Unit 1

Software and Software Engineering

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.
Software is 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, The communication of information (networks), and the creation and control of other programs.

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 , and provides the means for acquiring information in all of its forms.

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.
Programmers are the same questions that are asked when modern computer-based systems are built:
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?

Defining Software

Software is: (1) instructions 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.

Software has characteristics that are considerably different than those of hardware

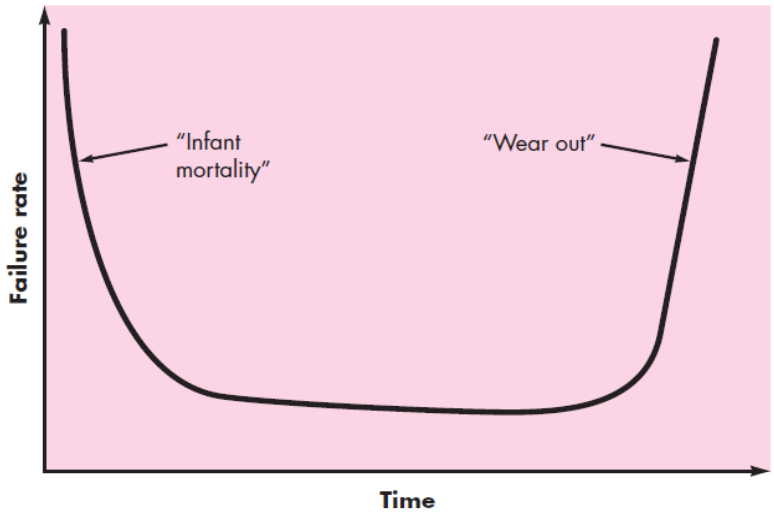
1. Software is developed or engineered; it is not manufactured in the classical sense.

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 for software. 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 defects are corrected and the failure rate drops to a steady-state level 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.

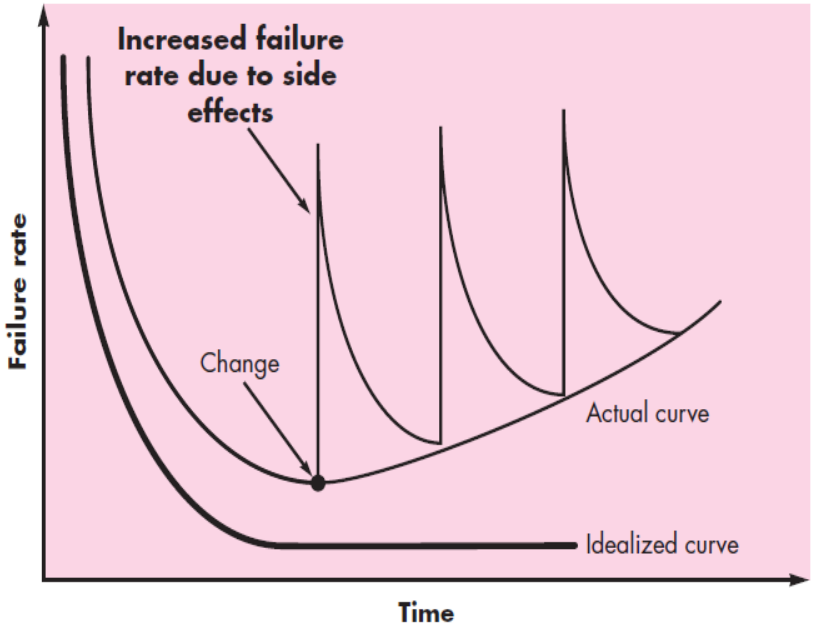
FIGURE 1.1
Failure curve for hardware



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.

During its life,2 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.

FIGURE 1.2
Failure curves for 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 create. 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.

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 processes complex, but determinate information structures. Other systems applications 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.

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 or provide significant function and control capability.

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.

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 non-numerical algorithms to solve complex problems that are not amenable to computation or straight forward analysis. Applications within this area include robotics, expert systems, pattern recognition, artificial neural networks, theorem proving, and game playing.

Legacy Software

These older programs—often referred to as legacy software—have been the focus of continuous attention and concern since the 1960s.

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.

Unfortunately, there is sometimes one additional characteristic that is present in legacy software—poor quality.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.

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.

Software engineering

In order to build software that is ready to meet the challenges of the twenty-first century, 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 application8 has grown dramatically. 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. 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

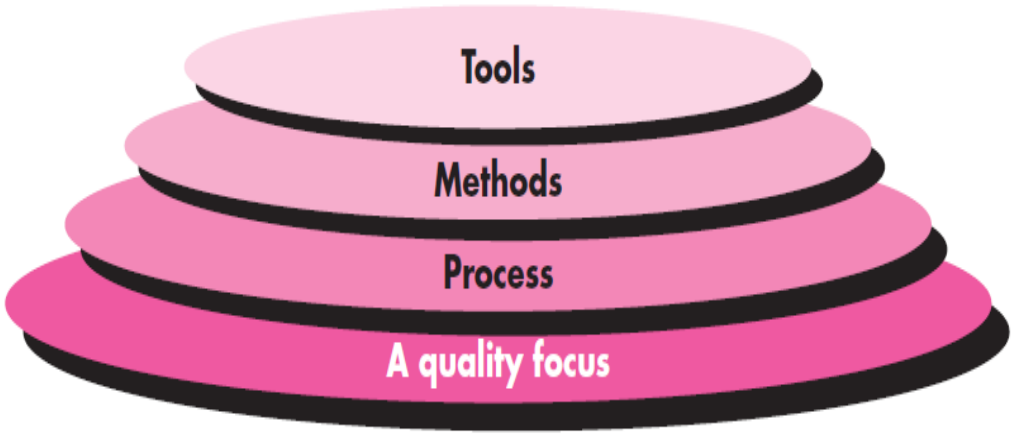
will also grow. As its user base and time-in-use increase, demands for adaptation and enhancement will also grow. It follows that software should be maintainable.

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

Software engineering is a layered technology. Referring to Figure 1.3, any engineering approach must rest on an organizational commitment to quality.

FIGURE 1.3

Software engineering layers



The foundation for software engineering is the process layer. The software engineering process is the glue that holds the technology layers together and enables rational and timely development of computer software. Process defines a framework that must be established for effective delivery of software engineering technology. The software process forms the basis for management control of software projects and establishes the context in which technical methods are 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 semi-automated support for the process and the methods. When tools are integrated so that information created by one tool can be used by another, a system for the support of software development, called computer-aided software engineering, is established.

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 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 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.

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. 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 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 and the testing that is required to uncover errors in the code.

Deployment. The software is delivered to the customer who evaluates the delivered product and provides feedback based on the evaluation.

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

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

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

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

Software engineering practice

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.

The Essence of Practice

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)

Understand the problem. It's sometimes difficult to admit, but most of us suffer from hubris when we're presented with a problem. 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. Understand the problem and 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 e created serves as a road map for the system you want to build.

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.

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?

General Principles

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).

David Hooker [Hoo96] has proposed seven principles that focus on software engineering practice as a whole

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

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.

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 minds" about itself. 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

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

The Sixth Principle: Plan Ahead for Reuse

Reuse saves time and effort.15Achieving 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!

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.

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.

Today, most knowledgeable software engineering professionals recognize myths for what they are—misleading attitudes that have caused serious problems for managers and practitioners alike.

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.

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

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 project.

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 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 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, the cost impact is relatively small.

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 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

A working program is only one part of a software configuration that includes many elements. A variety of work products 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.

Process Models:

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. 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.

Software process as a framework for the activities, actions, and tasks that are required to build high-quality software. But software engineering also encompasses technologies that populate the process—technical methods and automated tools.

A generic process model

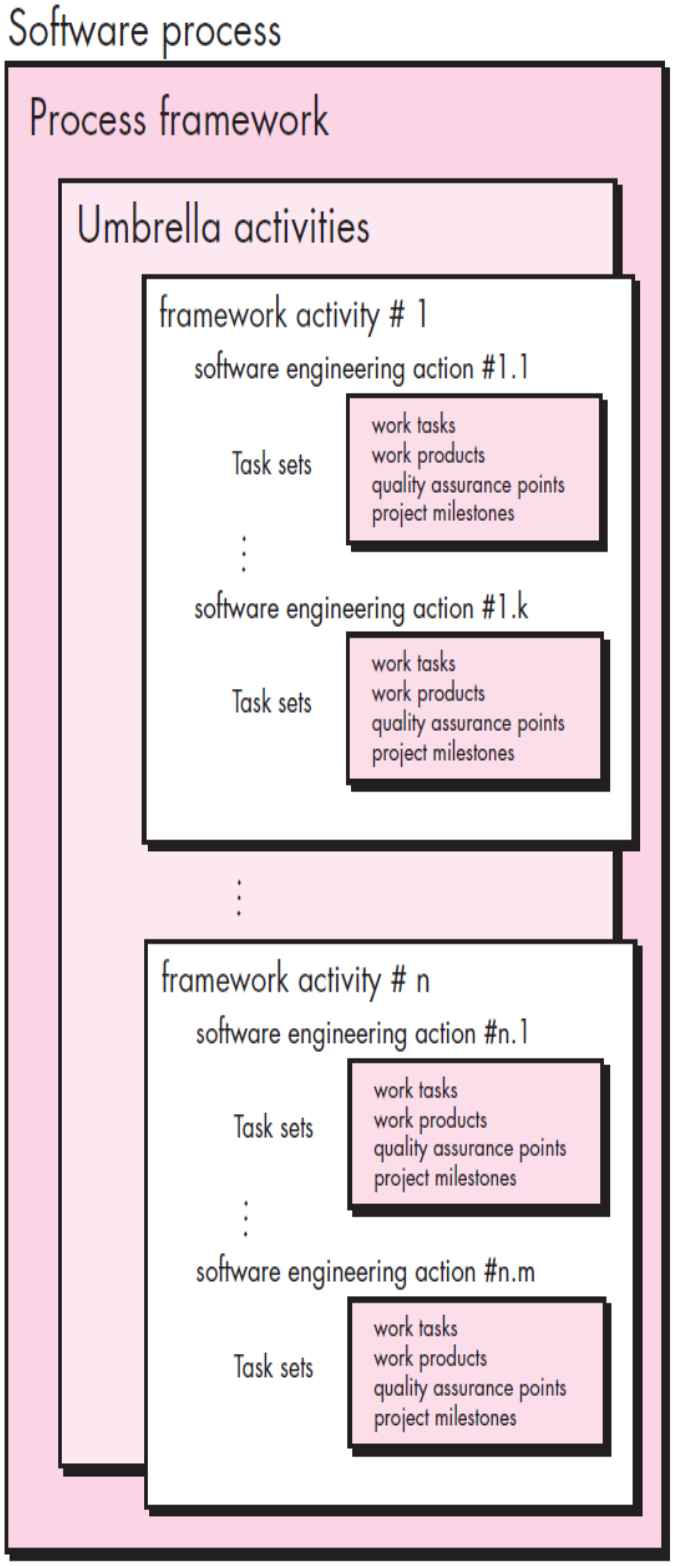
A process was defined as a collection of work activities, actions, and tasks that are performed when some work product is to be created. Each of these activities, actions, and tasks reside within a framework or model that defines their relationship with the process and with one another.

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.

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.

FIGURE 2.1

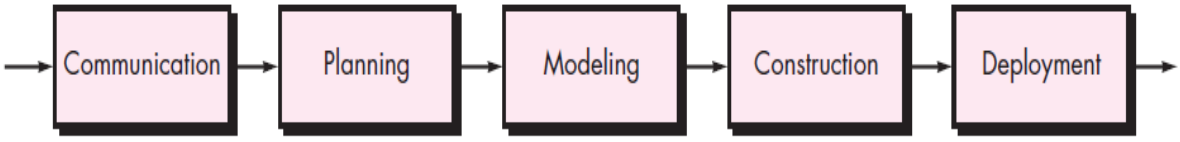
A software process framework



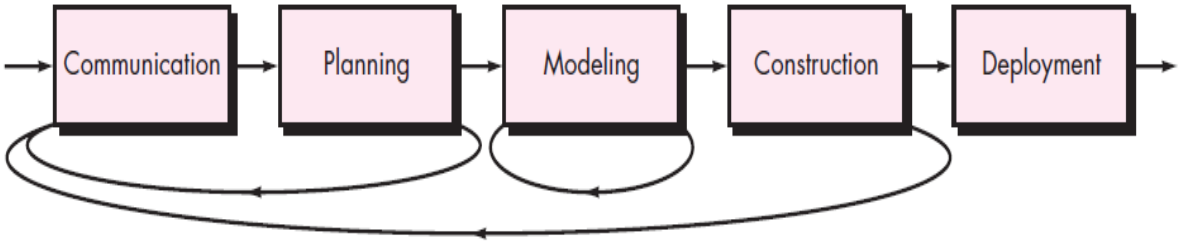
Process flow—describes how the framework activities and the actions and tasks that occur within each framework activity are organized with respect to sequence and time and is illustrated in Figure 2.2

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.

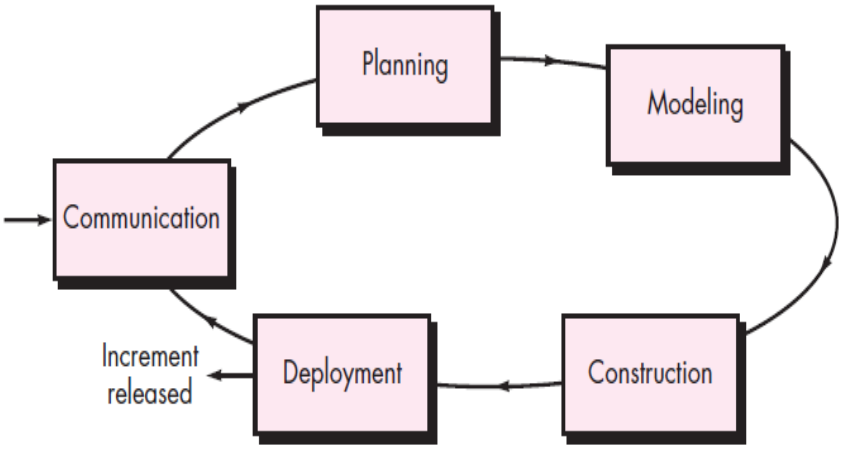
FIGURE 2.2 Process flow



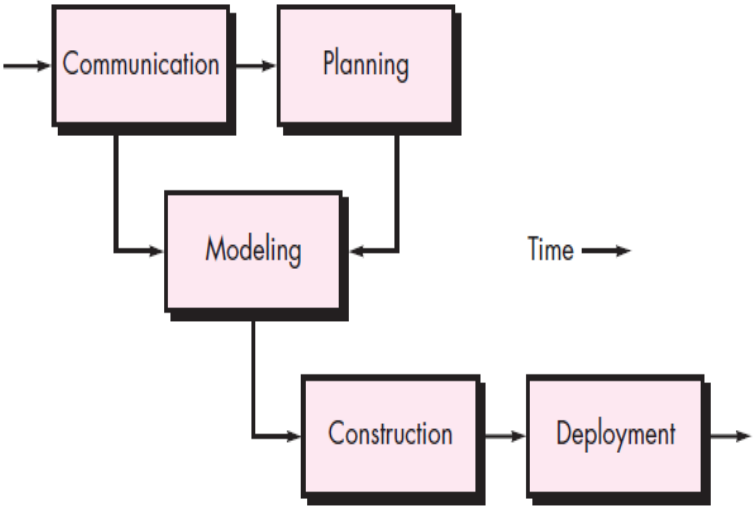
(a) Linear process flow



(b) Iterative process flow



(c) Evolutionary process flow



(d) Parallel process flow

Identifying a Task Set

Eeach software engineering action 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. 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.

Process Patterns

A process pattern 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 —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.2 In some cases, a pattern might be used to describe a problem 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 or an action within a framework activity.

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.

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

Type

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 that are relevant to the stage.
2. **Task pattern**—defines a problem associated with a software engineering action or work task and relevant to successful software engineering practice.

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 Spiral Model or Prototyping.

   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.

PROCESS ASSESSMENT AND IMPROVEMENT

Process patterns must be coupled with solid software engineering practice. 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.

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

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

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

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.

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.

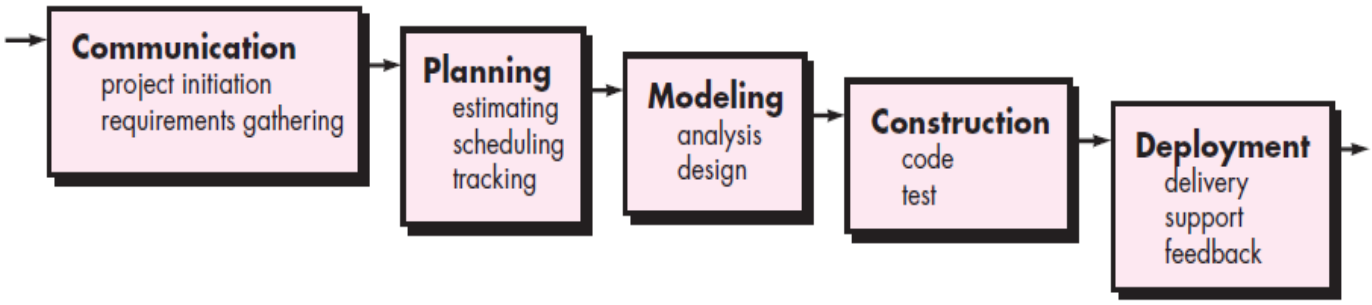
Prescriptive process models

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. "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.

The Waterfall Mode

The waterfall model, sometimes called the classic life cycle, suggests a systematic,sequential approach6 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.

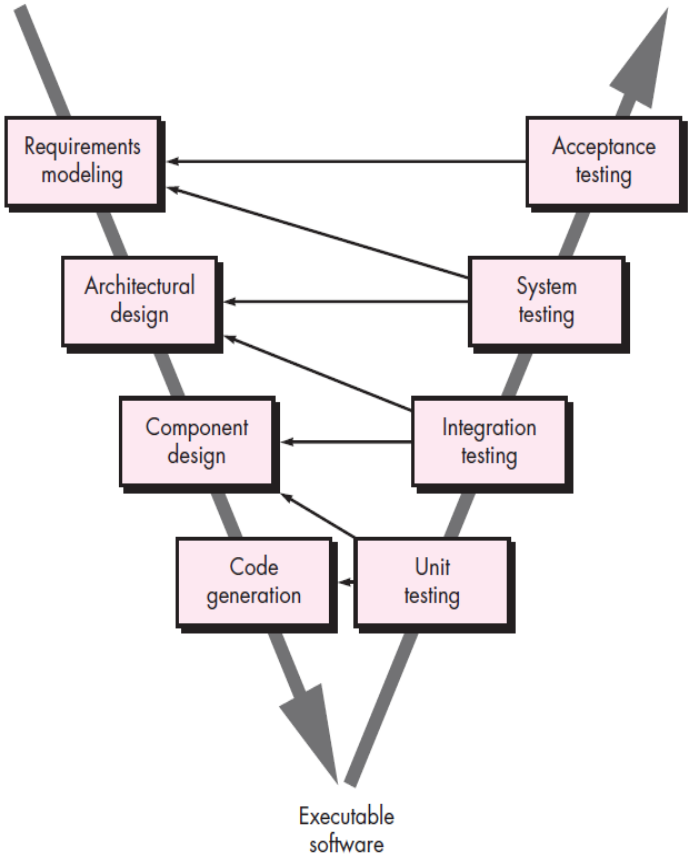
FIGURE 2.3 The waterfall model



A variation in the representation of the waterfall model is called the V-model. Represented in Figure the V-model depicts the relationship of quality assurance actions to the actions associated with communication, modeling, and early construction activities. As a software team moves down the left side of the V,basic problem requirements are refined into progressively more detailed and technical representations of the problem and its solution. Once code has been generated, the team moves up the right side of the V,

essentially performing a series of tests that validate each of the models created as the team moved down the left side. 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.

FIGURE 2.4
The V-model



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. Among the problems that are sometimes encountered when the waterfall model is applied are:

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.

Incremental Process Models

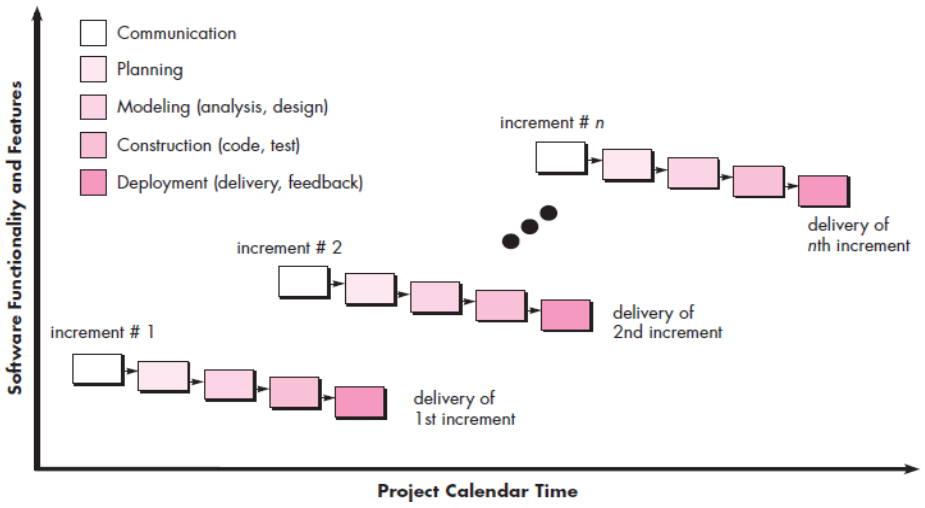
The incremental model combines elements of linear and parallel process flows Referring to figure the incremental model applies linear sequences in a staggered fashion as calendar time progresses. Each linear sequence produces deliverable "increments" of the software in a manner that is similar to the increments produced by an evolutionary process flow.

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

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.

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.

FIGURE 2.5
The incremental model



Evolutionary Process Models

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, 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.

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.

The prototyping paradigm begins with communication. 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 occurs. A quick design focuses on a representation of those aspects of the software that will be visible to end users . The quick design leads to the construction of a prototype. The prototype is deployed and evaluated by stakeholders, who provide feedback that is used to further refine requirements. Iteration occurs as the prototype is tuned to satisfy the needs of various stakeholders, while at the same time enabling you to better understand what needs to be done.

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

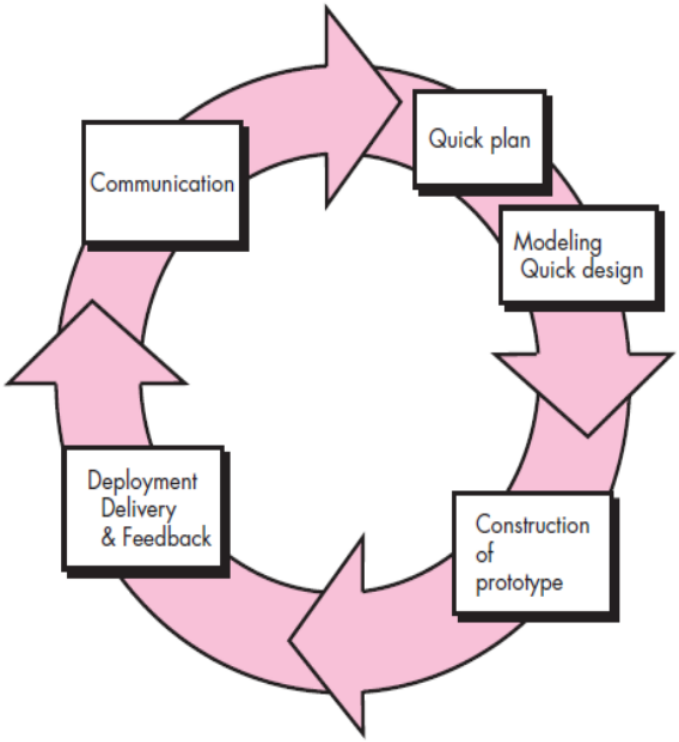
Both stakeholders and software engineers like the prototyping paradigm. Users get a feel for the actual system, and developers get to build something immediately. Prototyping can be problematic for the following reasons.

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 hasn’t considered overall software quality or long-term maintainability.

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.

FIGURE 2.6

The prototyping paradigm



The Spiral Model

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 describes the model in the following manner**:**

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

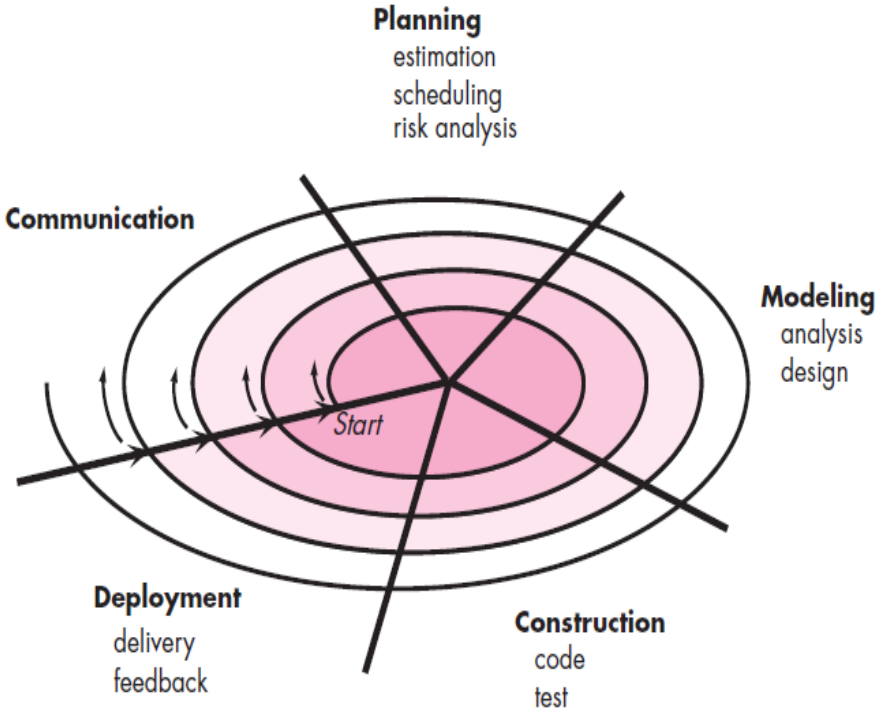
A spiral model is divided into a set of framework activities defined by the software engineering team As this evolutionary process begins, the software team performs activities that are implied by a circuit around the spiral in a clockwise direction, beginning at the center. Risk is considered as each revolution is made.

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 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.

FIGURE 2.7
A typical spiral model



Drawbacks of spiral model.

It may be difficult to convince customers 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**.**

Concurrent Models

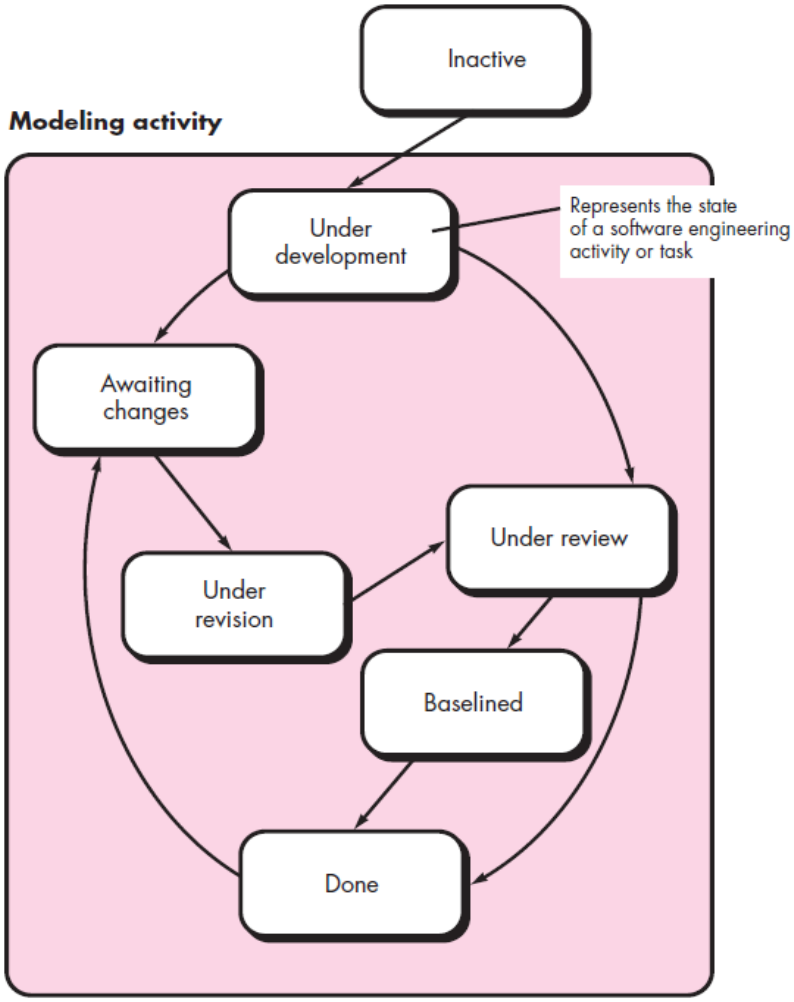
The concurrent development model, sometimes called concurrent engineering, allows a software team to represent iterative and concurrent elements of any of the process models.

Figure 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 states12 noted at any given time. Similarly, other activities, actions, or tasks can be represented in an analogous manner. All software engineering activities exist concurrently but reside in different states.

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, 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.

FIGURE 2.8
One element of the concurrent process model



Specialized process models

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, demanding an iterative approach to the creation of software. However, the component-based development model constructs applications from prepackaged software component.

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 of classes. Regardless of the technology that is used to create the components, the component-based development model incorporates the following steps.

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 Formal Methods Model

When formal methods 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 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.

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.

Aspect-Oriented Software Development

As modern computer-based systems become more sophisticated, 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"

The unified process

The Unified Process is an attempt to draw on the best features and characteristics of traditional software process models, but characterize them in a way that implements many of the best principles of agile software development.

The Unified Process recognizes the importance of customer communication and streamlined methods for describing the customer's view of a system. It emphasizes the important role of software architecture and "helps the architect focus on the right goals, such as understandability, reliance to future changes, and reuse". It suggests a process flow that is iterative and incremental, providing the evolutionary feel that is essential in modern software development.

Phases of the Unified Process

The inception phase of the UP encompasses both customer communication and planning activities. By collaborating with stakeholders, business requirements for the software are identified; a rough architecture for the system is proposed; and a plan for the iterative, incremental nature of the ensuing project is developed. Fundamental business requirements are described through a set of preliminary use cases that describe which features and functions each major class of users desires. Architecture at this point is nothing more than a tentative outline of major subsystems and the function and features that populate them.

The elaboration phase encompasses the communication and modeling activities of the generic process model. Elaboration refines and expands the preliminary use cases that were developed as part of the inception phase and expands the architectural representation to include five different views of the software—the use case model, the requirements model, the design model, the implementation model, and the deployment model. In some cases, elaboration creates an "executable architectural baseline "that represents a "first cut" executable system. The architectural baseline demonstrates the viability of the architecture but does not provide all features and functions required to use the system. In addition, the plan is carefully reviewed at

the culmination of the elaboration phase to ensure that scope, risks, and delivery dates remain reasonable. Modifications to the plan are often made at this time.

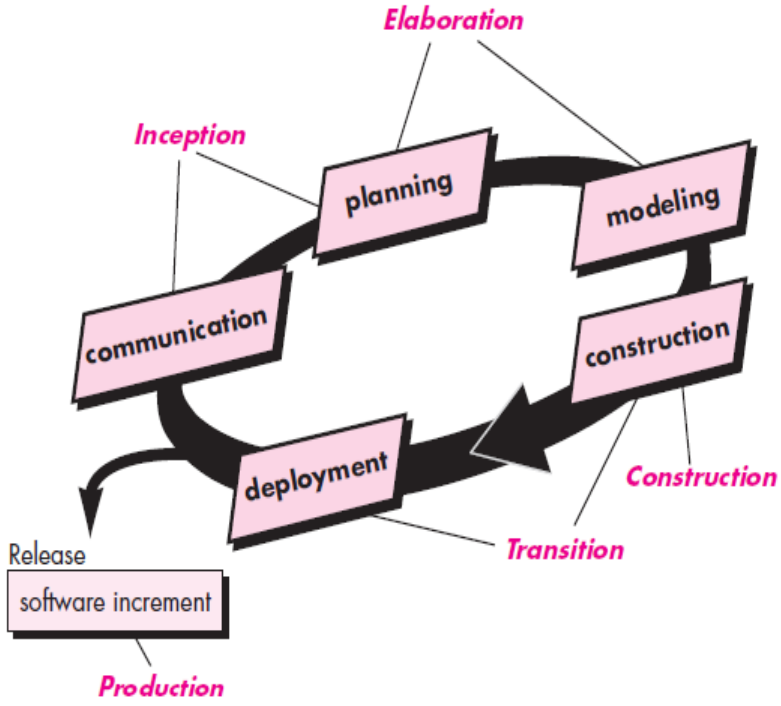
The construction phase of the UP is identical to the construction activity defined for the generic software process. Using the architectural model as input, the construction phase develops or acquires the software components that will make each use case operational for end users. To accomplish this, requirements and design models that were started during the elaboration phase are completed to reflect the final version of the software increment. All necessary and required features and functions for the software increment (i.e., the release) are then implemented in source code.

The transition phase of the UP encompasses the latter stages of the generic construction activity and the first part of the generic deployment. Software is given to end users for beta testing and user feedback reports both defects and necessary changes. In addition, the software team creates the necessary support information that is required for the release. At the conclusion of the transition phase, the software increment becomes a usable software release The production phase of the UP coincides with the deployment activity of the generic process. During this phase, the ongoing use of the software is monitored, support for the operating environment (infrastructure) is provided, and defect reports and requests for changes are submitted and evaluated.

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

FIGURE 2.9

The Unified Process



Personal and team process models

The best software process is one that is close to the people who will be doing the work. If a software process model has been developed at a corporate or organizational level, it can be effective only if it is amenable to significant adaptation to meet the needs of the project team that is actually doing software engineering work. Alternatively, the team itself can create its own process, and at the same time meet the narrower needs of individuals and the broader needs of the organization.

Personal Software Process (PSP)

The Personal Software Process (PSP) emphasizes personal measurement of both the work product that is produced and the resultant quality of the work product. In addition PSP makes the practitioner responsible for project planning (e.g., estimating and scheduling) and empowers the practitioner to control the quality of all software work products that are developed. The PSP model defines five framework activities.

Planning. This activity isolates requirements and develops both size and resource estimates. In addition, a defect estimates is made. All metrics are recorded on worksheets or templates. Finally, development tasks are identified and a project schedule is created.

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

High-level design review. Formal verification methods are applied to uncover errors in the design. Metrics are maintained for all important tasks and work result.

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

Postmortem. Using the measures and metrics collected, the effectiveness of the process is determined. Measures and metrics should provide guidance for modifying the process to improve its effectiveness.

PSP represents a disciplined, metrics-based approach to software engineering that may lead to culture shock for many practitioners. However, when PSP is properly introduced to software engineers, the resulting improvement in software engineering productivity and software quality are significant [Fer97]. However, PSP has not been widely adopted throughout the industry.

Team Software Process (TSP)

The goal of TSP is to build a "self-directed" project team that organizes itself to produce high-quality software. Humphrey defines the following objectives for TSP.

- Build self-directed teams that plan and track their work, establish goals, and own their processes and plans. These can be pure software teams or integrated product teams (IPTs) of 3 to about 20 engineers.

• Show managers how to coach and motivate their teams and how to help them sustain peak performance.

• Accelerate software process improvement by making CMM Level 5 behavior normal and expected.

• Provide improvement guidance to high-maturity organizations.

• Facilitate university teaching of industrial-grade team skills.

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

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

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

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