

# MODULE-1

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## SOFTWARE AND SOFTWARE ENGINEERING

**H**e had the classic look of a senior executive for a major software company—mid-40s, slightly graying at the temples, trim and athletic, with eyes that penetrated the listener as he spoke. But what he said shocked me. “Software is *dead*.”

I blinked with surprise and then smiled. “You’re joking, right? The world is driven by software and your company has profited handsomely because of it. It isn’t dead! It’s alive and growing.”

He shook his head emphatically. “No, it’s dead . . . at least as we once knew it.” I leaned forward. “Go on.”

He spoke while tapping the table for emphasis. “The old-school view of software—you buy it, you own it, and it’s your job to manage it—that’s coming to an end. Today, with Web 2.0 and pervasive computing coming on strong, we’re going to be seeing a completely different generation of software. It’ll be delivered via the Internet and will look exactly like it’s residing on each user’s computing device . . . but it’ll reside on a far-away server.”

### QUICK LOOK

**What is it?** Computer software is the product that software professionals build and then support over the long term. It encompasses programs that execute within a computer of any size and architecture, content that is presented as the computer programs execute, and descriptive information in both hard copy and virtual forms that encompass virtually any electronic media. Software engineering encompasses a process, a collection of methods (practice) and an array of tools that allow professionals to build high-quality computer software.

**Who does it?** Software engineers build and support software, and virtually everyone in the industrialized world uses it either directly or indirectly.

**Why is it important?** Software is important because it affects nearly every aspect of our lives and has become pervasive in our commerce, our culture, and our everyday activities.

Software engineering is important because it enables us to build complex systems in a timely manner and with high quality.

**What are the steps?** You build computer software like you build any successful product, by applying an agile, adaptable process that leads to a high-quality result that meets the needs of the people who will use the product. You apply a software engineering approach.

**What is the work product?** From the point of view of a software engineer, the work product is the set of programs, content (data), and other work products that are computer software. But from the user’s viewpoint, the work product is the resultant information that somehow makes the user’s world better.

**How do I ensure that I’ve done it right?**

Read the remainder of this book, select those ideas that are applicable to the software that you build, and apply them to your work.

I had to agree. “So, your life will be much simpler. You guys won’t have to worry about five different versions of the same App in use across tens of thousands of users.”

He smiled. “Absolutely. Only the most current version residing on our servers. When we make a change or a correction, we supply updated functionality and content to every user. Everyone has it instantly!”

I grimaced. “But if you make a mistake, everyone has that instantly as well.”

He chuckled. “True, that’s why we’re redoubling our efforts to do even better software engineering. Problem is, we have to do it ‘fast’ because the market has accelerated in every application area.”

I leaned back and put my hands behind my head. “You know what they say, . . . you can have it fast, you can have it right, or you can have it cheap. Pick two!”

“I’ll take it fast and right,” he said as he began to get up.

I stood as well. “Then you really do need software engineering.”

“I know that,” he said as he began to move away. “The problem is, we’ve got to convince still another generation of techies that it’s true!”

Is software *really* dead? If it was, you wouldn’t be reading this book!

Computer software continues to be the single most important technology on the world stage. And it’s also a prime example of the law of unintended consequences. Fifty years ago no one could have predicted that software would become an indispensable technology for business, science, and engineering; that software would enable the creation of new technologies (e.g., genetic engineering and nanotechnology), the extension of existing technologies (e.g., telecommunications), and the radical change in older technologies (e.g., the printing industry); that software would be the driving force behind the personal computer revolution; that shrink-wrapped software products would be purchased by consumers in neighborhood malls; that software would slowly evolve from a product to a service as “on-demand” software companies deliver just-in-time functionality via a Web browser; that a software company would become larger and more influential than almost all industrial-era companies; that a vast software-driven network called the Internet would evolve and change everything from library research to consumer shopping to political discourse to the dating habits of young (and not so young) adults.

No one could foresee that software would become embedded in systems of all kinds: transportation, medical, telecommunications, military, industrial, 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

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 or operates inside 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.

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 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:<sup>1</sup>

- 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:

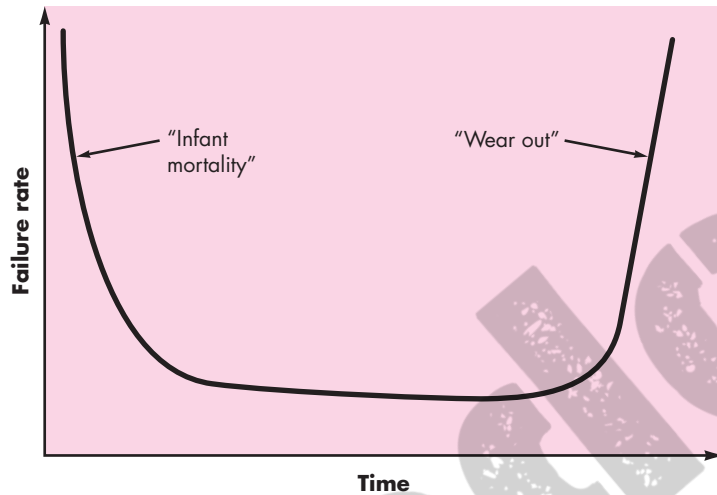
Software is: (1) instructions (computer programs) that when executed provide desired features, function, and performance; (2) data structures that enable the programs to adequately manipulate information, and (3) descriptive information in both hard copy and virtual forms that describes the operation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

1. *Software is developed or engineered; it is not manufactured in the classical sense.*

Although some similarities exist between software development and hardware manufacturing, the two activities are fundamentally different. In both activities, high quality is achieved through good design, but the manufacturing phase for hardware can introduce quality problems that are nonexistent

**FIGURE 1.1****Failure curve  
for hardware**

(or easily corrected) for software. Both activities are dependent on people, but the relationship between people applied and work accomplished is entirely different (see Chapter 24). Both activities require the construction of a “product,” but the approaches are different. Software costs are concentrated in engineering. This means that software projects cannot be managed as if they were manufacturing projects.

## 2. Software doesn’t “wear out.”

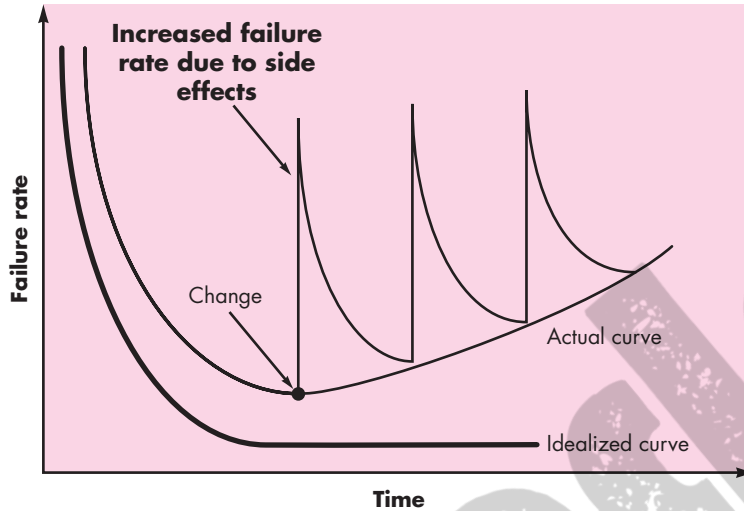
Figure 1.1 depicts failure rate as a function of time for hardware. The relationship, often called the “bathtub curve,” indicates that hardware exhibits relatively high failure rates early in its life (these failures are often attributable to design or manufacturing defects); defects are corrected and 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*!



**FIGURE 1.2**

Failure curves  
for software



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

3. *Although the industry is moving toward component-based construction, most software continues to be custom built.*

As an engineering discipline evolves, a collection of standard design components is created. Standard screws and off-the-shelf integrated circuits are only two of thousands of standard components that are used by mechanical and electrical engineers as they design new systems. The reusable components have been created so that the engineer can concentrate on the truly innovative elements of a design, that is, the parts of the design that represent

something new. In the hardware world, component reuse is a natural part of the engineering process. In the software world, it is something that has only begun to be achieved on a broad scale.

A software component should be designed and implemented so that it can be reused in many different programs. Modern reusable components encapsulate both data and the processing that is applied to the data, enabling the software engineer to create new applications from reusable parts.<sup>3</sup> For example, today's interactive user interfaces are built with reusable components that enable the creation of graphics windows, pull-down menus, and a wide variety of interaction mechanisms. The data structures and processing detail required to build the interface are contained within a library of reusable components for interface construction.

### 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,<sup>4</sup> information structures. Other systems applications (e.g., operating system components, drivers, networking software, telecommunications processors) process largely indeterminate data. In either case, the systems software area is characterized by heavy interaction with computer hardware; heavy usage by multiple users; concurrent operation that requires scheduling, resource sharing, and sophisticated process management; complex data structures; and multiple external interfaces.

**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. In addition to conventional data processing applications, application software is used to control business functions in real time (e.g., point-of-sale transaction processing, real-time manufacturing process control).

**Engineering/scientific software**—has been characterized by “number crunching” algorithms. Applications range from astronomy to volcanology, from automotive stress analysis to space shuttle orbital dynamics, and from molecular biology to automated manufacturing. However, modern applications within the engineering/scientific area are moving away from



conventional numerical algorithms. Computer-aided design, system simulation, and other interactive applications have begun to take on real-time and even system software characteristics.

**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 markets (e.g., word processing, spreadsheets, computer graphics, multimedia, entertainment, database management, and personal and business financial applications).

**Web applications**—called “WebApps,” this network-centric software category spans a wide array of applications. In their simplest form, WebApps can be little more than a set of linked hypertext files that present information using text and limited graphics. However, as Web 2.0 emerges, WebApps are evolving into sophisticated computing environments that not only provide stand-alone features, computing functions, and content to the end user, but also are integrated with corporate databases and business applications.

**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 a program that is older than she is! Past generations of software people have left a legacy in each of the categories I have discussed. Hopefully, the legacy to be left behind by this generation will ease the burden of future software engineers. And yet, new challenges (Chapter 31) have appeared on the horizon:

**Open-world computing**—the rapid growth of wireless networking may soon lead to true pervasive, distributed computing. The challenge for software engineers will be to develop systems and application software that will allow mobile devices, personal computers, and enterprise systems to communicate across vast networks.

**Netsourcing**—the World Wide Web is rapidly becoming a computing engine as well as a content provider. The challenge for software engineers is to architect simple (e.g., personal financial planning) and sophisticated applications that provide a benefit to targeted end-user markets worldwide.

**Open source**—a growing trend that results in distribution of source code for systems applications (e.g., operating systems, database, and development environments) so that many people can contribute to its development. The challenge for software engineers is to build source code that is self-descriptive, but more importantly, to develop techniques that will enable both customers and developers to know what changes have been made and how those changes manifest themselves within the software.

Each of these new challenges will undoubtedly obey the law of unintended consequences and have effects (for businesspeople, software engineers, and end users) that cannot be predicted today. However, software engineers can prepare by instantiating a process that is agile and adaptable enough to accommodate dramatic changes in technology and to business rules that are sure to come over the next decade.

### 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.

Unfortunately, there is sometimes one additional characteristic that is present in legacy software—*poor quality*.<sup>5</sup> 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:

- 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 network environment.

When these modes of evolution occur, a legacy system must be reengineered (Chapter 29) 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].

## 1.2 THE UNIQUE NATURE OF WEBAPPS

In the early days of the World Wide Web (circa 1990 to 1995), *websites* consisted of little more than a set of linked hypertext files that presented information using text and limited graphics. As time passed, the augmentation of HTML by development tools (e.g., XML, Java) enabled Web engineers to provide computing capability along with informational content. *Web-based systems and applications*<sup>6</sup> (I refer to these collectively as *WebApps*) were born. Today, WebApps have evolved into sophisticated computing tools that not only provide stand-alone function to the end user, but also have been integrated with corporate databases and business applications.

As noted in Section 1.1.2, WebApps are one of a number of distinct software categories. And yet, it can be argued that WebApps are different. Powell [Pow98] suggests that Web-based systems and applications “involve a mixture between print publishing and software development, between marketing and computing, between

internal communications and external relations, and between art and technology.” The following attributes are encountered in the vast majority of WebApps.

**Network intensiveness.** A WebApp resides on a network and must serve the needs of a diverse community of clients. The network may enable world-wide access and communication (i.e., the Internet) or more limited access and communication (e.g., a corporate Intranet).

**Concurrency.** A large number of users may access the WebApp at one time. In many cases, the patterns of usage among end users will vary greatly.

**Unpredictable load.** The number of users of the WebApp may vary by orders of magnitude from day to day. One hundred users may show up on Monday; 10,000 may use the system on Thursday.

**Performance.** If a WebApp user must wait too long (for access, for server-side processing, for client-side formatting and display), he or she may decide to go elsewhere.

**Availability.** Although expectation of 100 percent availability is unreasonable, users of popular WebApps often demand access on a 24/7/365 basis. Users in Australia or Asia might demand access during times when traditional domestic software applications in North America might be taken off-line for maintenance.

**Data driven.** The primary function of many WebApps is to use hypermedia to present text, graphics, audio, and video content to the end user. In addition, WebApps are commonly used to access information that exists on databases that are not an integral part of the Web-based environment (e.g., e-commerce or financial applications).

**Content sensitive.** The quality and aesthetic nature of content remains an important determinant of the quality of a WebApp.

**Continuous evolution.** Unlike conventional application software that evolves over a series of planned, chronologically spaced releases, Web applications evolve continuously. It is not unusual for some WebApps (specifically, their content) to be updated on a minute-by-minute schedule or for content to be independently computed for each request.

**Immediacy.** Although *immediacy*—the compelling need to get software to market quickly—is a characteristic of many application domains, WebApps often exhibit a time-to-market that can be a matter of a few days or weeks.<sup>7</sup>

**Security.** Because WebApps are available via network access, it is difficult, if not impossible, to limit the population of end users who may access the application. In order to protect sensitive content and provide secure modes

of data transmission, strong security measures must be implemented throughout the infrastructure that supports a WebApp and within the application itself.

**Aesthetics.** An undeniable part of the appeal of a WebApp is its look and feel. When an application has been designed to market or sell products or ideas, aesthetics may have as much to do with success as technical design.

It can be argued that other application categories discussed in Section 1.1.2 can exhibit some of the attributes noted. However, WebApps almost always exhibit all of them.

### 1.3 SOFTWARE ENGINEERING

In order to build software that is ready to meet the challenges of the twenty-first century, you must recognize a few simple realities:

- Software has become deeply embedded in virtually every aspect of our lives, and as a consequence, the number of people who have an interest in the features and functions provided by a specific application<sup>8</sup> has grown dramatically. When a new application or embedded system is to be built, many voices must be heard. And it sometimes seems that each of them has a slightly different idea of what software features and functions should be delivered. *It follows that a concerted effort should be made to understand the problem before a software solution is developed.*
- The information technology requirements demanded by individuals, businesses, and governments grow increasing complex with each passing year. Large teams of people now create computer programs that were once built by a single individual. Sophisticated software that was once implemented in a predictable, self-contained, computing environment is now embedded inside everything from consumer electronics to medical devices to weapons systems. The complexity of these new computer-based systems and products demands careful attention to the interactions of all system elements. *It follows that design becomes a pivotal activity.*
- 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.*

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.*

Although hundreds of authors have developed personal definitions of software engineering, a definition proposed by Fritz Bauer [Nau69] at the seminal conference on the subject still serves as a basis for discussion:

[Software engineering is] the establishment and use of sound engineering principles in order to obtain economically software that is reliable and works efficiently on real machines.

You will be tempted to add to this definition.<sup>9</sup> It says little about the technical aspects of software quality; it does not directly address the need for customer satisfaction or timely product delivery; it omits mention of the importance of measurement and metrics; it does not state the importance of an effective process. And yet, Bauer's definition provides us with a baseline. What are the "sound engineering principles" that can be applied to computer software development? How do we "economically" build software so that it is "reliable"? What is required to create computer programs that work "efficiently" on not one but many different "real machines"? These are the questions that continue to challenge software engineers.

The IEEE [IEE93a] has developed a more comprehensive definition when it states:

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.

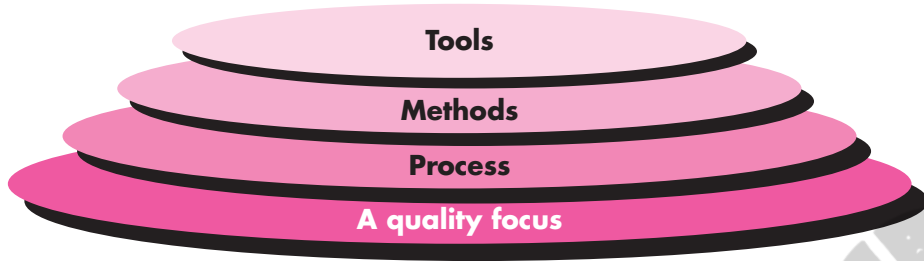
Software engineering is a layered technology. Referring to Figure 1.3, any engineering approach (including software engineering) must rest on an organizational commitment to quality. Total quality management, Six Sigma, and similar philosophies<sup>10</sup> foster a continuous process improvement culture, 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.

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



**FIGURE 1.3**

Software  
engineering  
layers



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 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.

Software engineering *tools* provide automated or semiautomated 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.

## 1.4 THE 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 design model). A *task* focuses on a small, but well-defined objective (e.g., conducting a unit test) that produces a tangible outcome.

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.

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)<sup>11</sup> The intent is to understand stakeholders' objectives for the project and to gather requirements that help define software features and functions.

**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.** 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 large Web applications, and for the engineering 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 project 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.

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:

**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**—assesses 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.

**Work product preparation and production**—encompasses 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.

Earlier in this section, I 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, I'll examine software process in considerable detail. *Prescriptive process models* (Chapter 2) stress detailed definition, identification, and application of process activities and tasks. Their intent is to improve system quality, make projects more manageable, make delivery dates and costs more predictable, and guide teams of software engineers as they perform the work required to build a system. Unfortunately, there have been times when these objectives were not achieved. If prescriptive models are applied dogmatically and without adaptation, they can increase the level of bureaucracy associated with building computer-based systems and inadvertently create difficulty for all stakeholders.

*Agile process models* (Chapter 3) emphasize project “agility” and follow a set of principles that lead to a more informal (but, proponents argue, no less effective) approach to software process. These process models are generally characterized as “agile” because they emphasize maneuverability and adaptability. They are appropriate for many types of projects and are particularly useful when Web applications are engineered.

## 1.5 SOFTWARE ENGINEERING PRACTICE

In Section 1.4, I 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.<sup>12</sup>

### 1.5.1 The Essence of Practice

In a 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).

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

**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?

**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?* Have 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.

### 1.5.2 General Principles

The dictionary defines the word *principle* as “an important underlying law or assumption required in a system of thought.” Throughout this book I'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.

David Hooker [Hoo96] has proposed seven principles that focus on software engineering practice as a whole. They are reproduced in the following paragraphs:<sup>13</sup>

#### **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.

#### **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 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**

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.<sup>14</sup> This could very possibly lead to the reuse of an entire system.

### The Sixth Principle: *Plan Ahead for Reuse*

Reuse saves time and effort.<sup>15</sup> Achieving a high level of reuse is arguably the hardest goal to accomplish in developing a software system. The reuse of code 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 conventional] 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.

## 1.6 SOFTWARE MYTHS

Software 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).

**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?*

**Reality:** The book of standards may very well exist, but is it used? Are software practitioners aware of its existence? Does it reflect modern software engineering practice? Is it complete? Is it adaptable? Is it streamlined to improve time-to-delivery while still maintaining a focus on quality? In many cases, the answer to all of these questions is "no."

**Myth:** *If we get behind schedule, we can add more programmers and catch up (sometimes called the "Mongolian horde" concept).*

**Reality:** Software development is not a mechanistic process like manufacturing. In the words of Brooks [Bro95]: "adding people to a late software project makes it later." At first, this statement may seem counterintuitive. However, as new people are added, people who were working must spend time educating the newcomers, thereby reducing the amount of time spent on productive development effort. People can be added but only in a planned and well-coordinated manner.

**Myth:** *If I decide to outsource the software project to a third party, I can just relax and let that firm build it.*

**Reality:** If an organization does not understand how to manage and control software projects internally, it will invariably struggle when it outsources software projects.

**Customer myths.** A customer who requests computer software may be a person at the next desk, a technical group down the hall, the marketing/sales department, or an outside company that has requested software under contract. In many cases, the customer believes myths about software because software managers and practitioners do little to correct misinformation. Myths lead to false expectations (by the customer) and, ultimately, dissatisfaction with the developer.

**Myth:** *A general statement of objectives is sufficient to begin writing programs—we can fill in the details later.*

**Reality:** Although a comprehensive and stable statement of requirements is not always possible, an ambiguous "statement of objectives" is a recipe for disaster. Unambiguous requirements (usually derived

iteratively) are developed only through effective and continuous communication between customer and developer.

**Myth:** *Software requirements continually change, but change can be easily accommodated because software is flexible.*

**Reality:** It is true that software requirements change, but the impact of change varies with the time at which it is introduced. When requirements changes are requested early (before design or code has been started), the cost impact is relatively small.<sup>16</sup> However, as time passes, the cost impact grows rapidly—resources have been committed, a design framework has been established, and change can cause upheaval that requires additional resources and major design modification.

**Practitioner's myths.** Myths that are still believed by software practitioners have been fostered by over 50 years of programming culture. During the early days, programming was viewed as an art form. Old ways and attitudes die hard.

**Myth:** *Once we write the program and get it to work, our job is done.*

**Reality:** Someone once said that “the sooner you begin ‘writing code,’ the longer it’ll take you to get done.” Industry data indicate that between 60 and 80 percent of all effort expended on software will be expended after it is delivered to the customer for the first time.

**Myth:** *Until I get the program “running” I have no way of assessing its quality.*

**Reality:** One of the most effective software quality assurance mechanisms can be applied from the inception of a project—the *technical review*. Software reviews (described in Chapter 15) are a “quality filter” that have been found to be more effective than testing for finding certain classes of software defects.

**Myth:** *The only deliverable work product for a successful project is the working program.*

**Reality:** A working program is only one part of a software configuration that includes many elements. A variety of work products (e.g., models, documents, plans) provide a foundation for successful engineering and, more important, guidance for software support.

**Myth:** *Software engineering will make us create voluminous and unnecessary documentation and will invariably slow us down.*

**Reality:** Software engineering is not about creating documents. It is about creating a quality product. Better quality leads to reduced rework. And reduced rework results in faster delivery times.

Many software professionals recognize the fallacy of the myths just described. Regrettably, habitual attitudes and methods foster poor management and technical practices, even when reality dictates a better approach. Recognition of software realities is the first step toward formulation of practical solutions for software engineering.

## 1.7 HOW IT ALL STARTS

Every software project is precipitated by some business need—the need to correct a defect in an existing application; the need to adapt a “legacy system” to a changing business environment; the need to extend the functions and features of an existing application; or the need to create a new product, service, or system.

At the beginning of a software project, the business need is often expressed informally as part of a simple conversation. The conversation presented in the sidebar is typical.

### SAFEHOME<sup>17</sup>



#### How a Project Starts

**The scene:** Meeting room at CPI

Corporation, a (fictional) company that makes consumer products for home and commercial use.

**The players:** Mal Golden, senior manager, product development; Lisa Perez, marketing manager; Lee Warren, engineering manager; Joe Camalleri, executive VP, business development

#### The conversation:

**Joe:** Okay, Lee, what's this I hear about your folks developing a what? A generic universal wireless box?

**Lee:** It's pretty cool . . . about the size of a small matchbook . . . we can attach it to sensors of all kinds, a digital camera, just about anything. Using the 802.11g wireless protocol. It allows us to access the device's output without wires. We think it'll lead to a whole new generation of products.

**Joe:** You agree, Mal?

**Mal:** I do. In fact, with sales as flat as they've been this year, we need something new. Lisa and I have been doing a little market research, and we think we've got a line of products that could be big.

**Joe:** How big . . . bottom line big?

**Mal (avoiding a direct commitment):** Tell him about our idea, Lisa.

**Lisa:** It's a whole new generation of what we call “home management products.” We call 'em *SafeHome*. They use the new wireless interface, provide homeowners or small-business people with a system that's controlled by their PC—home security, home surveillance, appliance and device control—you know, turn down the home air conditioner while you're driving home, that sort of thing.

**Lee (jumping in):** Engineering's done a technical feasibility study of this idea, Joe. It's doable at low manufacturing cost. Most hardware is off-the-shelf. Software is an issue, but it's nothing that we can't do.

**Joe:** Interesting. Now, I asked about the bottom line.

**Mal:** PCs have penetrated over 70 percent of all households in the USA. If we could price this thing right, it could be a killer-App. Nobody else has our wireless box . . . it's proprietary. We'll have a 2-year jump on the competition. Revenue? Maybe as much as 30 to 40 million dollars in the second year.

**Joe (smiling):** Let's take this to the next level. I'm interested.

With the exception of a passing reference, software was hardly mentioned as part of the conversation. And yet, software will make or break the *SafeHome* product line. The engineering effort will succeed only if *SafeHome* software succeeds. The market will accept the product only if the software embedded within it properly meets the customer's (as yet unstated) needs. We'll follow the progression of *SafeHome* software engineering in many of the chapters that follow.

WUICCODE



**I**n a fascinating book that provides an economist's view of software and software engineering, Howard Baetjer, Jr. [Bae98], comments on the software process:

Because software, like all capital, is embodied knowledge, and because that knowledge is initially dispersed, tacit, latent, and incomplete in large measure, software development is a social learning process. The process is a dialogue in which the knowledge that must become the software is brought together and embodied in the software. The process provides interaction between users and designers, between users and evolving tools, and between designers and evolving tools [technology]. It is an iterative process in which the evolving tool itself serves as the medium for communication, with each new round of the dialogue eliciting more useful knowledge from the people involved.

Indeed, building computer software is an iterative social learning process, and the outcome, something that Baetjer would call "software capital," is an embodiment of knowledge collected, distilled, and organized as the process is conducted.

### QUICK LOOK

**What is it?** When you work to build a product or system, it's important to go through a series of predictable steps—a road map that helps you create a timely, high-quality result. The road map that you follow is called a "software process."

**Who does it?** Software engineers and their managers adapt the process to their needs and then follow it. In addition, the people who have requested the software have a role to play in the process of defining, building, and testing it.

**Why is it important?** Because it provides stability, control, and organization to an activity that can, if left uncontrolled, become quite chaotic. However, a modern software engineering approach must be "agile." It must demand only those activities, controls, and work products that are appropriate for the project team and the product that is to be produced.

**What are the steps?** At a detailed level, the process that you adopt depends on the software that you're building. One process might be appropriate for creating software for an aircraft avionics system, while an entirely different process would be indicated for the creation of a website.

**What is the work product?** From the point of view of a software engineer, the work products are the programs, documents, and data that are produced as a consequence of the activities and tasks defined by the process.

**How do I ensure that I've done it right?**

There are a number of software process assessment mechanisms that enable organizations to determine the "maturity" of their software process. However, the quality, timeliness, and long-term viability of the product you build are the best indicators of the efficacy of the process that you use.

But what exactly is a software process from a technical point of view? Within the context of this book, I 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.

## 2.1 A GENERIC PROCESS MODEL

In Chapter 1, 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 reside within a framework or model that defines their relationship with the process and with one another.

The software process is represented schematically in Figure 2.1. 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.

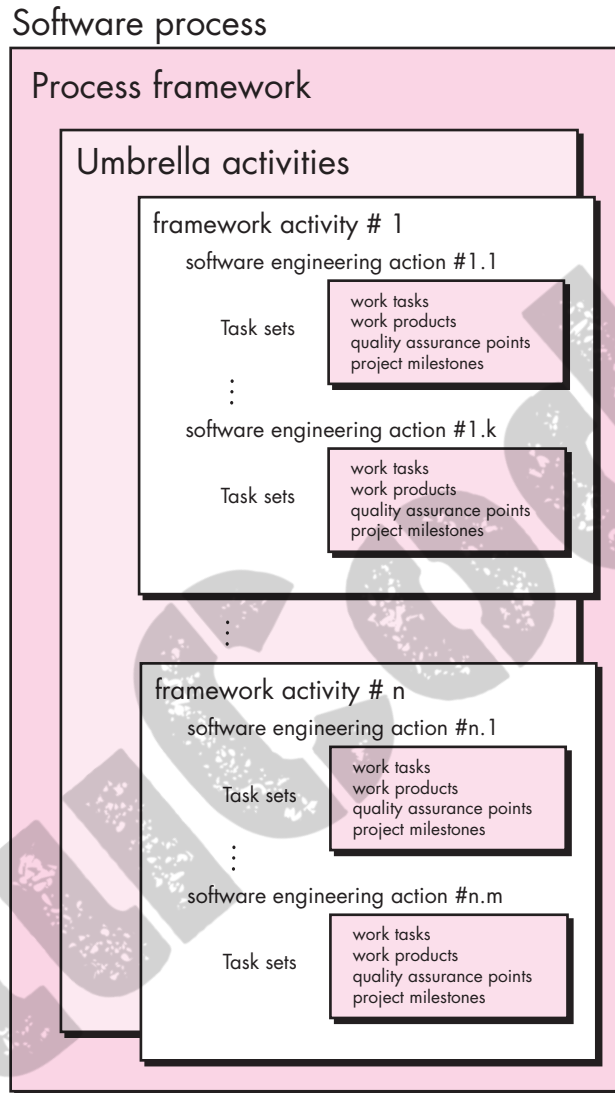
As I discussed in Chapter 1, a generic process framework for software engineering defines five framework activities—**communication, planning, modeling, construction, and deployment**. In addition, a set of umbrella activities—project tracking and control, risk management, quality assurance, configuration 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 2.2.

A *linear process flow* executes each of the five framework activities in sequence, beginning with communication and culminating with deployment (Figure 2.2a). An *iterative process flow* repeats one or more of the activities before proceeding to the next (Figure 2.2b). 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 2.2c). A *parallel process flow* (Figure 2.2d) 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).

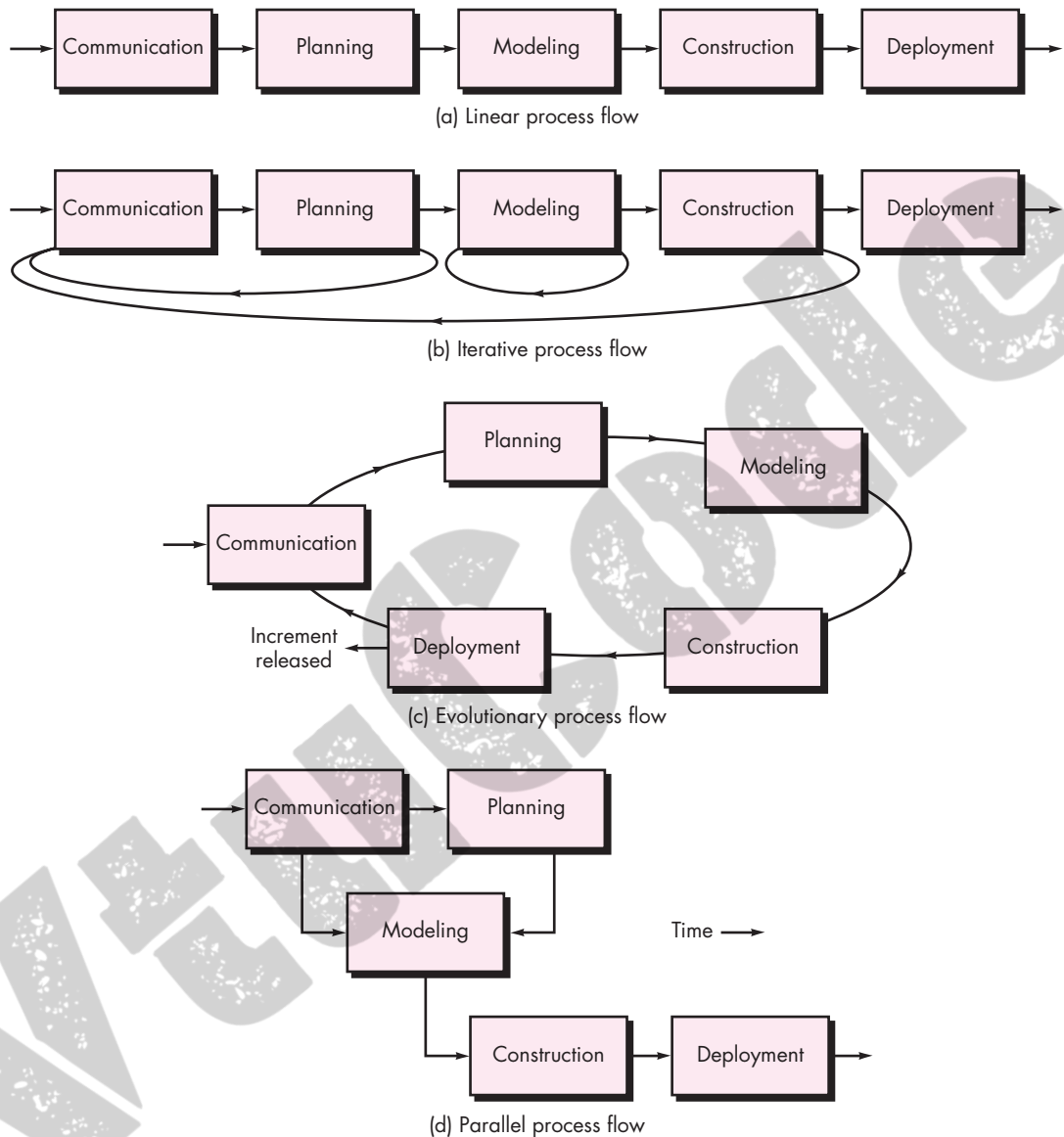
**FIGURE 2.1**

A software  
process  
framework



### 2.1.1 Defining a Framework Activity

Although I have described five framework activities and provided a basic definition of each in Chapter 1, 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?*

**FIGURE 2.2** Process flow

**? How does a framework activity change as the nature of the project changes?**

For a small software project requested by one person (at a remote location) with simple, straightforward requirements, the communication activity might encompass little more than a phone call with the appropriate stakeholder. Therefore, the only necessary action is *phone conversation*, and the work tasks (the *task set*) that this action encompasses are:

1. Make contact with stakeholder via telephone.
2. Discuss requirements and take notes.

3. Organize notes into a brief written statement of requirements.
4. E-mail to stakeholder for review and approval.

If the project was considerably more complex with many stakeholders, each with a different set of (sometime conflicting) requirements, the communication activity might have six distinct actions (described in Chapter 5): *inception*, *elicitation*, *elaboration*, *negotiation*, *specification*, and *validation*. Each of these software engineering actions would have many work tasks and a number of distinct work products.

### 2.1.2 Identifying a Task Set

Referring again to Figure 2.1, each software engineering action (e.g., *elicitation*, an action associated with the communication activity) can be represented by a number of different *task sets*—each a collection of software engineering work tasks, related work products, quality assurance points, and project milestones. You should choose a task set that best accommodates the needs of the project and the characteristics of your team. This implies that a software engineering action can be adapted to the specific needs of the software project and the characteristics of the project team.



#### Task Set

A task set defines the actual work to be done to accomplish the objectives of a software engineering action. For example, *elicitation* (more commonly called “requirements gathering”) is an important software engineering action that occurs during the communication activity. The goal of requirements gathering is to understand what various stakeholders want from the software that is to be built.

For a small, relatively simple project, the task set for requirements gathering might look like this:

1. Make a list of stakeholders for the project.
2. Invite all stakeholders to an informal meeting.
3. Ask each stakeholder to make a list of features and functions required.
4. Discuss requirements and build a final list.
5. Prioritize requirements.
6. Note areas of uncertainty.

For a larger, more complex software project, a different task set would be required. It might encompass the following work tasks:

1. Make a list of stakeholders for the project.
2. Interview each stakeholder separately to determine overall wants and needs.

#### INFO

3. Build a preliminary list of functions and features based on stakeholder input.
4. Schedule a series of facilitated application specification meetings.
5. Conduct meetings.
6. Produce informal user scenarios as part of each meeting.
7. Refine user scenarios based on stakeholder feedback.
8. Build a revised list of stakeholder requirements.
9. Use quality function deployment techniques to prioritize requirements.
10. Package requirements so that they can be delivered incrementally.
11. Note constraints and restrictions that will be placed on the system.
12. Discuss methods for validating the system.

Both of these task sets achieve “requirements gathering,” but they are quite different in their depth and formality. The software team chooses the task set that will allow it to achieve the goal of each action and still maintain quality and agility.



### 2.1.3 Process Patterns

Every software team encounters problems as it moves through the software process. It would be useful if proven solutions to these problems were readily available to the team so that the problems could be addressed and resolved quickly. A *process pattern*<sup>1</sup> describes a process-related problem that is encountered during software engineering work, identifies the environment in which the problem has been encountered, and suggests one or more proven solutions to the problem. Stated in more general terms, a process pattern provides you with a template [Amb98]—a consistent method for describing problem solutions within the context of the software process. By combining patterns, a software team can solve problems and construct a process that best meets the needs of a project.

Patterns can be defined at any level of abstraction.<sup>2</sup> In some cases, a pattern might be used to describe a problem (and solution) associated with a complete process model (e.g., prototyping). In other situations, patterns can be used to describe a problem (and solution) associated with a framework activity (e.g., **planning**) or an action within a framework activity (e.g., project estimating).

Ambler [Amb98] has proposed a template for describing a process pattern:

**Pattern Name.** The pattern is given a meaningful name describing it within the context of the software process (e.g., **TechnicalReviews**).

**Forces.** The environment in which the pattern is encountered and the issues that make the problem visible and may affect its solution.

**Type.** The pattern type is specified. Ambler [Amb98] suggests three types:

1. *Stage pattern*—defines a problem associated with a framework activity for the process. Since a framework activity encompasses multiple actions and work tasks, a stage pattern incorporates multiple task patterns (see the following) that are relevant to the stage (framework activity). An example of a stage pattern might be **EstablishingCommunication**. This pattern would incorporate the task pattern **RequirementsGathering** and others.
2. *Task pattern*—defines a problem associated with a software engineering action or work task and relevant to successful software engineering practice (e.g., **RequirementsGathering** is a task pattern).
3. *Phase pattern*—define the sequence of framework activities that occurs within the process, even when the overall flow of activities is iterative in nature. An example of a phase pattern might be **SpiralModel** or **Prototyping**.<sup>3</sup>



**Initial context.** Describes the conditions under which the pattern applies. Prior to the initiation of the pattern: (1) What organizational or team-related activities have already occurred? (2) What is the entry state for the process? (3) What software engineering information or project information already exists?

For example, the **Planning** pattern (a stage pattern) requires that (1) customers and software engineers have established a collaborative communication; (2) successful completion of a number of task patterns [specified] for the **Communication** pattern has occurred; and (3) the project scope, basic business requirements, and project constraints are known.

**Problem.** The specific problem to be solved by the pattern.

**Solution.** Describes how to implement the pattern successfully. This section describes how the initial state of the process (that exists before the pattern is implemented) is modified as a consequence of the initiation of the pattern. It also describes how software engineering information or project information that is available before the initiation of the pattern is transformed as a consequence of the successful execution of the pattern.

**Resulting Context.** Describes the conditions that will result once the pattern has been successfully implemented. Upon completion of the pattern: (1) What organizational or team-related activities must have occurred? (2) What is the exit state for the process? (3) What software engineering information or project information has been developed?

**Related Patterns.** Provide a list of all process patterns that are directly related to this one. This may be represented as a hierarchy or in some other diagrammatic form. For example, the stage pattern **Communication** encompasses the task patterns: **ProjectTeam**, **CollaborativeGuidelines**, **ScopelIsolation**, **RequirementsGathering**, **ConstraintDescription**, and **ScenarioCreation**.

**Known Uses and Examples.** Indicate the specific instances in which the pattern is applicable. For example, **Communication** is mandatory at the beginning of every software project, is recommended throughout the software project, and is mandatory once the deployment activity is under way.

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.



### 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 2.3.3.

**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.

#### INFO

## 2.2 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 (Chapters 14 and 16). Process patterns must be coupled with solid software engineering practice (Part 2 of this book). In addition, the process itself can be assessed to ensure that it meets a set of basic process criteria that have been shown to be essential for a successful software engineering.<sup>4</sup>

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

**? What formal techniques are available for assessing the software process?**

### 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].

**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 30.

## 2.3 PRESCRIPTIVE PROCESS MODELS

Prescriptive process models were originally proposed to bring order to the chaos of software development. History has indicated that these traditional models have brought a certain amount of useful structure to software engineering work and have provided a reasonably effective road map for software teams. However, software engineering work and the product that it produces remain on “the edge of chaos.”

In an intriguing paper on the strange relationship between order and chaos in the software world, Nogueira and his colleagues [Nog00] state

The edge of chaos is defined as “a natural state between order and chaos, a grand compromise between structure and surprise” [Kau95]. The edge of chaos can be visualized as an unstable, partially structured state. . . . It is unstable because it is constantly attracted to chaos or to absolute order.

We have the tendency to think that order is the ideal state of nature. This could be a mistake. Research . . . supports the theory that operation away from equilibrium generates creativity, self-organized processes, and increasing returns [Roo96]. Absolute order means the absence of variability, which could be an 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.

The philosophical implications of this argument are significant for software engineering. If prescriptive process models<sup>5</sup> strive for structure and order, are they inappropriate for a software world that thrives on change? Yet, 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, I examine the prescriptive process approach in which order and project consistency are dominant issues. I 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 Chapter 1, 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.

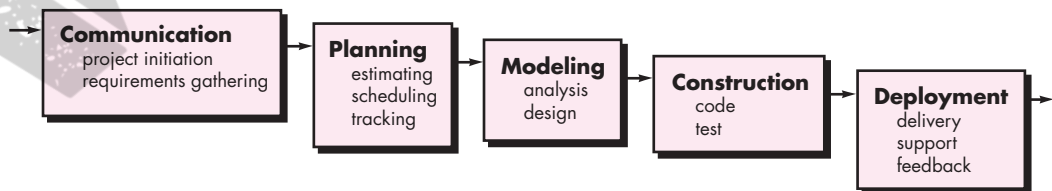
### 2.3.1 The Waterfall Model

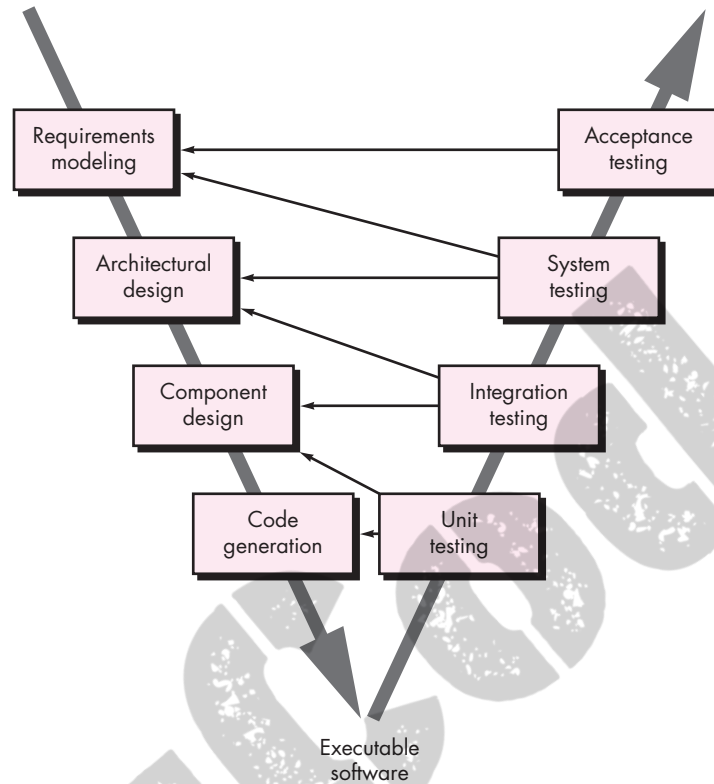
There are times when the requirements for a problem are well understood—when work flows from **communication** through **deployment** in a reasonably linear fashion. This situation is sometimes encountered when well-defined adaptations or enhancements to an existing system must be made (e.g., an adaptation 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.

The *waterfall model*, sometimes called the *classic life cycle*, suggests a systematic, sequential approach<sup>6</sup> 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 2.3).

A variation in the representation of the waterfall model is called the *V-model*. Represented in Figure 2.4, the V-model [Buc99] depicts the relationship of quality

**FIGURE 2.3** The waterfall model



**FIGURE 2.4****The V-model**

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 moved down the left side.<sup>7</sup> 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 three 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.
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.

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 states tend 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.

### 2.3.2 Incremental Process Models

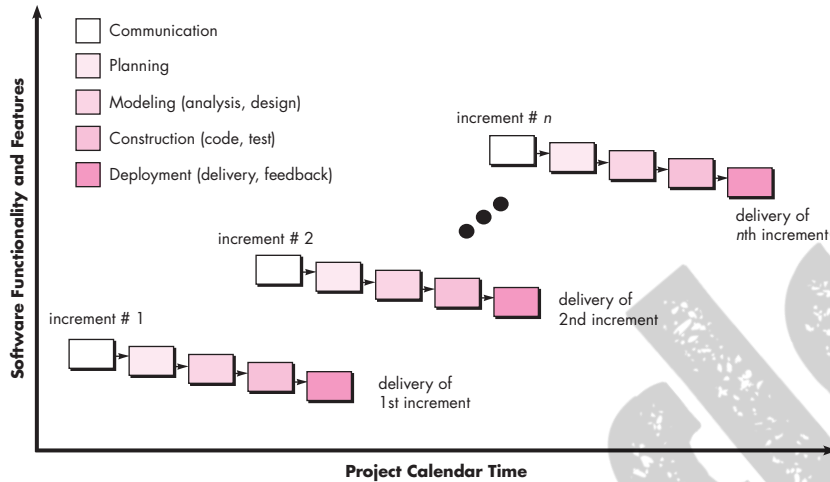
There are many situations in which initial software requirements are reasonably well defined, but the overall scope of the development effort precludes a purely linear process. In addition, there may be a compelling need to provide a limited set of software functionality to users quickly and then refine 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 elements of linear and parallel process flows discussed in Section 2.1. Referring to Figure 2.5, the incremental model applies linear sequences in a staggered fashion as calendar time progresses. Each linear sequence produces deliverable “increments” of the software [McD93] in a manner that is similar to the increments produced by an evolutionary process flow (Section 2.3.3).

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.

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



**FIGURE 2.5****The incremental model**

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.

The incremental process model focuses on the delivery of an operational product with each increment. Early increments are stripped-down versions of the final product, but they do provide capability that serves the user and also provide a platform for evaluation by the user.<sup>8</sup>

Incremental development is particularly useful when staffing is unavailable for a complete implementation by the business deadline that has been established for the project. Early increments can be implemented with fewer people. If the core product is well received, then additional staff (if required) can be added to implement the next increment. In addition, increments can be planned to manage technical risks. For example, a major system might require the availability of new hardware that is under development and whose delivery date is uncertain. It might be possible to plan early increments in a way that avoids the use of this hardware, thereby enabling partial functionality to be delivered to end users without inordinate delay.

### 2.3.3 Evolutionary Process Models

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 evolves over time.

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, I present two common evolutionary process models.

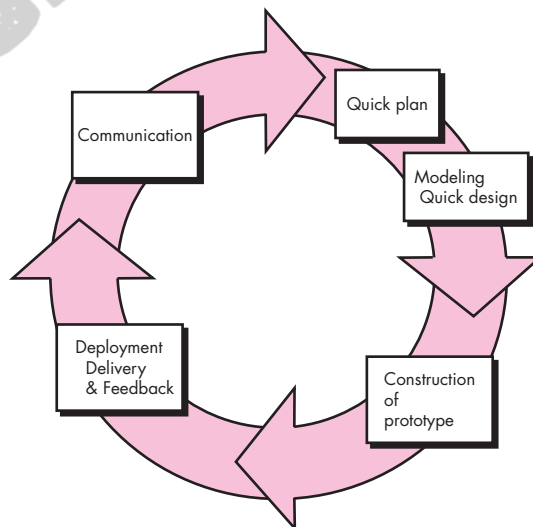
**Prototyping.** Often, a customer defines a set of general objectives for software, but does not identify detailed requirements for functions and features. In other cases, the developer may be unsure of the efficiency of an algorithm, the adaptability of an operating system, or the form that human-machine 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.

The prototyping paradigm (Figure 2.6) 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

**FIGURE 2.6**

The  
prototyping  
paradigm



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 (e.g., report generators and window managers) that enable working programs to be generated quickly.

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:

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 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.

## 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 this chapter 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 OK. 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.

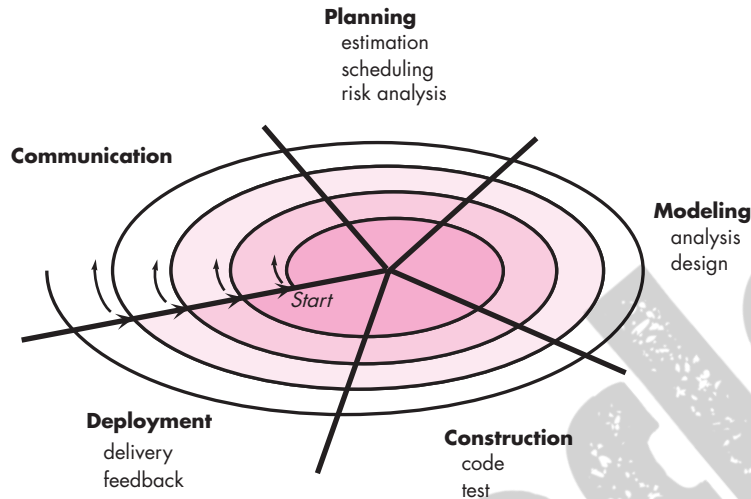
**The Spiral Model.** Originally proposed by Barry Boehm [Boe88], the *spiral model* is an evolutionary software process model that couples the iterative nature of prototyping with the controlled and systematic aspects of the waterfall model. It provides the potential for rapid development of increasingly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

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.

**FIGURE 2.7**

A typical  
spiral model



A spiral model is divided into a set of framework activities defined by the software engineering team. For illustrative purposes, I use the generic framework activities discussed earlier.<sup>9</sup> Each of the framework activities represent one segment of the spiral path illustrated in Figure 2.7. 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 28) 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.

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<sup>10</sup> 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).

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.

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.

## 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, replan, 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?

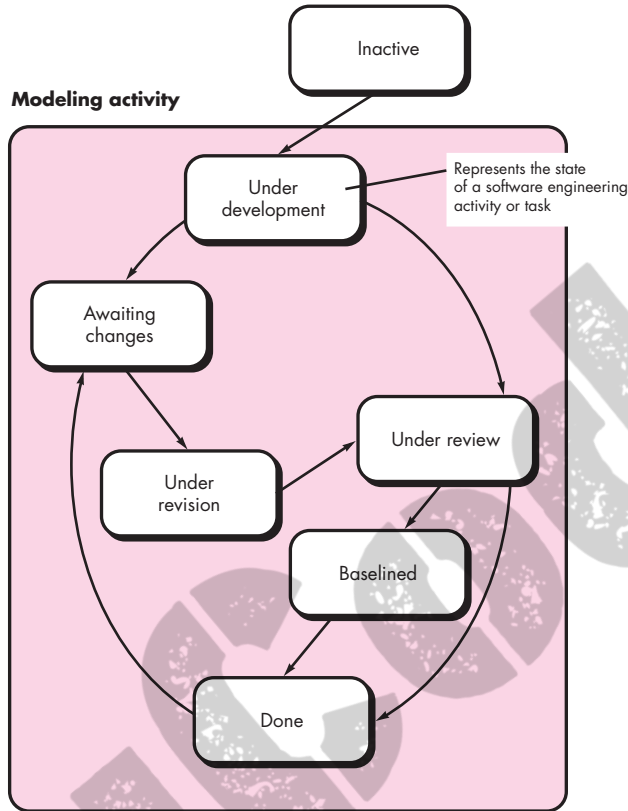
**Lee** (frowning): I suppose so, but . . . senior management's not going to like this . . . they want a fixed plan.

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



**FIGURE 2.8**

One element of  
the concurrent  
process model



### 2.3.4 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 defined for the spiral model is accomplished by invoking one or more of the following software engineering actions: prototyping, analysis, and design.<sup>11</sup>

Figure 2.8 provides a schematic representation of one software engineering activity within the modeling activity using a concurrent modeling approach. The activity—**modeling**—may be in any one of the states<sup>12</sup> 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 **inactive** 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 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.

### 2.3.5 A Final Word on Evolutionary Processes

I 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.<sup>13</sup>

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. Most project management and estimation techniques are based on linear layouts of activities, so they do not fit completely.

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, software processes should be focused on flexibility and extensibility rather than on high quality. This assertion sounds scary. However, we should prioritize the speed of the development over zero defects. Extending the development in order to reach high quality could result in a late delivery of the product, when the opportunity niche has disappeared. This paradigm shift is imposed by the competition on the edge of chaos.

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<sup>14</sup> 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).

## 2.4 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.<sup>15</sup>

### 2.4.1 Component-Based Development

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 constructs 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<sup>16</sup> 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. Your software engineering team can achieve a reduction in development cycle time as well as a reduction in project cost if component reuse becomes part of your culture. Component-based development is discussed in more detail in Chapter 10.

### 2.4.2 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.

When formal methods (Chapter 21) 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:

- 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.

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

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.

### 2.4.3 Aspect-Oriented Software Development

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).

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), 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].

Grundy [Gru02] provides further discussion of aspects in the context of what he calls *aspect-oriented component engineering* (AOCE):

AOCE uses a concept of horizontal slices through vertically-decomposed software components, called “aspects,” to characterize cross-cutting functional and non-functional properties of components. Common, systemic aspects include user interfaces, collaborative work, distribution, persistency, memory management, transaction processing, security, integrity and so on. Components may provide or require one or more “aspect details” relating to a particular aspect, such as a viewing mechanism, extensible affordance and interface kind (user interface aspects); event generation, transport and receiving (distribution aspects); data store/retrieve and indexing (persistency aspects); authentication, encoding and access rights (security aspects); transaction atomicity, concurrency control and logging strategy (transaction aspects); and so on. Each aspect detail has a number of properties, relating to functional and/or non-functional characteristics of the aspect detail.

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 [Saf08], [Cla05], [Jac04], and [Gra03].



### 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:<sup>17</sup>

*GDPA*, a research process definition tool suite, developed at Bremen University in Germany ([www.informatik](http://www.informatik.uni-bremen.de/uniform/gdpa/home.htm)

### SOFTWARE TOOLS

[.uni-bremen.de/uniform/gdpa/home.htm](http://www.informatik.uni-bremen.de/uniform/gdpa/home.htm)), provides a wide array of process modeling and management functions.

*SpeedDev*, developed by SpeedDev Corporation ([www.speedev.com](http://www.speedev.com)) encompasses a suite of tools for process definition, requirements management, issue resolution, project planning, and tracking.

*ProVision BPMx*, developed by Proforma ([www.proformacorp.com](http://www.proformacorp.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.processwave.net/Links/tool\\_links.htm](http://www.processwave.net/Links/tool_links.htm).