Chapter 1. Why We Model

In this chapter

- The importance of modeling
- Four principles of modeling
- The essential blueprints of a software system
- Object-oriented modeling

A successful software organization is one that consistently deploys quality software that meets the needs of its users. An organization that can develop such software in a timely and predictable fashion, with an efficient and effective use of resources, both human and material, is one that has a sustainable business.

There's an important implication in this message: The primary product of a development team is not beautiful documents, world-class meetings, great slogans, or Pulitzer prize-winning lines of source code. Rather, it is good software that satisfies the evolving needs of its users and the business. Everything else is secondary.

Unfortunately, many software organizations confuse "secondary" with "irrelevant." To deploy software that satisfies its intended purpose, you have to meet and engage users in a disciplined fashion, to expose the real requirements of your system. To develop software of lasting quality, you have to craft a solid architectural foundation that's resilient to change. To develop software rapidly, efficiently, and effectively, with a minimum of software scrap and rework, you need to have the right people, the right tools, and the right focus. To do all this consistently and predictably, with an appreciation for the lifetime costs of the system, you must have a sound development process that can adapt to the changing needs of your business and technology.

Modeling is a central part of all the activities that lead up to the deployment of good software. We build models to communicate the desired structure and behavior of our system. We build models to visualize and control the system's architecture. We build models to better understand the system we are building, often exposing opportunities for simplification and reuse. And we build models to manage risk.

The Importance of Modeling

If you want to build a dog house, you can pretty much start with a pile of lumber, some nails, and a few basic tools such as a hammer, saw, and tape measure. In a few hours, with little prior planning, you'll likely end up with a dog house that's reasonably functional, and you can probably do it with no one else's help. As long as it's big enough and doesn't leak too much, your dog will be happy. If it doesn't work out, you can always start over, or get a less demanding dog.

If you want to build a house for your family, you can start with a pile of lumber, some nails, and a few basic tools, but it's going to take you a lot longer, and your family will certainly be more demanding than the dog. In this case, unless you've already done it a few dozen times before, you'll be better served by doing some detailed planning before you pound the first nail or lay the foundation. At the very least, you'll want to make some sketches of how you want the house to look. If you want to build a quality house that meets the needs of your family and of local building codes, you'll need to draw some blueprints as well, so that you can think through the intended use of the rooms and the practical details of lighting, heating, and plumbing. Given these plans, you can start to make reasonable estimates of the amount of time and materials this job will require. Although it is humanly possible to build a house yourself, you'll find it is much more efficient to work with others, possibly subcontracting out many key work products or buying pre-built materials. As long as you stay true to your plans and stay within the limitations of time and money, your family will most likely be satisfied. If it doesn't work out, you can't exactly get a new family, so it is best to set expectations early and manage change carefully.

If you want to build a high-rise office building, it would be infinitely stupid for you to start with a pile of lumber, some nails, and a few basic tools. Because you are probably using other people's money, they will insist upon having input into the size, shape, and style of the building. Often, they will change their minds, even after you've started building. You will want to do extensive planning, because the cost of failure is high. You will be just a part of a much larger group responsible for developing and deploying the building, so the team will need all sorts of blueprints and models to communicate with one another. As long as you get the right people and the right tools and actively manage the process of transforming an architectural concept into reality, you will likely end up with a building that will satisfy its tenants. If you want to keep constructing buildings, then you will want to be certain to balance the desires of your tenants with the realities of building technology, and you will want to treat the rest of your team professionally, never placing them at any risk or driving them so hard that they burn out.

Curiously, a lot of software development organizations start out wanting to build high rises but approach the problem as if they were knocking out a dog house.

Sometimes, you get lucky. If you have the right people at the right moment and if all the planets align properly, then you might, just might, get your team to push out a software product that dazzles its users. Typically, however, you can't get all the right people (the right ones are often already overcommitted), it's never the right moment (yesterday would have been better), and the planets never seem to align (instead, they keep moving out of your control). Given the increasing demand to develop software quickly, development teams often fall back on the only thing they really know how to do wellpound out lines of code. Heroic programming efforts are legend in this industry, and it often seems that working harder is the proper reaction to any crisis in development. However, these are not necessarily the right lines of code, and some projects are of such a magnitude that even adding more hours to the workday is not enough to get the job done.

If you really want to build the software equivalent of a house or a high rise, the problem is more than just a matter of writing lots of softwarein fact, the trick is in creating the right software and in figuring out how to write less software. This makes quality software development an issue of architecture and process and tools. Even so, many projects start out looking like dog houses but grow to the magnitude of a high rise simply because they are a victim of their own success. There comes a time when, if there was no consideration given to architecture, process, or tools, the dog house, now grown into a

high rise, collapses of its own weight. The collapse of a dog house may annoy your dog; the failure of a high rise will materially affect its tenants.

Unsuccessful software projects fail in their own unique ways, but all successful projects are alike in many ways. There are many elements that contribute to a successful software organization; one common thread is the use of modeling.

Modeling is a proven and well-accepted engineering technique. We build architectural models of houses and high rises to help their users visualize the final product. We may even build mathematical models to analyze the effects of winds or earthquakes on our buildings.

Modeling is not just a part of the building industry. It would be inconceivable to deploy a new aircraft or an automobile without first building models from computer models to physical wind tunnel models to full-scale prototypes. New electrical devices, from microprocessors to telephone switching systems, require some degree of modeling in order to better understand the system and to communicate those ideas to others. In the motion picture industry, storyboarding, which is a form of modeling, is central to any production. In the fields of sociology, economics, and business management, we build models so that we can validate our theories or try out new ones with minimal risk and cost.

What, then, is a model? Simply put,

> *A model is a simplification of reality.*

A model provides the blueprints of a system. Models may encompass detailed plans, as well as more general plans that give a 30,000-foot view of the system under consideration. A good model includes those elements that have broad effect and omits those minor elements that are not relevant to the given level of abstraction. Every system may be described from different aspects using different models, and each model is therefore a semantically closed abstraction of the system. A model may be structural, emphasizing the organization of the system, or it may be behavioral, emphasizing the dynamics of the system.

Why do we model? There is one fundamental reason.

> *We build models so that we can better understand the system we are developing.*

Through modeling, we achieve four aims.

How UML addresses these four things is discussed in Chapter 2.

1. Models help us to visualize a system as it is or as we want it to be.
2. Models permit us to specify the structure or behavior of a system.
3. Models give us a template that guides us in constructing a system.
4. Models document the decisions we have made.

Modeling is not just for big systems. Even the software equivalent of a dog house can benefit from some modeling. However, it's definitely true that the larger and more complex the system, the more important modeling becomes, for one very simple reason:

> *We build models of complex systems because we cannot comprehend such a system in its entirety.*

There are limits to the human ability to understand complexity. Through modeling, we narrow the problem we are studying by focusing on only one aspect at a time. This is essentially the approach of

"divide-and-conquer" that Edsger Dijkstra spoke of years ago: Attack a hard problem by dividing it into a series of smaller problems that you can solve. Furthermore, through modeling, we amplify the human intellect. A model properly chosen can enable the modeler to work at higher levels of abstraction.

Saying that one ought to model does not necessarily make it so. In fact, a number of studies suggest that most software organizations do little if any formal modeling. Plot the use of modeling against the complexity of a project and you'll find that the simpler the project, the less likely it is that formal modeling will be used.

The operative word here is "formal." In reality, in even the simplest project, developers do some amount of modeling, albeit very informally. A developer might sketch out an idea on a blackboard or a scrap of paper to visualize a part of a system, or the team might use CRC cards to work through a scenario or the design of a mechanism. There's nothing wrong with any of these models. If it works, by all means use it. However, these informal models are often *ad hoc* and do not provide a common language that can easily be shared with others. Just as there exists a common language of blueprints for the construction industry, a common language for electrical engineering, and a common language for mathematical modeling, so too can a development organization benefit by using a common language for software modeling.

Every project can benefit from some modeling. Even in the realm of disposable software, where it's sometimes more effective to throw away inadequate software because of the productivity offered by visual programming languages, modeling can help the development team better visualize the plan of their system and allow them to develop more rapidly by helping them build the right thing. The more complex your project, the more likely it is that you will fail or that you will build the wrong thing if you do no modeling at all. All interesting and useful systems have a natural tendency to become more complex over time. So, although you might think you don't need to model today, as your system evolves you will regret that decision, after it is too late.

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Principles of Modeling

The use of modeling has a rich history in all the engineering disciplines. That experience suggests four basic principles of modeling. First,

> *The choice of what models to create has a profound influence on how a problem is attacked and how a solution is shaped.*

In other words, choose your models well. The right models will brilliantly illuminate the most wicked development problems, offering insight that you simply could not gain otherwise; the wrong models will mislead you, causing you to focus on irrelevant issues.

Setting aside software for a moment, suppose you are trying to tackle a problem in quantum physics. Certain problems, such as the interaction of photons in space-time, are full of wonderfully hairy mathematics. Choose a different model and suddenly this inherent complexity becomes doable, if not exactly easy. In this field, this is precisely the value of Feynmann diagrams, which provide a graphical rendering of a very complex problem. Similarly, in a totally different domain, suppose you are constructing a new building and you are concerned about how it might behave in high winds. If you build a physical model and then subject it to wind tunnel tests, you might learn some interesting things, although materials in the small don't flex exactly as they do in the large. Hence, if you build a mathematical model and then subject it to simulations, you will learn some different things, and you will also probably be able to play with more new scenarios than if you were using a physical model. By rigorously and continuously testing your models, you'll end up with a far higher level of confidence that the system you have modeled will behave as you expect it to in the real world.

In software, the models you choose can greatly affect your world view. If you build a system through the eyes of a database developer, you will likely focus on entity-relationship models that push behavior into triggers and stored procedures. If you build a system through the eyes of a structured analyst, you will likely end up with models that are algorithmic-centric, with data flowing from process to process. If you build a system through the eyes of an object-oriented developer, you'll end up with a system whose architecture is centered around a sea of classes and the patterns of interaction that direct how those classes work together. Executable models can greatly help testing. Any of these approaches might be right for a given application and development culture, although experience suggests that the object-oriented view is superior in crafting resilient architectures, even for systems that might have a large database or computational element. That fact notwithstanding, the point is that each world view leads to a different kind of system, with different costs and benefits.

Second,

> *Every model may be expressed at different levels of precision.*

If you are building a high rise, sometimes you need a 30,000-foot viewfor instance, to help your investors visualize its look and feel. Other times, you need to get down to the level of the studsfor instance, when there's a tricky pipe run or an unusual structural element.

The same is true with software models. Sometimes a quick and simple executable model of the user interface is exactly what you need; at other times you have to get down and dirty with the bits, such as when you are specifying cross-system interfaces or wrestling with networking bottlenecks. In any case, the best kinds of models are those that let you choose your degree of detail, depending on who is doing the viewing and why they need to view it. An analyst or an end user will want to focus on issues of what; a developer will want to focus on issues of how. Both of these stakeholders will want to visualize a system at different levels of detail at different times.

Third,

The best models are connected to reality.

A physical model of a building that doesn't respond in the same way as do real materials has only limited value; a mathematical model of an aircraft that assumes only ideal conditions and perfect manufacturing can mask some potentially fatal characteristics of the real aircraft. It's best to have models that have a clear connection to reality, and where that connection is weak, to know exactly how those models are divorced from the real world. All models simplify reality; the trick is to be sure that your simplifications don't mask any important details.

In software, the Achilles heel of structured analysis techniques is the fact that there is a basic disconnect between its analysis model and the system's design model. Failing to bridge this chasm causes the system as conceived and the system as built to diverge over time. In object-oriented systems, it is possible to connect all the nearly independent views of a system into one semantic whole.

Fourth,

No single model or view is sufficient. Every nontrivial system is best approached through a small set of nearly independent models with multiple viewpoints.

If you are constructing a building, there is no single set of blueprints that reveal all its details. At the very least, you'll need floor plans, elevations, electrical plans, heating plans, and plumbing plans. And within any kind of model, you need multiple views to capture the breadth of the system, such as blueprints of different floors.

The operative phrase here is "nearly independent." In this context, it means having models that can be built and studied separately but that are still interrelated. As in the case of a building, you can study electrical plans in isolation, but you can also see how they map to the floor plan and perhaps even their interaction with the routing of pipes in the plumbing plan.

The same is true of object-oriented software systems. To understand the architecture of such a system, you need several complementary and interlocking views: a use case view (exposing the requirements of the system), a design view (capturing the vocabulary of the problem space and the solution space), an interaction view (showing the interactions among the parts of the system and between the system and the environment), an implementation view (addressing the physical realization of the system), and a deployment view (focusing on system engineering issues). Each of these views may have structural, as well as behavioral, aspects. Together, these views represent the blueprints of software.

The five views of an architecture are discussed in Chapter 2.

Depending on the nature of the system, some views may be more important than others. For example, in data-intensive systems, views addressing static design will dominate. In GUI-intensive systems, static and dynamic use case views are quite important. In hard real time systems, dynamic process views tend to be more important. Finally, in distributed systems, such as one finds in Web-intensive applications, implementation and deployment models are the most important.

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Object-Oriented Modeling

Civil engineers build many kinds of models. Most commonly, there are structural models that help people visualize and specify parts of systems and the way those parts relate to one another. Depending on the most important business or engineering concerns, engineers might also build dynamic modelsfor instance, to help them to study the behavior of a structure in the presence of an earthquake. Each kind of model is organized differently, and each has its own focus. In software, there are several ways to approach a model. The two most common ways are from an algorithmic perspective and from an object-oriented perspective.

The traditional view of software development takes an algorithmic perspective. In this approach, the main building block of all software is the procedure or function. This view leads developers to focus on issues of control and the decomposition of larger algorithms into smaller ones. There's nothing inherently evil about such a point of view except that it tends to yield brittle systems. As requirements change (and they will) and the system grows (and it will), systems built with an algorithmic focus turn out to be very hard to maintain.

The contemporary view of software development takes an object-oriented perspective. In this approach, the main building block of all software systems is the object or class. Simply put, an object is a thing, generally drawn from the vocabulary of the problem space or the solution space. A class is a description of a set of objects that are similar enough (from the modeler's viewpoint) to share a specification. Every object has identity (you can name it or otherwise distinguish it from other objects), state (there's generally some data associated with it), and behavior (you can do things to the object, and it can do things to other objects as well).

For example, consider a simple three-tier architecture for a billing system, involving a user interface, business services, and a database. In the user interface, you will find concrete objects, such as buttons, menus, and dialog boxes. In the database, you will find concrete objects, such as tables representing entities from the problem domain, including customers, products, and orders. In the middle layer, you will find objects such as transactions and business rules, as well as higher-level views of problem entities, such as customers, products, and orders.

The object-oriented approach to software development is decidedly a part of the mainstream simply because it has proven to be of value in building systems in all sorts of problem domains and encompassing all degrees of size and complexity. Furthermore, most contemporary languages, operating systems, and tools are object-oriented in some fashion, giving greater cause to view the world in terms of objects. Object-oriented development provides the conceptual foundation for assembling systems out of components using technology such as J2EE or .NET.

A number of consequences flow from the choice of viewing the world in an object-oriented fashion: What is the structure of a good object-oriented architecture? What artifacts should the project create? Who should create them? How should they be measured?

These questions are discussed in Chapter 2.

Visualizing, specifying, constructing, and documenting object-oriented systems is exactly the purpose of the Unified Modeling Language.

Chapter 2. Introducing the UML

In this chapter

The Unified Modeling Language (UML) is a standard language for writing software blueprints. The UML may be used to visualize, specify, construct, and document the artifacts of a software-intensive system.

The UML is appropriate for modeling systems ranging from enterprise information systems to distributed Web-based applications and even to hard real time embedded systems. It is a very expressive language, addressing all the views needed to develop and then deploy such systems. Even though it is expressive, the UML is not difficult to understand and to use. Learning to apply the UML effectively starts with forming a conceptual model of the language, which requires learning three major elements: the UML's basic building blocks, the rules that dictate how these building blocks may be put together, and some common mechanisms that apply throughout the language.

The UML is only a language, so it is just one part of a software development method. The UML is process independent, although optimally it should be used in a process that is use case driven, architecture-centric, iterative, and incremental.

An Overview of the UML

The UML is a language for

- Visualizing
- Specifying
- Constructing
- Documenting

the artifacts of a software-intensive system.

The UML Is a Language

A language provides a vocabulary and the rules for combining words in that vocabulary for the purpose of communication. A *modeling* language is a language whose vocabulary and rules focus on the conceptual and physical representation of a system. A modeling language such as the UML is thus a standard language for software blueprints.

Modeling yields an understanding of a system. No one model is ever sufficient. Rather, you often need multiple models that are connected to one another to understand anything but the most trivial system. For software-intensive systems, this requires a language that addresses the different views of a system's architecture as it evolves throughout the software development life cycle.

The basic principles of modeling are discussed in Chapter 1.

The vocabulary and rules of a language such as the UML tell you how to create and read well-formed models, but they don't tell you what models you should create and when you should create them. That's the role of the software development process. A well-defined process will guide you in deciding what artifacts to produce, what activities and what workers to use to create them and manage them, and how to use those artifacts to measure and control the project as a whole.

The UML Is a Language for Visualizing

For many programmers, the distance between thinking of an implementation and then pounding it out in code is close to zero. You think it, you code it. In fact, some things are best cast directly in code. Text is a wonderfully minimal and direct way to write expressions and algorithms.

In such cases, the programmer is still doing some modeling, albeit entirely mentally. He or she may even sketch out a few ideas on a white board or on a napkin. However, there are several problems with this. First, communicating those conceptual models to others is error-prone unless everyone involved speaks the same language. Typically, projects and organizations develop their own language, and it is difficult to understand what's going on if you are an outsider or new to the group. Second, there are some things about a software system you can't understand unless you build models that

transcend the textual programming language. For example, the meaning of a class hierarchy can be inferred, but not directly grasped, by staring at the code for all the classes in the hierarchy. Similarly, the physical distribution and possible migration of the objects in a Web-based system can be inferred, but not directly grasped, by studying the system's code. Third, if the developer who cut the code never wrote down the models that are in his or her head, that information would be lost forever or, at best, only partially recreatable from the implementation once that developer moved on.

Writing models in the UML addresses the third issue: An explicit model facilitates communication.

Some things are best modeled textually; others are best modeled graphically. Indeed, in all interesting systems, there are structures that transcend what can be represented in a programming language. The UML is such a graphical language. This addresses the second problem described earlier.

The UML is more than just a bunch of graphical symbols. Rather, behind each symbol in the UML notation is a well-defined semantics. In this manner, one developer can write a model in the UML, and another developer, or even another tool, can interpret that model unambiguously. This addresses the first issue described earlier.

The complete semantics of the UML are discussed in **The Unified Modeling Language Reference Manual**.

The UML Is a Language for Specifying

In this context, *specifying* means building models that are precise, unambiguous, and complete. In particular, the UML addresses the specification of all the important analysis, design, and implementation decisions that must be made in developing and deploying a software-intensive system.

The UML Is a Language for Constructing

The UML is not a visual programming language, but its models can be directly connected to a variety of programming languages. This means that it is possible to map from a model in the UML to a programming language such as Java, C++, or Visual Basic, or even to tables in a relational database or the persistent store of an object-oriented database. Things that are best expressed graphically are done so graphically in the UML, whereas things that are best expressed textually are done so in the programming language.

This mapping permits forward engineeringthe generation of code from a UML model into a programming language. The reverse is also possible: You can reconstruct a model from an implementation back into the UML. Reverse engineering is not magic. Unless you encode that information in the implementation, information is lost when moving forward from models to code. Reverse engineering thus requires tool support with human intervention. Combining these two paths of forward code generation and reverse engineering yields round-trip engineering, meaning the ability to work in either a graphical or a textual view, while tools keep the two views consistent.

Modeling the structure of a system is discussed in Parts 2 and 3.

In addition to this direct mapping, the UML is sufficiently expressive and unambiguous to permit the direct execution of models, the simulation of systems, and the instrumentation of running systems.

Modeling the behavior of a system is discussed in Parts 4 and 5.

The UML Is a Language for Documenting

A healthy software organization produces all sorts of artifacts in addition to raw executable code. These artifacts include (but are not limited to)

- Requirements
- Architecture
- Design
- Source code
- Project plans
- Tests
- Prototypes
- Releases

Depending on the development culture, some of these artifacts are treated more or less formally than others. Such artifacts are not only the deliverables of a project, they are also critical in controlling, measuring, and communicating about a system during its development and after its deployment.

The UML addresses the documentation of a system's architecture and all of its details. The UML also provides a language for expressing requirements and for tests. Finally, the UML provides a language for modeling the activities of project planning and release management.

Where Can the UML Be Used?

The UML is intended primarily for software-intensive systems. It has been used effectively for such domains as

- Enterprise information systems
- Banking and financial services
- Telecommunications
- Transportation
- Defense/aerospace
- Retail
- Medical electronics
- Scientific
- Distributed Web-based services

The UML is not limited to modeling software. In fact, it is expressive enough to model nonsoftware systems, such as workflow in the legal system, the structure and behavior of a patient healthcare system, software engineering in aircraft combat systems, and the design of hardware.

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A Conceptual Model of the UML

To understand the UML, you need to form a conceptual model of the language, and this requires learning three major elements: the UML's basic building blocks, the rules that dictate how those building blocks may be put together, and some common mechanisms that apply throughout the UML. Once you have grasped these ideas, you will be able to read UML models and create some basic ones. As you gain more experience in applying the UML, you can build on this conceptual model, using more advanced features of the language.

Building Blocks of the UML

The vocabulary of the UML encompasses three kinds of building blocks:

1. Things
2. Relationships
3. Diagrams

Things are the abstractions that are first-class citizens in a model; relationships tie these things together; diagrams group interesting collections of things.

Things in the UML

There are four kinds of things in the UML:

1. Structural things
2. Behavioral things
3. Grouping things
4. Annotational things

These things are the basic object-oriented building blocks of the UML. You use them to write well-formed models.

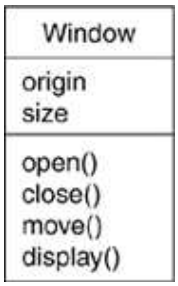
Structural Things

Structural things are the nouns of UML models. These are the mostly static parts of a model, representing elements that are either conceptual or physical. Collectively, the structural things are called *classifiers*.

Classes are discussed in Chapters 4 and 9.

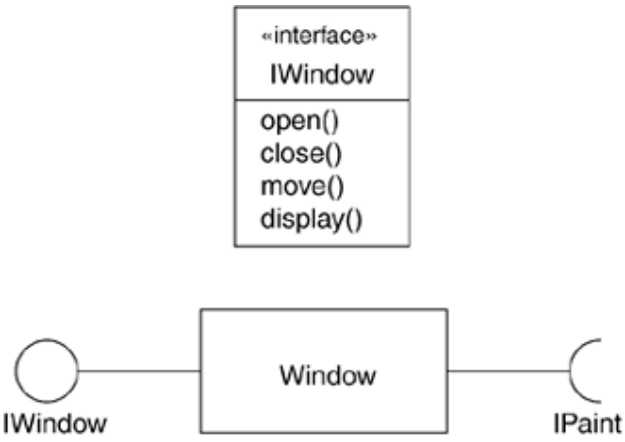
A *class* is a description of a set of objects that share the same attributes, operations, relationships, and semantics. A class implements one or more interfaces. Graphically, a class is rendered as a rectangle, usually including its name, attributes, and operations, as in Figure 2-1.

Figure 2-1. Classes



An *interface* is a collection of operations that specify a service of a class or component. An interface therefore describes the externally visible behavior of that element. An interface might represent the complete behavior of a class or component or only a part of that behavior. An interface defines a set of operation specifications (that is, their signatures) but never a set of operation implementations. The declaration of an interface looks like a class with the keyword «interface» above the name; attributes are not relevant, except sometimes to show constants. An interface rarely stands alone, however. An interface provided by a class to the outside world is shown as a small circle attached to the class box by a line. An interface required by a class from some other class is shown as a small semicircle attached to the class box by a line, as in Figure 2-2.

Figure 2-2. Interfaces



Interfaces are discussed in Chapter 11.

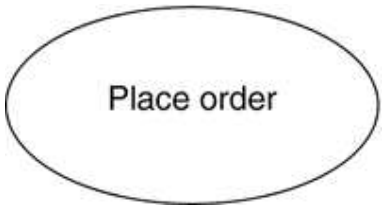
A *collaboration* defines an interaction and is a society of roles and other elements that work together to provide some cooperative behavior that's bigger than the sum of all the elements. Collaborations have structural, as well as behavioral, dimensions. A given class or object might participate in several collaborations. These collaborations therefore represent the implementation of patterns that make up a system. Graphically, a collaboration is rendered as an ellipse with dashed lines, sometimes including only its name, as in Figure 2-3.

Figure 2-3. Collaborations

Collaborations are discussed in Chapter 28.

A *use case* is a description of sequences of actions that a system performs that yield observable results of value to a particular actor. A use case is used to structure the behavioral things in a model. A use case is realized by a collaboration. Graphically, a use case is rendered as an ellipse with solid lines, usually including only its name, as in Figure 2-4.

Figure 2-4. Use Cases



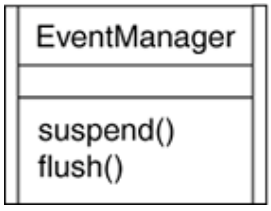
Use cases are discussed in Chapter 17.

The remaining three thingsactive classes, components, and nodesare all class-like, meaning they also describe sets of entities that share the same attributes, operations, relationships, and semantics.

However, these three are different enough and are necessary for modeling certain aspects of an object-oriented system, so they warrant special treatment.

An *active class* is a class whose objects own one or more processes or threads and therefore can initiate control activity. An active class is just like a class except that its objects represent elements whose behavior is concurrent with other elements. Graphically, an active class is rendered as a class with double lines on the left and right; it usually includes its name, attributes, and operations, as in Figure 2-5.

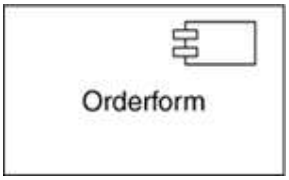
Figure 2-5. Active Classes



Active classes are discussed in Chapter 23.

A component is a modular part of the system design that hides its implementation behind a set of external interfaces. Within a system, components sharing the same interfaces can be substituted while preserving the same logical behavior. The implementation of a component can be expressed by wiring together parts and connectors; the parts can include smaller components. Graphically, a component is rendered like a class with a special icon in the upper right corner, as in Figure 2-6.

Figure 2-6. Components



Components and internal structure are discussed in Chapter 15.

The remaining two elementsartifacts and nodesare also different. They represent physical things, whereas the previous five things represent conceptual or logical things.

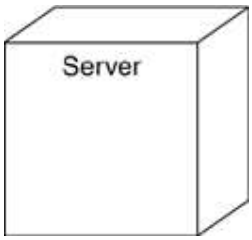
Artifacts are discussed in Chapter 26.

An *artifact* is a physical and replaceable part of a system that contains physical information ("bits"). In a system, you'll encounter different kinds of deployment artifacts, such as source code files, executables, and scripts. An artifact typically represents the physical packaging of source or run-time information. Graphically, an artifact is rendered as a rectangle with the keyword «artifact» above the name, as in Figure 2-7.

Figure 2-7. Artifacts

A *node* is a physical element that exists at run time and represents a computational resource, generally having at least some memory and, often, processing capability. A set of components may reside on a node and may also migrate from node to node. Graphically, a node is rendered as a cube, usually including only its name, as in Figure 2-8.

Figure 2-8. Nodes



Nodes are discussed in Chapter 27.

These elementsclasses, interfaces, collaborations, use cases, active classes, components, artifacts, and nodesare the basic structural things that you may include in a UML model. There are also variations on these, such as actors, signals, and utilities (kinds of classes); processes and threads (kinds of active classes); and applications, documents, files, libraries, pages, and tables (kinds of artifacts).

Behavioral Things

Behavioral things are the dynamic parts of UML models. These are the verbs of a model, representing behavior over time and space. In all, there are three primary kinds of behavioral things.

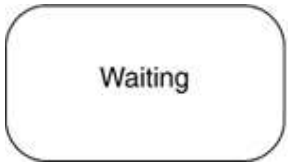
Use cases, which are used to structure the behavioral things in a model, are discussed in Chapter 17; interactions are discussed in Chapter 16.

First, an *interaction* is a behavior that comprises a set of messages exchanged among a set of objects or roles within a particular context to accomplish a specific purpose. The behavior of a society of objects or of an individual operation may be specified with an interaction. An interaction involves a number of other elements, including messages, actions, and connectors (the connection between objects). Graphically, a message is rendered as a directed line, almost always including the name of its operation, as in Figure 2-9.

Figure 2-9. Messages

Second, a *state machine* is a behavior that specifies the sequences of states an object or an interaction goes through during its lifetime in response to events, together with its responses to those events. The behavior of an individual class or a collaboration of classes may be specified with a state machine. A state machine involves a number of other elements, including states, transitions (the flow from state to state), events (things that trigger a transition), and activities (the response to a transition). Graphically, a state is rendered as a rounded rectangle, usually including its name and its substates, if any, as in Figure 2-10.

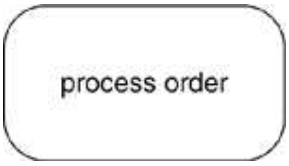
Figure 2-10. States



State machines are discussed in Chapter 22.

Third, an activity is a behavior that specifies the sequence of steps a computational process performs. In an interaction, the focus is on the set of objects that interact. In a state machine, the focus is on the life cycle of one object at a time. In an activity, the focus is on the flows among steps without regard to which object performs each step. A step of an activity is called an *action*. Graphically, an action is rendered as a rounded rectangle with a name indicating its purpose. States and actions are distinguished by their different contexts.

Figure 2-11. Actions



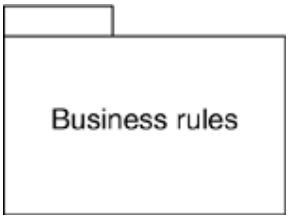
These three elementsinteractions, state machines, and activitiesare the basic behavioral things that you may include in a UML model. Semantically, these elements are usually connected to various structural elements, primarily classes, collaborations, and objects.

Grouping Things

Grouping things are the organizational parts of UML models. These are the boxes into which a model can be decomposed. There is one primary kind of grouping thing, namely, packages.

A *package* is a general-purpose mechanism for organizing the design itself, as opposed to classes, which organize implementation constructs. Structural things, behavioral things, and even other grouping things may be placed in a package. Unlike components (which exist at run time), a package is purely conceptual (meaning that it exists only at development time). Graphically, a package is rendered as a tabbed folder, usually including only its name and, sometimes, its contents, as in Figure 2-12.

Figure 2-12. Packages



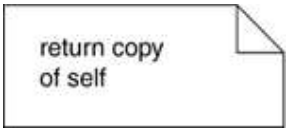
Packages are discussed in Chapter 12.

Packages are the basic grouping things with which you may organize a UML model. There are also variations, such as frameworks, models, and subsystems (kinds of packages).

Annotational Things

Annotational things are the explanatory parts of UML models. These are the comments you may apply to describe, illuminate, and remark about any element in a model. There is one primary kind of annotational thing, called a note. A *note* is simply a symbol for rendering constraints and comments attached to an element or a collection of elements. Graphically, a note is rendered as a rectangle with a dog-eared corner, together with a textual or graphical comment, as in Figure 2-13.

Figure 2-13. Notes



Notes are discussed in Chapter 6.

This element is the one basic annotational thing you may include in a UML model. You'll typically use notes to adorn your diagrams with constraints or comments that are best expressed in informal or formal text. There are also variations on this element, such as requirements (which specify some desired behavior from the perspective of outside the model).

Relationships in the UML

There are four kinds of relationships in the UML:

1. Dependency
2. Association
3. Generalization
4. Realization

These relationships are the basic relational building blocks of the UML. You use them to write well-formed models.

First, a *dependency* is a semantic relationship between two model elements in which a change to one element (the independent one) may affect the semantics of the other element (the dependent one). Graphically, a dependency is rendered as a dashed line, possibly directed, and occasionally including a label, as in Figure 2-14.

Figure 2-14. Dependencies

Dependencies are discussed in Chapters 5 and 10.

Second, an *association* is a structural relationship among classes that describes a set of links, a link being a connection among objects that are instances of the classes. Aggregation is a special kind of association, representing a structural relationship between a whole and its parts. Graphically, an association is rendered as a solid line, possibly directed, occasionally including a label, and often containing other adornments, such as multiplicity and end names, as in Figure 2-15.

Figure 2-15. Associations

Associations are discussed in Chapters 5 and 10.

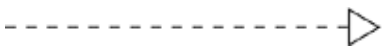
Third, a *generalization* is a specialization/generalization relationship in which the specialized element (the child) builds on the specification of the generalized element (the parent). The child shares the structure and the behavior of the parent. Graphically, a generalization relationship is rendered as a solid line with a hollow arrowhead pointing to the parent, as in Figure 2-16.

Figure 2-16. Generalizations

Generalizations are discussed in Chapters 5 and 10.

Fourth, a *realization* is a semantic relationship between classifiers, wherein one classifier specifies a contract that another classifier guarantees to carry out. You'll encounter realization relationships in two places: between interfaces and the classes or components that realize them, and between use cases and the collaborations that realize them. Graphically, a realization relationship is rendered as a cross between a generalization and a dependency relationship, as in Figure 2-17.

Figure 2-17. Realizations



Realizations are discussed in Chapter 10.

These four elements are the basic relational things you may include in a UML model. There are also variations on these four, such as refinement, trace, include, and extend.

Diagrams in the UML

A *diagram* is the graphical presentation of a set of elements, most often rendered as a connected graph of vertices (things) and paths (relationships). You draw diagrams to visualize a system from different perspectives, so a diagram is a projection into a system. For all but the most trivial systems, a diagram represents an elided view of the elements that make up a system. The same element may appear in all diagrams, only a few diagrams (the most common case), or in no diagrams at all (a very rare case). In theory, a diagram may contain any combination of things and relationships. In practice, however, a small number of common combinations arise, which are consistent with the five most useful views that comprise the architecture of a software-intensive system. For this reason, the UML includes thirteen kinds of diagrams:

1. Class diagram
2. Object diagram
3. Component diagram
4. Composite structure diagram
5. Use case diagram
6. Sequence diagram
7. Communication diagram
8. State diagram
9. Activity diagram
10. Deployment diagram
11. Package diagram
12. Timing diagram
13. Interaction overview diagram

The five views of an architecture are discussed later in this chapter.

A *class diagram* shows a set of classes, interfaces, and collaborations and their relationships. These diagrams are the most common diagram found in modeling object-oriented systems. Class diagrams address the static design view of a system. Class diagrams that include active classes address the static process view of a system. Component diagrams are variants of class diagrams.

Class diagrams are discussed in Chapter 8.

An *object diagram* shows a set of objects and their relationships. Object diagrams represent static snapshots of instances of the things found in class diagrams. These diagrams address the static design view or static process view of a system as do class diagrams, but from the perspective of real or prototypical cases.

Object diagrams are discussed in Chapter 14.

A *component diagram* is shows an encapsulated class and its interfaces, ports, and internal structure consisting of nested components and connectors. Component diagrams address the static design implementation view of a system. They are important for building large systems from smaller parts. (UML distinguishes a *composite structure diagram*, applicable to any class, from a component diagram, but we combine the discussion because the distinction between a component and a structured class is unnecessarily subtle.)

Component diagrams and internal structure are discussed in Chapter 15.

A *use case diagram* shows a set of use cases and actors (a special kind of class) and their relationships. Use case diagrams address the static use case view of a system. These diagrams are especially important in organizing and modeling the behaviors of a system.

Use case diagrams are discussed in Chapter 18.

Both sequence diagrams and communication diagrams are kinds of interaction diagrams. An *interaction diagram* shows an interaction, consisting of a set of objects or roles, including the messages that may be dispatched among them. Interaction diagrams address the dynamic view of a system. A *sequence diagram* is an interaction diagram that emphasizes the time-ordering of messages; a *communication diagram* is an interaction diagram that emphasizes the structural organization of the objects or roles that send and receive messages. Sequence diagrams and communication diagrams represent similar basic concepts, but each diagram emphasizes a different view of the concepts. Sequence diagrams emphasize temporal ordering, and communication diagrams emphasize the data structure through which messages flow. A *timing diagram* (not covered in this book) shows the actual times at which messages are exchanged.

Interaction diagrams are discussed in Chapter 19.

A *state diagram* shows a state machine, consisting of states, transitions, events, and activities. A state diagrams shows the dynamic view of an object. They are especially important in modeling the behavior of an interface, class, or collaboration and emphasize the event-ordered behavior of an object, which is especially useful in modeling reactive systems

State diagrams are discussed in Chapter 25.

An *activity diagram* shows the structure of a process or other computation as the flow of control and data from step to step within the computation. Activity diagrams address the dynamic view of a system. They are especially important in modeling the function of a system and emphasize the flow of control among objects.

Activity diagrams are discussed in Chapter 20.

A *deployment diagram* shows the configuration of run-time processing nodes and the components that live on them. Deployment diagrams address the static deployment view of an architecture. A node typically hosts one or more artifacts.

Deployment diagrams are discussed in Chapter 31.

An *artifact diagram* shows the physical constituents of a system on the computer. Artifacts include files, databases, and similar physical collections of bits. Artifacts are often used in conjunction with deployment diagrams. Artifacts also show the classes and components that they implement. (UML treats artifact diagrams as a variety of deployment diagram, but we discuss them separately.)

Artifact diagrams are discussed in Chapter 30.

A *package diagram* shows the decomposition of the model itself into organization units and their dependencies.

Package diagrams are discussed in Chapter 12.

A *timing diagram* is an interaction diagram that shows actual times across different objects or roles, as opposed to just relative sequences of messages. An *interaction overview diagram* is a hybrid of an

activity diagram and a sequence diagram. These diagrams have specialized uses and so are not discussed in this book. See the *UML Reference Manual* for more details.

This is not a closed list of diagrams. Tools may use the UML to provide other kinds of diagrams, although these are the most common ones that you will encounter in practice.

Rules of the UML

The UML's building blocks can't simply be thrown together in a random fashion. Like any language, the UML has a number of rules that specify what a well-formed model should look like. A *well-formed model* is one that is semantically self-consistent and in harmony with all its related models.

The UML has syntactic and semantic rules for

- Names — What you can call things, relationships, and diagrams
- Scope — The context that gives specific meaning to a name
- Visibility — How those names can be seen and used by others
- Integrity — How things properly and consistently relate to one another
- Execution — What it means to run or simulate a dynamic model

Models built during the development of a software-intensive system tend to evolve and may be viewed by many stakeholders in different ways and at different times. For this reason, it is common for the development team to not only build models that are well-formed, but also to build models that are

- Elided — Certain elements are hidden to simplify the view
- Incomplete — Certain elements may be missing
- Inconsistent — The integrity of the model is not guaranteed

These less-than-well-formed models are unavoidable as the details of a system unfold and churn during the software development life cycle. The rules of the UML encourage youbut do not force youto address the most important analysis, design, and implementation questions that push such models to become well-formed over time.

Common Mechanisms in the UML

A building is made simpler and more harmonious by the conformance to a pattern of common features. A house may be built in the Victorian or French country style largely by using certain architectural patterns that define those styles. The same is true of the UML. It is made simpler by the presence of four common mechanisms that apply consistently throughout the language.

1. Specifications
2. Adornments

3. Common divisions
4. Extensibility mechanisms

Specifications

The UML is more than just a graphical language. Rather, behind every part of its graphical notation there is a specification that provides a textual statement of the syntax and semantics of that building block. For example, behind a class icon is a specification that provides the full set of attributes, operations (including their full signatures), and behaviors that the class embodies; visually, that class icon might only show a small part of this specification. Furthermore, there might be another view of that class that presents a completely different set of parts yet is still consistent with the class's underlying specification. You use the UML's graphical notation to visualize a system; you use the UML's specification to state the system's details. Given this split, it's possible to build up a model incrementally by drawing diagrams and then adding semantics to the model's specifications, or directly by creating a specification, perhaps by reverse engineering an existing system, and then creating diagrams that are projections into those specifications.

The UML's specifications provide a semantic backplane that contains all the parts of all the models of a system, each part related to one another in a consistent fashion. The UML's diagrams are thus simply visual projections into that backplane, each diagram revealing a specific interesting aspect of the system.

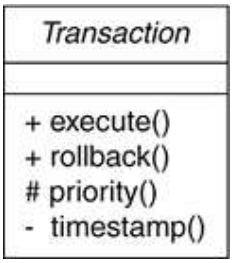
Adornments

Most elements in the UML have a unique and direct graphical notation that provides a visual representation of the most important aspects of the element. For example, the notation for a class is intentionally designed to be easy to draw, because classes are the most common element found in modeling object-oriented systems. The class notation also exposes the most important aspects of a class, namely its name, attributes, and operations.

Notes and other adornments are discussed in Chapter 6.

A class's specification may include other details, such as whether it is abstract or the visibility of its attributes and operations. Many of these details can be rendered as graphical or textual adornments to the class's basic rectangular notation. For example, Figure 2-18 shows a class, adorned to indicate that it is an abstract class with two public, one protected, and one private operation.

Figure 2-18. Adornments



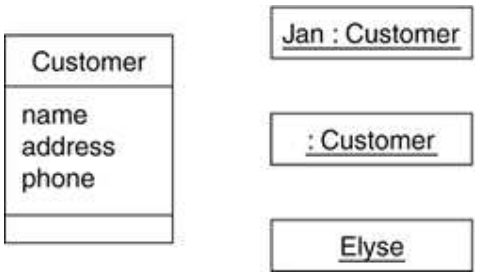
Every element in the UML's notation starts with a basic symbol, to which can be added a variety of adornments specific to that symbol.

Common Divisions

In modeling object-oriented systems, the world often gets divided in several ways.

First, there is the division of class and object. A class is an abstraction; an object is one concrete manifestation of that abstraction. In the UML, you can model classes as well as objects, as shown in Figure 2-19. Graphically, the UML distinguishes an object by using the same symbol as its class and then simply underlying the object's name.

Figure 2-19. Classes and Objects



Objects are discussed in Chapter 13.

In this figure, there is one class, named `Customer`, together with three objects: `Jan` (which is marked explicitly as being a `Customer` object), `:Customer` (an anonymous `Customer` object), and `Elyse` (which in its specification is marked as being a kind of `Customer` object, although it's not shown explicitly here).

Almost every building block in the UML has this same kind of class/object dichotomy. For example, you can have use cases and use case executions, components and component instances, nodes and node instances, and so on.

Second, there is the separation of interface and implementation. An interface declares a contract, and an implementation represents one concrete realization of that contract, responsible for faithfully carrying out the interface's complete semantics. In the UML, you can model both interfaces and their implementations, as shown in Figure 2-20.

Figure 2-20. Interfaces and Implementations

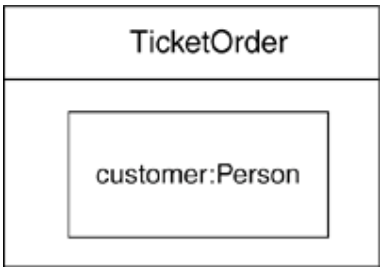
Interfaces are discussed in Chapter 11.

In this figure, there is one component named `SpellingWizard.dll` that provides (implements) two interfaces, `IUnknown` and `ISpelling`. It also requires an interface, `IDictionary`, that must be provided by another component.

Almost every building block in the UML has this same kind of interface/implementation dichotomy. For example, you can have use cases and the collaborations that realize them, as well as operations and the methods that implement them.

Third, there is the separation of type and role. The type declares the class of an entity, such as an object, an attribute, or a parameter. A role describes the meaning of an entity within its context, such as a class, component, or collaboration. Any entity that forms part of the structure of another entity, such as an attribute, has both characteristics: It derives some of its meaning from its inherent type and some of its meaning from its role within its context (Figure 2-21).

Figure 2-21. Part with role and type



Extensibility Mechanisms

The UML provides a standard language for writing software blueprints, but it is not possible for one closed language to ever be sufficient to express all possible nuances of all models across all domains across all time. For this reason, the UML is opened-ended, making it possible for you to extend the language in controlled ways. The UML's extensibility mechanisms include

- Stereotypes
- Tagged values
- Constraints

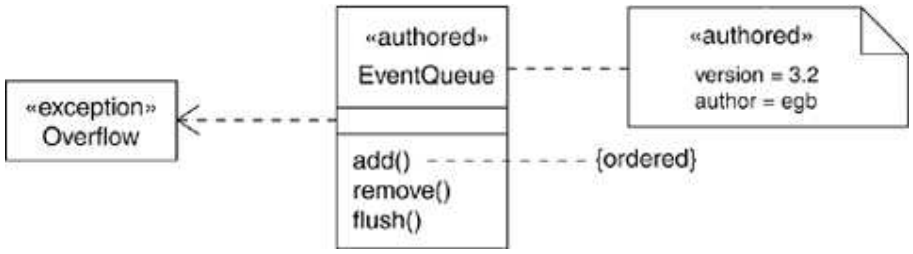
The UML's extensibility mechanisms are discussed in Chapter 6.

A *stereotype* extends the vocabulary of the UML, allowing you to create new kinds of building blocks that are derived from existing ones but that are specific to your problem. For example, if you are working in a programming language, such as Java or C++, you will often want to model exceptions. In these languages, exceptions are just classes, although they are treated in very special ways. Typically, you only want to allow them to be thrown and caught, nothing else. You can make exceptions first-class citizens in your modelsmeaning that they are treated like basic building blocksby marking them with an appropriate stereotype, as for the class `Overflow` in Figure 2-19.

A *tagged value* extends the properties of a UML stereotype, allowing you to create new information in the stereotype's specification. For example, if you are working on a shrink-wrapped product that undergoes many releases over time, you often want to track the version and author of certain critical abstractions. Version and author are not primitive UML concepts. They can be added to any building block, such as a class, by introducing new tagged values to that building block. In Figure 2-19, for example, the class `EventQueue` is extended by marking its version and author explicitly.

A *constraint* extends the semantics of a UML building block, allowing you to add new rules or modify existing ones. For example, you might want to constrain the `EventQueue` class so that all additions are done in order. As Figure 2-22 shows, you can add a constraint that explicitly marks these for the operation `add`.

Figure 2-22. Extensibility Mechanisms



Collectively, these three extensibility mechanisms allow you to shape and grow the UML to your project's needs. These mechanisms also let the UML adapt to new software technology, such as the likely emergence of more powerful distributed programming languages. You can add new building blocks, modify the specification of existing ones, and even change their semantics. Naturally, it's important that you do so in controlled ways so that through these extensions, you remain true to the UML's purposethe communication of information.

PREV NEXT

Architecture

Visualizing, specifying, constructing, and documenting a software-intensive system demands that the system be viewed from a number of perspectives. Different stakeholdersend users, analysts, developers, system integrators, testers, technical writers, and project managerseach bring different agendas to a project, and each looks at that system in different ways at different times over the project's life. A system's architecture is perhaps the most important artifact that can be used to manage these different viewpoints and thus control the iterative and incremental development of a system throughout its life cycle.

The need for viewing complex systems from different perspectives is discussed in Chapter 1.

Architecture is the set of significant decisions about

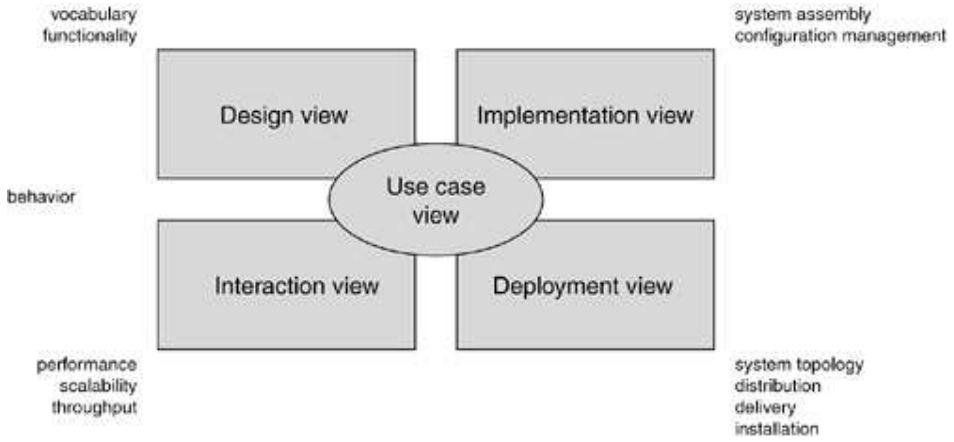
- The organization of a software system
- The selection of the structural elements and their interfaces by which the system is composed
- Their behavior, as specified in the collaborations among those elements
- The composition of these structural and behavioral elements into progressively larger subsystems
- The architectural style that guides this organization: the static and dynamic elements and their interfaces, their collaborations, and their composition

Software architecture is not only concerned with structure and behavior but also with usage, functionality, performance, resilience, reuse, comprehensibility, economic and technology constraints and trade-offs, and aesthetic concerns.

As Figure 2-23 illustrates, the architecture of a software-intensive system can best be described by five interlocking views. Each view is a projection into the organization and structure of the system, focused on a particular aspect of that system.

Figure 2-23. Modeling a System's Architecture

[View full size image]



Modeling the architecture of a system is discussed in Chapter 32.

The *use case view* of a system encompasses the use cases that describe the behavior of the system as seen by its end users, analysts, and testers. This view doesn't really specify the organization of a software system. Rather, it exists to specify the forces that shape the system's architecture. With the UML, the static aspects of this view are captured in use case diagrams; the dynamic aspects of this view are captured in interaction diagrams, state diagrams, and activity diagrams.

The *design view* of a system encompasses the classes, interfaces, and collaborations that form the vocabulary of the problem and its solution. This view primarily supports the functional requirements of the system, meaning the services that the system should provide to its end users. With the UML, the static aspects of this view are captured in class diagrams and object diagrams; the dynamic aspects of this view are captured in interaction diagrams, state diagrams, and activity diagrams. The internal structure diagram of a class is particularly useful.

The *interaction view* of a system shows the flow of control among its various parts, including possible concurrency and synchronization mechanisms. This view primarily addresses the performance, scalability, and throughput of the system. With the UML, the static and dynamic aspects of this view are captured in the same kinds of diagrams as for the design view, but with a focus on the active classes that control the system and the messages that flow between them.

The *implementation view* of a system encompasses the artifacts that are used to assemble and release the physical system. This view primarily addresses the configuration management of the system's releases, made up of somewhat independent files that can be assembled in various ways to produce a running system. It is also concerned with the mapping from logical classes and components to physical artifacts. With the UML, the static aspects of this view are captured in artifact diagrams; the dynamic aspects of this view are captured in interaction diagrams, state diagrams, and activity diagrams.

The *deployment view* of a system encompasses the nodes that form the system's hardware topology on which the system executes. This view primarily addresses the distribution, delivery, and installation of the parts that make up the physical system. With the UML, the static aspects of this view are captured in deployment diagrams; the dynamic aspects of this view are captured in interaction diagrams, state diagrams, and activity diagrams.

Each of these five views can stand alone so that different stakeholders can focus on the issues of the system's architecture that most concern them. These five views also interact with one another: Nodes in the deployment view hold components in the implementation view that, in turn, represent the physical realization of classes, interfaces, collaborations, and active classes from the design and process views. The UML permits you to express each of these five views.

Software Development Life Cycle

The UML is largely process-independent, meaning that it is not tied to any particular software development life cycle. However, to get the most benefit from the UML, you should consider a process that is

- Use case driven
- Architecture-centric
- Iterative and incremental

> ***The Rational Unified Process is summarized in Appendix B; a more complete treatment of this process is discussed in* The Unified Software Development Process *and* The Rational Unified Process**.

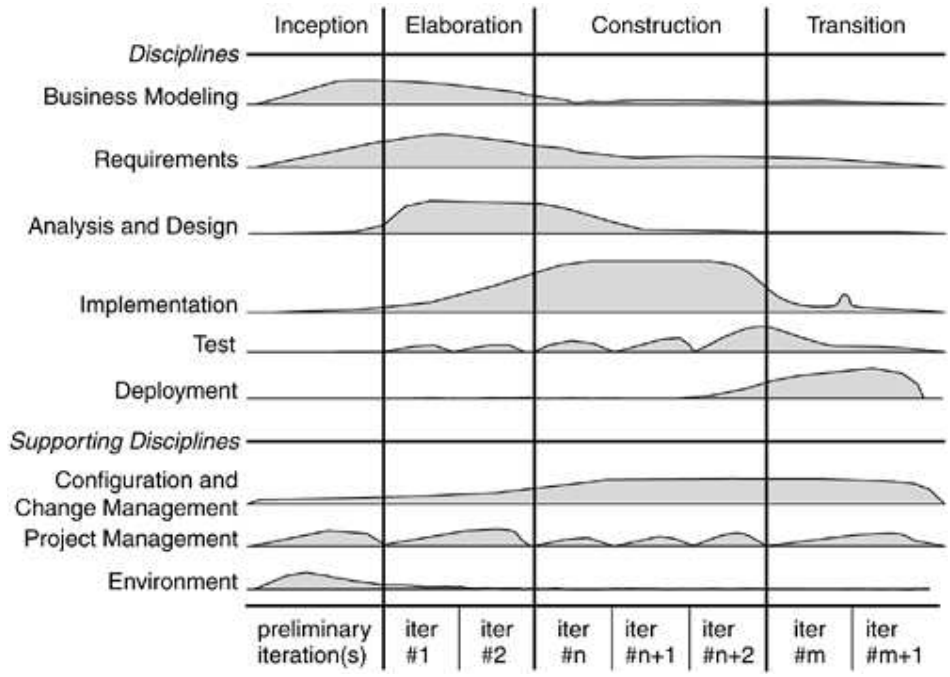
Use case driven means that use cases are used as a primary artifact for establishing the desired behavior of the system, for verifying and validating the system's architecture, for testing, and for communicating among the stakeholders of the project.

Architecture-centric means that a system's architecture is used as a primary artifact for conceptualizing, constructing, managing, and evolving the system under development.

An *iterative process* is one that involves managing a stream of executable releases. An *incremental process* is one that involves the continuous integration of the system's architecture to produce these releases, with each new release embodying incremental improvements over the other. Together, an iterative and incremental process is *risk-driven*, meaning that each new release is focused on attacking and reducing the most significant risks to the success of the project.

This use case driven, architecture-centric, and iterative/incremental process can be broken into phases. A *phase* is the span of time between two major milestones of the process, when a well-defined set of objectives are met, artifacts are completed, and decisions are made whether to move into the next phase. As Figure 2-24 shows, there are four phases in the software development life cycle: inception, elaboration, construction, and transition. In the diagram, workflows are plotted against these phases, showing their varying degrees of focus over time.

Figure 2-24. Software Development Life Cycle



Inception is the first phase of the process, when the seed idea for the development is brought up to the point of beingat least internallysufficiently well-founded to warrant entering into the elaboration phase.

Elaboration is the second phase of the process, when the product requirements and architecture are defined. In this phase, the requirements are articulated, prioritized, and baselined. A system's requirements may range from general vision statements to precise evaluation criteria, each specifying particular functional or nonfunctional behavior and each providing a basis for testing.

Construction is the third phase of the process, when the software is brought from an executable architectural baseline to being ready to be transitioned to the user community. Here also, the system's requirements and especially its evaluation criteria are constantly reexamined against the business needs of the project, and resources are allocated as appropriate to actively attack risks to the project.

Transition is the fourth phase of the process, when the software is delivered to the user community. Rarely does the software development process end here, for even during this phase, the system is continuously improved, bugs are eradicated, and features that didn't make an earlier release are added.

One element that distinguishes this process and that cuts across all four phases is an iteration. An *iteration* is a distinct set of work tasks, with a baselined plan and evaluation criteria that results in an executable system that can be run, tested, and evaluated. The executable system need not be released externally. Because the iteration yields an executable product, progress can be judged and risks can be reevaluated after each iteration. This means that the software development life cycle can be characterized as involving a continuous stream of executable releases of the system's architecture with a midcourse correction after each iteration to mitigate potential risk. It is this emphasis on architecture as an important artifact that drives the UML to focus on modeling the different views of a system's architecture.

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