \end{aligned}$$

This is slightly less than the 39 bugs predicted by the Lincoln index.

15. Here $E_1 = 7$, $E_2 = 5$, and $S = 0$, so the Seber estimator is:

$$\begin{aligned} Bugs &= \frac{(7 + 1) \times (5 + 1)}{(0 + 1)} - 1 \\ &= \frac{8 \times 6}{1} - 1 \\ &= 47 \end{aligned}$$

This is a lot of bugs but fewer than the infinite number estimated by the Lincoln index.

16. If $E_1 = E_2 = S$, the Seber estimator:

$$Bugs = \frac{(E_1 + 1) \times (E_1 + 1)}{(E_1 + 1)} - 1$$

If you cancel one set of $(E_1 + 1)$ terms, you get:

$$Bugs = (E_1 + 1) - 1 = E_1$$

Like the Lincoln index, the Seber estimator predicts that every bug has been found. This still seems unlikely, particularly if the testers have found only a few bugs so far.

CHAPTER 9

1. In this case, it doesn't matter too much because any mistakes you make will affect only you and not thousands of other users. To make your own life easier, however, you might start with staging so that you can test the new version before you start using it. Gradual cutover doesn't make sense in this example because there's only one user. Incremental deployment also seems like more trouble than it's worth. I would just make a backup of the data and start using the new version.

2. Staged deployment, gradual cutover, and parallel testing work for just about any project. Incremental deployment also works in this example because the application is already broken into separate pieces.

3. Yes. Because each of the pieces needs to use the database, you can't simply install the pieces one at a time. That makes incremental deployment harder. It may not be practical for some parts of the system to use the old database and other parts to use the new one. For example, you

probably couldn't create new orders using the new database but have the order-editing tool use the older database. That probably eliminates incremental deployment as a viable option.

Staged deployment, gradual cutover, and parallel testing would still work.

4. Because mistakes could affect so many users, you should do as much testing beforehand as possible. Use staged deployment so that you can work out as many kinks as possible before you start installing for users. After you understand deployment in the staging environment, use gradual cutover. Install one user and make sure everything works. Then install another user or two and make sure things still look good. When you're confident that you won't leave your thousands of users twiddling their thumbs, start deploying the application in larger batches.

5. A huge initial release with great fanfare that flops will destroy your company, so it's important that deployment goes smoothly. It must also continue to go smoothly after the initial installations as other users join in the fun.

   To minimize risk, you should start with a staging area in which you test installation and the application itself thoroughly. In fact, you probably need multiple staging computers so that you can test in Windows 7, Windows 8, Windows 8.1, Linux, OS X, and any other operating systems you plan to support. If the game is browser-based, you also need to test the browsers you support such as Internet Explorer, Firefox, Chrome, and others.

   After you've thoroughly tested installation on all the supported platforms, it's time to invite the customers to give it a try. You might like to do a gradual cutover, but as soon as you post the installation package on the Internet, you may have thousands of users installing the program.

   One way to reduce your risk in this situation is to offer a limited beta. Users can sign up for a beta version of the game, to give you feedback. This lets you control the number of users who install the program (so you can still have a gradual deployment), and it gives you some cover if things go wrong. (Users don't expect betas to be perfect.)

   After your limited beta test, you can release the final application to everyone. This still works sort of like a staged delivery. If the users find a problem, you can place a moratorium on new installs until you work it out.

   You also need to keep a close eye on performance as the number of users increases. A program that works with 10 or 100 or even 1,000 users may swamp your servers when there are 10,000 users.

6. The process of planning helps you think about what should happen and what can go wrong. Sometimes, you can guess the most likely ways a step will fail and you can have a work-around ready. Even if an emergency is completely unexpected, your planning will probably give you information that can help you deal with whatever weirdness actually occurs.

   A deployment plan doesn't plan only for emergencies. It's also a script of things that may very well go right. Having a plan ahead of time can help you coast through the easy stuff so that you can focus your energy on the hard parts.

7. These sorts of decisions are not cut and dried, so your answer may be different from mine, but here are my thoughts. This is a shareware application, so users probably don't expect the level of sophistication they require from the Big Dogs of software such as Microsoft, Apple, and Google. That means admitting a mistake isn't as earth-shattering as it would be for bigger companies.

This is a big problem for this program because it greatly reduces the program's usefulness. That means you can't hush things up and hope no one will notice. Users will probably start complaining as soon as they use the new version.

Start by taking down the broken version 3.0 installer so that no one else installs it. Where the download should be, post a notice explaining the problem and telling users how hard you're working on fixing it.

Next, burn the midnight oil to get the program working correctly. When the problem is fixed, *test it thoroughly* so that you don't release a new buggy version. Nothing is as embarrassing as fixing a bug with another bug. (Okay, I can think of a few things more embarrassing, but that's about as bad as it gets with software releases.)

After you're *sure* it's working, release version 3.1 into the wild. Post a letter announcing the fix, explaining how hard you work to make users' lives better and saying how generally wonderful you are. If you have customer e-mail addresses, send them a copy of the letter. This isn't an ideal situation, but you can get some goodwill and publicity out of it.

8. Because this happens only about once a month, and because there's a work-around, this isn't a super high-priority issue. It could be a problem if a tester gets the wrong results and doesn't notice, so you need to warn users about the problem. However, this is an internal software project, so your sales are not at risk, and your testers probably won't quit because the software is a little off. (If this greatly annoys the testers and they start to grumble, you may need to reevaluate that assumption.)

   Meanwhile, tracking down a bug that has no apparent cause can be time-consuming. A programmer could spend days or weeks chasing this bug and still not find it. Probably it won't take that long, but even the simplest bug takes a day or two to fix once all is said and done. (After all, you need to read the documentation, which you hopefully took the time to write; check out the code from source control; study the code; find, fix, test, and document the bug; check the code back into source control; and release the new version.)

   You're left with a choice: Have users waste a few minutes per month, or have a programmer spend at least a day or two finding and possibly weeks fixing the problem. The obvious choice is to ignore the problem, cover your ears, and say "la la la" whenever someone points it out to you.

   Unfortunately, as mentioned in Chapter 8, bugs often travel in swarms. This bug could hide the presence of others. Besides, it should offend the sensibilities of any developer to leave known bugs like this in an application.

   What I would do is warn the users, tell them about the work-around, and fix the bug *when time permits*. Then I would wait until the next scheduled release to provide the fix.

CHAPTER 10

1. Figure A-13 shows my Ishikawa diagram.

   Because it would be easy, I would first check the database contents to see if New Hampshire is in the States table. (Cross your fingers because this will be the easiest problem to fix. Simply add New Hampshire to the table and test again.)

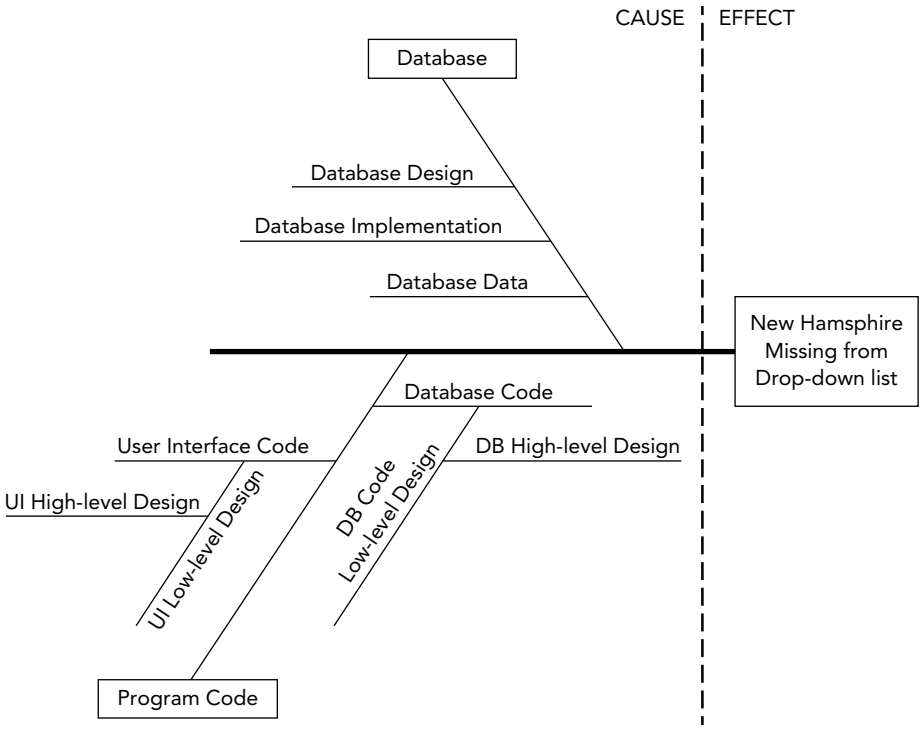


FIGURE A-13: This Ishikawa diagram shows possible causes for New Hampshire not being listed in the states' drop-down list.

It seems unlikely that the database design or implementation could be at fault because the database contains the other values required by the use cases (Maine, Vermont, and Massachusetts).

That leaves only problems with the database code or the user interface code. I would check each of those and then follow whichever of those is wrong upstream. For example, if the database code isn't returning the right values, I'd check the low-level database code design. If the problem were obviously there, I'd be done. If the problem didn't obviously start in the low-level database code design, I'd check the high-level database code design.

2. Size normalization is useful when you're trying to compare two projects of different sizes but roughly similar complexities. In contrast, FP normalization lets you compare projects that differ in complexity.

3. Size normalization takes into account project size. FP normalization takes into account both project size and complexity. That means you can use FP normalization any time you can use size normalization but not vice versa. In other words, you can use either method when the projects have roughly the same complexity.

4. You use the following equation to perform the final FP calculation:

$$FP = (\text{raw FP}) \times (0.65 + 0.01 \times CAV)$$

This has its largest value if CAV is as large as possible. That happens when you assign all the complexity adjustment factors the weight Essential, so they all get the value 5. There are 14 of those values, so you add them up to get $14 \times 5 = 70$. The calculation becomes:

$$FP = (500) \times (0.65 + 0.01 \times 70) = 675$$

The final FP has the smallest value if all the complexity adjustment values are 0. Then the calculation becomes:

$$FP = (500) \times (0.65 + 0.01 \times 0) = 325$$

5. Suppose project A has 12,500 LOC and 158 bugs so it has 12.6 bugs/KLOC. Project B has 3,250 LOC and 47 bugs so it has 14.4 bugs/KLOC. In this case, project A has more bugs in total but fewer bugs per KLOC, so it's doing better in that sense.

   Assuming everything else is roughly equal for the two projects, you need to know how many developers they each have. Then you can calculate bugs per developer to decide which project will need more time to finish clearing out the bugs.

   For example, suppose project A has 10 developers so it has 15.8 bugs per developer, and project B has 5 developers so it has 9.4 bugs per developer. In that case, project B has fewer bugs per developer so it will probably finish first.

6. If you know from past experience either in those projects or previous projects about how many bugs per day each developer can fix, then you can multiply that value by the number of bugs per developer to get the number of days remaining.

   $$\text{Days/Bug} \times \text{Bugs/Developer} = \text{Days/Developer}$$

   Of course, you can never really find every bug, so this probably tells you only when you've found enough of the bugs to have a reasonably stable application.

7. The way you count an application's inputs, outputs, and other complexity values can vary greatly, so if you're doing this for actual applications, you may want to develop some guidelines about what to count. That means your result may differ greatly from mine. Here are the values I used.

   Inputs—WordPad can open approximately six kinds of files. The user can also type inputs into a document, so I'll make this count seven. (For some applications, you might want to make this the number of different files the application uses instead of the number of *types* of files it can open. WordPad can open a practically unlimited number of different files, so counting the number of file types seems more meaningful.)

   Loading text files isn't too hard, but loading .rtf, .docx, and .odt files would be tricky. (There are tools that could make these a lot easier, but remember we're trying to assess the complexity of the application from the user's point of view, not from the programmer's point of view. The results of these operations are complex, even if tools make them easier.) Working with the user's current file could also be hard. I'll give this category an average of medium complexity.

   Outputs—WordPad can save approximately six kinds of files and it can print the current document, so I'll make this count seven. (Again, WordPad can save an unlimited *number* of different files, so I'll count *types* of files.)

Saving text files isn't hard, but saving .rtf, .docx, and .odt files is. Printing could also be complex. I'll give this category an average of medium complexity.

Inquiries—WordPad doesn't handle inquiries so I'll make this 0.

Internal Files—WordPad works on one file at a time, so I'll count its current document as one internal file. The program doesn't save configuration information, so that doesn't add to the internal file count.

It lets the user set a fair number of values (such as font face, size, style, and color), so I'll give this high complexity.

External Files—WordPad doesn't use any external files.

Figure A-14 shows my final counts.

			Complexity			
Category	**Number**	**Low**	**Medium**	**High**		**Result**
Inputs	7 ×	3	(4)	6	=	28
Outputs	7 ×	4	(5)	7	=	35
Inquiries	0 ×	3	4	6	=	0
Internal Files	1 ×	7	10	(15)	=	15
External Files	0 ×	5	7	10	=	10
				Total (raw FP)		**78**

FIGURE A-14: This table shows Microsoft WordPad's raw FP value.

Table A-2 shows my complexity adjustment factors for WordPad.

The following equation shows the final FP calculation.

$$\text{FP} = (\text{raw FP}) \times (0.65 + 0.01 \times \text{CAV}) = 78 \times (0.65 + 0.01 \times 27) = 71.76$$

8. Your result may differ greatly from mine, but here are the values I used.

Inputs—Word can open approximately 16 kinds of files. Many of those file types (such as .docx, .xlsx, .wps, .odt) are complicated, so I'll give this category high complexity.

Outputs—Word can save approximately 16 kinds of files and it can print the current document, so I'll make this count 17. Again, some of the file formats are complicated, so I'll give this category high complexity.

Inquiries—Word doesn't handle inquiries exactly, but it does have an automation server mode that lets other programs use it to open, manipulate, print, and save files. You could count those actions as more inputs and outputs and increase the count of those categories by 16. However, the server feature doesn't actually double the complexity.

The program can already open and save the 16 file types, so this is just another way to use that same capability. For that reason, I'm going to count this as 1 very complex feature.

TABLE A-2: Complexity Adjustment Factors for WordPad

FACTOR	RATING
Data communication	0
Distributed data processing	0
Performance	5
Heavily used configuration	0
Transaction rate	0
Online data entry	5
End user efficiency	5
Online update	0
Complex processing	3
Reusability	0
Installation ease	4
Operational ease	5
Multiple sites	0
Facilitate change	0
Total (CAV)	27

Internal Files—Word works on one file at a time, so I'll count its current document as 1 internal file. It also saves a lot of configuration and customization information. If you select File ➢ Options, you'll see approximately 10 pages of options, so I'll count this as 10 additional items for a total of 11. The configuration information includes low, medium, and high-complexity items, so I'll give this category an average of medium complexity.

External Files—Word uses external document templates to determine a document's initial layout and properties. You can actually use Word to modify those templates, but in that case it's being used as a separate application. For example, when I select File ➢ New (don't press Ctrl+N), the program shows me a list of more than 30 `Office.com` templates. Those aren't maintained by me, so I'm counting them as external files.

You could have access to a practically unlimited number of templates, so you can't actually count individual templates here. Instead I'll do the same thing I did for inputs and outputs and count the template file type as a single complex item.

Figure A-15 shows my final counts.

			Complexity			
Category	**Number**	**Low**	**Medium**	**High**		**Result**
Inputs	16 ×	3	4	(6)	=	96
Outputs	17 ×	4	5	(7)	=	119
Inquiries	1 ×	3	4	(6)	=	6
Internal Files	11 ×	7	(10)	15	=	110
External Files	1 ×	5	(7)	10	=	7
				Total (raw FP)		**338**

FIGURE A-15: This table shows Microsoft Word's raw FP value.

Table A-3 shows my complexity adjustment factors for Microsoft Word.

Before making the final calculation, I want to briefly explain the reusability value. As mentioned earlier, Microsoft Word can act as an automation server. When it acts as a server, it can do just about anything it can do interactively. To allow it to do the same things both interactively and as a server, the code must be written in a reusable style, so I'm giving this factor high importance.

TABLE A-3: Complexity Adjustment Factors for Microsoft Word

FACTOR	RATING
Data communication	0
Distributed data processing	0
Performance	5
Heavily used configuration	5
Transaction rate	0
Online data entry	5
End user efficiency	5
Online update	4
Complex processing	5
Reusability	5
Installation ease	4
Operational ease	5
Multiple sites	0
Facilitate change	0
Total (CAV)	**43**

The following equation shows the final FP calculation.

$$FP = (\text{raw FP}) \times (0.65 + 0.01 \times CAV) = 338 \times (0.65 + 0.01 \times 43) = 365.04$$

9. In performing those FP calculations, I had to make a lot of assumptions about what should be counted and how. It's unlikely that someone else will make exactly the same assumptions, so our FP results may differ greatly. (How closely did your calculations agree with mine?)

   You could improve consistency by writing a lot of rules about what should be counted and how. For example, how do you count the number of input files when a program could open a practically unlimited number of different files? This could be a lot of work but it would be important.

   You would probably even need that kind of documentation even if the same person were calculating FP for all your projects. Otherwise, when I perform the calculation for a project a year from now, I may not remember exactly how I made my decisions today.

10. Microsoft WordPad's FP of 71.76 and Microsoft Word's FP of 365.04 tell you that Word is a *lot* more complicated than WordPad.

    This agrees with what I would expect; although, my calculations made me realize how much more complicated Word is than WordPad. Both programs enable you to edit files, format documents, and open and save .docx files, so you might think their complexities are similar. However, Word provides an abundance of extra features that you might not think about until you try to count them for the calculation.

11. Of course, "better" is a subjective term. Function point normalization lets you compare very different projects, but it's much harder to apply consistently. Size normalization doesn't help you compare projects with different complexities, but it's much easier to use. So I would use size normalization if possible and function-point normalization when the projects' complexities vary greatly.

12. Because the projects have similar complexities, you can use size normalization.

    If you divide total LOC by number of weeks, you'll get lines of code per week. That's still not a great way to compare the projects, because ten developers can probably produce a lot more code than five programmers. To get the number of lines of code produced per developer per week, divide total LOC by number of person-weeks (pw).

    You could similarly divide the total number of bugs by person-weeks to get number of bugs per developer per week.

    Another (and simpler) method for thinking about the number of bugs is to look at the number of bugs per KLOC.

    Table A-4 shows those three calculations.

    The LOC/pw values show that project Griffin was least productive and project Jackalope was most productive.

TABLE A-4: Normalized LOC and Bugs

PROJECT	PW	LOC/PW	BUGS/PW	BUGS/KLOC
Unicorn	80	149	3.41	22.95
Pegasus	40	150	2.60	17.30
Griffin	72	135	2.43	17.95
Jackalope	28	185	3.14	17.00

The Bugs/pw values show that project Jackalope produced the most bugs and project Griffin produced the fewest per person-week. That's a bit misleading, however, because the teams didn't all generate code at the same rate. Project Jackalope created a lot of bugs per person-week because the developers generated a lot of code quickly. Project Griffin created fewer bugs per person week because the developers wrote code relatively slowly.

A better measure of code quality is bugs/KLOC. Those numbers show that projects Pegasus, Griffin, and Jackalope produced roughly the same numbers of bugs per line of code, and project Unicorn produced significantly more bugs.

To make process improvements, you could try to figure out how project Jackalope increased productivity without sacrificing quality. Perhaps you can use whatever the magical factor was in future projects.

Similarly, you can look at project Unicorn to see why their bugs/KLOC was higher. Perhaps there's something they did (or someone on the team did) that you should avoid in the future.

13. The projects described in Exercise 12 produced between 135 and 185 LOC/pw, with an average of approximately 155 LOC/pw. Dividing 7,000 lines of code by those numbers gives the following estimates.

CASE	EXPECTED TIME
Best Case	7,000 LOC ÷ 185 LOC/pw ≈ 37.8 pw
Average Case	7,000 LOC ÷ 155 LOC/pw ≈ 46.2 pw
Worst Case	7,000 LOC ÷ 135 LOC/pw ≈ 51.9 pw

Similarly the previous projects produced between 17.00 and 22.95 bugs/KLOC with an average of 18.80. Multiplying those values by 7,000 lines of code gives the following estimates.

CASE	EXPECTED BUGS
Best Case	7 KLOC × 17.00 Bugs/KLOC ≈ 119.0 bugs
Average Case	7 KLOC × 18.80 Bugs/KLOC ≈ 131.6 bugs
Worst Case	7 KLOC × 22.95 Bugs/KLOC ≈ 160.7 bugs

14. It's a bit harder to evaluate a project in the middle (project metrics) than it is to compare projects after the fact (process metrics). One way to do this is to graph the project's progress (LOC and number of bugs) over time and compare it to similar values for other projects.

However, unless the projects just happen to have the same durations, they won't line up properly. In other words, you can't directly compare a 5-week project and a 10-week project week by week.

Instead you can compare the percentage of the project that's finished with the percentage of the time that has elapsed. For example, consider a typical 10-week project. Suppose after week 5, the team has written 40 percent of the total code. Then you would expect future projects to also have written 40 percent of the code when one-half of the project's time has elapsed.

Table A-5 shows the percentages of LOC and time for each of the projects during their durations.

TABLE A-5: Project LOC and Percentage of Time for Previous Projects

	UNICORN		PEGASUS		GRIFFIN		JACKALOPE	
WEEK	LOC	TIME	LOC	TIME	LOC	TIME	LOC	TIME
1	9.3	12.5	9.0	20.0	4.6	16.7	2.4	25.0
2	19.7	25.0	22.9	40.0	24.5	33.3	23.2	50.0
3	29.3	37.5	45.9	60.0	52.7	50.0	67.9	75.0
4	35.9	50.0	77.8	80.0	61.6	66.7	100.0	100.0
5	50.5	62.5	100.0	100.0	80.1	83.3		
6	63.2	75.0			100.0	100.0		
7	82.0	87.5						
8	100.0	100.0						

Figure A-16 shows a graph of the percent of LOC versus percent of elapsed time for the four previous projects.

Table A-6 shows the percent of LOC and percent of elapsed time values for project Hydra after 4 weeks. (Remember, this project is expected to include 7,000 LOC and take 9 weeks.)

Figure A-17 shows the graph from Figure A-16 with project Hydra's data added.

Referring to Figure A-17 you can see that project Hydra is generating code more slowly than the previous projects. If you extend its curve to the right, only approximately 40 percent of the project's code will be written by the end of week 9.

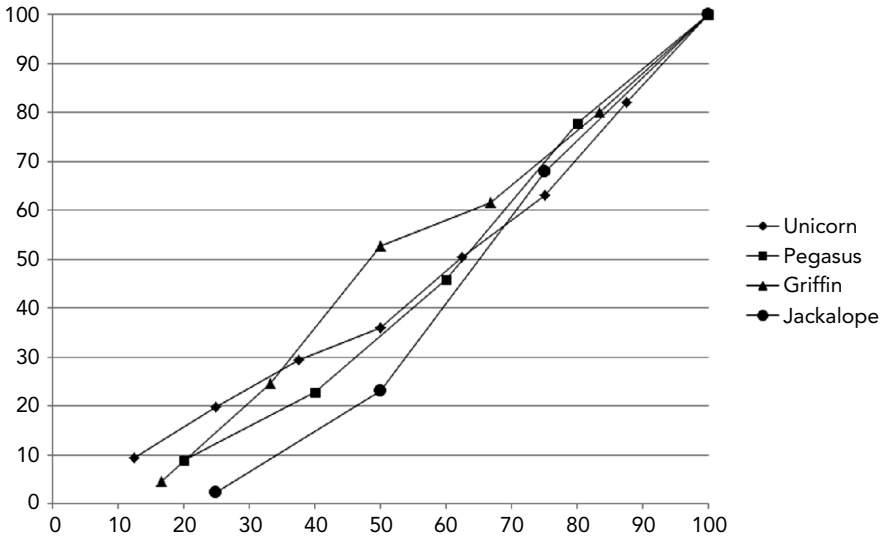


FIGURE A-16: This graph shows percent of LOC versus percent of elapsed time for previous projects.

All the projects started off relatively slowly and then picked up speed, but project Hydra shows no signs of an increase yet. If it doesn't pick up the pace soon, it won't finish on time.

So the answer to the original question is yes, you should be concerned about this project. It's not hopeless yet, but if something doesn't change soon, it will be. I would keep a close eye on it for the next couple weeks.

You can perform a similar analysis on the project's known bug data if you like. For example, you can graph bugs/LOC versus percent of time. If the graph shows that project Hydra's bugs/LOC is much lower than the other projects' values approximately 44.4 percent of the way through the project, then the project team may not be detecting bugs as effectively. (Or they may just be writing extra good code with fewer bugs. You'll have to dig deeper if you want to know exactly what's happening.)

TABLE A-6: Project LOC and Percentage of Time for Project Hydra

WEEK	LOC	TIME
1	5.3	11.1
2	9.9	22.2
3	13.8	33.3
4	17.9	44.4

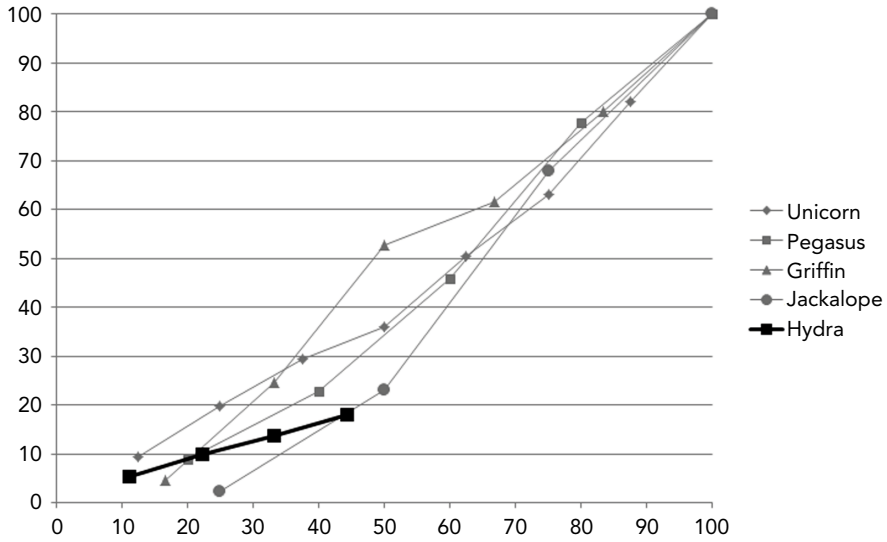


FIGURE A-17: Project Hydra is generating code slowly compared to the previous projects.

CHAPTER 11

1. In percentages, the chance of a new line of code creating a bug is roughly 2 percent. The chance of a modified line of code generating a bug is approximately 4 percent. In writing 10 KLOC, the team generates around 10,000 × 0.02 = 200 bugs. Fixing those 200 bugs generates 200 × 0.04 = 8 additional bugs. Fixing 8 bugs generates 8 × 0.04 = 0.32 new bugs. Let's pessimistically round that up to 1.

   After this point, the number of expected new bugs is small, so there's a chance that you're actually fixing something without adding new bugs. Adding up the numbers gives 10,000 + 200 + 8 + 1 = 10,209 total lines of code.

2. Of course, maintenance isn't done! If you keep careful track during development and testing, you can estimate the number of bugs per KLOC, but it's always an estimate. You can never be sure of exactly how many bugs are present.

   Besides, maintenance includes adding new features and improving old ones, so maintenance is never done for successful applications.

3. This is simply a matter of dividing the number of lines of each type of code by the appropriate number lines of code per day. Those numbers are:

   - 10,000 lines / 20 lines per day = 500
   - 200 lines / 4 lines per day = 50
   - 8 lines / 2 lines per day = 4
   - 1 line / 1 lines per day = 1

   Adding the numbers of days gives 500 + 50 + 4 + 1 = 555 days.

4. If the whole project requires 555 days and you have two team members, then you should expect the project to take approximately 277.5 days. There is an average of approximately 21 working days per month, so the project should take around $277.5 \div 21 \approx 13.2$ months.

   If you have five team members, the project should take around $555 \div 5 = 111$ days or $111 \div 21 \approx 5.3$ months.

   If you have 10 team members, the project should take around $555 \div 10 = 55.5$ days or $55.5 \div 21 \approx 2.6$ months.

   Finally, if you have 111 team members, the project should take approximately $555 \div 111 = 5$ days or 1 week. Wait, what? That doesn't make any sense! There's no way any number of developers can write 10,209 lines of code in a week and produce an application that can do something useful. As the team grows large, communication and administrative tasks will start to dominate the total amount of time. Eventually, you'll spend all your time bickering about what kinds of bagels to serve at team meetings. (What about those on low-carb diets? And those who are gluten-free? And the vegans will veto cream cheese or lox.)

   Larger projects definitely have extra overhead. The optimal team size for a project depends on a lot of factors such as the project's size and complexity, and the skills of the team members. In general, it seems that projects start to pay a significant size penalty when they grow to more than seven or more members.

5. Figure A-18 shows the flowchart.

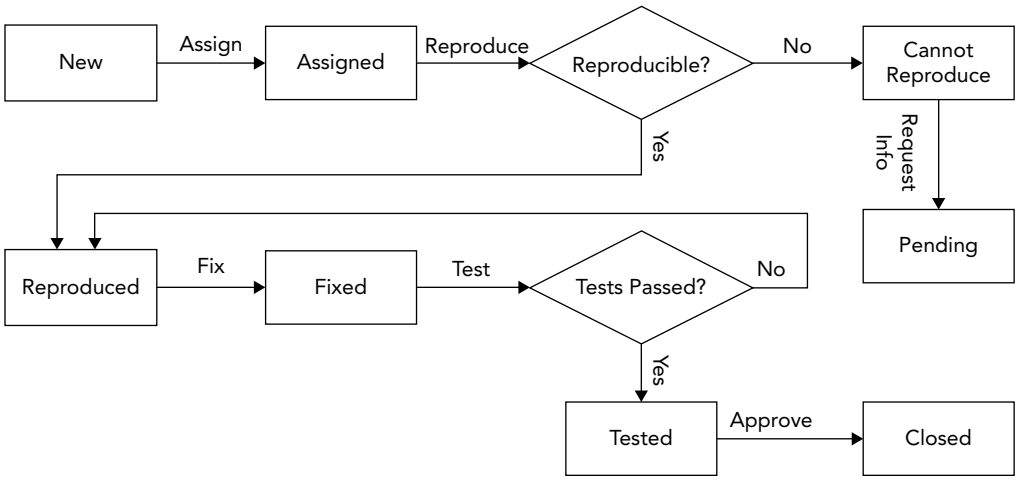


FIGURE A-18: This flowchart shows the states through which most bugs pass.

6. A bug could enter the Pending state from almost any other state because a team member might want more information at any time. Technically, a bug probably shouldn't go directly from Closed to Pending but should pass through Reopened first. However, that's a technicality. If a bug needs to be reopened for more information, so be it. But you might want to require that the bug first go through Reopened just to add that transition to the bug's history.

A bug can move to Deferred from any state except Closed if the team decides that bug won't be fixed right away. A bug probably won't move from Tested or Closed into Deferred because in those states the bug is already fixed.

A bug can only move into the Reopened state from the Closed state. (You can't reopen a bug that is still open.)

7. This would be unusual because the bug is already fixed, but there might be a reason why you don't want to release the fix to users. For example, if the bug fix is a breaking change so it would mess up work users have previously done, you might want to wait until a later release.
8. These values are simply the percentages for the maintenance task (Perfective—50%, Adaptive—25%, Corrective—20%, Preventive—5%) multiplied by the 75% allowed for maintenance. The results are Perfective—37.5%, Adaptive—18.75%, Corrective—15%, and Preventive—3.75%.
9. The following list gives the tasks' categories.
    a. Corrective.
    b. Perfective (adding a new feature).
    c. Perfective (adding a new feature).
    d. Preventive.
    e. Preventive.
    f. Preventive.
    g. Adaptive (dealing with a change to the environment).
    h. Perfective (improving an existing feature). You could consider this as corrective depending on whether you think of the slow performance as a bug.
    i. This is probably a bad idea. If the code works, leave it alone. (You could also add comments or documentation if they are currently insufficient.)
    j. Preventive (removing a bug swarm).
    k. Preventive (making the code easier to maintain). You might want to defer this until you need to modify the code anyway. If it ain't broke, don't fix it.
    l. Preventive (understanding the code). You should also write documentation and comments if they are currently insufficient. (This can be a good exercise for understanding the code.)
    m. Perfective (adding a new feature).
    n. Adaptive (dealing with a change to the environment).
    o. Perfective (adding a new feature).
10. Most of these are bad signs, but you could probably leave most of them alone as long as they're working correctly.
    a. That's too long. Consider rewriting the method the next time you need to modify it.
    b. Don't change the code. The next time you need to modify it, add comments and documentation to make it easier to understand.

c. That's too deep to understand easily. Consider rewriting the method the next time you need to modify it.

d. This is a tough situation. Ideally, you would consider rewriting the next time you had to modify the code. Unfortunately, with so many methods involved (assuming it's not one method calling itself in deep recursion), you'll probably have to modify something at some point. Also unfortunately this will probably be confusing and hard to rewrite successfully. This may require a major rebuild. (I've worked with code like that and it's practically impossible to keep track of what's happening, so you have my sympathy.)

e. As long as it works, I would ignore this. If you have nothing better to do, you should think about perfective tasks.

f. This method doesn't have a tightly focused purpose, so it should be rewritten as three separate methods. You might invoke the "if it ain't broke, don't fix it" rule, but this method's lack of focus makes it hard to use correctly. That means if you write new code that uses the method, that code is at risk. So the real question is, "Are you going to need to write a lot of new code that uses this method?" If you will use it with new code, rewrite it. If you won't need to write new code that calls this method, you can leave it alone (and feel slightly guilty).

g. This probably violates the nonfunctional specifications, so you may be forced to fix it regardless if you think it's a good idea. This is a big burden on the users, so I would fix it if at all possible. (Otherwise users will start the login process and then wander off to get coffee while they wait for it to finish.)

h. This is a bug swarm. You should rewrite the method.

i. This is a bad bug. That means it's a corrective tasks, not a preventive task. Whatever you call it, you should fix it.

j. This is also a bug and hence a corrective task. However, because the program crashes only when it's shutting down anyway, it should have low priority. I would fix it, but I would fix other bugs first.

k. This doesn't mean there's anything wrong with the method, other than the initial bug. I would carefully review and test the latest bug fix to make sure it actually works. I would also review the method as a whole to see if it's particularly confusing and needs extra comments or documentation to prevent this from happening again.

l. As in the preceding case, the method itself is only responsible for the single original bug. In this case, however, three different people (again, definitely not you) had problems fixing bugs in this method, so there may be a bigger problem here. You should examine the method and try to figure out what the problem is. If your coworkers are just making silly mistakes, they may be burned out. (Have they been working too many late nights?) If the method is particularly confusing, it may need more study, comments, and documentation. (It's also a good idea to have developers fix their own bugs, so ideally this series of bugs should have been handled by a single person. That person should have a better idea of what's going wrong here.)

m. This is a bug so it's a corrective task, not a preventive one. Because users can easily recover, this is a low-priority bug if the application is used in-house. If the program is sold to customers, however, any crash looks extremely bad, so this would be a high-priority bug.

CHAPTER 12

1. The following list explains whether the tasks would be better handled predictively or adaptively.

   a. This is a well-understood task, so you can do it predictively. (Unless you're doing something weird like trying an experimental architectural technique or building an art project.)

   b. Because you don't know where the clues will lead you, you're going to have to be adaptive. You might not even know how many clues there will be.

   c. When you follow a scavenger hunt, you don't know where each clue will lead. When you're building a scavenger hunt, however, you have control over the clues, so you can handle it predictively.

   d. This is a mostly well-understood task, so you can do it predictively. There may be some uncertainty about the weather, so you should use risk management to have a backup plan in place.

   e. In Seattle, there's less question about the weather: It will be wet. You can still do this predictively, but now the dry weather plan should probably be the backup plan instead of the primary plan.

   f. A major motion picture is a huge undertaking involving hundreds of people and months or even years of work. Sometimes things go wrong during shooting, but the basic schedule is more or less fixed, so this is a predictive task.

   g. This is mostly predictive because you need to hit certain milestones within a set period of time. For example, in a semester you need to cover a certain number of chapters, giving a reasonable number of tests, and regularly hold office hours. Those tasks all fit nicely into a predictive model.

      At the same time, a class's focus often wanders around a bit depending on the students' interests, how well they can sit still for certain subjects, and the instructor's creativity. Students learn best if the subject is something that interests them personally. For example, you might ask students to build a simple database application but let them pick the domain. They could store car specifications, football team statistics, dessert recipes, or information about their DVD collections. This requires the instructor to be adaptive.

      To handle both the predictive and adaptive needs, the instructors I know use predictive lesson plans that explain more or less what will happen during class with varying levels of detail depending on the instructor. Then they adjust the lesson in progress and sometimes modify future lessons if necessary.

   h. Without GPS you would look up where the restaurant is on a map (or call it and get directions), plan out a route, and follow it. If something went wrong (like a

DeLorean breaking down in front of you), you would be more or less stuck. You could reroute (if you didn't leave the map at the hotel), but it would take significant time and effort.

i. This would still be predictive, only this time the GPS would plan the route. If something went wrong (like an SUV running out of gas and blocking the road in front of you), you could make the GPS plan a new route. However, the GPS unit's user interface can make it cumbersome to plan a new route that avoids a particular blockage.

j. This would probably still feel predictive to you because people like to know what's going to happen. (This is one of the more attractive features of predictive models, particularly for management and customers.) However, the car and its computer systems could handle this completely adaptively. The car would plot a route and present it to you for your piece of mind. Then as the drive progresses, the car could watch for blockages (like a flying saucer landing in front of you and blocking the road) and instantly revise the route if necessary. That means this would probably look predictive to you, and you would follow the original plan most of the time, but behind the scenes the car could handle this adaptively.

2. All these projects have trouble indicators for predictive projects.

   a. This is an incredibly large and complex project. A predictive project would provide a level of control that the FAA would probably like, but the sheer size of the project would make it difficult.

   b. Lack of clear vision. If you do pry requirements out of the partners, they'll probably be inconsistent and unclear.

   c. Unrealistic expectations and lack of resources. It might be possible to build this application predictively, but probably not in 15 person-months.

   d. Lack of experience. Your team has experience with vacation-costing not housing development. (Unless you're not telling me about a previous project.)

   e. Lack of user involvement. Unless the customer is willing to help define the requirements, it will be hard to satisfy the specification you've been given. (Although you could spend the 3 weeks working on requirements and then finish them up after the customer returns from vacation. That would probably work, all else being equal, but it doesn't seem like a promising start to a new project.)

   f. Unestablished technology. Perhaps 3-D concrete printers will be common in a year or two, but until then, this would be very speculative. (However, it would also be very fun! I'd be tempted to take the project anyway, although perhaps with a different development model.)

3. A predictive model can save money if you correctly plot out the development effort's path. Adaptive models sometimes take extra time chasing unprofitable lines of development and refactoring.

   However, if you don't map out the development plan correctly and need to make major changes, a predictive project can cost much more than an adaptive approach.

4. Waterfall with feedback and Sashimi are very similar. In fact, some developers use the names more or less interchangeably. Both allow some overlap of project phases, but they have different intent.

   Waterfall with feedback enables you to move backward to a previous phase if you need to make corrections and adjustments. In contrast, Sashimi enables some developers to move ahead of other developers so they can get a jump on future tasks.

5. As many as you like. In theory, the project could run indefinitely adding new features with each increment.

6. Operation and Maintenance ➢ Concept: The concept represents the way users see the application. After the application is built, users see its operation and (to a lesser extent) maintenance.

   Verification and Validation ➢ Requirements: The requirements represent the customers' needs and the behavior that the application should have. Verification confirms that the application provides the behavior described in the requirements. Validation confirms that the application satisfies the customers' needs, which are represented in the requirements.

   Testing ➢ Design: In a sense, testing validates the design. If the design is correct, then testing should show that the application works properly. (In practice, testing may uncover problems and fixing them may require you to make the program deviate from the design. In that case, you should go back and update the design to reflect the program's actual structure, so the maintenance crew can use the design to understand how the application works.)

CHAPTER 13

1. The iterative, incremental, and agile approaches enable you to release partial applications as soon as you've implemented enough features with enough fidelity to be useful. However, you don't have to take advantage of that capability if you don't want to. You could still use those approaches to build the application and give the customer the application only when it was complete. Then you would still get the other benefits of those techniques. For example, those approaches would help you refine the requirements throughout the project.

2. The point of a throwaway prototype is to quickly demonstrate one or more features so that you can decide where to go from there. To avoid wasting a lot of time building features you don't need, a throwaway prototype should start with the fewest features and the lowest fidelity possible. If a feature isn't demonstrated adequately and customers want to see a more realistic version, you can improve its fidelity. If customers want to see other features, they can request them and you can add them. Starting with minimal features of low fidelity, improving them, and adding more features are the characteristics of an agile approach.

3. In an incremental prototype, you build the application's features in separate prototypes and then integrate them to create the final application. If you don't release anything to the users before you finish integrating these features, then the project isn't incremental.

   To make the project incremental, you would simply release the program any time its current set of integrated features was usable.

4. Sort of. In a predictive project, you fix the requirements and build a design before you start programming. An evolutionary prototype continues to grow and evolve throughout the project's lifetime. Normally, the prototype continues to refine the project's features as it grows, so the requirements and design are not fixed up-front.

   However, you could fix the requirements and design in the beginning and then implement the code with an evolutionary prototype approach. That kind of subverts the purpose of the prototype (to help refine the requirements), so most people don't do it that way. If the requirements and design are fixed, you can just write the code and skip the evolutionary prototype.

5. This question's answer is similar to the answer for Exercise 4. Normally in an incremental prototype, you build prototypes for the application's pieces and you use them to refine the requirements for those pieces. In that case, the requirements are not fixed up-front, so that's not predictive development.

   However, if you really want to, you could fix the requirements and design in advance and then build the application through an incremental prototype. It would be an unusual way to look at things, but it should work.

6. The deployment tasks include everything necessary for deployment. You can start working on some of those tasks as soon as you know what's necessary. If you wait until the start of the transition phase, you'll probably be late because you can't purchase and install things such as desks and computers instantly.

   During elaboration, the requirements start to coalesce, so you can start writing user documentation. You can also start planning the physical setup (items such as desks, chairs, computers, printers, and networks). However, you shouldn't commit to those items too early in case plans change later. (It would be expensive to buy 1,000 computers early in the project only to discover later that you need a different type of computer or that you need only 150 of them.)

   So you can start planning the installation of the physical equipment during elaboration, but you generally won't actually start installing that equipment until the later iterations of construction when plans are more concrete.

7. During the inception phase, the team can test the project's general ideas, assumptions, and approach. Team members can think of scenarios that need to be handled and decide whether the requirements can handle them. Those thought experiments can help refine the project's overall shape.

8. Code written during the elaboration phase is usually exploratory. It is written to try out new techniques and ideas that may be used in the application's design. The results of those experiments help refine the requirements.

   You don't need to do a lot of testing on exploratory code because that code won't be used in the final application. Tests performed during elaboration are more likely to be applied to the requirements and design. For example, you can create and walk through use cases to verify that the application's design can handle them.

9. Figure A-19 shows my drawing.

   Your results may differ, but here's the general idea. Customer representatives play a big role during inception and elaboration when the basic requirements are determined.

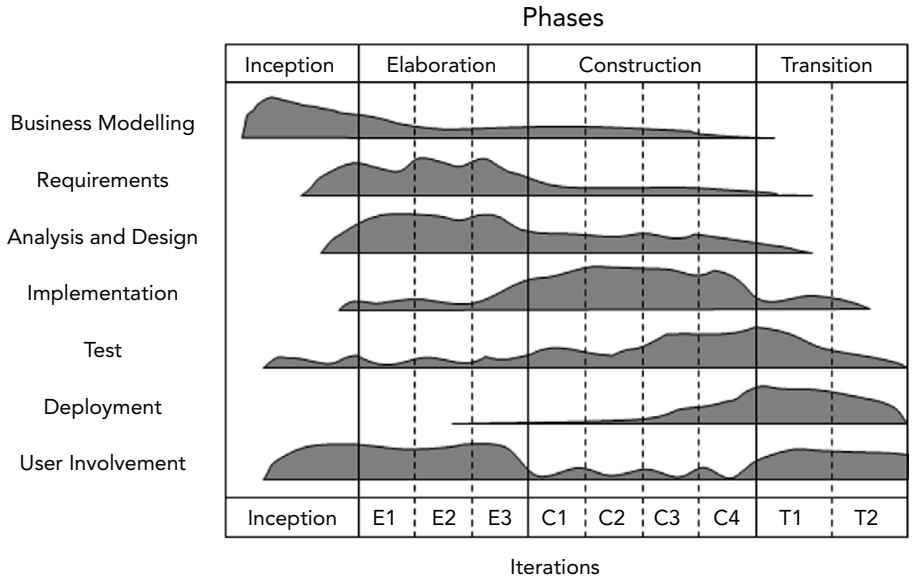


FIGURE A-19: Users play a large role as requirements are created and refined and a smaller role during development. They may play a larger role during deployment.

During construction, customers play a relatively small role; although, they pop up to review each of the iterations to make sure the project is still on track.

Depending on the division of duties, the customer organization may also play a large role in deployment, taking on tasks such as preparing the users' environment and training the users.

10. Figure A-20 shows how waterfall tasks match up with Unified Process tasks.

The waterfall requirements phase corresponds mostly to the Unified Process inception and elaboration phases; although, elaboration includes some architectural design so it also overlaps the waterfall design phase. The waterfall design, implementation, and verification phases mostly correspond to the Unified Process construction phase. The two approaches' deployment and transition phases are reasonably comparable.

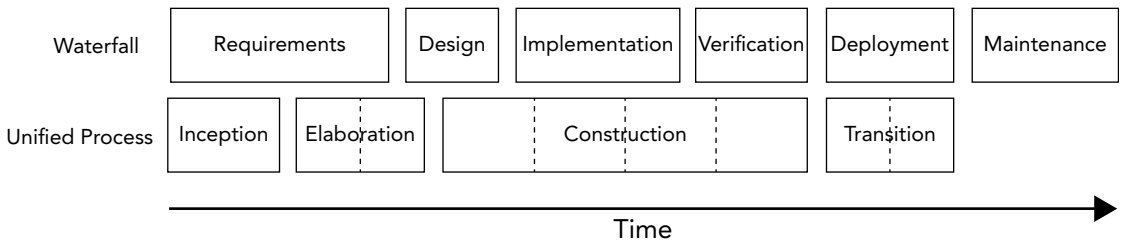


FIGURE A-20: This diagram shows how waterfall tasks match up with Unified Process tasks.

Aside from the minor misalignment of the design and elaboration phases, the biggest difference between the two approaches is the iterative nature of the Unified Process elaboration, construction, and transition phases. The iterations help keep the project moving in the right direction. (There's also no maintenance phase in the standard Unified Process. You can add it if you like. Or you can consider ongoing transition iterations to be maintenance.)

11. Those sentences describe:
    a. Agile
    b. Incremental
    c. Predictive
    d. Iterative

12. The agile approach gives the users a working program soonest because it releases a version as soon as any of its features are usable. The predictive approach releases its application the latest because it waits until every feature is fully implemented.

    Without more information, you can't know whether the iterative or incremental approach will release a working program sooner. The iterative approach will release sooner if you can quickly implement all the features with low (but usable) fidelity. The incremental approach will release sooner if you can quickly implement a single feature with full fidelity.

13. In a predictive model, you wouldn't let anyone move in until every house was complete. That would work.

    In an iterative approach, people would immediately move into every house but with limited fidelity. Here "limited fidelity" would mean the houses initially wouldn't have water, sewer, electricity, appliances, or (worst of all) cable TV and Internet access! This wouldn't work very well. (Although it seems to have been the approach the Russians used when they built the athlete housing for the 2012 Olympics.)

    In an incremental approach, people would move into each house as soon as it was completely finished. Some people would move in relatively early and some would move in later. This would work well.

    In an agile approach, people would move into each house as soon as it was partly finished with low fidelity. Over time, the occupied houses would be improved and new houses would be started. This wouldn't work. (Unless, perhaps, you're building a refugee camp.)

    In practice, developers want to get money out of the project as soon as possible, so it's natural to try for an agile approach. Unfortunately, people can't move into houses that aren't finished. Not only would people refuse (at least I would), but it's a lot easier to install carpeting, paint walls, and finish hardwood floors before people move all their junk into a house. However, it's not too hard to do the landscaping while people live in the house.

    So here's the typical approach. First, specialized teams move through the development. First, one team pours the foundations. After the foundations are dry, another team does the framing. Electricians and plumbers move through next, and so on with other teams installing drywall, roofing, carpeting, appliances, and everything else in waves. Sometimes, the teams can even work at the same time. For example, one team might be installing plumbing on one house while another installs drywall on another house.

The result is that the houses are all in different stages of construction. As soon as a house is habitable, people move in. Later, as weather and scheduling permit, the final teams do the landscaping, paint house numbers on the curbs, and do anything else that can wait for this late stage.

The result is most similar to incremental development with a dash of agile thrown in at the end.

14. In a predictive model, you wouldn't let anyone into the park until every ride, snack shack, and game was fully complete and tested. Then you would hold a grand opening. That would work.

In an iterative approach, you would allow people to use the facilities when they had limited fidelity. You probably shouldn't allow people to ride a half-finished Tilt-A-Whirl or untested roller coasters (I've seen the *Final Destination* 3 movie), so this wouldn't work.

In an incremental approach, people would be allowed to use any facilities that were completely finished. For example, during the first few weeks of operation, you might have only two rides, a Guess-Your-Weight attraction, and one restroom. This would work, but it would probably be better to wait until everything (or at least almost everything) was finished so that you can hold a grand opening to build excitement.

In an agile approach, you would let people use facilities as soon as they were partly functional. This won't work. (I won't spoil the plot of *Final Destination 3*, but I will say it involves a roller coaster and the result isn't pretty.)

CHAPTER 14

1. The following list explains how the four agile values apply to the one-pass waterfall model.

- **Individuals and interactions over processes and tools**—The waterfall model doesn't necessarily violate this value. There's nothing in the waterfall model that says you can't value individuals and interactions highly. However, waterfall is process-oriented, so the project manager will have to work hard to make sure processes don't come first. Also Stodgy Megacorp doesn't sound like a company that values people over processes.
- **Working software over comprehensive documentation**—The intent of this value is to represent the application's functionality with the evolving application. The main way information passes from one waterfall stage to the next is thorough documentation, not a working application. In fact, you can't actually have much in the way of working software until the implementation stage.
- **Customer collaboration over contract negotiation**—The waterfall model goes directly against this. It assumes the requirements are negotiated and carved in granite in the first stage of the project.
- **Responding to change over following a plan**—As the Brits would say, "Pull the other one, it's got bells on!" The waterfall model is all about making the best possible plan and then following it to the (possibly bitter) end. It doesn't respond well to change.

To summarize, the Stodgy Megacorp waterfall model can sort of satisfy the first value, but it doesn't fulfill the others at all.

2. The following list explains how the 12 agile principles apply to the one-pass waterfall model.

   a. Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.

      The waterfall model's goal is also to satisfy the customer, but it doesn't provide early and continuous delivery.

   b. Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.

      The waterfall model doesn't handle change well, particularly later in the development process.

   c. Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.

      Most waterfall projects have longer timespans than a couple weeks or even a couple months.

   d. Business people and developers must work together daily throughout the project.

      Business people (such as customers, domain experts, and other stakeholders) can work together throughout a waterfall project, but the benefit is limited because the plan can't change significantly later in the process. It is sometimes useful to have domain experts work with developers to help them understand the finer details of how the application should work, but most of the design should be wrapped up in the requirements and design phases so that interactions after that point aren't super helpful.

   e. Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.

      This is always a good idea in anything, not just software engineering. Motivated people can achieve remarkable things if they're given the freedom to do so.

      Like everything else, the waterfall model works best with motivated people.

   f. The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.

      A waterfall project can use face-to-face meetings to convey information, but they also need written records. Documentation helps keep everyone focused on the same vision. It also helps bring new team members up to speed if they join the project after it has begun. (And these tend to be large projects that last for a long time, so that's definitely a concern.)

   g. Working software is the primary measure of progress.

      In a waterfall project, there usually isn't much working software until the implementation phase. You can use working software to measure progress during that phase, but it's not too helpful during the other phases.

   h. Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.

This is another sensible goal in anything, not just software engineering, and the waterfall model is no exception. Management can occasionally bully developers into working extra hours to meet a deadline, but there's a limit to how many late nights they can work without their quality suffering no matter how many pizzas and energy drinks you provide. Eventually, the best people will leave for companies with better working environments and Stodgy Megacorp will be left with only the dregs who can't get jobs elsewhere. Artificially compressing the development schedule isn't worth permanently destroying your development capabilities.

i. Continuous attention to technical excellence and good design enhances agility.

   This is another good idea in anything, not just software engineering. It's almost always better to do something right the first time than to have to go back and fix it later, and that's particularly true in software engineering.

   Because the waterfall model makes it hard to go back and fix earlier mistakes, this is particularly important. You don't want to get to the deployment phase and discover there was a mistake all the way back in the requirements phase.

j. Simplicity—the art of maximizing the amount of work not done—is essential.

   This is also a great idea for just about anything. In software engineering, the simpler something is, the fewer chances you have to mess it up. That applies to the waterfall model as well as any other development methodology.

k. The best architectures, requirements, and designs emerge from self-organizing teams.

   You could probably use self-organizing teams in a waterfall project; although it's more normal for everyone's role to be decided at the beginning and remain unchanged throughout the project. That seems like the approach Stodgy Megacorp would take.

l. At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.

   One more piece of advice that can apply to just about anything. It's always good to reflect on what you're doing and how you're doing it to see if you can make improvements. (For example, after the first three chapters, I stopped writing this book by candlelight with a quill and scrolls of papyrus and started using a computer.)

   You can use this kind of reflection in a waterfall project; although, you may be unable to act on some of your insights. For example, you might be able to increase the number of code reviews if you think that would help improve the code. In contrast, you probably couldn't decide in the verification phase to switch to Unified Process if you decided that would be better than waterfall.

In summary, the waterfall model is reasonably compatible with principles 5, 8, 9, 10, and 12. With a score of 5 out of 12, it would receive an F on the agile final exam.

3. No. Agile models don't work well with all projects. For example, big-design-up-front models tend to work better with large projects that last longer, that have specific requirements, and that are well understood. For those kinds of projects, waterfall (or Sashimi or iterated waterfall) might work better than agile approaches.

4. The following list explains how the four agile values apply to James Martin RAD.
   - **Individuals and interactions over processes and tools**—As is the case with the Stodgy Megacorp waterfall model, James Martin RAD can embrace this value. The way the user design and construction phases overlap with the users constantly providing guidance and feedback gives the users a position of respect and importance.
   - **Working software over comprehensive documentation**—In James Martin RAD, you start by writing requirements. After that, the overlapping user design and construction phases make the application evolve to suit the changing requirements. The initial requirements are important, but not as important as the changes requested by the users.
   - **Customer collaboration over contract negotiation**—The initial requirements represent negotiation. After that, customer collaboration (in the form of user design) guides development (in the form of the construction phase).
   - **Responding to change over following a plan**—The overlapping user design and construction phases makes it reasonably easy to respond to change.
   - In summary, James Martin RAD satisfies all four agile values fairly well, so it deserves the agile stamp of approval.
5. The following list explains how the 12 agile principles apply to James Martin RAD.
   a. Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.

      The goal of James Martin RAD is also to satisfy the customer, but it doesn't provide early and continuous delivery. It provides one delivery at the end.

   b. Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.

      James Martin RAD handles changes relatively easily during the user design and construction phases.

   c. Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.

      James Martin RAD is aimed at producing a single delivery. A short project might span only a few months or weeks, but it isn't intended to produce multiple incremental releases.

   d. Business people and developers must work together daily throughout the project.

      Business people and developers work closely during all four phases of James Martin RAD.

   e. Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.

      This is always a good idea in anything, including James Martin RAD.

f. The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.

   James Martin RAD doesn't require you to use extensive documentation for communication, so you can make it meet this principle if you try. You'll still want to create written requirements during the requirements planning phase, but communication between customers and developers during the user design and construction phases is faster and more effective face-to-face.

g. Working software is the primary measure of progress.

   During the user design and construction phases, you can measure progress by the growing application. You still need to keep an eye on the project to ensure that it's headed somewhere and not just undergoing a never-ending series of change requests. However, as long as the application is growing toward a useful end, then it's a reasonable measure of progress.

h. Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.

   This applies to James Martin RAD as well as it applies to anything else.

i. Continuous attention to technical excellence and good design enhances agility.

   This is another principle that applies to everything, including James Martin RAD.

j. Simplicity—the art of maximizing the amount of work not done—is essential.

   To paraphrase Leonardo da Vinci, "Simplicity is the ultimate sophistication, including in James Martin RAD."

k. The best architectures, requirements, and designs emerge from self-organizing teams.

   There's no reason why you can't use a self-organizing team in James Martin RAD, particularly in the iterations of user design and construction.

l. At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.

   Again, this applies to everything including James Martin RAD.

In summary, James Martin RAD doesn't actually follow principles 1 or 3, which deal with frequent releases. It handles the other principles very well, particularly those that mention constant interaction between the users and the developers. With a score of 10 out of 12, it would receive a solid B on the agile final exam.

6. Velocity won't equal the difference in the size of the backlog if anything is added, removed, or modified in the backlog. For example, suppose the backlog contains 100 story points. A sprint delivers 10 of them, but you add 10 more story points in new features to the backlog. In that case, the velocity for the sprint was 10 but there has been no change in the backlog's size.

   The velocity will match the backlog difference if you don't add, remove, or modify anything in the backlog.

7. The quick and glib answer is that all sprints have the same duration, so velocity would always be the same if you measure actual hours. For example, if you have four people working one-week sprints, then every sprint should have a velocity of $4 \times 5 = 20$ days. If the sprint includes too many features, you might need to drop some of them to fit in the one-week time box, but the velocity would always be the same.

   What you actually want to know is not how many hours the developers work, but how many user stories they completed. If it turns out that you put too many stories into a sprint and you remove some, then the number of story points implemented during that sprint *does* change, and the velocity would be lower than you had hoped.

8. If the number of actual days is lower than the number of story points, that means your story point estimates are too high. For example, you predicted that a story would take eight hours but it took only six.

   Conversely, if actual days is higher than story points, that means your story point estimates are too low. For example, you predicted that a story would take three hours but it took eight.

   In either case, you could revise your story point estimates, but you don't need to. The sprint velocity tells you how many story points you can implement during a sprint. As long as you use the measured velocity to plan the following sprints, you can pick roughly the right amount of work for each sprint. The velocity implicitly corrects for imperfect estimates, as long as all the estimates are incorrect in the same way.

9. Improving velocity allows the team to add more features to each iteration, but it's important not to sacrifice quality. You could increase velocity by skimping on unit tests, but you'd pay a price later in increased debugging time.

10. The following list summarizes those phrases:

    - **Think big**—See the whole. Keep the customers' needs in mind and make sure whatever you're doing adds value for the customer.
    - **Act small**—Keep things simple. Only make them more complicated later if it turns out that you must.
    - **Fail fast**—Discovering that some approach won't work isn't itself a bad thing. In particular, test code as soon as it is written, so you can learn whether it works correctly as quickly as possible. If you're going to fail, fail quickly, learn from it, and move on.
    - **Learn rapidly**—Learn from mistakes and the changing environment and take action accordingly. If your iteration process isn't working well, fix it right away. If the customers' needs change, change the project's direction before you waste any more time building features no one needs.

11. The following list explains whether the situations are Kanban-like:

    - This is Kanban-like. When the red edges appear, the cashier knows it's time to put in a new tape.

- This actually isn't Kanban-like because the customer won't replace the register tape when the red edges appear. (Many customers don't even know what the red edges mean.)
- This is only Kanban-like in the vaguest sense. The burned out bulb sort of tells you that you need to get a new one, but calling this Kanban is a stretch.
- This is Kanban-like. The entry on the shopping list is similar to a Kanban card sent to a supplier.
- This isn't Kanban-like. A Kanban-friendly pen would give you some warning, perhaps switching to red ink when it was running low.

GLOSSARY

1NF See first normal form.

2NF *See second normal form.*

3NF *See third normal form.*

80/20-rule In the Dynamic Systems Development Method, the assumption that 80-percent of an application's features will take 20-percent of the project's total time to implement. (The 80/20-rule often applies to other situations, too. For example, 80-percent of the bugs are usually contained in 20-percent of the code.)

acceptance test A test to determine whether the finished application meets the requirements. Normally, a user or other customer representative sits down the with application and runs through all the use cases you identified during the requirements gathering phase to make sure everything works as advertised.

activation *See execution specification.*

activity diagram In UML, a diagram that represents work flows for activities. They include several kinds of symbols connected with arrows to show the direction of the work flow.

adaptive development model A development model that enables you to change the project's goals if necessary during development.

administrator Someone who manages the development team's computers, network, and other tools. Also called a system administrator.

advisor user Any user who brings an important viewpoint to the project.

agile development A development model where you initially provide the fewest possible features at the lowest fidelity to still have a useful application. Over time, you add more features and improve existing features until all features have been implemented at full fidelity.

Agile Manifesto A set of four guiding principles for agile development. In brief the principles are:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

Agile Unified Process (AUP) A simplified version of Rational Unified Process that includes agile methods such as test-driven development and agile modeling. In 2012 AUP was superseded by Disciplined Agile Delivery.

algorithm A software recipe that explains how to solve a particular programming problem.

ambassador user Someone who acts as a liaison between the users and the developers.

anchoring A phenomenon where an early decision made by one person influences later decisions by others.

anomaly In a relational database, an error caused by a design flaw such as records holding inconsistent values or being unable to delete a piece of data because it is necessary to record some unrelated piece of information.

architect Someone who focuses on the application's overall high-level design.

artifact In a UML deployment diagram, a file, a script, an executable program or another item that is deployed. In development models, something generated by the model such as a requirements document, user story, or piece of code.

assertion A statement about the program and its data that is supposed to be true. If the statement isn't true, the assertion throws an exception to tell you that something is wrong.

attribute Some feature of a project that you can measure such as the number of lines of code, the number of defects, or the number of times the word "mess" appears in code comments. See also *metric* and *indicator*.

audit trail A record of actions taken by an application's users for security auditing purposes.

AUP *See Agile Unified Process.*

BDUF *See big design up front.*

behavior diagram In UML, a diagram that shows the behavior of some entity. There are three kinds of behavior diagrams: activity diagrams, use case diagrams, and state machine diagrams.

Big Board A large board used by many agile models that is posted in a visible location so that everyone can see the project's status at a glance. Also called an information radiator.

big design up front (BDUF) See *predictive development model.*

big O notation A system for studying the limiting behavior of algorithms as the size of the problem grows large.

black-box test A test designed by someone who doesn't know how the code works internally.

brainstorming A group technique for discovering creative solutions to a problem.

bug A flaw in a program that causes it to produce an incorrect result or to behave unexpectedly. Bugs are generally evil.

build engineer In Feature-Driven Development, someone who sets up and controls the build process.

burndown chart In Scrum, a graph showing the amount of work remaining over time.

business advisor See business analyst.

business ambassador Someone who provides business information from the viewpoint of the users.

business analyst A domain expert who helps define the application's purpose and who provides feedback during development. Also called a business advisor.

business requirements The project's high-level business goals. They explain what the customer hopes to achieve with the project.

business visionary Someone who has a clear vision of the application's business role, particularly early in the process when that role isn't clearly written down.

cause-and-effect diagram See *Ishikawa diagram*.

CAV See complexity adjustment value.

CBSE See component-based software engineering.

change A change to an application that is requested by customers. This may happen when customers understand the application better, when customers think of a new feature or a modification they want, or when the users' environment changes so the application needs to be changed to be useful.

change control board A group of project members, possibly including one or two customers, that reviews and approves or rejects change requests.

change management See *version management*.

change tracking See *version management*.

chief architect In Feature-driven Development, the person responsible for the project's overall programmatic design.

chief programmer In Feature-driven Development, an experienced developer who is familiar with all the functions of development (design, analysis, coding, and so on). Chief programmers lead project teams.

child class A class derived from a parent class. The child class inherits properties, methods, and events from the parent class.

child table See *foreign key*.

class In object-oriented programming, a construct that defines a type (or class) of items. For example, if you define a `Customer` class, you can then create many `Customer` objects representing different real-world customers.

class diagram In UML, a diagram that describes the classes that make up the system, their properties and methods, and their relationships.

class owner In Feature-driven Development, the person who is responsible for a particular class's code.

Cleanroom A development model that emphasizes defect prevention rather than defect removal. It uses formal methods, statistical quality control, and statistical testing to prevent and detect bugs.

client tier The tier in a multitier architecture that consumes a service. This is often an application's user interface.

client-server architecture A design that separates pieces of the system that need to use a particular function (clients) from parts of the system that provide those functions (servers). That decouples the client and server pieces of the system so that developers can work on them separately.

coach Someone who helps a development team follow its chosen path (XP, Scrum, Lean, and so forth).

code coverage The lines of code that are executed during a demonstration or a suite of tests.

code inspection See *code review*.

code review When two or more programmers walk through a piece of code to look for problems. Also called a *code inspection*.

coding standards Standards used by a development team to ensure consistency. Standards may define conventions for variable names, comments, documentation, specific code style, and more. Coding standards make the code easier to read and debug.

column See *field*.

communication diagram In UML, a diagram that shows communication among objects during some sort of collaboration. This is similar to a sequence diagram except a sequence diagram focuses on the sequence of messages, and a communication diagram focuses more on the objects involved in the collaboration.

complexity adjustment factors In function point calculations, values that take into account the importance of general features of the application (such as transaction rate).

complexity adjustment value (CAV) In function point calculations, the sum of the complexity adjustment factors.

complexity factor In function point calculations, you multiply each function point metric by a complexity factor to indicate how complex each activity is.

component diagram In UML, a diagram that shows how components are combined to form larger parts of the system.

component interface test A test that studies the interactions between components. This is a bit like regression testing in the sense that both examine the application as a whole to look for trouble, but component interface testing focuses on component interactions.

component-based software engineering (CBSE) A design that regards the system as a collection of loosely coupled components that provide services for each other.

composite structure diagram In UML, a diagram that shows a class's internal structure and the collaborations that the class allows.

configuration management Managing the items produced by the project such as requirements documents, designs, and, of course, source code. This may include controlling changes to those items so that changes don't happen willy-nilly.

coprime See relatively prime.

COTS Commercial off-the-shelf as in a COTS application.

cowboy coding A development methodology where the programmers have complete control over the process and generally do what they want. This is often a derogatory term, although for very small projects and very experienced developers it can sometimes produce good results.

critical path A longest path through a PERT chart network. If any task along a critical path is delayed, the project's final completion is also delayed. Note that a network may have multiple critical paths.

cross-functional team A team where every member can play every role. Every member can participate in requirements analysis, design, programming, testing, and the rest.

Crystal A family of development methodologies that take into account a project's team size and criticality. Team size determines the project's "color" and can be Clear (1–6), Yellow (7–20), Orange (21–40), Orange Web (21–40 with ongoing releases), Red (41–80), Maroon (81–200), Diamond (201–500), and Sapphire (501–1,000). Criticality is measured by the type of thing that could be at risk. Criticality values include comfort, discretionary money, essential money, and life.

Crystal Clear A relatively relaxed and easy-going approach to development using a small team and low criticality. Crystal Clear defines only three required roles: sponsor, senior designer, and programmer. See also *Crystal*.

Crystal Orange A development approach that is slightly more formal than Crystal Yellow. Projects may add the new roles business analyst, project manager, architect, and team leader. They also add requirements, tracking, a release schedule, object models, code reviews, acceptance testing, and more formal delivery.

Crystal Yellow A development approach that is slightly more formal than Crystal Clear. These projects adopt new practices above the roles defined by Crystal Clear including easy communication, code ownership, feedback, automated testing, a mission statement, and more formal increments.

customer A person for whom a project is being built. Typically, the customer defines requirements and verifies that the finished application meets those requirements. In some models, the customer also provides feedback during development.

cutover The process of moving users to a new application.

DAD See Disciplined Agile Delivery.

daily scrum Scrum's version of a daily standup meeting. Also simply called a scrum. See also *standup meeting*.

data tier The server tier in a three-tier architecture.

data warehouse A secondary database that holds older data for analysis. In some applications, you may want to analyze the data and store modified or aggregated forms in the warehouse instead of keeping every outdated record.

database-centric architecture See *data-centric architecture*.

data-centric architecture A design where the application is centered around some kind of database.

decomposition In a V-model project, the steps on the left side of the V that break the application down into pieces that you can implement.

deep dive See *spike*.

defect Incorrect feature in an application. Defects can be broadly grouped into two categories: bugs and changes.

defensive programming The idea that the code should work no matter what kind of garbage is passed into it for data. The code should work and produce some kind of result no matter what. See also *offensive programming*.

deployer In Feature-driven Development, someone who handles deployment.

deployment The process of delivering a finished application to the users. Also called implementation or installation.

deployment diagram In UML, a diagram that describes the deployment of artifacts (files, scripts, executables, and the like) on nodes (hardware devices or execution environments that can execute artifacts).

derive To subclass a child class from a parent class. The child class inherits properties, methods, and events from the parent class.

design inspection A review of a design to look for problems before writing code to implement the design. In Feature-Driven Development, a chief programmer holds a design inspection before the team implements the design.

design package In Feature-Driven Development, the result of a design-by-feature phase. The design package includes a description of the package, sequence diagrams showing how the features will work, alternatives, an updated object model, and method prologues.

design pattern In object-oriented programming, an arrangement of classes that interact to perform some common and useful task. Similar to an object-oriented algorithm.

developer Someone who participates in the project development. Sometimes this term is used interchangeably with programmer.

development manager In Feature-Driven Development, someone who manages day-to-day development activities.

Disciplined Agile Delivery (DAD) A development framework that incorporates features of UP, Scrum, XP, Kanban, Lean, and others. It uses the three UP phases: inception, construction, and construction.

distributed architecture A design where different parts of the application run on different processors and may run at the same time. The processors could be on different computers scattered across the network, or they could be different cores on a single computer.

domain expert A customer, user, executive champion, or other person who knows about the project domain and how the finished application should work. Also called subject matter expert (SME).

domain manager In Feature-Driven Development, someone who leads the domain experts and provides a single point of contact to resolve domain issues.

domain walk-through In Feature-Driven Development, a walk-through of a scenario by a domain expert to verify that the scenario is correct and to answer questions for the developers about the scenario.

don't repeat yourself principle (DRY) In programming, a rule of thumb that says if you need to write the same piece of code twice, you should extract it into a separate method that you can call from multiple places so you don't have to write it a third time. (Or a fourth time, or a fifth time, and so on.)

driver In pair programming, the programmer who types.

DRY See *don't repeat yourself principle*.

DSDM See *Dynamic Systems Development Method*.

Dynamic Systems Development Method (DSDM) An agile framework designed with a more business-oriented focus. It can be used to add extra business control to other development models. It uses the phase's pro-project, project life cycle (which includes study, functional modeling, design and build, and implementation) and post-project.

EDA See *event-driven architecture*.

environment The environment in which the application will run. This includes the users' computers, networks, printers, other applications, and physical environment (chairs, lamps, coffee machines, and so forth).

event In object-oriented programming, an event occurs to notify the application that something interesting occurred. For example, the user might have clicked a button or a timer might have expired.

event-driven architecture (EDA) A design where various parts of the system respond to events as they occur.

evolutionary prototype A prototype that evolves over time with new features added and the existing features improved until the prototype eventually becomes the finished application.

exception An unexpected condition in a program such as a divide by zero or trying to access a missing file. If the code doesn't catch and handle the exception, the program crashes.

execution See *execution specification*.

execution specification In a UML sequence diagram, a gray or white rectangle that represents a participant doing something. Also called an *execution* or *activation*.

executive champion The highest-ranking executive who supports the project.

executive sponsor See *executive champion*.

expert system See *rule-based architecture*.

Extreme Programming (XP) A development model that takes typical programming practices (such as code reviews) to extremes (pair programming).

FDD See *Feature-Driven Development*.

feature list In Feature-Driven Development, a prioritized list of features that the application should have.

feature team In Feature-Driven Development, when a new feature requires changes to several classes, the class owners are assembled into a feature team to study and implement the changes.

Feature-Driven Development (FDD) An iterative and incremental development model that was designed to work with large teams. The large teams mean this model requires more roles. It starts with two phases: develop model and build feature list. It then iterates three more phases: plan-by feature, design-by feature, and build-by feature.

field In a relational database, a single piece of data in a record. For example, each record in a `Students` table would contain a `FirstName` field. Also called a column.

first normal form (1NF) The least normalized level of a table in a relational database. To be in 1NF:

1. Each column must have a unique name.
2. The order of the rows and columns doesn't matter.
3. Each column must have a single data type.
4. No two rows can contain identical values.
5. Each column must contain a single value.
6. Columns cannot contain repeating groups.

fishbone diagram See *Ishikawa diagram*.

Fishikawa diagram See *Ishikawa diagram*.

foreign key In a relational database, a set of one or more fields in one table with values that uniquely define a record in another table. The table containing the foreign key is the child table, and the table that contains the uniquely identified record is the parent table. See also *foreign key constraint*.

foreign key constraint When two tables are related by a foreign key, a foreign key constraint requires that a child record cannot exist unless the corresponding record exists in the parent table. For example, a `StudentAddress` record might not be allowed to contain a `State` value that isn't defined in the `States` lookup table.

function point metric In function point calculations, a metric used to calculate a project's function points such as the number of inputs and the number of outputs.

function point normalization Dividing a metric by the project's function points to allow you to compare projects of different sizes and complexities.

function point value Calculated as a weighted average of the raw FP and the CAV.

functional prototype A prototype that looks like a finished application (or part of one) but that doesn't necessarily work the way the real application will. For example, it could use faked data or predetermined responses to user actions.

functional requirements Detailed statements of the project's wanted capabilities. They're similar to the user requirements but may also include things that the users won't see directly such as interfaces to other applications.

Gantt chart A kind of bar chart that shows a schedule for a collection of related tasks. Bar lengths indicate task durations. Arrows show the relationships between tasks and their predecessors.

gradual cutover Deployment technique where you install the new application for some users while others continue working with the existing system. You test the system for the first users and when everything's working correctly, you start moving other users to the new system until everyone has been moved.

gray-box test A combination white-box test and black-box test. The tester knows some but not all of the internals of the method being tested. The partial knowledge lets the tester design some specific tests to attack the code.

heuristic An algorithm that gives a good solution for a problem but that doesn't guarantee to give you the best solution possible.

horizontal prototype A prototype that demonstrates a lot of the application's features but with little depth.

IDE See *integrated development environment*.

implementation When used by programmers, this term usually means writing the code. When used by managers, this often means deployment.

implementation requirements Temporary features that are needed to transition to using the new system but that will be later discarded.

increment The result of a single iteration of an incremental development model. The increment is a fully tested piece of software suitable for release to the users.

incremental deployment Deployment where you release the new system's features to the users gradually. First, you install one tool (possibly using staged deployment or gradual cutover to ease the pain). After the users are used to the new tool, you give them the next tool. You continue until all the tools have been deployed.

incremental development A development model where you initially provide only some features at full fidelity. Over time, you add more features (always at full fidelity) until all features have been implemented at full fidelity.

incremental prototyping A development model where you build a collection of prototypes that separately demonstrate the finished application's features. You then combine the prototypes (or at least their code) to build the finished application.

incremental waterfall model A development model that uses a series of waterfall cascades. Each cascade ends with the delivery of a usable application called an increment. Also called the multiwaterfall model.

indicator A metric that you can use to predict the project's future. For example, if the metric "comments per KLOC" is 3, that may be an indicator that the project will be hard to maintain.

information radiator See *big board*.

inheritance hierarchy In object-oriented programming, a "family tree" showing inheritance relationships among classes. In a language that doesn't support multiple inheritance, the relationships form a hierarchy.

installation See *deployment*.

instrumentation Code added to a program by a profiler to allow it to track the program's performance.

integrated development environment (IDE) An environment for building, compiling, and debugging software. An IDE may include other tools such as source code control, profiling, code editors with syntax highlighting and auto-completion, and more.

integration In a V-model project, the steps on the right side of the V that work back up to the conceptual top of the application.

integration test A test that verifies that a new piece of code works with the rest of the system. It checks that the new code can call existing code and that the existing code can call the new code.

interaction diagram In UML, a category of activity diagram that includes sequence diagrams, communication diagrams, timing diagrams, and interaction overview diagrams.

interaction overview diagram In UML, basically an activity diagram where the nodes can be frames that contain other kinds of diagrams. Those nodes can contain sequence, communication, timing, and other interaction overview diagrams. That lets you show more detail for nodes that represent complicated tasks.

invariant A state of the program and its data that should remain unchanged over some period of time. Often used in assertions.

Ishikawa diagram Named after Kaoru Ishikawa, a diagram that shows possible causes of effects that you want to study such as excessive bugs, delays, and other failures in the development process. Also called fishbone diagrams, Fishikawa diagrams, and cause-and-effect diagrams.

iteration 0 A pseudo-iteration that includes startup tasks that must be performed before the project's code development starts such as planning, initial requirements gathering, and building the development environment.

iterative development A development model where you initially provide all the application's features at a low fidelity. Over time, you improve the features' fidelity, occasionally releasing improved versions of the application until all features have been implemented at full fidelity.

James Martin RAD A specific RAD development model that uses four phases: requirements planning, user design, construction, and cutover. The user design and construction phases iterate.

JBGE See *just barely good enough*.

JIT See *just-in-time*.

joint code ownership See *shared code ownership*.

just barely good enough (JBGE) The idea that you should include only the bare minimum of comments and documentation to get the job done.

just-in-time (JIT) An inventory management practice where inventory items are supplied just in time for use to minimize inventory levels.

Kanban (production chain) A just-in-time technique that uses kanban cards to indicate when a production station needs more parts. When a station is out of parts (or is running low), a kanban card is sent to a supply station to request more parts.

Kanban (software engineering) An agile methodology where a team member who finishes his current item takes the next highest priority item from the project's backlog. Kanban seeks to restrict the amount of work in progress at any given time.

Kanban board A big board. (See *big board*.) Typically, columns indicate each task's status. Columns might be labeled Backlog, Ready, Coding, Testing, Approval, and Done. In some variations, rows indicate the person assigned to each task.

key In a relational database, a set of one or more fields that uniquely identifies a record.

KLOC Kilo lines of code.

knowledge base system See *rule-based architecture*.

language guru Someone who is an expert in the programming language, technology, and other arcane items being used by the team. The other developers call on this person as needed. Also called a language lawyer.

language lawyer See *language guru*.

Lean See *Lean Software Development*.

Lean Software Development (LSD) An agile development methodology that focuses on removing waste (such as unclear requirements, repetition, and unnecessary meetings) from the development process.

lifeline In a UML sequence diagram, a vertical dashed line that represents an object's existence.

load test A test that simulates a lot of users all running simultaneously to measure the application's performance under stress.

logic tier The middle tier in a three-tier architecture. This tier usually contains business logic.

lookup table In a relational database, a table that contains values just to use as foreign keys.

LSD See *Lean Software Development*.

magic number A value that just appears in the code with no explanation. For example, it might represent an error code or database connection status. Use constants and named variables instead of magic numbers to make the code easier to read and understand.

member In object-oriented programming, a general name for a class's properties, methods, and events.

method In object-oriented programming, a piece of code that makes an object do something.

method prologue A description of a method that includes its purpose, input and output parameters, return type, possible exceptions (ways the method can fail), and assumptions.

metric A value that you use to study some aspect of a project. A metric can be an attribute (such as the number of bugs) or a calculated value (such as the number of bugs per line of code). See also *attribute* and *indicator*.

monolithic architecture A design where a single program does everything.

MOSCOW (or MoSCoW) A scale for prioritizing application features. The initials stand for Must, Should, Could, and Won't.

multiple inheritance In object-oriented programming, when a child class inherits from multiple parent classes. (Most object-oriented languages do not support multiple inheritance.)

multitier architecture A design that uses multiple tiers to allow a client to use services provided by a server. Examples include client-server architectures, two-tier architectures, and three-tier architectures.

multiwaterfall model See *incremental waterfall model*.

navigator In pair programming, the programmer who watches as the driver types.

node In a UML deployment diagram, a hardware device on which an artifact is deployed.

nonfunctional prototype A prototype that looks like an application but that doesn't actually do anything.

nonfunctional requirements Statements about the quality of an application's behavior or constraints on how it produces a wanted result such as the application's performance, reliability, and security characteristics.

normalization For metrics, performing some calculation on a metric to account for possible differences in project size or complexity. Two general approaches are size normalization and function point normalization. (See also *function point normalization* and *size normalization*.) In database design, the process of rearranging tables to put them into standard (normal) forms that prevent anomalies.

not invented here syndrome (NIHS) In programming, the mistake of thinking you need to rewrite a piece of code just because someone else wrote it and it doesn't work the way you would have written it.

N-tier architecture See *multitier architecture*.

object An instance of a class.

object composition In object-oriented programming, a technique where an object is composed of other objects, sometimes used to simulate multiple inheritance.

object diagram In UML, a diagram that focuses on a particular set of objects and their relationships at a specific time.

object model A model showing the classes that make up an application, the class details (such as properties, methods, and events), and interactions among the classes.

observer See *navigator*.

offensive programming The idea that the code immediately flags an error if it receives unexpected inputs so that you can decide whether they are valid. See also *defensive programming*.

Open Unified Process (OpenUP) An open source tool built by the Eclipse Foundation to help in using the Unified Process development model.

OpenUP See *Open Unified Process*.

Osborn method A basic brainstorming approach developed by Alex Faickney Osborn.

over refinement In object-oriented programming, a design problem that occurs when you refine a class hierarchy unnecessarily, making too many classes that make the code complicated and confusing.

package diagram In UML, a diagram that describes relationships among the packages that make up a system. For example, if one package in the system uses features provided by another package, then the diagram would show the first "importing" the second.

pair programming An Extreme Programming practice where two (or three) programmers work together at the same computer. The driver or pilot types while the observer, navigator, or pointer watches and reviews each line of code as it is typed.

parent class A class from which a child class is derived. The child class inherits properties, methods, and events from the parent class.

parent table See *foreign key*.

PERT Program Evaluation and Review Technique. See *PERT chart*.

PERT chart A graph that uses nodes (circles or boxes) and links (arrows) to show the precedence relationships among the tasks in a project.

pilot See *driver*.

planning game A game where team members use cards containing user stories and try to see how many cards they can fit into a release. There are two kinds of planning games: release planning and iteration planning.

planning poker In Scrum, a game where developers use card decks based on the Fibonacci numbers to estimate the amount of work for the project's tasks. Cards might have numbers ace, 2, 3, 5, 8, and king; or 0, 1, 2, 3, 5, 8, 13, 21, 34, 55, and 89; or 0, ½, 1, 2, 3, 5, 8, 13, 20, 40, and 100. Also called Scrum poker.

point of no return The point during a project where the expense of canceling a project is greater than the expense of moving forward.

pointer See *navigator*.

point-release A minor application build that isn't necessarily released to the customers.

polymorphism The ability to treat a child object as if it were actually from a parent class. For example, it lets you treat a `Student` object as if it were a `Person` object because a `Student` is a type of `Person`.

potentially shippable increment (PSI) In Scrum, the result of a sprint. This is a fully tested application that could be shipped to the users.

predictive development model A development model where you predict in advance what needs to be done and then you go out and do it. Also called big design up front (BDUF).

presentation tier The client tier in a multi-tier architecture.

process metric A metric designed to measure your organization's development process. They are collected over a long period across many projects and used to fine-tune the software engineering process.

product backlog In Scrum, the list of features not yet implemented by the application.

product burndown chart In Scrum, a graph showing the amount of work remaining in a whole project over time. Also called a release burndown chart.

product metric See *project metric*.

product owner Someone who represents the customers, users, and other stakeholders and for whom the application is being built. Sometimes called the sponsor.

profiler A program that monitors another program to identify the parts that are slow, that use the most memory, or that otherwise might be bottlenecks.

programmer An underpaid, overworked person who writes the code and complains about excessive management and restrictive coding standards.

project manager Monitors the project's progress to ensure that work is heading in the right direction at an acceptable pace. Meets with customers and other stakeholders to verify that the finished product meets their requirements. If the development model allows changes, the project manager ensures that changes are made and tracked in an organized manner so they don't get lost and don't overwhelm the rest of the team.

project metric Metrics that measure and track the current project to predict future results for that project.

property In object-oriented programming, an attribute of an object that helps define the object's characteristics.

prototype A mockup of some or all of the application to let the developers and customers study an aspect of the system. Typically a software prototype is a program that mimics part of the application you want to build.

pseudocode Text that looks a lot like a programming language but isn't one. You can use pseudocode to see how a piece of code would work if you wrote it in an actual programming language such as C#, Java, or Visual Basic.

PSI See *potentially shippable increment*.

quality manager Someone who ensures the application's quality. This person tracks bug reports, test results, and reviews; uses statistical methods to estimate quality; defines the project's quality procedures (such as testing and review guidelines); and uses other techniques used to improve quality.

race condition In distributed computing, a situation in which multiple processes interfere with each other when one incorrectly overwrites the results of another.

RAD See *rapid application development*.

raise In object-oriented programming, an object raises an event to notify the application that something interesting occurred.

rapid application development (RAD) Development models that emphasize producing code and deemphasize planning. These models produce code iteratively and incrementally as quickly as possible. RAD principles include small teams, frequent customer interaction, frequent integration and testing, and short time-boxed iterations.

Rational Unified Process (RUP) IBM's version of the Unified Process.

raw FP value In function point calculations, the sum of the function point metrics multiplied by their complexity factors.

record In a relational database, a single set of values in a table. For example, a particular student's data would be contained in a record in the `Students` table. Also called rows or tuples.

refactor The process of rearranging and rewriting code to make it easier to understand, debug, and maintain.

refinement In object-oriented programming, the process of breaking a parent class into multiple subclasses to capture some difference between objects in the class.

regression test A test that exercises the entire application to verify that a new piece of code didn't break anything.

relational database A database that stores related data in rows and columns in tables.

relatively prime Two integers are relatively prime (or coprime) if they have no common factors other than 1. For example, $21 = 3 \times 7$ and $8 = 2 \times 2 \times 2$ are relatively prime because they have no common factors other than 1. By definition –1 and 1 are relatively prime to every integer, and they are the only numbers relatively prime to 0.

release burndown chart See *product burndown chart*.

release manager In Feature-Driven Development, someone who gathers information from the chief programmers to track the project's progress.

requirement validation The process of making sure that the requirements say the right things.

requirement verification The process of checking that the finished application actually satisfies the requirements.

requirements The features an application must provide to be successful.

retrospective meeting In Scrum, a meeting after a sprint where the Scrum Master and the project team discuss the sprint and ask the questions: (1) What went well and how can we make that happen again? (2) What went poorly and how can we avoid that in the future? (3) How can we improve future sprints?

row See record.

rule-based architecture A design that uses a collection of rules to decide what to do next. These systems are sometimes called expert systems or knowledge-based systems.

RUP See *Rational Unified Process*.

sashimi A variation on the waterfall model where phases overlap. Also called sashimi waterfall and waterfall with overlapping phases.

SCA Service Component Architecture.

scribe Someone who keeps records of requirements, agreements, assumptions, and other important facts discovered at meetings, particularly at DSDM workshops.

scrum See *daily scrum*.

Scrum A development methodology that uses frequent small increments to build an application iteratively and incrementally.

Scrum Master In Scrum, someone who helps the team follow Scrum practices, challenges the team to improve itself, and removes obstacles for the team.

Scrum poker See *planning poker*.

SDLC See *software development life cycle*.

second normal form (2NF) The second level of normalization for a table in a relational database. A table is in 2NF if:

1. It is in 1NF.
2. All nonkey fields depend on all key fields.

self-organizing team A team that has the flexibility and authority to find its own methods for achieving its goals. Team members are motivated to take work without waiting for it to be assigned. They take responsibility for their work and track their own progress.

senior developer A software engineering ninja that other developers can call when they need help.

sequence diagram In UML, a diagram that shows how objects collaborate in a particular scenario. This is similar to a communication diagram except a sequence diagram focuses on the sequence of messages, and a communication diagram focuses more on the objects involved in the collaboration.

service A self-contained program that runs on its own and provides some kind of service for its clients.

Service Component Architecture (SCA) A set of specifications for service-oriented architecture defined by vendors such as IBM and Oracle. See *service-oriented architecture*.

service-oriented architecture (SOA) A design similar to a component-based architecture except the pieces are implemented as services.

shared code ownership In Extreme Programming, code ownership is joint so anyone can modify any piece of code if necessary to make changes or fix bugs. In contrast, in Feature-Driven Development, each class is owned by a class owner.

side effect A non-obvious result of a method call that makes using the method confusing.

size normalization For metrics, dividing a metric by an indicator of size such as lines of code or days of work. For example, bugs/KLOC tells you how buggy the code is normalized for the size of the project.

size-oriented normalization See *size normalization*.

SME Subject matter expert.

soapbox In planning poker, after each hand the people with the highest and lowest estimates are given a brief soapbox to explain why they feel their estimates are correct.

SOA Service-oriented architecture.

software development life cycle (SDLC) All the tasks that go into a software engineering project from start to finish: requirements, design, implementation, and so forth. Also called the application development life cycle.

spike A quick prototype, design, or piece of code that lets you explore some feature of an application in depth. Also called a deep dive.

spike solution See *spike*.

spiral development model A development model that uses a risk-driven approach to decide what development approach to take for each stage of the project. It uses four phases: planning, risk analysis, engineering, and evaluation.

sponsor See *product owner*.

sprint In Scrum, the name given to the time-boxed incremental iterations. Typically a sprint is 30 days; although, some projects use shorter sprints of one, two, or three weeks.

sprint backlog In Scrum, the list of features not yet implemented by a sprint.

sprint burndown chart In Scrum, a graph showing the amount of work remaining in a sprint over time.

sprint planning meeting In Scrum, a time boxed (typically a maximum of four hours) meeting before a sprint begins to decide what features should move from the project backlog into the sprint backlog so that they will be implemented during the sprint.

sprint review meeting In Scrum, after a sprint ends, this is the meeting where the team presents the potentially shippable increment to the product owner, who verifies that it meets the sprint's goals.

staged deployment Deployment that begins with building the application in a fully functional staging environment, so you can practice deployment until you've worked out all the kinks.

stakeholder Someone who has a stake in the outcome of the project. Typically, this includes users, customers (if those are different from users), sponsors, managers, and development team members.

stakeholder requirements These describe the goals of the project from the stakeholders' point of view. This term is often used interchangeably with "user requirements."

standup See *standup meeting*.

standup meeting in Extreme Programming, a brief (15 minutes or less) daily meeting where team members say what they did since the last meeting, what they hope to do before the next meeting, and any problems they foresee in getting that work done.

state In bug tracking, a bug's state tracks its progress through the system. Example states include New, Assigned, Reproduced (or Verified), Cannot Reproduce, Pending, Fixed, Tested, Deferred, Closed, and Reopened.

state machine diagram In UML, a diagram that shows the states through which an object passes in response to various events. States are represented by rounded rectangles. Arrows indicate transitions from one state to another. Sometimes annotations on the arrows indicate what causes a transition.

stepwise refinement See *top-down design*.

story points The number of points assigned to a story by planning poker. See *planning poker*.

structure diagram In UML, a diagram that describes things that will be in the system you are designing. For example, a class diagram shows relationships among the classes that will be used to represent objects in the system such as inventory items, customers, and invoices.

subject matter expert (SME) See *domain expert*.

system administrator See *administrator*.

system integrator Someone who builds and tests the interfaces between the application and other applications.

system test An end-to-end run-through of the whole system. Ideally, a system test exercises every part of the system to discover as many bugs as possible.

table In a relational database, a set of records that all contain the same fields; although, each record's fields may contain different values. For example, a `Student` table would contain data about students.

TCO See *total cost of ownership*.

TDD See *test-driven development*.

team lead See *team leader*.

team leader The leader of a programming team, particularly if a large project is broken into separate teams. Typically, a team leader is a more experienced developer. Also called a team lead.

team member A member of the development team. Depending on the development model, this can include many different kinds of participants. The team may include customer representatives in addition to developers.

technical writer Someone who writes online and printed documentation and training materials.

test-driven development (TDD) A programming technique where you; (1) Write a test to verify a feature; (2) Verify that the program fails the test; (3) Write code to implement the feature; and (4) Verify that the code passes the test.

tester Someone designated to test the application and look for holes in the design. Often programmers perform their own unit testing and the tester focuses on acceptance testing.

test-first development (TFD) A programming technique where you write all the unit tests for a piece of code before you write the code. You then write all the code, run the tests, and fix the code if it doesn't pass the tests.

TFD See *test-first development*.

third second normal form (3NF) The third level of normalization for a table in a relational database. A table is in 3NF if:

1. It is in 2NF.
2. It contains no transitive dependencies.

three-tier architecture A design where a middle tier provides insulation between client and server tiers. The middle tier can map data between the format provided by the server and the format needed by the client.

throwaway prototype A prototype that is used to study some aspect of a system and is then discarded.

timing diagram In UML, a diagram that shows one or more objects' changes in state over time.

toolsmith Someone whose job is to build tools for use by other developers.

top-down design A design process where you start with a high-level statement of a problem and then successively break the problem into more detailed and smaller pieces until the pieces are small enough to implement. Also called stepwise refinement.

total cost of ownership (TCO) The total expected cost of a software application including development costs, deployment costs, and maintenance costs over the expected lifetime of the application. (Often maintenance costs account for 75 percent of TCO.)

tracker In XP, someone who monitors the team's progress and the team members' progress, and who calculates metrics.

transitive dependency In a relational database, when a nonkey field's value depends on another nonkey field's value.

tuple See *record*.

two-tier architecture A design where a client (often the user interface) is separated from the server (normally the database).

UML See *Unified Modeling Language*.

Unified Modeling Language (UML) A collection of diagramming techniques for describing different aspects of a system.

Unified Process (UP) An iterative and incremental development framework that involves four stages: inception, elaboration, construction, and transition.

unit test A test that verifies the correctness of a specific piece of code.

UP See *Unified Process*.

use case A description of a series of interactions between actors. The actors can be users or parts of the application. A simple template might include a title, main success scenario, and extensions (other variations on the scenario).

use case diagram In UML, a diagram that represents a user's interaction with the system. Use case diagrams show stick figures representing actors (someone or something that performs a task) connected to tasks represented by ellipses.

user requirements These describe how the project will be used by the eventual end users.

user story A short story explaining how the system will let the user do something.

velocity In Scrum, the amount of work the team can perform during a sprint, usually measured in story points per sprint.

version management Managing the versions of items produced by the project such as requirements documents, designs, and, of course, source code. You should be able to retrieve any earlier version of those items if necessary. Also called version tracking, change management, and change tracking.

version tracking See *version management*.

vertical prototype A prototype that has little breadth but great depth.

visionary Someone who has a clear vision about what the application should do.

V-model Basically, a waterfall model that's been bent into a V shape to emphasize that each task on the left side of the V corresponds to a task on the right side.

waterfall A predictive development where each project phase flows into the next.

waterfall with feedback A variation on the waterfall model where each phase is allowed to feed information back to the preceding phase.

web service A service that provides a standardized web-based interface so that it is easy to invoke over the Internet.

white-box test A test designed by someone who knows how the code works internally. That person can guess where problems may lie and create tests specifically to look for those problems.

WIP See *work in progress*.

work in progress (WIP) The work being done at a given moment, particularly in a Kanban project.

working prototype See *functional prototype*.

workshop facilitator Someone who plans, runs, and encourages participation at workshops, particularly DSDM workshops.

XP See *Extreme Programming*.

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