entertainment, office machines, . . . the list is almost endless. And if you believe the law of unintended consequences, there are many effects that we cannot yet predict.

No one could predict that millions of computer programs would have to be corrected, adapted, and enhanced as time passed. The burden of performing these "maintenance" activities would absorb more people and more resources than all work applied to the creation of new software.

As software's importance has grown, the software community has continually attempted to develop technologies that will make it easier, faster, and less expensive to build and maintain high-quality computer programs. Some of these technologies are targeted at a specific application domain (e.g., website design and implementation); others focus on a technology domain (e.g., object-oriented systems or aspect-oriented programming); and still others are broad-based (e.g., operating systems such as Linux). However, we have yet to develop a software technology that does it all, and the likelihood of one arising in the future is small. And yet, people bet their jobs, their comforts, their safety, their entertainment, their decisions, and their very lives on computer software. It better be right.

This book presents a framework that can be used by those who build computer software—people who must get it right. The framework encompasses a process, a set of methods, and an array of tools that we call *software engineering*.

1.1 The Nature of Software

Software is both a product and a vehicle that delivers a product.

Today, software takes on a dual role. It is a product, and at the same time, the vehicle for delivering a product. As a product, it delivers the computing potential embodied by computer hardware or more broadly, by a network of computers that are accessible by local hardware. Whether it resides within a mobile phone, a hand-held tablet, on the desktop, or within a mainframe computer, software is an information transformer—producing, managing, acquiring, modifying, displaying, or transmitting information that can be as simple as a single bit or as complex as a multimedia presentation derived from data acquired from dozens of independent sources. As the vehicle used to deliver the product, software acts as the basis for the control of the computer (operating systems), the communication of information (networks), and the creation and control of other programs (software tools and environments).

Software delivers the most important product of our time—*information*. It transforms personal data (e.g., an individual's financial transactions) so that the data can be more useful in a local context; it manages business information to enhance competitiveness; it provides a gateway to worldwide information networks (e.g., the Internet), and provides the means for acquiring information in all of its forms. It also provides a vehicle that can threaten personal privacy and a gateway that enables those with malicious intent to commit criminal acts.

Quote:

"Software is a place where dreams are planted and nightmares harvested, an abstract, mystical swamp where terrible demons compete with magical panaceas, a world of werewolves and silver bullets."

Brad J. Cox

The role of computer software has undergone significant change over the last half-century. Dramatic improvements in hardware performance, profound changes in computing architectures, vast increases in memory and storage capacity, and a wide variety of exotic input and output options have all precipitated more sophisticated and complex computer-based systems. Sophistication and complexity can produce dazzling results when a system succeeds, but they can also pose huge problems for those who must build and protect complex systems.

Today, a huge software industry has become a dominant factor in the economies of the industrialized world. Teams of software specialists, each focusing on one part of the technology required to deliver a complex application, have replaced the lone programmer of an earlier era. And yet, the questions that were asked of the lone programmer are the same questions that are asked when modern computer-based systems are built:[1]

- Why does it take so long to get software finished?
- Why are development costs so high?
- Why can't we find all errors before we give the software to our customers?
- Why do we spend so much time and effort maintaining existing programs?
- Why do we continue to have difficulty in measuring progress as software is being developed and maintained?

These, and many other questions, are a manifestation of the concern about software and the manner in which it is developed—a concern that has led to the adoption of software engineering practice.

1.1.1 Defining Software

Today, most professionals and many members of the public at large feel that they understand software. But do they?

A textbook description of software might take the following form:

? How should we define *software*?

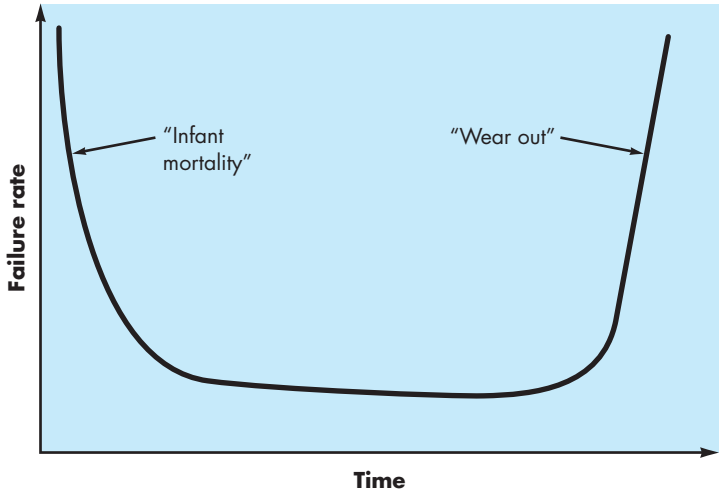
> Software is: (1) instructions (computer programs) that when executed provide desired features, function, and performance; (2) data structures that enable the programs to adequately manipulate information, and (3) descriptive information in both hard copy and virtual forms that describes the operation and use of the programs.

There is no question that other more complete definitions could be offered. But a more formal definition probably won't measurably improve your understanding.

---

1 In an excellent book of essays on the software business, Tom DeMarco [DeM95] argues the counterpoint. He states: "Instead of asking why software costs so much, we need to begin asking 'What have we done to make it possible for today's software to cost so little?' The answer to that question will help us continue the extraordinary level of achievement that has always distinguished the software industry."

FIGURE 1.1
Failure curve for hardware



ADVICE

If you want to reduce software deterioration, you'll have to do better software design (Chapters 12 to 18).

To accomplish that, it's important to examine the characteristics of software that make it different from other things that human beings build. Software is a logical rather than a physical system element. Therefore, software has one fundamental characteristic that makes it considerably different from hardware: *Software doesn't "wear out."*

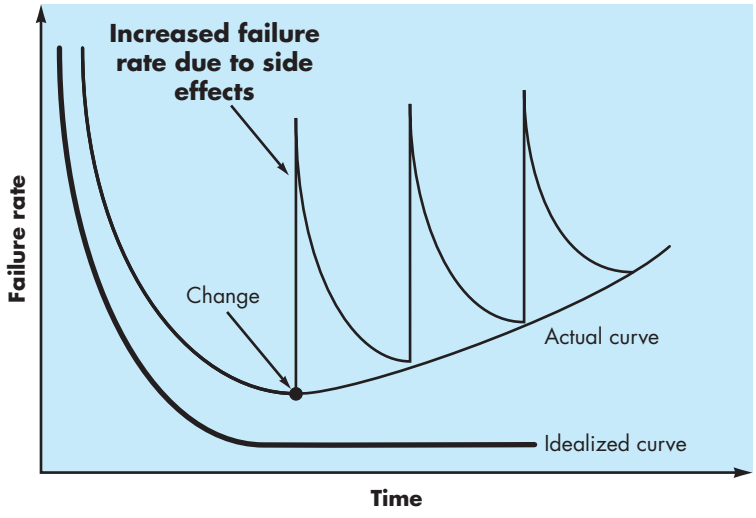
Figure 1.1 depicts failure rate as a function of time for hardware. The relationship, often called the "bathtub curve," indicates that hardware exhibits relatively high failure rates early in its life (these failures are often attributable to design or manufacturing defects); defects are corrected and the failure rate drops to a steady-state level (hopefully, quite low) for some period of time. As time passes, however, the failure rate rises again as hardware components suffer from the cumulative effects of dust, vibration, abuse, temperature extremes, and many other environmental maladies. Stated simply, the hardware begins to *wear out*.

Software is not susceptible to the environmental maladies that cause hardware to wear out. In theory, therefore, the failure rate curve for software should take the form of the "idealized curve" shown in Figure 1.2. Undiscovered defects will cause high failure rates early in the life of a program. However, these are corrected and the curve flattens as shown. The idealized curve is a gross oversimplification of actual failure models for software. However, the implication is clear—software doesn't wear out. But it does *deteriorate!*

This seeming contradiction can best be explained by considering the actual curve in Figure 1.2. During its life,[2] software will undergo change. As changes are

2 In fact, from the moment that development begins and long before the first version is delivered, changes may be requested by a variety of different stakeholders.

FIGURE 1.2
Failure curves for software



Software engineering methods strive to reduce the magnitude of the spikes and the slope of the actual curve in Figure 1.2.

made, it is likely that errors will be introduced, causing the failure rate curve to spike as shown in the "actual curve" (Figure 1.2). Before the curve can return to the original steady-state failure rate, another change is requested, causing the curve to spike again. Slowly, the minimum failure rate level begins to rise—the software is deteriorating due to change.

Another aspect of wear illustrates the difference between hardware and software. When a hardware component wears out, it is replaced by a spare part. There are no software spare parts. Every software failure indicates an error in design or in the process through which design was translated into machine executable code. Therefore, the software maintenance tasks that accommodate requests for change involve considerably more complexity than hardware maintenance.

1.1.2 Software Application Domains

Today, seven broad categories of computer software present continuing challenges for software engineers:

System software—a collection of programs written to service other programs. Some system software (e.g., compilers, editors, and file management utilities) processes complex, but determinate,[3] information structures. Other systems applications (e.g., operating system components, drivers, networking software, telecommunications processors) process largely indeterminate data.

3 Software is *determinate* if the order and timing of inputs, processing, and outputs is predictable. Software is *indeterminate* if the order and timing of inputs, processing, and outputs cannot be predicted in advance.

WebRef

One of the most comprehensive libraries of shareware/freeware can be found at shareware.cnet.com

Application software—stand-alone programs that solve a specific business need. Applications in this area process business or technical data in a way that facilitates business operations or management/technical decision making.

Engineering/scientific software—a broad array of "number-crunching programs that range from astronomy to volcanology, from automotive stress analysis to orbital dynamics, and from computer-aided design to molecular biology, from genetic analysis to meteorology.

Embedded software—resides within a product or system and is used to implement and control features and functions for the end user and for the system itself. Embedded software can perform limited and esoteric functions (e.g., key pad control for a microwave oven) or provide significant function and control capability (e.g., digital functions in an automobile such as fuel control, dashboard displays, and braking systems).

Product-line software—designed to provide a specific capability for use by many different customers. Product-line software can focus on a limited and esoteric marketplace (e.g., inventory control products) or address mass consumer.

Web/Mobile applications—this network-centric software category spans a wide array of applications and encompasses both browser-based apps and software that resides on mobile devices.

Quote:

"What a computer is to me is the most remarkable tool that we have ever come up with. It's the equivalent of a bicycle for our minds."

Steve Jobs

Artificial intelligence software—makes use of nonnumerical algorithms to solve complex problems that are not amenable to computation or straightforward analysis. Applications within this area include robotics, expert systems, pattern recognition (image and voice), artificial neural networks, theorem proving, and game playing.

Millions of software engineers worldwide are hard at work on software projects in one or more of these categories. In some cases, new systems are being built, but in many others, existing applications are being corrected, adapted, and enhanced. It is not uncommon for a young software engineer to work on a program that is older than she is! Past generations of software people have left a legacy in each of the categories we have discussed. Hopefully, the legacy to be left behind by this generation will ease the burden on future software engineers.

1.1.3 Legacy Software

Hundreds of thousands of computer programs fall into one of the seven broad application domains discussed in the preceding subsection. Some of these are state-of-the-art software—just released to individuals, industry, and government. But other programs are older, in some cases *much* older.

These older programs—often referred to as *legacy software*—have been the focus of continuous attention and concern since the 1960s. Dayani-Fard and his colleagues [Day99] describe legacy software in the following way:

> Legacy software systems . . . were developed decades ago and have been continually modified to meet changes in business requirements and computing platforms. The proliferation of such systems is causing headaches for large organizations who find them costly to maintain and risky to evolve.

Liu and his colleagues [Liu98] extend this description by noting that "many legacy systems remain supportive to core business functions and are 'indispensable' to the business." Hence, legacy software is characterized by longevity and business criticality.

? What do I do if I encounter a legacy system that exhibits poor quality?

Unfortunately, there is sometimes one additional characteristic that is present in legacy software—*poor quality*.[4] Legacy systems sometimes have inextensible designs, convoluted code, poor or nonexistent documentation, test cases and results that were never archived, a poorly managed change history—the list can be quite long. And yet, these systems support "core business functions and are indispensable to the business." What to do?

The only reasonable answer may be: *Do nothing,* at least until the legacy system must undergo some significant change. If the legacy software meets the needs of its users and runs reliably, it isn't broken and does not need to be fixed. However, as time passes, legacy systems often evolve for one or more of the following reasons:

? What types of changes are made to legacy systems?

- The software must be adapted to meet the needs of new computing environments or technology.
- The software must be enhanced to implement new business requirements.
- The software must be extended to make it interoperable with other more modern systems or databases.
- The software must be re-architected to make it viable within a evolving computing environment.

Every software engineer must recognize that change is natural. Don't try to fight it.

When these modes of evolution occur, a legacy system must be reengineered (Chapter 36) so that it remains viable into the future. The goal of modern software engineering is to "devise methodologies that are founded on the notion of evolution;" that is, the notion that software systems continually change, new software systems are built from the old ones, and . . . all must interoperate and cooperate with each other." [Day99]

4 In this case, quality is judged based on modern software engineering thinking—a somewhat unfair criterion since some modern software engineering concepts and principles may not have been well understood at the time that the legacy software was developed.

KEY POINT
Understand the problem before you build a solution.

- Individuals, businesses, and governments increasingly rely on software for strategic and tactical decision making as well as day-to-day operations and control. If the software fails, people and major enterprises can experience anything from minor inconvenience to catastrophic failures. *It follows that software should exhibit high quality.*
- As the perceived value of a specific application grows, the likelihood is that its user base and longevity will also grow. As its user base and time-in-use increase, demands for adaptation and enhancement will also grow. *It follows that software should be maintainable.*

KEY POINT
Both quality and maintainability are an outgrowth of good design.

These simple realities lead to one conclusion: *software in all of its forms and across all of its application domains should be engineered.* And that leads us to the topic of this book—*software engineering*.

2.1 Defining the Discipline

? How do we define software engineering?

The IEEE [IEE93a] has developed the following definition for software engineering:

> Software Engineering : (1) The application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software; that is, the application of engineering to software. (2) The study of approaches as in (1).

And yet, a "systematic, disciplined, and quantifiable" approach applied by one software team may be burdensome to another. We need discipline, but we also need adaptability and agility.

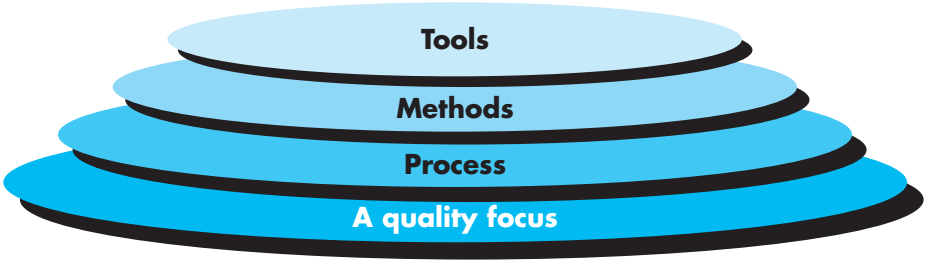
Software engineering is a layered technology. Referring to Figure 2.1, any engineering approach (including software engineering) must rest on an organizational commitment to quality. Total quality management, Six Sigma, and similar philosophies[2] foster a continuous process improvement culture, and it is this culture that ultimately leads to the development of increasingly more effective approaches to software engineering. The bedrock that supports software engineering is a quality focus.

KEY POINT
Software engineering encompasses a process, methods for managing and engineering software, and tools.

The foundation for software engineering is the *process* layer. The software engineering process is the glue that holds the technology layers together and enables rational and timely development of computer software. Process defines a framework that must be established for effective delivery of software engineering technology. The software process forms the basis for management control of software projects and establishes the context in which technical methods are

2 Quality management and related approaches are discussed throughout Part 3 of this book.

FIGURE 2.1 Software engineering layers



applied, work products (models, documents, data, reports, forms, etc.) are produced, milestones are established, quality is ensured, and change is properly managed.

Software engineering *methods* provide the technical how-to's for building software. Methods encompass a broad array of tasks that include communication, requirements analysis, design modeling, program construction, testing, and support. Software engineering methods rely on a set of basic principles that govern each area of the technology and include modeling activities and other descriptive techniques.

WebRef

CrossTalk is a journal that provides pragmatic information on process, methods, and tools. It can be found at: www.stsc.hill.af.mil,

Software engineering *tools* provide automated or semi-automated support for the process and the methods. When tools are integrated so that information created by one tool can be used by another, a system for the support of software development, called *computer-aided software engineering*, is established.

2.2 THE SOFTWARE PROCESS

? What are the elements of a software process?

A *process* is a collection of activities, actions, and tasks that are performed when some work product is to be created. An *activity* strives to achieve a broad objective (e.g., communication with stakeholders) and is applied regardless of the application domain, size of the project, complexity of the effort, or degree of rigor with which software engineering is to be applied. An *action* (e.g., architectural design) encompasses a set of tasks that produce a major work product (e.g., an architectural model). A *task* focuses on a small, but well-defined objective (e.g., conducting a unit test) that produces a tangible outcome.

Quote:

"A process defines who is doing *what* *when* and *how* to reach a certain goal."

Ivar Jacobson, Grady Booch, and James Rumbaugh

In the context of software engineering, a process is *not* a rigid prescription for how to build computer software. Rather, it is an adaptable approach that enables the people doing the work (the software team) to pick and choose the appropriate set of work actions and tasks. The intent is always to deliver software in a timely manner and with sufficient quality to satisfy those who have sponsored its creation and those who will use it.

2.2.1 The Process Framework

What are the five generic process framework activities?

A *process framework* establishes the foundation for a complete software engineering process by identifying a small number of *framework activities* that are applicable to all software projects, regardless of their size or complexity. In addition, the process framework encompasses a set of *umbrella activities* that are applicable across the entire software process. A generic process framework for software engineering encompasses five activities:

Communication. Before any technical work can commence, it is critically important to communicate and collaborate with the customer (and other stakeholders).[3] The intent is to understand stakeholders' objectives for the project and to gather requirements that help define software features and functions.

Quote:

"Einstein argued that there must be a simplified explanation of nature, because God is not capricious or arbitrary. No such faith comforts the software engineer. Much of the complexity that he must master is arbitrary complexity."

Fred Brooks

Planning. Any complicated journey can be simplified if a map exists. A software project is a complicated journey, and the planning activity creates a "map" that helps guide the team as it makes the journey. The map—called a software project plan—defines the software engineering work by describing the technical tasks to be conducted, the risks that are likely, the resources that will be required, the work products to be produced, and a work schedule.

Modeling. Whether you're a landscaper, a bridge builder, an aeronautical engineer, a carpenter, or an architect, you work with models every day. You create a "sketch" of the thing so that you'll understand the big picture—what it will look like architecturally, how the constituent parts fit together, and many other characteristics. If required, you refine the sketch into greater and greater detail in an effort to better understand the problem and how you're going to solve it. A software engineer does the same thing by creating models to better understand software requirements and the design that will achieve those requirements.

Construction. What you design must be built. This activity combines code generation (either manual or automated) and the testing that is required to uncover errors in the code.

Deployment. The software (as a complete entity or as a partially completed increment) is delivered to the customer who evaluates the delivered product and provides feedback based on the evaluation.

These five generic framework activities can be used during the development of small, simple programs, the creation of Web applications, and for the engineering

3 A *stakeholder* is anyone who has a stake in the successful outcome of the project—business managers, end users, software engineers, support people, etc. Rob Thomsett jokes that, "a stakeholder is a person holding a large and sharp stake . . . If you don't look after your stakeholders, you know where the stake will end up."

of large, complex computer-based systems. The details of the software process will be quite different in each case, but the framework activities remain the same.

For many software projects, framework activities are applied iteratively as a project progresses. That is, communication, planning, modeling, construction, and deployment are applied repeatedly through a number of project iterations. Each iteration produces a *software increment* that provides stakeholders with a subset of overall software features and functionality. As each increment is produced, the software becomes more and more complete.

2.2.2 Umbrella Activities

Software engineering process framework activities are complemented by a number of *umbrella activities*. In general, umbrella activities are applied throughout a software project and help a software team manage and control progress, quality, change, and risk. Typical umbrella activities include:

Umbrella activities occur throughout the software process and focus primarily on project management, tracking, and control.

Software project tracking and control—allows the software team to assess progress against the project plan and take any necessary action to maintain the schedule.

Risk management—assesses risks that may affect the outcome of the project or the quality of the product.

Software quality assurance—defines and conducts the activities required to ensure software quality.

Technical reviews—assess software engineering work products in an effort to uncover and remove errors before they are propagated to the next activity.

Measurement—defines and collects process, project, and product measures that assist the team in delivering software that meets stakeholders' needs; can be used in conjunction with all other framework and umbrella activities.

Software configuration management—manages the effects of change throughout the software process.

Reusability management—defines criteria for work product reuse (including software components) and establishes mechanisms to achieve reusable components.

Software process adaptation is essential for project success.

Work product preparation and production—encompass the activities required to create work products such as models, documents, logs, forms, and lists.

Each of these umbrella activities is discussed in detail later in this book.

2.2.3 Process Adaptation

Previously in this section, we noted that the software engineering process is not a rigid prescription that must be followed dogmatically by a software team. Rather, it should be agile and adaptable (to the problem, to the project, to the team,

and to the organizational culture). Therefore, a process adopted for one project might be significantly different than a process adopted for another project. Among the differences are

- Overall flow of activities, actions, and tasks and the interdependencies among them.
- Degree to which actions and tasks are defined within each framework activity.
- Degree to which work products are identified and required.
- Manner in which quality assurance activities are applied.
- Manner in which project tracking and control activities are applied.
- Overall degree of detail and rigor with which the process is described.
- Degree to which the customer and other stakeholders are involved with the project.
- Level of autonomy given to the software team.
- Degree to which team organization and roles are prescribed.

In Part 1 of this book, we examine software process in considerable detail.

Quote:

"I feel a recipe is only a theme which an intelligent cook can play each time with a variation."

Madame Benoit

2.3 Software Engineering Practice

In Section 2.2, we introduced a generic software process model composed of a set of activities that establish a framework for software engineering practice. Generic framework activities—**communication, planning, modeling, construction,** and **deployment**—and umbrella activities establish a skeleton architecture for software engineering work. But how does the practice of software engineering fit in? In the sections that follow, you'll gain a basic understanding of the generic concepts and principles that apply to framework activities.[4]

WebRef

A variety of thought-provoking quotes on the practice of software engineering can be found at **www.literateprogramming.com.**

2.3.1 The Essence of Practice

ADVICE

You might argue that Polya's approach is simply common sense. True. But it's amazing how often common sense is uncommon in the software world.

In the classic book, *How to Solve It,* written before modern computers existed, George Polya [Pol45] outlined the essence of problem solving, and consequently, the essence of software engineering practice:

1. *Understand the problem* (communication and analysis).
2. *Plan a solution* (modeling and software design).
3. *Carry out the plan* (code generation).
4. *Examine the result for accuracy* (testing and quality assurance).

4 You should revisit relevant sections within this chapter as we discuss specific software engineering methods and umbrella activities later in this book.

In the context of software engineering, these commonsense steps lead to a series of essential questions [adapted from Pol45]:

The most important element of problem understanding is listening.

Understand the problem. It's sometimes difficult to admit, but most of us suffer from hubris when we're presented with a problem. We listen for a few seconds and then think, *Oh yeah, I understand, let's get on with solving this thing*. Unfortunately, understanding isn't always that easy. It's worth spending a little time answering a few simple questions:

- *Who has a stake in the solution to the problem?* That is, who are the stakeholders?
- *What are the unknowns?* What data, functions, and features are required to properly solve the problem?
- *Can the problem be compartmentalized?* Is it possible to represent smaller problems that may be easier to understand?
- *Can the problem be represented graphically?* Can an analysis model be created?

Plan the solution. Now you understand the problem (or so you think), and you can't wait to begin coding. Before you do, slow down just a bit and do a little design:

- *Have you seen similar problems before?* Are there patterns that are recognizable in a potential solution? Is there existing software that implements the data, functions, and features that are required?
- *Has a similar problem been solved?* If so, are elements of the solution reusable?
- *Can subproblems be defined?* If so, are solutions readily apparent for the subproblems?
- *Can you represent a solution in a manner that leads to effective implementation?* Can a design model be created?

"There is a grain of discovery in the solution of any problem."

George Polya

Carry out the plan. The design you've created serves as a road map for the system you want to build. There may be unexpected detours, and it's possible that you'll discover an even better route as you go, but the "plan" will allow you to proceed without getting lost.

- *Does the solution conform to the plan?* Is source code traceable to the design model?
- *Is each component part of the solution provably correct?* Has the design and code been reviewed, or better, have correctness proofs been applied to the algorithm?

Examine the result. You can't be sure that your solution is perfect, but you can be sure that you've designed a sufficient number of tests to uncover as many errors as possible.

- *Is it possible to test each component part of the solution?* Has a reasonable testing strategy been implemented?
- *Does the solution produce results that conform to the data, functions, and features that are required?* Has the software been validated against all stakeholder requirements?

It shouldn't surprise you that much of this approach is common sense. In fact, it's reasonable to state that a commonsense approach to software engineering will never lead you astray.

2.3.2 General Principles

The dictionary defines the word *principle* as "an important underlying law or assumption required in a system of thought." Throughout this book we'll discuss principles at many different levels of abstraction. Some focus on software engineering as a whole, others consider a specific generic framework activity (e.g., **communication**), and still others focus on software engineering actions (e.g., architectural design) or technical tasks (e.g., write a usage scenario). Regardless of their level of focus, principles help you establish a mind-set for solid software engineering practice. They are important for that reason.

Before beginning a software project, be sure the software has a business purpose and that users perceive value in it.

David Hooker [Hoo96] has proposed seven principles that focus on software engineering practice as a whole. They are reproduced in the following paragraphs:[5]

The First Principle: *The Reason It All Exists*

A software system exists for one reason: *to provide value to its users*. All decisions should be made with this in mind. Before specifying a system requirement, before noting a piece of system functionality, before determining the hardware platforms or development processes, ask yourself questions such as: "Does this add real value to the system?" If the answer is no, don't do it. All other principles support this one.

"There is a certain majesty in simplicity which is far above all the quaintness of wit."

Alexander Pope (1688–1744)

The Second Principle: *KISS (Keep It Simple, Stupid!)*

Software design is not a haphazard process. There are many factors to consider in any design effort. *All design should be as simple as possible, but no simpler*. This facilitates having a more easily understood and easily maintained system. This is not to say that features, even internal features, should be discarded in the name of simplicity. Indeed, the more elegant designs are usually the more simple ones. Simple also does not mean "quick and dirty." In fact, it

5 Reproduced with permission of the author [Hoo96]. Hooker defines patterns for these principles at **http://c2.com/cgi/wiki?SevenPrinciplesOfSoftwareDevelopment**.

often takes a lot of thought and work over multiple iterations to simplify. The payoff is software that is more maintainable and less error-prone.

The Third Principle: *Maintain the Vision*

A clear vision is essential to the success of a software project. Without one, a project almost unfailingly ends up being "of two [or more] minds" about itself. Without conceptual integrity, a system threatens to become a patchwork of incompatible designs, held together by the wrong kind of screws . . . Compromising the architectural vision of a software system weakens and will eventually break even the well-designed systems. Having an empowered architect who can hold the vision and enforce compliance helps ensure a very successful software project.

The Fourth Principle: *What You Produce, Others Will Consume*

KEY POINT

If software has value, it will change over its useful life. For that reason, software must be built to be maintainable.

Seldom is an industrial-strength software system constructed and used in a vacuum. In some way or other, someone else will use, maintain, document, or otherwise depend on being able to understand your system. So, *always specify, design, and implement knowing someone else will have to understand what you are doing*. The audience for any product of software development is potentially large. Specify with an eye to the users. Design, keeping the implementers in mind. Code with concern for those that must maintain and extend the system. Someone may have to debug the code you write, and that makes them a user of your code. Making their job easier adds value to the system.

The Fifth Principle: *Be Open to the Future*

A system with a long lifetime has more value. In today's computing environments, where specifications change on a moment's notice and hardware platforms are obsolete just a few months old, software lifetimes are typically measured in months instead of years. However, true "industrial-strength" software systems must endure far longer. To do this successfully, these systems must be ready to adapt to these and other changes. Systems that do this successfully are those that have been designed this way from the start. *Never design yourself into a corner*. Always ask "what if," and prepare for all possible answers by creating systems that solve the general problem, not just the specific one.[6] This could very possibly lead to the reuse of an entire system.

The Sixth Principle: *Plan Ahead for Reuse*

Reuse saves time and effort.[7] Achieving a high level of reuse is arguably the hardest goal to accomplish in developing a software system. The reuse of code

6 This advice can be dangerous if it is taken to extremes. Designing for the "general problem" sometimes requires performance compromises and can make specific solutions inefficient.

7 Although this is true for those who reuse the software on future projects, reuse can be expensive for those who must design and build reusable components. Studies indicate that designing and building reusable components can cost between 25 to 200 percent more than targeted software. In some cases, the cost differential cannot be justified.

and designs has been proclaimed as a major benefit of using object-oriented technologies. However, the return on this investment is not automatic. To leverage the reuse possibilities that object-oriented [or conventionall programming provides requires forethought and planning. There are many techniques to realize reuse at every level of the system development process . . . *Planning ahead for reuse reduces the cost and increases the value of both the reusable components and the systems into which they are incorporated.*

The Seventh Principle: *Think!*

This last Principle is probably the most overlooked. *Placing clear, complete thought before action almost always produces better results*. When you think about something, you are more likely to do it right. You also gain knowledge about how to do it right again. If you do think about something and still do it wrong, it becomes a valuable experience. A side effect of thinking is learning to recognize when you don't know something, at which point you can research the answer. When clear thought has gone into a system, value comes out. Applying the first six principles requires intense thought, for which the potential rewards are enormous.

If every software engineer and every software team simply followed Hooker's seven principles, many of the difficulties we experience in building complex computer-based systems would be eliminated.

2.4 Software Development Myths

Software development myths—erroneous beliefs about software and the process that is used to build it—can be traced to the earliest days of computing. Myths have a number of attributes that make them insidious. For instance, they appear to be reasonable statements of fact (sometimes containing elements of truth), they have an intuitive feel, and they are often promulgated by experienced practitioners who "know the score."

Today, most knowledgeable software engineering professionals recognize myths for what they are—misleading attitudes that have caused serious problems for managers and practitioners alike. However, old attitudes and habits are difficult to modify, and remnants of software myths remain.

Management myths. Managers with software responsibility, like managers in most disciplines, are often under pressure to maintain budgets, keep schedules from slipping, and improve quality. Like a drowning person who grasps at a straw, a software manager often grasps at belief in a software myth, if that belief will lessen the pressure (even temporarily).

WebRef

The Software Project Managers Network at **www.spmn.com** can help you dispel these and other myths.

Myth: *We already have a book that's full of standards and procedures for building software. Won't that provide my people with everything they need to know?*

But what exactly is a software process from a technical point of view? Within the context of this book, we define a *software process* as a framework for the activities, actions, and tasks that are required to build high-quality software. Is "process" synonymous with "software engineering"? The answer is yes and no. A software process defines the approach that is taken as software is engineered. But software engineering also encompasses technologies that populate the process—technical methods and automated tools.

More important, software engineering is performed by creative, knowledgeable people who should adapt a mature software process so that it is appropriate for the products that they build and the demands of their marketplace.

3.1 A Generic Process Model

In Chapter 2, a process was defined as a collection of work activities, actions, and tasks that are performed when some work product is to be created. Each of these activities, actions, and tasks resides within a framework or model that defines their relationship with the process and with one another.

The hierarchy of technical work within the software process is activities, encompassing actions, populated by tasks.

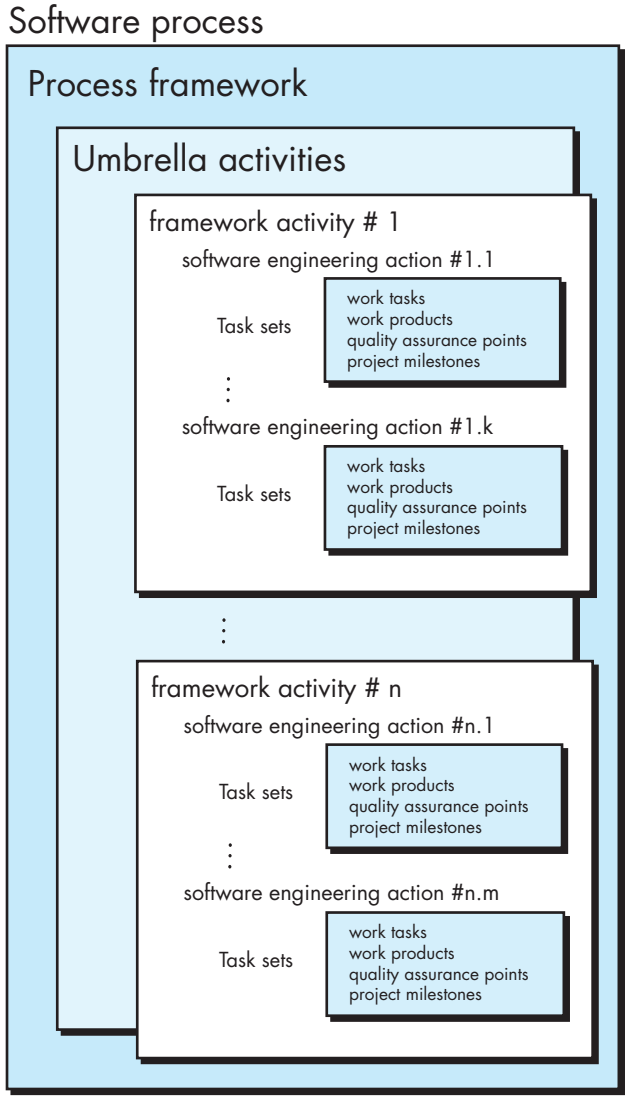
The software process is represented schematically in Figure 3.1. Referring to the figure, each framework activity is populated by a set of software engineering actions. Each software engineering action is defined by a *task set* that identifies the work tasks that are to be completed, the work products that will be produced, the quality assurance points that will be required, and the milestones that will be used to indicate progress.

As we discussed in Chapter 2, a generic process framework for software engineering defines five framework activities—**communication, planning, modeling, construction,** and **deployment**. In addition, a set of umbrella activities—project tracking and control, risk management, quality assurance, configuration management, technical reviews, and others—are applied throughout the process.

You should note that one important aspect of the software process has not yet been discussed. This aspect—called *process flow*—describes how the framework activities and the actions and tasks that occur within each framework activity are organized with respect to sequence and time and is illustrated in Figure 3.2.

A *linear process flow* executes each of the five framework activities in sequence, beginning with communication and culminating with deployment (Figure 3.2a). An *iterative process flow* repeats one or more of the activities before proceeding to the next (Figure 3.2b). An *evolutionary process flow* executes the activities in a "circular" manner. Each circuit through the five activities leads to a more complete version of the software (Figure 3.2c). A *parallel process flow* (Figure 3.2d) executes one or more activities in parallel with other activities (e.g., modeling for one aspect of the software might be executed in parallel with construction of another aspect of the software).

FIGURE 3.1
A software process framework



3.2 DEFINING A FRAMEWORK ACTIVITY

Quote:
"If the process is right, the results will take care of themselves."
Takashi Osada

Although we have described five framework activities and provided a basic definition of each in Chapter 2, a software team would need significantly more information before it could properly execute any one of these activities as part of the software process. Therefore, you are faced with a key question: *What actions are appropriate for a framework activity, given the nature of the problem to be solved, the characteristics of the people doing the work, and the stakeholders who are sponsoring the project?*

WebRef

Comprehensive resources on process patterns can be found at www.ambysoft.com/processPatternsPage.html.

Process patterns provide an effective mechanism for addressing problems associated with any software process. The patterns enable you to develop a hierarchical process description that begins at a high level of abstraction (a phase pattern). The description is then refined into a set of stage patterns that describe framework activities and are further refined in a hierarchical fashion into more detailed task patterns for each stage pattern. Once process patterns have been developed, they can be reused for the definition of process variants—that is, a customized process model can be defined by a software team using the patterns as building blocks for the process model.

INFO

An Example Process Pattern

The following abbreviated process pattern describes an approach that may be applicable when stakeholders have a general idea of what must be done but are unsure of specific software requirements.

Pattern Name. **RequirementsUnclear**

Intent. This pattern describes an approach for building a model (a prototype) that can be assessed iteratively by stakeholders in an effort to identify or solidify software requirements.

Type. Phase pattern.

Initial Context. The following conditions must be met prior to the initiation of this pattern: (1) stakeholders have been identified; (2) a mode of communication between stakeholders and the software team has been established; (3) the overriding software problem to be solved has been identified by stakeholders; (4) an initial understanding of project scope, basic business requirements, and project constraints has been developed.

Problem. Requirements are hazy or nonexistent, yet there is clear recognition that there is a problem to be solved, and the problem must be addressed with a software solution. Stakeholders are unsure of what they want; that is, they cannot describe software requirements in any detail.

Solution. A description of the prototyping process would be presented here and is described later in Section 4.1.3.

Resulting Context. A software prototype that identifies basic requirements (e.g., modes of interaction, computational features, processing functions) is approved by stakeholders. Following this, (1) the prototype may evolve through a series of increments to become the production software or (2) the prototype may be discarded and the production software built using some other process pattern.

Related Patterns. The following patterns are related to this pattern: **CustomerCommunication, IterativeDesign, IterativeDevelopment, CustomerAssessment, RequirementExtraction.**

Known Uses and Examples. Prototyping is recommended when requirements are uncertain.

3.5 PROCESS ASSESSMENT AND IMPROVEMENT

The existence of a software process is no guarantee that software will be delivered on time, that it will meet the customer's needs, or that it will exhibit the technical characteristics that will lead to long-term quality characteristics (Chapter 19). Process patterns must be coupled with solid software engineering practice (Part 2 of this book). In addition, the process itself can be assessed to

KEY POINT
Assessment attempts to understand the current state of the software process with the intent of improving it.

ensure that it meets a set of basic process criteria that have been shown to be essential for a successful software engineering.[4]

A number of different approaches to software process assessment and improvement have been proposed over the past few decades:

Standard CMMI Assessment Method for Process Improvement (SCAMPI)— provides a five-step process assessment model that incorporates five phases: initiating, diagnosing, establishing, acting, and learning. The SCAMPI method uses the SEI CMMI as the basis for assessment [SEI00].

CMM-Based Appraisal for Internal Process Improvement (CBA IPI)— provides a diagnostic technique for assessing the relative maturity of a software organization; uses the SEI CMM as the basis for the assessment [Dun01].

Quote:
"Software organizations have exhibited significant shortcomings in their ability to capitalize on the experiences gained from completed projects."
NASA

SPICE (ISO/IEC15504)—a standard that defines a set of requirements for software process assessment. The intent of the standard is to assist organizations in developing an objective evaluation of the efficacy of any defined software process [ISO08].

ISO 9001:2000 for Software—a generic standard that applies to any organization that wants to improve the overall quality of the products, systems, or services that it provides. Therefore, the standard is directly applicable to software organizations and companies [Ant06].

A more detailed discussion of software assessment and process improvement methods is presented in Chapter 37.

3.6 Summary

A generic process model for software engineering encompasses a set of framework and umbrella activities, actions, and work tasks. Each of a variety of process models can be described by a different process flow—a description of how the framework activities, actions, and tasks are organized sequentially and chronologically. Process patterns can be used to solve common problems that are encountered as part of the software process.

Problems and Points to Ponder

3.1. In the introduction to this chapter Baetjer notes: "The process provides interaction between users and designers, between users and evolving tools, and between designers and evolving tools [technology]." List five questions that (1) designers should ask users, (2) users should ask designers, (3) users should ask themselves about the software product that is to be built, (4) designers should ask themselves about the software product that is to be built and the process that will be used to build it.

4 The SEI's CMMI [CMM07] describes the characteristics of a software process and the criteria for a successful process in voluminous detail.

advantage under unpredictable environments. Change occurs when there is some structure so that the change can be organized, but not so rigid that it cannot occur. Too much chaos, on the other hand, can make coordination and coherence impossible. Lack of structure does not always mean disorder.

KEY POINT
The purpose of process models is to try to reduce the chaos present in developing new software products.

The philosophical implications of this argument are significant for software engineering. Each process model described in this chapter tries to strike a balance between the need to impart order in a chaotic world and the need to be adaptable when things change constantly.

4.1 Prescriptive Process Models

WebRef
An award-winning "process simulation game" that includes most important prescriptive process models can be found at: **http://www.ics.uci.edu/~emilyo/SimSE/downloads.html**.

A *prescriptive process model*[1] strives for structure and order in software development. Activities and tasks occur sequentially with defined guidelines for progress. But are prescriptive models appropriate for a software world that thrives on change? If we reject traditional process models (and the order they imply) and replace them with something less structured, do we make it impossible to achieve coordination and coherence in software work?

There are no easy answers to these questions, but there are alternatives available to software engineers. In the sections that follow, we examine the prescriptive process approach in which order and project consistency are dominant issues. We call them "prescriptive" because they prescribe a set of process elements—framework activities, software engineering actions, tasks, work products, quality assurance, and change control mechanisms for each project. Each process model also prescribes a process flow (also called a *work flow*)—that is, the manner in which the process elements are interrelated to one another.

All software process models can accommodate the generic framework activities described in Chapters 2 and 3, but each applies a different emphasis to these activities and defines a process flow that invokes each framework activity (as well as software engineering actions and tasks) in a different manner.

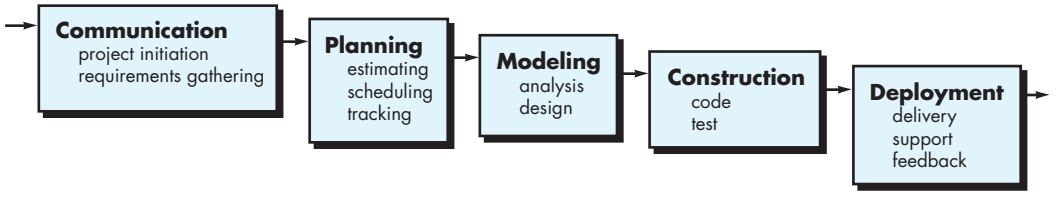
4.1.1 The Waterfall Model

KEY POINT
Prescriptive process models define a prescribed set of process elements and a predictable process work flow.

There are times when the requirements for a problem are well understood—when work flows from communication through deployment in a reasonably linear fashion. This situation is sometimes encountered when well-defined adaptations or enhancements to an existing system must be made (e.g., an adaptation to accounting software that has been mandated because of changes to government regulations). It may also occur in a limited number of new development efforts, but only when requirements are well defined and reasonably stable.

1 Prescriptive process models are sometimes referred to as "traditional" process models.

FIGURE 4.1 The waterfall model



KEY POINT
The V-model illustrates how verification and validation actions are associated with earlier engineering actions.

The *waterfall model*, sometimes called the *classic life cycle*, suggests a systematic, sequential approach[2] to software development that begins with customer specification of requirements and progresses through planning, modeling, construction, and deployment, culminating in ongoing support of the completed software (Figure 4.1).

A variation in the representation of the waterfall model is called the *V-model*. Represented in Figure 4.2, the V-model [Buc99] depicts the relationship of quality assurance actions to the actions associated with communication, modeling, and early construction activities. As a software team moves down the left side of the V, basic problem requirements are refined into progressively more detailed and technical representations of the problem and its solution. Once code has been generated, the team moves up the right side of the V, essentially performing a series of tests (quality assurance actions) that validate each of the models created as the team moves down the left side.[3] In reality, there is no fundamental difference between the classic life cycle and the V-model. The V-model provides a way of visualizing how verification and validation actions are applied to earlier engineering work.

The waterfall model is the oldest paradigm for software engineering. However, over the past four decades, criticism of this process model has caused even ardent supporters to question its efficacy [Han95]. Among the problems that are sometimes encountered when the waterfall model is applied are:

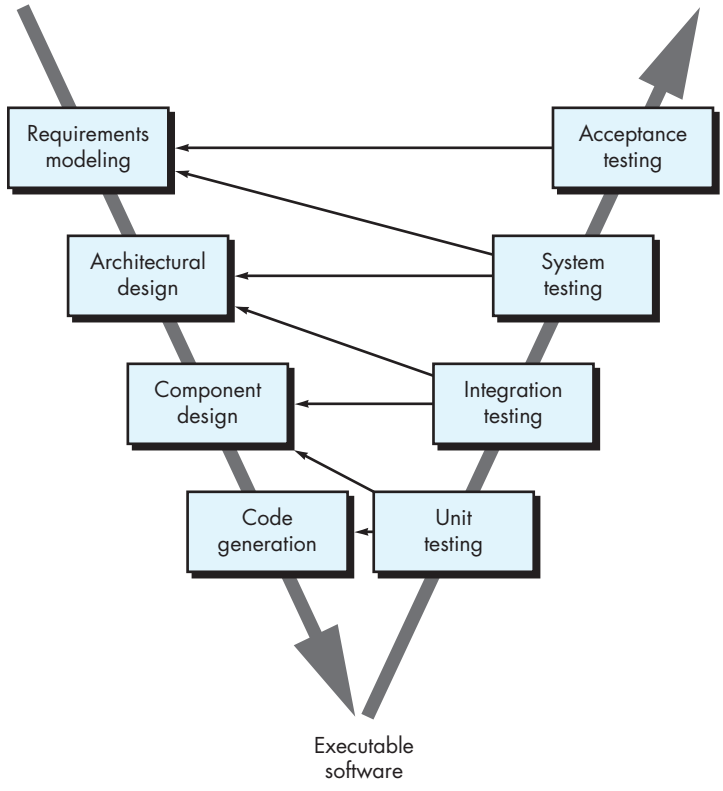
? Why does the waterfall model sometimes fail?

1. Real projects rarely follow the sequential flow that the model proposes. Although the linear model can accommodate iteration, it does so indirectly. As a result, changes can cause confusion as the project team proceeds.
2. It is often difficult for the customer to state all requirements explicitly. The waterfall model requires this and has difficulty accommodating the natural uncertainty that exists at the beginning of many projects.

2 Although the original waterfall model proposed by Winston Royce [Roy70] made provision for "feedback loops," the vast majority of organizations that apply this process model treat it as if it were strictly linear.

3 A detailed discussion of quality assurance actions is presented in Part 3 of this book.

FIGURE 4.2
The V-model



3. The customer must have patience. A working version of the program(s) will not be available until late in the project time span. A major blunder, if undetected until the working program is reviewed, can be disastrous.

Quote:

"Too often, software work follows the first law of bicycling: No matter where you're going, it's uphill and against the wind."

Author unknown

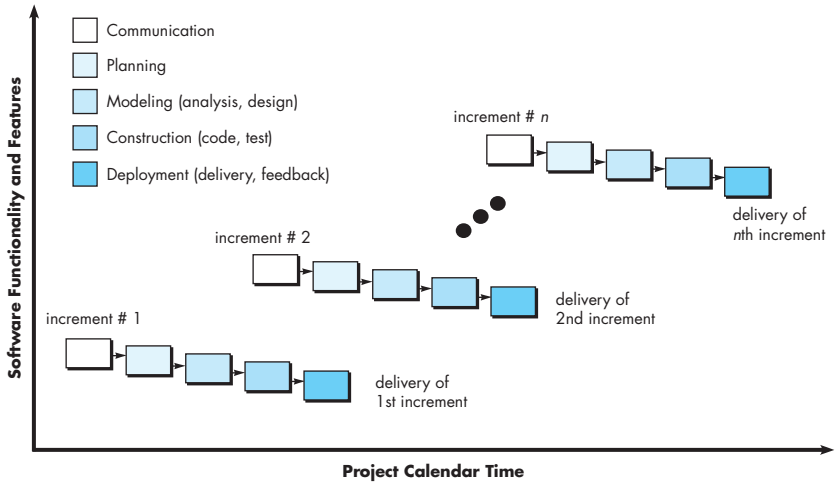
In an interesting analysis of actual projects, Bradac [Bra94] found that the linear nature of the classic life cycle leads to "blocking states" in which some project team members must wait for other members of the team to complete dependent tasks. In fact, the time spent waiting can exceed the time spent on productive work! The blocking state tends to be more prevalent at the beginning and end of a linear sequential process.

Today, software work is fast paced and subject to a never-ending stream of changes (to features, functions, and information content). The waterfall model is often inappropriate for such work. However, it can serve as a useful process model in situations where requirements are fixed and work is to proceed to completion in a linear manner.

4.1.2 Incremental Process Models

There are many situations in which initial software requirements are reasonably well defined, but the overall scope of the development effort precludes a purely

FIGURE 4.3
The incremental model



linear process. In addition, there may be a compelling need to provide a limited set of software functionality to users quickly and then refine and expand on that functionality in later software releases. In such cases, you can choose a process model that is designed to produce the software in increments.

The incremental model combines the elements' linear and parallel process flows discussed in Chapter 3. Referring to Figure 4.3, the incremental model applies linear sequences in a staggered fashion as calendar time progresses. Each linear sequence produces deliverable "increments" of the software [McD93].

KEY POINT
The incremental model delivers a series of releases, called increments, that provide progressively more functionality for the customer as each increment is delivered.

For example, word-processing software developed using the incremental paradigm might deliver basic file management, editing, and document production functions in the first increment; more sophisticated editing and document production capabilities in the second increment; spelling and grammar checking in the third increment; and advanced page layout capability in the fourth increment. It should be noted that the process flow for any increment can incorporate the prototyping paradigm discussed in the next subsection.

ADVICE
Your customer demands delivery by a date that is impossible to meet. Suggest delivering one or more increments by that date and the rest of the software (additional increments) later.

When an incremental model is used, the first increment is often a *core product*. That is, basic requirements are addressed but many supplementary features (some known, others unknown) remain undelivered. The core product is used by the customer (or undergoes detailed evaluation). As a result of use and/or evaluation, a plan is developed for the next increment. The plan addresses the modification of the core product to better meet the needs of the customer and the delivery of additional features and functionality. This process is repeated following the delivery of each increment, until the complete product is produced.

4.1.3 Evolutionary Process Models

Evolutionary process models produce an increasingly more complete version of the software with each iteration.

Software, like all complex systems, evolves over a period of time. Business and product requirements often change as development proceeds, making a straight line path to an end product unrealistic; tight market deadlines make completion of a comprehensive software product impossible, but a limited version must be introduced to meet competitive or business pressure; a set of core product or system requirements is well understood, but the details of product or system extensions have yet to be defined. In these and similar situations, you need a process model that has been explicitly designed to accommodate a product that grows and changes.

Evolutionary models are iterative. They are characterized in a manner that enables you to develop increasingly more complete versions of the software. In the paragraphs that follow, we present two common evolutionary process models.

"Plan to throw one away. You will do that, anyway. Your only choice is whether to try to sell the throwaway to customers."

Frederick P. Brooks

Prototyping. Often, a customer defines a set of general objectives for software, but does not identify detailed requirements for functions and features. In other cases, the developer may be unsure of the efficiency of an algorithm, the adaptability of an operating system, or the form that human-machine interaction should take. In these, and many other situations, a *prototyping paradigm* may offer the best approach.

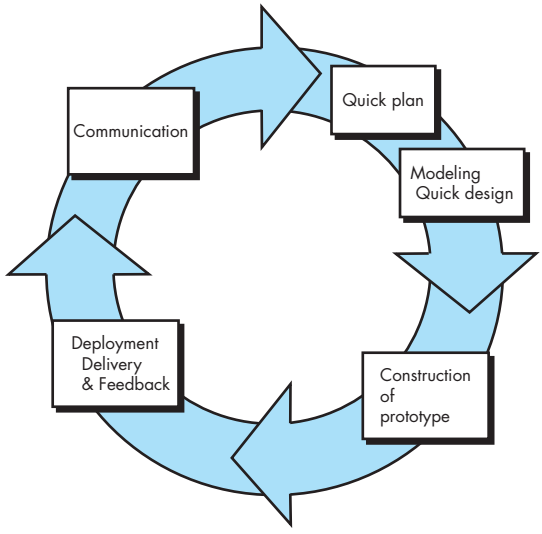
Although prototyping can be used as a stand-alone process model, it is more commonly used as a technique that can be implemented within the context of any one of the process models noted in this chapter. Regardless of the manner in which it is applied, the prototyping paradigm assists you and other stakeholders to better understand what is to be built when requirements are fuzzy.

When your customer has a legitimate need, but is clueless about the details, develop a prototype as a first step.

The prototyping paradigm (Figure 4.4) begins with communication. You meet with other stakeholders to define the overall objectives for the software, identify whatever requirements are known, and outline areas where further definition is mandatory. A prototyping iteration is planned quickly, and modeling (in the form of a "quick design") occurs. A quick design focuses on a representation of those aspects of the software that will be visible to end users (e.g., human interface layout or output display formats). The quick design leads to the construction of a prototype. The prototype is deployed and evaluated by stakeholders, who provide feedback that is used to further refine requirements. Iteration occurs as the prototype is tuned to satisfy the needs of various stakeholders, while at the same time enabling you to better understand what needs to be done.

Ideally, the prototype serves as a mechanism for identifying software requirements. If a working prototype is to be built, you can make use of existing program fragments or apply tools that enable working programs to be generated quickly.

FIGURE 4.4
The prototyping paradigm



But what do you do with the prototype when it has served the purpose described earlier? Brooks [Bro95] provides one answer:

> In most projects, the first system built is barely usable. It may be too slow, too big, awkward in use or all three. There is no alternative but to start again, smarting but smarter, and build a redesigned version in which these problems are solved.

The prototype can serve as "the first system." The one that Brooks recommends you throw away. But this may be an idealized view. Although some prototypes are built as "throwaways," others are evolutionary in the sense that the prototype slowly evolves into the actual system.

Both stakeholders and software engineers like the prototyping paradigm. Users get a feel for the actual system, and developers get to build something immediately. Yet, prototyping can be problematic for the following reasons:

Resist pressure to extend a rough prototype into a production product. Quality almost always suffers as a result.

1. Stakeholders see what appears to be a working version of the software, unaware that the prototype is held together haphazardly, unaware that in the rush to get it working you haven't considered overall software quality or long-term maintainability. When informed that the product must be rebuilt so that high levels of quality can be maintained, stakeholders cry foul and demand that "a few fixes" be applied to make the prototype a working product. Too often, software development management relents.
2. As a software engineer, you often make implementation compromises in order to get a prototype working quickly. An inappropriate operating system or programming language may be used simply because it is

SafeHome

Selecting a Process Model, Part 1

The scene: Meeting room for the software engineering group at CPI Corporation, a (fictional) company that makes consumer products for home and commercial use.

The players: Lee Warren, engineering manager; Doug Miller, software engineering manager; Jamie Lazar, software team member; Vinod Raman, software team member; and Ed Robbins, software team member.

The conversation:

Lee: So let's recapitulate. I've spent some time discussing the *SafeHome* product line as we see it at the moment. No doubt, we've got a lot of work to do to simply define the thing, but I'd like you guys to begin thinking about how you're going to approach the software part of this project.

Doug: Seems like we've been pretty disorganized in our approach to software in the past.

Ed: I don't know, Doug, we always got product out the door.

Doug: True, but not without a lot of grief, and this project looks like it's bigger and more complex than anything we've done in the past.

Jamie: Doesn't look that hard, but I agree . . . our ad hoc approach to past projects won't work here, particularly if we have a very tight time line.

Doug (smiling): I want to be a bit more professional in our approach. I went to a short course last week and learned a lot about software engineering . . . good stuff. We need a process here.

Jamie (with a frown): My job is to build computer programs, not push paper around.

Doug: Give it a chance before you go negative on me. Here's what I mean. (Doug proceeds to describe the process framework described in Chapter 3 and the prescriptive process models presented to this point.)

Doug: So anyway, it seems to me that a linear model is not for us . . . assumes we have all requirements up front and, knowing this place, that's not likely.

Vinod: Yeah, and it sounds way too IT-oriented . . . probably good for building an inventory control system or something, but it's just not right for *SafeHome*.

Doug: I agree.

Ed: That prototyping approach seems okay. A lot like what we do here anyway.

Vinod: That's a problem. I'm worried that it doesn't provide us with enough structure.

Doug: Not to worry. We've got plenty of other options, and I want you guys to pick what's best for the team and best for the project.

available and known; an inefficient algorithm may be implemented simply to demonstrate capability. After a time, you may become comfortable with these choices and forget all the reasons why they were inappropriate. The less-than-ideal choice has now become an integral part of the system.

Although problems can occur, prototyping can be an effective paradigm for software engineering. The key is to define the rules of the game at the beginning; that is, all stakeholders should agree that the prototype is built to serve as a mechanism for defining requirements. It is then discarded (at least in part), and the actual software is engineered with an eye toward quality.

The Spiral Model. Originally proposed by Barry Boehm [Boe88], the *spiral model* is an evolutionary software process model that couples the iterative nature of prototyping with the controlled and systematic aspects of the waterfall model. It provides the potential for rapid development of increasingly more

complete versions of the software. Boehm [Boe01a] describes the model in the following manner:

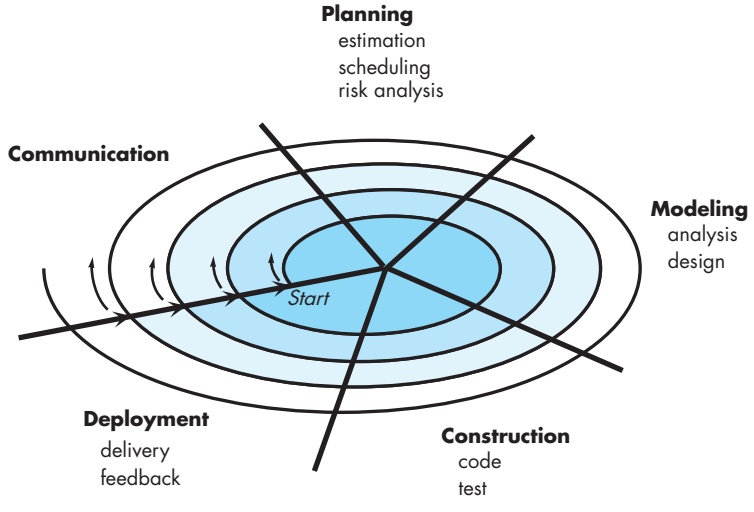
> The spiral development model is a *risk*-driven *process model* generator that is used to guide multi-stakeholder concurrent engineering of software intensive systems. It has two main distinguishing features. One is a *cyclic* approach for incrementally growing a system's degree of definition and implementation while decreasing its degree of risk. The other is a set of *anchor point milestones* for ensuring stakeholder commitment to feasible and mutually satisfactory system solutions.

KEY POINT
The spiral model can be adapted to apply throughout the entire life cycle of an application, from concept development to maintenance.

Using the spiral model, software is developed in a series of evolutionary releases. During early iterations, the release might be a model or prototype. During later iterations, increasingly more complete versions of the engineered system are produced.

A spiral model is divided into a set of framework activities defined by the software engineering team. For illustrative purposes, we use the generic framework activities discussed earlier.[4] Each of the framework activities represent one segment of the spiral path illustrated in Figure 4.5. As this evolutionary process begins, the software team performs activities that are implied by a circuit around the spiral in a clockwise direction, beginning at the center. Risk (Chapter 35) is considered as each revolution is made. *Anchor point milestones*—a combination of work products and conditions that are attained along the path of the spiral—are noted for each evolutionary pass.

FIGURE 4.5
A typical spiral model



4 The spiral model discussed in this section is a variation on the model proposed by Boehm. For further information on the original spiral model, see [Boe88]. More recent discussion of Boehm's spiral model can be found in [Boe98].

WebRef

Useful information about the spiral model can be obtained at: **www.sei.cmu.edu/publications/documents/00.reports/00sr008.html**.

The first circuit around the spiral might result in the development of a product specification; subsequent passes around the spiral might be used to develop a prototype and then progressively more sophisticated versions of the software. Each pass through the planning region results in adjustments to the project plan. Cost and schedule are adjusted based on feedback derived from the customer after delivery. In addition, the project manager adjusts the planned number of iterations required to complete the software.

Unlike other process models that end when software is delivered, the spiral model can be adapted to apply throughout the life of the computer software. Therefore, the first circuit around the spiral might represent a "concept development project" that starts at the core of the spiral and continues for multiple iterations[5] until concept development is complete. If the concept is to be developed into an actual product, the process proceeds outward on the spiral and a "new product development project" commences. The new product will evolve through a number of iterations around the spiral. Later, a circuit around the spiral might be used to represent a "product enhancement project." In essence, the spiral, when characterized in this way, remains operative until the software is retired. There are times when the process is dormant, but whenever a change is initiated, the process starts at the appropriate entry point (e.g., product enhancement).

If your management demands fixed-budget development (generally a bad idea), the spiral can be a problem. As each circuit is completed, project cost is revisited and revised.

The spiral model is a realistic approach to the development of large-scale systems and software. Because software evolves as the process progresses, the developer and customer better understand and react to risks at each evolutionary level. The spiral model uses prototyping as a risk reduction mechanism but, more important, enables you to apply the prototyping approach at any stage in the evolution of the product. It maintains the systematic stepwise approach suggested by the classic life cycle but incorporates it into an iterative framework that more realistically reflects the real world. The spiral model demands a direct consideration of technical risks at all stages of the project and, if properly applied, should reduce risks before they become problematic.

"I'm only this far and only tomorrow leads my way."

Dave Matthews Band

But like other paradigms, the spiral model is not a panacea. It may be difficult to convince customers (particularly in contract situations) that the evolutionary approach is controllable. It demands considerable risk assessment expertise and relies on this expertise for success. If a major risk is not uncovered and managed, problems will undoubtedly occur.

4.1.4 Concurrent Models

The *concurrent development model,* sometimes called *concurrent engineering,* allows a software team to represent iterative and concurrent elements of any of the process models described in this chapter. For example, the modeling activity

5 The arrows pointing inward along the axis separating the *deployment* region from the *communication* region indicate a potential for local iteration along the same spiral path.

SafeHome

Selecting a Process Model, Part 2

The scene: Meeting room for the software engineering group at CPI Corporation, a company that makes consumer products for home and commercial use.

The players: Lee Warren, engineering manager; Doug Miller, software engineering manager; Vinod and Jamie, members of the software engineering team.

The conversation: (Doug describes evolutionary process options.)

Jamie: Now I see something I like. An incremental approach makes sense, and I really like the flow of that spiral model thing. That's keepin' it real.

Vinod: I agree. We deliver an increment, learn from customer feedback, re-plan, and then deliver another increment. It also fits into the nature of the product. We can have something on the market fast and then add functionality with each version, er, increment.

Lee: Wait a minute. Did you say that we regenerate the plan with each tour around the spiral, Doug? That's not so great; we need one plan, one schedule, and we've got to stick to it.

Doug: That's old-school thinking, Lee. Like the guys said, we've got to keep it real. I submit that it's better to tweak the plan as we learn more and as changes are requested. It's way more realistic. What's the point of a plan if it doesn't reflect reality?

Lee (frowning): I suppose so, but . . . senior management's not going to like this . . . they want a fixed plan.

Doug (smiling): Then you'll have to reeducate them, buddy.

Project plans must be viewed as living documents; progress must be assessed often and revised to take changes into account.

The concurrent model is often more appropriate for product engineering projects where different engineering teams are involved.

"Every process in your organization has a customer, and without a customer a process has no purpose."

V. Daniel Hunt

defined for the spiral model is accomplished by invoking one or more of the following software engineering actions: prototyping, analysis, and design.[6]

Figure 4.6 provides an example of the concurrent modeling approach. An activity—**modeling**—may be in any one of the states[7] noted at any given time. Similarly, other activities, actions, or tasks (e.g., **communication** or **construction**) can be represented in an analogous manner. All software engineering activities exist concurrently but reside in different states.

For example, early in a project the communication activity (not shown in the figure) has completed its first iteration and exists in the **awaiting changes** state. The modeling activity (which existed in the **none** state while initial communication was completed) now makes a transition into the **under development** state. If, however, the customer indicates that changes in requirements must be made, the modeling activity moves from the **under development** state into the **awaiting changes** state.

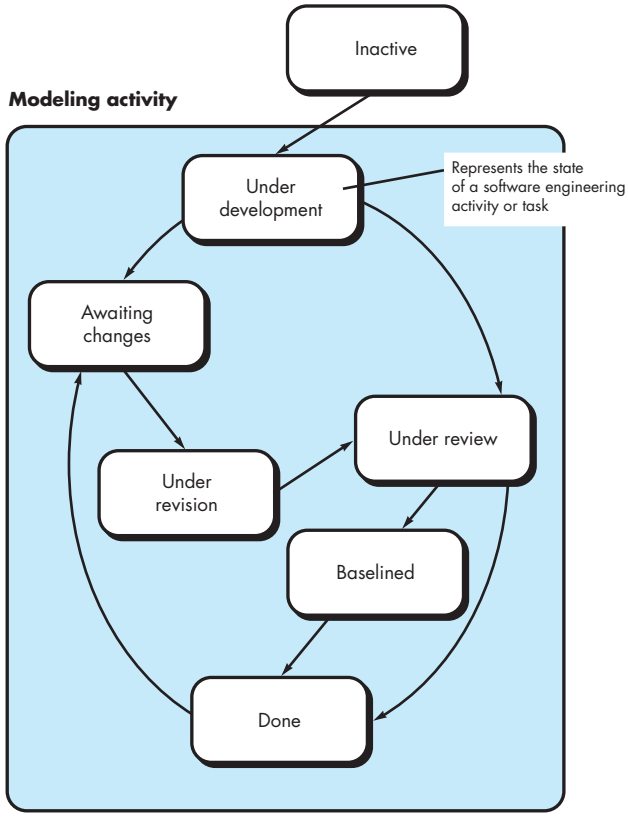
Concurrent modeling defines a series of events that will trigger transitions from state to state for each of the software engineering activities, actions, or tasks. For example, during early stages of design (a major software engineering action that occurs during the modeling activity), an inconsistency in the requirements

6 It should be noted that analysis and design are complex tasks that require substantial discussion. Part 2 of this book considers these topics in detail.

7 A *state* is some externally observable mode of behavior.

FIGURE 4.6

One element of the concurrent process model



model is uncovered. This generates the event *analysis model correction*, which will trigger the requirements analysis action from the **done** state into the **awaiting changes** state.

Concurrent modeling is applicable to all types of software development and provides an accurate picture of the current state of a project. Rather than confining software engineering activities, actions, and tasks to a sequence of events, it defines a process network. Each activity, action, or task on the network exists simultaneously with other activities, actions, or tasks. Events generated at one point in the process network trigger transitions among the states associated with each activity.

4.1.5 A Final Word on Evolutionary Processes

We have already noted that modern computer software is characterized by continual change, by very tight time lines, and by an emphatic need for customer–user satisfaction. In many cases, time-to-market is the most important management

requirement. If a market window is missed, the software project itself may be meaningless.[8]

Evolutionary process models were conceived to address these issues, and yet, as a general class of process models, they too have weaknesses. These are summarized by Nogueira and his colleagues [Nog00]:

> Despite the unquestionable benefits of evolutionary software processes, we have some concerns. The first concern is that prototyping [and other more sophisticated evolutionary processes] poses a problem to project planning because of the uncertain number of cycles required to construct the product . . .
>
> Second, evolutionary software processes do not establish the maximum speed of the evolution. If the evolutions occur too fast, without a period of relaxation, it is certain that the process will fall into chaos. On the other hand if the speed is too slow then productivity could be affected . . .
>
> Third, [evolutionary] software processes should be focused on flexibility and extensibility rather than on high quality. This assertion sounds scary.

? What are the potential weaknesses of evolutionary process models?

Indeed, a software process that focuses on flexibility, extensibility, and speed of development over high quality does sound scary. And yet, this idea has been proposed by a number of well-respected software engineering experts (e.g., [You95], [Bac97]).

The intent of evolutionary models is to develop high-quality software[9] in an iterative or incremental manner. However, it is possible to use an evolutionary process to emphasize flexibility, extensibility, and speed of development. The challenge for software teams and their managers is to establish a proper balance between these critical project and product parameters and customer satisfaction (the ultimate arbiter of software quality).

4.2 Specialized Process Models

Specialized process models take on many of the characteristics of one or more of the traditional models presented in the preceding sections. However, these models tend to be applied when a specialized or narrowly defined software engineering approach is chosen.[10]

---

8 It is important to note, however, that being the first to reach a market is no guarantee of success. In fact, many very successful software products have been second or even third to reach the market (learning from the mistakes of their predecessors).

9 In this context software quality is defined quite broadly to encompass not only customer satisfaction, but also a variety of technical criteria discussed in Part 2 of this book.

10 In some cases, these specialized process models might better be characterized as a collection of techniques or a "methodology" for accomplishing a specific software development goal. However, they do imply a process.

4.2.1 Component-Based Development

WebRef
Useful information on component-based development can be obtained at: **www.cbd-hq.com**.

Commercial off-the-shelf (COTS) software components, developed by vendors who offer them as products, provide targeted functionality with well-defined interfaces that enable the component to be integrated into the software that is to be built. The *component-based development model* incorporates many of the characteristics of the spiral model. It is evolutionary in nature [Nie92], demanding an iterative approach to the creation of software. However, the component-based development model comprises applications from prepackaged software components.

Modeling and construction activities begin with the identification of candidate components. These components can be designed as either conventional software modules or object-oriented classes or packages[11] of classes. Regardless of the technology that is used to create the components, the component-based development model incorporates the following steps (implemented using an evolutionary approach):

1. Available component-based products are researched and evaluated for the application domain in question.
2. Component integration issues are considered.
3. A software architecture is designed to accommodate the components.
4. Components are integrated into the architecture.
5. Comprehensive testing is conducted to ensure proper functionality.

The component-based development model leads to software reuse, and reusability provides software engineers with a number of measurable benefits including a reduction in development cycle time and a reduction in project cost if component reuse becomes part of your organization's culture. Component-based development is discussed in more detail in Chapter 14.

4.2.2 The Formal Methods Model

The *formal methods model* encompasses a set of activities that leads to formal mathematical specification of computer software. Formal methods enable you to specify, develop, and verify a computer-based system by applying a rigorous, mathematical notation. A variation on this approach, called *cleanroom software engineering* [Mil87, Dye92], is currently applied by some software development organizations.

11 Object-oriented concepts are discussed in Appendix 2 and are used throughout Part 2 of this book. In this context, a class encompasses a set of data and the procedures that process the data. A package of classes is a collection of related classes that work together to achieve some end result.

When formal methods (Appendix 3) are used during development, they provide a mechanism for eliminating many of the problems that are difficult to overcome using other software engineering paradigms. Ambiguity, incompleteness, and inconsistency can be discovered and corrected more easily—not through ad hoc review, but through the application of mathematical analysis. When formal methods are used during design, they serve as a basis for program verification and therefore enable you to discover and correct errors that might otherwise go undetected.

Although not a mainstream approach, the formal methods model offers the promise of defect-free software. Yet, concern about its applicability in a business environment has been voiced:

? If formal methods can demonstrate software correctness, why is it they are not widely used?

- The development of formal models is currently quite time consuming and expensive.
- Because few software developers have the necessary background to apply formal methods, extensive training is required.
- It is difficult to use the models as a communication mechanism for technically unsophisticated customers.

These concerns notwithstanding, the formal methods approach has gained adherents among software developers who must build safety-critical software (e.g., developers of aircraft avionics and medical devices) and among developers that would suffer severe economic hardship should software errors occur.

4.2.3 Aspect-Oriented Software Development

WebRef
A wide array of resources and information on AOP can be found at: **aosd.net**.

Regardless of the software process that is chosen, the builders of complex software invariably implement a set of localized features, functions, and information content. These localized software characteristics are modeled as components (e.g., object-oriented classes) and then constructed within the context of a system architecture. As modern computer-based systems become more sophisticated (and complex), certain *concerns*—customer required properties or areas of technical interest—span the entire architecture. Some concerns are high-level properties of a system (e.g., security, fault tolerance). Other concerns affect functions (e.g., the application of business rules), while others are systemic (e.g., task synchronization or memory management).

KEY POINT
AOSD defines "aspects" that express customer concerns that cut across multiple system functions, features, and information.

When concerns cut across multiple system functions, features, and information, they are often referred to as *crosscutting concerns*. *Aspectual requirements* define those crosscutting concerns that have an impact across the software architecture. *Aspect-oriented software development* (AOSD), often referred to as *aspect-oriented programming* (AOP) or *aspect-oriented component engineering* (AOCE) [Gru02], is a relatively new software engineering paradigm that provides a process and methodological approach for defining, specifying, designing, and

constructing *aspects*—"mechanisms beyond subroutines and inheritance for localizing the expression of a crosscutting concern" [Elr01].

A distinct aspect-oriented process has not yet matured. However, it is likely that such a process will adopt characteristics of both evolutionary and concurrent process models. The evolutionary model is appropriate as aspects are identified and then constructed. The parallel nature of concurrent development is essential because aspects are engineered independently of localized software components and yet, aspects have a direct impact on these components. Hence, it is essential to instantiate asynchronous communication between the software process activities applied to the engineering and construction of aspects and components.

A detailed discussion of aspect-oriented software development is best left to books dedicated to the subject. If you have further interest, see [Ras11], [Saf08], [Cla05], [Fil05], [Jac04], and [Gra03].

SOFTWARE TOOLS

Process Management

Objective: To assist in the definition, execution, and management of prescriptive process models.

Mechanics: Process management tools allow a software organization or team to define a complete software process model (framework activities, actions, tasks, QA checkpoints, milestones, and work products). In addition, the tools provide a road map as software engineers do technical work and a template for managers who must track and control the software process.

Representative tools:[12]

GDPA, a research process definition tool suite, developed at Bremen University in Germany (**www.informatik.uni-bremen.de/uniform/gdpa/home.htm**), provides a wide array of process modeling and management functions.

ALM Studio, developed by Kovair Corporation (**http://www.kovair.com/**) encompasses a suite of tools for process definition, requirements management, issue resolution, project planning, and tracking.

ProVision BPMx, developed by OpenText (**http://bps.opentext.com/**), is representative of many tools that assist in process definition and workflow automation.

A worthwhile listing of many different tools associated with the software process can be found at **www.computer.org/portal/web/swebok/html/ch10**.

4.3 THE UNIFIED PROCESS

In their seminal book on the *Unified Process (UP),* Ivar Jacobson, Grady Booch, and James Rumbaugh [Jac99] discuss the need for a "use case driven, architecture-centric, iterative and incremental" software process when they state:

> Today, the trend in software is toward bigger, more complex systems. That is due in part to the fact that computers become more powerful every year, leading users to expect more from them. This trend has also been influenced by the expanding use of

12 Tools noted here do not represent an endorsement, but rather a sampling of tools in this category. In most cases, tool names are trademarked by their respective developers.

> the Internet for exchanging all kinds of information . . . Our appetite for ever-more sophisticated software grows as we learn from one product release to the next how the product could be improved. We want software that is better adapted to our needs, but that, in turn, merely makes the software more complex. In short, we want more.

In some ways the Unified Process is an attempt to draw on the best features and characteristics of traditional software process models, but characterize them in a way that implements many of the best principles of agile software development (Chapter 5). The Unified Process recognizes the importance of customer communication and streamlined methods for describing the customer's view of a system (the use case).[13] It emphasizes the important role of software architecture and "helps the architect focus on the right goals, such as understandability, reliance to future changes, and reuse" [Jac99]. It suggests a process flow that is iterative and incremental, providing the evolutionary feel that is essential in modern software development.

4.3.1 A Brief History

During the early 1990s James Rumbaugh [Rum91], Grady Booch [Boo94], and Ivar Jacobson [Jac92] began working on a "unified method" that would combine the best features of each of their individual object-oriented analysis and design methods and adopt additional features proposed by other experts (e.g., [Wir90]) in object-oriented modeling. The result was UML—a *unified modeling language* that contains a robust notation for the modeling and development of object-oriented systems. By 1997, UML became a de facto industry standard for object-oriented software development.

UML is used throughout Part 2 of this book to represent both requirements and design models. Appendix 1 presents an introductory tutorial for those who are unfamiliar with basic UML notation and modeling rules. A comprehensive presentation of UML is best left to textbooks dedicated to the subject. Recommended books are listed in Appendix 1.

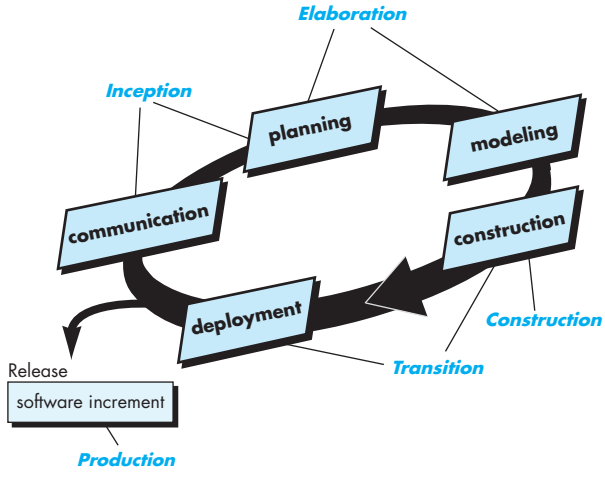
4.3.2 Phases of the Unified Process[14]

In Chapter 3, we discussed five generic framework activities and argued that they may be used to describe any software process model. The Unified Process

13 A *use case* (Chapter 8) is a text narrative or template that describes a system function or feature from the user's point of view. A use case is written by the user and serves as a basis for the creation of a more comprehensive analysis model.

14 The Unified Process is sometimes called the *Rational Unified Process* (RUP) after the Rational Corporation (subsequently acquired by IBM), an early contributor to the development and refinement of the UP and a builder of complete environments (tools and technology) that support the process.

FIGURE 4.7
The Unified Process



is no exception. Figure 4.7 depicts the "phases" of the UP and relates them to the generic activities that have been discussed in Chapter 1 and earlier in this chapter.

KEY POINT
UP *phases* are similar in intent to the generic framework activities defined in this book.

The *inception phase* of the UP encompasses both customer communication and planning activities. By collaborating with stakeholders, business requirements for the software are identified; a rough architecture for the system is proposed; and a plan for the iterative, incremental nature of the ensuing project is developed. Fundamental business requirements are described through a set of preliminary use cases (Chapter 8) that describe which features and functions each major class of users desires. Architecture at this point is nothing more than a tentative outline of major subsystems and the functions and features that populate them. Later, the architecture will be refined and expanded into a set of models that will represent different views of the system. Planning identifies resources, assesses major risks, defines a schedule, and establishes a basis for the phases that are to be applied as the software increment is developed.

The *elaboration phase* encompasses the communication and modeling activities of the generic process model (Figure 4.7). Elaboration refines and expands the preliminary use cases that were developed as part of the inception phase and expands the architectural representation to include five different views of the software—the use case model, the analysis model, the design model, the implementation model, and the deployment model. In some cases, elaboration creates an "executable architectural baseline" [Arl02] that represents a "first cut" executable system.[15] The architectural baseline demonstrates the viability of the

15 It is important to note that the architectural baseline is not a prototype in that it is not thrown away. Rather, the baseline is fleshed out during the next UP phase.

architecture but does not provide all features and functions required to use the system. In addition, the plan is carefully reviewed at the culmination of the elaboration phase to ensure that scope, risks, and delivery dates remain reasonable. Modifications to the plan are often made at this time.

WebRef

An interesting discussion of the UP in the context of agile development can be found at **www.ambysoft.com/unifiedprocess/agileUP.html**.

The *construction phase* of the UP is identical to the construction activity defined for the generic software process. Using the architectural model as input, the construction phase develops or acquires the software components that will make each use case operational for end users. To accomplish this, analysis and design models that were started during the elaboration phase are completed to reflect the final version of the software increment. All necessary and required features and functions for the software increment (i.e., the release) are then implemented in source code. As components are being implemented, unit tests[16] are designed and executed for each. In addition, integration activities (component assembly and integration testing) are conducted. Use cases are used to derive a suite of acceptance tests that are executed prior to the initiation of the next UP phase.

The *transition phase* of the UP encompasses the latter stages of the generic construction activity and the first part of the generic deployment (delivery and feedback) activity. Software is given to end users for beta testing, and user feedback reports both defects and necessary changes. In addition, the software team creates the necessary support information (e.g., user manuals, troubleshooting guides, installation procedures) that is required for the release. At the conclusion of the transition phase, the software increment becomes a usable software release.

The *production phase* of the UP coincides with the deployment activity of the generic process. During this phase, the ongoing use of the software is monitored, support for the operating environment (infrastructure) is provided, and defect reports and requests for changes are submitted and evaluated.

It is likely that at the same time the construction, transition, and production phases are being conducted, work may have already begun on the next software increment. This means that the five UP phases do not occur in a sequence, but rather with staggered concurrency.

A software engineering workflow is distributed across all UP phases. In the context of UP, a *workflow* is analogous to a task set (described in Chapter 3). That is, a workflow identifies the tasks required to accomplish an important software engineering action and the work products that are produced as a consequence of successfully completing the tasks. It should be noted that not every task identified for a UP workflow is conducted for every software project. The team adapts the process (actions, tasks, subtasks, and work products) to meet its needs.

16 A comprehensive discussion of software testing (including *unit tests*) is presented in Chapters 22 through 26).

4.4 Personal and Team Process Models

Quote:

"A person who is successful has simply formed the habit of doing things that unsuccessful people will not do."

Dexter Yager

The best software process is one that is close to the people who will be doing the work. If a software process model has been developed at a corporate or organizational level, it can be effective only if it is amenable to significant adaptation to meet the needs of the project team that is actually doing software engineering work. In an ideal setting, you would create a process that best fits your needs, and at the same time, meets the broader needs of the team and the organization. Alternatively, the team itself can create its own process, and at the same time meet the narrower needs of individuals and the broader needs of the organization. Watts Humphrey ([Hum05] and [Hum00]) argues that it is possible to create a "personal software process" and/or a "team software process." Both require hard work, training, and coordination, but both are achievable.[17]

4.4.1 Personal Software Process

WebRef

A wide array of resources for PSP can be found at **http://www.sei.cmu.edu/tsp/tools/academic/**.

Every developer uses some process to build computer software. The process may be haphazard or ad hoc; may change on a daily basis; may not be efficient, effective, or even successful; but a "process" does exist. Watts Humphrey [Hum05] suggests that in order to change an ineffective personal process, an individual must move through four phases, each requiring training and careful instrumentation. The *Personal Software Process* (PSP) emphasizes personal measurement of both the work product that is produced and the resultant quality of the work product. In addition PSP makes the practitioner responsible for project planning (e.g., estimating and scheduling) and empowers the practitioner to control the quality of all software work products that are developed. The PSP model defines five framework activities:

Planning. This activity isolates requirements and develops both size and resource estimates. In addition, a defect estimate (the number of defects projected for the work) is made. All metrics are recorded on worksheets or templates. Finally, development tasks are identified and a project schedule is created.

What framework activities are used during PSP?

High-level design. External specifications for each component to be constructed are developed and a component design is created. Prototypes are built when uncertainty exists. All issues are recorded and tracked.

17 It's worth noting the proponents of agile software development (Chapter 5) also argue that the process should remain close to the team. They propose an alternative method for achieving this.

High-level design review. Formal verification methods (Appendix 3) are applied to uncover errors in the design. Metrics are maintained for important tasks and work results.

Development. The component-level design is refined and reviewed. Code is generated, reviewed, compiled, and tested. Metrics are maintained for important tasks and work results.

Postmortem. Using the measures and metrics collected (this is a substantial amount of data that should be analyzed statistically), the effectiveness of the process is determined. Measures and metrics should provide guidance for modifying the process to improve its effectiveness.

KEY POINT

PSP emphasizes the need to record and analyze the types of errors you make, so that you can develop strategies to eliminate them.

PSP stresses the need for you to identify errors early and, just as important, to understand the types of errors that you are likely to make. This is accomplished through a rigorous assessment activity performed on all work products you produce.

PSP represents a disciplined, metrics-based approach to software engineering that may lead to culture shock for many practitioners. However, when PSP is properly introduced to software engineers [Hum96], the resulting improvement in software engineering productivity and software quality are significant [Fer97]. However, PSP has not been widely adopted throughout the industry. The reasons, sadly, have more to do with human nature and organizational inertia than they do with the strengths and weaknesses of the PSP approach. PSP is intellectually challenging and demands a level of commitment (by practitioners and their managers) that is not always possible to obtain. Training is relatively lengthy, and training costs are high. The required level of measurement is culturally difficult for many software people.

Can PSP be used as an effective software process at a personal level? The answer is an unequivocal "yes." But even if PSP is not adopted in its entirely, many of the personal process improvement concepts that it introduces are well worth learning.

4.4.2 Team Software Process

WebRef

Information on building high-performance teams using TSP and PSP can be obtained at **www.sei.cmu.edu/tsp/**.

Because many industry-grade software projects are addressed by a team of practitioners, Watts Humphrey extended the lessons learned from the introduction of PSP and proposed a *Team Software Process* (TSP). The goal of TSP is to build a "self-directed" project team that organizes itself to produce high-quality software. Humphrey [Hum98] defines the following objectives for TSP:

- Build self-directed teams that plan and track their work, establish goals, and own their processes and plans. These can be pure software teams or integrated product teams (IPTs) of 3 to about 20 engineers.
- Show managers how to coach and motivate their teams and how to help them sustain peak performance.

- Accelerate software process improvement by making CMM[18] level 5 behavior normal and expected.
- Provide improvement guidance to high-maturity organizations.
- Facilitate university teaching of industrial-grade team skills.

To form a self-directed team, you must collaborate well internally and communicate well externally.

A self-directed team has a consistent understanding of its overall goals and objectives; defines roles and responsibilities for each team member; tracks quantitative project data (about productivity and quality); identifies a team process that is appropriate for the project and a strategy for implementing the process; defines local standards that are applicable to the team's software engineering work; continually assesses risk and reacts to it; and tracks, manages, and reports project status.

TSP defines the following framework activities: *project launch, high-level design, implementation, integration and test,* and *postmortem*. Like their counterparts in PSP (note that terminology is somewhat different), these activities enable the team to plan, design, and construct software in a disciplined manner while at the same time quantitatively measuring the process and the product. The postmortem sets the stage for process improvements.

TSP scripts define elements of the team process and activities that occur within the process.

TSP makes use of a wide variety of scripts, forms, and standards that serve to guide team members in their work. "Scripts" define specific process activities (i.e., project launch, design, implementation, integration and system testing, postmortem) and other more detailed work functions (e.g., development planning, requirements development, software configuration management, unit test) that are part of the team process.

TSP recognizes that the best software teams are self-directed.[19] Team members set project objectives, adapt the process to meet their needs, control the project schedule, and through measurement and analysis of the metrics collected, work continually to improve the team's approach to software engineering.

Like PSP, TSP is a rigorous approach to software engineering that provides distinct and quantifiable benefits in productivity and quality. The team must make a full commitment to the process and must undergo thorough training to ensure that the approach is properly applied.

4.5 Process Technology

One or more of the process models discussed in the preceding sections must be adapted for use by a software team. To accomplish this, *process technology tools* have been developed to help software organizations analyze their current process, organize work tasks, control and monitor progress, and manage technical quality.

18 The Capability Maturity Model (CMM), a measure of the effectiveness of a software process, is discussed in Chapter 37.

19 In Chapter 5 we discuss the importance of "self-organizing" teams as a key element in agile software development.

5.1 What Is Agility?

Just what is agility in the context of software engineering work? Ivar Jacobson [Jac02a] provides a useful discussion:

> *Agility* has become today's buzzword when describing a modern software process. Everyone is agile. An agile team is a nimble team able to appropriately respond to changes. Change is what software development is very much about. Changes in the software being built, changes to the team members, changes because of new technology, changes of all kinds that may have an impact on the product they build or the project that creates the product. Support for changes should be built-in everything we do in software, something we embrace because it is the heart and soul of software. An agile team recognizes that software is developed by individuals working in teams and that the skills of these people, their ability to collaborate is at the core for the success of the project.

In Jacobson's view, the pervasiveness of change is the primary driver for agility. Software engineers must be quick on their feet if they are to accommodate the rapid changes that Jacobson describes.

Don't make the mistake of assuming that agility gives you license to hack out solutions. A process is required and discipline is essential.

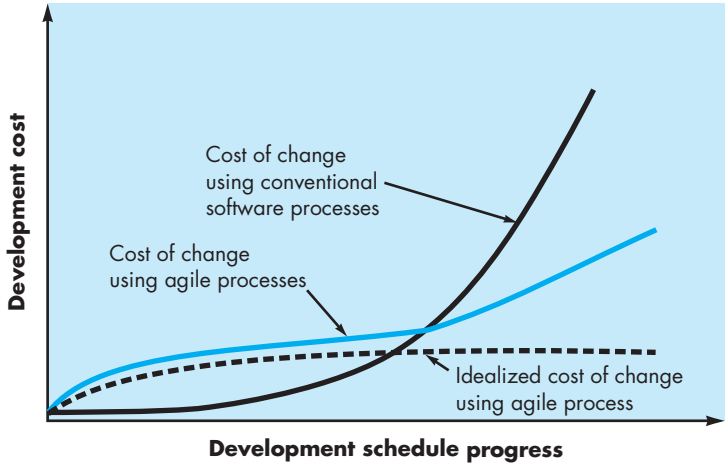
But agility is more than an effective response to change. It also encompasses the philosophy espoused in the manifesto noted at the beginning of this chapter. It encourages team structures and attitudes that make communication (among team members, between technologists and business people, between software engineers and their managers) more facile. It emphasizes rapid delivery of operational software and deemphasizes the importance of intermediate work products (not always a good thing); it adopts the customer as a part of the development team and works to eliminate the "us and them" attitude that continues to pervade many software projects; it recognizes that planning in an uncertain world has its limits and that a project plan must be flexible.

Agility can be applied to any software process. However, to accomplish this, it is essential that the process be designed in a way that allows the project team to adapt tasks and to streamline them, conduct planning in a way that understands the fluidity of an agile development approach, eliminate all but the most essential work products and keep them lean, and emphasize an incremental delivery strategy that gets working software to the customer as rapidly as feasible for the product type and operational environment.

5.2 Agility and the Cost of Change

The conventional wisdom in software development (supported by decades of experience) is that the cost of change increases nonlinearly as a project progresses (Figure 5.1, solid black curve). It is relatively easy to accommodate a change when a software team is gathering requirements (early in a project). A usage scenario might have to be modified, a list of functions may be extended, or a written

FIGURE 5.1
Change costs as a function of time in development



Quote:

"Agility is dynamic, content specific, aggressively change embracing, and growth oriented."

Steven Goldman et al.

specification can be edited. The costs of doing this work are minimal, and the time required will not adversely affect the outcome of the project. But what if we fast-forward a number of months? The team is in the middle of validation testing (something that occurs relatively late in the project), and an important stakeholder is requesting a major functional change. The change requires a modification to the architectural design of the software, the design and construction of three new components, modifications to another five components, the design of new tests, and so on. Costs escalate quickly, and the time and cost required to ensure that the change is made without unintended side effects is nontrivial.

Proponents of agility (e.g., [Bec00], [Amb04]) argue that a well-designed agile process "flattens" the cost of change curve (Figure 5.1, shaded, solid curve), allowing a software team to accommodate changes late in a software project without dramatic cost and time impact. You've already learned that the agile process encompasses incremental delivery. When incremental delivery is coupled with other agile practices such as continuous unit testing and pair programming (discussed later in this chapter), the cost of making a change is attenuated. Although debate about the degree to which the cost curve flattens is ongoing, there is evidence [Coc01a] to suggest that a significant reduction in the cost of change can be achieved.

KEY POINT

An agile process reduces the cost of change because software is released in increments and change can be better controlled within an increment.

5.3 What Is an Agile Process?

Any agile software process is characterized in a manner that addresses a number of key assumptions [Fow02] about the majority of software projects:

1. It is difficult to predict in advance which software requirements will persist and which will change. It is equally difficult to predict how customer priorities will change as the project proceeds.

WebRef

A comprehensive collection of articles on the agile process can be found at **http://www.agilemodeling.com/.**

2. For many types of software, design and construction are interleaved. That is, both activities should be performed in tandem so that design models are proven as they are created. It is difficult to predict how much design is necessary before construction is used to prove the design.
3. Analysis, design, construction, and testing are not as predictable (from a planning point of view) as we might like.

Given these three assumptions, an important question arises: How do we create a process that can manage *unpredictability*? The answer, as we have already noted, lies in process adaptability (to rapidly changing project and technical conditions). An agile process, therefore, must be *adaptable*.

But continual adaptation without forward progress accomplishes little. Therefore, an agile software process must adapt *incrementally*. To accomplish incremental adaptation, an agile team requires customer feedback (so that the appropriate adaptations can be made). An effective catalyst for customer feedback is an operational prototype or a portion of an operational system. Hence, an *incremental development strategy* should be instituted. *Software increments* (executable prototypes or portions of an operational system) must be delivered in short time periods so that adaptation keeps pace with change (unpredictability). This iterative approach enables the customer to evaluate the software increment regularly, provide necessary feedback to the software team, and influence the process adaptations that are made to accommodate the feedback.

5.3.1 Agility Principles

Although agile processes embrace change, it is still important to examine the reasons for change.

The Agile Alliance (see [Agi03], [Fow01]) defines 12 agility principles for those who want to achieve agility:

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.

Working software is important, but don't forget that it must also exhibit a variety of quality attributes including reliability, usability, and maintainability.

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.

Not every agile process model applies these 12 principles with equal weight, and some models choose to ignore (or at least downplay) the importance of one or more of the principles. However, the principles define an *agile spirit* that is maintained in each of the process models presented in this chapter.

5.3.2 The Politics of Agile Development

You don't have to choose between agility and software engineering. Rather, define a software engineering approach that is agile.

There has been considerable debate (sometimes strident) about the benefits and applicability of agile software development as opposed to more conventional software engineering processes. Jim Highsmith [Hig02a] (facetiously) states the extremes when he characterizes the feeling of the pro-agility camp ("agilists"). "Traditional methodologists are a bunch of stick-in-the-muds who'd rather produce flawless documentation than a working system that meets business needs." As a counterpoint, he states (again, facetiously) the position of the traditional software engineering camp: "Lightweight, er, 'agile' methodologists are a bunch of glorified hackers who are going to be in for a heck of a surprise when they try to scale up their toys into enterprise-wide software."

Like all software technology arguments, this methodology debate risks degenerating into a religious war. If warfare breaks out, rational thought disappears and beliefs rather than facts guide decision making.

No one is against agility. The real question is: What is the best way to achieve it? As important, how do you build software that meets customers' needs today and exhibits the quality characteristics that will enable it to be extended and scaled to meet customers' needs over the long term?

There are no absolute answers to either of these questions. Even within the agile school itself, there are many proposed process models (Section 5.4), each with a subtly different approach to the agility problem. Within each model there is a set of "ideas" (agilists are loath to call them "work tasks") that represent a significant departure from traditional software engineering. And yet, many agile concepts are simply adaptations of good software engineering concepts. Bottom line: there is much that can be gained by considering the best of both schools and virtually nothing to be gained by denigrating either approach.

If you have further interest, see [Hig01], [Hig02a], and [DeM02] for an entertaining summary of other important technical and political issues.

5.4 Extreme Programming

WebRef

An award-winnng "process simulation game" that includes an XP process module can be found at **http://www.ics.uci.edu/~emilyo/SimSE/downloads.html.**

In order to illustrate an agile process in a bit more detail, we'll provide you with an overview of *Extreme Programming* (XP), the most widely used approach to agile software development. Although early work on the ideas and methods associated with XP occurred during the late 1980s, the seminal work on the subject has been written by Kent Beck [Bec04a]. A variant of XP, called *Industrial XP* (IXP), refines XP and targets the agile process specifically for use within large organizations [Ker05].

5.4.1 The XP Process

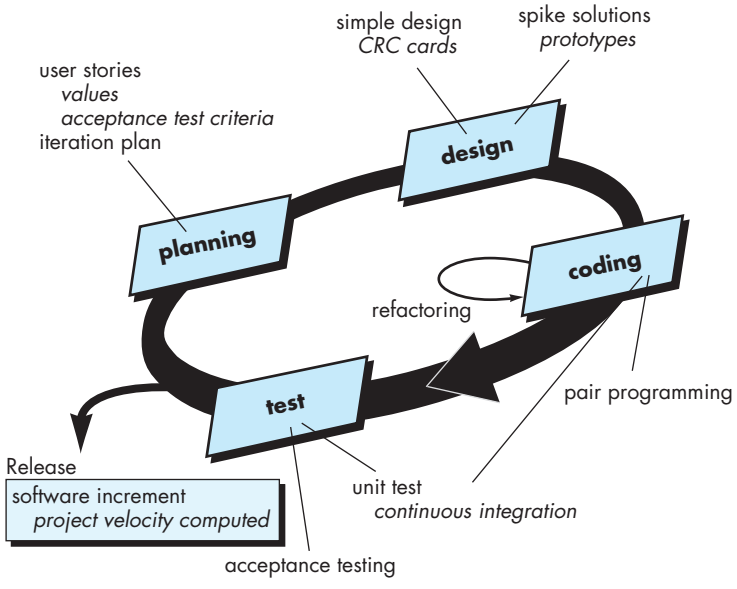
What is an XP "story"?

Extreme Programming uses an object-oriented approach (Appendix 2) as its preferred development paradigm and encompasses a set of rules and practices that occur within the context of four framework activities: planning, design, coding, and testing. Figure 5.2 illustrates the XP process and notes some of the key ideas and tasks that are associated with each framework activity. Key XP activities are summarized in the paragraphs that follow.

Planning. The planning activity (also called *the planning game*) begins with *listening*—a requirements gathering activity that enables the technical members

Figure 5.2

The Extreme Programming process



WebRef

A worthwhile XP "planning game" can be found at: **http://csis.pace.edu/~bergin/xp/planninggame.html.**

of the XP team to understand the business context for the software and to get a broad feel for required output and major features and functionality. Listening leads to the creation of a set of "stories" (also called *user stories*) that describe required output, features, and functionality for software to be built. Each *story* (similar to use cases described in Chapter 8) is written by the customer and is placed on an index card. The customer assigns a *value* (i.e., a priority) to the story based on the overall business value of the feature or function.[2] Members of the XP team then assess each story and assign a *cost*—measured in development weeks—to it. If the story is estimated to require more than three development weeks, the customer is asked to split the story into smaller stories and the assignment of value and cost occurs again. It is important to note that new stories can be written at any time.

Customers and developers work together to decide how to group stories into the next release (the next software increment) to be developed by the XP team. Once a basic *commitment* (agreement on stories to be included, delivery date, and other project matters) is made for a release, the XP team orders the stories that will be developed in one of three ways: (1) all stories will be implemented immediately (within a few weeks), (2) the stories with highest value will be moved up in the schedule and implemented first, or (3) the riskiest stories will be moved up in the schedule and implemented first.

Project velocity is a subtle measure of team productivity.

After the first project release (also called a software increment) has been delivered, the XP team computes project velocity. Stated simply, *project velocity* is the number of customer stories implemented during the first release. Project velocity can then be used to (1) help estimate delivery dates and schedule for subsequent releases and (2) determine whether an overcommitment has been made for all stories across the entire development project. If an overcommitment occurs, the content of releases is modified or end delivery dates are changed.

XP deemphasizes the importance of design. Not everyone agrees. In fact, there are times when design should be emphasized.

As development work proceeds, the customer can add stories, change the value of an existing story, split stories, or eliminate them. The XP team then reconsiders all remaining releases and modifies its plans accordingly.

Design. XP design rigorously follows the KIS (keep it simple) principle. A simple design is always preferred over a more complex representation. In addition, the design provides implementation guidance for a story as it is written—nothing less, nothing more. The design of extra functionality (because the developer assumes it will be required later) is discouraged.[3]

XP encourages the use of CRC cards (Chapter 10) as an effective mechanism for thinking about the software in an object-oriented context. CRC

2 The value of a story may also be dependent on the presence of another story.

3 These design guidelines should be followed in every software engineering method, although there are times when sophisticated design notation and terminology may get in the way of simplicity.

WebRef
Refactoring techniques and tools can be found at: **www.refactoring.com.**

(class-responsibility-collaborator) cards identify and organize the object-oriented classes[4] that are relevant to the current software increment. The XP team conducts the design exercise using a process similar to the one described in Chapter 10. The CRC cards are the only design work product produced as part of the XP process.

If a difficult design problem is encountered as part of the design of a story, XP recommends the immediate creation of an operational prototype of that portion of the design. Called a *spike solution*, the design prototype is implemented and evaluated. The intent is to lower risk when true implementation starts and to validate the original estimates for the story containing the design problem.

KEY POINT
Refactoring improves the internal structure of a design (or source code) without changing its external functionality or behavior.

XP encourages *refactoring*—a construction technique that is also a design technique. Fowler [Fow00] describes refactoring in the following manner:

> Refactoring is the process of changing a software system in such a way that it does not alter the external behavior of the code yet improves the internal structure. It is a disciplined way to clean up code [and modify/simplify the internal design] that minimizes the chances of introducing bugs. In essence, when you refactor you are improving the design of the code after it has been written.

Because XP design uses virtually no notation and produces few, if any, work products other than CRC cards and spike solutions, design is viewed as a transient artifact that can and should be continually modified as construction proceeds. The intent of refactoring is to control these modifications by suggesting small design changes that "can radically improve the design" [Fow00]. It should be noted, however, that the effort required for refactoring can grow dramatically as the size of an application grows.

A central notion in XP is that design occurs both before *and after* coding commences. Refactoring means that design occurs continuously as the system is constructed. In fact, the construction activity itself will provide the XP team with guidance on how to improve the design.

WebRef
Useful information on XP can be obtained at **www.xprogramming.com.**

Coding. After stories are developed and preliminary design work is done, the team does *not* move to code, but rather develops a series of unit tests that will exercise each of the stories that is to be included in the current release (software increment).[5] Once the unit test[6] has been created, the developer is better able to focus on what must be implemented to pass the test. Nothing extraneous is added

4 Object-oriented classes are discussed in Appendix 2, in Chapter10, and throughout Part 2 of this book.

5 This approach is analogous to knowing the exam questions before you begin to study. It makes studying much easier by focusing attention only on the questions that will be asked.

6 Unit testing, discussed in detail in Chapter 22, focuses on an individual software component, exercising the component's interface, data structures, and functionality in an effort to uncover errors that are local to the component.

(KIS). Once the code is complete, it can be unit-tested immediately, thereby providing instantaneous feedback to the developers.

What is pair programming?

A key concept during the coding activity (and one of the most talked-about aspects of XP) is *pair programming*. XP recommends that two people work together at one computer workstation to create code for a story. This provides a mechanism for real-time problem solving (two heads are often better than one) and real-time quality assurance (the code is reviewed as it is created). It also keeps the developers focused on the problem at hand. In practice, each person takes on a slightly different role. For example, one person might think about the coding details of a particular portion of the design while the other ensures that coding standards (a required part of XP) are being followed or that the code for the story will satisfy the unit test that has been developed to validate the code against the story.[7]

Many software teams are populated by individualists. You'll have to work to change that culture if pair programming is to work effectively.

As pair programmers complete their work, the code they develop is integrated with the work of others. In some cases this is performed on a daily basis by an integration team. In other cases, the pair programmers have integration responsibility. This "continuous integration" strategy helps to avoid compatibility and interfacing problems and provides a "smoke testing" environment (Chapter 22) that helps to uncover errors early.

How are unit tests used in XP?

Testing. The unit tests that are created should be implemented using a framework that enables them to be automated (hence, they can be executed easily and repeatedly). This encourages a regression testing strategy (Chapter 22) whenever code is modified (which is often, given the XP refactoring philosophy).

As the individual unit tests are organized into a "universal testing suite" [Wel99], integration and validation testing of the system can occur on a daily basis. This provides the XP team with a continual indication of progress and also can raise warning flags early if things go awry. Wells [Wel99] states: "Fixing small problems every few hours takes less time than fixing huge problems just before the deadline."

XP acceptance tests are derived from user stories.

XP *acceptance tests*, also called *customer tests,* are specified by the customer and focus on overall system features and functionality that are visible and reviewable by the customer. Acceptance tests are derived from user stories that have been implemented as part of a software release.

5.4.2 Industrial XP

What new practices are appended to XP to create IXP?

Joshua Kerievsky [Ker05] describes *Industrial Extreme Programming* (IXP) in the following manner: "IXP is an organic evolution of XP. It is imbued with XP's minimalist, customer-centric, test-driven spirit. IXP differs most from the original XP in its greater inclusion of management, its expanded role for customers, and its upgraded technical practices." IXP incorporates six new practices that

7 Pair programming has become so widespread throughout the software community that *The Wall Street Journal* [Wal12] ran a front-page story about the subject.

are designed to help ensure that an XP project works successfully for significant projects within a large organization:

Readiness assessment. The IXP team ascertains whether all members of the project community (e.g., stakeholders, developers, management) are on board, have the proper environment established, and understand the skill levels involved.

Project community. The IXP team determines whether the right people, with the right skills and training have been staged for the project. The "community" encompasses technologists and other stakeholders.

Project chartering. The IXP team assesses the project itself to determine whether an appropriate business justification for the project exists and whether the project will further the overall goals and objectives of the organization.

Test-driven management. An IXP team establishes a series of measurable "destinations" [Ker05] that assess progress to date and then defines mechanisms for determining whether or not these destinations have been reached.

Retrospectives. An IXP team conducts a specialized technical review (Chapter 20) after a software increment is delivered. Called a *retrospective,* the review examines "issues, events, and lessons-learned" [Ker05] across a software increment and/or the entire software release.

Continuous learning. The IXP team is encouraged (and possibly, incented) to learn new methods and techniques that can lead to a higher-quality product.

Quote:

"Ability is what you're capable of doing. Motivation determines what you do. Attitude determines how well you do it."

Lou Holtz

In addition to the six new practices discussed, IXP modifies a number of existing XP practices and redefines certain roles and responsibilities to make them more amenable to significant projects for large organizations. For further discussion of IXP, visit **http://industrialxp.org.**

SafeHome

Considering Agile Software Development

The scene: Doug Miller's office.

The Players: Doug Miller, software engineering manager; Jamie Lazar, software team member; Vinod Raman, software team member.

The conversation:

(A knock on the door, Jamie and Vinod enter Doug's office.)

Jamie: Doug, you got a minute?

Doug: Sure Jamie, what's up?

Jamie: We've been thinking about our process discussion yesterday . . . you know, what process we're going to choose for this new *SafeHome* project.

Doug: And?

Vinod: I was talking to a friend at another company, and he was telling me about Extreme Programming. It's an agile process model . . . heard of it?

Doug: Yeah, some good, some bad.

Jamie: Well, it sounds pretty good to us. Lets you develop software really fast, uses something called pair programming to do real-time quality checks . . . it's pretty cool, I think.

Doug: It does have a lot of really good ideas. I like the pair-programming concept, for instance, and the idea that stakeholders should be part of the team.

Jamie: Huh? You mean that marketing will work on the project team with us?

Doug (nodding): They're a stakeholder, aren't they?

Jamie: Jeez . . . they'll be requesting changes every five minutes.

Vinod: Not necessarily. My friend said that there are ways to "embrace" changes during an XP project.

Doug: So you guys think we should use XP?

Jamie: It's definitely worth considering.

Doug: I agree. And even if we choose an incremental model as our approach, there's no reason why we can't incorporate much of what XP has to offer.

Vinod: Doug, before you said "some good, some bad." What was the bad?

Doug: The thing I don't like is the way XP downplays analysis and design . . . sort of says that writing code is where the action is . . .

(The team members look at one another and smile.)

Doug: So you agree with the XP approach?

Jamie (speaking for both): Writing code is what we do, Boss!

Doug (laughing): True, but I'd like to see you spend a little less time coding and then recoding and a little more time analyzing what has to be done and designing a solution that works.

Vinod: Maybe we can have it both ways, agility with a little discipline.

Doug: I think we can, Vinod. In fact, I'm sure of it.

5.5 Other Agile Process Models

Quote:

"Our profession goes through methodologies like a 14-year-old goes through clothing."

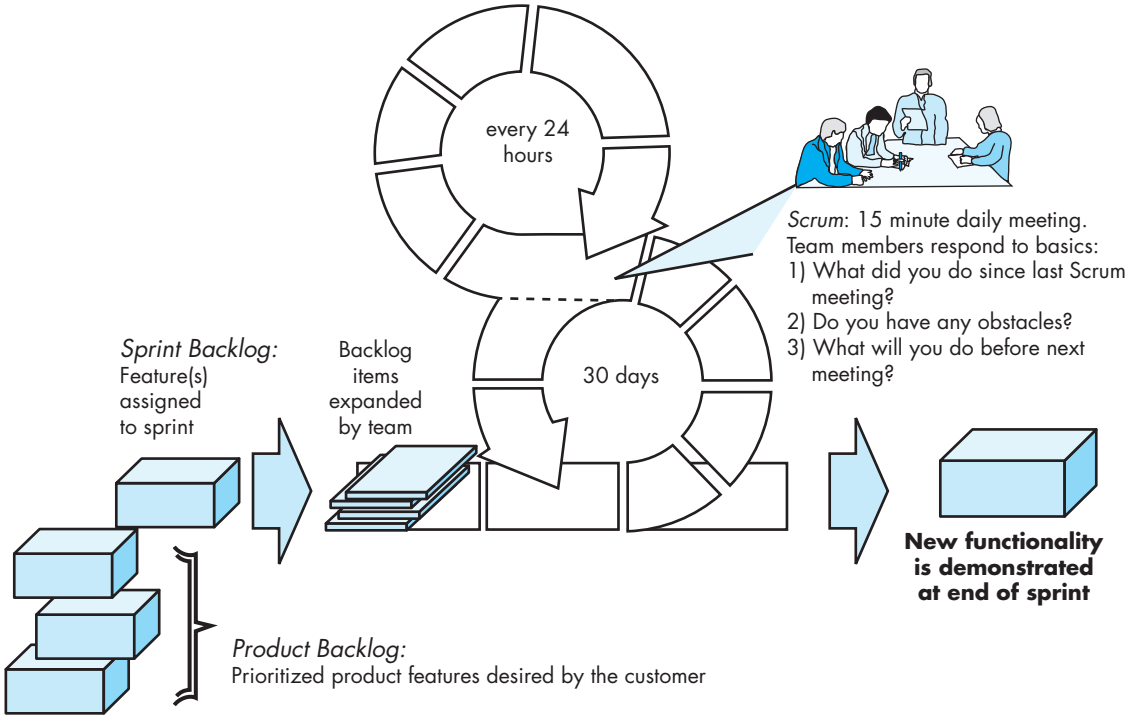
Stephen Hawrysh and Jim Ruprecht

The history of software engineering is littered with dozens of obsolete process descriptions and methodologies, modeling methods and notations, tools, and technology. Each flared in notoriety and was then eclipsed by something new and (purportedly) better. With the introduction of a wide array of agile process models—each contending for acceptance within the software development community—the agile movement is following the same historical path.[8]

As we noted in the last section, the most widely used of all agile process models is Extreme Programming (XP). But many other agile process models have been proposed and are in use across the industry. In this section, we present a brief overview of four common agile methods: Scrum, DSSD, Agile Modeling (AM), and Agile Unified Process (AUP).

8 This is not a bad thing. Before one or more models or methods are accepted as a de facto standard, all must contend for the hearts and minds of software engineers. The "winners" evolve into best practice, while the "losers" either disappear or merge with the winning models.

FIGURE 5.3 Scrum process flow



5.5.1 Scrum

WebRef
Useful Scrum information and resources can be found at **www.controlchaos.com.**

Scrum (the name is derived from an activity that occurs during a rugby match)[9] is an agile software development method that was conceived by Jeff Sutherland and his development team in the early 1990s. In recent years, further development on the Scrum methods has been performed by Schwaber and Beedle [Sch01b].

Scrum principles are consistent with the agile manifesto and are used to guide development activities within a process that incorporates the following framework activities: requirements, analysis, design, evolution, and delivery. Within each framework activity, work tasks occur within a process pattern (discussed in the following paragraph) called a *sprint*. The work conducted within a sprint (the number of sprints required for each framework activity will vary depending on product complexity and size) is adapted to the problem at hand and is defined and often modified in real time by the Scrum team. The overall flow of the Scrum process is illustrated in Figure 5.3.

9 A group of players forms around the ball and the teammates work together (sometimes violently!) to move the ball downfield.

Scrum emphasizes the use of a set of software process patterns [Noy02] that have proven effective for projects with tight timelines, changing requirements, and business criticality. Each of these process patterns defines a set of development activities:

Scrum incorporates a set of process patterns that emphasize project priorities, compartmentalized work units, communication, and frequent customer feedback.

Backlog—a prioritized list of project requirements or features that provide business value for the customer. Items can be added to the backlog at any time (this is how changes are introduced). The product manager assesses the backlog and updates priorities as required.

Sprints—consist of work units that are required to achieve a requirement defined in the backlog that must be fit into a predefined time-box[10] (typically 30 days). Changes (e.g., backlog work items) are not introduced during the sprint. Hence, the sprint allows team members to work in a short-term, but stable environment.

Scrum meetings—are short (typically 15-minute) meetings held daily by the Scrum team. Three key questions are asked and answered by all team members [Noy02]:

- What did you do since the last team meeting?
- What obstacles are you encountering?
- What do you plan to accomplish by the next team meeting?

A team leader, called a *Scrum master*, leads the meeting and assesses the responses from each person. The Scrum meeting helps the team to uncover potential problems as early as possible. Also, these daily meetings lead to "knowledge socialization" [Bee99] and thereby promote a self-organizing team structure.

Demos—deliver the software increment to the customer so that functionality that has been implemented can be demonstrated and evaluated by the customer. It is important to note that the demo may not contain all planned functionality, but rather those functions that can be delivered within the time-box that was established.

Beedle and his colleagues [Bee99] present a comprehensive discussion of these patterns in which they state: "Scrum assumes up-front the existence of chaos . . ." The Scrum process patterns enable a software team to work successfully in a world where the elimination of uncertainty is impossible.

5.5.2 Dynamic Systems Development Method

WebRef

Useful resources for DSDM can be found at **www.dsdm.org.**

The *Dynamic Systems Development Method* (DSDM) [Sta97] is an agile software development approach that "provides a framework for building and maintaining systems which meet tight time constraints through the use of incremental

10 A *time-box* is a project management term (see Part 4 of this book) that indicates a period of time that has been allocated to accomplish some task.

prototyping in a controlled project environment" [CCS02]. The DSDM philosophy is borrowed from a modified version of the Pareto principle—80 percent of an application can be delivered in 20 percent of the time it would take to deliver the complete (100 percent) application.

DSDM is an iterative software process in which each iteration follows the 80 percent rule. That is, only enough work is required for each increment to facilitate movement to the next increment. The remaining detail can be completed later when more business requirements are known or changes have been requested and accommodated.

The DSDM Consortium (**www.dsdm.org**) is a worldwide group of member companies that collectively take on the role of "keeper" of the method. The consortium has defined an agile process model, called the *DSDM life cycle,* that begins with a *feasibility study* that establishes basic business requirements and constraints and is followed by a *business study* that identifies functional and information requirements. DSDM then defines three different iterative cycles:

DSDM is a process framework that can adopt the tactics of another agile approach such as XP.

Functional model iteration—produces a set of incremental prototypes that demonstrate functionality for the customer. (Note: All DSDM prototypes are intended to evolve into the deliverable application.) The intent during this iterative cycle is to gather additional requirements by eliciting feedback from users as they exercise the prototype.

Design and build iteration—revisits prototypes built during the functional model iteration to ensure that each has been engineered in a manner that will enable it to provide operational business value for end users. In some cases, the functional model iteration and the design and build iteration occur concurrently.

Implementation—places the latest software increment (an "operationalized" prototype) into the operational environment. It should be noted that (1) the increment may not be 100 percent complete or (2) changes may be requested as the increment is put into place. In either case, DSDM development work continues by returning to the functional model iteration activity.

DSDM can be combined with XP (Section 5.4) to provide a combination approach that defines a solid process model (the DSDM life cycle) with the nuts and bolts practices (XP) that are required to build software increments.

5.5.3 Agile Modeling

WebRef

Comprehensive information on agile modeling can be found at: **www.agilemodeling.com.**

There are many situations in which software engineers must build large, business-critical systems. The scope and complexity of such systems must be modeled so that (1) all constituencies can better understand what needs to be accomplished, (2) the problem can be partitioned effectively among the people who must solve it, and (3) quality can be assessed as the system is being engineered and built. But in some cases, it can be daunting to manage the volume of notation

required, the degree of formalism suggested, the sheer size of the models for large projects, and the difficulty in maintaining the model(s) as changes occur. Is there an agile approach to software engineering modeling that might provide some relief?

At "The Official Agile Modeling Site," Scott Ambler [Amb02a] describes *agile modeling* (AM) in the following manner:

> Agile Modeling (AM) is a practice-based methodology for effective modeling and documentation of software-based systems. Simply put, Agile Modeling (AM) is a collection of values, principles, and practices for modeling software that can be applied on a software development project in an effective and light-weight manner. Agile models are more effective than traditional models because they are just barely good, they don't have to be perfect.

Quote:

"I was in the drugstore the other day trying to get a cold medication . . . Not easy. There's an entire wall of products you need. You stand there going, Well, this one is quick acting but this is long lasting ... Which is more important, the present or the future?"

Jerry Seinfeld

Agile modeling adopts all of the values that are consistent with the agile manifesto. The agile modeling philosophy recognizes that an agile team must have the courage to make decisions that may cause it to reject a design and refactor. The team must also have the humility to recognize that technologists do not have all the answers and that business experts and other stakeholders should be respected and embraced.

Although AM suggests a wide array of "core" and "supplementary" modeling principles, those that make AM unique are [Amb02a]:

Model with a purpose. A developer who uses AM should have a specific goal (e.g., to communicate information to the customer or to help better understand some aspect of the software) in mind before creating the model. Once the goal for the model is identified, the type of notation to be used and level of detail required will be more obvious.

Use multiple models. There are many different models and notations that can be used to describe software. Only a small subset is essential for most projects. AM suggests that to provide needed insight, each model should present a different aspect of the system and only those models that provide value to their intended audience should be used.

ADVICE

"Traveling light" is an appropriate philosophy for all software engineering work. Build only those models that provide value . . . no more, no less.

Travel light. As software engineering work proceeds, keep only those models that will provide long-term value and jettison the rest. Every work product that is kept must be maintained as changes occur. This represents work that slows the team down. Ambler [Amb02a] notes that "Every time you decide to keep a model you trade off agility for the convenience of having that information available to your team in an abstract manner (hence potentially enhancing communication within your team as well as with project stakeholders)."

Content is more important than representation. Modeling should impart information to its intended audience. A syntactically perfect model that imparts little useful content is not as valuable as a model with flawed notation that nevertheless provides valuable content for its audience.

Know the models and the tools you use to create them. Understand the strengths and weaknesses of each model and the tools that are used to create it.

Adapt locally. The modeling approach should be adapted to the needs of the agile team.

A major segment of the software engineering community has adopted the Unified Modeling Language (UML)[11] as the preferred method for representing analysis and design models. The Unified Process (Chapter 4) has been developed to provide a framework for the application of UML. Scott Ambler [Amb06] has developed a simplified version of the UP that integrates his agile modeling philosophy.

5.5.4 Agile Unified Process

The *Agile Unified Process* (AUP) adopts a "serial in the large" and "iterative in the small" [Amb06] philosophy for building computer-based systems. By adopting the classic UP phased activities—inception, elaboration, construction, and transition—AUP provides a serial overlay (i.e., a linear sequence of software engineering activities) that enables a team to visualize the overall process flow for a software project. However, within each of the activities, the team iterates to achieve agility and to deliver meaningful software increments to end users as rapidly as possible. Each AUP iteration addresses the following activities [Amb06]:

- *Modeling*. UML representations of the business and problem domains are created. However, to stay agile, these models should be "just barely good enough" [Amb06] to allow the team to proceed.
- *Implementation*. Models are translated into source code.
- *Testing*. Like XP, the team designs and executes a series of tests to uncover errors and ensure that the source code meets its requirements.
- *Deployment*. Like the generic process activity discussed in Chapters 3, deployment in this context focuses on the delivery of a software increment and the acquisition of feedback from end users.
- *Configuration and project management*. In the context of AUP, configuration management (Chapter 29) addresses change management, risk management, and the control of any persistent work products[12] that are produced by the team. Project management tracks and controls the progress of the team and coordinates team activities.

11 A brief tutorial on UML is presented in Appendix 1.

12 A *persistent work product* is a model or document or test case produced by the team that will be kept for an indeterminate period of time. It will *not* be discarded once the software increment is delivered.

- *Environment management.* Environmental management coordinates a process infrastructure that includes standards, tools, and other support technology available to the team.

Although the AUP has historical and technical connections to the Unified Modeling Language, it is important to note that UML modeling can be used in conjunction with any of the agile process models described in this chapter.

SOFTWARE TOOLS

Agile Development

Objective: The objective of agile development tools is to assist in one or more aspects of agile development with an emphasis on facilitating the rapid generation of operational software. These tools can also be used when prescriptive process models (Chapter 4) are applied.

Mechanics: Tool mechanics vary. In general, agile tool sets encompass automated support for project planning, use case development and requirements gathering, rapid design, code generation, and testing.

Representative tools:[13]

Note: Because agile development is a hot topic, most software tools vendors purport to sell tools that support the agile approach. The tools noted here have characteristics that make them particularly useful for agile projects.

OnTime, developed by Axosoft (**www.axosoft.com**), provides agile process management support for various technical activities within the process.

Ideogramic UML, developed by Ideogramic (**http://ideogramic-uml.software.informer.com/**) is a UML tool set specifically developed for use within an agile process.

Together Tool Set, distributed by Borland (**www.borland.com**), provides a tools suite that supports many technical activities within XP and other agile processes.

5.6 A TOOL SET FOR THE AGILE PROCESS

Some proponents of the agile philosophy argue that automated software tools (e.g., design tools) should be viewed as a minor supplement to the team's activities, and not at all pivotal to the success of the team. However, Alistair Cockburn [Coc04] suggests that tools can have a benefit and that "agile teams stress using tools that permit the rapid flow of understanding. Some of those tools are social, starting even at the hiring stage. Some tools are technological, helping distributed teams simulate being physically present. Many tools are physical, allowing people to manipulate them in workshops."

The "tool set" that supports agile processes focuses more on people issues than it does on technology issues.

Collaborative and communication "tools" are generally low tech and incorporate any mechanism ("physical proximity, whiteboards, poster sheets, index cards, and sticky notes" [Coc04] or modern social networking techniques) that provides information and coordination among agile developers. Active communication is achieved via the team dynamics (e.g., pair programming), while

13 Tools noted here do not represent an endorsement, but rather a sampling of tools in this category. In most cases, tool names are trademarked by their respective developers.

All of us who have worked in the systems and software business for more than a few years have lived this nightmare, and yet, few of us have learned to make it go away. We struggle when we try to elicit requirements from our customers. We have trouble understanding the information that we do acquire. We often record requirements in a disorganized manner, and we spend far too little time verifying what we do record. We allow change to control us, rather than establishing mechanisms to control change. In short, we fail to establish a solid foundation for the system or software. Each of these problems is challenging. When they are combined, the outlook is daunting for even the most experienced managers and practitioners. But solutions do exist.

It's reasonable to argue that the techniques we'll discuss in this chapter are not a true "solution" to the challenges just noted. But they do provide a solid approach for addressing these challenges.

8.1 Requirements Engineering

Quote:

"The hardest single part of building a software system is deciding what to build. No part of the work so cripples the resulting system if done wrong. No other part is more difficult to rectify later."

Fred Brooks

Designing and building computer software is challenging, creative, and just plain fun. In fact, building software is so compelling that many software developers want to jump right in before they have a clear understanding of what is needed. They argue that things will become clear as they build, that project stakeholders will be able to understand need only after examining early iterations of the software, that things change so rapidly that any attempt to understand requirements in detail is a waste of time, that the bottom line is producing a working program, and that all else is secondary. What makes these arguments seductive is that they contain elements of truth.[1] But each argument is flawed and can lead to a failed software project.

The broad spectrum of tasks and techniques that lead to an understanding of requirements is called *requirements engineering*. From a software process perspective, requirements engineering is a major software engineering action that begins during the communication activity and continues into the modeling activity. It must be adapted to the needs of the process, the project, the product, and the people doing the work.

KEY POINT

Requirements engineering establishes a solid base for design and construction. Without it, the resulting software has a high probability of not meeting customer's needs.

Requirements engineering builds a bridge to design and construction. But where does the bridge originate? One could argue that it begins at the feet of the project stakeholders (e.g., managers, customers, and end users), where business need is defined, user scenarios are described, functions and features are delineated, and project constraints are identified. Others might suggest that it

1 This is particularly true for small projects (less than one month) and smaller, relatively simple software efforts. As software grows in size and complexity, these arguments begin to break down.

begins with a broader system definition, where software is but one component of the larger system domain. But regardless of the starting point, the journey across the bridge takes you high above the project, allowing you to examine the context of the software work to be performed; the specific needs that design and construction must address; the priorities that guide the order in which work is to be completed; and the information, functions, and behaviors that will have a profound impact on the resultant design.

Over the past decade, there have been many technology changes that impact the requirements engineering process [Wev11]. Ubiquitous computing allows computer technology to be integrated into many everyday objects. When these objects are networked they can allow the creation of more complete user profiles, with the accompanying concerns for privacy and security.

Expect to do a bit of design during requirements work and a bit of requirements work during design.

Widespread availability of applications in the electronic marketplace will lead to more diverse stakeholder requirements. Stakeholders can customize a product to meet specific, targeted requirements that are applicable to only a small subset of all end users. As product development cycles shorten, there are pressures to streamline requirements engineering so that products come to market more quickly. But the fundamental problem remains the same, getting timely, accurate, and stable stakeholder input.

Requirements engineering encompasses seven distinct tasks: inception, elicitation, elaboration, negotiation, specification, validation, and management. It is important to note that some of these tasks occur in parallel and all are adapted to the needs of the project.

"The seeds of major software disasters are usually sown in the first three months of commencing the software project."

Caper Jones

Inception. How does a software project get started? Is there a single event that becomes the catalyst for a new computer-based system or product, or does the need evolve over time? There are no definitive answers to these questions. In some cases, a casual conversation is all that is needed to precipitate a major software engineering effort. But in general, most projects begin when a business need is identified or a potential new market or service is discovered. Stakeholders from the business community (e.g., business managers, marketing people, product managers) define a business case for the idea, try to identify the breadth and depth of the market, do a rough feasibility analysis, and identify a working description of the project's scope. All of this information is subject to change, but it is sufficient to precipitate discussions with the software engineering organization.[2] At project inception,[3] you establish a basic understanding of the problem,

2 If a computer-based system is to be developed, discussions begin within the context of a system engineering process. For a detailed discussion of system engineering, visit the website that accompanies this book: www.mhhe.com/pressman

3 Recall that the Unified Process (Chapter 4) defines a more comprehensive "inception phase" that encompasses the inception, elicitation, and elaboration tasks discussed in this chapter.

the people who want a solution, the nature of the solution that is desired, and the effectiveness of preliminary communication and collaboration between the other stakeholders and the software team.

Elicitation. It certainly seems simple enough—ask the customer, the users, and others what the objectives for the system or product are, what is to be accomplished, how the system or product fits into the needs of the business, and finally, how the system or product is to be used on a day-to-day basis. But it isn't simple—it's very hard.

An important part of elicitation is to establish business goals [Cle10]. Your job is to engage stakeholders and to encourage them to share their goals honestly. Once the goals have been captured, a prioritization mechanism should be established, and a design rationale for a potential architecture (that meets stakeholder goals) can be created.

INFO

Goal-Oriented Requirements Engineering

A *goal* is a long-term aim that a system or product must achieve. Goals may deal with either functional or nonfunctional (e.g., reliability, security, usability, etc.) concerns. Goals are often a good way to explain requirements to stakeholders and, once established, can be used to manage conflicts among stakeholders.

Object models (Chapters 10 and 11) and requirements can be derived systematically from goals. A goal graph showing links among goals can provide some degree of traceability (Section 8.2.6) between high-level strategic concerns to low-level technical details. Goals should be specified precisely and serve as the basis for requirements elaboration, verification/validation, conflict management, negotiation, explanation, and evolution.

Conflicts detected in requirements are often a result of conflicts present in the goals themselves. Conflict resolution is achieved by negotiating a set of mutually agreed-upon goals that are consistent with one another and with stakeholder desires. A more complete discussion on goals and requirements engineering can be found in a paper by Lamsweweerde [LaM01b].

? Why is it difficult to gain a clear understanding of what the customer wants?

Christel and Kang [Cri92] identify a number of problems that are encountered as elicitation occurs. *Problems of scope* occur when the boundary of the system is ill-defined or the customers and users specify unnecessary technical detail that may confuse, rather than clarify, overall system objectives. *Problems of understanding* are encountered when customers and users are not completely sure of what is needed, have a poor understanding of the capabilities and limitations of their computing environment, don't have a full understanding of the problem domain, have trouble communicating needs, omit information that is believed to be "obvious," specify requirements that conflict with the needs of other customers and users, or specify requirements that are ambiguous or untestable. *Problems of volatility* occur when the requirements change over time. To help

overcome these problems, you must approach the requirements-gathering activity in an organized manner.

ADVICE

Elaboration is a good thing, but you have to know when to stop. The key is to describe the problem in a way that establishes a firm base for design. If you work beyond that point, you're doing design.

Elaboration. The information obtained from the customer during inception and elicitation is expanded and refined during elaboration. This task focuses on developing a refined requirements model (Chapters 9 through 11) that identifies various aspects of software function, behavior, and information.

Elaboration is driven by the creation and refinement of user scenarios that describe how the end user (and other actors) will interact with the system. Each user scenario is parsed to extract analysis classes—business domain entities that are visible to the end user. The attributes of each analysis class are defined, and the services[4] that are required by each class are identified. The relationships and collaboration between classes are identified, and a variety of supplementary diagrams are produced.

ADVICE

There should be no winner and no loser in an effective negotiation. Both sides win, because a "deal" that both can live with is solidified.

Negotiation. It isn't unusual for customers and users to ask for more than can be achieved, given limited business resources. It's also relatively common for different customers or users to propose conflicting requirements, arguing that their version is "essential for our special needs."

You have to reconcile these conflicts through a process of negotiation. Customers, users, and other stakeholders are asked to rank requirements and then discuss conflicts in priority. Using an iterative approach that prioritizes requirements, assesses their cost and risk, and addresses internal conflicts, requirements are eliminated, combined, and/or modified so that each party achieves some measure of satisfaction.

Specification. In the context of computer-based systems (and software), the term *specification* means different things to different people. A specification can be a written document, a set of graphical models, a formal mathematical model, a collection of usage scenarios, a prototype, or any combination of these.

KEY POINT

The formality and format of a specification varies with the size and the complexity of the software to be built.

Some suggest that a "standard template" [Som97] should be developed and used for a specification, arguing that this leads to requirements that are presented in a consistent and therefore more understandable manner. However, it is sometimes necessary to remain flexible when a specification is to be developed. For large systems, a written document, combining natural language descriptions and graphical models may be the best approach. However, usage scenarios may be all that are required for smaller products or systems that reside within well-understood technical environments.

4 A *service* manipulates the data encapsulated by the class. The terms *operation* and *method* are also used. If you are unfamiliar with object-oriented concepts, a basic introduction is presented in Appendix 2.

INFO

Software Requirements Specification Template

A *software requirements specification* (SRS) is a work product that is created when a detailed description of all aspects of the software to be built must be specified before the project is to commence. It is important to note that a formal SRS is not always written. In fact, there are many instances in which effort expended on an SRS might be better spent in other software engineering activities. However, when software is to be developed by a third party, when a lack of specification would create severe business issues, or when a system is extremely complex or business critical, an SRS may be justified.

Karl Wiegers [Wie03] of Process Impact Inc. has developed a worthwhile template (available at **www.processimpact.com/process_assets/srs_template.doc**) that can serve as a guideline for those who must create a complete SRS. A topic outline follows:

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Appendix A: Glossary

Appendix B: Analysis Models

Appendix C: Issues List

A detailed description of each SRS topic can be obtained by downloading the SRS template at the URL noted in this sidebar.

A key concern during requirements validation is consistency. Use the analysis model to ensure that requirements have been consistently stated.

Validation. The work products produced as a consequence of requirements engineering are assessed for quality during a validation step. Requirements validation examines the specification[5] to ensure that all software requirements have been stated unambiguously; that inconsistencies, omissions, and errors have been detected and corrected; and that the work products conform to the standards established for the process, the project, and the product.

The primary requirements validation mechanism is the technical review (Chapter 20). The review team that validates requirements includes software engineers, customers, users, and other stakeholders who examine the specification looking for errors in content or interpretation, areas where clarification may be required, missing information, inconsistencies (a major problem when

5 Recall that the nature of the specification will vary with each project. In some cases, the "specification" is a collection of user scenarios and little else. In others, the specification may be a document that contains scenarios, models, and written descriptions.

large products or systems are engineered), conflicting requirements, or unrealistic (unachievable) requirements.

To illustrate some of the problems that occur during requirements validation, consider two seemingly innocuous requirements:

- The software should be user friendly.
- The probability of a successful unauthorized database intrusion should be less than 0.0001.

The first requirement is too vague for developers to test or assess. What exactly does "user friendly" mean? To validate it, it must be quantified or qualified in some manner.

The second requirement has a quantitative element ("less than 0.0001"), but intrusion testing will be difficult and time consuming. Is this level of security even warranted for the application? Can other complementary requirements associated with security (e.g., password protection, specialized handshaking) replace the quantitative requirement noted?

Glinz [Gli09] writes that quality requirements need to be represented in a manner that delivers optimal value. This means assessing the risk (Chapter 35) of delivering a system that fails to meet the stakeholders' quality requirements and attempting to mitigate this risk at minimum cost. The more critical the quality requirement is, the greater the need to state it in quantifiable terms. Less-critical quality requirements can be stated in general terms. In some cases, a general quality requirement can be verified using a qualitative technique (e.g., user survey or check list). In other situations, quality requirements can be verified using a combination of qualitative and quantitative assessment.

INFO

Requirements Validation Checklist

It is often useful to examine each requirement against a set of checklist questions. Here is a small subset of those that might be asked:

- Are requirements stated clearly? Can they be misinterpreted?
- Is the source (e.g., a person, a regulation, a document) of the requirement identified? Has the final statement of the requirement been examined by or against the original source?
- Is the requirement bounded in quantitative terms?
- What other requirements relate to this requirement? Are they clearly noted via a cross-reference matrix or other mechanism?
- Does the requirement violate any system domain constraints?
- Is the requirement testable? If so, can we specify tests (sometimes called validation criteria) to exercise the requirement?
- Is the requirement traceable to any system model that has been created?
- Is the requirement traceable to overall system/product objectives?
- Is the specification structured in a way that leads to easy understanding, easy reference, and easy translation into more technical work products?
- Has an index for the specification been created?
- Have requirements associated with performance, behavior, and operational characteristics been clearly stated? What requirements appear to be implicit?

Requirements management. Requirements for computer-based systems change, and the desire to change requirements persists throughout the life of the system. Requirements management is a set of activities that help the project team identify, control, and track requirements and changes to requirements at any time as the project proceeds.[6] Many of these activities are identical to the software configuration management (SCM) techniques discussed in Chapter 29.

SOFTWARE TOOLS

Requirements Engineering

Objective: Requirements engineering tools assist in requirements gathering, requirements modeling, requirements management, and requirements validation.

Mechanics: Tool mechanics vary. In general, requirements engineering tools build a variety of graphical (e.g., UML) models that depict the informational, functional, and behavioral aspects of a system. These models form the basis for all other activities in the software process.

Representative Tools:[7]
A reasonably comprehensive (and up-to-date) listing of requirements engineering tools can be found at the Volvere Requirements resources site at **www.volere.co.uk/tools.htm**. Requirements modeling tools are discussed in Chapters 9 and 10. Tools noted below focus on requirement management.

EasyRM, developed by Cybernetic Intelligence GmbH (**http://www.visuresolutions.com/visure-requirements-software**), Visure Requirements is a flexible and complete requirements engineering life-cycle solution, supporting requirements capture, analysis, specification, validation and verification, management, and reuse.

Rational RequisitePro, developed by Rational Software (**www-03.ibm.com/software/products/us/en/reqpro**), allows users to build a requirements database; represent relationships among requirements; and organize, prioritize, and trace requirements.

Many additional requirements management tools can be found at the Volvere site noted earlier and at **www.jiludwig.com/Requirements_Management_Tools.html**.

8.2 ESTABLISHING THE GROUNDWORK

In an ideal setting, stakeholders and software engineers work together on the same team.[8] In such cases, requirements engineering is simply a matter of conducting meaningful conversations with colleagues who are well-known members of the team. But reality is often quite different.

Customer(s) or end users may be located in a different city or country, may have only a vague idea of what is required, may have conflicting opinions about the system to be built, may have limited technical knowledge, and may have

6 Formal requirements management is initiated only for large projects that have hundreds of identifiable requirements. For small projects, this requirements engineering function is considerably less formal.

7 Tools noted here do not represent an endorsement, but rather a sampling of tools in this category. In most cases, tool names are trademarked by their respective developers.

8 This approach is strongly recommended for projects that adopt an agile software development philosophy.

limited time to interact with the requirements engineer. None of these things are desirable, but all are fairly common, and you are often forced to work within the constraints imposed by this situation.

In the sections that follow, we discuss the steps required to establish the groundwork for an understanding of software requirements—to get the project started in a way that will keep it moving forward toward a successful solution.

8.2.1 Identifying Stakeholders

KEY POINT

A *stakeholder* is anyone who has a direct interest in or benefits from the system that is to be developed.

Sommerville and Sawyer [Som97] define a *stakeholder* as "anyone who benefits in a direct or indirect way from the system which is being developed." We have already identified the usual suspects: business operations managers, product managers, marketing people, internal and external customers, end users, consultants, product engineers, software engineers, support and maintenance engineers, and others. Each stakeholder has a different view of the system, achieves different benefits when the system is successfully developed, and is open to different risks if the development effort should fail.

At inception, you should create a list of people who will contribute input as requirements are elicited (Section 8.3). The initial list will grow as stakeholders are contacted because every stakeholder will be asked: "Whom else do you think I should talk to?"

8.2.2 Recognizing Multiple Viewpoints

Quote:

"Put three stakeholders in a room and ask them what kind of system they want. You're likely to get four or more different opinions."

Author unknown

Because many different stakeholders exist, the requirements of the system will be explored from many different points of view. For example, the marketing group is interested in functions and features that will excite the potential market, making the new system easy to sell. Business managers are interested in a feature set that can be built within budget and that will be ready to meet defined market windows. End users may want features that are familiar to them and that are easy to learn and use. Software engineers may be concerned with functions that are invisible to nontechnical stakeholders but that enable an infrastructure that supports more marketable functions and features. Support engineers may focus on the maintainability of the software.

Each of these constituencies (and others) will contribute information to the requirements engineering process. As information from multiple viewpoints is collected, emerging requirements may be inconsistent or may conflict with one another. You should categorize all stakeholder information (including inconsistent and conflicting requirements) in a way that will allow decision makers to choose an internally consistent set of requirements for the system.

There are several things that can make it hard to elicit requirements for software that satisfies its users: project goals are unclear, stakeholders' priorities differ, people have unspoken assumptions, stakeholders interpret meanings differently, and requirements are stated in a way that makes them difficult to

verify [Ale11]. The goal of effective requirements engineering is to eliminate or at least reduce these problems.

8.2.3 Working toward Collaboration

If five stakeholders are involved in a software project, you may have five (or more) different opinions about the proper set of requirements. Throughout earlier chapters, we have noted that customers (and other stakeholders) should collaborate among themselves (avoiding petty turf battles) and with software engineering practitioners if a successful system is to result. But how is this collaboration accomplished?

The job of a requirements engineer is to identify areas of commonality (i.e., requirements on which all stakeholders agree) and areas of conflict or inconsistency (i.e., requirements that are desired by one stakeholder but conflict with the needs of another stakeholder). It is, of course, the latter category that presents a challenge.

INFO

Using "Priority Points"

One way of resolving conflicting requirements and at the same time better understanding the relative importance of all requirements is to use a "voting" scheme based on *priority points*. All stakeholders are provided with some number of priority points that can be "spent" on any number of requirements. A list of requirements is presented, and each stakeholder indicates the relative importance of each (from his or her viewpoint) by spending one or more priority points on it. Points spent cannot be reused. Once a stakeholder's priority points are exhausted, no further action on requirements can be taken by that person. Overall points spent on each requirement by all stakeholders provide an indication of the overall importance of each requirement.

Collaboration does not necessarily mean that requirements are defined by committee. In many cases, stakeholders collaborate by providing their view of requirements, but a strong "project champion" (e.g., a business manager or a senior technologist) may make the final decision about which requirements make the cut.

Quote:

"It is better to know some of the questions than all of the answers."

James Thurber

8.2.4 Asking the First Questions

Questions asked at the inception of the project should be "context free" [Gau89]. The first set of context-free questions focuses on the customer and other stakeholders, the overall project goals and benefits. For example, you might ask:

- Who is behind the request for this work?
- Who will use the solution?
- What will be the economic benefit of a successful solution?
- Is there another source for the solution that you need?

These questions help to identify all stakeholders who will have interest in the software to be built. In addition, the questions identify the measurable benefit of a successful implementation and possible alternatives to custom software development.

The next set of questions enables you to gain a better understanding of the problem and allows the customer to voice his or her perceptions about a solution:

? What questions will help you gain a preliminary understanding of the problem?

- How would you characterize "good" output that would be generated by a successful solution?
- What problem(s) will this solution address?
- Can you show me (or describe) the business environment in which the solution will be used?
- Will special performance issues or constraints affect the way the solution is approached?

The final set of questions focuses on the effectiveness of the communication activity itself. Gause and Weinberg [Gau89] call these "meta-questions" and propose the following (abbreviated) list:

- Are you the right person to answer these questions? Are your answers "official"?
- Are my questions relevant to the problem that you have?
- Am I asking too many questions?
- Can anyone else provide additional information?
- Should I be asking you anything else?

Quote:

"He who asks a question is a fool for five minutes; he who does not ask a question is a fool forever."

Chinese proverb

These questions (and others) will help to "break the ice" and initiate the communication that is essential to successful elicitation. But a question-and-answer meeting format is not an approach that has been overwhelmingly successful. In fact, the Q&A session should be used for the first encounter only and then replaced by a requirements elicitation format that combines elements of problem solving, negotiation, and specification. An approach of this type is presented in Section 8.3.

8.2.5 Nonfunctional Requirements

A *nonfunctional requirement* (NFR) can be described as a quality attribute, a performance attribute, a security attribute, or a general constraint on a system. These are often not easy for stakeholders to articulate. Chung [Chu09] suggests that there is a lopsided emphasis on functionality of the software, yet the software may not be useful or usable without the necessary non-functional characteristics.

In Section 8.3.2, we discuss a technique called *quality function deployment* (QFD). Quality function deployment attempts to translate unspoken customer

needs or goals into system requirements. Nonfunctional requirements are often listed separately in a software requirements specification.

As an adjunct to QFD, it is possible to define a two-phase approach [Hne11] that can assist a software team and other stakeholders in identifying nonfunctional requirements. During the first phase, a set of software engineering guidelines is established for the system to be built. These include guidelines for best practice, but also address architectural style (Chapter 13) and the use of design patterns (Chapter 16). A list of NFRs (e.g., requirements that address usability, testability, security or maintainability) is then developed. A simple table lists NFRs as *column labels* and software engineering guidelines as *row labels*. A relationship matrix compares each guideline to all others, helping the team to assess whether each pair of guidelines is *complementary*, *overlapping*, *conflicting*, or *independent*.

In the second phase, the team prioritizes each nonfunctional requirement by creating a homogeneous set of nonfunctional requirements using a set of decision rules [Hne11] that establish which guidelines to implement and which to reject.

8.2.6 Traceability

Traceability is a software engineering term that refers to documented links between software engineering work products (e.g., requirements and test cases). A *traceability matrix* allows a requirements engineer to represent the relationship between requirements and other software engineering work products. Rows of the traceability matrix are labeled using requirement names and columns can be labeled with the name of a software engineering work product (e.g., a design element or a test case). A matrix cell is marked to indicate the presence of a link between the two.

The traceability matrices can support a variety of engineering development activities. They can provide continuity for developers as a project moves from one project phase to another, regardless of the process model being used. Traceability matrices often can be used to ensure the engineering work products have taken all requirements into account.

As the number of requirements and the number of work products grows, it becomes increasingly difficult to keep the traceability matrix up to date. Nonetheless, it is important to create some means for tracking the impact and evolution of the product requirements [Got11].

8.3 Eliciting Requirements

Requirements elicitation (also called *requirements gathering*) combines elements of problem solving, elaboration, negotiation, and specification. In order to encourage a collaborative, team-oriented approach to requirements gathering,

stakeholders work together to identify the problem, propose elements of the solution, negotiate different approaches, and specify a preliminary set of solution requirements [Zah90].[9]

8.3.1 Collaborative Requirements Gathering

Many different approaches to collaborative requirements gathering have been proposed. Each makes use of a slightly different scenario, but all apply some variation on the following basic guidelines:

? What are the basic guidelines for conducting a collaborative requirements gathering meeting?

- Meetings (either real or virtual) are conducted and attended by both software engineers and other stakeholders.
- Rules for preparation and participation are established.
- An agenda is suggested that is formal enough to cover all important points but informal enough to encourage the free flow of ideas.
- A "facilitator" (can be a customer, a developer, or an outsider) controls the meeting.
- A "definition mechanism" (can be work sheets, flip charts, or wall stickers or an electronic bulletin board, chat room, or virtual forum) is used.

WebRef

Joint Application Development (JAD) is a popular technique for requirements gathering. A good description can be found at **www.carolla.com/wp-jad.htm.**

The goal is to identify the problem, propose elements of the solution, negotiate different approaches, and specify a preliminary set of solution requirements.

A one- or two-page "product request" is generated during inception (Section 8.2). A meeting place, time, and date are selected; a facilitator is chosen; and attendees from the software team and other stakeholder organizations are invited to participate. The product request is distributed to all attendees before the meeting date.

As an example,[10] consider an excerpt from a product request written by a marketing person involved in the *SafeHome* project. This person writes the following narrative about the home security function that is to be part of *SafeHome:*

> Our research indicates that the market for home management systems is growing at a rate of 40 percent per year. The first *SafeHome* function we bring to market should be the home security function. Most people are familiar with "alarm systems" so this would be an easy sell.
>
> The home security function would protect against and/or recognize a variety of undesirable "situations" such as illegal entry, fire, flooding, carbon monoxide levels, and others. It'll use our wireless sensors to detect each situation, can be programmed by the homeowner, and will automatically telephone a monitoring agency when a situation is detected.

9 This approach is sometimes called a *facilitated application specification technique* (FAST).

10 This example (with extensions and variations) is used to illustrate important software engineering methods in many of the chapters that follow. As an exercise, it would be worthwhile to conduct your own requirements-gathering meeting and develop a set of lists for it.

If a system or product will serve many users, be absolutely certain that requirements are elicited from a representative cross section of users. If only one user defines all requirements, acceptance risk is high.

In reality, others would contribute to this narrative during the requirements-gathering meeting and considerably more information would be available. But even with additional information, ambiguity is present, omissions are likely to exist, and errors might occur. For now, the preceding "functional description" will suffice.

While reviewing the product request in the days before the meeting, each attendee is asked to make a list of objects that are part of the environment that surrounds the system, other objects that are to be produced by the system, and objects that are used by the system to perform its functions. In addition, each attendee is asked to make another list of services (processes or functions) that manipulate or interact with the objects. Finally, lists of constraints (e.g., cost, size, business rules) and performance criteria (e.g., speed, accuracy) are also developed. The attendees are informed that the lists are not expected to be exhaustive but are expected to reflect each person's perception of the system.

"Facts do not cease to exist because they are ignored."

Aldous Huxley

Objects described for *SafeHome* might include the control panel, smoke detectors, window and door sensors, motion detectors, an alarm, an event (a sensor has been activated), a display, a PC, telephone numbers, a telephone call, and so on. The list of services might include *configuring* the system, *setting* the alarm, *monitoring* the sensors, *dialing* the phone, *programming* the control panel, and *reading* the display (note that services act on objects). In a similar fashion, each attendee will develop lists of constraints (e.g., the system must recognize when sensors are not operating, must be user friendly, must interface directly to a standard phone line) and performance criteria (e.g., a sensor event should be recognized within one second, and an event priority scheme should be implemented).

Avoid the impulse to shoot down a customer's idea as "too costly" or "impractical." The idea here is to negotiate a list that is acceptable to all. To do this, you must keep an open mind.

The lists of objects can be pinned to the walls of the room using large sheets of paper, stuck to the walls using adhesive-backed sheets, or written on a wall board. Alternatively, the lists may have been posted on a group forum, at an internal website, or posed in a social networking environment for review prior to the meeting. Ideally, each listed entry should be capable of being manipulated separately so that lists can be combined, entries can be deleted, and additions can be made. At this stage, critique and debate are strictly prohibited.

After individual lists are presented in one topic area, the group creates a combined list by eliminating redundant entries, adding any new ideas that come up during the discussion, but not deleting anything. After you create combined lists for all topic areas, discussion—coordinated by the facilitator—ensues. The combined list is shortened, lengthened, or reworded to properly reflect the product or system to be developed. The objective is to develop a consensus list of objects, services, constraints, and performance for the system to be built.

In many cases, an object or service described on a list will require further explanation. To accomplish this, stakeholders develop *mini-specifications* for

entries on the lists or by creating a use case (Section 8.4) that involves the object or service. For example, the mini-spec for the *SafeHome* object **Control Panel** might be:

> The control panel is a wall-mounted unit that is approximately 230 x 130 mm in size. The control panel has wireless connectivity to sensors and a PC. User interaction occurs through a keypad containing 12 keys. A 75 x 75 mm OLED color display provides user feedback. Software provides interactive prompts, echo, and similar functions.

The mini-specs are presented to all stakeholders for discussion. Additions, deletions, and further elaboration are made. In some cases, the development of mini-specs will uncover new objects, services, constraints, or performance requirements that will be added to the original lists. During all discussions, the team may raise an issue that cannot be resolved during the meeting. An *issues list* is maintained so that these ideas will be acted on later.

SAFEHOME

Conducting a Requirements-Gathering Meeting

The scene: A meeting room. The first requirements-gathering meeting is in progress.

The players: Jamie Lazar, software team member; Vinod Raman, software team member; Ed Robbins, software team member; Doug Miller, software engineering manager; three members of marketing; a product engineering representative; and a facilitator.

The conversation:

Facilitator (pointing at whiteboard): So that's the current list of objects and services for the home security function.

Marketing person: That about covers it from our point of view.

Vinod: Didn't someone mention that they wanted all *SafeHome* functionality to be accessible via the Internet? That would include the home security function, no?

Marketing person: Yes, that's right . . . we'll have to add that functionality and the appropriate objects.

Facilitator: Does that also add some constraints?

Jamie: It does, both technical and legal.

Production rep: Meaning?

Jamie: We better make sure an outsider can't hack into the system, disarm it, and rob the place or worse. Heavy liability on our part.

Doug: Very true.

Marketing: But we still need that . . . just be sure to stop an outsider from getting in.

Ed: That's easier said than done and . . .

Facilitator (interrupting): I don't want to debate this issue now. Let's note it as an action item and proceed.

(Doug, serving as the recorder for the meeting, makes an appropriate note.)

Facilitator: I have a feeling there's still more to consider here.

(The group spends the next 20 minutes refining and expanding the details of the home security function.)

Many stakeholder concerns (e.g., accuracy, data accessibility, security) are the basis for nonfunctional system requirements (Section 8.2). As stakeholders enunciate these concerns, software engineers must consider them within the context

of the system to be built. Among the questions that must be answered [Lag10] are as follows:

- Can we build the system?
- Will this development process allow us to beat our competitors to market?
- Do adequate resources exist to build and maintain the proposed system?
- Will the system performance meet the needs of our customers?

The answers to these and other questions will evolve over time.

8.3.2 Quality Function Deployment

KEY POINT

QFD defines requirements in a way that maximizes customer satisfaction.

Quality function deployment (QFD) is a quality management technique that translates the needs of the customer into technical requirements for software. QFD "concentrates on maximizing customer satisfaction from the software engineering process" [Zul92]. To accomplish this, QFD emphasizes an understanding of what is valuable to the customer and then deploys these values throughout the engineering process.

ADVICE

Everyone wants to implement lots of exciting requirements, but be careful. That's how "requirements creep" sets in. On the other hand, exciting requirements lead to a breakthrough product!

Within the context of QFD, *normal requirements* identify the objectives and goals that are stated for a product or system during meetings with the customer. If these requirements are present, the customer is satisfied. *Expected requirements* are implicit to the product or system and may be so fundamental that the customer does not explicitly state them. Their absence will be a cause for significant dissatisfaction. *Exciting requirements* go beyond the customer's expectations and prove to be very satisfying when present.

WebRef

Useful information on QFD can be obtained at **www.qfdi.org.**

Although QFD concepts can be applied across the entire software process [Par96a]; specific QFD techniques are applicable to the requirements elicitation activity. QFD uses customer interviews and observation, surveys, and examination of historical data (e.g., problem reports) as raw data for the requirements gathering activity. These data are then translated into a table of requirements—called the *customer voice table*—that is reviewed with the customer and other stakeholders. A variety of diagrams, matrices, and evaluation methods are then used to extract expected requirements and to attempt to derive exciting requirements [Aka04].

8.3.3 Usage Scenarios

As requirements are gathered, an overall vision of system functions and features begin to materialize. However, it is difficult to move into more technical software engineering activities until you understand how these functions and features will be used by different classes of end users. To accomplish this, developers and users can create a set of scenarios that identify a thread of usage for the system to be constructed. The scenarios, often called *use cases* [Jac92], provide a description of how the system will be used. Use cases are discussed in greater detail in Section 8.4.

SafeHome

Developing a Preliminary User Scenario

The scene: A meeting room, continuing the first requirements gathering meeting.

The players: Jamie Lazar, software team member; Vinod Raman, software team member; Ed Robbins, software team member; Doug Miller, software engineering manager; three members of marketing; a product engineering representative; and a facilitator.

The conversation:

Facilitator: We've been talking about security for access to *SafeHome* functionality that will be accessible via the Internet. I'd like to try something. Let's develop a usage scenario for access to the home security function.

Jamie: How?

Facilitator: We can do it a couple of different ways, but for now, I'd like to keep things really informal. Tell us (he points at a marketing person) how you envision accessing the system.

Marketing person: Um . . . well, this is the kind of thing I'd do if I was away from home and I had to let someone into the house, say a housekeeper or repair guy, who didn't have the security code.

Facilitator (smiling): That's the reason you'd do it . . . tell me how you'd actually do this.

Marketing person: Um . . . the first thing I'd need is a PC. I'd log on to a website we'd maintain for all users of *SafeHome*. I'd provide my user ID and . . .

Vinod (interrupting): The Web page would have to be secure, encrypted, to guarantee that we're safe and . . .

Facilitator (interrupting): That's good information, Vinod, but it's technical. Let's just focus on how the end user will use this capability. OK?

Vinod: No problem.

Marketing person: So as I was saying, I'd log on to a website and provide my user ID and two levels of passwords.

Jamie: What if I forget my password?

Facilitator (interrupting): Good point, Jamie, but let's not address that now. We'll make a note of that and call it an *exception*. I'm sure there'll be others.

Marketing person: After I enter the passwords, a screen representing all *SafeHome* functions will appear. I'd select the home security function. The system might request that I verify who I am, say, by asking for my address or phone number or something. It would then display a picture of the security system control panel along with a list of functions that I can perform—arm the system, disarm the system, disarm one or more sensors. I suppose it might also allow me to reconfigure security zones and other things like that, but I'm not sure.

(As the marketing person continues talking, Doug takes copious notes; these form the basis for the first informal usage scenario. Alternatively, the marketing person could have been asked to write the scenario, but this would be done outside the meeting.)

8.3.4 Elicitation Work Products

? What information is produced as a consequence of requirements gathering?

The work products produced as a consequence of requirements elicitation will vary depending on the size of the system or product to be built. For most systems, the work products include: (1) a statement of need and feasibility, (2) a bounded statement of scope for the system or product, (3) a list of customers, users, and other stakeholders who participated in requirements elicitation, (4) a description of the system's technical environment, (5) a list of requirements (preferably organized by function) and the domain constraints that applies to each, (6) a set of usage scenarios that provide insight into the use of the system or product under different operating conditions, and (7) any prototypes developed to better

define requirements. Each of these work products is reviewed by all people who have participated in requirements elicitation.

8.3.5 Agile Requirements Elicitation

KEY POINT

User stories are the way to document requirements elicited from customers in agile process models.

Within the context of an agile process, requirements are elicited by asking all stakeholders to create *user stories*. Each user story describes a simple system requirement written from the user's perspective. User stories can be written on small note cards, making it easy for developers to select and manage a subset of requirements to implement for the next product increment. Proponents claim that using note cards written in the user's own language allows developers to shift their focus to communication with stakeholders on the selected requirements rather than their own agenda [Mai10a].

Although the agile approach to requirements elicitation is attractive for many software teams, critics argue that a consideration of overall business goals and nonfunctional requirements is often lacking. In some cases, rework is required to accommodate performance and security issues. In addition, user stories may not provide a sufficient basis for system evolution over time

8.3.6 Service-Oriented Methods

? What is a *service* in the context of service-oriented methods?

Service-oriented development views a system as an aggregation of services. A *service* can be "as simple as providing a single function, for example, a request/response-based mechanism that provides a series of random numbers, or can be an aggregation of complex elements, such as the Web service API" [Mic12].

Requirements elicitation in service-oriented development focuses on the definition of services to be rendered by an application. As a metaphor, consider the service provided when you visit a fine hotel. A doorperson greets guests. A valet parks their cars. The desk clerk checks the guests in. A bellhop manages the bags. The concierge assists guest with local arrangements. Each contact or *touchpoint* between a guest and a hotel employee is designed to enhance the hotel visit and represents a service offered.

KEY POINT

Requirements elicitation for service-oriented methods fines services render by an app. A touchpoint *represents an opportunity for the user to interact with the system to receive a desired service.*

Most service design methods emphasize understanding the customer, thinking creatively, and building solutions quickly [Mai10b]. To achieve these goals, requirements elicitation can include ethnographic studies,[11] innovation workshops, and early low-fidelity prototypes. Techniques for eliciting requirements must also acquire information about the brand and the stakeholders' perceptions of it. In addition to studying how the brand is used by customers, analysts need strategies to discover and document requirements about the desired qualities of new user experiences. User stories are helpful in this regard.

11 Studying user behavior in the environment where the proposed software product will be used.

The requirements for touchpoints should be characterized in a manner that indicates achievement of the overall service requirements. This suggests that each requirement should be traceable to a specific service.

8.4 Developing Use Cases

Use cases are defined from an actor's point of view. An actor is a role that people (users) or devices play as they interact with the software.

In a book that discusses how to write effective use cases, Alistair Cockburn [Coc01b] notes that "a use case captures a contract . . . [that] describes the system's behavior under various conditions as the system responds to a request from one of its stakeholders . . ." In essence, a use case tells a stylized story about how an end user (playing one of a number of possible roles) interacts with the system under a specific set of circumstances. The story may be narrative text, an outline of tasks or interactions, a template-based description, or a diagrammatic representation. Regardless of its form, a use case depicts the software or system from the end user's point of view.

The first step in writing a use case is to define the set of "actors" that will be involved in the story. *Actors* are the different people (or devices) that use the system or product within the context of the function and behavior that is to be described. Actors represent the roles that people (or devices) play as the system operates. Defined somewhat more formally, an actor is anything that communicates with the system or product and that is external to the system itself. Every actor has one or more goals when using the system.

WebRef

An excellent paper on use cases can be downloaded from **www.ibm.com/developerworks/webservices/library/co-design7.html.**

It is important to note that an actor and an end user are not necessarily the same thing. A typical user may play a number of different roles when using a system, whereas an actor represents a class of external entities (often, but not always, people) that play just one role in the context of the use case. As an example, consider a machine operator (a user) who interacts with the control computer for a manufacturing cell that contains a number of robots and numerically controlled machines. After careful review of requirements, the software for the control computer requires four different modes (roles) for interaction: programming mode, test mode, monitoring mode, and troubleshooting mode. Therefore, four actors can be defined: programmer, tester, monitor, and troubleshooter. In some cases, the machine operator can play all of these roles. In others, different people may play the role of each actor.

Because requirements elicitation is an evolutionary activity, not all actors are identified during the first iteration. It is possible to identify primary actors [Jac92] during the first iteration and secondary actors as more is learned about the system. *Primary actors* interact to achieve required system function and derive the intended benefit from the system. They work directly and frequently with the software. *Secondary actors* support the system so that primary actors can do their work.

What do I need to know in order to develop an effective use case?

Once actors have been identified, use cases can be developed. Jacobson [Jac92] suggests a number of questions[12] that should be answered by a use case:

- Who is the primary actor, the secondary actor(s)?
- What are the actor's goals?
- What preconditions should exist before the story begins?
- What main tasks or functions are performed by the actor?
- What exceptions might be considered as the story is described?
- What variations in the actor's interaction are possible?
- What system information will the actor acquire, produce, or change?
- Will the actor have to inform the system about changes in the external environment?
- What information does the actor desire from the system?
- Does the actor wish to be informed about unexpected changes?

Recalling basic *SafeHome* requirements, we define four actors: **homeowner** (a user), **setup manager** (likely the same person as **homeowner,** but playing a different role), **sensors** (devices attached to the system), and the **monitoring and response subsystem** (the central station that monitors the *SafeHome* home security function). For the purposes of this example, we consider only the **homeowner** actor. The **homeowner** actor interacts with the home security function in a number of different ways using either the alarm control panel or a PC. The homeowner (1) enters a password to allow all other interactions, (2) inquires about the status of a security zone, (3) inquires about the status of a sensor, (4) presses the panic button in an emergency, and (5) activates/deactivates the security system.

Considering the situation in which the homeowner uses the control panel, the basic use case for system activation follows:[13]

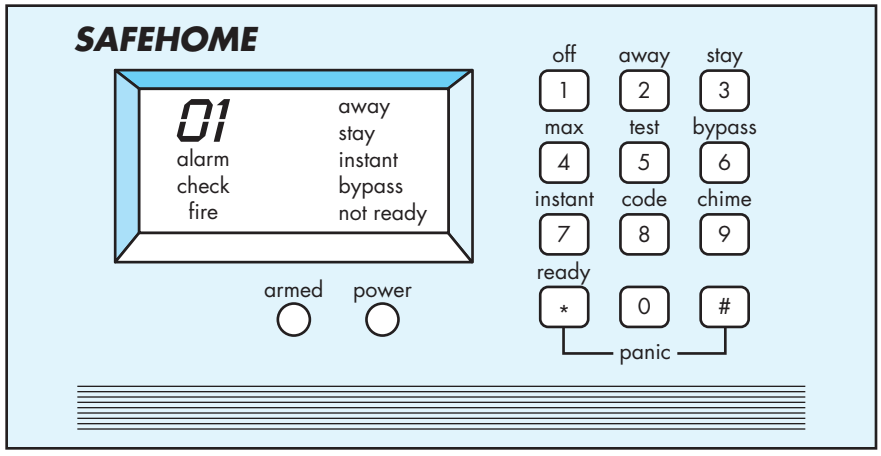
1. The homeowner observes the *SafeHome* control panel (Figure 8.1) to determine if the system is ready for input. If the system is not ready, a *not ready* message is displayed on the LCD display, and the homeowner must physically close windows or doors so that the *not ready* message disappears. [A *not ready* message implies that a sensor is open; i.e., that a door or window is open.]

12 Jacobson's questions have been extended to provide a more complete view of use case content.

13 Note that this use case differs from the situation in which the system is accessed via the Internet. In this case, interaction occurs via the control panel, not the GUI provided when a PC or mobile device is used.

FIGURE 8.1

SafeHome **control panel**



2. The homeowner uses the keypad to key in a four-digit password. The password is compared with the valid password stored in the system. If the password is incorrect, the control panel will beep once and reset itself for additional input. If the password is correct, the control panel awaits further action.
3. The homeowner selects and keys in *stay* or *away* (see Figure 8.1) to activate the system. *Stay* activates only perimeter sensors (inside motion detecting sensors are deactivated). *Away* activates all sensors.
4. When activation occurs, a red alarm light can be observed by the homeowner.

The basic use case presents a high-level story that describes the interaction between the actor and the system.

In many instances, uses cases are further elaborated to provide considerably more detail about the interaction. For example, Cockburn [Coc01b] suggests the following template for detailed descriptions of use cases:

Use cases are often written informally. However, use the template shown here to ensure that you've addressed all key issues.

Use case:	*InitiateMonitoring*
Primary actor:	Homeowner.
Goal in context:	To set the system to monitor sensors when the homeowner leaves the house or remains inside.
Preconditions:	System has been programmed for a password and to recognize various sensors.
Trigger:	The homeowner decides to "set" the system, that is, to turn on the alarm functions.

Scenario:

1. Homeowner: observes control panel
2. Homeowner: enters password
3. Homeowner: selects "stay" or "away"
4. Homeowner: observes read alarm light to indicate that *SafeHome* has been armed

Exceptions:

1. Control panel is *not ready:* homeowner checks all sensors to determine which are open; closes them.
2. Password is incorrect (control panel beeps once): homeowner reenters correct password.
3. Password not recognized: monitoring and response subsystem must be contacted to reprogram password.
4. *Stay* is selected: control panel beeps twice and a *stay* light is lit; perimeter sensors are activated.
5. *Away* is selected: control panel beeps three times and an *away* light is lit; all sensors are activated.

Priority:	Essential, must be implemented
When available:	First increment
Frequency of use:	Many times per day
Channel to actor:	Via control panel interface
Secondary actors:	Support technician, sensors

Channels to secondary actors:

Support technician: phone line

Sensors: hardwired and radio frequency interfaces

Open issues:

1. Should there be a way to activate the system without the use of a password or with an abbreviated password?
2. Should the control panel display additional text messages?
3. How much time does the homeowner have to enter the password from the time the first key is pressed?
4. Is there a way to deactivate the system before it actually activates?

Use cases for other **homeowner** interactions would be developed in a similar manner. It is important to review each use case with care. If some element of the interaction is ambiguous, it is likely that a review of the use case will indicate a problem.

SafeHome

Developing a High-Level Use Case Diagram

The scene: A meeting room, continuing the requirements-gathering meeting

The players: Jamie Lazar, software team member; Vinod Raman, software team member; Ed Robbins, software team member; Doug Miller, software engineering manager; three members of marketing; a product engineering representative; and a facilitator.

The conversation:

Facilitator: We've spent a fair amount of time talking about *SafeHome* home security functionality. During the break I sketched a use case diagram to summarize the important scenarios that are part of this function. Take a look.

(All attendees look at Figure 8.2.)

Jamie: I'm just beginning to learn UML notation.[14] So the home security function is represented by the big box with the ovals inside it? And the ovals represent use cases that we've written in text?

Facilitator: Yep. And the stick figures represent actors—the people or things that interact with the system as described by the use case . . . oh, I use the labeled square to represent an actor that's not a person . . . in this case, sensors.

Doug: Is that legal in UML?

Facilitator: Legality isn't the issue. The point is to communicate information. I view the use of a humanlike stick figure for representing a device to be misleading. So I've adapted things a bit. I don't think it creates a problem.

Vinod: Okay, so we have use case narratives for each of the ovals. Do we need to develop the more detailed template-based narratives I've read about?

Facilitator: Probably, but that can wait until we've considered other *SafeHome* functions.

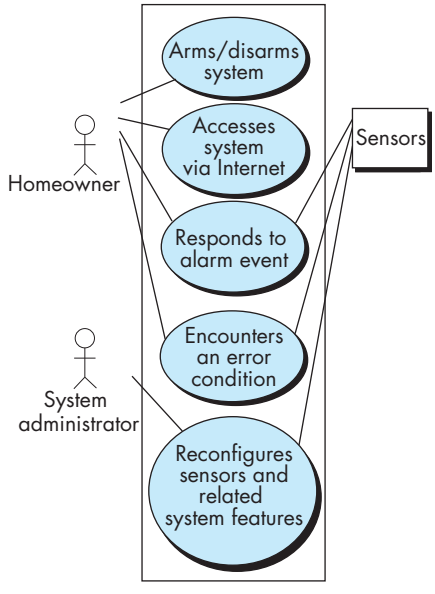
Marketing person: Wait, I've been looking at this diagram and all of a sudden I realize we missed something.

Facilitator: Oh really. Tell me what we've missed.

(The meeting continues.)

FIGURE 8.2

UML use case diagram for *SafeHome* home security function



14 A brief UML tutorial is presented in Appendix 1 for those who are unfamiliar with the notation.

SOFTWARE TOOLS

Use Case Development

Objective: Assist in the development of use cases by providing automated templates and mechanisms for assessing clarity and consistency.

Mechanics: Tool mechanics vary. In general, use case tools provide fill-in-the-blank templates for creating effective use cases. Most use case functionality is embedded into a set of broader requirements engineering functions.

Representative Tools:[15]
The vast majority of UML-based analysis modeling tools provide both text and graphical support for use case development and modeling.
Objects by Design
(**www.objectsbydesign.com/tools/umltools_byCompany.html**) provides comprehensive links to tools of this type.

8.5 BUILDING THE ANALYSIS MODEL[16]

The intent of the analysis model is to provide a description of the required informational, functional, and behavioral domains for a computer-based system. The model changes dynamically as you learn more about the system to be built, and other stakeholders understand more about what they really require. For that reason, the analysis model is a snapshot of requirements at any given time. You should expect it to change.

As the analysis model evolves, certain elements will become relatively stable, providing a solid foundation for the design tasks that follow. However, other elements of the model may be more volatile, indicating that stakeholders do not yet fully understand requirements for the system. The analysis model and the methods that are used to build it are presented in detail in Chapters 9 to 11. We present a brief overview in the sections that follow.

It is always a good idea to get stakeholders involved. One of the best ways to do this is to have each stakeholder write use cases that describe how the software will be used.

8.5.1 Elements of the Analysis Model

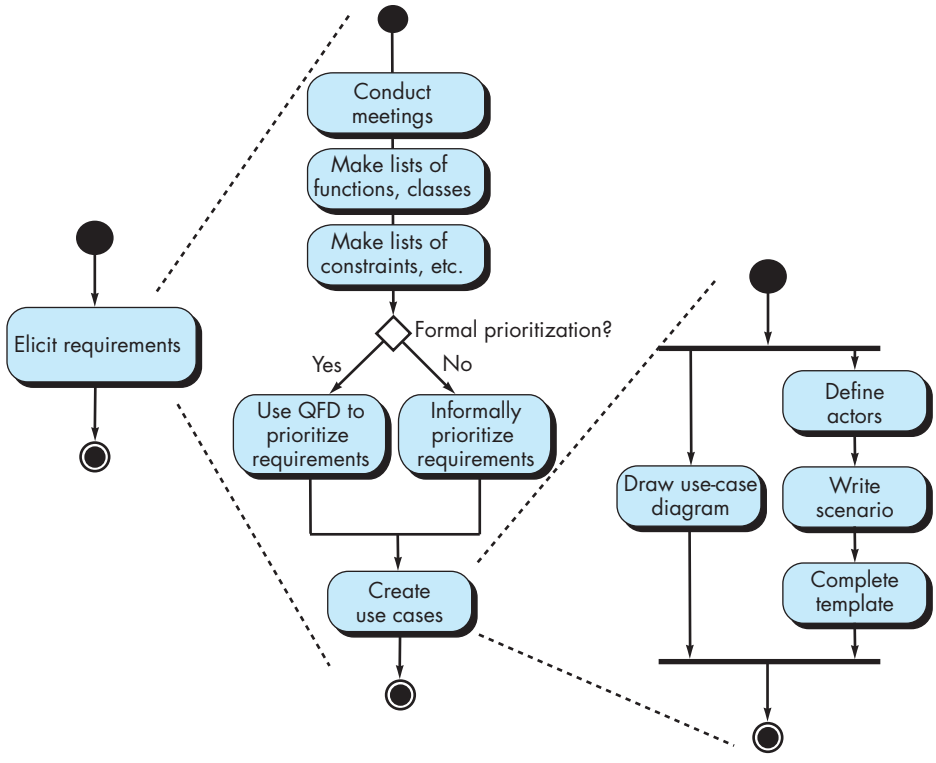
There are many different ways to look at the requirements for a computer-based system. Some software people argue that it's best to select one mode of representation (e.g., the use case) and apply it to the exclusion of all other modes. Other practitioners believe that it's worthwhile to use a number of different modes of representation to depict the analysis model. Different modes of representation force you to consider requirements from different viewpoints—an approach that has a higher probability of uncovering omissions, inconsistencies, and ambiguity. A set of generic elements is common to most analysis models.

15 Tools noted here do not represent an endorsement, but rather a sampling of tools in this category. In most cases, tool names are trademarked by their respective developers.

16 Throughout this book, we use the terms *analysis model* and *requirements model* synonymously. Both refer to representations of the information, functional, and behavioral domains that describe problem requirements.

FIGURE 8.3

UML activity diagrams for eliciting requirements



Scenario-based elements. The system is described from the user's point of view using a scenario-based approach. For example, basic use cases (Section 8.4) and their corresponding use case diagrams (Figure 8.2) evolve into more elaborate template-based use cases. Scenario-based elements of the requirements model are often the first part of the model that is developed. As such, they serve as input for the creation of other modeling elements. Figure 8.3 depicts a UML activity diagram[17] for eliciting requirements and representing them using use cases. Three levels of elaboration are shown, culminating in a scenario-based representation.

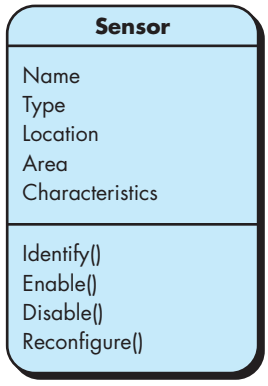
ADVICE

One way to isolate classes is to look for descriptive nouns in a use case script. At least some of the nouns will be candidate classes. More on this in Chapter 12.

Class-based elements. Each usage scenario implies a set of objects that are manipulated as an actor interacts with the system. These objects are categorized into classes—a collection of things that have similar attributes and common behaviors. For example, a UML class diagram can be used to depict a **Sensor** class for the *SafeHome* security function (Figure 8.4). Note that the diagram lists the attributes of sensors (e.g., name, type) and the operations (e.g., *identify, enable*) that can be applied to modify these attributes. In addition to class diagrams, other analysis modeling elements depict the manner in which classes collaborate with

17 A brief UML tutorial is presented in Appendix 1 for those who are unfamiliar with the notation.

FIGURE 8.4
Class diagram for sensor



one another and the relationships and interactions between classes. These are discussed in more detail in Chapter 10.

KEY POINT
A state is an externally observable mode of behavior. External stimuli cause transitions between states.

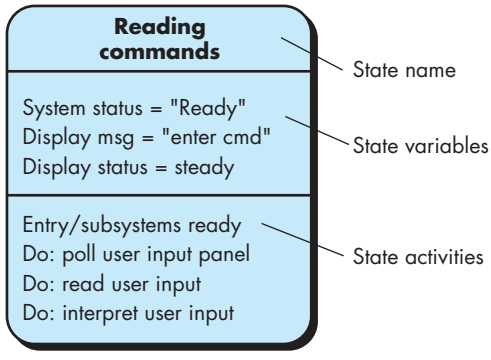
Behavioral elements. The behavior of a computer-based system can have a profound effect on the design that is chosen and the implementation approach that is applied. Therefore, the requirements model must provide modeling elements that depict behavior.

The *state diagram* is one method for representing the behavior of a system by depicting its states and the events that cause the system to change state. A *state* is any observable mode of behavior. In addition, the state diagram indicates what actions (e.g., process activation) are taken as a consequence of a particular event.

To illustrate the use of a state diagram, consider software embedded within the *SafeHome* control panel that is responsible for reading user input. A simplified UML state diagram is shown in Figure 8.5.

In addition to behavioral representations of the system as a whole, the behavior of individual classes can also be modeled. Further discussion of behavioral modeling is presented in Chapter 11.

FIGURE 8.5
UML state diagram notation



SafeHome

Preliminary Behavioral Modeling

The scene: A meeting room, continuing the requirements meeting.

The players: Jamie Lazar, software team member; Vinod Raman, software team member; Ed Robbins, software team member; Doug Miller, software engineering manager; three members of marketing; a product engineering representative; and a facilitator.

The conversation:

Facilitator: We've just about finished talking about *SafeHome* home security functionality. But before we do, I want to discuss the behavior of the function.

Marketing person: I don't understand what you mean by behavior.

Ed (smiling): That's when you give the product a "timeout" if it misbehaves.

Facilitator: Not exactly. Let me explain.

(The facilitator explains the basics of behavioral modeling to the requirements gathering team.)

Marketing person: This seems a little technical. I'm not sure I can help here.

Facilitator: Sure you can. What behavior do you observe from the user's point of view?

Marketing person: Uh . . . well, the system will be *monitoring* the sensors. It'll be *reading commands* from the homeowner. It'll be *displaying* its status.

Facilitator: See, you can do it.

Jamie: It'll also be *polling* the PC to determine if there is any input from it, for example, Internet-based access or configuration information.

Vinod: Yeah, in fact, *configuring the system* is a state in its own right.

Doug: You guys are rolling. Let's give this a bit more thought . . . is there a way to diagram this stuff?

Facilitator: There is, but let's postpone that until after the meeting.

8.5.2 Analysis Patterns

If you want to obtain solutions to customer requirements more rapidly and provide your team with proven approaches, use analysis patterns.

Anyone who has done requirements engineering on more than a few software projects begins to notice that certain problems reoccur across all projects within a specific application domain.[18] These *analysis patterns* [Fow97] suggest solutions (e.g., a class, a function, a behavior) within the application domain that can be reused when modeling many applications.

Geyer-Schulz and Hahsler [Gey01] suggest two benefits that can be associated with the use of analysis patterns:

> First, analysis patterns speed up the development of abstract analysis models that capture the main requirements of the concrete problem by providing reusable analysis models with examples as well as a description of advantages and limitations. Second, analysis patterns facilitate the transformation of the analysis model into a design model by suggesting design patterns and reliable solutions for common problems.

Analysis patterns are integrated into the analysis model by reference to the pattern name. They are also stored in a repository so that requirements

18 In some cases, problems reoccur regardless of the application domain. For example, the features and functions used to solve user interface problems are common regardless of the application domain under consideration.

engineers can use search facilities to find and reuse them. Information about an analysis pattern (and other types of patterns) is presented in a standard template [Gey01][19] that is discussed in more detail in Chapter 16. Examples of analysis patterns and further discussion of this topic are presented in Chapter 11.

8.5.3 Agile Requirements Engineering

The intent of agile requirements engineering is to transfer ideas from stakeholders to the software team rather than create extensive analysis work products. In many situations, requirements are not predefined but emerge as each iteration of product development begins. As the agile team acquires a high-level understanding of a product's critical features use stories (Chapter 5) relevant to the next product increment are refined. The agile process encourages the early identification and implementation of the highest priority product features. This allows the early creation and testing of working prototypes.

Agile requirements engineering addresses important issues that are common in software projects: high requirements volatility, incomplete knowledge of development technology, and customers not able to articulate their visions until they see a working prototype. The agile process interleaves requirements engineering and design activities.

8.5.4 Requirements for Self-Adaptive Systems

Self-adaptive systems[20] can reconfigure themselves, augment their functionality, protect themselves, recover from failure, and accomplish all of this while hiding most of their internal complexity from their users [Qur09]. Adaptive requirements document the variability needed for self-adaptive systems. This means that a requirement must encompass the notion of variability or flexibility while at the same time specifying either a functional or quality aspect of the software product. Variability might include timing uncertainty, user profile differences (e.g., end users versus systems administrators), behavior changes based on problem domain (e.g., commercial or educational), or predefined behaviors exploiting system assets.

? What are the characteristics of a self-adaptive system?

Capturing adaptive requirements focuses on the same questions that are used for requirements engineering of more conventional systems. However, significant variability can be present when answering each of these questions. The more variable the answers, the more complex the resulting system will need to be to accommodate the requirements.

---

19 A variety of patterns templates have been proposed in the literature. If you have interest, see [Fow97], [Gam95], [Yac03], and [Bus07] among many sources.

20 An example of a self-adaptive system is a "location aware" app that adapts its behavior to the location of the mobile platform on which it resides.

8.6 Negotiating Requirements

Quote:

"A compromise is the art of dividing a cake in such a way that everyone believes he has the biggest piece."

Ludwig Erhard

WebRef

A brief paper on negotiation for software requirements can be downloaded from **www.alexander-egyed.com/publications/Software_Requirements_Negotiation-Some_Lessons_Learned.html.**

In an ideal requirements engineering context, the inception, elicitation, and elaboration tasks determine customer requirements in sufficient detail to proceed to subsequent software engineering activities. Unfortunately, this rarely happens. In reality, you may have to enter into a *negotiation* with one or more stakeholders. In most cases, stakeholders are asked to balance functionality, performance, and other product or system characteristics against cost and time-to-market. The intent of this negotiation is to develop a project plan that meets stakeholder needs while at the same time reflecting the real-world constraints (e.g., time, people, budget) that have been placed on the software team.

The best negotiations strive for a "win-win" result.[21] That is, stakeholders win by getting the system or product that satisfies the majority of their needs and you (as a member of the software team) win by working to realistic and achievable budgets and deadlines.

Boehm [Boe98] defines a set of negotiation activities at the beginning of each software process iteration. Rather than a single customer communication activity, the following activities are defined:

1. Identification of the system or subsystem's key stakeholders.
2. Determination of the stakeholders' "win conditions."
3. Negotiation of the stakeholders' win conditions to reconcile them into a set of win-win conditions for all concerned (including the software team).

Successful completion of these initial steps achieves a win-win result, which becomes the key criterion for proceeding to subsequent software engineering activities.

INFO

The Art of Negotiation

Learning how to negotiate effectively can serve you well throughout your personal and technical life. The following guidelines are well worth considering:

1. *Recognize that it's not a competition.* To be successful, both parties have to feel they've won or achieved something. Both will have to compromise.
2. *Map out a strategy.* Decide what you'd like to achieve, what the other party wants to achieve, and how you'll go about making both happen.
3. *Listen actively.* Don't work on formulating your response while the other party is talking. Listen to her. It's likely you'll gain knowledge that will help you to better negotiate your position.
4. *Focus on the other party's interests.* Don't take hard positions if you want to avoid conflict.
5. *Don't let it get personal.* Focus on the problem that needs to be solved.
6. *Be creative.* Don't be afraid to think out of the box if you're at an impasse.
7. *Be ready to commit.* Once an agreement has been reached, don't waffle; commit to it and move on.

21 Dozens of books have been written on negotiating skills (e.g., [Fis11], [Lew09], [Rai06]). It is one of the more important skills that you can learn. Read one.

Fricker [Fri10] and his colleagues suggest replacing the traditional handoff of requirements specifications to software teams with a bidirectional communication process called *handshaking*. In handshaking, the software team proposes solutions to requirements, describes their impact, and communicates their intentions to customer representatives. The customer representatives review the proposed solutions, focusing on missing features and seeking clarification of novel requirements. Requirements are determined to be *good enough* if the customers accept the proposed solution.

Handshaking allows detailed requirements to be delegated to software teams. The teams need to elicit requirements from customers (e.g., product users and domain experts), thereby improving product acceptance. Handshaking tends to improve identification, analysis, and selection of variants and promotes win-win negotiation.

SAFEHOME

The Start of a Negotiation

The scene: Lisa Perez's office, after the first requirements gathering meeting.

The players: Doug Miller, software engineering manager and Lisa Perez, marketing manager.

The conversation:

Lisa: So, I hear the first meeting went really well.

Doug: Actually, it did. You sent some good people to the meeting . . . they really contributed.

Lisa (smiling): Yeah, they actually told me they got into it and it wasn't a "propeller head activity."

Doug (laughing): I'll be sure to take off my techie beanie the next time I visit . . . Look, Lisa, I think we may have a problem with getting all of the functionality for the home security system out by the dates your management is talking about. It's early, I know, but I've already been doing a little back-of-the-envelope planning and . . .

Lisa (frowning): We've got to have it by that date, Doug. What functionality are you talking about?

Doug: I figure we can get full home security functionality out by the drop-dead date, but we'll have to delay Internet access 'til the second release.

Lisa: Doug, it's the Internet access that gives *SafeHome* "gee whiz" appeal. We're going to build our entire marketing campaign around it. We've gotta have it!

Doug: I understand your situation, I really do. The problem is that in order to give you Internet access, we'll have to have a fully secure website up and running. That takes time and people. We'll also have to build a lot of additional functionality into the first release . . . I don't think we can do it with the resources we've got.

Lisa (still frowning): I see, but you've got to figure out a way to get it done. It's pivotal to home security functions and to other functions as well . . . those can wait until the next releases . . . I'll agree to that.

Lisa and Doug appear to be at an impasse, and yet they must negotiate a solution to this problem. Can they both "win" here? Playing the role of a mediator, what would you suggest?

8.7 REQUIREMENTS MONITORING

Today, incremental development is commonplace. This means that use cases evolve, new test cases are developed for each new software increment, and continuous integration of source code occurs throughout a project. *Requirements*

monitoring can be extremely useful when incremental development is used. It encompasses five tasks: (1) *distributed debugging* uncovers errors and determines their cause, (2) *run-time verification* determines whether software matches its specification, (3) *run-time validation* assesses whether the evolving software meets user goals, (4) *business activity monitoring* evaluates whether a system satisfies business goals, and (5) *evolution and codesign* provides information to stakeholders as the system evolves.

Incremental development implies the need for incremental validation. Requirements monitoring supports continuous validation by analyzing user goal models against the system in use. For example, a monitoring system might continuously assess user satisfaction and use feedback to guide incremental improvements [Rob10].

8.8 Validating Requirements

As each element of the requirements model is created, it is examined for inconsistency, omissions, and ambiguity. The requirements represented by the model are prioritized by stakeholders and grouped within requirements packages that will be implemented as software increments. A review of the requirements model addresses the following questions:

When I review requirements, what questions should I ask?

- Is each requirement consistent with the overall objectives for the system or product?
- Have all requirements been specified at the proper level of abstraction? That is, do some requirements provide a level of technical detail that is inappropriate at this stage?
- Is the requirement really necessary or does it represent an add-on feature that may not be essential to the objective of the system?
- Is each requirement bounded and unambiguous?
- Does each requirement have attribution? That is, is a source (generally, a specific individual) noted for each requirement?
- Do any requirements conflict with other requirements?
- Is each requirement achievable in the technical environment that will house the system or product?
- Is each requirement testable, once implemented?
- Does the requirements model properly reflect the information, function, and behavior of the system to be built?
- Has the requirements model been "partitioned" in a way that exposes progressively more detailed information about the system?

- Have requirements patterns been used to simplify the requirements model? Have all patterns been properly validated? Are all patterns consistent with customer requirements?

These and other questions should be asked and answered to ensure that the requirements model is an accurate reflection of stakeholder needs and that it provides a solid foundation for design.

8.9 Avoiding Common Mistakes

Buschmann [Bus10] describes three related mistakes that must be avoided as a software team performs requirements engineering. He calls them: featuritis, flexibilitis, and performitis.

Fearturitis describes the practice of trading functional coverage for overall system quality. There is a tendency in some organizations to equate the quantity of functions delivered at the earliest possible time with the overall quality of the end product. This is driven in part by business stakeholders who think more is better. There is also a tendency of software developers to want to implement easy functions quickly without thought to their quality. The reality is that one of the most common causes of software project failure is lack of operational quality—*not* missing functionality. To avoid this trap, you should initiate a discussion (with other stakeholders) about the key functions the system requires and ensure that each delivered function exhibits all necessary quality attributes.

Flexibilitis happens when software engineers overload product with adaptation and configuration facilities. Overly flexible systems are hard to configure and exhibit poor operational performance. This can be a symptom of poorly defined system scope. The root cause, however, may be developers who use flexibility as a cover for uncertainty. Rather than making tough design decisions early, they provide design "hooks" to allow the addition of unplanned features. The result is a "flexible" system that is unnecessarily complex, more difficult to test, and more challenging to manage.

Performitis occurs when software developers become overly focused on system performance at the expense of quality attributes like maintainability, reliability, or security. System performance characteristics should be determined as part of an evaluation of nonfunctional software requirements. Performance should conform to the business need for a product and must be compatible with the other system characteristics.

8.10 Summary

Requirements engineering tasks are conducted to establish a solid foundation for design and construction. Requirements engineering occurs during the communication and modeling activities that have been defined for the generic software

uml models 179
use cases 173
use case exception 177

particularly to the Target Document [software requirements specification]. Problems of size must be dealt with using an effective method of partitioning. The Victorian novel specification is out. Graphics have to be used whenever possible. We have to differentiate between logical [essential] and physical [implementation] considerations . . . At the very least, we need . . . Something to help us partition our requirements and document that partitioning before specification . . . Some means of keeping track of and evaluating interfaces . . . New tools to describe logic and policy, something better than narrative text

Although DeMarco wrote about the attributes of analysis modeling more than three decades ago, his comments still apply to modern requirements modeling methods and notation.

9.1 Requirements Analysis

Quote:

"Any one 'view' of requirements is insufficient to understand or describe the desired behavior of a complex system."

Alan M. Davis

Requirements analysis results in the specification of software's operational characteristics, indicates software's interface with other system elements, and establishes constraints that software must meet. Requirements analysis allows you (regardless of whether you're called a *software engineer,* an *analyst,* or a *modeler*) to elaborate on basic requirements established during the inception, elicitation, and negotiation tasks that are part of requirements engineering (Chapter 8).

The requirements modeling action results in one or more of the following types of models:

- *Scenario-based models* of requirements from the point of view of various system "actors."
- *Class-oriented models* that represent object-oriented classes (attributes and operations) and the manner in which classes collaborate to achieve system requirements.
- *Behavioral and patterns-based models* that depict how the software behaves as a consequence of external "events."
- *Data models* that depict the information domain for the problem.
- *Flow-oriented models* that represent the functional elements of the system and how they transform data as they move through the system.

KEY POINT

The analysis model and requirements specification provide a means for assessing quality once the software is built.

These models provide a software designer with information that can be translated to architectural-, interface-, and component-level designs. Finally, the requirements model (and the software requirements specification) provides the developer and the customer with the means to assess quality once software is built.

In this chapter, we focus on *scenario-based modeling*—a technique that is growing increasingly popular throughout the software engineering community. In Chapters 10 and 11 we consider class-based models and behavioral models. Over the past decade, flow and data modeling have become less commonly used, while scenario and class-based methods, supplemented with behavioral approaches and pattern-based techniques have grown in popularity.[2]

Quote:

"Requirements are not architecture. Requirements are not design, nor are they the user interface. Requirements are need."

Andrew Hunt and David Thomas

9.1.1 Overall Objectives and Philosophy

Throughout analysis modeling, your primary focus is on *what,* not *how.* What user interaction occurs in a particular circumstance, what objects does the system manipulate, what functions must the system perform, what behaviors does the system exhibit, what interfaces are defined, and what constraints apply?[3]

In previous chapters, we noted that complete specification of requirements may not be possible at this stage. The customer may be unsure of precisely what is required for certain aspects of the system. The developer may be unsure that a specific approach will properly accomplish function and performance. These realities mitigate in favor of an iterative approach to requirements analysis and modeling. The analyst should model what is known and use that model as the basis for design of the software increment.[4]

KEY POINT

The analysis model should describe what the customer wants, establish a basis for design, and establish a target for validation.

The requirements model must achieve three primary objectives: (1) to describe what the customer requires, (2) to establish a basis for the creation of a software design, and (3) to define a set of requirements that can be validated once the software is built. The analysis model bridges the gap between a system-level description that describes overall system or business functionality as it is achieved by applying software, hardware, data, human, and other system elements and a software design (Chapters 12 through 18) that describes the software's application architecture, user interface, and component-level structure. This relationship is illustrated in Figure 9.1.

It is important to note that all elements of the requirements model will be directly traceable to parts of the design model. A clear division of analysis and design tasks between these two important modeling activities is not always possible. Some design invariably occurs as part of analysis, and some analysis will be conducted during design.

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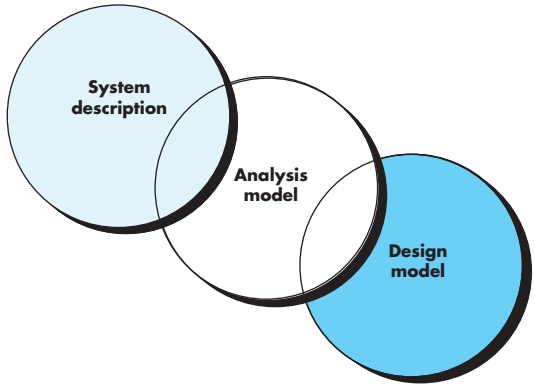
2 Our presentation of flow-oriented modeling and data modeling has been omitted from this edition. However, copious information about these older requirements modeling methods can be found on the Web. If you have interest, use the search phrase "structured analysis."

3 It should be noted that as customers become more technologically sophisticated, there is a trend toward the specification of *how* as well as *what.* However, the primary focus should remain on *what.*

4 Alternatively, the software team may choose to create a prototype (Chapter 4) in an effort to better understand requirements for the system.

FIGURE 9.1
The requirements model as a bridge between the system description and the design model



9.1.2 Analysis Rules of Thumb

Arlow and Neustadt [Arl02] suggest a number of worthwhile rules of thumb that should be followed when creating the analysis model:

? Are there some basic guidelines that can guide us as we do requirements analysis work?

- *The model should focus on requirements that are visible within the problem or business domain. The level of abstraction should be relatively high.* "Don't get bogged down in details" [Arl02] that try to explain how the system will work.
- *Each element of the requirements model should add to an overall understanding of software requirements and provide insight into the information domain, function, and behavior of the system.*
- *Delay consideration of infrastructure and other nonfunctional models until design.* That is, a database may be required, but the classes necessary to implement it, the functions required to access it, and the behavior that will be exhibited as it is used should be considered only after problem domain analysis has been completed.
- *Minimize coupling throughout the system.* It is important to represent relationships between classes and functions. However, if the level of "interconnectedness" is extremely high, efforts should be made to reduce it.
- *Be certain that the requirements model provides value to all stakeholders.* Each constituency has its own use for the model. For example, business stakeholders should use the model to validate requirements; designers should use the model as a basis for design; QA people should use the model to help plan acceptance tests.
- *Keep the model as simple as it can be.* Don't add additional diagrams when they add no new information. Don't use complex notational forms when a simple list will do.

Quote:
"Problems worthy of attack, prove their worth by hitting back."
Piet Hein

9.1.3 Domain Analysis

WebRef

Many useful resources for domain analysis and many other topics can be found at **http://www.sei.cmu.edu/**.

In the discussion of requirements engineering (Chapter 8), we noted that analysis patterns often reoccur across many applications within a specific business domain. If these patterns are defined and categorized in a manner that allows you to recognize and apply them to solve common problems, the creation of the analysis model is expedited. More important, the likelihood of applying design patterns and executable software components grows dramatically. This improves time-to-market and reduces development costs.

But how are analysis patterns and classes recognized in the first place? Who defines them, categorizes them, and readies them for use on subsequent projects? The answers to these questions lie in *domain analysis*. Firesmith [Fir93] describes domain analysis in the following way:

> Software domain analysis is the identification, analysis, and specification of common requirements from a specific application domain, typically for reuse on multiple projects within that application domain . . . [Object-oriented domain analysis is] the identification, analysis, and specification of common, reusable capabilities within a specific application domain, in terms of common objects, classes, subassemblies, and frameworks.

KEY POINT

Domain analysis doesn't look at a specific application, but rather at the domain in which the application resides. The intent is to identify common problem solving elements that are applicable to all applications within the domain.

The "specific application domain" can range from avionics to banking, from multimedia video games to software embedded within medical devices. The goal of domain analysis is straightforward: to find or create those analysis classes and/or analysis patterns that are broadly applicable so that they may be reused.[5]

Using terminology that was introduced previously in this book, domain analysis may be viewed as an umbrella activity for the software process. By this we mean that domain analysis is an ongoing software engineering activity that is not connected to any one software project. In a way, the role of a domain analyst is similar to the role of a master toolsmith in a heavy manufacturing environment. The job of the toolsmith is to design and build tools that may be used by many people doing similar but not necessarily the same jobs. The role of the domain analyst[6] is to discover and define analysis patterns, analysis classes, and related information that may be used by many people working on similar but not necessarily the same applications.

Figure 9.2 [Arn89] illustrates key inputs and outputs for the domain analysis process. Sources of domain knowledge are surveyed in an attempt to identify objects that can be reused across the domain.

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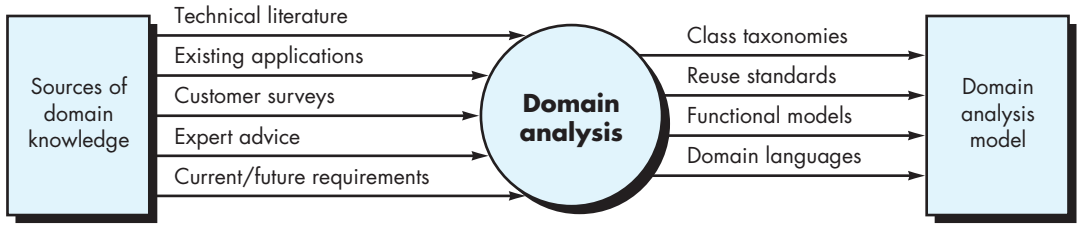
5 A complementary view of domain analysis "involves modeling the domain so that software engineers and other stakeholders can better learn about it . . . not all domain classes necessarily result in the development of reusable classes." [Let03a]

6 Do not make the assumption that because a domain analyst is at work, a software engineer need not understand the application domain. Every member of a software team should have some understanding of the domain in which the software is to be placed.

FIGURE 9.2 Input and output for domain analysis



SAFEHOME

Domain Analysis

The scene: Doug Miller's office, after a meeting with marketing.

The players: Doug Miller, software engineering manager, and Vinod Raman, a member of the software engineering team.

The conversation:

Doug: I need you for a special project, Vinod. I'm going to pull you out of the requirements-gathering meetings.

Vinod (frowning): Too bad. That format actually works . . . I was getting something out of it. What's up?

Doug: Jamie and Ed will cover for you. Anyway, marketing insists that we deliver the Internet capability along with the home security function in the first release of *SafeHome*. We're under the gun on this . . . not enough time or people, so we've got to solve both problems—the PC interface and the Web interface—at once.

Vinod (looking confused): I didn't know the plan was set . . . we're not even finished with requirements gathering.

Doug (a wan smile): I know, but the time lines are so short that I decided to begin strategizing with marketing right now . . . anyhow, we'll revisit any tentative plan once we have the info from all of the requirements-gathering meetings.

Vinod: Okay, what's up? What do you want me to do?

Doug: Do you know what "domain analysis" is?

Vinod: Sort of. You look for similar patterns in Apps that do the same kinds of things as the App you're building. If possible, you then steal the patterns and reuse them in your work.

Doug: Not sure I like the word *steal,* but basically you have it right. What I'd like you to do is to begin researching existing user interfaces for systems that control something like *SafeHome*. I want you to propose a set of patterns and analysis classes that can be common to both the PC-based interface that'll sit in the house and the browser-based interface that is accessible via the Internet.

Vinod: We can save time by making them the same . . . why don't we just do that?

Doug: Ah . . . it's nice to have people who think like you do. That's the whole point—we can save time and effort if both interfaces are nearly identical, implemented with the same code, blah, blah, that marketing insists on.

Vinod: So you want, what—classes, analysis patterns, design patterns?

Doug: All of 'em. Nothing formal at this point. I just want to get a head start on our internal analysis and design work.

Vinod: I'll go to our class library and see what we've got. I'll also use a patterns template I saw in a book I was reading a few months back.

Doug: Good. Go to work.

9.1.4 Requirements Modeling Approaches

One view of requirements modeling, called *structured analysis*, considers data and the processes that transform the data as separate entities. Data objects are modeled in a way that defines their attributes and relationships. Processes that

Quote:

"[A]nalysis is frustrating, full of complex interpersonal relationships, indefinite, and difficult. In a word, it is fascinating. Once you're hooked, the old easy pleasures of system building are never again enough to satisfy you."

Tom DeMarco

manipulate data objects are modeled in a manner that shows how they transform data as data objects flow through the system.

A second approach to analysis modeling, called *object-oriented analysis*, focuses on the definition of classes and the manner in which they collaborate with one another to effect customer requirements. UML and the Unified Process (Chapter 4) are predominantly object oriented.

In this edition of the book, we have chosen to emphasize elements of object-oriented analysis as it is modeled using UML. Our goal is to suggest a combination of representations will provide stakeholders with the best model of software requirements and the most effective bridge to software design.

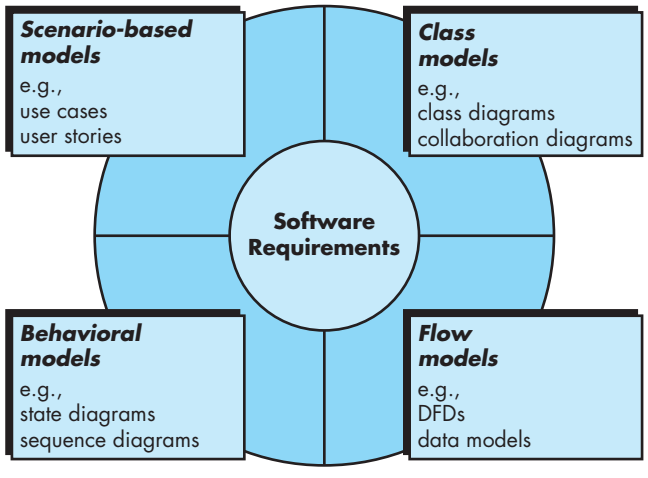
Each element of the requirements model (Figure 9.3) presents the problem from a different point of view. Scenario-based elements depict how the user interacts with the system and the specific sequence of activities that occur as the software is used. Class-based elements model the objects that the system will manipulate, the operations that will be applied to the objects to effect the manipulation, relationships (some hierarchical) between the objects, and the collaborations that occur between the classes that are defined. Behavioral elements depict how external events change the state of the system or the classes that reside within it. Finally, flow-oriented elements represent the system as an information transform, depicting how data objects are transformed as they flow through various system functions.

? What different points of view can be used to describe the requirements model?

Analysis modeling leads to the derivation of one or more of these modeling elements. However, the specific content of each element (i.e., the diagrams that are used to construct the element and the model) may differ from project to project. As we have noted a number of times in this book, the software team must work to keep it simple. Only those modeling elements that add value to the model should be used.

FIGURE 9.3

Elements of the analysis model



9.2 Scenario-Based Modeling

Although the success of a computer-based system or product is measured in many ways, user satisfaction resides at the top of the list. If you understand how end users (and other actors) want to interact with a system, your software team will be better able to properly characterize requirements and build meaningful analysis and design models. Hence, requirements modeling with UML[7] begins with the creation of scenarios in the form of use cases, activity diagrams, and swimlane diagrams.

9.2.1 Creating a Preliminary Use Case

Quote:

"[Use cases] are simply an aid to defining what exists outside the system (actors) and what should be performed by the system (use cases)."

Ivar Jacobson

Alistair Cockburn characterizes a use case as a "contract for behavior" [Coc01b]. As we discussed in Chapter 8, the "contract" defines the way in which an actor[8] uses a computer-based system to accomplish some goal. In essence, a use case captures the interactions that occur between producers and consumers of information and the system itself. In this section, we examine how use cases are developed as part of the analysis modeling activity.[9]

In Chapter 8, we noted that a use case describes a specific usage scenario in straightforward language from the point of view of a defined actor. But how do you know (1) what to write about, (2) how much to write about it, (3) how detailed to make your description, and (4) how to organize the description? These are the questions that must be answered if use cases are to provide value as a requirements modeling tool.

ADVICE

In some situations, use cases become the dominant requirements engineering mechanism. However, this does not mean that you should discard other modeling methods when they are appropriate.

What to Write About? The first two requirements engineering tasks—inception and elicitation—provide you with the information you'll need to begin writing use cases. Requirements-gathering meetings, quality function deployment (QFD), and other requirements engineering mechanisms are used to identify stakeholders, define the scope of the problem, specify overall operational goals, establish priorities, outline all known functional requirements, and describe the things (objects) that will be manipulated by the system.

To begin developing a set of use cases, list the functions or activities performed by a specific actor. You can obtain these from a list of required system functions, through conversations with stakeholders, or by an evaluation of activity diagrams (Section 9.3.1) developed as part of requirements modeling.

---

7 UML will be used as the modeling notation throughout this book. Appendix 1 provides a brief tutorial for those readers who may be unfamiliar with basic UML notation.

8 An actor is not a specific person, but rather a role that a person (or a device) plays within a specific context. An actor "calls on the system to deliver one of its services " [Coc01b].

9 Use cases are a particularly important part of analysis modeling for user interfaces. Interface analysis and design is discussed in detail in Chapter 15.

SafeHome

Developing Another Preliminary User Scenario

The scene: A meeting room, during the second requirements-gathering meeting.

The players: Jamie Lazar, software team member; Ed Robbins, software team member; Doug Miller, software engineering manager; three members of marketing; a product engineering representative; and a facilitator.

The conversation:

Facilitator: It's time that we begin talking about the *SafeHome* surveillance function. Let's develop a user scenario for access to the surveillance function.

Jamie: Who plays the role of the actor on this?

Facilitator: I think Meredith (a marketing person) has been working on that functionality. Why don't you play the role?

Meredith: You want to do it the same way we did it last time, right?

Facilitator: Right . . . same way.

Meredith: Well, obviously the reason for surveillance is to allow the homeowner to check out the house while he or she is away, to record and play back video that is captured . . . that sort of thing.

Ed: Will we use compression to store the video?

Facilitator: Good question, Ed, but let's postpone implementation issues for now. Meredith?

Meredith: Okay, so basically there are two parts to the surveillance function . . . the first configures the system including laying out a floor plan—we have to have tools to help the homeowner do this—and the second part is the actual surveillance function itself. Since the layout is part of the configuration activity, I'll focus on the surveillance function.

Facilitator (smiling): Took the words right out of my mouth.

Meredith: Um . . . I want to gain access to the surveillance function either via the PC or via the Internet. My feeling is that the Internet access would be more frequently used. Anyway, I want to be able to display camera views on a PC and control pan and zoom for a specific camera. I specify the camera by selecting it from the house floor plan. I want to selectively record camera output and replay camera output. I also want to be able to block access to one or more cameras with a specific password. I also want the option of seeing small windows that show views from all cameras and then be able to pick the one I want enlarged.

Jamie: Those are called thumbnail views.

Meredith: Okay, then I want thumbnail views of all the cameras. I also want the interface for the surveillance function to have the same look and feel as all other *SafeHome* interfaces. I want it to be intuitive, meaning I don't want to have to read a manual to use it.

Facilitator: Good job. Now, let's go into this function in a bit more detail . . .

The *SafeHome* home surveillance function (subsystem) discussed in the sidebar identifies the following functions (an abbreviated list) that are performed by the **homeowner** actor:

- Select camera to view.
- Request thumbnails from all cameras.
- Display camera views in a PC window.
- Control pan and zoom for a specific camera.
- Selectively record camera output.
- Replay camera output.
- Access camera surveillance via the Internet.

As further conversations with the stakeholder (who plays the role of a homeowner) progress, the requirements-gathering team develops use cases for each of the functions noted. In general, use cases are written first in an informal narrative fashion. If more formality is required, the same use case is rewritten using a structured format similar to the one proposed in Chapter 8 and reproduced later in this section as a sidebar.

To illustrate, consider the function *access camera surveillance via the Internet—display camera views* (**ACS-DCV**). The stakeholder who takes on the role of the **homeowner** actor might write the following narrative:

Use case: Access camera surveillance via the Internet—display camera views (ACS-DCV)

Actor: homeowner

If I'm at a remote location, I can use any PC with appropriate browser software to log on to the *SafeHome Products* website. I enter my user ID and two levels of passwords and once I'm validated, I have access to all functionality for my installed *SafeHome* system. To access a specific camera view, I select "surveillance" from the major function buttons displayed. I then select "pick a camera" and the floor plan of the house is displayed. I then select the camera that I'm interested in. Alternatively, I can look at thumbnail snapshots from all cameras simultaneously by selecting "all cameras" as my viewing choice. Once I choose a camera, I select "view" and a one-frame-per-second view appears in a viewing window that is identified by the camera ID. If I want to switch cameras, I select "pick a camera" and the original viewing window disappears and the floor plan of the house is displayed again. I then select the camera that I'm interested in. A new viewing window appears.

A variation of a narrative use case presents the interaction as an ordered sequence of user actions. Each action is represented as a declarative sentence. Revisiting the **ACS-DCV** function, you would write:

Use case: Access camera surveillance via the Internet—display camera views (ACS-DCV)

Actor: homeowner

1. The homeowner logs onto the *SafeHome Products* website.
2. The homeowner enters his or her user ID.
3. The homeowner enters two passwords (each at least eight characters in length).
4. The system displays all major function buttons.
5. The homeowner selects the "surveillance" from the major function buttons.
6. The homeowner selects "pick a camera."
7. The system displays the floor plan of the house.
8. The homeowner selects a camera icon from the floor plan.
9. The homeowner selects the "view" button.

Quote:

"Use cases can be used in many [software] processes. Our favorite is a process that is iterative and risk driven."

Geri Schneider and Jason Winters

10. The system displays a viewing window that is identified by the camera ID.
11. The system displays video output within the viewing window at one frame per second.

It is important to note that this sequential presentation does not consider any alternative interactions (the narrative is more free flowing and did represent a few alternatives). Use cases of this type are sometimes referred to as *primary scenarios* [Sch98a].

9.2.2 Refining a Preliminary Use Case

A description of alternative interactions is essential for a complete understanding of the function that is being described by a use case. Therefore, each step in the primary scenario is evaluated by asking the following questions [Sch98a]:

? How do I examine alternative courses of action when I develop a use case?

- *Can the actor take some other action at this point?*
- *Is it possible that the actor will encounter some error condition at this point?* If so, what might it be?
- *Is it possible that the actor will encounter some other behavior at this point (e.g., behavior that is invoked by some event outside the actor's control)?* If so, what might it be?

Answers to these questions result in the creation of a set of *secondary scenarios* that are part of the original use case but represent alternative behavior. For example, consider steps 6 and 7 in the primary scenario presented earlier:

6. The homeowner selects "pick a camera."
7. The system displays the floor plan of the house.

Can the actor take some other action at this point? The answer is yes. Referring to the free-flowing narrative, the actor may choose to view thumbnail snapshots of all cameras simultaneously. Hence, one secondary scenario might be "View thumbnail snapshots for all cameras."

Is it possible that the actor will encounter some error condition at this point? Any number of error conditions can occur as a computer-based system operates. In this context, we consider only error conditions that are likely as a direct result of the action described in step 6 or step 7. Again the answer to the question is yes. A floor plan with camera icons may have never been configured. Hence, selecting "pick a camera" results in an error condition: "No floor plan configured for this house."[10] This error condition becomes a secondary scenario.

10 In this case, another actor, the **system administrator,** would have to configure the floor plan, install and initialize (e.g., assign an equipment ID) all cameras, and test each camera to be certain that it is accessible via the system and through the floor plan.

Is it possible that the actor will encounter some other behavior at this point? Again the answer to the question is yes. As steps 6 and 7 occur, the system may encounter an alarm condition. This would result in the system displaying a special alarm notification (type, location, system action) and providing the actor with a number of options relevant to the nature of the alarm. Because this secondary scenario can occur at any time for virtually all interactions, it will not become part of the **ACS-DCV** use case. Rather, a separate use case—**Alarm condition encountered**—would be developed and referenced from other use cases as required.

What is a use case exception and how do I determine what exceptions are likely?

Each of the situations described in the preceding paragraphs is characterized as a use case exception. An *exception* describes a situation (either a failure condition or an alternative chosen by the actor) that causes the system to exhibit somewhat different behavior.

Cockburn [Coc01b] recommends a "brainstorming" session to derive a reasonably complete set of exceptions for each use case. In addition to the three generic questions suggested earlier in this section, the following issues should also be explored:

- *Are there cases in which some "validation function" occurs during this use case?* This implies that validation function is invoked and a potential error condition might occur.
- *Are there cases in which a supporting function (or actor) will fail to respond appropriately?* For example, a user action awaits a response but the function that is to respond times out.
- *Can poor system performance result in unexpected or improper user actions?* For example, a Web-based interface responds too slowly, resulting in a user making multiple selects on a processing button. These selects queue inappropriately and ultimately generate an error condition.

The list of extensions developed as a consequence of asking and answering these questions should be "rationalized" [Co01b] using the following criteria: an exception should be noted within the use case if the software can detect the condition described and then handle the condition once it has been detected. In some cases, an exception will precipitate the development of another use case (to handle the condition noted).

9.2.3 Writing a Formal Use Case

The informal use cases presented in Section 9.2.1 are sometimes sufficient for requirements modeling. However, when a use case involves a critical activity or describes a complex set of steps with a significant number of exceptions, a more formal approach may be desirable.

The **ACS-DCV** use case shown in the sidebar follows a typical outline for formal use cases. The *goal in context* identifies the overall scope of the use case.

The *precondition* describes what is known to be true before the use case is initiated. The *trigger* identifies the event or condition that "gets the use case started" [Coc01b]. The *scenario* lists the specific actions that are required by the actor and the appropriate system responses. *Exceptions* identify the situations uncovered as the preliminary use case is refined (Section 9.2.2). Additional headings may or may not be included and are reasonably self-explanatory.

SafeHome

Use Case Template for Surveillance

Use case: Access camera surveillance via the Internet—display camera views (ACS-DCV)

Iteration: 2, last modification: January 14 by V. Raman.

Primary actor: Homeowner.

Goal in context: To view output of camera placed throughout the house from any remote location via the Internet.

Preconditions: System must be fully configured; appropriate user ID and passwords must be obtained.

Trigger: The homeowner decides to take a look inside the house while away.

Scenario:

1. The homeowner logs onto the *SafeHome Products* website.
2. The homeowner enters his or her user ID.
3. The homeowner enters two passwords (each at least eight characters in length).
4. The system displays all major function buttons.
5. The homeowner selects the "surveillance" from the major function buttons.
6. The homeowner selects "pick a camera."
7. The system displays the floor plan of the house.
8. The homeowner selects a camera icon from the floor plan.
9. The homeowner selects the "view" button.
10. The system displays a viewing window that is identified by the camera ID.
11. The system displays video output within the viewing window at one frame per second.

Exceptions:

1. ID or passwords are incorrect or not recognized—see use case **Validate ID and passwords.**
2. Surveillance function not configured for this system—system displays appropriate error message; see use case **Configure surveillance function.**
3. Homeowner selects "View thumbnail snapshots for all camera"—see use case **View thumbnail snapshots for all cameras.**
4. A floor plan is not available or has not been configured—display appropriate error message and see use case **Configure floor plan.**
5. An alarm condition is encountered—see use case **alarm condition encountered.**

Priority: Moderate priority, to be implemented after basic functions.

When available: Third increment.

Frequency of use: Infrequent.

Channel to actor: Via PC-based browser and Internet connection.

Secondary actors: System administrator, cameras.

Channels to secondary actors:

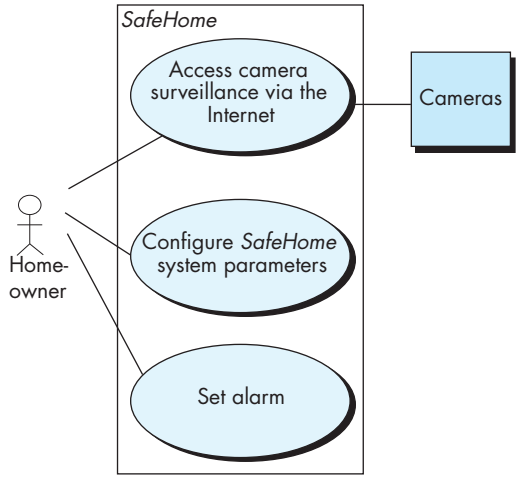
1. System administrator: PC-based system.
2. Cameras: wireless connectivity.

Open issues:

1. What mechanisms protect unauthorized use of this capability by employees of *SafeHome Products*?
2. Is security sufficient? Hacking into this feature would represent a major invasion of privacy.
3. Will system response via the Internet be acceptable given the bandwidth required for camera views?
4. Will we develop a capability to provide video at a higher frames-per-second rate when high-bandwidth connections are available?

FIGURE 9.4

Preliminary use case diagram for the *SafeHome* system



WebRef

When are you finished writing use cases? For a worthwhile discussion of this topic, see **ootips.org/use-cases-done.html**.

In many cases, there is no need to create a graphical representation of a usage scenario. However, diagrammatic representation can facilitate understanding, particularly when the scenario is complex. As we noted earlier in this book, UML does provide use case diagramming capability. Figure 9.4 depicts a preliminary use case diagram for the *SafeHome* product. Each use case is represented by an oval. Only the **ACS-DCV** use case has been discussed in this section.

Every modeling notation has limitations, and the use case is no exception. Like any other form of written description, a use case is only as good as its author(s). If the description is unclear, the use case can be misleading or ambiguous. A use case focuses on function and behavioral requirements and is generally inappropriate for nonfunctional requirements. For situations in which the requirements model must have significant detail and precision (e.g., safety critical systems), a use case may not be sufficient.

However, scenario-based modeling is appropriate for a significant majority of all situations that you will encounter as a software engineer. If developed properly, the use case can provide substantial benefit as a modeling tool.

9.3 UML MODELS THAT SUPPLEMENT THE USE CASE

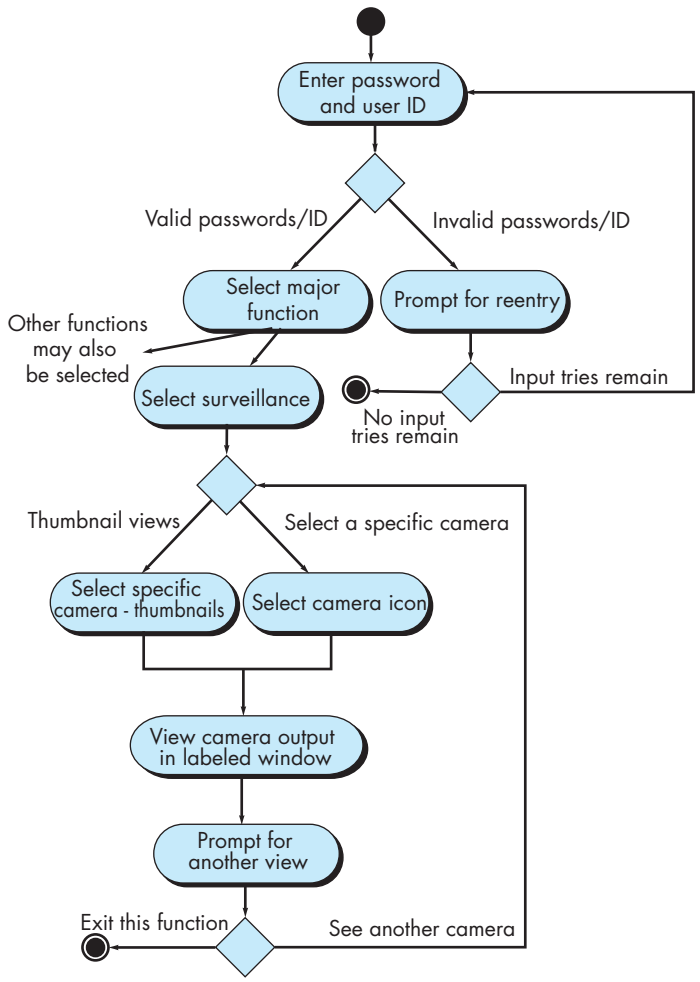
There are many requirements modeling situations in which a text-based model—even one as simple as a use case—may not impart information in a clear and concise manner. In such cases, you can choose from a broad array of UML graphical models.

9.3.1 Developing an Activity Diagram

The UML activity diagram supplements the use case by providing a graphical representation of the flow of interaction within a specific scenario. Similar to the flowchart, an activity diagram uses rounded rectangles to imply a specific system function, arrows to represent flow through the system, decision diamonds to depict a branching decision (each arrow emanating from the diamond is labeled), and solid horizontal lines to indicate that parallel activities are occurring. An activity diagram for the **ACS-DCV** use case is shown in Figure 9.5. It should be noted that the activity diagram adds additional detail not directly mentioned (but implied) by the use case. For example, a user may only attempt to enter **userID** and **password** a limited number of times. This is represented by a decision diamond below "Prompt for reentry."

FIGURE 9.5

Activity diagram for Access camera surveillance via the Internet—display camera views function.



9.3.2 Swimlane Diagrams

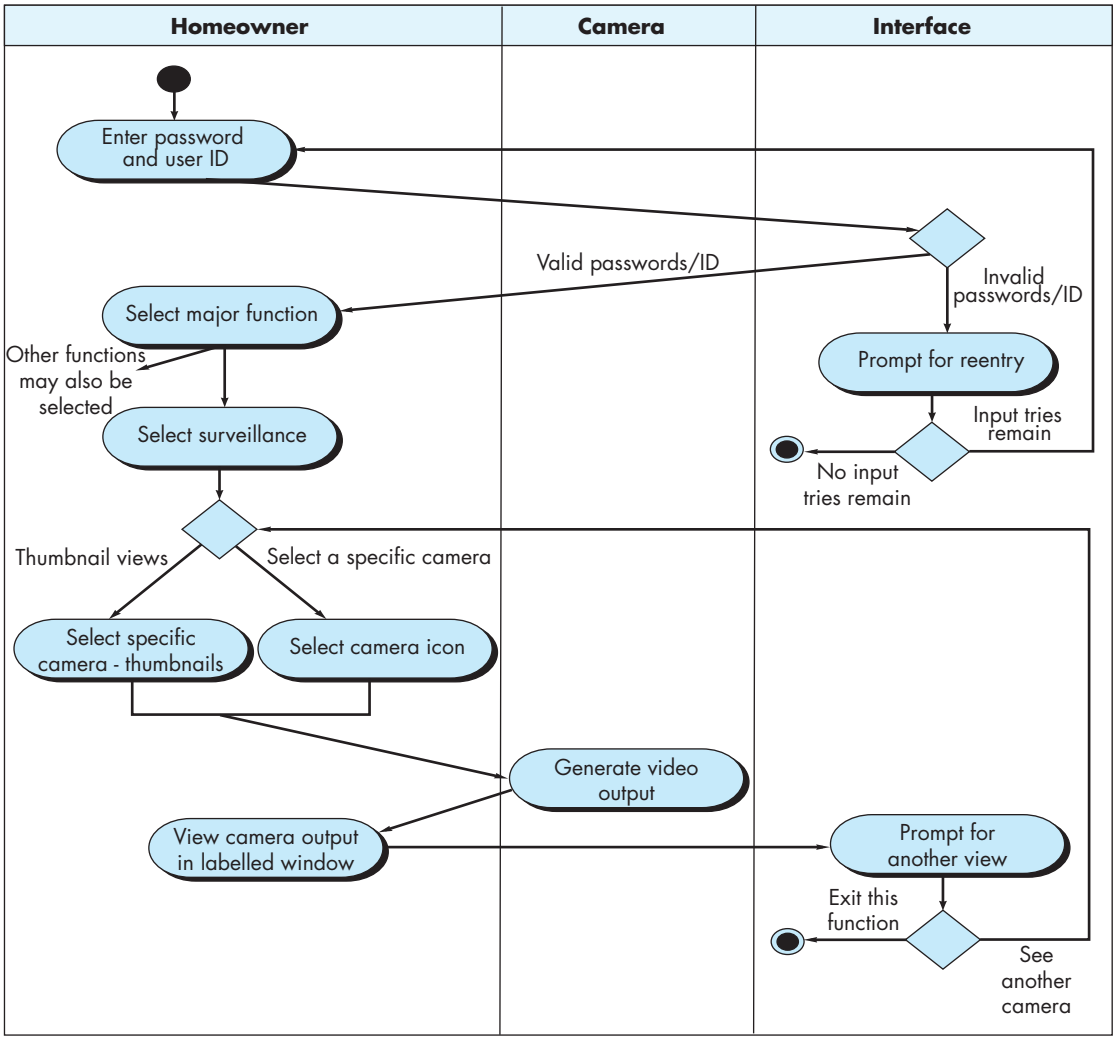
KEY POINT

A UML swimlane diagram represents the flow of actions and decisions and indicates which actors perform each.

The UML *swimlane diagram* is a useful variation of the activity diagram and allows you to represent the flow of activities described by the use case and at the same time indicate which actor (if there are multiple actors involved in a specific use case) or analysis class (Chapter 10) has responsibility for the action described by an activity rectangle. Responsibilities are represented as parallel segments that divide the diagram vertically, like the lanes in a swimming pool.

Three analysis classes—**Homeowner**, **Camera**, and **Interface**—have direct or indirect responsibilities in the context of the activity diagram represented in Figure 9.5. Referring to Figure 9.6, the activity diagram is rearranged so that

FIGURE 9.6 **Swimlane diagram for Access camera surveillance via the Internet—display camera views function.**



activities associated with a particular analysis class fall inside the swimlane for that class. For example, the **Interface** class represents the user interface as seen by the homeowner. The activity diagram notes two prompts that are the responsibility of the interface—"prompt for reentry" and "prompt for another view." These prompts and the decisions associated with them fall within the **Interface** swimlane. However, arrows lead from that swimlane back to the **Homeowner** swimlane, where homeowner actions occur.

Quote:

"A good model guides your thinking, a bad one warps it."

Brian Marick

Use cases, along with the activity and swimlane diagrams, are procedurally oriented. They represent the manner in which various actors invoke specific functions (or other procedural steps) to meet the requirements of the system. But a procedural view of requirements represents only a single dimension of a system In Chapters 10 and 11, we examine other dimensions of requirements modeling.

9.4 Summary

The objective of requirements modeling is to create a variety of representations that describe what the customer requires, establish a basis for the creation of a software design, and define a set of requirements that can be validated once the software is built. The requirements model bridges the gap between a system-level description that describes overall system and business functionality and a software design that describes the software's application architecture, user interface, and component-level structure.

Scenario-based models depict software requirements from the user's point of view. The use case—a narrative or template-driven description of an interaction between an actor and the software—is the primary modeling element. Derived during requirements elicitation, the use case defines the keys steps for a specific function or interaction. The degree of use case formality and detail varies, but the end result provides necessary input to all other analysis modeling activities. Scenarios can also be described using an activity diagram—a flowchart-like graphical representation that depicts the processing flow within a specific scenario. Swimlane diagrams illustrate how the processing flow is allocated to various actors or classes.

Problems and Points to Ponder

9.1. Is it possible to begin coding immediately after a requirements model has been created? Explain your answer and then argue the counterpoint.

9.2. An analysis rule of thumb is that the model "should focus on requirements that are visible within the problem or business domain." What types of requirements are *not* visible in these domains? Provide a few examples.