Cocoa Fundamentals Guide

Developer

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Introduction

To a developer new to it, Cocoa might seem like a vast, uncharted new world of technology. The features, tools, concepts, designs, terminology, programming interfaces, and even programming language of this development environment may all be unfamiliar. *Cocoa Fundamentals Guide* eases the initial steps to Cocoa proficiency. It provides an orientation to the technological landscape that is Cocoa. It introduces its features, basic concepts, terminology, architectures, and underlying design patterns.

You can build Cocoa applications for two platforms: the OS X operating system and iOS, the operating system for Multi-Touch devices such as iPhone, iPad, and iPod touch. *Cocoa Fundamentals Guide* presents Cocoa-related information for both platforms, integrating the information as much as possible and pointing out platform differences when necessary. The intent is that, as you become familiar with Cocoa for one platform, it will become easier to transfer that knowledge to software development for the other platform.

Cocoa Fundamentals Guide is structured to lead gradually to a general understanding of what Cocoa development is all about. It starts with the most basic information—what Cocoa is in terms of its components and capabilities—and ends with an examination of its major architectures. Each chapter builds on what was explained in previous chapters. Each section gives the important details about a subject, yet describes it at only a high level. A section frequently refers you to another document that offers a more comprehensive description.

In the set of Cocoa developer documentation, *Cocoa Fundamentals Guide* is the conceptual entry-point document. It is prerequisite reading for other essential Cocoa guides, such as *Cocoa Drawing Guide*, *View Programming Guide*, and *iOS Application Programming Guide*. *Cocoa Fundamentals Guide* assumes little in terms of prerequisite reading, but readers should be proficient C programmers and should be familiar with the capabilities and technologies of the platform they will be developing for. For OS X, you can acquire this familiarity by reading *Mac Technology Overview*; for iOS, read *iOS Technology Overview*.

Organization of This Document

Cocoa Fundamentals Guide has the following chapters:

- "What Is Cocoa?" (page 11) introduces Cocoa from a functional and broadly architectural perspective, describing its features, frameworks, and development environment.
- "Cocoa Objects" (page 61) explains the advantages and basic use of Objective-C, plus the common behavior, interface, and life cycle of all Cocoa objects.

- "Adding Behavior to a Cocoa Program" (page 126) describes what it's like to write a program using a Cocoa framework and explains how to create a subclass.
- "Cocoa Design Patterns" (page 165) describes the Cocoa adaptations of design patterns, especially Model-View-Controller and object modeling.
- "Communicating with Objects" (page 209) discusses the programming interfaces and mechanisms for communication between Cocoa objects, including delegation, notification, and bindings.

See Also

You can find several excellent third-party introductions to Cocoa in technical book stores. You can use these books to supplement what you learn in *Cocoa Fundamentals Guide*. In addition, there are a few other Apple publications that you should read when starting out as a Cocoa developer:

- *The Objective-C Programming Language* describes the Objective-C programming language and runtime environment.
- *Model Object Implementation Guide* discusses basic issues of subclass design and implementation.
- *Developing Cocoa Objective-C Applications: A Tutorial* shows you how to build a simple Cocoa application for OS X using the Xcode development environment, the Cocoa frameworks, and Objective-C. *Your First iOS Application* is a tutorial that guides you through the creation of a simple iOS application, showing you along the way the basics of the Xcode development environment, Objective-C, and the Cocoa frameworks.
- *iOS Application Programming Guide* presents information specific to the frameworks used to develop applications for devices running iOS.

What Is Cocoa?

Cocoa is an application environment for both the OS X operating system and iOS, the operating system used on Multi-Touch devices such as iPhone, iPad, and iPod touch. It consists of a suite of object-oriented software libraries, a runtime system, and an integrated development environment.

This chapter expands on this definition, describing the purpose, capabilities, and components of Cocoa on both platforms. Reading this functional description of Cocoa is an essential first step for a developer trying to understand Cocoa.

The Cocoa Environment

Cocoa is a set of object-oriented frameworks that provides a runtime environment for applications running in OS X and iOS. Cocoa is the preeminent application environment for OS X and the *only* application environment for iOS. (Carbon is an alternative environment in OS X, but it is a compatibility framework with procedural programmatic interfaces intended to support existing OS X code bases.) Most of the applications you see in OS X and iOS, including Mail and Safari, are Cocoa applications. An integrated development environment called Xcode supports application development for both platforms. The combination of this development environment and Cocoa makes it easy to create a well-factored, full-featured application.

Introducing Cocoa

As with all application environments, Cocoa presents two faces; it has a runtime aspect and a development aspect. In its runtime aspect, Cocoa applications present the user interface and are tightly integrated with the other visible components of the operating system; in OS X, these include the Finder, the Dock, and other applications from all environments.

But it is the development aspect that is the more interesting one to programmers. Cocoa is an integrated suite of object-oriented software components—classes—that enables you to rapidly create robust, full-featured OS X and iOS applications. These classes are reusable and adaptable software building blocks; you can use them as-is or extend them for your specific requirements. Cocoa classes exist for just about every conceivable development necessity, from user-interface objects to data formatting. Where a development need hasn't been anticipated, you can easily create a subclass of an existing class that answers that need.

Cocoa has one of the most distinguished pedigrees of any object-oriented development environment. From its introduction as NeXTSTEP in 1989 to the present day, it has been continually refined and tested (see "A Bit of History" (page 59)). Its elegant and powerful design is ideally suited for the rapid development of software of all kinds, not only applications but command-line tools, plug-ins, and various types of bundles. Cocoa gives your application much of its behavior and appearance "for free," freeing up more of your time to work on those features that are distinctive. (For details on what Cocoa offers, see "Features of a Cocoa Application" (page 17).)

> **iOS Note** Cocoa for iOS supports only application development and not development of any other kind of executable.

You can use several programming languages when developing Cocoa software, but the essential, required language is Objective-C. Objective-C is a superset of ANSI C that has been extended with certain syntactical and semantic features (derived from Smalltalk) to support object-oriented programming. The few added conventions are easy to learn and use. Because Objective-C rests on a foundation of ANSI C, you can freely intermix straight C code with Objective-C code. Moreover, your code can call functions defined in non-Cocoa programmatic interfaces, such as the BSD library interfaces in `/usr/include`. You can even mix C++ code with your Cocoa code and link the compiled code into the same executable.

> **OS X Note** In OS X, you can also program in Cocoa using scripting bridges such as PyObjC (the Python–Objective-C bridge) and RubyCocoa (the Ruby–Cocoa bridge). Both bridged languages let you write Cocoa applications in the respective scripting languages, Python and Ruby. Both of these are interpreted, interactive, and object-oriented programming languages that make it possible for Python or Ruby objects to send messages to Objective-C objects as if they were Python or Ruby objects, and also for Objective-C objects to send messages to Python or Ruby objects. For more information, see *Ruby and Python Programming Topics for Mac*.

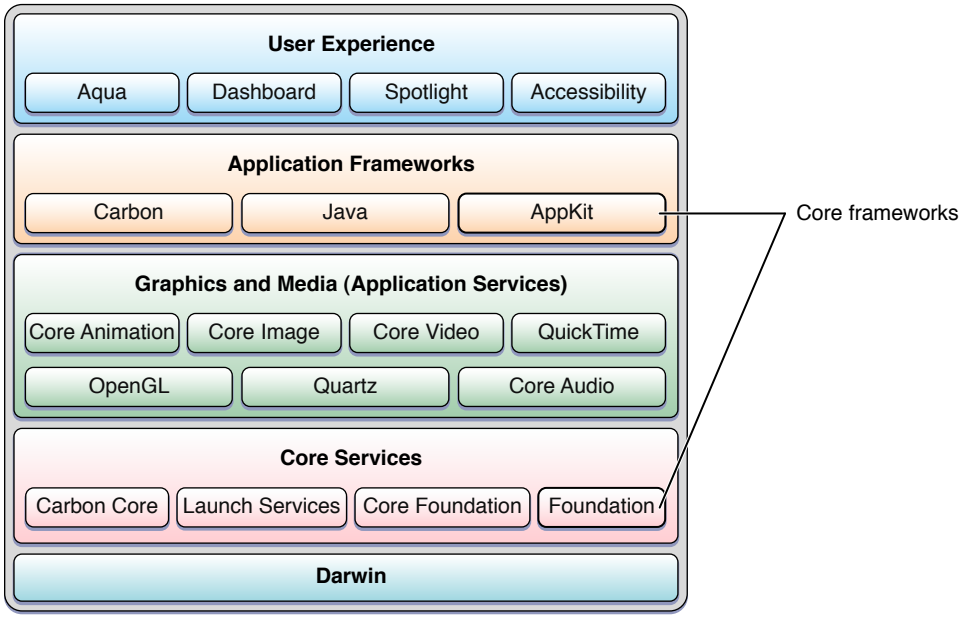
The most important Cocoa class libraries come packaged in two core frameworks for each platform: Foundation and AppKit for OS X, and Foundation and UIKit for iOS. As with all frameworks, these contain not only a dynamically sharable library (or sometimes several versions of libraries required for backward compatibility), but header files, API documentation, and related resources. The pairing of Foundation with AppKit or UIKit reflects the division of the Cocoa programmatic interfaces into those classes that are not related to a graphical user interface and those that are. For each platform, its two core frameworks are essential to any Cocoa project whose end product is an application. Both platforms additionally support the Core Data framework, which is as important and useful as the core frameworks.

OS X also ships with several other frameworks that publish Cocoa programmatic interfaces, such as the WebKit and Address Book frameworks; more Cocoa frameworks will be added to the operating system over time. See "The Cocoa Frameworks" (page 30) for further information.

How Cocoa Fits into OS X

Architecturally, OS X is a series of software layers going from the foundation of Darwin to the various application frameworks and the user experience they support. The intervening layers represent the system software largely (but not entirely) contained in the two major umbrella frameworks, Core Services and Application Services. A component at one layer generally has dependencies on the layer beneath it. Figure 1-1 situates Cocoa in this architectural setting.

Figure 1-1 Cocoa in the architecture of OS X



For example, the system component that is largely responsible for rendering the Aqua user interface, Quartz (implemented in the Core Graphics framework), is part of the Application Services layer. And at the base of the architectural stack is Darwin; everything in OS X, including Cocoa, ultimately depends on Darwin to function.

In OS X, Cocoa has two *core* Objective-C frameworks that are essential to application development for OS X:

- **AppKit.** AppKit, one of the application frameworks, provides the objects an application displays in its user interface and defines the structure for application behavior, including event handling and drawing. For a description of AppKit, see "AppKit (OS X)" (page 41).

- **Foundation.** This framework, in the Core Services layer, defines the basic behavior of objects, establishes mechanisms for their management, and provides objects for primitive data types, collections, and operating-system services. Foundation is essentially an object-oriented version of the Core Foundation framework; see "Foundation" (page 31) for a discussion of the Foundation framework.

AppKit has close, direct dependences on Foundation, which functionally is in the Core Services layer. If you look closer, at individual, or groups, of Cocoa classes and at particular frameworks, you begin to see where Cocoa either has specific dependencies on other parts of OS X or where it exposes underlying technology with its interfaces. Some major underlying frameworks on which Cocoa depends or which it exposes through its classes and methods are Core Foundation, Carbon Core, Core Graphics (Quartz), and Launch Services:

- **Core Foundation**. Many classes of the Foundation framework are based on equivalent Core Foundation opaque types. This close relationship is what makes "toll-free bridging"—cast-conversion between compatible Core Foundation and Foundation types—possible. Some of the implementation of Core Foundation, in turn, is based on the BSD part of the Darwin layer.
- **Carbon Core**. AppKit and Foundation tap into the Carbon Core framework for some of the system services it provides. For example, Carbon Core has the File Manager, which Cocoa uses for conversions between various file-system representations.
- **Core Graphics**. The Cocoa drawing and imaging classes are (quite naturally) closely based on the Core Graphics framework, which implements Quartz and the window server.
- **Launch Services**. The `NSWorkspace` class exposes the underlying capabilities of Launch Services. Cocoa also uses the application-registration feature of Launch Services to get the icons associated with applications and documents.

> **Note** The intent of this architectural overview is not to itemize every relationship that Cocoa has to other parts of OS X. Instead, it surveys the more interesting ones in order to give you a general idea of the architectural context of the framework.

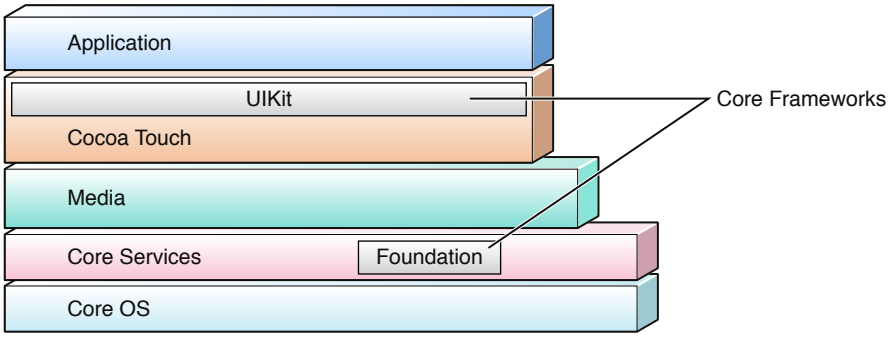
Apple has carefully designed Cocoa so that some of its programmatic interfaces give access to the capabilities of underlying technologies that applications typically need. But if you require some capability that is not exposed through the programmatic interfaces of Cocoa, or if you need some finer control of what happens in your application, you may be able to use an underlying framework directly. (A prime example is Core Graphics; by calling its functions or those of OpenGL, your code can draw more complex and nuanced images than is possible with the Cocoa drawing methods.) Fortunately, using these lower-level frameworks is not a problem because the programmatic interfaces of most dependent frameworks are written in standard ANSI C, of which Objective-C language is a superset.

Further Reading *Mac Technology Overview* gives an overview of the frameworks, services, technologies, and other components of OS X. *OS X Human Interface Guidelines* specifies how the Aqua human interface should appear and behave.

How Cocoa Fits into iOS

The application-framework layer of iOS is called Cocoa Touch. Although the iOS infrastructure on which Cocoa Touch depends is similar to that for Cocoa in OS X, there are some significant differences. Compare Figure 1-2, which depicts the architectural setting of iOS, to the diagram in Figure 1-1 (page 13). The iOS diagram also shows the software supporting its platform as a series of layers going from a Core OS foundation to a set of application frameworks, the most critical (for applications) being the UIKit framework. As in the OS X diagram, the iOS diagram has middle layers consisting of core-services frameworks and graphics and media frameworks and libraries. Here also, a component at one layer often has dependencies on the layer beneath it.

Figure 1-2 Cocoa in the architecture of iOS



Generally, the system libraries and frameworks of iOS that ultimately support UIKit are a subset of the libraries and frameworks in OS X. For example, there is no Carbon application environment in iOS, there is no command-line access (the BSD environment in Darwin), there are no printing frameworks and services, and QuickTime is absent from the platform. However, because of the nature of the devices supported by iOS, there are some frameworks, both public and private, that are specific to iOS.

The following summarizes some of the frameworks found at each layer of the iOS stack, starting from the foundation layer.

- **Core OS.** This level contains the kernel, the file system, networking infrastructure, security, power management, and a number of device drivers. It also has the libSystem library, which supports the POSIX/BSD 4.4/C99 API specifications and includes system-level APIs for many services.
- **Core Services.** The frameworks in this layer provide core services, such as string manipulation, collection management, networking, URL utilities, contact management, and preferences. They also provide services based on hardware features of a device, such as the GPS, compass, accelerometer, and gyroscope. Examples of frameworks in this layer are Core Location, Core Motion, and System Configuration.

This layer includes both Foundation and Core Foundation, frameworks that provide abstractions for common data types such as strings and collections. The Core Frameworks layer also contains Core Data, a framework for object graph management and object persistence.

- **Media.** The frameworks and services in this layer depend on the Core Services layer and provide graphical and multimedia services to the Cocoa Touch layer. They include Core Graphics, Core Text, OpenGL ES, Core Animation, AVFoundation, Core Audio, and video playback.
- **Cocoa Touch.** The frameworks in this layer directly support applications based in iOS. They include frameworks such as Game Kit, Map Kit, and iAd.

The Cocoa Touch layer and the Core Services layer each has an Objective-C framework that is especially important for developing applications for iOS. These are the *core* Cocoa frameworks in iOS:

- **UIKit.** This framework provides the objects an application displays in its user interface and defines the structure for application behavior, including event handling and drawing. For a description of UIKit, see "UIKit (iOS)" (page 48).
- **Foundation.** This framework defines the basic behavior of objects, establishes mechanisms for their management, and provides objects for primitive data types, collections, and operating-system services. Foundation is essentially an object-oriented version of the Core Foundation framework; see "Foundation" (page 31) for a discussion of the Foundation framework.

Notes This document uses "Cocoa" generically when referring to things that are common between the platforms. When it is necessary to say something specific about Cocoa on a given platform, it uses a phrase such as "Cocoa in OS X."

As with Cocoa in OS X, the programmatic interfaces of Cocoa in iOS give your applications access to the capabilities of underlying technologies. Usually there is a Foundation or UIKit method or function that can tap into a lower-level framework to do what you want. But, as with Cocoa in OS X, if you require some capability that is not exposed through a Cocoa API, or if you need some finer control of what happens in your application, you may choose to use an underlying framework directly. For example, UIKit uses the WebKit to draw text and publishes some methods for drawing text; however, you may decide to use Core Text to draw text because that gives you the control you need for text layout and font management. Again, using these lower-level frameworks is not a problem because the programmatic interfaces of most dependent frameworks are written in standard ANSI C, of which the Objective-C language is a superset.

Further Reading To learn more about the frameworks, services, and other aspects of the iOS platform, see *iOS Technology Overview*.

Features of a Cocoa Application

In OS X it is possible to create a Cocoa application without adding a single line of code. You make a new Cocoa application project using Xcode and then build the project. That's it. Of course, this application won't do much, or at least much that's interesting. But this extremely simple application still launches when double-clicked, displays its icon in the Dock, displays its menus and window (titled "Window"), hides itself on command, behaves nicely with other running applications, and quits on command. You can move, resize, minimize, and close the window. You can even print the emptiness contained by the window.

You can do the same with an iOS application. Create a project in Xcode using one of the project templates, immediately build it, and run it in the iOS Simulator. The application quits when you click the Home button (or press it on a device). To launch the application, click its icon in Simulator. It may even have additional behaviors; for example, with an application made from the Utility Application template, the initial view "flips" to a second view when you click or tap the information ("i") icon.

Imagine what you could do with a little code.

iOS Note The features and behavior of an application running in iOS are considerably different from a Mac app, largely because it runs in a more constrained environment. For discussions of application capabilities and constraints in iOS, see *iOS Application Programming Guide*.

In terms of programming effort, Cocoa gives you, the developer, much that is free and much that is low-cost. Of course, to become a productive Cocoa developer means becoming familiar with possibly new concepts, design patterns, programming interfaces, and development tools, and this effort is not negligible. But familiarity yields greater productivity. Programming becomes largely an exercise in assembling the programmatic components that Cocoa provides along with the custom objects and code that define your program's particular logic, then fitting everything together.

What follows is a short list of how Cocoa adds value to an application with only a little (and sometimes no) effort on your part:

- **Basic application framework**—Cocoa provides the infrastructure for event-driven behavior and for management of applications, windows, and (in the case of OS X) workspaces. In most cases, you won't have to handle events directly or send any drawing commands to a rendering library.

- **User-interface objects**—Cocoa offers a rich collection of ready-made objects for your application's user interface. Most of these objects are available in the library of Interface Builder, a development application for creating user interfaces; you simply drag an object from the library onto the surface of your interface, configure its attributes, and connect it to other objects. (And, of course, you can always instantiate, configure, and connect these objects programmatically.)

  Here is a sampling of Cocoa user-interface objects:

  - Windows
  - Text fields
  - Image views
  - Date pickers
  - Sheets and dialogs
  - Segmented controls
  - Table views
  - Progress indicators
  - Buttons
  - Sliders
  - Radio buttons (OS X)
  - Color wells (OS X)
  - Drawers (OS X)
  - Page controls (iOS)
  - Navigation bars (iOS)
  - Switch controls (iOS)

  Cocoa in OS X also features technologies that support user interfaces, including those that promote accessibility, perform validation, and facilitate the connections between objects in the user interface and custom objects.
- **Drawing and imaging**—Cocoa enables efficient drawing of custom views with a framework for locking graphical focus and marking views (or portions of views) as "dirty." Cocoa includes programmatic tools for drawing Bezier paths, performing affine transforms, compositing images, generating PDF content, and (in OS X) creating various representations of images.
- **System interaction**—In OS X, Cocoa gives your application ways to interact with (and use the services of) the file system, the workspace, and other applications. In iOS, Cocoa lets you pass URLs to applications to have them handle the referenced resource (for example, email or websites); it also provides support for managing user interactions with files in the local system and for scheduling local notifications.

- **Performance**—To enhance the performance of your application, Cocoa provides programmatic support for concurrency, multithreading, lazy loading of resources, memory management, and run-loop manipulation.
- **Internationalization**—Cocoa provides a rich architecture for internationalizing applications, making it possible for you to support localized resources such as text, images, and even user interfaces. The Cocoa approach is based on users' lists of preferred languages and puts localized resources in bundles of the application. Based on the settings it finds, Cocoa automatically selects the localized resource that best matches the user's preferences. It also provides tools and programmatic interfaces for generating and accessing localized strings. Moreover, text manipulation in Cocoa is based on Unicode by default, and is thus an asset for internationalization.
- **Text**—In OS X, Cocoa provides a sophisticated text system that allows you to do things with text ranging from the simple (for example, displaying a text view with editable text) to the more complex, such as controlling kerning and ligatures, spell checking, regular expressions, and embedding images in text. Although Cocoa in iOS has no native text system (it uses WebKit for string drawing) and its text capabilities are more limited, it still includes support for spellchecking, regular expressions, and interacting with the text input system.
- **Preferences**—The user defaults system is based on a systemwide database in which you can store global and application-specific preferences. The procedure for specifying application preferences is different for OS X and iOS.
- **Networking**—Cocoa also offers programmatic interfaces for communicating with servers using standard Internet protocols, communicating via sockets, and taking advantage of Bonjour, which lets your application publish and discover services on an IP network.

  In OS X, Cocoa includes a distributed objects architecture that allows one Cocoa process to communicate with another process on the same computer or on a different one. In iOS, Cocoa supports the capability for servers to push notifications to devices for applications registered to received such notifications.
- **Printing**—Cocoa on both platforms supports printing. Their printing architecture lets you print images, documents, and other application content along a range of control and sophistication. At the simplest level, you can print the contents of any view or print an image or PDF document with just a little code. At a more complicated level, you can define the content and format of printed content, control how a print job is performed, and do pagination. In OS X, you can add an accessory view to the Print dialog.
- **Undo management**—You can register user actions that occur with an undo manager, and it will take care of undoing them (and redoing them) when users choose the appropriate menu items. The manager maintains undo and redo operations on separate stacks.
- **Multimedia**—Both platforms programmatically support video and audio. In OS X, Cocoa offers support for QuickTime video.

- **Data exchange**—Cocoa simplifies the exchange of data within an application and between applications using the copy-paste model. In OS X, Cocoa also supports drag-and-drop models and the sharing of application capabilities through the Services menu.

Cocoa in OS X has a couple of other features:

- **Document-based applications**—Cocoa specifies an architecture for applications composed of a potentially unlimited number of documents, with each contained in its own window (a word processor, for example). Indeed, if you choose the "Document-based application" project type in Xcode, many of the components of this sort of application are created for you.
- **Scripting**— Through application scriptability information and a suite of supporting Cocoa classes, you can make your application scriptable; that is, it can respond to commands emitted by AppleScript scripts. Applications can also execute scripts or use individual Apple events to send commands to, and receive data from, other applications. As a result, every scriptable application can supply services to both users and other applications.

The Development Environment

You develop Cocoa software primarily by using the two developer applications, Xcode and Interface Builder. It is possible to develop Cocoa applications without using these applications at all. For example, you could write code using a text editor such as Emacs, build the application from the command line using makefiles, and debug the application from the command line using the `gdb` debugger. But why would you want to give yourself so much grief?

> **Note** "Xcode" is sometimes used to refer to the complete suite of development tools and frameworks, and other times specifically to the application that allows you to manage projects, edit source code, and build executable code.

The origins of Xcode and Interface Builder coincide with the origins of Cocoa itself, and consequently there is a high degree of compatibility between tools and frameworks. Together, Xcode and Interface Builder make it extraordinarily easy to design, manage, build, and debug Cocoa software projects.

When you install the development tools and documentation, you may select the installation location. Traditionally that location has been `/Developer`, but it can be anywhere in the file system you wish. To designate this installation location, the documentation uses `<Xcode>`. Thus, the development applications are installed in `<Xcode>/Applications`.

Platform SDKs

Beginning with Xcode 3.1 and the introduction of iOS, when you create a software project you must choose a platform SDK. The SDK enables you to build an executable that is targeted for a particular release of OS X or iOS.

The platform SDK contains everything that is required for developing software for a given platform and operating-system release. An OS X SDK consists of frameworks, libraries, header files, and system tools. The SDK for iOS has the same components, but includes a platform-specific compiler and other tools. There is also a separate SDK for iOS Simulator (see "The iOS Simulator Application" (page 26)). All SDKs include build settings and project templates appropriate to their platform.

Further reading For more on platform SDKs, see *SDK Compatibility Guide*.

Overview of Development Workflows

Application development differs for OS X and iOS, not only in the tools used but in the development workflow.

In OS X, the typical development workflow is the following:

1. In Xcode, create a project using a template from the OS X SDK.
2. Write code and, using Interface Builder, construct your application's user interface.
3. Define the targets and executable environment for your project.
4. Test and debug the application using the Xcode debugging facilities.

   As part of debugging, you can check the system logs in the Console window.
5. Measure application performance using one or more of the available performance tools.

For iOS development, the workflow when developing an application is a bit more complex. Before you can develop for iOS, you must register as a developer for the platform. Thereafter, building an application that's ready to deploy requires that you go through the following steps:

1. Configure the remote device.

   This configuration results in the required tools, frameworks, and other components being installed on the device.
2. In Xcode, create a project using a template from the iOS SDK.
3. Write code, and construct your application's user interface.
4. Define the targets and executable environment for the project.
5. Build the application (locally).

6. Test and debug the application, either in iOS Simulator or remotely in the device. (If remotely, your debug executable is downloaded to the device.)

   As you debug, you can check the system logs for the device in the Console window.

7. Measure application performance using one or more of the available performance tools.

Further reading For more on the development workflow in iOS, see *iOS Development Guide*.

Xcode

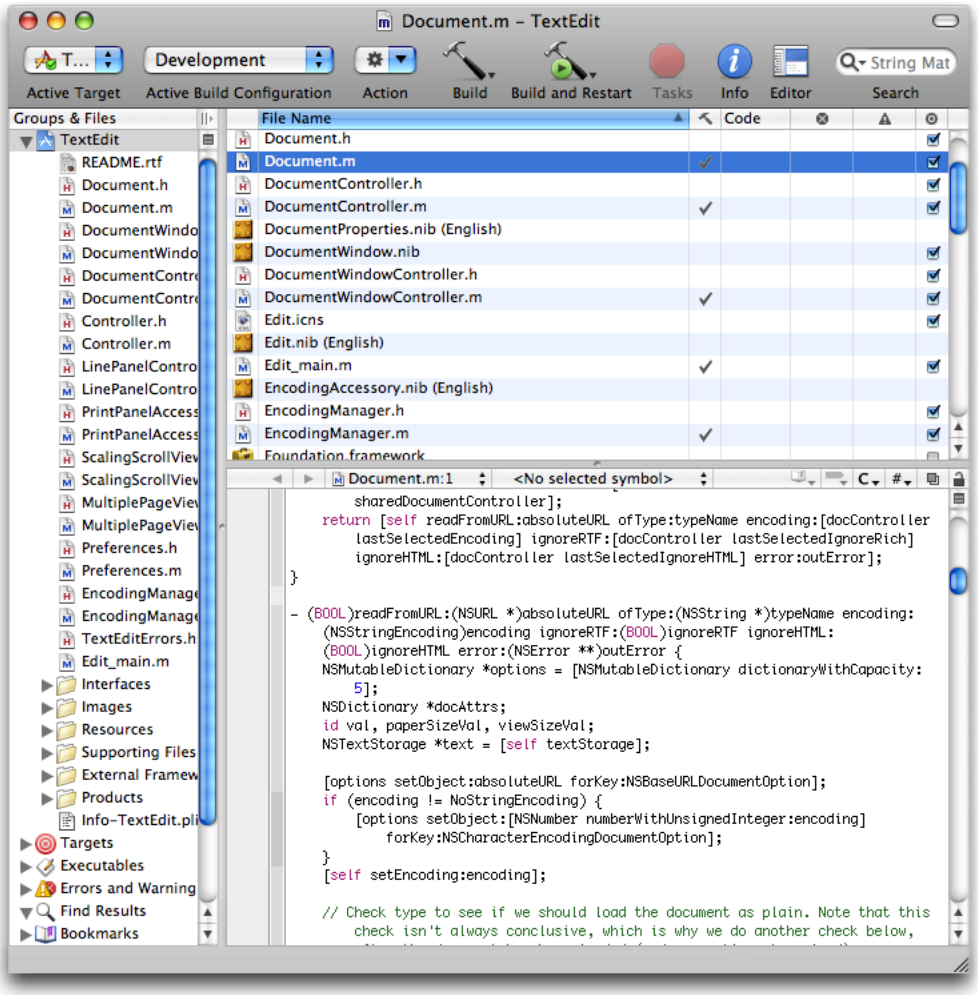
Xcode is the engine that powers Apple's integrated development environment (IDE) for OS X and iOS. It is also an application that takes care of most project details from inception to deployment. It allows you to:

- Create and manage projects, including specifying platforms, target requirements, dependencies, and build configurations.
- Write source code in editors with features such as syntax coloring and automatic indenting.
- Navigate and search through the components of a project, including header files and documentation.
- Build the project.
- Debug the project locally, in iOS Simulator, or remotely, in a graphical source-level debugger.

Xcode builds projects from source code written in C, C++, Objective-C, and Objective-C++. It generates executables of all types supported in OS X, including command-line tools, frameworks, plug-ins, kernel extensions, bundles, and applications. (For iOS, only application executables are possible.) Xcode permits almost unlimited customization of build and debugging tools, executable packaging (including information property lists and localized bundles), build processes (including copy-file, script-file, and other build phases), and the user interface (including detached and multiview code editors). Xcode also supports several source-code management systems—namely CVS, Subversion, and Perforce—allowing you to add files to a repository, commit changes, get updated versions, and compare versions.

Figure 1-3 shows an example of a project in Xcode.

Figure 1-3 The TextEdit example project in Xcode



Xcode is especially suited for Cocoa development. When you create a project, Xcode sets up your initial development environment using project templates corresponding to Cocoa project types: application, document-based application, Core Data application, tool, bundle, framework, and others. For compiling Cocoa software, Xcode gives you several options:

- GCC—The GNU C compiler (`gcc`).
- LLVM-GCC—A configuration where GCC is used as the front end for the LLVM (Low Level Virtual Machine) compiler. LLVM offers fast optimization times and high-quality code generation.

  This option is available only for projects built for OS X v10.6 and later.
- Clang—A front end specifically designed for the LLVM compiler. Clang offers fast compile times and excellent diagnostics.

This option is available only for projects built for OS X v10.6 and later.

For details about these compiler options, see *Xcode Build System Guide*.

For debugging software, Xcode offers the GNU source-level debugger (`gdb`) and the Clang Static Analyzer. The Clang Static Analyzer consists of a framework for source-code analysis and a standalone tool that finds bugs in C and Objective-C programs. See http://clang-analyzer.llvm.org/ for more information.

Xcode is well integrated with the other major development application, Interface Builder. See "Interface Builder" for details.

Further Reading *A Tour of Xcode* gives an overview of Xcode and provides links to additional development-tools documentation.

Interface Builder

The second major development application for Cocoa projects is Interface Builder. As its name suggests, Interface Builder is a graphical tool for creating user interfaces. Interface Builder has been around almost since the inception of Cocoa as NeXTSTEP. Not surprisingly, its integration with Cocoa is airtight.

Interface Builder is centered around four main design elements:

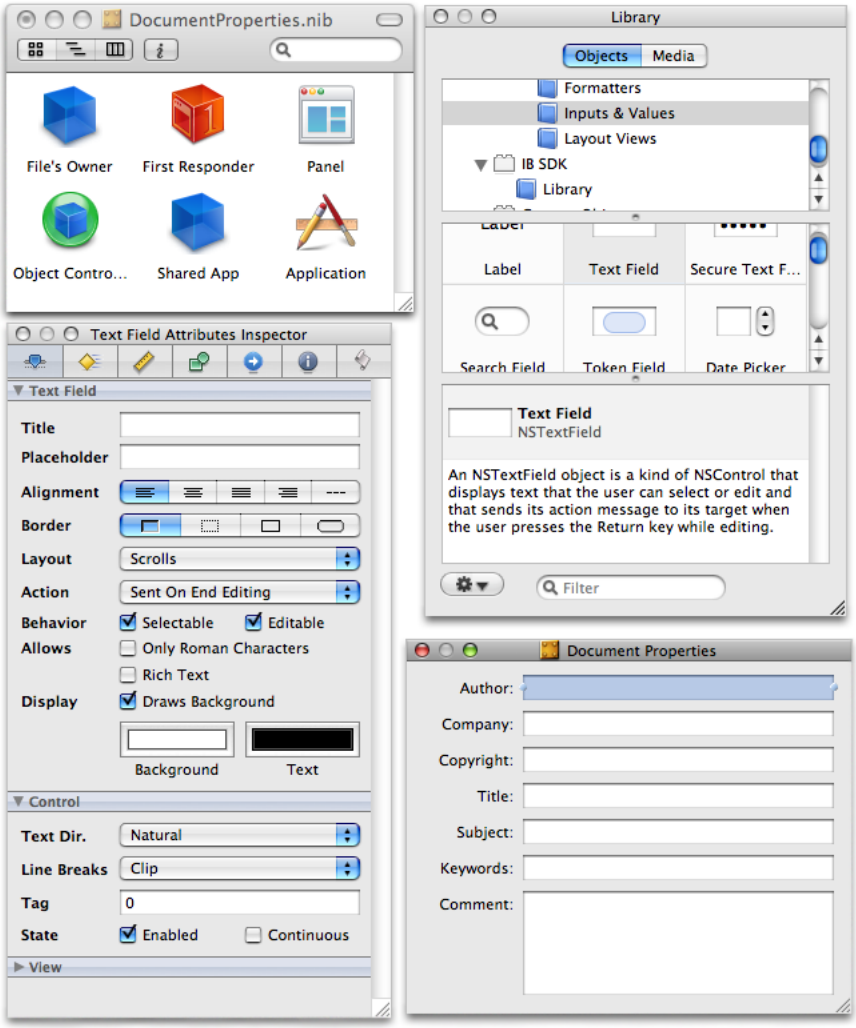
- **Nib files**. A nib file is a file wrapper (an opaque directory) that contains the objects appearing on a user interface in an archived form. Essentially, the archive is an object graph that contains information about each object, including its size and location, about the connections between objects, and about proxy references for custom classes. When you create and save a user interface in Interface Builder, all information necessary to re-create the interface is stored in the nib file.

  Nib files offer a way to easily localize user interfaces. Interface Builder stores a nib file in a localized directory inside a Cocoa project; when that project is built, the nib file is copied to a corresponding localized directory in the created bundle.

  Interface Builder presents the contents of a nib file in a nib document window (also called a *nib file window*). The nib document window gives you access to the important objects in a nib file, especially top-level objects such as windows, menus, and controller objects that have no parent in their object graph. (Controller objects mediate between user-interface objects and the model objects that represent application data; they also provide overall management for an application.)

Figure 1-4 shows a nib file opened in Interface Builder and displayed in a nib document window, along with supporting windows.

Figure 1-4 The TextEdit Document Properties window in Interface Builder

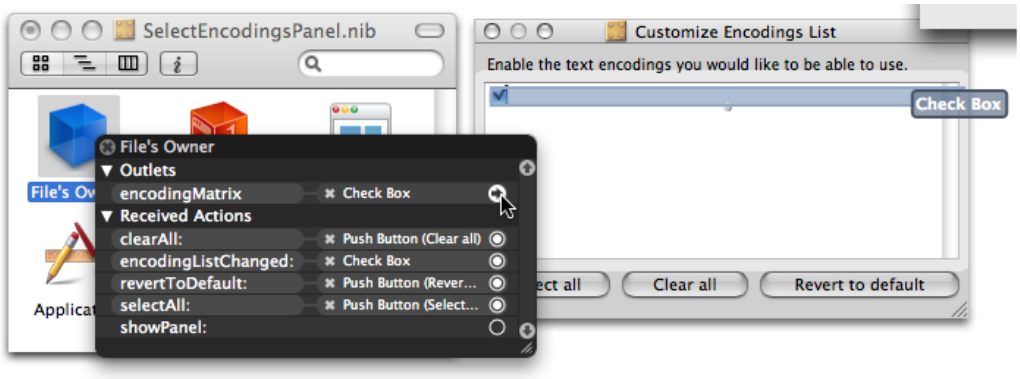


- **Object library**. The Library window of Interface Builder contains objects that you can place on a user interface. They range from typical UI objects—for example, windows, controls, menus, text views, and outline views—to controller objects, custom view objects, and framework-specific objects, such as the Image Kit browser view. The Library groups the objects by categories and lets you browse through them and search for specific objects. When an object is dragged from the Library to an interface, Interface Builder instantiates a default instance of that object. You can resize, configure, and connect the object to other objects using the inspector.
- **Inspector**. Interface Builder has the inspector, a window for configuring the objects of a user interface. The inspector has a number of selectable panes for setting the initial runtime configuration of objects (although size and some attributes can also be set by direct manipulation). The inspector in Figure 1-4

shows the primary attributes for a text field; note that different collapsible sections of the pane reveal attributes at various levels of the inheritance hierarchy (text field, control, and view). In addition to primary attributes and size, the inspector features panes for animation effects, event handlers, and target-action connections between objects; for nib files in OS X projects, there are additional panes for AppleScript and bindings.

- **Connections panel**. The connections panel is a context-sensitive display that shows the current outlet and action connections for a selected object and lets you manage those connections. To get the connections panel to appear, Control-click the target object. Figure 1-5 shows what the connections panel looks like.

Figure 1-5 The Interface Builder connections panel



Interface Builder uses blue lines that briefly appear to show the compliance of each positioned object, when moved or resized, to the Aqua human interface guidelines. This compliance includes recommended size, alignment, and position relative to other objects on the user interface and to the boundaries of the window.

Interface Builder is tightly integrated with Xcode. It "knows" about the outlets, actions, and bindable properties of your custom classes. When you add, remove, or modify any of these things, Interface Builder detects those changes and updates its presentation of them.

> **Further Reading** For further information on Interface Builder, see *Interface Builder User Guide*. Also refer to "Communicating with Objects" (page 209) for overviews of outlets, the target-action mechanism, and the Cocoa bindings technology.

The iOS Simulator Application

For iOS projects, you can select iOS Simulator as the platform SDK for the project. When you build and run the project, Xcode runs Simulator, which presents your application as it would appear on the device (iPhone or iPad) and allows you to manipulate parts of the user interface. You can use Simulator to help you debug the application prior to loading it onto the device.

You should always perform the final phase of debugging on the device. Simulator does not perfectly simulate the device. For example, you must use the mouse pointer instead of finger touches, and so manipulations of the interface requiring multiple fingers are not possible. In addition, Simulator does not use versions of the OpenGL framework that are specific to iOS, and it uses the OS X versions of the Foundation, Core Foundation, and CFNetwork frameworks, as well as the OS X version of libSystem.

More importantly, you should not assume that the performance of your application on Simulator is the same as it would be on the device. Simulator is essentially running your iOS application as a "guest" Mac app. As such, it has a 4 GB memory partition and swap space available to it as it runs on a processor that is more powerful than the one on the device.

Further reading For more on iOS Simulator, see *iOS Development Guide*.

Performance Applications and Tools

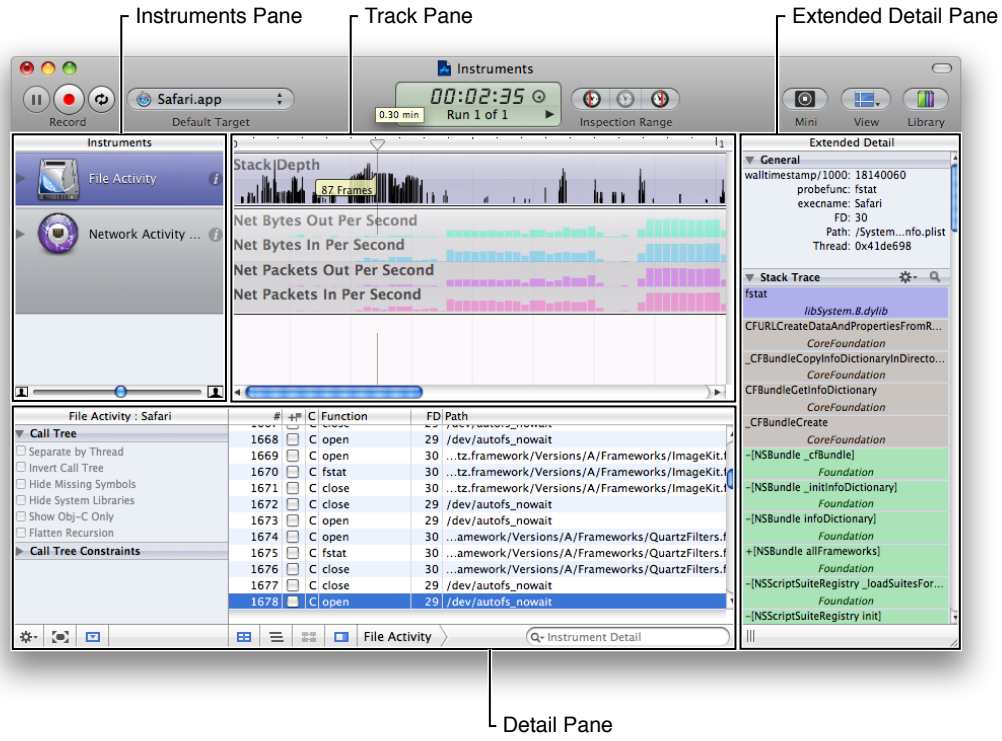
Although Xcode and Interface Builder are the major tools you use to develop Cocoa applications, there are dozens of other tools at your disposal. Many of these tools are performance applications.

Instruments

Instruments is an application introduced in Xcode 3.0 that lets you run multiple performance-testing tools simultaneously and view the results in a timeline-based graphical presentation. It can show you CPU usage, disk reads and writes, memory statistics, thread activity, garbage collection, network statistics, directory and file usage, and other measurements—individually or in different combinations—in the form of graphs tied to time. This simultaneous presentation of instrumentation data helps you to discover the relationships between what is being measured. It also displays the specific data behind the graphs.

Further Reading See the *Instruments User Guide* for complete information about the Instruments application.

Figure 1-6 The Instruments application



Shark

Shark is a performance-analysis application that creates a time-based profile of your program's execution; over a given period it traces function calls and graphs memory allocations. You can use Shark to track information for a single program or for the entire system, which in OS X includes kernel components such as drivers and kernel extensions. Shark also monitors file-system calls, traces system calls and memory allocations, performs static analyses of your code, and gathers information about cache misses, page faults, and other system metrics. Shark supports the analysis of code written in C, Objective-C, C++, and other languages.

Other Performance Applications (OS X)

Many applications are used in measuring and analyzing aspects of an OS X program's performance. These applications are located in `<Xcode>/Applications/Performance Tools`.

- **BigTop** graphs performance trends over time, providing a real-time display of memory usage, page faults, CPU usage, and other data.

- **Spin Control** automatically samples unresponsive applications. You leave Spin Control running in the background while you launch and test your applications. If applications become unresponsive to the point where the spinning cursor appears, Spin Control automatically samples your application to gather information about what your application was doing during that time.
- **MallocDebug** shows all currently allocated blocks of memory in your program, organized by the call stack at the time of allocation. At a glance you can see how much allocated memory your application consumes, where that memory was allocated from, and which functions allocated large amounts of memory. MallocDebug can also find allocated memory that is not referenced elsewhere in the program, thus helping you find leaks and track down exactly where the memory was allocated.
- **QuartzDebug** is a tool to help you debug how your application displays itself. It is especially useful for applications that do significant amounts of drawing and imaging. QuartzDebug has several debugging options, including the following:
    - Auto-flush drawing, which flushes the contents of graphics contexts after each drawing operation
    - A mode that paints regions of the screen in yellow just before they're updated
    - An option that takes a static snapshot of the systemwide window list, showing the owner of each window and how much memory each window consumes

For performance analysis, you can also use command-line tools such as:

- `top`, which shows a periodically sampled set of statistics on currently running processes
- `gprof`, which produces an execution profile of a program
- `fs_usage`, which displays file-system access statistics

Many other command-line tools for performance analysis and other development tasks are available. Some are located in `/usr/bin` and `/usr/sbin`, and some Apple-developed command-line tools are installed in `<Xcode>/Tools`. For many of these tools you can consult their manual page for usage information. (To do this, either choose Help > Open man page in Xcode or type `man` followed by the name of the tool in a Terminal shell.)

Further Reading For more on the performance tools and applications you can use in Cocoa application development, as well as information on concepts, techniques, guidelines, and strategy related to performance, see *Performance Overview*. *Cocoa Performance Guidelines* covers the performance guidelines for Cocoa.

The Cocoa Frameworks

What makes a program a Cocoa program? It's not really the language, because you can use a variety of languages in Cocoa development. It's not the development tools, because you could create a Cocoa application from the command line (although that would be a complex, time-consuming task). No, what all Cocoa programs have in common—what makes them distinctive—is that they are composed of objects that inherit ultimately from the root class, `NSObject`, and that are ultimately based upon the Objective-C runtime. This statement is also true of all Cocoa frameworks.

Note The statement about the root class needs to be qualified a bit. First, the Foundation framework supplies another root class, `NSProxy`; however, `NSProxy` is rarely used in Cocoa programming. Second, you could create your own root class, but this would be a lot of work (entailing the writing of code that interacts with the Objective-C runtime) and probably not worth your time.

On any system there are many Cocoa frameworks, and Apple and third-party vendors are releasing more frameworks all the time. Despite this abundance of Cocoa frameworks, two of them stand out on each platform as core frameworks:

- In OS X: Foundation and AppKit
- In iOS: Foundation and UIKit

The Foundation, AppKit, and UIKit frameworks are essential to Cocoa application development, and all other frameworks are secondary and elective. You cannot develop a Cocoa application for OS X unless you link against (and use the classes of) the AppKit, and you cannot develop a Cocoa application for iOS unless you link against (and use the classes of) UIKit. Moreover, you cannot develop Cocoa software of any kind unless you link against and use the classes of the Foundation framework. (Linking against the right frameworks in OS X happens automatically when you link against the Cocoa umbrella framework.) Classes, functions, data types, and constants in Foundation and the AppKit have a prefix of "NS"; classes, functions, data types, and constants in UIKit have a prefix of "UI".

Note In OS X version 10.5 the Cocoa frameworks were ported to support 64-bit addressing. iOS also supports 64-bit addressing. As part of this effort, various general changes have been made to the Cocoa API, most significantly the introduction of the `NSInteger` and `NSUInteger` types (replacing `int` and `unsigned int` where appropriate) and the `CGFloat` type (replacing most instances of `float`). Most Cocoa applications have no immediate need to make the transition to 64-bit, but for those that do, porting tools and guidelines are available. *64-Bit Transition Guide for Cocoa* discusses these matters in detail.

The Cocoa frameworks handle many low-level tasks for you. For example, classes that store and manipulate integer and floating-point values automatically handle the endianness of those values for you.

The following sections survey the features and classes of the three core Cocoa frameworks and briefly describe some of the secondary frameworks. Because each of these core frameworks has dozens of classes, the descriptions of the core frameworks categorize classes by their function. Although these categorizations have a strong logical basis, one can plausibly group classes in other ways.

Foundation

The Foundation framework defines a base layer of classes that can be used for any type of Cocoa program. The criterion separating the classes in Foundation from those in the AppKit is the user interface. If an object doesn't either appear in a user interface or isn't *exclusively* used to support a user interface, then its class belongs in Foundation. You can create Cocoa programs that use Foundation and no other framework; examples of these are command-line tools and Internet servers.

The Foundation framework was designed with certain goals in mind:

- Define basic object behavior and introduce consistent conventions for such things as memory management, object mutability, and notifications.
- Support internationalization and localization with (among other things) bundle technology and Unicode strings.
- Support object persistence.
- Support object distribution.
- Provide some measure of operating-system independence to support portability.
- Provide object wrappers or equivalents for programmatic primitives, such as numeric values, strings, and collections. It also provides utility classes for accessing underlying system entities and services, such as ports, threads, and file systems.

Cocoa applications, which by definition link either against the AppKit framework or UIKit framework, invariably must link against the Foundation framework as well. The class hierarchies share the same root class, `NSObject`, and many if not most of the AppKit and UIKit methods and functions have Foundation objects as parameters or return values. Some Foundation classes may seem designed for applications—`NSUndoManager` and `NSUserDefaults`, to name two—but they are included in Foundation because there can be uses for them that do not involve a user interface.

Foundation Paradigms and Policies

Foundation introduces several paradigms and policies to Cocoa programming to ensure consistent behavior and expectations among the objects of a program in certain situations.:

- **Object retention and object disposal**. The Objective-C runtime and Foundation give Cocoa programs two ways to ensure that objects persist when they're needed and are freed when they are no longer needed. Garbage collection, which was introduced in Objective-C 2.0, automatically tracks and disposes of objects that your program no longer needs, thus freeing up memory. Foundation also still offers the traditional approach of memory management. It institutes a policy of object ownership that specifies that objects are responsible for releasing other objects that they have created, copied, or explicitly retained. `NSObject` (class and protocol) defines methods for retaining and releasing objects. Autorelease pools (defined in the `NSAutoreleasePool` class) implement a delayed-release mechanism and enable Cocoa programs to have a consistent convention for returning objects for which the caller is not responsible. For more about garbage collection and explicit memory management, see "Object Retention and Disposal" (page 81).

  > **iOS Note** Garbage collection is not available to applications running in iOS.

- **Mutable class variants**. Many value and container classes in Foundation have a mutable variant of an immutable class, with the mutable class always being a subclass of the immutable one. If you need to dynamically change the encapsulated value or membership of such an object, you create an instance of the mutable class. Because it inherits from the immutable class, you can pass the mutable instance in methods that take the immutable type. For more on object mutability, see "Object Mutability" (page 105).
- **Class clusters**. A class cluster is an abstract class and a set of private concrete subclasses for which the abstract class acts as an umbrella interface. Depending on the context (particularly the method you use to create an object), an instance of the appropriate optimized class is returned to you. `NSString` and `NSMutableString`, for example, act as brokers for instances of various private subclasses optimized for different kinds of storage needs. Over the years the set of concrete classes has changed several times without breaking applications. For more on class clusters, see "Class Clusters" (page 111).

- **Notifications**. Notification is a major design pattern in Cocoa. It is based on a broadcast mechanism that allows objects (called *observers*) to be kept informed of what another object is doing or is encountering in the way of user or system events. The object originating the notification can be unaware of the existence or identity of the observers of the notification. There are several types of notifications: synchronous, asynchronous, and distributed. The Foundation notification mechanism is implemented by the `NSNotification`, `NSNotificationCenter`, `NSNotificationQueue`, and `NSDistributedNotificationCenter` classes. For more on notifications, see "Notifications" (page 227).

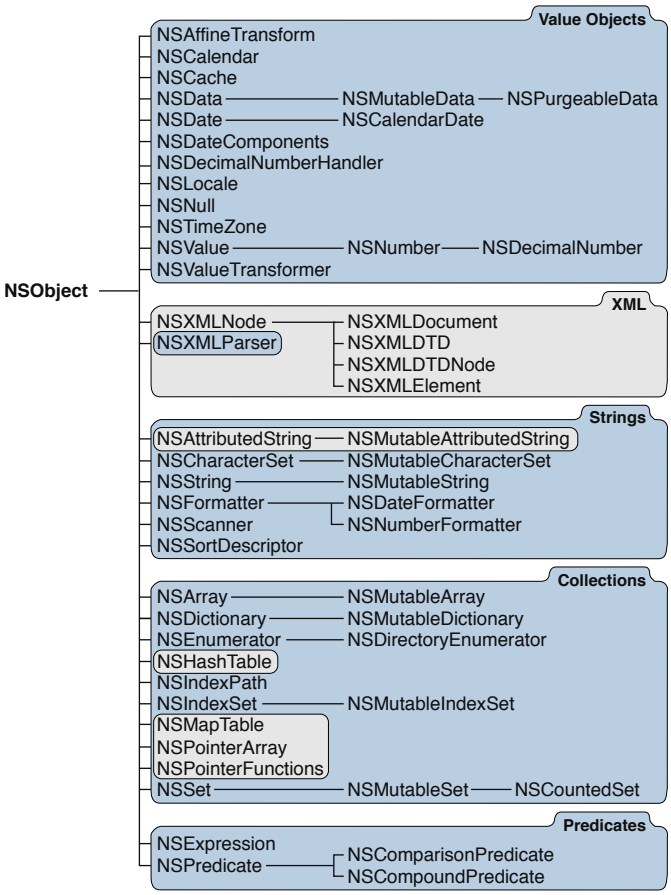
Foundation Classes

The Foundation class hierarchy is rooted in the `NSObject` class, which (along with the `NSObject` and `NSCopying` protocols) define basic object attributes and behavior. For further information on `NSObject` and basic object behavior, see "The Root Class" (page 76).

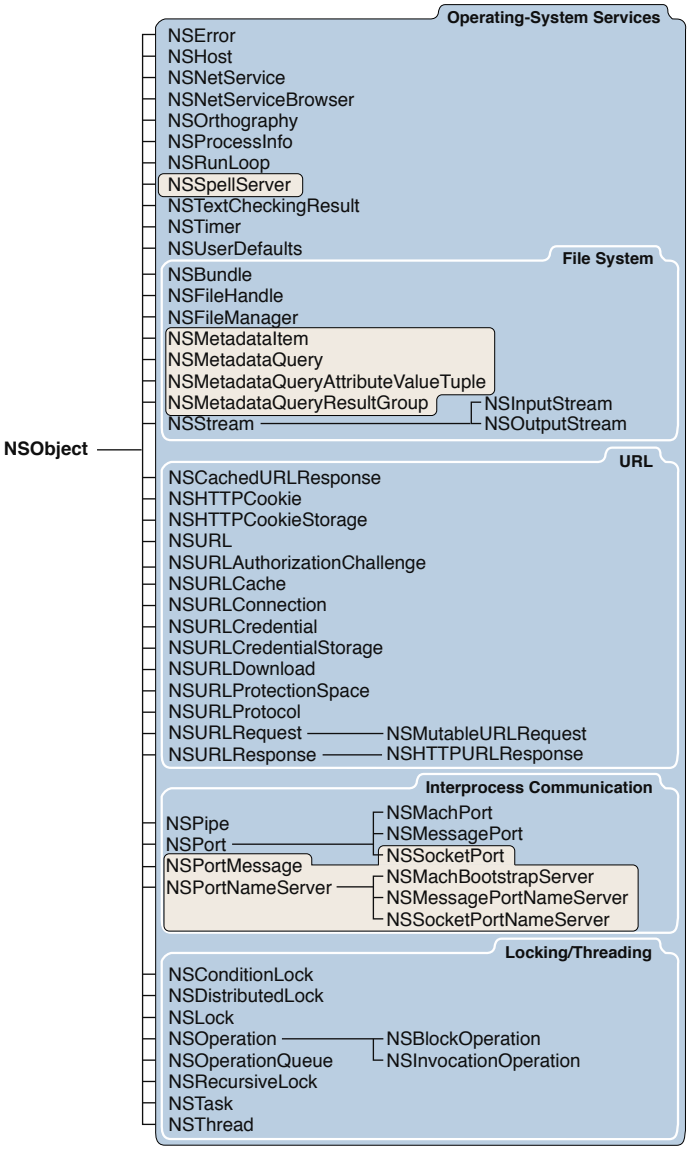
The remainder of the Foundation framework consists of several related groups of classes as well as a few individual classes. There are classes representing basic data types such as strings and byte arrays, collection classes for storing other objects, classes representing system information such as dates, and classes representing system entities such as ports, threads, and processes. The class hierarchy charts in Figure 1-7 (for printing

purposes, in three parts) depict the logical groups these classes form as well as their inheritance relationships. Classes in blue-shaded areas are present in both the OS X and iOS versions of Foundation; classes in gray-shaded areas are present only in the OS X version.

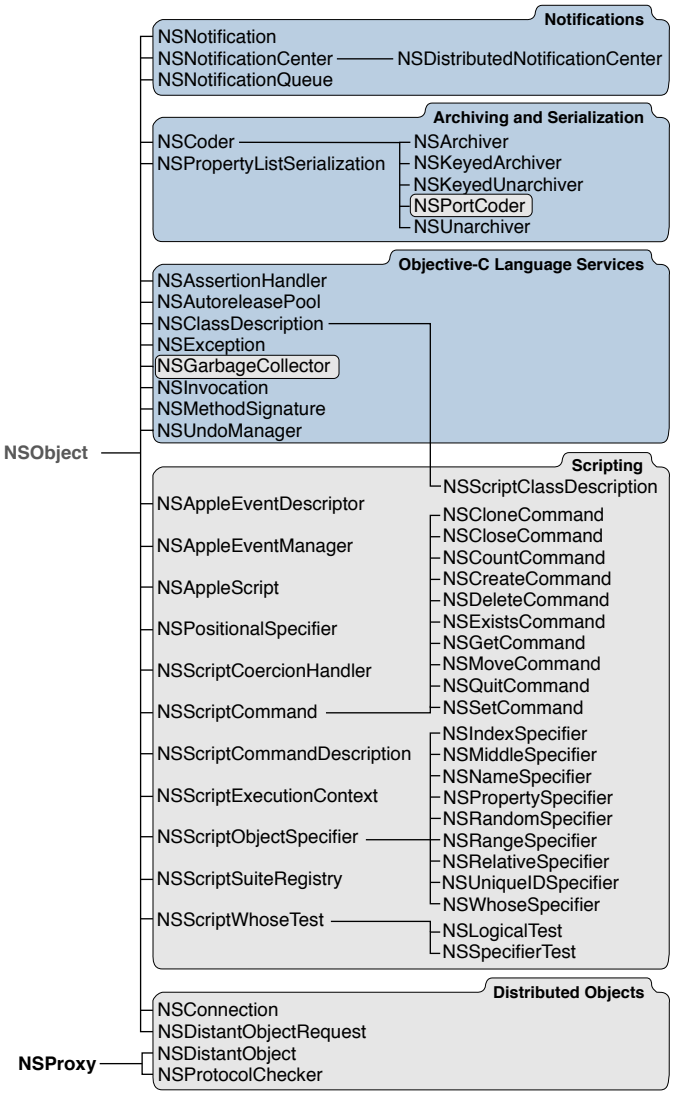
Figure 1-7 The Foundation class hierarchy



Objective-C Foundation Continued



Objective-C Foundation Continued



These diagrams logically group the classes of the Foundation framework in categories (with other associations pointed out). Of particular importance are the classes whose instances are value objects and collections.

Value Objects

Value objects encapsulate values of various primitive types, including strings, numbers (integers and floating-point values), dates, and even structures and pointers. They mediate access to these values and manipulate them in suitable ways. When you compare two value objects of the same class type, it is their encapsulated values that are compared, not their pointer values. Value objects are frequently the attributes of other objects, including custom objects.

Of course, you may choose to use scalars and other primitive values directly in your program—after all, Objective-C is a superset of ANSI C—and in many cases using scalars is a reasonable thing to do. But in other situations, wrapping these values in objects is either advantageous or required. For example, because value objects are objects, you can, at runtime, find out their class type, determine the messages that can be sent to them, and perform other tasks that can be done with objects. The elements of collection objects such as arrays and dictionaries must be objects. And many if not most methods of the Cocoa frameworks that take and return values such as strings, numbers, and dates require that these values be encapsulated in objects. (With string values, in particular, you should always use `NSString` objects and not C-strings.)

Some classes for value objects have mutable and immutable variants—for example, there are the `NSMutableData` and `NSData` classes. The values encapsulated by immutable objects cannot be modified after they are created, whereas the values encapsulated by mutable objects can be modified. ("Object Mutability" (page 105) discusses mutable and immutable objects in detail.)

The following are descriptions of what the more important value objects do:

- Instances of the `NSValue` class encapsulate a single ANSI C or Objective-C data item—for example, scalar types such as floating-point values as well as pointers and structures
- The `NSNumber` class (a subclass of `NSValue`) instantiates objects that contain numeric values such as integers, floats, and doubles.
- Instances of the `NSData` class provides object-oriented storage for streams of bytes (for example, image data). The class has methods for writing data objects to the file system and reading them back.
- The `NSDate` class, along with the supporting `NSTimeZone`, `NSCalendar`, `NSDateComponents`, and `NSLocale` classes, provide objects that represent times, dates, calendar, and locales. They offer methods for calculating date and time differences, for displaying dates and times in many formats, and for adjusting times and dates based on location in the world.
- Objects of the `NSString` class (commonly referred to as *strings*) are a type of value object that provides object-oriented storage for a sequence of Unicode characters. Methods of `NSString` can convert between representations of character strings, such as between UTF-8 and a null-terminated array of bytes in a particular encoding. `NSString` also offers methods for searching, combining, and comparing strings and for manipulating file-system paths. Similar to `NSData`, `NSString` includes methods for writing strings to the file system and reading them back.

  The `NSString` class also has a few associated classes. You can use an instance of the `NSScanner` utility class to parse numbers and words from an `NSString` object. `NSCharacterSet` represents a set of characters that are used by various `NSString` and `NSScanner` methods. Attributed strings, which are instances of the `NSAttributedString` class, manage ranges of characters that have attributes such as font and kerning associated with them.

Formatter objects—that is, objects derived from `NSFormatter` and its descendent classes—are not themselves value objects, but they perform an important function related to value objects. They convert value objects such as `NSDate` and `NSNumber` instances to and from specific string representations, which are typically presented in the user interface.

Collections

Collections are objects that store other objects in a particular ordering scheme for later retrieval. Foundation defines three major collection classes that are common to both iOS and OS X: `NSArray`, `NSDictionary`, and `NSSet`. As with many of the value classes, these collection classes have immutable and mutable variants. For example, once you create an `NSArray` object that holds a certain number of elements, you cannot add new elements or remove existing ones; for that purpose you need the `NSMutableArray` class. (To learn about mutable and immutable objects, see "Object Mutability" (page 105).)

Objects of the major collection classes have some common behavioral characteristics and requirements. The items they contain must be objects, but the objects may be of any type. Collection objects, as with value objects, are essential components of property lists and, like all objects, can be archived and distributed. Moreover, collection objects automatically retain—that is, keep a strong reference to—any object they contain. If you remove an object from a mutable collection, it is released, which results in the object being freed if no other object claims it.

> **Note** "Retain," "release," and related terms refer to memory-management of objects in Cocoa. To learn about this important topic, see "Object Retention and Disposal" (page 81).

The collection classes provide methods to access specific objects they contain. In addition, there are special enumerator objects (instances of `NSEnumerator`) and language-level support to iterate through collections and access each element in sequence.

The major collection classes are differentiated by the ordering schemes they use:

- Arrays (`NSArray`) are ordered collections that use zero-based indexing for accessing the elements of the collection.
- Dictionaries (`NSDictionary`) are collections managing pairs of keys and values; the key is an object that identifies the value, which is also an object. Because of this key-value scheme, the elements in a dictionary are unordered. Within a dictionary, the keys must be unique. Although they are typically string objects, keys can be any object that can be copied.
- Sets (`NSSet`) are similar to arrays, but they provide unordered storage of their elements instead of ordered storage. In other words, the order of elements in a set is not important. The items in an `NSSet` object must be distinct from each other; however, an instance of the `NSCountedSet` class (a subclass of `NSMutableSet`) may include the same object more than once.

In OS X, the Foundation framework includes several additional collection classes. `NSMapTable` is a mutable dictionary-like collection class; however, unlike `NSDictionary`, it can hold pointers as well as objects and it maintains weak references to its contained objects rather than strong references. `NSPointerArray` is an array that can hold pointers and `NULL` values and can maintain either strong or weak references to them. The `NSHashTable` class is modeled after `NSSet` but it can store pointers to functions and it provides different options, in particular to support weak relationships in a garbage-collected environment.

For more on collection classes and objects, see *Collections Programming Topics*.

Other Categories of Foundation Classes

The remaining classes of the Foundation framework fall into various categories, as indicated by the diagram in Figure 1-7 (page 34). The major categories of classes, shown in Figure 1-7, are described here:

- **Operating-system services**. Many Foundation classes facilitate access of various lower-level services of the operating system and, at the same time, insulate you from operating-system idiosyncrasies. For example, `NSProcessInfo` lets you query the environment in which an application runs and `NSHost` yields the names and addresses of host systems on a network. You can use an `NSTimer` object to send a message to another object at specific intervals, and `NSRunLoop` lets you manage the input sources of an application or other type of program. `NSUserDefaults` provides a programmatic interface to a system database of global (per-host) and per-user default values (preferences).
    - **File system and URL**. `NSFileManager` provides a consistent interface for file operations such as creating, renaming, deleting, and moving files. `NSFileHandle` permits file operations at a lower level (for example, seeking within a file). `NSBundle` finds resources stored in bundles and can dynamically load some of them (for example, nib files and code). You use `NSURL` and related `NSURL...` classes to represent, access, and manage URL sources of data.
    - **Concurrency**. `NSThread` lets you create multithreaded programs, and various lock classes offer mechanisms for controlling access to process resources by competing threads. You can use `NSOperation` and `NSOperationQueue` to perform multiple operations (concurrent or nonconcurrent) in priority and dependence order. With `NSTask`, your program can fork off a child process to perform work and monitor its progress.
    - **Interprocess communication**. Most of the classes in this category represent various kinds of system ports, sockets, and name servers and are useful in implementing low-level IPC. `NSPipe` represents a BSD pipe, a unidirectional communications channel between processes.

      iOS Note The name server classes are not in the iOS version of Foundation.

    - **Networking**. The `NSNetService` and `NSNetServiceBrowser` classes support the zero-configuration networking architecture called *Bonjour*. Bonjour is a powerful system for publishing and browsing for services on an IP network.

- **Notifications**. See the summary of the notification classes in "Foundation Paradigms and Policies" (page 32).
- **Archiving and serialization**. The classes in this category make object distribution and persistence possible. `NSCoder` and its subclasses, along with the `NSCoding` protocol, represent the data an object contains in an architecture-independent way by allowing class information to be stored along with the data. `NSKeyedArchiver` and `NSKeyedUnarchiver` offer methods for encoding objects and scalar values and decoding them in a way that is not dependent on the ordering of encoding messages.
- **Objective-C language services**. `NSException` and `NSAssertionHandler` provide an object-oriented way of making assertions and handling exceptions in code. An `NSInvocation` object is a static representation of an Objective-C message that your program can store and later use to invoke a message in another object; it is used by the undo manager (`NSUndoManager`) and by the distributed objects system. An `NSMethodSignature` object records the type information of a method and is used in message forwarding. `NSClassDescription` is an abstract class for defining and querying the relationships and properties of a class.
- **XML processing**. Foundation on both platforms has the `NSXMLParser` class, which is an object-oriented implementation of a streaming parser that enables you to process XML data in an event-driven way.

  Foundation in OS X includes the NSXML classes (so called because the class names begin with "NSXML"). Objects of these classes represent an XML document as a hierarchical tree structure. This approach lets you to query this structure and manipulate its nodes. The NSXML classes support several XML-related technologies and standards, such as XQuery, XPath, XInclude, XSLT, DTD, and XHTML.
- **Predicates and expressions**. The predicate classes—`NSPredicate`, `NSCompoundPredicate`, and `NSComparisonPredicate`—encapsulate the logical conditions to constrain a fetch or filter object. `NSExpression` objects represent expressions in a predicate.

The Foundation framework for iOS has a subset of the classes for OS X. The following categories of classes are present only in the OS X version of Foundation:

- **Spotlight queries**. The `NSMetadataItem`, `NSMetadataQuery` and related query classes encapsulate file-system metadata and make it possible to query that metadata.
- **Scripting**. The classes in this category help to make your program responsive to AppleScript scripts and Apple event commands.
- **Distributed objects**. You use the distributed object classes for communication between processes on the same computer or on different computers on a network. Two of these classes, `NSDistantObject` and `NSProtocolChecker`, have a root class (`NSProxy`) different from the root class of the rest of Cocoa.

AppKit (OS X)

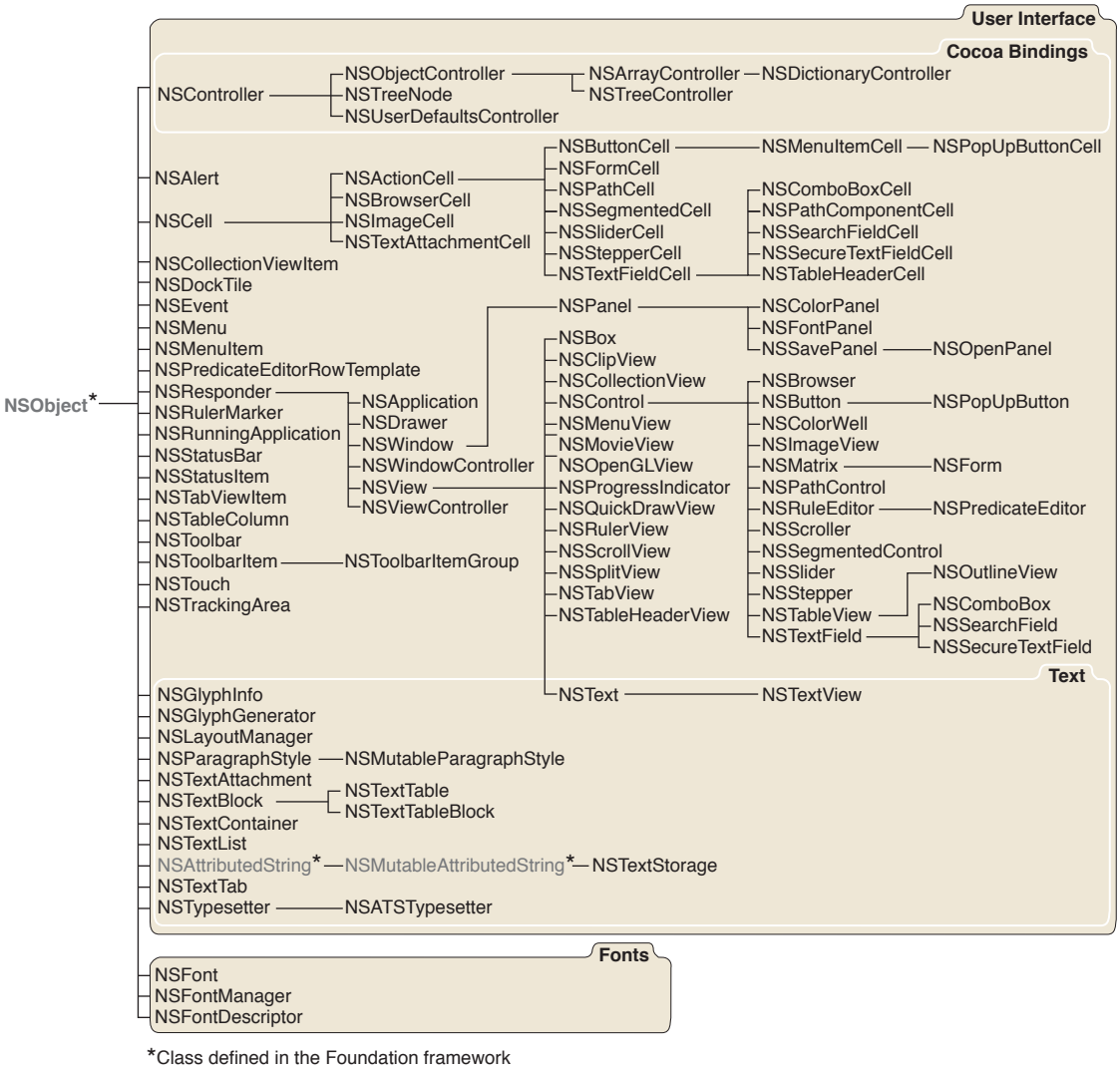
AppKit is a framework containing all the objects you need to implement your graphical, event-driven user interface in OS X: windows, dialogs, buttons, menus, scrollers, text fields—the list goes on. AppKit handles all the details for you as it efficiently draws on the screen, communicates with hardware devices and screen buffers, clears areas of the screen before drawing, and clips views. The number of classes in AppKit may seem daunting at first. However, most AppKit classes are support classes that you use indirectly. You also have the choice at which level you use AppKit:

- Use Interface Builder to create connections from user-interface objects to your application's controller objects, which manage the user interface and coordinate the flow of data between the user interface and internal data structures. For this, you might use off-the-shelf controller objects (for Cocoa bindings) or you may need to implement one or more custom controller classes—particularly the action and delegate methods of those classes. For example, you would need to implement a method that is invoked when the user chooses a menu item (unless it has a default implementation that is acceptable).
- Control the user interface programmatically, which requires more familiarity with AppKit classes and protocols. For example, allowing the user to drag an icon from one window to another requires some programming and familiarity with the `NSDragging...` protocols.
- Implement your own objects by subclassing `NSView` or other classes. When subclassing `NSView`, you write your own drawing methods using graphics functions. Subclassing requires a deeper understanding of how AppKit works.

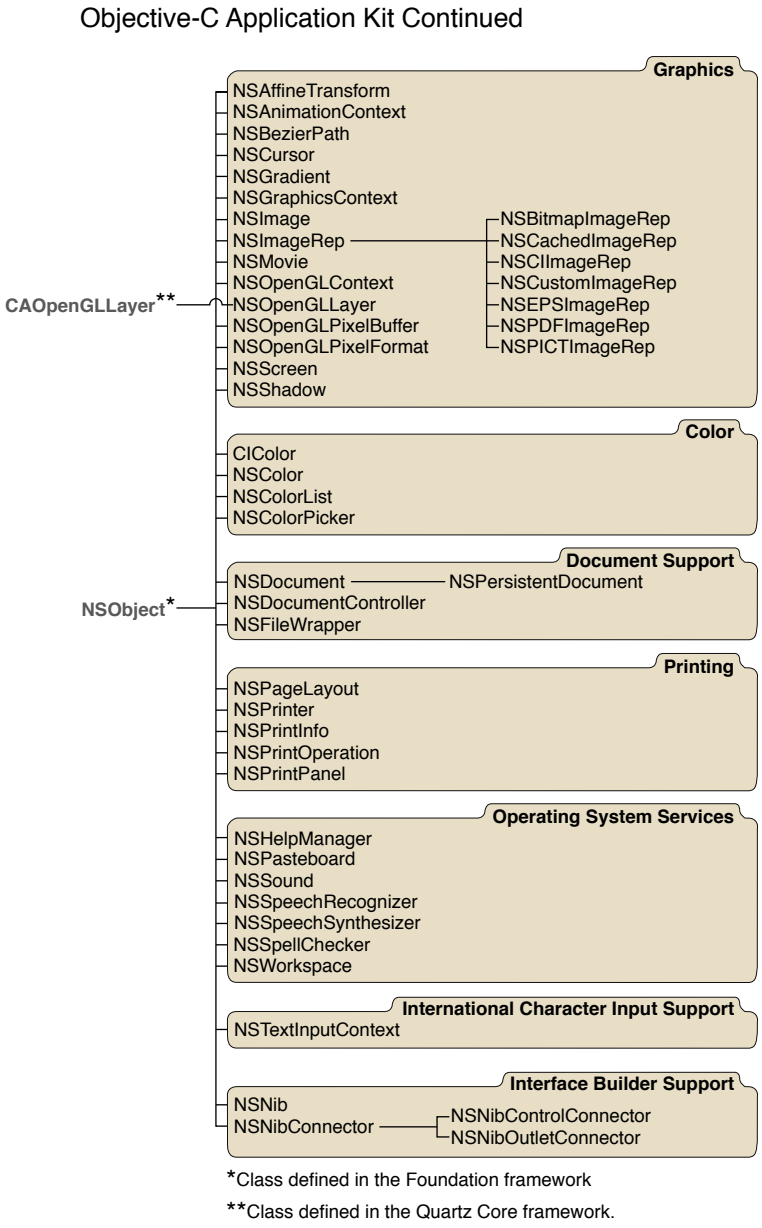
Overview of the AppKit Framework

The AppKit framework consists of more than 125 classes and protocols. All classes ultimately inherit from the Foundation framework's `NSObject` class. The diagrams in Figure 1-8 show the inheritance relationships of the AppKit classes.

Figure 1-8 AppKit class hierarchy—Objective-C



*Class defined in the Foundation framework



As you can see, the hierarchy tree of AppKit is broad but fairly shallow; the classes deepest in the hierarchy are a mere five superclasses away from the root class and most classes are much closer than that. Some of the major branches in this hierarchy tree are particularly interesting.

At the root of the largest branch in AppKit is the `NSResponder` class. This class defines the responder chain, an ordered list of objects that respond to user events. When the user clicks the mouse button or presses a key, an event is generated and passed up the responder chain in search of an object that can respond to it. Any object that handles events must inherit from the `NSResponder` class. The core AppKit classes—`NSApplication`, `NSWindow`, and `NSView`—inherit from `NSResponder`.

The second largest branch of classes in AppKit descend from `NSCell`. The noteworthy thing about this group of classes is that they roughly mirror the classes that inherit from `NSControl`, which inherits from `NSView`. For its user-interface objects that respond to user actions, AppKit uses an architecture that divides the labor between control objects and cell objects. The `NSControl` and `NSCell` classes, and their subclasses, define a common set of user-interface objects such as buttons, sliders, and browsers that the user can manipulate graphically to control some aspect of your application. Most control objects are associated with one or more cell objects that implement the details of drawing and handling events. For example, a button comprises both an `NSButton` object and an `NSButtonCell` object.

Controls and cells implement a mechanism that is based on an important design pattern of the AppKit: the target-action mechanism. A cell can hold information that identifies the message that should be sent to a particular object when the user clicks (or otherwise acts upon) the cell. When a user manipulates a control (by, for example, clicking it), the control extracts the required information from its cell and sends an action message to the target object. Target-action allows you to give meaning to a user action by specifying what the target object and invoked method should be. You typically use Interface Builder to set these targets and actions by Control-dragging from the control object to your application or other object. You can also set targets and actions programmatically.

Another important design pattern–based mechanism of AppKit (and also UIKit) is delegation. Many objects in a user interface, such as text fields and table views, define a delegate. A delegate is an object that acts on behalf of, or in coordination with, the delegating object. It is thus able to impart application-specific logic to the operation of the user interface. For more on delegation, target–action, and other paradigms and mechanisms of AppKit, see "Communicating with Objects" (page 209). For a discussion of the design patterns on which these paradigms and mechanisms are based, see "Cocoa Design Patterns" (page 165).

One of the general features of OS X v10.5 and later system versions is resolution independence: The resolution of the screen is decoupled from the drawing done by code. The system automatically scales content for rendering on the screen. The AppKit classes support resolution independence in their user-interface objects. However, for your own applications to take advantage of resolution independence, you might have to supply images at a higher resolution or make minor adjustments in your drawing code that take the current scaling factor into account.

The following sections briefly describe some of the capabilities and architectural aspects of the AppKit framework and its classes and protocols. It groups classes according to the class hierarchy diagrams shown in Figure 1-8 (page 42).

General User-Interface Classes

For the overall functioning of a user interface, the AppKit provides the following classes:

- **The global application object**. Every application uses a singleton instance of `NSApplication` to control the main event loop, keep track of the application's windows and menus, distribute events to the appropriate objects (that is, itself or one of its windows), set up top-level autorelease pools, and receive notification of application-level events. An `NSApplication` object has a delegate (an object that you assign) that is notified when the application starts or terminates, is hidden or activated, should open a file selected by the user, and so forth. By setting the `NSApplication` object's delegate and implementing the delegate methods, you customize the behavior of your application without having to subclass `NSApplication`.
- **Windows and views**. The window and view classes, `NSWindow` and `NSView`, also inherit from `NSResponder`, and so are designed to respond to user actions. An `NSApplication` object maintains a list of `NSWindow` objects—one for each window belonging to the application—and each `NSWindow` object maintains a hierarchy of `NSView` objects. The view hierarchy is used for drawing and handling events within a window. An `NSWindow` object handles window-level events, distributes other events to its views, and provides a drawing area for its views. An `NSWindow` object also has a delegate allowing you to customize its behavior.

  Beginning with OS X v10.5, the window and view classes of the AppKit support enhanced animation features.

  `NSView` is the superclass for all objects displayed in a window. All subclasses implement a drawing method using graphics functions; `drawRect:` is the primary method you override when creating a new `NSView`.
- **Controller classes for Cocoa bindings**. The abstract `NSController` class and its concrete subclasses `NSObjectController`, `NSArrayController`, `NSDictionaryController`, and `NSTreeController` are part of the implementation of Cocoa bindings. This technology automatically synchronizes the application data stored in objects and the presentation of that data in a user interface. See "The Model-View-Controller Design Pattern" (page 193) for a description of these types of controller objects.
- **Panels (dialogs)**. The `NSPanel` class is a subclass of `NSWindow` that you use to display transient, global, or pressing information. For example, you would use an instance of `NSPanel`, rather than an instance of `NSWindow`, to display error messages or to query the user for a response to remarkable or unusual circumstances. The AppKit implements some common dialogs for you such as the Save, Open, and Print dialogs, used to save, open, and print documents. Using these dialogs gives the user a consistent look and feel across applications for common operations.
- **Menus and cursors**. The `NSMenu`, `NSMenuItem`, and `NSCursor` classes define the look and behavior of the menus and cursors that your application displays to the user.
- **Grouping and scrolling views**. The `NSBox`, `NSScrollView`, and `NSSplitView` classes provide graphic "accessories" to other view objects or collections of views in windows. With the `NSBox` class, you can group elements in windows and draw a border around the entire group. The `NSSplitView` class lets you append views vertically or horizontally, apportioning to each view some amount of a common territory; a sliding control bar lets the user redistribute the territory among views. The `NSScrollView` class and its helper class, `NSClipView`, provide a scrolling mechanism as well as the graphic objects that let the user initiate and control a scroll. The `NSRulerView` class allows you to add a ruler and markers to a scroll view.

- **Table views and outline views**. The `NSTableView` class displays data in rows and columns. `NSTableView` is ideal for, but not limited to, displaying database records, where rows correspond to each record and columns contain record attributes. The user can edit individual cells and rearrange the columns. You control the behavior and content of an `NSTableView` object by setting its delegate and data source objects. Outline views (instances of `NSOutlineView`, a subclass of `NSTableView`) offer another approach to displaying tabular data. With the `NSBrowser` class you can create an object with which users can display and navigate hierarchical data.

Text and Fonts

The Cocoa text system is based on the Core Text framework, which was introduced in OS X v10.5. The Core Text framework provides a modern, low-level, high-performance technology for laying out text. If you use the Cocoa text system, you should rarely have reason to use Core Text directly.

The `NSTextField` class implements a simple editable text-input field, and the `NSTextView` class provides more comprehensive editing features for larger text bodies.

`NSTextView`, a subclass of the abstract `NSText` class, defines the interface to the extended text system. `NSTextView` supports rich text, attachments (graphics, file, and other), input management and key binding, and marked text attributes. `NSTextView` works with the Fonts window and Font menu, rulers and paragraph styles, the Services facility, and the pasteboard (Clipboard). `NSTextView` also allows customizing through delegation and notifications—you rarely need to subclass `NSTextView`. You rarely create instances of `NSTextView` programmatically either, because objects in the Interface Builder library, such as `NSTextField`, `NSForm`, and `NSScrollView`, already contain `NSTextView` objects.

It is also possible to do more powerful and more creative text manipulation (such as displaying text in a circle) using `NSTextStorage`, `NSLayoutManager`, `NSTextContainer`, and related classes. The Cocoa text system also supports lists, tables, and noncontiguous selections.

The `NSFont` and `NSFontManager` classes encapsulate and manage font families, sizes, and variations. The `NSFont` class defines a single object for each distinct font; for efficiency, these objects, which can represent a lot of data, are shared by all the objects in your application. The `NSFontPanel` class defines the Fonts window that's presented to the user.

Graphics and Colors

The classes `NSImage` and `NSImageRep` encapsulate graphics data, allowing you to easily and efficiently access images stored in files on the disk and displayed on the screen. `NSImageRep` subclasses each know how to draw an image from a particular kind of source data. The `NSImage` class provides multiple representations of the same image, and it also provides behaviors such as caching. The imaging and drawing capabilities of Cocoa are integrated with the Core Image framework.

Color is supported by the classes `NSColor`, `NSColorSpace`, `NSColorPanel`, `NSColorList`, `NSColorPicker`, and `NSColorWell`. `NSColor` and `NSColorSpace` support a rich set of color formats and representations, including custom ones. The other classes are mostly interface classes: They define and present panels and views that allow the user to select and apply colors. For example, the user can drag colors from the Colors window to any color well.

The `NSGraphicsContext`, `NSBezierPath`, and `NSAffineTransform` classes help you with vector drawing and support graphical transformations such as scaling, rotation, and translation.

Printing and Faxing

The `NSPrinter`, `NSPrintPanel`, `NSPageLayout`, and `NSPrintInfo` classes work together to provide the means for printing and faxing the information that your application displays in its windows and views. You can also create a PDF representation of an `NSView` object.

Document and File-System Support

You can use the `NSFileWrapper` class to create objects that correspond to files or directories on disk. `NSFileWrapper` holds the contents of the file in memory so that it can be displayed, changed, or transmitted to another application. It also provides an icon for dragging the file or representing it as an attachment. You can use the `NSFileManager` class in the Foundation framework to access and enumerate file and directory contents. The `NSOpenPanel` and `NSSavePanel` classes also provide a convenient and familiar user interface to the file system.

The `NSDocumentController`, `NSDocument`, and `NSWindowController` classes define an architecture for creating document-based applications. (The `NSWindowController` class is shown in the User Interface group of classes in the class hierarchy charts.) Such applications can generate identical window containers that hold uniquely composed sets of data that can be stored in files. They have built-in or easily acquired capabilities for saving, opening, reverting, closing, and managing these documents.

Internationalization and Character Input Support

If an application is to be used in more than one part of the world, its resources may need to be customized, or localized, for language, country, or cultural region. For example, an application may need to have separate Japanese, English, French, and German versions of character strings, icons, nib files, or context help. Resource files specific to a particular language are grouped together in a subdirectory of the bundle directory (the directories with the `.lproj` extension). Usually you set up localization resource files using Interface Builder. See *Internationalization Programming Topics* for more information on the Cocoa internationalization facilities.

The `NSInputServer` and `NSInputManager` classes, along with the `NSTextInput` protocol, give your application access to the text input management system. This system interprets keystrokes generated by various international keyboards and delivers the appropriate text characters or Control-key events to text view objects. (Typically the text classes deal with these classes and you won't have to.)

Operating-System Services

The AppKit provides operating-system support for your application through classes that implement the following features:

- **Sharing data with other applications**. The `NSPasteboard` class defines the pasteboard, a repository for data that's copied from your application, making this data available to any application that cares to use it. `NSPasteboard` implements the familiar cut/copy-and-paste operation.
- **Dragging**. With very little programming on your part, custom view objects can be dragged and dropped anywhere. Objects become part of this dragging mechanism by conforming to `NSDragging...` protocols; draggable objects conform to the `NSDraggingSource` protocol, and destination objects (receivers of a drop) conform to the `NSDraggingDestination` protocol. The AppKit hides all the details of tracking the cursor and displaying the dragged image.
- **Spell Checking**. The `NSSpellServer` class lets you define a spell-checking service and provide it as a service to other applications. To connect your application to a spell-checking service, you use the `NSSpellChecker` class. The `NSIgnoreMisspelledWords` and `NSChangeSpelling` protocols support the spell-checking mechanism.

Interface Builder Support

The abstract `NSNibConnector` class and its two concrete subclasses, `NSNibControlConnector` and `NSNibOutletConnector`, represent connections in Interface Builder. `NSNibControlConnector` manages an action connection in Interface Builder and `NSNibOutletConnector` manages an outlet connection.

UIKit (iOS)

The UIKit framework in iOS is the sister framework of the AppKit framework in OS X. Its purpose is essentially the same: to provide all the classes that an application needs to construct and manage its user interface. However, there are significant differences in how the frameworks realize this purpose.

One of the greatest differences is that, in iOS, the objects that appear in the user interface of a Cocoa application look and behave in a way that is different from the way their counterparts in a Cocoa application running in OS X look and behave. Some common examples are text views, table views, and buttons. In addition, the event-handling and drawing models for Cocoa applications on the two platforms are significantly different. The following sections explain the reasons for these and other differences.

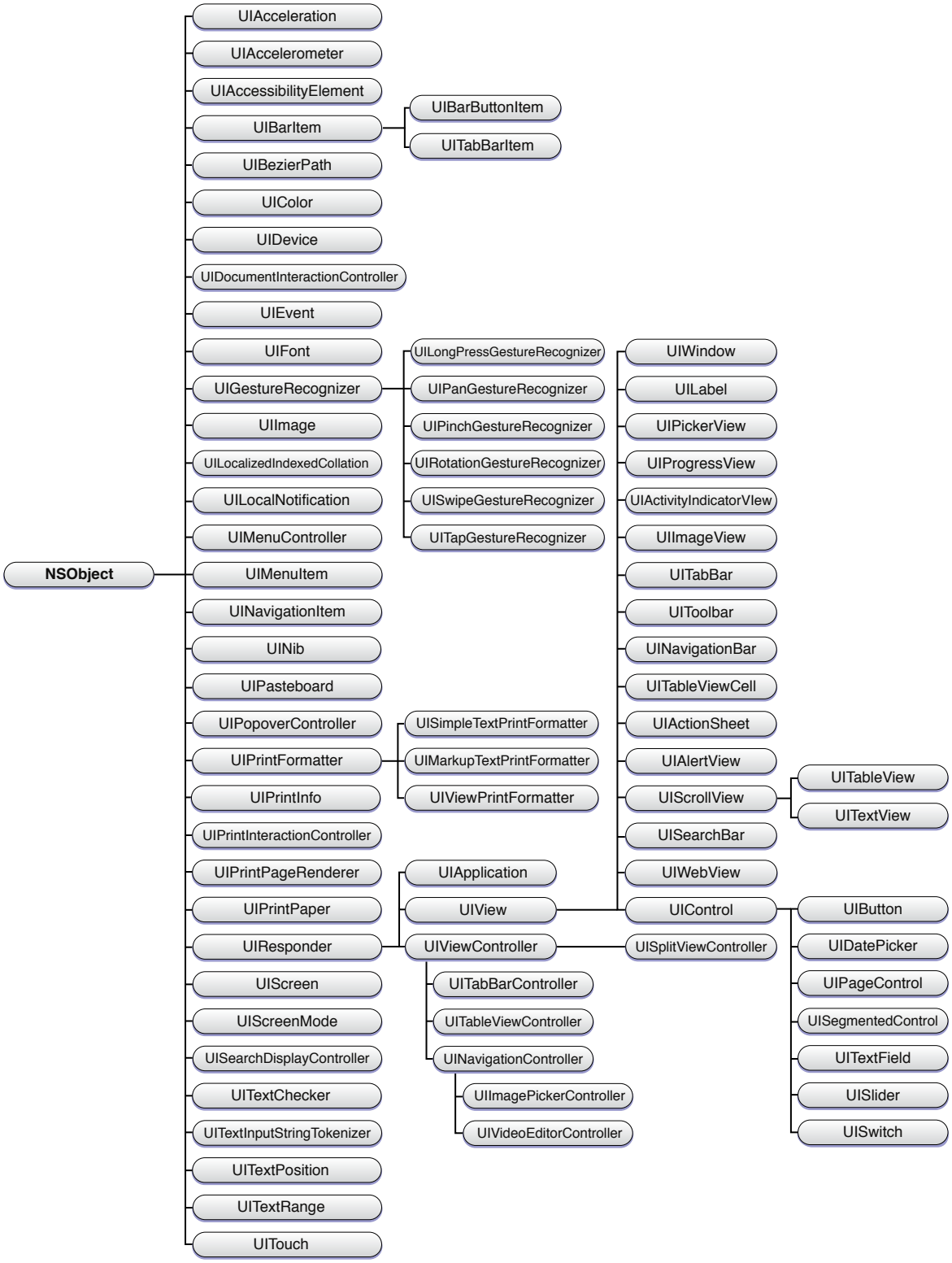
You can add UIKit objects to your application's user interface in three ways:

- Use the Interface Builder development application to drag windows, views, and other objects from an object library.
- Create, position, and configure framework objects programmatically.
- Implement custom user-interface objects by subclassing `UIView` or classes that inherit from `UIView`.

Overview of UIKit Classes

As with AppKit, the classes of the UIKit framework ultimately inherit from `NSObject`. Figure 1-9 presents the classes of the UIKit framework in their inheritance relationship.

Figure 1-9 UIKit class hierarchy



As with AppKit, a base responder class is at the root of the largest branch of UIKit classes. `UIResponder` also defines the interface and default behavior (if any) for event-handling methods and for the responder chain, which is a chain of objects that are potential event handlers. When the user scrolls a table view with his or her finger or types characters in a virtual keyboard, UIKit generates an event and that event is passed up the responder chain until an object handles it. The corresponding core objects—application (`UIApplication`), window (`UIWindow`), and view (`UIView`)—all directly or indirectly inherit from `UIResponder`.

Unlike the AppKit, UIKit does not make use of cells. Controls in UIKit—that is, all objects that inherit from `UIControl`—do not require cells to carry out their primary role: sending action messages to a target object. Yet the way UIKit implements the target-action mechanism is different from the way it is implemented in AppKit. The `UIControl` class defines a set of event types for controls; if, for example, you want a button (`UIButton`) to send an action message to a target object, you call `UIControl` methods to associate the action and target with one or more of the control event types. When one of those events happens, the control sends the action message.

The UIKit framework makes considerable use of delegation, another design pattern of AppKit. Yet the UIKit implementation of delegation is different. Instead of using informal protocols, UIKit uses formal protocols with possibly some protocol methods marked optional.

> **Note** For a complete description of the target-action mechanism in UIKit and the AppKit, see "The Target-Action Mechanism" (page 217). To learn more about delegation and protocols, both formal and informal, see "Delegates and Data Sources" (page 211) and "Protocols" (page 67).

Application Coordination

Each application running in iOS is managed by a singleton application object, and this object has a job that is almost identical to that for the global `NSApplication` object. A `UIApplication` object controls the main event loop, keeps track of the application's windows and views, and dispatches incoming events to the appropriate responder objects.

The `UIApplication` object also receives notification of system-level and application-level events. Many of these it passes to its delegate, allowing it to inject application-specific behavior when the application launches and terminates, to respond to low-memory warnings and changes in time, and to handle other tasks.

Differences in Event and Drawing Models

In OS X, the mouse and keyboard generate most user events. AppKit uses `NSEvent` objects to encapsulate these events. In iOS, however, a user's finger movements on the screen are what originate events. UIKit also has a class, `UIEvent`, to represent these events. But finger touches are different in nature from mouse clicks; two or more touches occurring over a period could form a discrete event—a pinch gesture, for example. Thus a `UIEvent` object contains one or more objects representing finger touches (`UITouch`). The model for

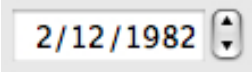
distributing and dispatching events to objects that can handle them on the two platforms is almost identical. However, to handle an event, an object must take into consideration the sequence of touches specific to that event.

UIKit also has gesture recognizers, objects that automate the detection of touches as gestures. A gesture recognizer analyzes a series of touches and, when it recognizes its gesture, sends an action message to a target. UIKit provides ready-made gesture recognizers for gestures such as tap, swipe, rotate, and pan. You can also create custom gesture recognizers that detect application-specific gestures.

The drawing models are similar for AppKit and UIKit. Animation is integrated into the UIKit drawing implementation. The programmatic support that UIKit directly provides for drawing is a bit more limited compared to AppKit. The framework offers classes and functions for Bezier paths, PDF generation, and simple line and rectangle drawing (through functions declared in `UIGraphics.h`). You use `UIColor` objects to set colors in the current graphics context and `UIImage` objects to represent and encapsulate images. For drawing of greater sophistication, an application must use the Core Graphics or OpenGL ES framework.

General User-Interface Classes

Objects on an iOS user interface are visibly different than objects on an OS X user interface. Because of the nature of the device—specifically the smaller screen size and the use of fingers instead of the mouse and keyboard for input—user-interface objects in iOS must typically be larger (to be an adequate target for touches) while at the same time make as efficient use of screen real estate as possible. These objects are sometimes based on visual and tactile analogs of an entirely different sort. As an example, consider the date picker object, which is instantiated from a class that both the UIKit and AppKit frameworks define. In OS X, the date picker looks like this:



This style of date picker has a two tiny areas for incrementing date components, and thus is suited to manipulation by a mouse pointer. Contrast this with the date picker seen in iOS applications:

This style of date picker is more suited for finger touches as an input source; users can swipe a month, day, or year column to spin it to a new value.

As with AppKit classes, many of UIKit classes fall into functional groups:

- **Controls**. The subclasses of `UIControl` instantiate objects that let users communicate their intent to an application. In addition to the standard button object (`UIButton`) and slider object (`UISlider`), there is a control that simulates off/on switches (`UISwitch`), a spinning-wheel control for selecting from multidimensional sets of values (`UIPickerView`), a control for paging through documents (`UIPageControl`), and other controls.
- **Modal views**. The two classes inheriting from `UIModalView` are for displaying messages to users either in the form of "sheets" attached to specific views or windows (`UIActionSheet`) or as unattached alert dialogs (`UIAlertView`). On iPad, an application can uses popover views (`UIPopoverController`) instead of action sheets.
- **Scroll views**. The `UIScrollView` class enables instances of its subclasses to respond to touches for scrolling within large views. As users scroll, the scroll view displays transient indicators of position within the document. The subclasses of `UIScrollView` implement table views, text views, and web views.
- **Toolbars, navigation bars, split views, and view controllers**. The `UIViewController` class is a base class for managing a view. A view controller provides methods for creating and observing views, overlaying views, handling view rotation, and responding to low-memory warnings. UIKit includes concrete subclasses of `UIViewController` for managing toolbars, navigation bars, and image pickers.

  Applications use both toolbars and navigation bars to manage behavior related to the "main" view on the screen; typically, toolbars are placed beneath the main view and navigation bars above it. You use toolbar (`UIToolbar`) objects to switch between modes or views of an application; you can also use them to display a set of functions that perform some action related to the current main view. You use navigation bars (`UINavigationBar`) to manage sequences of windows or views in an application and, in effect, to "drill down" a hierarchy of objects defined by the application; the Mail application, for example, uses a navigation bar to navigate from accounts to mailbox folders and from there to individual email messages. On iPad, applications can use a `UISplitViewController` object to present a master-detail interface.

Text

Users can enter text in an iOS application either through a text view (`UITextView`) or a text field (`UITextField`). These classes adopt the `UITextInputTraits` protocol to specify the appearance and behavior of the virtual keyboard that is presented when users touch the text-entry object; any subclasses that enable entry of text should also conform to this protocol. Applications can draw text in views using `UIStringDrawing` methods, a category on the `NSString` class. And with the `UIFont` class you can specify the font characteristics of text in all objects that display text, including table cells, navigation bars, and labels.

Applications that do their own text layout and font management can adopt the `UITextInput` protocol and use related classes and protocols to communicate with the text input system of iOS.

Comparing AppKit and UIKit Classes

AppKit and UIKit are Cocoa application frameworks that are designed for different platforms, one for OS X and the other for iOS. Because of this affinity, it is not surprising that many of the classes in each framework have similar names; in most cases, the prefix ("NS" versus "UI") is the only name difference. These similarly named classes fulfill mostly similar roles, but there are differences. These differences can be a matter of scope, of inheritance, or of design. Generally, UIKit classes have fewer methods than their AppKit counterparts.

Table 1-1 describes the differences between the major classes in each framework.

Table 1-1 Major classes of the AppKit and UIKit frameworks

Classes	Comparison
`NSApplication` `UIApplication`	The classes are strikingly similar in their primary roles. They provide a singleton object that sets up the application's display environment and event loop, distributes events, and notifies a delegate when application-specific events occur (such as launch and termination). However, the `NSApplication` class performs functions (for example, managing application suspension, reactivation, and hiding) that are not available to an iOS application.
`NSResponder` `UIResponder`	These classes also have nearly identical roles. They are abstract classes that define an interface for responding to events and managing the responder chain. The main difference is that the `NSResponder` event-handling methods are defined for the mouse and keyboard, whereas the `UIResponder` methods are defined for the Multi-Touch event model.
`NSWindow` `UIWindow`	The `UIWindow` class occupies a place in the class hierarchy different from the place `NSWindow` occupies in AppKit; it is a subclass of `UIView`, whereas the AppKit class inherits directly from `NSResponder`. `UIWindow` has a much more restricted role in an application than does `NSWindow`. It also provides an area for displaying views, dispatches events to those views, and converts between window and view coordinates.
`NSView` `UIView`	These classes are very similar in purpose and in their basic sets of methods. They allow you to move and resize views, manage the view hierarchy, draw view content, and convert view coordinates. The design of `UIView`, however, makes view objects inherently capable of animation.
`NSControl` `UIControl`	Both classes define a mechanism for objects such as buttons and sliders so that, when manipulated, the control object sends an action message to a target object. The classes implement the target-action mechanism in different ways, largely because of the difference between event models. See "The Target-Action Mechanism" (page 217) for information.

Classes	Comparison
`NSViewController` `UIViewController`	The role of both of these classes is, as their names suggest, to manage views. How they accomplish this task is different. The management provided by an `NSViewController` object is dependent on bindings, which is a technology supported only in OS X. `UIViewController` objects are used in the iOS application model for modal and navigation user interfaces (for example, the views controlled by navigation bars).
`NSTableView` `UITableView`	`NSTableView` inherits from `NSControl`, but `UITableView` does not inherit from `UIControl`. More importantly, `NSTableView` objects support multiple columns of data; `UITableView` objects display only a single column of data at a time, and thus function more as lists than presentations of tabular data.

Among the minor classes you can find some differences too. For example, UIKit has the `UITextField` and `UILabel` classes, the former for editable text fields and the latter for noneditable text fields used as labels; with the `NSTextField` class you can create both kinds of text fields simply by setting text-field attributes. Similarly, the `NSProgressIndicator` class can create objects in styles that correspond to instances of the `UIProgressIndicator` and `UIProgressBar` classes.

Core Data

Core Data is a Cocoa framework that provides an infrastructure for managing object graphs, including support for persistent storage in a variety of file formats. Object-graph management includes features such as undo and redo, validation, and ensuring the integrity of object relationships. Object persistence means that Core Data saves model objects to a persistent store and fetches them when required. The persistent store of a Core Data application—that is, the ultimate form in which object data is archived—can range from XML files to SQL databases. Core Data is ideally suited for applications that act as front ends for relational databases, but any Cocoa application can take advantage of its capabilities.

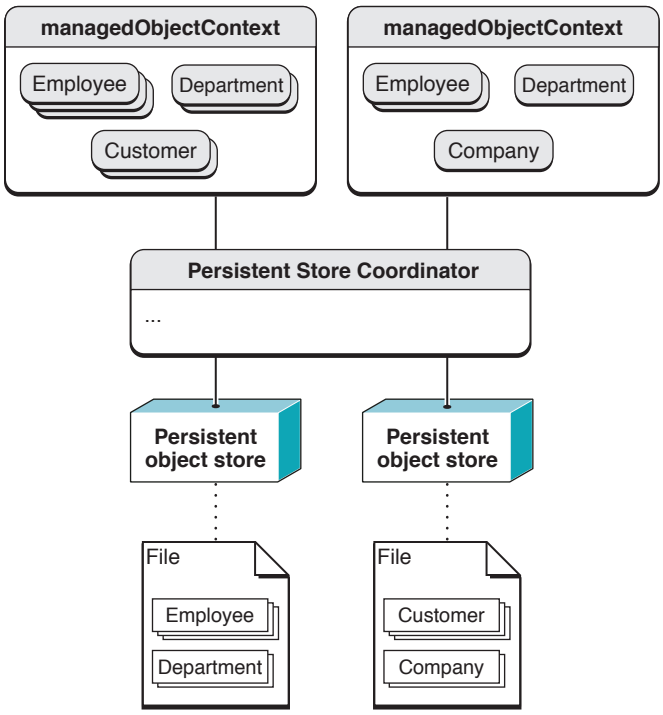
The central concept of Core Data is the managed object. A managed object is simply a model object that is managed by Core Data, but it must be an instance of the `NSManagedObject` class or a subclass of that class. You describe the managed objects of your Core Data application using a schema called a managed object model. (The Xcode application includes a data modeling tool to assist you in creating these schemas.) A managed object model contains descriptions of an application's managed objects (also referred to as *entities*). Each description specifies the attributes of an entity, its relationships with other entities, and metadata such as the names of the entity and the representing class.

In a running Core Data application, an object known as a *managed object context* is responsible for a graph of managed objects. All managed objects in the graph must be registered with a managed object context. The context allows an application to add objects to the graph and remove them from it. It also tracks changes

made to those objects, and thus can provide undo and redo support. When you're ready to save changes made to managed objects, the managed object context ensures that those objects are in a valid state. When a Core Data application wants to retrieve data from its external data store, it sends a fetch request—an object that specifies a set of criteria—to a managed object context. The managed object context returns the objects from the store that match the request after automatically registering them.

A managed object context also functions as a gateway to an underlying collection of Core Data objects called the *persistence stack*. The persistence stack mediates between the objects in your application and external data stores. The stack consists of two different types of objects, persistent stores and persistent store coordinators. Persistent stores are at the bottom of the stack. They map between data in an external store—for example, an XML file—and corresponding objects in a managed object context. They don't interact directly with managed object contexts, however. Above a persistence store in the stack is a persistent store coordinator, which presents a facade to one or more managed object contexts so that multiple persistence stores below it appear as a single aggregate store. Figure 1-10 shows the relationships between objects in the Core Data architecture.

Figure 1-10 Examples of managed object contexts and the persistence stack



Core Data includes the `NSPersistentDocument` class, a subclass of `NSDocument` that helps to integrate Core Data and the document architecture. A persistent-document object creates its own persistence stack and managed object context, mapping the document to an external data store. An `NSPersistentDocument` object provides default implementations of the `NSDocument` methods for reading and writing document data.

Other Frameworks with a Cocoa API

As part of a standard installation, Apple includes, in addition to the core frameworks for both platforms, several frameworks that vend Cocoa programmatic interfaces. You can use these secondary frameworks to give your application capabilities that are desirable, if not essential. Some notable secondary frameworks include:

- Sync Services—(OS X only) Using Sync Services you can sync existing contacts, calendars and bookmarks schemas as well as your own application data. You can also extend existing schemas. See *Sync Services Programming Guide* for more information.
- Address Book—This framework implements a centralized database for contact and other personal information. Applications that use the Address Book framework can share this contact information with other applications, including Apple's Mail and iChat. See *Address Book Programming Guide for Mac* for more information.

  iOS Note There are different versions of this framework in OS X and iOS. In addition, the Address Book framework in iOS has only ANSI C (procedural) programmatic interfaces.

- Preference Panes—(OS X only) With this framework you can create plug-ins that your application dynamically loads to obtain a user interface for recording user preferences, either for the application itself or systemwide. See *Preference Pane Programming Guide* for more information.
- Screen Saver—(OS X only) The Screen Saver framework helps you create Screen Effects modules, which can be loaded and run via System Preferences. See *Screen Saver Framework Reference* for more information.
- WebKit—(not public in iOS) The WebKit framework provides a set of core classes to display web content in windows, and by default, implements features such as following links clicked by the user. See *WebKit Objective-C Programming Guide* for more information.
- iAd—(iOS only) This framework allows your application to earn revenue by displaying advertisements to the user.
- Map Kit—(iOS only) This framework lets an application embed maps into its own windows and views. It also supports map annotation, overlays, and reverse-geocoding lookups.
- Event Kit—(iOS only) With the Event Kit framework, an application can access event information from a user's Calendar database and enable users to create and edit events for their calendars. The framework also supports efficient fetching of event records, notifications of event changes, and automatic syncing with appropriate calendar databases.
- Core Motion—(iOS only) The Core Motion processes low-level data received from a device's accelerometer and gyroscope (if available) and presents that to applications for handling.

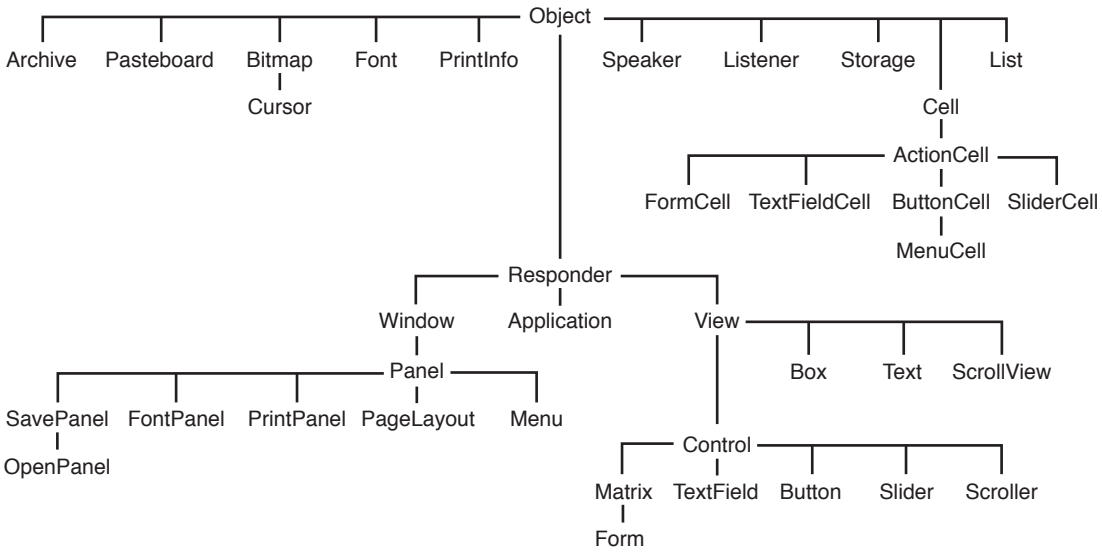
- Core Location—(iOS only) Core Location lets an application determine the current location or heading associated with a device. With it an application can also define geographic regions and monitor when the user crosses the boundaries of those regions.
- Media Player—(iOS only) This framework enables an application to play movies, music, audio podcasts, and audio book files. It also gives your application access to the iPod library.

A Bit of History

Many years ago Cocoa was known as NeXTSTEP. NeXT Computer developed and released version 1.0 of NeXTSTEP in September of 1989, and versions 2.0 and 3.0 followed not far behind (in 1990 and 1992, respectively). In this early phase, NeXTSTEP was more than an application environment; the term referred to the entire operating system, including the windowing and imaging system (which was based on Display PostScript), the Mach kernel, device drivers, and so on.

Back then, there was no Foundation framework. Indeed, there were no frameworks; instead, the software libraries (dynamically shared) were known as *kits*, the most prominent of them being Application Kit. Much of the role that Foundation now occupies was taken by an assortment of functions, structures, constants, and other types. Application Kit itself had a much smaller set of classes than it does today. Figure 1-11 shows a class hierarchy chart of NeXTSTEP 0.9 (1988).

Figure 1-11 Application Kit class hierarchy in 1988



In addition to Application Kit, the early NeXTSTEP included the Sound Kit and the Music Kit, libraries containing a rich set of Objective-C classes that provided high-level access to the Display Postscript layer for audio and music synthesis.

In early 1993, NeXTSTEP 3.1 was ported to (and shipped on) Intel, Sparc, and Hewlett-Packard computers. NeXTSTEP 3.3 also marked a major new direction, for it included a preliminary version of Foundation. Around this time (1993), the OpenStep initiative also took form. OpenStep was a collaboration between Sun and NeXT to port the higher levels of NeXTSTEP (particularly Application Kit and Display PostScript) to Solaris. The "Open" in the name referred to the open API specification that the companies would publish jointly. The official OpenStep API, published in September of 1994, was the first to split the API between Foundation and Application Kit and the first to use the "NS" prefix. Eventually, Application Kit became known as, simply, AppKit.

By June 1996, NeXT had ported and shipped versions of OpenStep 4.0 that could run Intel, Sparc, and Hewlett-Packard computers as well as an OpenStep runtime that could run on Windows systems. Sun also finished their port of OpenStep to Solaris and shipped it as part of their Network Object Computing Environment. OpenStep, however, never became a significant part of Sun's overall strategy.

When Apple acquired NeXT Software (as it was then called) in 1997, OpenStep became the Yellow Box and was included with OS X Server (also known as Rhapsody) and Windows. Then, with the evolution of the OS X strategy, it was finally renamed to "Cocoa."

Cocoa Objects

To say that Cocoa is object-oriented is to invite the question, What is a Cocoa object and what is its relation to the primary programming language for such objects, Objective-C? This chapter describes what is distinctive about Objective-C objects and what advantages the language brings to software development in Cocoa. It also shows you how to use Objective-C to send messages to objects and how to handle return values from those messages. (Objective-C is an elegantly simple language, so this is not too hard to do.) This chapter also describes the root class, `NSObject`, and explains how to use its programmatic interface to create objects, introspect them, and manage object life cycles

A Simple Cocoa Command-Line Tool

Let's begin with a simple command-line program created using the Foundation framework for OS X. Given a series of arbitrary words as parameters, the program removes redundant occurrences, sorts the remaining list of words in alphabetical order, and prints the list to standard output. Listing 2-1 shows a typical execution of this program.

Listing 2-1 Output from a simple Cocoa tool

```
localhost> SimpleCocoaTool a z c a l q m z
a
c
l
m
q
z
```

Listing 2-2 shows the Objective-C code for this program.

Listing 2-2 Cocoa code for the SimpleCocoaTool program

```
#import <Foundation/Foundation.h>


int main (int argc, const char * argv[]) {
```

```
    NSAutoreleasePool *pool = [[NSAutoreleasePool alloc] init];
    NSArray *param = [[NSProcessInfo processInfo] arguments];
    NSCountedSet *cset = [[NSCountedSet alloc] initWithArray:param];
    NSArray *sorted_args = [[cset allObjects]
        sortedArrayUsingSelector:@selector(compare:)];
    NSEnumerator *enm = [sorted_args objectEnumerator];
    id word;
    while (word = [enm nextObject]) {
        printf("%s\n", [word UTF8String]);
    }

    [cset release];
    [pool release];
    return 0;
}
```

This code creates and uses several objects: an autorelease pool for memory management, collection objects (arrays and a set) for "uniquing" and sorting the specified words, and an enumerator object for iterating through the elements in the final array and printing them to standard output.

The first thing you probably notice about this code is that it is short, perhaps much shorter than a typical ANSI C version of the same program. Although much of this code might look strange to you, many of its elements are familiar ANSI C. These include assignment operators, control-flow statements (`while`), calls to C-library routines (`printf`), and primitive scalar types. Objective-C obviously has ANSI C underpinnings.

The rest of this chapter examines the Objective-C elements of this code, using them as examples in discussions on subjects ranging from the mechanics of message-sending to the techniques of memory management. If you haven't seen Objective-C code before, the code in the example might seem formidably convoluted and obscure, but that impression will melt away soon. Objective-C is actually a simple, elegant programming language that is easy to learn and intuitive to program with.

Object-Oriented Programming with Objective-C

Cocoa is pervasively object-oriented, from its paradigms and mechanisms to its event-driven architecture. Objective-C, the development language for Cocoa, is thoroughly object-oriented too, despite its grounding in ANSI C. It provides runtime support for message dispatch and specifies syntactical conventions for defining new classes. Objective-C supports most of the abstractions and mechanisms found in other object-oriented languages such as C++ and Java. These include inheritance, encapsulation, reusability, and polymorphism.

But Objective-C is different from these other object-oriented languages, often in important ways. For example, Objective-C, unlike C++, doesn't allow operator overloading, templates, or multiple inheritance.

Although Objective-C doesn't have these features, its strengths as an object-oriented programming language more than compensate. What follows is an exploration of the special capabilities of Objective-C.

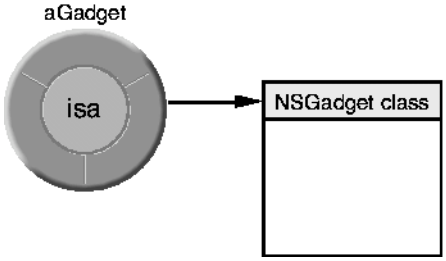
> **Further Reading** Much of this section summarizes information from the definitive guide to Objective-C, *The Objective-C Programming Language*. Consult this document for a detailed and comprehensive description of Objective-C.

The Objective-C Advantage

If you're a procedural programmer new to object-oriented concepts, it might help at first to think of an object as essentially a structure with functions associated with it. This notion is not too far off the reality, particularly in terms of runtime implementation.

Every Objective-C object hides a data structure whose first member—or instance variable—is the `isa` pointer. (Most remaining members are defined by the object's class and superclasses.) The `isa` pointer, as the name suggests, points to the object's class, which is an object in its own right (see Figure 2-1) and is compiled from the class definition. The class object maintains a dispatch table consisting essentially of pointers to the methods it implements; it also holds a pointer to its superclass, which has its own dispatch table and superclass pointer. Through this chain of references, an object has access to the method implementations of its class and all its superclasses (as well as all inherited public and protected instance variables). The `isa` pointer is critical to the message-dispatch mechanism and to the dynamism of Cocoa objects.

Figure 2-1 An object's isa pointer



This peek behind the object facade gives a highly simplified view of what happens in the Objective-C runtime to enable message-dispatch, inheritance, and other facets of general object behavior. But this information is essential to understanding the major strength of Objective-C, its dynamism.

The Dynamism of Objective-C

Objective-C is a very dynamic language. Its dynamism frees a program from compile-time and link-time constraints and shifts much of the responsibility for symbol resolution to runtime, when the user is in control. Objective-C is more dynamic than other programming languages because its dynamism springs from three sources:

- Dynamic typing—determining the class of an object at runtime
- Dynamic binding—determining the method to invoke at runtime
- Dynamic loading—adding new modules to a program at runtime

For dynamic typing, Objective-C introduces the `id` data type, which can represent any Cocoa object. A typical use of this generic object type is shown in this part of the code example from Listing 2-2 (page 61):

```
id word;
while (word = [enm nextObject]) {
    // do something with 'word' variable....
}
```

The `id` data type makes it possible to substitute any type of object at runtime. You can thereby let runtime factors dictate what kind of object is to be used in your code. Dynamic typing permits associations between objects to be determined at runtime rather than forcing them to be encoded in a static design. Static type checking at compile time may ensure stricter data integrity, but in exchange for that stricter integrity, dynamic typing gives your program much greater flexibility. And through object introspection (for example, asking a dynamically typed, anonymous object what its class is) you can still verify the type of an object at runtime and thus validate its suitability for a particular operation. (Of course, you can always statically check the types of objects when you need to.)

Dynamic typing gives substance to dynamic binding, the second kind of dynamism in Objective-C. Just as dynamic typing defers the resolution of an object's class membership until runtime, dynamic binding defers the decision of which method to invoke until runtime. Method invocations are not bound to code during compilation; they are bound only when a message is actually delivered. With both dynamic typing and dynamic binding, you can obtain different results in your code each time you execute it. Runtime factors determine which receiver is chosen and which method is invoked.

The runtime's message-dispatch machinery enables dynamic binding. When you send a message to a dynamically typed object, the runtime system uses the receiver's isa pointer to locate the object's class, and from there the method implementation to invoke. The method is dynamically bound to the message. And you don't have to do anything special in your Objective-C code to reap the benefits of dynamic binding. It happens routinely and transparently every time you send a message, especially one to a dynamically typed object.

Dynamic loading, the final type of dynamism, is a feature of Cocoa that depends on Objective-C for runtime support. With dynamic loading, a Cocoa program can load executable code and resources as they're needed instead of having to load all program components at launch time. The executable code (which is linked prior to loading) often contains new classes that become integrated into the runtime image of the program. Both code and localized resources (including nib files) are packaged in bundles and are explicitly loaded with methods defined in Foundation's `NSBundle` class.

This "lazy-loading" of program code and resources improves overall performance by placing lower memory demands on the system. Even more importantly, dynamic loading makes applications extensible. You can devise a plug-in architecture for your application that allows you and other developers to customize it with additional modules that the application can dynamically load months or even years after the application is released. If the design is right, the classes in these modules will not clash with the classes already in place because each class encapsulates its implementation and has its own namespace.

Extensions to the Objective-C Language

Objective-C features four types of extensions that are powerful tools in software development: categories, protocols, declared properties, and fast enumeration. Some extensions introduce different techniques for declaring methods and associating them with a class. Others offer convenient ways to declare and access object properties, enumerate quickly over collections, handle exceptions, and perform other tasks.

Categories

Categories give you a way to add methods to a class without having to make a subclass. The methods in the category become part of the class type (within the scope of your program) and are inherited by all the class's subclasses. There is no difference at runtime between the original methods and the added methods. You can send a message to any instance of the class (or its subclasses) to invoke a method defined in the category.

Categories are more than a convenient way to add behavior to a class. You can also use categories to compartmentalize methods, grouping related methods in different categories. Categories can be particularly handy for organizing large classes; you can even put different categories in different source files if, for instance, there are several developers working on the class.

You declare and implement a category much as you do a subclass. Syntactically, the only difference is the name of the category, which follows the `@interface` or `@implementation` directive and is put in parentheses. For example, say you want to add a method to the `NSArray` class that prints the description of the collection in a more structured way. In the header file for the category, you would write declaration code similar to the following:

```
#import <Foundation/NSArray.h> // if Foundation not already imported

@interface NSArray (PrettyPrintElements)
- (NSString *)prettyPrintDescription;
@end
```

Then in the implementation file you'd write code such as:

```
#import "PrettyPrintCategory.h"

@implementation NSArray (PrettyPrintElements)
- (NSString *)prettyPrintDescription {
    // implementation code here...
}
@end
```

There are some limitations to categories. You cannot use a category to add any new instance variables to the class. Although a category method can override an existing method, it is not recommended that you do so, especially if you want to augment the current behavior. One reason for this caution is that the category method is part of the class's interface, and so there is no way to send a message to `super` to get the behavior already defined by the class. If you need to change what an existing method of a class does, it is better to make a subclass of the class.

You can define categories that add methods to the root class, `NSObject`. Such methods are available to *all* instances and class objects that are linked into your code. Informal protocols—the basis for the Cocoa delegation mechanism—are declared as categories on `NSObject`. This wide exposure, however, has its dangers as well as its uses. The behavior you add to every object through a category on `NSObject` could have consequences that you might not be able to anticipate, leading to crashes, data corruption, or worse.

Protocols

The Objective-C extension called a *protocol* is very much like an interface in Java. Both are simply a list of method declarations publishing an interface that any class can choose to implement. The methods in the protocol are invoked by messages sent by an instance of some other class.

The main value of protocols is that they, like categories, can be an alternative to subclassing. They yield some of the advantages of multiple inheritance in C++, allowing sharing of interfaces (if not implementations). A protocol is a way for a class to declare an interface while concealing its identity. That interface may expose all or (as is usually the case) only a range of the services the class has to offer. Other classes throughout the class hierarchy, and not necessarily in any inheritance relationship (not even to the root class), can implement the methods of that protocol and so access the published services. With a protocol, even classes that have no knowledge of another's identity (that is, class type) can communicate for the specific purpose established by the protocol.

There are two types of protocols: formal and informal. Informal protocols were briefly introduced in "Categories" (page 65). These are categories on `NSObject`; as a consequence, every object with `NSObject` as its root object (as well as class objects) implicitly adopts the interface published in the category. To use an informal protocol, a class does not have to implement every method in it, just those methods it's interested in. For an informal protocol to work, the class declaring the informal protocol must get a positive response to a `respondsToSelector:` message from a target object before sending that object the protocol message. (If the target object did not implement the method, there would be a runtime exception.)

A formal protocol is usually what is designated by the term *protocol* in Cocoa. It allows a class to formally declare a list of methods that are an interface to a vended service. The Objective-C language and runtime system support formal protocols; the compiler can check for types based on protocols, and objects can introspect at runtime to verify conformance to a protocol. Formal protocols have their own terminology and syntax. The terminology is different for provider and client:

- A provider (which usually is a class) *declares* the formal protocol.
- A client class *adopts* a formal protocol, and by doing so agrees to implement all required methods of the protocol.
- A class is said to *conform* to a formal protocol if it adopts the protocol or inherits from a class that adopts it. (Protocols are inherited by subclasses.)

Both the declaration and the adoption of a protocol have their own syntactical forms in Objective-C. To declare a protocol you must use the `@protocol` compiler directive. The following example shows the declaration of the `NSCoding` protocol (in the Foundation framework's header file `NSObject.h`).

```
@protocol NSCoding
- (void)encodeWithCoder:(NSCoder *)aCoder;
```

```
- (id)initWithCoder:(NSCoder *)aDecoder;
@end
```

Objective-C 2.0 adds a refinement to formal protocols by giving you the option of declaring *optional* protocol methods as well as required ones. In Objective-C 1.0, the adopter of a protocol had to implement all methods of the protocol. In Objective-C 2.0, protocol methods are still implicitly required and can be specifically marked as such using the `@required` directive. But you can also mark blocks of protocol methods for optional implementation using the `@optional` directive; all methods declared after this directive, unless there is an intervening `@required`, can be optionally implemented. Consider these declarations:

```
@protocol MyProtocol
// implementation of this method is required implicitly
- (void)requiredMethod;

@optional
// implementation of these methods is optional
- (void)anOptionalMethod;
- (void)anotherOptionalMethod;

@required
// implementation of this method is required
- (void)anotherRequiredMethod;
@end
```

The class that declares the protocol methods typically does not implement those methods; however, it should invoke these methods in instances of the class that conforms to the protocol. Before invoking optional methods, it should verify that they're implemented using the `respondsToSelector:` method.

A class adopts a protocol by specifying the protocol, enclosed by angle brackets, at the end of its `@interface` directive, just after the superclass. A class can adopt multiple protocols by delimiting them with commas. This is how the Foundation `NSData` class adopts three protocols:

```
@interface NSData : NSObject <NSCopying, NSMutableCopying, NSCoding>
```

By adopting these protocols, `NSData` commits itself to implementing all required methods declared in the protocols. It may also choose to implement methods marked with the `@optional` directive. Categories can also adopt protocols, and their adoption becomes part of the definition of their class.

Objective-C types classes by the protocols they conform to as well as the classes they inherit from. You can check whether a class conforms to a particular protocol by sending it a `conformsToProtocol:` message:

```
if ([anObject conformsToProtocol:@protocol(NSCoding)]) {
        // do something appropriate
}
```

In a declaration of a type—a method, instance variable, or function—you can specify protocol conformance as part of the type. You thus get another level of type checking by the compiler, one that's more abstract because it's not tied to particular implementations. You use the same syntactical convention as for protocol adoption: Put the protocol name between angle brackets to specify protocol conformance in the type. You often see the dynamic object type, `id`, used in these declarations—for example:

```
- (void)draggingEnded:(id <NSDraggingInfo>)sender;
```

Here the object referred to in the parameter can be of any class type, but it must conform to the `NSDraggingInfo` protocol.

Cocoa provides several examples of protocols other than the ones shown so far. An interesting one is the `NSObject` protocol. Not surprisingly, the `NSObject` class adopts it, but so does the other root class, `NSProxy`. Through the protocol, the `NSProxy` class can interact with the parts of the Objective-C runtime essential to reference counting, introspection, and other basic aspects of object behavior.

Declared Properties

In the object modeling design pattern (see "Object Modeling" (page 202)) objects have properties. Properties consist of an object's attributes, such as title and color, and an object's relationships with other objects. In traditional Objective-C code, you define properties by declaring instance variables and, to enforce encapsulation, by implementing accessor methods to get and set the values of those variables. This is a tedious and error-prone task, especially when memory management is a concern (see "Storing and Accessing Properties" (page 146)).

Objective-C 2.0, which was introduced in OS X v10.5, offers a syntax for declaring properties and specifying how they are to be accessed. Declaring a property becomes a kind of shorthand for declaring a setter and getter method for the property. With properties, you no longer have to implement accessor methods. Direct access to property values is also available through a new dot-notation syntax. There are three aspects to the syntax of properties: declaration, implementation, and access.

You can declare properties wherever methods can be declared in a class, category, or protocol declarative section. The syntax for declaring properties is:

`@property(`*attributes...* `)` *type propertyName*

where *attributes* are one or more optional attributes (comma-separated if multiple) that affect how the compiler stores instance variables and synthesizes accessor methods. The *type* element specifies an object type, declared type, or scalar type, such as `id`, `NSString *`, `NSRange`, or `float`. The property must be backed by an instance variable of the same type and name.

The possible attributes in a property declaration are listed in Table 2-1.

Table 2-1 Attributes for declared properties

Attribute	Effect
`getter=`*getterName* `setter=`*setterName*	Specifies the names of getter and setter accessor methods (see "Storing and Accessing Properties" (page 146)). You specify these attributes when you are implementing your own accessor methods and want to control their names.
`readonly`	Indicates that the property can only be read from, not written to. The compiler does not synthesize a setter accessor or allow a nonsynthesized one to be called.
`readwrite`	Indicates that the property can be read from and written to. This is the default if `readonly` is not specified.
`assign`	Specifies that simple assignment should be used in the implementation of the setter; this is the default. If properties are declared in a non–garbage-collected program, you must specify `retain` or `copy` for properties that are objects.
`retain`	Specifies that `retain` should be sent to the property (which must be of an object type) upon assignment. Note that `retain` is a no-op in a garbage-collected environment.
`copy`	Specifies that `copy` should be sent to the property (which must be of an object type) upon assignment. The object's class must implement the `NSCopying` protocol.

Attribute	Effect
`nonatomic`	Specifies that accessor methods are synthesized as nonatomic. By default, all synthesized accessor methods are atomic: A getter method is guaranteed to return a valid value, even when other threads are executing simultaneously. For a discussion of atomic versus nonatomic properties, especially with regard to performance, see "Declared Properties" in *The Objective-C Programming Language*.

If you specify no attributes and specify `@synthesize` for the implementation, the compiler synthesizes getter and setter methods for the property that use simple assignment and that have the forms *propertyName* for the getter and `set`*PropertyName*`:` for the setter.

In the `@implementation` blocks of a class definition, you can use the `@dynamic` and `@synthesize` directives to control whether the compiler synthesizes accessor methods for particular properties. Both directives have the same general syntax:

```
@dynamic propertyName [, propertyName2...];
@synthesize propertyName [, propertyName2...];
```

The `@dynamic` directive tells the compiler that you are implementing accessor methods for the property, either directly or dynamically (such as when dynamically loading code). The `@synthesize` directive, on the other hand, tells the compiler to synthesize the getter and setter methods if they do not appear in the `@implementation` block. The syntax for `@synthesize` also includes an extension that allows you to use different names for the property and its instance-variable storage. Consider, for example, the following statement:

```
@synthesize title, directReports, role = jobDescrip;
```

This tells the computer to synthesize accessor methods for properties `title`, `directReports`, and `role`, and to use the `jobDescrip` instance variable to back the `role` property.

Finally, the Objective-C properties feature supports a simplified syntax for accessing (getting and setting) properties through the use of dot notation and simple assignment. The following examples show how easy it is to get the values of properties and set them using this syntax:

```
NSString *title = employee.title; // assigns employee title to local variable
employee.ID = "A542309"; // assigns literal string to employee ID
// gets last name of this employee's manager
NSString *lname = employee.manager.lastName;
```

Note that dot-notation syntax works only for attributes and simple one-to-one relationships, not for to-many relationships.

> **Further Reading** To learn more about declared properties, read "Declared Properties" in *The Objective-C Programming Language*.

Fast Enumeration

Fast enumeration is a language feature introduced in Objective-C 2.0 that gives you a concise syntax for efficient enumeration of collections. It is much faster than the traditional use of `NSEnumerator` objects to iterate through arrays, sets, and dictionaries. Moreover, it ensures safe enumeration by including a mutation guard to prevent modification of a collection during enumeration. (An exception is thrown if a mutation is attempted.)

The syntax for fast enumeration is similar to that used in scripting languages such as Perl and Ruby; there are two supported versions:

```
for ( type newVariable in expression ) { statements }
```

and

```
type existingVariable;
for( existingVariable in expression ) { statements }
```

expression must evaluate to an object whose class conforms to the `NSFastEnumeration` protocol. The fast-enumeration implementation is shared between the Objective-C runtime and the Foundation framework. Foundation declares the `NSFastEnumeration` protocol, and the Foundation collection classes—`NSArray`, `NSDictionary`, and `NSSet`—and the `NSEnumerator` class adopt the protocol. Other classes that hold collections of other objects, including custom classes, may adopt `NSFastEnumeration` to take advantage of this feature.

The following snippet of code illustrates how you might use fast enumeration with `NSArray` and `NSSet` objects:

```
NSArray *array = [NSArray arrayWithObjects:
        @"One", @"Two", @"Three", @"Four", nil];

for (NSString *element in array) {
    NSLog(@"element: %@", element);
}
```

```
NSSet *set = [NSSet setWithObjects:
        @"Alpha", @"Beta", @"Gamma", @"Delta", nil];

NSString *setElement;
for (setElement in set) {
    NSLog(@"element: %@", setElement);
}
```

Further Reading To find out more about fast enumeration, including how a custom collection class can take advantage of this feature, see "Fast Enumeration" in *The Objective-C Programming Language*.

Using Objective-C

Work gets done in an object-oriented program through messages; one object sends a message to another object. Through the message, the sending object requests something from the receiving object (receiver). It requests that the receiver perform some action, return some object or value, or do both things.

Objective-C adopts a unique syntactical form for messaging. Take the following statement from the SimpleCocoaTool code in Listing 2-2 (page 61):

```
NSEnumerator *enm = [sorted_args objectEnumerator];
```

The message expression is on the right side of the assignment, enclosed by the square brackets. The left-most item in the message expression is the receiver, a variable or expression representing the object to which the message is sent. In this case, the receiver is `sorted_args`, an instance of the `NSArray` class. Following the receiver is the message proper, in this case `objectEnumerator`. (For now, the discussion focuses on message syntax and does not look too deeply into what this and other messages in SimpleCocoaTool actually do.) The message `objectEnumerator` invokes a method of the `sorted_args` object named `objectEnumerator`, which returns a reference to an object that is held by the variable `enm` on the left side of the assignment. This variable is statically typed as an instance of the `NSEnumerator` class. You can diagram this statement as:

NSClassName **variable* = [*receiver* **message**];

However, this diagram is simplistic and not really accurate. A message consists of a selector name and the parameters of the message. The Objective-C runtime uses a selector name, such as `objectEnumerator` above, to look up a selector in a table in order to find the method to invoke. A selector is a unique identifier that

represents a method and that has a special type, `SEL`. Because it's so closely related, the selector name used to look up a selector is frequently called a selector as well. The above statement thus is more correctly shown as:

NSClassName *_variable_ = [_receiver_ **selector**];

Messages often have parameters, which are sometimes called *arguments*. A message with a single parameter affixes a colon to the selector name and puts the parameter right after the colon. This construct is called a *keyword*; a keyword ends with a colon, and an parameter follows the colon. Thus we could diagram a message expression with a single parameter (and assignment) as follows:

NSClassName *_variable_ = [_receiver_ **keyword:**_parameter_];

If a message has multiple parameters, the selector has multiple keywords. A selector name includes all keywords, including colons, but does not include anything else, such as return type or parameter types. A message expression with multiple keywords (plus assignment) could be diagrammed as follows:

NSClassName *_variable_ = [_receiver_ **keyword1:**_param1_ **keyword2:**_param2_];

As with function parameters, the type of a parameter must match the type specified in the method declaration. Take as an example the following message expression from SimpleCocoaTool:

```
NSCountedSet *cset = [[NSCountedSet alloc] initWithArray:param];
```

Here `param`, which is also an instance of the `NSArray` class, is the parameter of the message named `initWithArray:`.

The `initWithArray:` example cited above is interesting in that it illustrates nesting. With Objective-C, you can nest one message inside another message; the object returned by one message expression is used as the receiver by the message expression that encloses it. So to interpret nested message expressions, start with the inner expression and work your way outward. The interpretation of the above statement would be:

1. The `alloc` message is sent to the `NSCountedSet` class, which creates (by allocating memory for it) an uninitialized instance of the class.

   Note Objective-C classes are objects in their own right and you can send messages to them as well as to their instances. In a message expression, the receiver of a class message is always a class object.

2. The `initWithArray:` message is sent to the uninitialized instance, which initializes itself with the array `args` and returns a reference to itself.

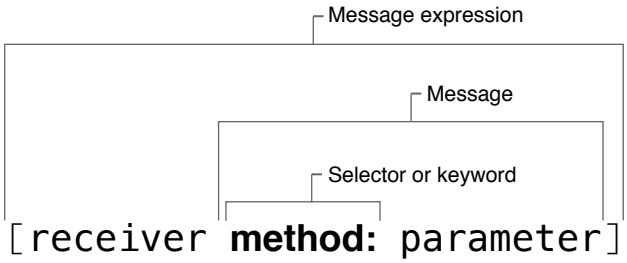
Next consider this statement from the `main` routine of SimpleCocoaTool:

```
NSArray *sorted_args = [[cset allObjects]
sortedArrayUsingSelector:@selector(compare:)];
```

What's noteworthy about this message expression is the parameter of the `sortedArrayUsingSelector:` message. This parameter requires the use of the `@selector` compiler directive to create a selector to be used as a parameter.

Let's pause a moment to review message and method terminology. A method is essentially a function defined and implemented by the class of which the receiver of a message is a member. A message is a selector name (perhaps consisting of one of more keywords) along with its parameters; a message is sent to a receiver and this results in the invocation (or execution) of the method. A message expression encompasses both receiver and message. Figure 2-2 depicts these relationships.

Figure 2-2 Message terminology



Objective-C uses a number of defined types and literals that you won't find in ANSI C. In some cases, these types and literals replace their ANSI C counterparts. Table 2-2 describes a few of the important ones, including the allowable literals for each type.

Table 2-2 Important Objective-C defined types and literals

Type	Description and literal
`id`	The dynamic object type. Its negative literal is `nil`.
`Class`	The dynamic class type. Its negative literal is `Nil`.
`SEL`	The data type (`typedef`) of a selector. The negative literal of this type is `NULL`.
`BOOL`	A Boolean type. The literal values are `YES` and `NO`.

In your program's control-flow statements, you can test for the presence (or absence) of the appropriate negative literal to determine how to proceed. For example, the following `while` statement from the SimpleCocoaTool code implicitly tests the `word` object variable for the presence of a returned object (or, in another sense, the absence of `nil`):

```
while (word = [enm nextObject]) {
    printf("%s\n", [word UTF8String]);
}
```

In Objective-C, you can often send a message to `nil` with no ill effects. Return values from messages sent to `nil` are guaranteed to work as long as what is returned is typed as an object. See "Sending Messages to nil" in *The Objective-C Programming Language* for details.

One final thing to note about the SimpleCocoaTool code is something that is not readily apparent if you're new to Objective-C. Compare this statement:

```
NSEnumerator *enm = [sorted_args objectEnumerator];
```

with this one:

```
NSAutoreleasePool *pool = [[NSAutoreleasePool alloc] init];
```

On the surface, they seem to do identical things; both return a reference to an object. However there is an important semantic difference (for memory-managed code) that has to do with the ownership of the returned object, and hence the responsibility for freeing it. In the first statement, the SimpleCocoaTool program does not own the returned object. In the second statement, the program creates the object and so owns it. The last thing the program does is to send the `release` message to the created object, thus freeing it. The only other explicitly created object (the `NSCountedSet` instance) is also explicitly released at the end of the program. For a summary of the memory-management policy for object ownership and disposal, and the methods to use to enforce this policy, see "How Memory Management Works" (page 84).

The Root Class

Just by themselves, the Objective-C language and runtime are not enough to construct even the simplest object-oriented program, at least not easily. Something is still missing: a definition of the fundamental behavior and interface common to all objects. A root class supplies that definition.

A root class is so-called because it lies at the root of a class hierarchy—in this case, the Cocoa class hierarchy. The root class inherits from no other class, and all other classes in the hierarchy ultimately inherit from it. Along with the Objective-C language, the root class is primarily where Cocoa directly accesses and interacts with the Objective-C runtime. Cocoa objects derive the ability to behave as objects in large part from the root class.

Cocoa supplies two root classes: `NSObject` and `NSProxy`. Cocoa defines the latter class, an abstract superclass, for objects that act as stand-ins for other objects; thus `NSProxy` is essential in the distributed objects architecture. Because of this specialized role, `NSProxy` appears infrequently in Cocoa programs. When Cocoa developers refer to a root or base class, they almost always mean `NSObject`.

This section looks at `NSObject`, how it interacts with the runtime, and the basic behavior and interface it defines for all Cocoa objects. It especially discusses the methods `NSObject` declares for allocation, initialization, memory management, introspection, and runtime support. These concepts are fundamental to an understanding of Cocoa.

NSObject

`NSObject` is the root class of most Objective-C class hierarchies; it has no superclass. From `NSObject`, other classes inherit a basic interface to the runtime system for the Objective-C language, and its instances obtain their ability to behave as objects.

Although it is not strictly an abstract class, `NSObject` is virtually one. By itself, an `NSObject` instance cannot do anything useful beyond being a simple object. To add any attributes and logic specific to your program, you must create one or more classes inheriting from `NSObject` or from any other class derived from `NSObject`.

`NSObject` adopts the `NSObject` protocol (see "Root Class—and Protocol" (page 77)). The `NSObject` protocol allows for multiple root objects. For example, `NSProxy`, the other root class, does not inherit from `NSObject` but adopts the `NSObject` protocol so that it shares a common interface with other Objective-C objects.

Root Class—and Protocol

`NSObject` is the name not only of a class but of a protocol. Both are essential to the definition of an object in Cocoa. The `NSObject` protocol specifies the basic programmatic interface required of *all* root classes in Cocoa. Thus not only the `NSObject` class adopts the identically named protocol, but the other Cocoa root class, `NSProxy`, adopts it as well. The `NSObject` class further specifies the basic programmatic interface for any Cocoa object that is not a proxy object.

The design of Objective-C uses a protocol such as `NSObject` in the overall definition of Cocoa objects (rather than making the methods of the protocol part of the class interface) to make multiple root classes possible. Each root class shares a common interface, as defined by the protocols they adopt.

In another sense, NSObject is not the only root protocol. Although the NSObject class does not formally adopt the NSCopying, NSMutableCopying, and NSCoding protocols, it declares and implements methods related to those protocols. (Moreover, the NSObject.h header file, which contains the definition of the NSObject class, also contains the definitions of the root protocols NSObject, NSCopying, NSMutableCopying, and NSCoding.) Object copying, encoding, and decoding are fundamental aspects of object behavior. Many, if not most, subclasses are expected to adopt or conform to these protocols.

> **Note** Other Cocoa classes can (and do) add methods to NSObject through categories. These categories are often informal protocols used in delegation; they permit the delegate to choose which methods of the category to implement. However, these categories on NSObject are not considered part of the fundamental object interface.

Overview of Root-Class Methods

The NSObject root class, along with the adopted NSObject protocol and other root protocols, specify the following interface and behavioral characteristics for all nonproxy Cocoa objects:

- **Allocation, initialization, and duplication**. Some methods of NSObject (including some from adopted protocols) deal with the creation, initialization, and duplication of objects:
  - The alloc and allocWithZone: methods allocate memory for an object from a memory zone and set the object to point to its runtime class definition.
  - The init method is the prototype for object initialization, the procedure that sets the instance variables of an object to a known initial state. The class methods initialize and load give classes a chance to initialize themselves.
  - The new method is a convenience method that combines simple allocation and initialization.
  - The copy and copyWithZone: methods make copies of any object that is a member of a class implementing these methods (from the NSCopying protocol); the mutableCopy and mutableCopyWithZone: (defined in the NSMutableCopying protocol) are implemented by classes that want to make mutable copies of their objects.

  See "Object Creation" (page 89) for more information.
- **Object retention and disposal**. The following methods are particularly important to an object-oriented program that uses the traditional, and explicit, form of memory management:
  - The retain method increments an object's retain count.
  - The release method decrements an object's retain count.
  - The autorelease method also decrements an object's retain count, but in a deferred fashion.
  - The retainCount method returns an object's current retain count.

- The `dealloc` method is implemented by a class to release its objects' instance variables and free dynamically allocated memory.

See "How Memory Management Works" (page 84) for more information about explicit memory management.

- **Introspection and comparison**. Many `NSObject` methods enable you to make runtime queries about an object. These introspection methods help to discover an object's position in the class hierarchy, determine whether it implements a certain method, and test whether it conforms to a specific protocol. Some of these are class methods only.
  - The `superclass` and `class` methods (class and instance) return the receiver's superclass and class, respectively, as `Class` objects.
  - You can determine the class membership of objects with the methods `isKindOfClass:` and `isMemberOfClass:`; the latter method is for testing whether the receiver is an instance of the specified class. The class method `isSubclassOfClass:` tests class inheritance.
  - The `respondsToSelector:` method tests whether the receiver implements a method identified by a selector. The class method `instancesRespondToSelector:` tests whether instances of a given class implement the specified method.
  - The `conformsToProtocol:` method tests whether the receiver (object or class) conforms to a given protocol.
  - The `isEqual:` and `hash` methods are used in object comparison.
  - The `description` method allows an object to return a string describing its contents; this output is often used in debugging (the print-object command) and by the `%@` specifier for objects in formatted strings.

  See "Introspection" (page 101) for more information.
- **Object encoding and decoding**. The following methods pertain to object encoding and decoding (as part of the archiving process):
  - The `encodeWithCoder:` and `initWithCoder:` methods are the sole members of the `NSCoding` protocol. The first allows an object to encode its instance variables and the second enables an object to initialize itself from decoded instance variables.
  - The `NSObject` class declares other methods related to object encoding: `classForCoder`, `replacementObjectForCoder:`, and `awakeAfterUsingCoder:`.

  See *Archives and Serializations Programming Guide* for further information.
- **Message forwarding**. The `forwardInvocation:` method and related methods permit an object to forward a message to another object.
- **Message dispatch**. A set of methods beginning with `performSelector` allows you to dispatch messages after a specified delay and to dispatch messages (synchronously or asynchronously) from a secondary thread to the main thread.

NSObject has several other methods, including class methods for versioning and posing (the latter lets a class present itself to the runtime as another class). It also includes methods that let you access runtime data structures, such as method selectors and function pointers to method implementations.

Interface Conventions

Some NSObject methods are meant only to be invoked, whereas others are intended to be overridden. For example, most subclasses should not override allocWithZone:, but they should implement init—or at least an initializer that ultimately invokes the root-class init method (see "Object Creation" (page 89)). Of those methods that subclasses are expected to override, the NSObject implementations of those methods either do nothing or return some reasonable default value such as self. These default implementations make it possible to send basic messages such as init to any Cocoa object—even to an object whose class doesn't override them—without risking a runtime exception. It's not necessary to check (using respondsToSelector:) before sending the message. More importantly, the "placeholder" methods of NSObject define a common structure for Cocoa objects and establish conventions that, when followed by all classes, make object interactions more reliable.

Instance and Class Methods

The runtime system treats methods defined in the root class in a special way. Instance methods defined in a root class can be performed both by instances and by class objects. Therefore, all class objects have access to the instance methods defined in the root class. Any class object can perform any root instance method, provided it doesn't have a class method with the same name.

For example, a class object could be sent messages to perform the NSObject instance methods respondsToSelector: and performSelector:withObject:, as shown in this example:

```
SEL method = @selector(riskAll:);

if ([MyClass respondsToSelector:method])
    [MyClass performSelector:method withObject:self];
```

Note that the only instance methods available to a class object are those defined in its root class. In the example above, if MyClass had reimplemented either respondsToSelector: or performSelector:withObject:, those new versions would be available only to instances. The class object for MyClass could perform only the versions defined in the NSObject class. (Of course, if MyClass had implemented respondsToSelector: or performSelector:withObject: as class methods rather than instance methods, the class would perform those new versions.)

Object Retention and Disposal

Objective-C gives you two ways to ensure that objects persist when they are needed and are destroyed when they are no longer needed, thus freeing up memory. The preferred approach is to use the technology of *garbage collection*: The runtime detects objects that are no longer needed and disposes of them automatically. (The preferred approach also happens to be the simpler approach in most cases.) The second approach, called *memory management*, is based on reference counting: An object carries with it a numerical value reflecting the current claims on the object; when this value reaches zero, the object is deallocated.

The amount of work that you, as a developer writing Objective-C code, must do to take advantage of garbage collection or memory management varies considerably.

- **Garbage Collection**. To enable garbage collection, you turn on the Enable Objective-C Garbage Collection build setting (the `-fobjc-gc` flag) in Xcode. For each of your custom classes, you might also have to implement the `finalize` method to remove instances as notification observers and to free any resources that are not instance variables. Also, you should ensure that in your nib files the object acting as File's Owner maintains an outlet connection to each top-level nib object that you want to persist.

  iOS Note: Garbage collection is not supported in iOS.

- **Memory Management**. In memory-managed code, each call that makes a claim of ownership on an object—object allocation and initialization, object copying, and `retain`—must be balanced with a call that removes that claim—`release` and `autorelease`. When the object's retain count (reflecting the number of claims on it) reaches zero, the object is deallocated and the memory occupied by the object is freed.

In addition to being easier to implement, garbage-collected code has several advantages over memory-managed code. Garbage collection provides a simple, consistent model for all participating programs while avoiding problems such as retain cycles. It also simplifies the implementation of accessor methods and makes it easier to ensure thread and exception safety.

Important Although memory-management methods are no-ops in a garbage-collected application, there are still intractable differences between certain programming paradigms and patterns used in the two models. Therefore it is not recommended that you migrate a memory-managed application to a source base that tries to support both memory management and garbage collection. Instead, create a new full-version release that supports garbage collection.

The following sections explore how garbage collection and memory management work by following the life cycle of objects from their creation to their destruction.

Further Reading To learn all about about the garbage collection feature of Objective-C, read *Garbage Collection Programming Guide*. Memory management is discussed in detail in *Advanced Memory Management Programming Guide*.

How the Garbage Collector Works

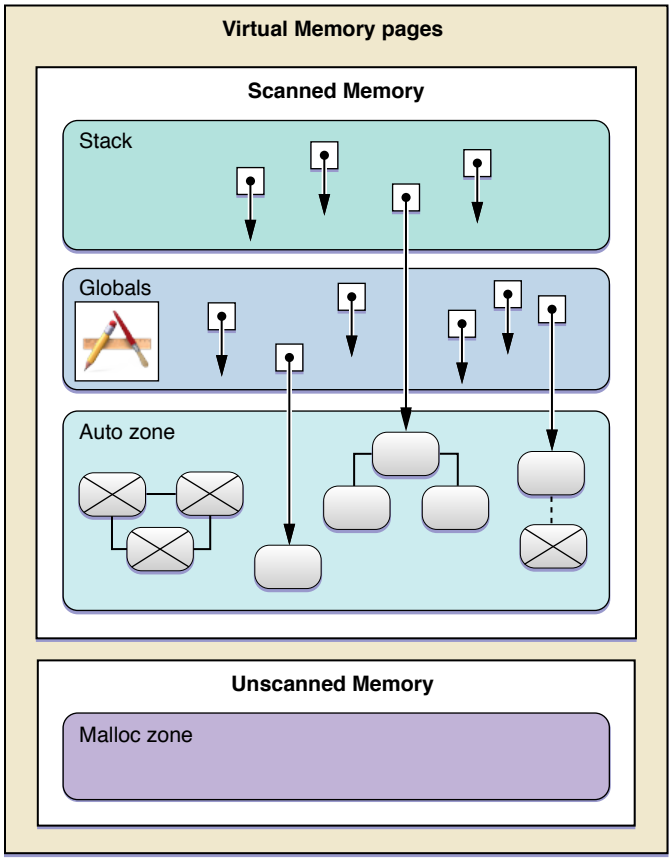
The work of garbage collection is done by an entity known as the *garbage collector*. To the garbage collector, objects in a program are either reachable or are not reachable. Periodically the collector scans through the objects and collects those that are reachable. Those objects that aren't reachable—the garbage objects—are finalized (that is, their `finalize` method is invoked). Subsequently, the memory they had occupied is freed.

The critical notion behind the architecture of the Objective-C garbage collector is the set of factors that constitute a reachable object. These factors start with an initial root set of objects: global variables (including `NSApp`), stack variables, and objects with external references (that is, outlets). The objects of the initial root set are never treated as garbage and therefore persist throughout the runtime life of the program. The collector adds to this initial set all objects that are directly reachable through strong references as well as all possible references found in the call stacks of every Cocoa thread. The garbage collector recursively follows strong references from the root set of objects to other objects, and from those objects to other objects, until all potentially reachable objects have been accounted for. (All references from one object to another object are considered strong references by default; weak references have to be explicitly marked as such.) In other words, a nonroot object persists at the end of a collection cycle only if the collector can reach it via strong references from a root object.

Figure 2-3 illustrates the general path the collector follows when it looks for reachable objects. But it also shows a few other important aspects of the garbage collector. The collector scans only a portion of a Cocoa program's virtual memory for reachable objects. Scanned memory includes the call stacks of threads, global variables,

and the auto zone, an area of memory from which all garbage-collected blocks of memory are dispensed. The collector does not scan the malloc zone, which is the zone from which blocks of memory are allocated via the `malloc` function.

Figure 2-3 Reachable and unreachable objects



Another thing the diagram illustrates is that objects may have strong references to other objects, but if there is no chain of strong references that leads back to a root object, the object is considered unreachable and is disposed of at the end of a collection cycle. These references can be circular, but in garbage collection the circular references do not cause memory leaks, as do retain cycles in memory-managed code. All of these objects are disposed of when they are no longer reachable.

The Objective-C garbage collector is request-driven, not demand-driven. It initiates collection cycles only upon request; Cocoa makes requests at intervals optimized for performance or when a certain memory threshold has been exceeded. You can also request collections using methods of the `NSGarbageCollector` class. The garbage collector is also generational. It makes not only exhaustive, or full, collections of program objects periodically, but it makes incremental collections based on the "generation" of objects. A object's generation is determined by when it was allocated. Incremental collections, which are faster and more frequent than full collections, affect the more recently allocated objects. (Most objects are assumed to "die young"; if an object survives the first collection, it is likely to be intended to have a longer life.)

The garbage collector runs on one thread of a Cocoa program. During a collection cycle it will stop secondary threads to determine which objects in those threads are unreachable. But it never stops all threads at once, and it stops each thread for as short a time as possible. The collector is also conservative in that it never compacts auto-zone memory by relocating blocks of memory or updating pointers; once allocated, an object always stays in its original memory location.

How Memory Management Works

In memory-managed Objective-C code, a Cocoa object exists over a life span which, potentially at least, has distinct stages. It is created, initialized, and used (that is, other objects send messages to it). It is possibly retained, copied, or archived, and eventually it is released and destroyed. The following discussion charts the life of a typical object without going into much detail—yet.

Let's begin at the end, at the way objects are disposed of when garbage collection is turned off. In this context Cocoa and Objective-C opt for a voluntary, policy-driven procedure for keeping objects around and disposing of them when they're no longer needed.

This procedure and policy rest on the notion of reference counting. Each Cocoa object carries with it an integer indicating the number of other objects (or even procedural code sites) that are interested in its persistence. This integer is referred to as the object's *retain count* ("retain" is used to avoid overloading the term "reference"). When you create an object, either by using a class factory method or by using the `alloc` or `allocWithZone:` class methods, Cocoa does a couple of very important things:

- It sets the object's `isa` pointer—the `NSObject` class's sole public instance variable—to point to the object's class, thus integrating the object into the runtime's view of the class hierarchy. (See "Object Creation" (page 89) for further information.)
- It sets the object's retain count—a kind of hidden instance variable managed by the runtime—to one. (The assumption here is that an object's creator is interested in its persistence.)

After object allocation, you generally initialize an object by setting its instance variables to reasonable initial values. (`NSObject` declares the `init` method as the prototype for this purpose.) The object is now ready to be used; you can send messages to it, pass it to other objects, and so on.

Note Because an initializer can return an object other than the one explicitly allocated, the convention is to nest the `alloc` message expression in the `init` message (or other initializer)—for example:

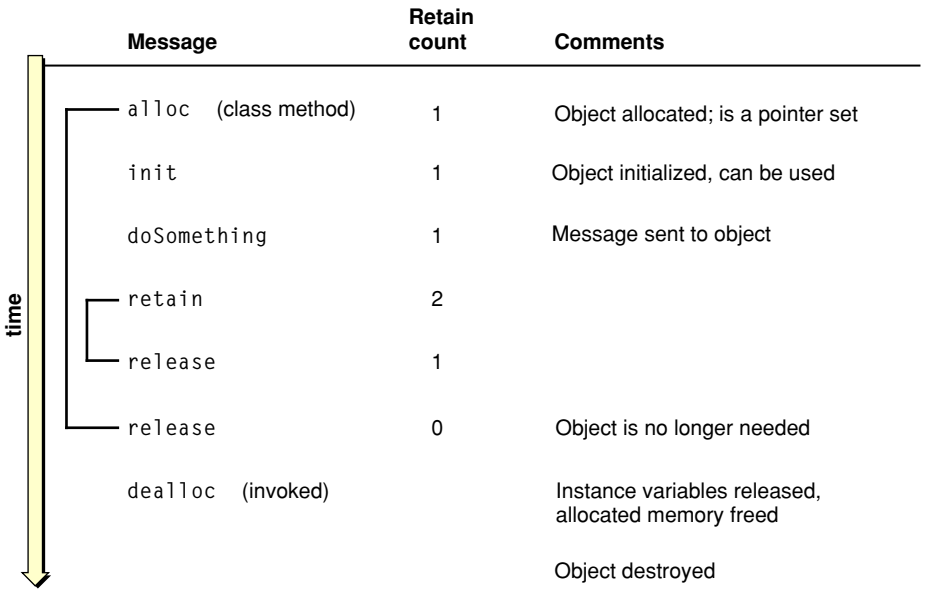
```
id anObj = [[MyClass alloc] init];
```

When you release an object—that is, send a `release` message to it—`NSObject` decrements its retain count. If the retain count falls from one to zero, the object is deallocated. Deallocation takes place in two steps. First, the object's `dealloc` method is invoked to release instance variables and free dynamically allocated memory. Then the operating system destroys the object itself and reclaims the memory the object once occupied.

Important You should never directly invoke an object's `dealloc` method.

What if you don't want an object to go away any time soon? If after receiving an object from somewhere you send it a `retain` message, the object's retain count is incremented to two. Now two `release` messages are required before deallocation occurs. Figure 2-4 depicts this rather simplistic scenario.

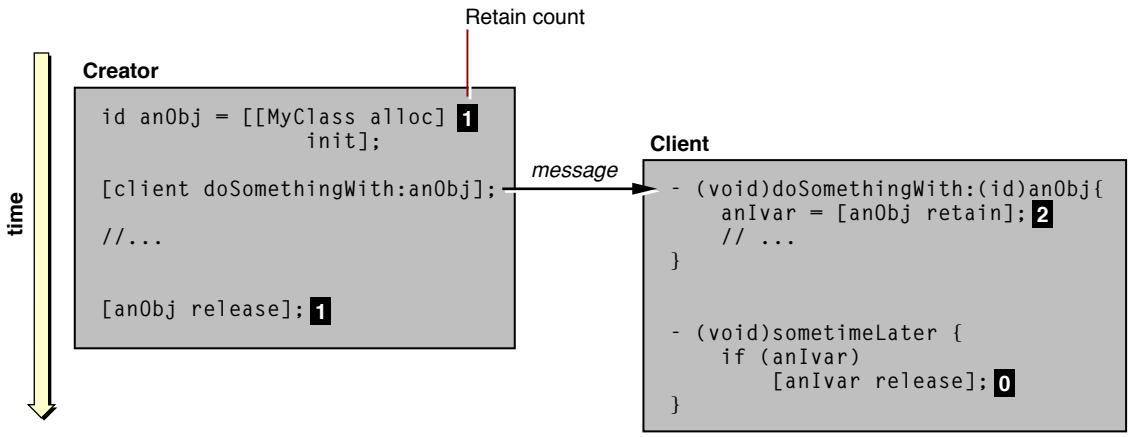
Figure 2-4 The life cycle of an object—simplified view



Of course, in this scenario the creator of an object has no need to retain the object. It owns the object already. But if this creator were to pass the object to another object in a message, the situation changes. In an Objective-C program, an object received from some other object is always assumed to be valid within the scope in which it is obtained. The receiving object can send messages to the received object and can pass it to other objects. This assumption requires the sending object to behave appropriately and not prematurely free the object while a client object has a reference to it.

If the client object wants to keep the received object around after it goes out of programmatic scope, it can retain it—that is, send it a `retain` message. Retaining an object increments its retain count, thereby expressing an ownership interest in the object. The client object assumes a responsibility to release the object at some later time. If the creator of an object releases it, but a client object has retained that same object, the object persists until the client releases it. Figure 2-5 illustrates this sequence.

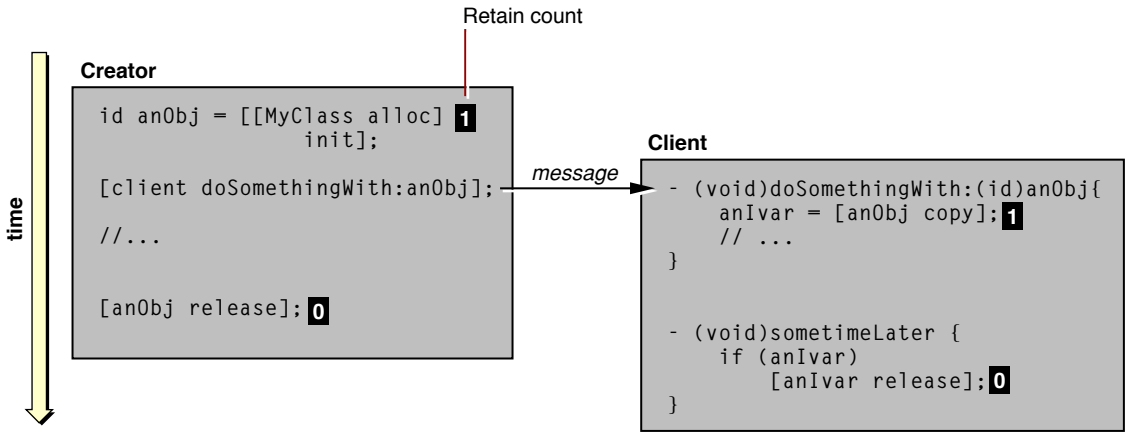
Figure 2-5 Retaining a received object



Instead of retaining an object, you could copy it by sending it a `copy` or `copyWithZone:` message. (Many, if not most, subclasses encapsulating some kind of data adopt or conform to this protocol.) Copying an object not only duplicates it but almost always resets its retain count to one (see Figure 2-6). The copy can be shallow or deep, depending on the nature of the object and its intended usage. A deep copy duplicates the objects held as instance variables of the copied object, whereas a shallow copy duplicates only the references to those instance variables.

In terms of usage, what differentiates `copy` from `retain` is that the former claims the object for the sole use of the new owner; the new owner can mutate the copied object without regard to its origin. Generally you copy an object instead of retaining it when it is a value object—that is, an object encapsulating some primitive value. This is especially true when that object is mutable, such as an instance of `NSMutableString`. For immutable objects, `copy` and `retain` can be equivalent and might be implemented similarly.

Figure 2-6 Copying a received object

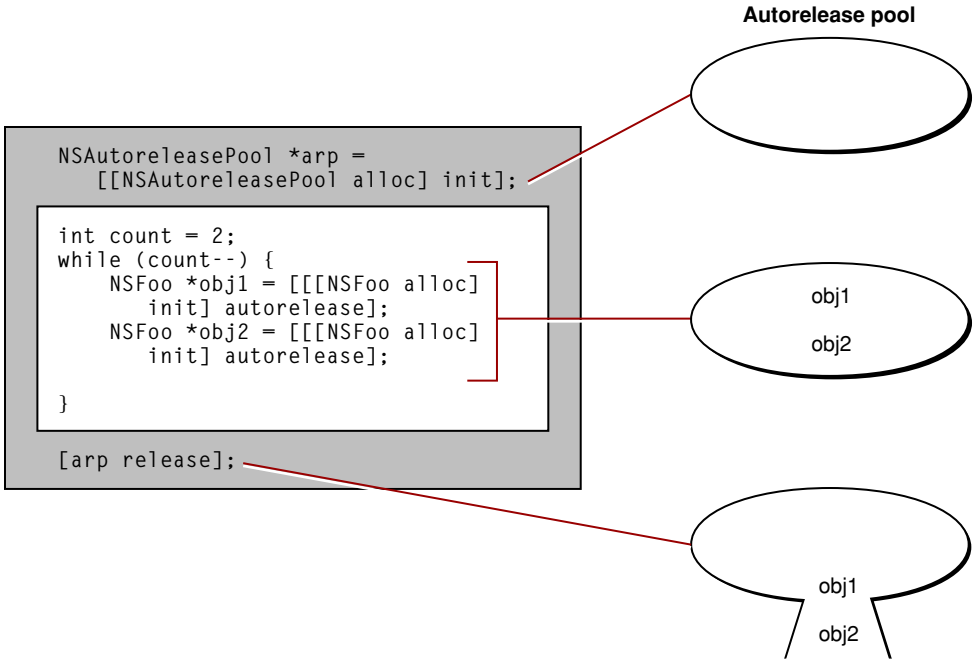


You might have noticed a potential problem with this scheme for managing the object life cycle. An object that creates an object and passes it to another object cannot always know when it can release the object safely. There could be multiple references to that object on the call stack, some by objects unknown to the creating object. If the creating object releases the created object and then some other object sends a message to that now-destroyed object, the program could crash. To get around this problem, Cocoa introduces a mechanism for deferred deallocation called *autoreleasing*.

Autoreleasing makes use of autorelease pools (defined by the `NSAutoreleasePool` class). An autorelease pool is a collection of objects within an explicitly defined scope that are marked for eventual release. Autorelease pools can be nested. When you send an object an `autorelease` message, a reference to that object is put into the most immediate autorelease pool. It is still a valid object, so other objects within the scope defined by the autorelease pool can send messages to it. When program execution reaches the end of the scope, the

pool is released and, as a consequence, all objects in the pool are released as well (see Figure 2-7). If you are developing an application you may not need to set up an autorelease pool; the AppKit framework automatically sets up an autorelease pool scoped to the application's event cycle.

Figure 2-7 An autorelease pool



iOS Note Because in iOS an application executes in a more memory-constrained environment, the use of autorelease pools is discouraged in methods or blocks of code (for example, loops) where an application creates many objects. Instead, you should explicitly release objects whenever possible.

So far the discussion of the object life cycle has focused on the mechanics of managing objects through that cycle. But a policy of object ownership guides the use of these mechanisms. This policy can be summarized as follows:

- If you *create* an object by allocating and initializing it (for example, `[[MyClass alloc] init]`), you own the object and are responsible for releasing it. This rule also applies if you use the `NSObject` convenience method `new`.
- If you *copy* an object, you own the copied object and are responsible for releasing it.
- If you *retain* an object, you have partial ownership of the object and must release it when you no longer need it.

Conversely, if you *receive* an object from some other object, you do not own the object and should not release it. (There are a handful of exceptions to this rule, which are explicitly noted in the reference documentation.)

As with any set of rules, there are exceptions and "gotchas":

- If you create an object using a class factory method (such as the `NSMutableArray arrayWithCapacity:` method), assume that the object you receive has been autoreleased. You should not release the object yourself and should retain it if you want to keep it around.
- To avoid cyclic references, a child object should never retain its parent. (A parent is the creator of the child or is an object holding the child as an instance variable.)

> **Note** "Release" in the above guidelines means sending either a `release` message or an `autorelease` message to an object.

If you do not follow this ownership policy, two bad things are likely to happen in your Cocoa program. Because you did not release created, copied, or retained objects, your program is now leaking memory. Or your program crashes because you sent a message to an object that was deallocated out from under you. And here's a further caveat: Debugging these problems can be a time-consuming affair.

A further basic event that could happen to an object during its life cycle is archiving. Archiving converts the web of interrelated objects that constitute an object-oriented program—the object graph—into a persistent form (usually a file) that preserves the identity and relationships of each object in the graph. When the program is unarchived, its object graph is reconstructed from this archive. To participate in archiving (and unarchiving), an object must be able to encode (and decode) its instance variables using the methods of the `NSCoder` class. `NSObject` adopts the `NSCoding` protocol for this purpose. For more information on the archiving of objects, see *Archives and Serializations Programming Guide*.

Object Creation

The creation of a Cocoa object always takes place in two stages: allocation and initialization. Without both steps an object generally isn't usable. Although in almost all cases initialization immediately follows allocation, the two operations play distinct roles in the formation of an object.

Allocating an Object

When you allocate an object, part of what happens is what you might expect, given the term *allocate*. Cocoa allocates enough memory for the object from a region of application virtual memory. To calculate how much memory to allocate, it takes the object's instance variables into account—including their types and order—as specified by the object's class.

To allocate an object, you send the message `alloc` or `allocWithZone:` to the object's class. In return, you get a "raw" (uninitialized) instance of the class. The `alloc` variant of the method uses the application's default zone. A zone is a page-aligned area of memory for holding related objects and data allocated by an application. See *Advanced Memory Management Programming Guide* for more information on zones.

An allocation message does other important things besides allocating memory:

- It sets the object's retain count to one (as described in "How Memory Management Works" (page 84)).
- It initializes the object's `isa` instance variable to point to the object's class, a runtime object in its own right that is compiled from the class definition.
- It initializes all other instance variables to zero (or to the equivalent type for zero, such as `nil`, `NULL`, and `0.0`).

An object's `isa` instance variable is inherited from `NSObject`, so it is common to all Cocoa objects. After allocation sets `isa` to the object's class, the object is integrated into the runtime's view of the inheritance hierarchy and the current network of objects (class and instance) that constitute a program. Consequently an object can find whatever information it needs at runtime, such as another object's place in the inheritance hierarchy, the protocols that other objects conform to, and the location of the method implementations it can perform in response to messages.

In summary, allocation not only allocates memory for an object but initializes two small but very important attributes of any object: its `isa` instance variable and its retain count. It also sets all remaining instance variables to zero. But the resulting object is not yet usable. Initializing methods such as `init` must yet initialize objects with their particular characteristics and return a functional object.

Initializing an Object

Initialization sets the instance variables of an object to reasonable and useful initial values. It can also allocate and prepare other global resources needed by the object, loading them if necessary from an external source such as a file. Every object that declares instance variables should implement an initializing method—unless the default set-everything-to-zero initialization is sufficient. If an object does not implement an initializer, Cocoa invokes the initializer of the nearest ancestor instead.

The Form of Initializers

`NSObject` declares the `init` prototype for initializers; it is an instance method typed to return an object of type `id`. Overriding `init` is fine for subclasses that require no additional data to initialize their objects. But often initialization depends on external data to set an object to a reasonable initial state. For example, say you have an `Account` class; to initialize an `Account` object appropriately requires a unique account number, and

this must be supplied to the initializer. Thus initializers can take one or more parameters; the only requirement is that the initializing method begins with the letters "init". (The stylistic convention `init...` is sometimes used to refer to initializers.)

> **Note** Instead of implementing an initializer with parameters, a subclass can implement only a simple `init` method and then use "set" accessor methods immediately after initialization to set the object to a useful initial state. (Accessor methods enforce encapsulation of object data by setting and getting the values of instance variables.) Or, if the subclass uses properties and the related access syntax, it may assign values to the properties immediately after initialization.

Cocoa has plenty of examples of initializers with parameters. Here are a few (with the defining class in parentheses):

- `- (id)initWithArray:(NSArray *)array;` (from `NSSet`)
- `- (id)initWithTimeInterval:(NSTimeInterval)secsToBeAdded sinceDate:(NSDate *)anotherDate;` (from `NSDate`)
- `- (id)initWithContentRect:(NSRect)contentRect styleMask:(unsigned int)aStyle backing:(NSBackingStoreType)bufferingType defer:(BOOL)flag;` (from `NSWindow`)
- `- (id)initWithFrame:(NSRect)frameRect;` (from `NSControl` and `NSView`)

These initializers are instance methods that begin with "init" and return an object of the dynamic type `id`. Other than that, they follow the Cocoa conventions for multiparameter methods, often using `With`*Type*`:` or `From`*Source*`:` before the first and most important parameter.

Issues with Initializers

Although `init...` methods are required by their method signature to return an object, that object is not necessarily the one that was most recently allocated—the receiver of the `init...` message. In other words, the object you get back from an initializer might not be the one you thought was being initialized.

Two conditions prompt the return of something other than the just-allocated object. The first involves two related situations: when there must be a singleton instance or when the defining attribute of an object must be unique. Some Cocoa classes—`NSWorkspace`, for instance—allow only one instance in a program; a class in such a case must ensure (in an initializer or, more likely, in a class factory method) that only one instance is created, returning this instance if there is any further request for a new one. (See "Creating a Singleton Instance" (page 123) for information on implementing a singleton object.)

A similar situation arises when an object is required to have an attribute that makes it unique. Recall the hypothetical `Account` class mentioned earlier. An account of any sort must have a unique identifier. If the initializer for this class—say, `initWithAccountID:`—is passed an identifier that has already been associated with an object, it must do two things:

- Release the newly allocated object (in memory-managed code)
- Return the `Account` object previously initialized with this unique identifier

By doing this, the initializer ensures the uniqueness of the identifier while providing what was asked for: an `Account` instance with the requested identifier.

Sometimes an `init...` method cannot perform the initialization requested. For example, an `initFromFile:` method expects to initialize an object from the contents of a file, the path to which is passed as a parameter. But if no file exists at that location, the object cannot be initialized. A similar problem happens if an `initWithArray:` initializer is passed an `NSDictionary` object instead of an `NSArray` object. When an `init...` method cannot initialize an object, it should:

- Release the newly allocated object (in memory-managed code)
- Return `nil`

Returning `nil` from an initializer indicates that the requested object cannot be created. When you create an object, you should generally check whether the returned value is `nil` before proceeding:

```
id anObject = [[MyClass alloc] init];
if (anObject) {
    [anObject doSomething];
    // more messages...
} else {
    // handle error
}
```

Because an `init...` method might return `nil` or an object other than the one explicitly allocated, it is dangerous to use the instance returned by `alloc` or `allocWithZone:` instead of the one returned by the initializer. Consider the following code:

```
id myObject = [MyClass alloc];
[myObject init];
[myObject doSomething];
```

The `init` method in this example could have returned `nil` or could have substituted a different object. Because you can send a message to `nil` without raising an exception, nothing would happen in the former case except (perhaps) a debugging headache. But you should always rely on the initialized instance instead of the "raw" just-allocated one. Therefore, you should nest the allocation message inside the initialization message and test the object returned from the initializer before proceeding.

```
id myObject = [[MyClass alloc] init];
if ( myObject ) {
    [myObject doSomething];
} else {
    // error recovery...
}
```

Once an object is initialized, you should not initialize it again. If you attempt a reinitialization, the framework class of the instantiated object often raises an exception. For example, the second initialization in this example would result in `NSInvalidArgumentException` being raised.

```
NSString *aStr = [[NSString alloc] initWithString:@"Foo"];
aStr = [aStr initWithString:@"Bar"];
```

Implementing an Initializer

There are several critical rules to follow when implementing an `init...` method that serves as a class's sole initializer or, if there are multiple initializers, its *designated initializer* (described in "Multiple Initializers and the Designated Initializer" (page 95)):

- Always invoke the superclass (`super`) initializer *first*.
- Check the object returned by the superclass. If it is `nil`, then initialization cannot proceed; return `nil` to the receiver.
- When initializing instance variables that are references to objects, retain or copy the object as necessary (in memory-managed code).
- After setting instance variables to valid initial values, return `self` unless:
  - It was necessary to return a substituted object, in which case release the freshly allocated object first (in memory-managed code).
  - A problem prevented initialization from succeeding, in which case return `nil`.

The method in Listing 2-3 illustrates these rules.

Listing 2-3 An example of an initializer

```
- (id)initWithAccountID:(NSString *)identifier {
    if ( self = [super init] ) {
        Account *ac = [accountDictionary objectForKey:identifier];
        if (ac) { // object with that ID already exists
            [self release];
            return [ac retain];
        }
        if (identifier) {
            accountID = [identifier copy]; // accountID is instance variable
            [accountDictionary setObject:self forKey:identifier];
            return self;
        } else {
            [self release];
            return nil;
        }
    } else
        return nil;
}
```

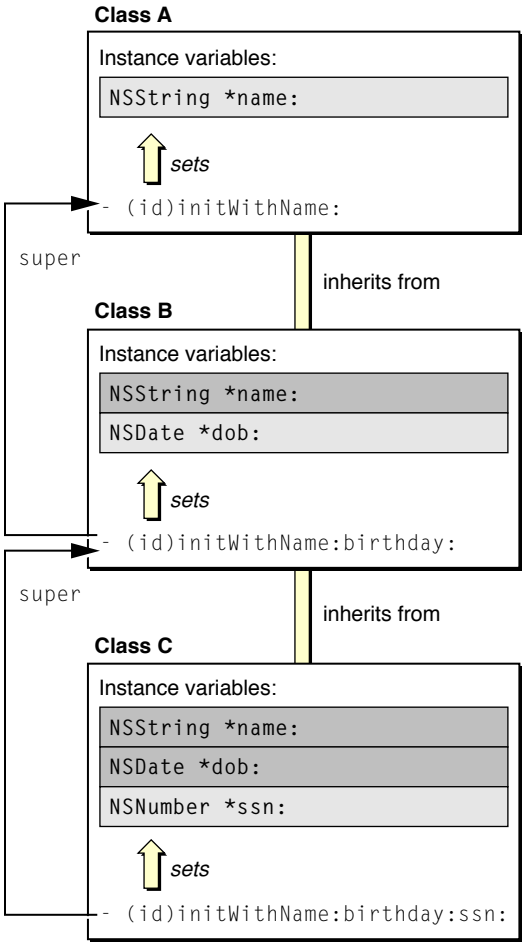
Note Although, for the sake of simplicity, this example returns `nil` if the parameter is `nil`, the better Cocoa practice is to raise an exception.

It isn't necessary to initialize all instance variables of an object explicitly, just those that are necessary to make the object functional. The default set-to-zero initialization performed on an instance variable during allocation is often sufficient. Make sure that you retain or copy instance variables, as required for memory management.

The requirement to invoke the superclass's initializer as the first action is important. Recall that an object encapsulates not only the instance variables defined by its class but the instance variables defined by all of its ancestor classes. By invoking the initializer of `super` first, you help to ensure that the instance variables defined by classes up the inheritance chain are initialized first. The immediate superclass, in its initializer, invokes the

initializer of its superclass, which invokes the main `init...` method of its superclass, and so on (see Figure 2-8). The proper order of initialization is critical because the later initializations of subclasses may depend on superclass-defined instance variables being initialized to reasonable values.

Figure 2-8 Initialization up the inheritance chain



Inherited initializers are a concern when you create a subclass. Sometimes a superclass `init...` method sufficiently initializes instances of your class. But because it is more likely it won't, you should override the superclass's initializer. If you don't, the superclass's implementation is invoked, and because the superclass knows nothing about your class, your instances may not be correctly initialized.

Multiple Initializers and the Designated Initializer

A class can define more than one initializer. Sometimes multiple initializers let clients of the class provide the input for the same initialization in different forms. The `NSSet` class, for example, offers clients several initializers that accept the same data in different forms; one takes an `NSArray` object, another a counted list of elements, and another a `nil`-terminated list of elements:

```
- (id)initWithArray:(NSArray *)array;
- (id)initWithObjects:(id *)objects count:(unsigned)count;
- (id)initWithObjects:(id)firstObj, ...;
```

Some subclasses provide convenience initializers that supply default values to an initializer that takes the full complement of initialization parameters. This initializer is usually the designated initializer, the most important initializer of a class. For example, assume there is a `Task` class and it declares a designated initializer with this signature:

```
- (id)initWithTitle:(NSString *)aTitle date:(NSDate *)aDate;
```

The `Task` class might include secondary, or convenience, initializers that simply invoke the designated initializer, passing it default values for those parameters the secondary initializer doesn't explicitly request (Listing 2-4).

Listing 2-4 Secondary initializers

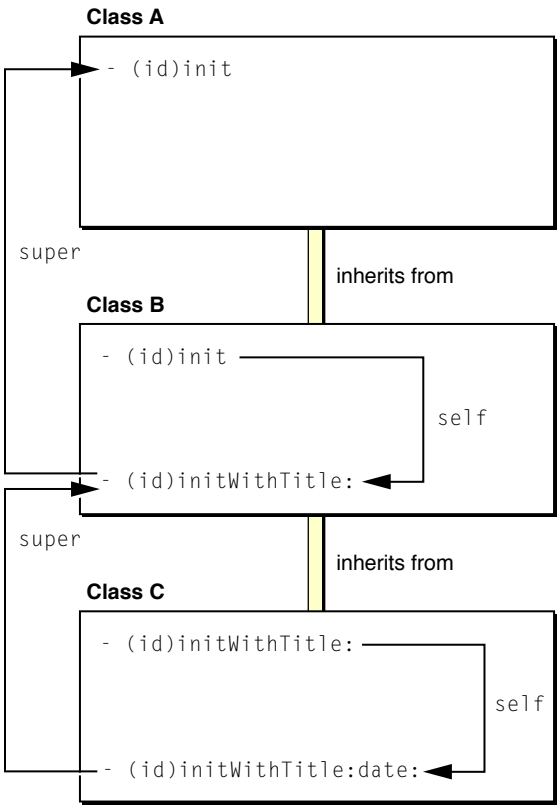
```
- (id)initWithTitle:(NSString *)aTitle {
    return [self initWithTitle:aTitle date:[NSDate date]];
}

- (id)init {
    return [self initWithTitle:@"Task"];
}
```

The designated initializer plays an important role for a class. It ensures that inherited instance variables are initialized by invoking the designated initializer of the superclass. It is typically the `init...` method that has the most parameters and that does most of the initialization work, and it is the initializer that secondary initializers of the class invoke with messages to `self`.

When you define a subclass, you must be able to identify the designated initializer of the superclass and invoke it in your subclass's designated initializer through a message to `super`. You must also make sure that inherited initializers are covered in some way. And you may provide as many convenience initializers as you deem necessary. When designing the initializers of your class, keep in mind that designated initializers are chained to each other through messages to `super`; whereas other initializers are chained to the designated initializer of their class through messages to `self`.

An example will make this clearer. Let's say there are three classes, A, B, and C; class B inherits from class A, and class C inherits from class B. Each subclass adds an attribute as an instance variable and implements an `init...` method—the designated initializer—to initialize this instance variable. They also define secondary initializers and ensure that inherited initializers are overridden, if necessary. Figure 2-9 illustrates the initializers of all three classes and their relationships.

Figure 2-9 Interactions of secondary and designated initializers



The designated initializer for each class is the initializer with the most coverage; it is the method that initializes the attribute added by the subclass. The designated initializer is also the `init...` method that invokes the designated initializer of the superclass in a message to `super`. In this example, the designated initializer of class C, `initWithTitle:date:`, invokes the designated initializer of its superclass, `initWithTitle:`, which in turn invokes the `init` method of class A. When creating a subclass, it's always important to know the designated initializer of the superclass.

Although designated initializers are thus connected up the inheritance chain through messages to `super`, secondary initializers are connected to their class's designated initializer through messages to `self`. Secondary initializers (as in this example) are frequently overridden versions of inherited initializers. Class C overrides `initWithTitle:` to invoke its designated initializer, passing it a default date. This designated initializer, in turn, invokes the designated initializer of class B, which is the overridden method, `initWithTitle:`. If you sent an `initWithTitle:` message to objects of class B and class C, you'd be invoking different method

implementations. On the other hand, if class C did *not* override `initWithTitle:` and you sent the message to an instance of class C, the class B implementation would be invoked. Consequently, the C instance would be incompletely initialized (since it would lack a date). When creating a subclass, it's important to make sure that all inherited initializers are adequately covered.

Sometimes the designated initializer of a superclass may be sufficient for the subclass, and so there is no need for the subclass to implement its own designated initializer. Other times, a class's designated initializer may be an overridden version of its superclass's designated initializer. This is frequently the case when the subclass needs to supplement the work performed by the superclass's designated initializer, even though the subclass does not add any instance variables of its own (or the instance variables it does add don't require explicit initialization).

The dealloc and finalize Methods

In Cocoa classes that use garbage collection, the `finalize` method is where the class disposes of any remaining resources and attachments of its instances before those instances are freed. In Cocoa classes that use traditional memory management, the comparable method for resource cleanup is the `dealloc` method. Although similar in purpose, there are significant differences in how these methods should be implemented.

In many respects, the `dealloc` method is the counterpart to a class's `init...` method, especially its designated initializer. Instead of being invoked just after the allocation of an object, `dealloc` is invoked just prior to the object's destruction. Instead of ensuring that the instance variables of an object are properly initialized, the `dealloc` method makes sure that object instance variables are released and that any dynamically allocated memory has been freed.

The final point of parallelism has to do with the invocation of the superclass implementation of the same method. In an initializer, you invoke the superclass's designated initializer as the first step. In `dealloc`, you invoke the superclass's implementation of `dealloc` as the *last* step. The reason for this order of invocation is mirror-opposite to that for initializers; subclasses should release or free the instance variables they own first before the instance variables of ancestor classes are released or freed.

Listing 2-5 shows how you might implement this method.

Listing 2-5 A typical `dealloc` method

```
- (void)dealloc {
    [accountDictionary release];
    free(mallocdChunk);
    [super dealloc];
}
```

Note that this example does not verify that `accountDictionary` (an instance variable) is something other than `nil` before releasing it. That is because Objective-C lets you safely send a message to `nil`.

Similar to the `dealloc` method, the `finalize` method is the place to close resources used by an object in a garbage-collected environment prior to that object being freed and its memory reclaimed. As in `dealloc`, the final line of a `finalize` implementation should invoke the superclass implementation of the method. However, unlike `dealloc`, a `finalize` implementation does not have to release instance variables because the garbage collector destroys these objects at the proper time.

But there is a more significant difference between the `dealloc` and `finalize` methods. Whereas implementing a `dealloc` method is usually required, you should *not* implement a `finalize` method if possible. And, if you must implement `finalize`, you should reference as few other objects as possible. The primary reason for this admonition is that the order in which garbage-collected objects are sent `finalize` messages is indeterminate, even if there are references between them. Thus the consequences are indeterminate, and potentially negative, if messages pass between objects being finalized. Your code cannot depend on the side effects arising from the order of deallocation, as it can in `dealloc`. Generally, you should try to design your code so that such actions as freeing memory allocated with `malloc`, closing file descriptors, and unregistering observers happen before `finalize` is invoked.

> **Further Reading** To learn about approaches to implementing the `finalize` method, read "Implementing a finalize Method" in *Garbage Collection Programming Guide*.

Class Factory Methods

Class factory methods are implemented by a class as a convenience for clients. They combine allocation and initialization in one step and return the created object. However, the client receiving this object does not own the object and thus (per the object-ownership policy) is not responsible for releasing it. These methods are of the form `+ (`*type*`)`*className*`...` (where *className* excludes any prefix).

Cocoa provides plenty of examples, especially among the "value" classes. `NSDate` includes the following class factory methods:

```
+ (id)dateWithTimeIntervalSinceNow:(NSTimeInterval)secs;
+ (id)dateWithTimeIntervalSinceReferenceDate:(NSTimeInterval)secs;
+ (id)dateWithTimeIntervalSince1970:(NSTimeInterval)secs;
```

And `NSData` offers the following factory methods:

```
+ (id)dataWithBytes:(const void *)bytes length:(unsigned)length;
```

```
+ (id)dataWithBytesNoCopy:(void *)bytes length:(unsigned)length;
+ (id)dataWithBytesNoCopy:(void *)bytes length:(unsigned)length
        freeWhenDone:(BOOL)b;
+ (id)dataWithContentsOfFile:(NSString *)path;
+ (id)dataWithContentsOfURL:(NSURL *)url;
+ (id)dataWithContentsOfMappedFile:(NSString *)path;
```

Factory methods can be more than a simple convenience. They can not only combine allocation and initialization, but the allocation can inform the initialization. As an example, let's say you must initialize a collection object from a property-list file that encodes any number of elements for the collection (`NSString` objects, `NSData` objects, `NSNumber` objects, and so on). Before the factory method can know how much memory to allocate for the collection, it must read the file and parse the property list to determine how many elements there are and what object type these elements are.

Another purpose for a class factory method is to ensure that a certain class (`NSWorkspace`, for example) vends a singleton instance. Although an `init...` method could verify that only one instance exists at any one time in a program, it would require the prior allocation of a "raw" instance and then, in memory-managed code, would have to release that instance. A factory method, on the other hand, gives you a way to avoid blindly allocating memory for an object that you might not use (see Listing 2-6).

Listing 2-6 A factory method for a singleton instance

```
static AccountManager *DefaultManager = nil;

+ (AccountManager *)defaultManager {
    if (!DefaultManager) DefaultManager = [[self allocWithZone:NULL] init];
    return DefaultManager;
}
```

Further Reading For a more detailed discussion of issues relating to the allocation and initialization of Cocoa objects, see "The Runtime System" in *The Objective-C Programming Language*.

Introspection

Introspection is a powerful feature of object-oriented languages and environments, and introspection in Objective-C and Cocoa is no exception. Introspection refers to the capability of objects to divulge details about themselves as objects at runtime. Such details include an object's place in the inheritance tree, whether it conforms to a specific protocol, and whether it responds to a certain message. The `NSObject` protocol and class define many introspection methods that you can use to query the runtime in order to characterize objects.

Used judiciously, introspection makes an object-oriented program more efficient and robust. It can help you avoid message-dispatch errors, erroneous assumptions of object equality, and similar problems. The following sections show how you might effectively use the `NSObject` introspection methods in your code.

Evaluating Inheritance Relationships

Once you know the class an object belongs to, you probably know quite a bit about the object. You might know what its capabilities are, what attributes it represents, and what kinds of messages it can respond to. Even if after introspection you are unfamiliar with the class to which an object belongs, you now know enough to not send it certain messages.

The `NSObject` protocol declares several methods for determining an object's position in the class hierarchy. These methods operate at different granularities. The `class` and `superclass` instance methods, for example, return the `Class` objects representing the class and superclass, respectively, of the receiver. These methods require you to compare one `Class` object with another. Listing 2-7 gives a simple (one might say trivial) example of their use.

Listing 2-7 Using the class and superclass methods

```
// ...
while ( id anObject = [objectEnumerator nextObject] ) {
    if ( [self class] == [anObject superclass] ) {
        // do something appropriate...
    }
}
```

> **Note** Sometimes you use the `class` or `superclass` methods to obtain an appropriate receiver for a class message.

More commonly, to check an object's class affiliation, you would send it a `isKindOfClass:` or `isMemberOfClass:` message. The former method returns whether the receiver is an instance of a given class or an instance of any class that inherits from that class. A `isMemberOfClass:` message, on the other hand, tells you if the receiver is an instance of the specified class. The `isKindOfClass:` method is generally more useful because from it you can know at once the complete range of messages you can send to an object. Consider the code snippet in Listing 2-8.

Listing 2-8 Using isKindOfClass:

```
if ([item isKindOfClass:[NSData class]]) {
    const unsigned char *bytes = [item bytes];
    unsigned int length = [item length];
    // ...
}
```

By learning that the object *item* inherits from the `NSData` class, this code knows it can send it the `NSData` `bytes` and `length` messages. The difference between `isKindOfClass:` and `isMemberOfClass:` becomes apparent if you assume that *item* is an instance of `NSMutableData`. If you use `isMemberOfClass:` instead of `isKindOfClass:`, the code in the conditionalized block is never executed because *item* is not an instance of `NSData` but rather of `NSMutableData`, a subclass of `NSData`.

Method Implementation and Protocol Conformance

Two of the more powerful introspection methods of `NSObject` are `respondsToSelector:` and `conformsToProtocol:`. These methods tell you, respectively, whether an object implements a certain method and whether an object conforms to a specified formal protocol (that is, adopts the protocol, if necessary, and implements all the methods of the protocol).

You use these methods in a similar situation in your code. They enable you to discover whether some potentially anonymous object can respond appropriately to a particular message or set of messages *before* you send it any of those messages. By making this check before sending a message, you can avoid the risk of runtime exceptions resulting from unrecognized selectors. The AppKit framework implements informal protocols—the basis of delegation—by checking whether delegates implement a delegation method (using `respondsToSelector:`) prior to invoking that method.

Listing 2-9 illustrates how you might use the `respondsToSelector:` method in your code.

Listing 2-9 Using `respondsToSelector:`

```
- (void)doCommandBySelector:(SEL)aSelector {
    if ([self respondsToSelector:aSelector]) {
        [self performSelector:aSelector withObject:nil];
    } else {
        [_client doCommandBySelector:aSelector];
    }
}
```

Listing 2-10 illustrates how you might use the `conformsToProtocol:` method in your code.

Listing 2-10 Using `conformsToProtocol:`

```
// ...
if (!([((id)testObject) conformsToProtocol:@protocol(NSMenuItem)])) {
    NSLog(@"Custom MenuItem, '%@', not loaded; it must conform to the
        'NSMenuItem' protocol.\n", [testObject class]);
    [testObject release];
    testObject = nil;
}
```

Object Comparison

Although they are not strictly introspection methods, the `hash` and `isEqual:` methods fulfill a similar role. They are indispensable runtime tools for identifying and comparing objects. But instead of querying the runtime for information about an object, they rely on class-specific comparison logic.

The `hash` and `isEqual:` methods, both declared by the `NSObject` protocol, are closely related. The `hash` method must be implemented to return an integer that can be used as a table address in a hash table structure. If two objects are equal (as determined by the `isEqual:` method), they must have the same hash value. If your object could be included in collections such as `NSSet` objects, you need to define `hash` and verify the invariant that if two objects are equal, they return the same hash value. The default `NSObject` implementation of `isEqual:` simply checks for pointer equality.

Using the `isEqual:` method is straightforward; it compares the receiver against the object supplied as a parameter. Object comparison frequently informs runtime decisions about what should be done with an object. As Listing 2-11 illustrates, you can use `isEqual:` to decide whether to perform an action, in this case to save user preferences that have been modified.

Listing 2-11 Using isEqual:

```
- (void)saveDefaults {
    NSDictionary *prefs = [self preferences];
    if (![origValues isEqual:prefs])
        [Preferences savePreferencesToDefaults:prefs];
}
```

If you are creating a subclass, you might need to override `isEqual:` to add further checks for points of equality. The subclass might define an extra attribute that has to be the same value in two instances for them to be considered equal. For example, say you create a subclass of `NSObject` called `MyWidget` that contains two instance variables, `name` and `data`. Both of these must be the same value for two instances of `MyWidget` to be considered equal. Listing 2-12 illustrates how you might implement `isEqual:` for the `MyWidget` class.

Listing 2-12 Overriding `isEqual:`

```
- (BOOL)isEqual:(id)other {
    if (other == self)
        return YES;
    if (!other || ![other isKindOfClass:[self class]])
        return NO;
    return [self isEqualToWidget:other];
}

- (BOOL)isEqualToWidget:(MyWidget *)aWidget {
    if (self == aWidget)
        return YES;
    if (![(id)[self name] isEqual:[aWidget name]])
        return NO;
    if (![[self data] isEqualToData:[aWidget data]])
        return NO;
    return YES;
}
```

This `isEqual:` method first checks for pointer equality, then class equality, and finally invokes an object comparator whose name indicates the class of object involved in the comparison. This type of comparator, which forces type checking of the object passed in, is a common convention in Cocoa; the `isEqualToString:`

method of the `NSString` class and the `isEqualToTimeZone:` method of the `NSTimeZone` class are but two examples. The class-specific comparator—`isEqualToWidget:` in this case—performs the checks for name and data equality.

In all `isEqualTo`*Type* `:` methods of the Cocoa frameworks, `nil` is not a valid parameter and implementations of these methods may raise an exception upon receiving a `nil`. However, for backward compatibility, `isEqual:` methods of the Cocoa frameworks do accept `nil`, returning `NO`.

Object Mutability

Cocoa objects are either mutable or immutable. You cannot change the encapsulated values of immutable objects; once such an object is created, the value it represents remains the same throughout the object's life. But you can change the encapsulated value of a mutable object at any time. The following sections explain the reasons for having mutable and immutable variants of an object type, describe the characteristics and side-effects of object mutability, and recommend how best to handle objects when their mutability is an issue.

Why Mutable and Immutable Object Variants?

Objects by default are mutable. Most objects allow you to change their encapsulated data through setter accessor methods. For example, you can change the size, positioning, title, buffering behavior, and other characteristics of an `NSWindow` object. A well-designed model object—say, an object representing a customer record—*requires* setter methods to change its instance data.

The Foundation framework adds some nuance to this picture by introducing classes that have mutable and immutable variants. The mutable subclasses are typically subclasses of their immutable superclass and have "Mutable" embedded in the class name. These classes include the following:

```
NSMutableArray
NSMutableDictionary
NSMutableSet
NSMutableIndexSet
NSMutableCharacterSet
NSMutableData
NSMutableString
NSMutableAttributedString
NSMutableURLRequest
```

> **Note** Except for `NSMutableParagraphStyle` in the AppKit framework, the Foundation framework currently defines all explicitly named mutable classes. However, any Cocoa framework can potentially have its own mutable and immutable class variants.

Although these classes have atypical names, they are closer to the mutable norm than their immutable counterparts. Why this complexity? What purpose does having an immutable variant of a mutable object serve?

Consider a scenario where all objects are capable of being mutated. In your application you invoke a method and are handed back a reference to an object representing a string. You use this string in your user interface to identify a particular piece of data. Now another subsystem in your application gets its own reference to that same string and decides to mutate it. Suddenly your label has changed out from under you. Things can become even more dire if, for instance, you get a reference to an array that you use to populate a table view. The user selects a row corresponding to an object in the array that has been removed by some code elsewhere in the program, and problems ensue. Immutability is a guarantee that an object won't unexpectedly change in value while you're using it.

Objects that are good candidates for immutability are ones that encapsulate collections of discrete values or contain values that are stored in buffers (which are themselves kinds of collections, either of characters or bytes). But not all such value objects necessarily benefit from having mutable versions. Objects that contain a single simple value, such as instances of `NSNumber` or `NSDate`, are not good candidates for mutability. When the represented value changes in these cases, it makes more sense to replace the old instance with a new instance.

Performance is also a reason for immutable versions of objects representing things such as strings and dictionaries. Mutable objects for basic entities such as strings and dictionaries bring some overhead with them. Because they must dynamically manage a changeable backing store—allocating and deallocating chunks of memory as needed—mutable objects can be less efficient than their immutable counterparts.

Although in theory immutability guarantees that an object's value is stable, in practice this guarantee isn't always assured. A method may choose to hand out a mutable object under the return type of its immutable variant; later, it may decide to mutate the object, possibly violating assumptions and choices the recipient has made based on the earlier value. The mutability of an object itself may change as it undergoes various transformations. For example, serializing a property list (using the `NSPropertyListSerialization` class) does not preserve the mutability aspect of objects, only their general kind—a dictionary, an array, and so on. Thus, when you deserialize this property list, the resulting objects might not be of the same class as the original objects. For instance, what was once an `NSMutableDictionary` object might now be a `NSDictionary` object.

Programming with Mutable Objects

When the mutability of objects is an issue, it's best to adopt some defensive programming practices. Here are a few general rules or guidelines:

- Use a mutable variant of an object when you need to modify its contents frequently and incrementally after it has been created.
- Sometimes it's preferable to replace one immutable object with another; for example, most instance variables that hold string values should be assigned immutable `NSString` objects that are replaced with setter methods.
- Rely on the return type for indications of mutability.
- If you have any doubts about whether an object is, or should be, mutable, go with immutable.

This section explores the gray areas in these guidelines, discussing typical choices you have to make when programming with mutable objects. It also gives an overview of methods in the Foundation framework for creating mutable objects and for converting between mutable and immutable object variants.

Creating and Converting Mutable Objects

You can create a mutable object through the standard nested `alloc-init` message—for example:

```
NSMutableDictionary *mutDict = [[NSMutableDictionary alloc] init];
```

However, many mutable classes offer initializers and factory methods that let you specify the initial or probable capacity of the object, such as the `arrayWithCapacity:` class method of `NSMutableArray`:

```
NSMutableArray *mutArray = [NSMutableArray arrayWithCapacity:[timeZones count]];
```

The capacity hint enables more efficient storage of the mutable object's data. (Because the convention for class factory methods is to return autoreleased instances, be sure to retain the object if you wish to keep it viable in your code.)

You can also create a mutable object by making a mutable copy of an existing object of that general type. To do so, invoke the `mutableCopy` method that each immutable super class of a Foundation mutable class implements:

```
NSMutableSet *mutSet = [aSet mutableCopy];
```

In the other direction, you can send `copy` to a mutable object to make an immutable copy of the object.

Many Foundation classes with immutable and mutable variants include methods for converting between the variants, including:

- *type*`WithType:`—for example, `arrayWithArray:`
- `set`*Type*`:`—for example, `setString:` (mutable classes only)
- `initWith`*Type*`:copyItems:`—for example, `initWithDictionary:copyItems:`

Storing and Returning Mutable Instance Variables

In Cocoa development you often have to decide whether to make an instance variable mutable or immutable. For an instance variable whose value can change, such as a dictionary or string, when is it appropriate to make the object mutable? And when is it better to make the object immutable and replace it with another object when its represented value changes?

Generally, when you have an object whose contents change wholesale, it's better to use an immutable object. Strings (`NSString`) and data objects (`NSData`) usually fall into this category. If an object is likely to change incrementally, it is a reasonable approach to make it mutable. Collections such as arrays and dictionaries fall into this category. However, the frequency of changes and the size of the collection should be factors in this decision. For example, if you have a small array that seldom changes, it's better to make it immutable.

There are a couple of other considerations when deciding on the mutability of a collection held as an instance variable:

- If you have a mutable collection that is frequently changed and that you frequently hand out to clients (that is, you return it directly in a getter accessor method), you run the risk of mutating something that your clients might have a reference to. If this risk is probable, the instance variable should be immutable.
- If the value of the instance variable frequently changes but you rarely return it to clients in getter methods, you can make the instance variable mutable but return an immutable copy of it in your accessor method; in memory-managed programs, this object would be autoreleased (Listing 2-13).

Listing 2-13 Returning an immutable copy of a mutable instance variable

```
@interface MyClass : NSObject {
    // ...
    NSMutableSet *widgets;
}
// ...
@end
```

```
@implementation MyClass
- (NSSet *)widgets {
    return (NSSet *)[[widgets copy] autorelease];
}
```

One sophisticated approach for handling mutable collections that are returned to clients is to maintain a flag that records whether the object is currently mutable or immutable. If there is a change, make the object mutable and apply the change. When handing out the collection, make the object immutable (if necessary) before returning it.

Receiving Mutable Objects

The invoker of a method is interested in the mutability of a returned object for two reasons:

- It wants to know if it can change the object's value.
- It wants to know if the object's value will change unexpectedly while it has a reference to it.

Use Return Type, Not Introspection

To determine whether it can change a received object, the receiver of a message must rely on the formal type of the return value. If it receives, for example, an array object typed as immutable, it should not attempt to mutate it. It is not an acceptable programming practice to determine if an object is mutable based on its class membership—for example:

```
if ( [anArray isKindOfClass:[NSMutableArray class]] ) {
    // add, remove objects from anArray
}
```

For reasons related to implementation, what `isKindOfClass:` returns in this case may not be accurate. But for reasons other than this, you should not make assumptions about whether an object is mutable based on class membership. Your decision should be guided solely by what the signature of the method vending the object says about its mutability. If you are not sure whether an object is mutable or immutable, assume it's immutable.

A couple of examples might help clarify why this guideline is important:

- You read a property list from a file. When the Foundation framework processes the list, it notices that various subsets of the property list are identical, so it creates a set of objects that it shares among all those subsets. Afterward you look at the created property list objects and decide to mutate one subset. Suddenly, and without being aware of it, you've changed the tree in multiple places.

- You ask `NSView` for its subviews (with the `subviews` method) and it returns an object that is declared to be an `NSArray` but which could be an `NSMutableArray` internally. Then you pass that array to some other code that, through introspection, determines it to be mutable and changes it. By changing this array, the code is mutating internal data structures of the `NSView` class.

So don't make an assumption about object mutability based on what introspection tells you about an object. Treat objects as mutable or not based on what you are handed at the API boundaries (that is, based on the return type). If you need to unambiguously mark an object as mutable or immutable when you pass it to clients, pass that information as a flag along with the object.

Make Snapshots of Received Objects

If you want to ensure that a supposedly immutable object received from a method does not mutate without your knowing about it, you can make snapshots of the object by copying it locally. Then occasionally compare the stored version of the object with the most recent version. If the object has mutated, you can adjust anything in your program that is dependent on the previous version of the object. Listing 2-14 shows a possible implementation of this technique.

Listing 2-14 Making a snapshot of a potentially mutable object

```
static NSArray *snapshot = nil;
- (void)myFunction {
    NSArray *thingArray = [otherObj things];
    if (snapshot) {
        if ( ![thingArray isEqualToArray:snapshot] ) {
            [self updateStateWith:thingArray];
        }
    }
    snapshot = [thingArray copy];
}
```

A problem with making snapshots of objects for later comparison is that it is expensive. You're required to make multiple copies of the same object. A more efficient alternative is to use key-value observing. See "Key-Value Observing" (page 185) for an overview of this protocol.

Mutable Objects in Collections

Storing mutable objects in collection objects can cause problems. Certain collections can become invalid or even corrupt if objects they contain mutate because, by mutating, these objects can affect the way they are placed in the collection. First, the properties of objects that are keys in hashing collections such as `NSDictionary` objects or `NSSet` objects will, if changed, corrupt the collection if the changed properties affect the results of the object's `hash` or `isEqual:` methods. (If the `hash` method of the objects in the collection does not depend on their internal state, corruption is less likely.) Second, if an object in an ordered collection such as a sorted array has its properties changed, this might affect how the object compares to other objects in the array, thus rendering the ordering invalid.

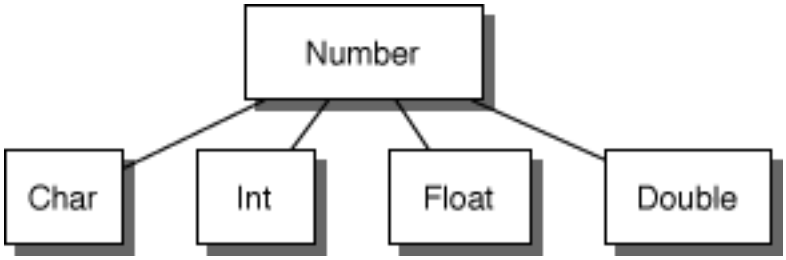
Class Clusters

Class clusters are a design pattern that the Foundation framework makes extensive use of. Class clusters group a number of private concrete subclasses under a public abstract superclass. The grouping of classes in this way simplifies the publicly visible architecture of an object-oriented framework without reducing its functional richness. Class clusters are based on the Abstract Factory design pattern discussed in "Cocoa Design Patterns" (page 165).

Without Class Clusters: Simple Concept but Complex Interface

To illustrate the class cluster architecture and its benefits, consider the problem of constructing a class hierarchy that defines objects to store numbers of different types (`char`, `int`, `float`, `double`). Because numbers of different types have many features in common (they can be converted from one type to another and can be represented as strings, for example), they could be represented by a single class. However, their storage requirements differ, so it's inefficient to represent them all by the same class. Taking this fact into consideration, one could design the class architecture depicted in Figure 2-10 to solve the problem.

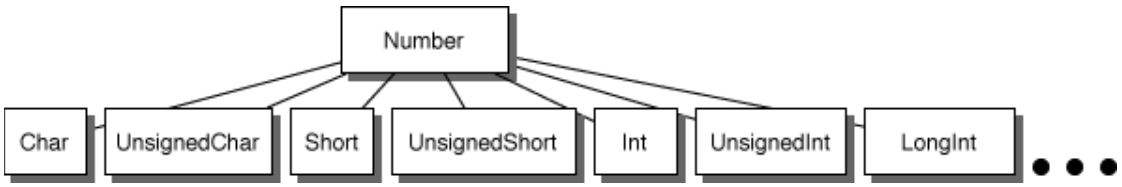
Figure 2-10 A simple hierarchy for number classes



`Number` is the abstract superclass that declares in its methods the operations common to its subclasses. However, it doesn't declare an instance variable to store a number. The subclasses declare such instance variables and share in the programmatic interface declared by `Number`.

So far, this design is relatively simple. However, if the commonly used modifications of these basic C types are taken into account, the class hierarchy diagram looks more like Figure 2-11.

Figure 2-11 A more complete number class hierarchy

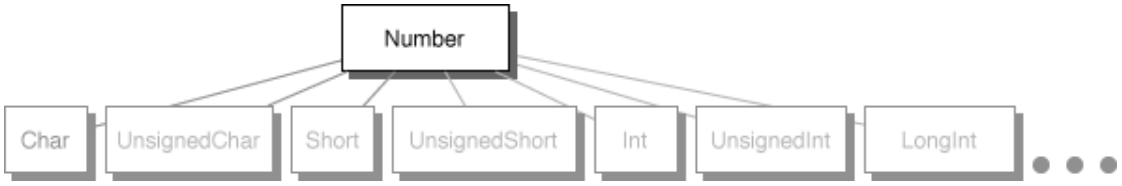


The simple concept—creating a class to hold number values—can easily burgeon to over a dozen classes. The class cluster architecture presents a design that reflects the simplicity of the concept.

With Class Clusters: Simple Concept and Simple Interface

Applying the class cluster design pattern to this problem yields the class hierarchy in Figure 2-12 (private classes are in gray).

Figure 2-12 Class cluster architecture applied to number classes



Users of this hierarchy see only one public class, `Number`, so how is it possible to allocate instances of the proper subclass? The answer is in the way the abstract superclass handles instantiation.

Creating Instances

The abstract superclass in a class cluster must declare methods for creating instances of its private subclasses. It's the superclass's responsibility to dispense an object of the proper subclass based on the creation method that you invoke—you don't, and can't, choose the class of the instance.

In the Foundation framework, you generally create an object by invoking a *+className* `...` method or the `alloc...` and `init...` methods. Taking the Foundation framework's `NSNumber` class as an example, you could send these messages to create number objects:

```
NSNumber *aChar = [NSNumber numberWithChar:'a'];
NSNumber *anInt = [NSNumber numberWithInt:1];
```

```
NSNumber *aFloat = [NSNumber numberWithFloat:1.0];
NSNumber *aDouble = [NSNumber numberWithDouble:1.0];
```

You are not responsible for releasing the objects returned from factory methods; see "Class Factory Methods" (page 99) for more information. Many classes also provide the standard `alloc...` and `init...` methods to create objects that require you to manage their deallocation.

Each object returned—`aChar`, `anInt`, `aFloat`, and `aDouble`—may belong to a different private subclass (and in fact does). Although each object's class membership is hidden, its interface is public, being the interface declared by the abstract superclass, `NSNumber`. Although it is not precisely correct, it's convenient to consider the `aChar`, `anInt`, `aFloat`, and `aDouble` objects to be instances of the `NSNumber` class, because they're created by `NSNumber` class methods and accessed through instance methods declared by `NSNumber`.

Class Clusters with Multiple Public Superclasses

In the example above, one abstract public class declares the interface for multiple private subclasses. This is a class cluster in the purest sense. It's also possible, and often desirable, to have two (or possibly more) abstract public classes that declare the interface for the cluster. This is evident in the Foundation framework, which includes the clusters listed in Table 2-3.

Table 2-3 Class clusters and their public superclasses

Class cluster	Public superclasses
`NSData`	`NSData`
	`NSMutableData`
`NSArray`	`NSArray`
	`NSMutableArray`
`NSDictionary`	`NSDictionary`
	`NSMutableDictionary`
`NSString`	`NSString`
	`NSMutableString`

Other clusters of this type also exist, but these clearly illustrate how two abstract nodes cooperate in declaring the programmatic interface to a class cluster. In each of these clusters, one public node declares methods that all cluster objects can respond to, and the other node declares methods that are only appropriate for cluster objects that allow their contents to be modified.

This factoring of the cluster's interface helps make an object-oriented framework's programmatic interface more expressive. For example, imagine an object representing a book that declares this method:

```
- (NSString *)title;
```

The book object could return its own instance variable or create a new string object and return that—it doesn't matter. It's clear from this declaration that the returned string can't be modified. Any attempt to modify the returned object will elicit a compiler warning.

Creating Subclasses Within a Class Cluster

The class cluster architecture involves a trade-off between simplicity and extensibility: Having a few public classes stand in for a multitude of private ones makes it easier to learn and use the classes in a framework but somewhat harder to create subclasses within any of the clusters. However, if it's rarely necessary to create a subclass, then the cluster architecture is clearly beneficial. Clusters are used in the Foundation framework in just these situations.

If you find that a cluster doesn't provide the functionality your program needs, then a subclass may be in order. For example, imagine that you want to create an array object whose storage is file-based rather than memory-based, as in the `NSArray` class cluster. Because you are changing the underlying storage mechanism of the class, you'd have to create a subclass.

On the other hand, in some cases it might be sufficient (and easier) to define a class that embeds within it an object from the cluster. Let's say that your program needs to be alerted whenever some data is modified. In this case, creating a simple class that wraps a data object that the Foundation framework defines may be the best approach. An object of this class could intervene in messages that modify the data, intercepting the messages, acting on them, and then forwarding them to the embedded data object.

In summary, if you need to manage your object's storage, create a true subclass. Otherwise, create a composite object, one that embeds a standard Foundation framework object in an object of your own design. The following sections give more detail on these two approaches.

A True Subclass

A new class that you create within a class cluster must:

- Be a subclass of the cluster's abstract superclass

- Declare its own storage
- Override all initializer methods of the superclass
- Override the superclass's primitive methods (described below)

Because the cluster's abstract superclass is the only publicly visible node in the cluster's hierarchy, the first point is obvious. This implies that the new subclass will inherit the cluster's interface but no instance variables, because the abstract superclass declares none. Thus the second point: The subclass must declare any instance variables it needs. Finally, the subclass must override any method it inherits that directly accesses an object's instance variables. Such methods are called *primitive methods*.

A class's primitive methods form the basis for its interface. For example, take the `NSArray` class, which declares the interface to objects that manage arrays of objects. In concept, an array stores a number of data items, each of which is accessible by index. `NSArray` expresses this abstract notion through its two primitive methods, `count` and `objectAtIndex:`. With these methods as a base, other methods—*derived methods*—can be implemented; Table 2-4 gives two examples of derived methods.

Table 2-4 Derived methods and their possible implementations

Derived Method	Possible Implementation
`lastObject`	Find the last object by sending the array object this message: `[self objectAtIndex: ([self count] –1)]`.
`containsObject:`	Find an object by repeatedly sending the array object an `objectAtIndex:` message, each time incrementing the index until all objects in the array have been tested.

The division of an interface between primitive and derived methods makes creating subclasses easier. Your subclass must override inherited primitives, but having done so can be sure that all derived methods that it inherits will operate properly.

The primitive-derived distinction applies to the interface of a fully initialized object. The question of how `init...` methods should be handled in a subclass also needs to be addressed.

In general, a cluster's abstract superclass declares a number of `init...` and `+ className` methods. As described in "Creating Instances" (page 112), the abstract class decides which concrete subclass to instantiate based your choice of `init...` or `+ className` method. You can consider that the abstract class declares these methods for the convenience of the subclass. Since the abstract class has no instance variables, it has no need of initialization methods.

Your subclass should declare its own `init...` (if it needs to initialize its instance variables) and possibly `+ className` methods. It should not rely on any of those that it inherits. To maintain its link in the initialization chain, it should invoke its superclass's designated initializer within its own designated initializer method. It should also override all other inherited initializer methods and implement them to behave in a reasonable manner. (See ""The Runtime System"" in *The Objective-C Programming Language* for a discussion of designated initializers.) Within a class cluster, the designated initializer of the abstract superclass is always `init`.

True Subclasses: An Example

Let's say that you want to create a subclass of `NSArray`, named `MonthArray`, that returns the name of a month given its index position. However, a `MonthArray` object won't actually store the array of month names as an instance variable. Instead, the method that returns a name given an index position (`objectAtIndex:`) will return constant strings. Thus, only twelve string objects will be allocated, no matter how many `MonthArray` objects exist in an application.

The `MonthArray` class is declared as:

```
#import <foundation/foundation.h>
@interface MonthArray : NSArray
{
}

+ monthArray;
- (unsigned)count;
- (id)objectAtIndex:(unsigned)index;

@end
```

Note that the `MonthArray` class doesn't declare an `init...` method because it has no instance variables to initialize. The `count` and `objectAtIndex:` methods simply cover the inherited primitive methods, as described above.

The implementation of the `MonthArray` class looks like this:

```
#import "MonthArray.h"

@implementation MonthArray
```

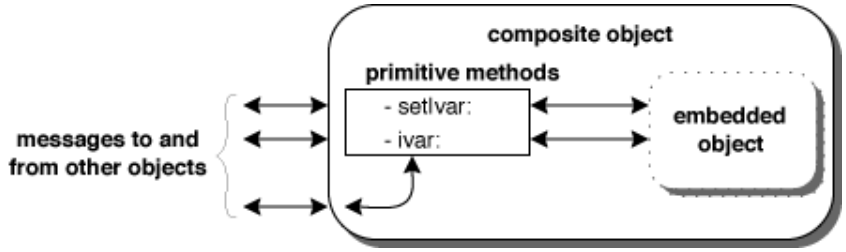
```
static MonthArray *sharedMonthArray = nil;
static NSString *months[] = { @"January", @"February", @"March",
    @"April", @"May", @"June", @"July", @"August", @"September",
    @"October", @"November", @"December" };

+ monthArray
{
    if (!sharedMonthArray) {
        sharedMonthArray = [[MonthArray alloc] init];
    }
    return sharedMonthArray;
}

- (unsigned)count
{
 return 12;
}

- objectAtIndex:(unsigned)index
{
    if (index >= [self count])
        [NSException raise:NSRangeException format:@"***%s: index
            (%d) beyond bounds (%d)", sel_getName(_cmd), index,
            [self count] - 1];
    else
        return months[index];
}

@end
```

Because `MonthArray` overrides the inherited primitive methods, the derived methods that it inherits will work properly without being overridden. `NSArray`'s `lastObject`, `containsObject:`, `sortedArrayUsingSelector:`, `objectEnumerator`, and other methods work without problems for `MonthArray` objects.

A Composite Object

By embedding a private cluster object in an object of your own design, you create a composite object. This composite object can rely on the cluster object for its basic functionality, only intercepting messages that the composite object wants to handle in some particular way. This architecture reduces the amount of code you must write and lets you take advantage of the tested code provided by the Foundation Framework. Figure 2-13 depicts this architecture.

Figure 2-13 An object that embeds a cluster object



The composite object must declare itself to be a subclass of the cluster's abstract superclass. As a subclass, it must override the superclass's primitive methods. It can also override derived methods, but this isn't necessary because the derived methods work through the primitive ones.

The `count` method of the `NSArray` class is an example; the intervening object's implementation of a method it overrides can be as simple as:

```
- (unsigned)count {
    return [embeddedObject count];
}
```

However, your object could put code for its own purposes in the implementation of any method it overrides.

A Composite Object: An Example

To illustrate the use of a composite object, imagine you want a mutable array object that tests changes against some validation criteria before allowing any modification to the array's contents. The example that follows describes a class called `ValidatingArray`, which contains a standard mutable array object. `ValidatingArray` overrides all of the primitive methods declared in its superclasses, `NSArray` and `NSMutableArray`. It also declares the `array`, `validatingArray`, and `init` methods, which can be used to create and initialize an instance:

```
#import <foundation/foundation.h>
```

```
@interface ValidatingArray : NSMutableArray
{
    NSMutableArray *embeddedArray;
}

+ validatingArray;
- init;
- (unsigned)count;
- objectAtIndex:(unsigned)index;
- (void)addObject:object;
- (void)replaceObjectAtIndex:(unsigned)index withObject:object;
- (void)removeLastObject;
- (void)insertObject:object atIndex:(unsigned)index;
- (void)removeObjectAtIndex:(unsigned)index;

@end
```

The implementation file shows how, in an `init` method of the `ValidatingArray`class , the embedded object is created and assigned to the `embeddedArray` variable. Messages that simply access the array but don't modify its contents are relayed to the embedded object. Messages that could change the contents are scrutinized (here in pseudocode) and relayed only if they pass the hypothetical validation test.

```
#import "ValidatingArray.h"

@implementation ValidatingArray

- init
{
    self = [super init];
    if (self) {
        embeddedArray = [[NSMutableArray allocWithZone:[self zone]] init];
    }
    return self;
}
```

```
+ validatingArray
{
    return [[[self alloc] init] autorelease];
}

- (unsigned)count
{
    return [embeddedArray count];
}

- objectAtIndex:(unsigned)index
{
    return [embeddedArray objectAtIndex:index];
}

- (void)addObject:object
{
    if (/* modification is valid */) {
        [embeddedArray addObject:object];
    }
}

- (void)replaceObjectAtIndex:(unsigned)index withObject:object;
{
    if (/* modification is valid */) {
        [embeddedArray replaceObjectAtIndex:index withObject:object];
    }
}

- (void)removeLastObject;
{
    if (/* modification is valid */) {
        [embeddedArray removeLastObject];
```

```
    }
}
- (void)insertObject:object atIndex:(unsigned)index;
{
    if (/* modification is valid */) {
        [embeddedArray insertObject:object atIndex:index];
    }
}
- (void)removeObjectAtIndex:(unsigned)index;
{
    if (/* modification is valid */) {
        [embeddedArray removeObjectAtIndex:index];
    }
}
```

Toll-Free Bridging

There are a number of data types in the Core Foundation framework and the Foundation framework that can be used interchangeably. This capability, called *toll-free bridging*, means that you can use the same data type as the parameter to a Core Foundation function call or as the receiver of an Objective-C message. For example, `NSLocale` (see *NSLocale Class Reference*) is interchangeable with its Core Foundation counterpart, CFLocale (see *CFLocale Reference*). Therefore, in a method where you see an `NSLocale *` parameter, you can pass a `CFLocaleRef`, and in a function where you see a `CFLocaleRef` parameter, you can pass an `NSLocale` instance. You cast one type to the other to suppress compiler warnings, as illustrated in the following example.

```
NSLocale *gbNSLocale = [[NSLocale alloc] initWithLocaleIdentifier:@"en_GB"];
CFLocaleRef gbCFLocale = (CFLocaleRef) gbNSLocale;
CFStringRef cfIdentifier = CFLocaleGetIdentifier (gbCFLocale);
NSLog(@"cfIdentifier: %@", (NSString *)cfIdentifier);
// logs: "cfIdentifier: en_GB"
CFRelease((CFLocaleRef) gbNSLocale);

CFLocaleRef myCFLocale = CFLocaleCopyCurrent();
NSLocale * myNSLocale = (NSLocale *) myCFLocale;
[myNSLocale autorelease];
```

```
NSString *nsIdentifier = [myNSLocale localeIdentifier];
CFShow((CFStringRef) [@"nsIdentifier: " stringByAppendingString:nsIdentifier]);
// logs identifier for current locale
```

Note from the example that the memory management functions and methods are also interchangeable—you can use `CFRelease` with a Cocoa object and `release` and `autorelease` with a Core Foundation object.

> **Note** When using garbage collection, there are important differences to how memory management works for Cocoa objects and Core Foundation objects. See "Using Core Foundation with Garbage Collection" for details.

Toll-free bridging has been available since Mac OS X v10.0. Table 2-5 provides a list of the data types that are interchangeable between Core Foundation and Foundation. For each pair, the table also lists the version of Mac OS X in which toll-free bridging between them became available.

Table 2-5 Data types that can be used interchangeably between Core Foundation and Foundation

Core Foundation type	Foundation class	Availability
`CFArrayRef`	`NSArray`	Mac OS X v10.0
`CFAttributedStringRef`	`NSAttributedString`	Mac OS X v10.4
`CFCalendarRef`	`NSCalendar`	Mac OS X v10.4
`CFCharacterSetRef`	`NSCharacterSet`	Mac OS X v10.0
`CFDataRef`	`NSData`	Mac OS X v10.0
`CFDateRef`	`NSDate`	Mac OS X v10.0
`CFDictionaryRef`	`NSDictionary`	Mac OS X v10.0
`CFErrorRef`	`NSError`	Mac OS X v10.5
`CFLocaleRef`	`NSLocale`	Mac OS X v10.4
`CFMutableArrayRef`	`NSMutableArray`	Mac OS X v10.0
`CFMutableAttributedStringRef`	`NSMutableAttributedString`	Mac OS X v10.4
`CFMutableCharacterSetRef`	`NSMutableCharacterSet`	Mac OS X v10.0

Core Foundation type	Foundation class	Availability
CFMutableDataRef	NSMutableData	Mac OS X v10.0
CFMutableDictionaryRef	NSMutableDictionary	Mac OS X v10.0
CFMutableSetRef	NSMutableSet	Mac OS X v10.0
CFMutableStringRef	NSMutableString	Mac OS X v10.0
CFNumberRef	NSNumber	Mac OS X v10.0
CFReadStreamRef	NSInputStream	Mac OS X v10.0
CFRunLoopTimerRef	NSTimer	Mac OS X v10.0
CFSetRef	NSSet	Mac OS X v10.0
CFStringRef	NSString	Mac OS X v10.0
CFTimeZoneRef	NSTimeZone	Mac OS X v10.0
CFURLRef	NSURL	Mac OS X v10.0
CFWriteStreamRef	NSOutputStream	Mac OS X v10.0

Note Not all data types are toll-free bridged, even though their names might suggest that they are. For example, NSRunLoop is not toll-free bridged to CFRunLoop, NSBundle is not toll-free bridged to CFBundle, and NSDateFormatter is not toll-free bridged to CFDateFormatter.

Creating a Singleton Instance

Some classes of the Foundation and AppKit frameworks create singleton objects. In a strict implementation, a singleton is the sole allowable instance of a class in the current process. But you can also have a more flexible singleton implementation in which a factory method always returns the same instance, but you can allocate and initialize additional instances.The NSFileManager class fits this latter pattern, whereas the UIApplication fits the former. When you ask for an instance of UIApplication, it passes you a reference to the sole instance, allocating and initializing it if it doesn't yet exist.

A singleton object acts as a kind of control center, directing or coordinating the services of the class. Your class should generate a singleton instance rather than multiple instances when there is conceptually only one instance (as with, for example, NSWorkspace). You use singleton instances rather than factory methods or functions when it is conceivable that there might be multiple instances someday.

To create a singleton as the sole allowable instance of a class in the current process, you need to have an implementation similar to Listing 2-15. This code does the following:

- It declares a static instance of your singleton object and initializes it to `nil`.
- In your class factory method for the class (named something like “sharedInstance” or “sharedManager”), it generates an instance of the class but only if the static instance is `nil`.
- It overrides the `allocWithZone:` method to ensure that another instance is not allocated if someone tries to allocate and initialize an instance of your class directly instead of using the class factory method. Instead, it just returns the shared object.
- It implements the base protocol methods `copyWithZone:`, `release`, `retain`, `retainCount`, and `autorelease` to do the appropriate things to ensure singleton status. (The last four of these methods apply to memory-managed code, not to garbage-collected code.)

Listing 2-15 Strict implementation of a singleton

```
static MyGizmoClass *sharedGizmoManager = nil;

+ (MyGizmoClass*)sharedManager
{
    if (sharedGizmoManager == nil) {
        sharedGizmoManager = [[super allocWithZone:NULL] init];
    }
    return sharedGizmoManager;
}

+ (id)allocWithZone:(NSZone *)zone
{
    return [[self sharedManager] retain];
}

- (id)copyWithZone:(NSZone *)zone
{
    return self;
}

- (id)retain
```

```
{
    return self;
}

- (NSUInteger)retainCount
{
    return NSUIntegerMax;  //denotes an object that cannot be released
}

- (void)release
{
    //do nothing
}

- (id)autorelease
{
    return self;
}
```

If you want a singleton instance (created and controlled by the class factory method) but also have the ability to create other instances as needed through allocation and initialization, do not override `allocWithZone:` and the other methods following it as shown in Listing 2-15 (page 124).

Adding Behavior to a Cocoa Program

When you develop a Cocoa program in Objective-C, you won't be on your own. You'll be drawing on the work done by Apple and others, on the classes they've developed and packaged in Objective-C frameworks. These frameworks give you a set of interdependent classes that work together to structure a part—often a substantial part—of your program.

This chapter describes what it's like to write an Objective-C program using a Cocoa framework. It also gives you the basic information you need to know to make a subclass of a framework class.

Starting Up

Using a framework of Objective-C classes and their methods differs from using a library of C functions. With a library of C functions, you can pretty much pick and choose which functions to use and when to use them, depending on the program you're trying to write. A framework, on the other hand, imposes a design on your program, or at least on a certain problem space your program is trying to address. With a procedural program, you call library functions as necessary to get the work of the program done. Using an object-oriented framework is similar in that you must invoke methods of the framework to do much of the work of the program. However, you'll also need to customize the framework and adapt it to your needs by implementing methods that the framework will invoke at the appropriate time. These methods are hooks that introduce your code into the structure imposed by the framework, augmenting it with the behavior that characterizes your program. In a sense, the usual roles of program and library are reversed. Instead of incorporating library code into your program, you incorporate your program code into the framework.

You can gain some insight on the relationship between custom code and framework by considering what takes place when a Cocoa program begins executing.

What Happens in the main Function

Objective-C programs begin executing where C programs do, in the `main` function. In a complex Objective-C program, the job of `main` is fairly simple. It consists of two steps:

- Set up a core group of objects.
- Turn program control over to those objects.

Objects in the core group might create other objects as the program runs, and those objects might create still other objects. From time to time, the program might also load classes, unarchive instances, connect to remote objects, and find other resources as they're needed. However, all that's required at the outset is enough structure—enough of the object network—to handle the program's initial tasks. The `main` function puts this initial structure in place and gets it ready for the task ahead.

Typically, one of the core objects has the responsibility for overseeing the program or controlling its input. When the core structure is ready, `main` sets this overseer object to work. If the program is a command-line tool or a background server, what this entails might be as simple as passing command-line parameters or opening a remote connection. But for the most common type of Cocoa program, an application, what happens is a bit more involved.

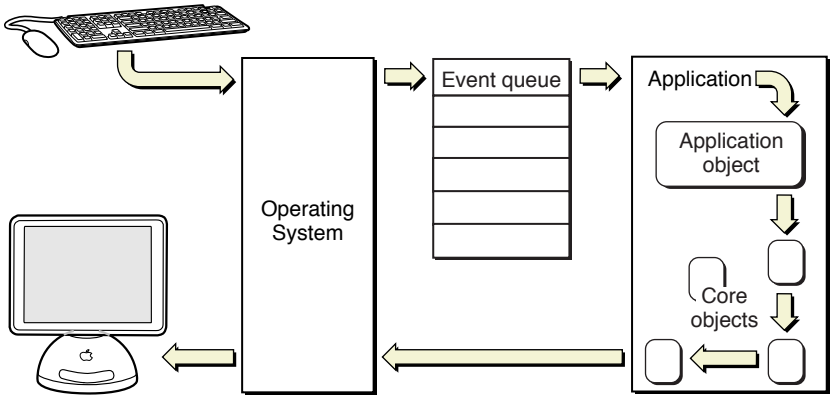
For an application, the core group of objects that `main` sets up must include some objects that draw the user interface. This interface, or at least part of it (such as an application's menu), must appear on the screen when the user launches the application. Once the initial user interface is on the screen, the application is thereafter driven by external events, the most important of which are those originated by users: clicking a button, choosing a menu item, dragging an icon, typing something in a field, and so on. Each such event is reported to the application along with a good deal of information about the circumstances of the user action—for example, which key was pressed, whether the mouse button was pressed or released, where the cursor was located, and which window was affected.

An application gets an event, looks at it, responds to it—often by drawing a part of the user interface—then waits for the next event. It keeps getting events, one after another, as long as the user or some other source (such as a timer) initiates them. From the time it's launched to the time it terminates, almost everything the application does is driven by user actions in the form of events.

The mechanism for getting and responding to events is the main event loop (called *main* because an application can set up subordinate events loops for brief periods). An event loop is essentially a run loop with one or more input sources attached to it. One object in the core group is responsible for running the main event loop—getting an event, dispatching the event to the object or objects that can best handle it, and then getting

the next event. In a Cocoa application, this coordinating object is the global application object. In OS X, this object is an instance of `NSApplication`, and in iOS, it's an instance of `UIApplication`. Figure 3-1 illustrates the main event loop for Cocoa applications in OS X.

Figure 3-1 The main event loop in OS X



The `main` function in almost all Cocoa applications is extremely simple. In OS X, it consists of only one function call (see Listing 3-1). The `NSApplicationMain` function creates the application object, sets up an autorelease pool, loads the initial user interface from the main nib file, and runs the application, thereby requesting it to begin handling events received on the main event loop.

Listing 3-1 The main function for a Cocoa application in OS X

```
#import <AppKit/AppKit.h>

int main(int argc, const char *argv[]) {
    return NSApplicationMain(argc, argv);
}
```

The `main` function for iOS-based applications calls a similar function: `UIApplicationMain`.

Using a Cocoa Framework

Library functions impose few restrictions on the programs that use them; you can call them whenever you need to. The methods in an object-oriented library or framework, on the other hand, are tied to class definitions and can't be invoked unless you create or obtain an object that has access to those definitions. Moreover, in

most programs the object must be connected to at least one other object so that it can operate in the program network. A class defines a program component; to access its services, you need to craft it into the structure of your application.

That said, some framework classes generate instances that behave much as a set of library functions does. You simply create an instance, initialize it, and either send it a message to accomplish a task or insert it into a waiting slot in your application. For example, you can use the `NSFileManager` class to perform various file-system operations, such as moving, copying, and deleting files. If you need to display an alert dialog, you would create an instance of the `NSAlert` class—or, with UIKit, an instance of the `UIAlertView` class—and send the instance the appropriate message.

In general, however, environments such as Cocoa are more than a grab bag of individual classes that offer their services. They consist of object-oriented frameworks, collections of classes that structure a problem space and present an integrated solution to it. Instead of providing discrete services that you can use as needed (as with function libraries), a framework maps out and implements an entire program structure—or model—that your own code must adapt to. Because this program model is generic, you can specialize it to meet the requirements of your particular program. Rather than design a program that you plug library functions into, you plug your own code into the design provided by the framework.

To use a framework, you must accept the program model it defines and employ and customize as many of its classes as necessary to mold your particular program to that model. The classes are mutually dependent and come as a group, not individually. At first glance, the need to adapt your code to a framework's program model might seem restrictive. But the reality is quite the opposite. A framework offers you many ways in which you can alter and extend its generic behavior. It simply requires you to accept that all Cocoa programs behave in the same fundamental ways because they are all based on the same program model.

Kinds of Framework Classes

The classes in a Cocoa framework deliver their services in four ways:

- **Off the shelf**. Some classes define off-the-shelf objects, ready to be used. You simply create instances of the class and initialize them as needed. For the AppKit framework, subclasses of `NSControl`, such as `NSTextField`, `NSButton`, and `NSTableView`, fall into this category. The corresponding UIKit classes are `UIControl`, `UITextField`, `UIButton`, and `UITableView`. You typically create and initialize off-the-shelf objects using Interface Builder, although you can create and initialize them programmatically.
- **Behind the scenes**. As a program runs, Cocoa creates some framework objects for it behind the scenes. You don't need to explicitly allocate and initialize these objects; it's done for you. Often the classes are private, but they are necessary to implement the desired behavior.

- **Generically**. Some framework classes are generic. A framework might provide some concrete subclasses of the generic class that you can use unchanged. Yet you can—and *must* in some circumstances—define your own subclasses and override the implementations of certain methods. `NSView` and `NSDocument` are examples of this kind of class in AppKit, and `UIView` and `UIScrollView` are UIKit examples.
- **Through delegation and notification**. Many framework objects keep other objects informed of their actions and even delegate certain responsibilities to those other objects. The mechanisms for delivering this information are delegation and notification. A delegating object publishes an interface known as a protocol (see "Protocols" (page 67) for details). Client objects must first register as delegates and then implement one or more methods of this interface. A notifying object publishes the list of notifications it broadcasts, and any client is free to observe one or more of them. Many framework classes broadcast notifications.

Some classes provide more than one of these general kinds of services. For example, you can drag a ready-made `NSWindow` object from the Interface Builder library and use it with only minor initializations. Thus the `NSWindow` class provides off-the-shelf instances. But an `NSWindow` object also sends messages to its delegate and posts a variety of notifications. You can even subclass `NSWindow` if, for example, you want to have round windows.

It is the Cocoa classes in the last two categories—generic and delegation/notification—that offer the most possibilities for integrating your program-specific code into the structure provided by the frameworks. "Inheriting from a Cocoa Class" (page 133) discusses in general terms how you create subclasses of framework classes, particularly generic classes. See "Communicating with Objects" (page 209) for information on delegation, notification, and other mechanisms for communication between objects in a program network.

Cocoa API Conventions

When you start using the classes, methods, and other symbols declared by the Cocoa frameworks, you should be aware of a few conventions that are intended to ensure efficiency and consistency in usage.

- Methods that return objects typically return `nil` to indicate that there was a failure to create an object or that, for any other reason, no object was returned. They do not directly return a status code.

  The convention of returning `nil` is often used to indicate a runtime error or other nonexceptional condition. The Cocoa frameworks deal with errors such as an array index out of bounds or an unrecognized method selector by raising an exception (which is handled by a top-level handler) and, if the method signature so requires, returning `nil`.
- Some of these same methods that might return `nil` include a final parameter for returning error information by reference.

  This final parameter takes a pointer to an `NSError` object. Upon return from a method call that fails (that is, returns `nil`), you can inspect the returned error object to determine the cause of the error or you can display the error to the user in a dialog.

As an example, here's a method from the `NSDocument` class:

```
- (id)initWithType:(NSString *)typeName error:(NSError **)outError;
```

- In a similar fashion, methods that perform some system operation (such as reading or writing a file) often return a Boolean value to indicate success or failure.

  These methods might also include a pointer to an `NSError` object as a final by-reference parameter. For example, there's this method from the `NSData` class:

  ```
  - (BOOL)writeToFile:(NSString *)path options:(unsigned)writeOptionsMask
  error:(NSError **)errorPtr;
  ```

- Empty container objects are used to indicate a default value or no value—`nil` is usually not a valid object parameter.

  Many objects encapsulate values or collections of objects—for example, instances of `NSString`, `NSDate`, `NSArray`, and `NSDictionary`. Methods that take these objects as parameters may accept an empty object (for example, `@""`) to indicate that there is no value or to request that the default value be used. For example, the following message sets the represented filename for a window to "no value" by specifying an empty string:

  ```
  [aWindow setRepresentedFilename:@""];
  ```

  Note The Objective-C construct `@"`*characters*`"` creates an `NSString` object containing the literal *characters*. Thus, `@""` would create a string object with no characters—or, an empty string. For more information, see *String Programming Guide*.

- The Cocoa frameworks expect that global string constants rather than string literals are used for dictionary keys, notification and exception names, and some method parameters that take strings.

  You should always prefer string constants over string literals when you have a choice. By using string constants, you enlist the help of the compiler to check your spelling and thus avoid runtime errors.

- The Cocoa frameworks use types consistently, giving higher impedance matching across their API sets.

  For example, the frameworks use `float` for coordinate values, `CGFloat` for both graphical and coordinate values, `NSPoint` (AppKit) or `CGPoint` (UIKit) for a location in a coordinate system, `NSString` objects for string values, `NSRange` for ranges, and `NSInteger` and `NSUInteger` for, respectively, signed and unsigned integral values. When you design your own APIs, you should strive for similar type consistency.

- Unless stated otherwise in the documentation or header files, sizes that are returned in methods such as `frame` and `bounds` (`NSView`) are in points.

A substantial subset of Cocoa API conventions concerns the naming of classes, methods, functions, constants, and other symbols. You should be aware of these conventions when you begin designing your own programmatic interfaces. Some of the more important of these naming conventions are the following:

- Use prefixes for class names and for symbols associated with the class, such as functions and type definitions (`typedef`).

  A prefix protects against collisions and helps to differentiate functional areas. The prefix convention is two or three unique uppercase letters, for example, the "AC" in `ACCircle`.

- With API names, it's better to be clear than brief.

  For example, it's easy to understand what `removeObjectAtIndex:` does but `remove:` is ambiguous.

- Avoid ambiguous names.

  For example, `displayName` is ambiguous because it's unclear whether it displays the name or returns the display name.

- Use verbs in the names of methods or functions that represent actions.

- If a method returns an attribute or computed value, the name of the method is the name of the attribute.

  These methods are known as "getter" accessor methods. For example, if the attribute is background color, the getter method should be named `backgroundColor`. Getter methods that return a Boolean value are of a slight variation, using an "is" or "has" prefix—for example, `hasColor`.

- If a method sets the value of an attribute—that is, a "setter" accessor method—it begins with "set" followed by the attribute name.

  The first letter of the attribute name is in uppercase—for example, `setBackgroundColor:`.

  > **Note** The implementation of setter and getter methods is discussed in detail in "Storing and Accessing Properties" (page 146) and in *Model Object Implementation Guide*.

- Do not abbreviate parts of API names unless the abbreviation is well known (for example, HTML or TIFF).

For the complete set of naming guidelines for Objective-C programmatic interfaces, see *Coding Guidelines for Cocoa*.

A general, overarching API convention pertains to object ownership with memory-managed applications (versus garbage-collected applications). Briefly stated, the convention is that a client owns an object if it creates the object (by allocation then initialization), copies it, or retains it (by sending it `retain`). An owner of an object

is responsible for its disposal by sending `release` or `autorelease` to the object when it no longer needs it. For more on this subject, see "How Memory Management Works" (page 84) and *Advanced Memory Management Programming Guide*.

Inheriting from a Cocoa Class

A framework such as AppKit or UIKit defines a program model that, because it is generic, many different types of applications can share. Because the model is generic, it is not surprising that some framework classes are abstract or intentionally incomplete. A class often does much of its work in low-level and common code, but leaves significant portions of the work either undone or completed in a safe but generic "default" fashion.

An application often needs to create a subclass that fills in these gaps in its superclass, supplying the pieces the framework class is missing. A subclass is the primary way to add application-specific behavior to a framework. An instance of your custom subclass takes its place in the network of objects the framework defines. It inherits the ability to work with other objects from the framework. For example, if you create a subclass of `NSCell` (AppKit), instances of this new class are able to appear in an `NSMatrix` object, just as `NSButtonCell`, `NSTextFieldCell`, and other framework-defined cell objects can.

When you make a subclass, one of your primary tasks is to implement a specific set of methods declared by a superclass (or in a protocol adopted by a superclass). Reimplementing an inherited method is known as *overriding* that method.

When to Override a Method

Most methods defined in a framework class are fully implemented; they exist so you can invoke them to obtain the services the class provides. You rarely need to override such methods and shouldn't attempt to. The framework depends on them doing just what they do—nothing more and nothing less. In other cases, you can override a method, but there's no real reason to do so. The framework's version of the method does an adequate job. But just as you might implement your own version of a string-comparison function rather than use `strcmp`, you can choose to override the framework method.

Some framework methods, however, are intended to be overridden; they exist to let you add program-specific behavior to the framework. Often the method, as implemented by the framework, does little or nothing that's of value to your application, but is invoked in messages initiated by other framework methods. To give content to these kinds of methods, an application must implement its own version.

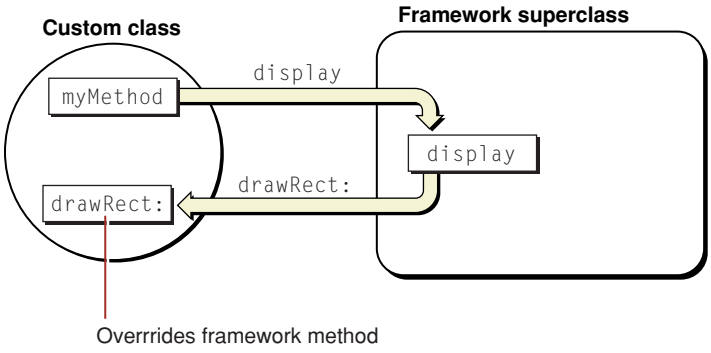
Invoke or Override?

The framework methods you override in a subclass generally won't be ones that you'll invoke yourself, at least directly. You simply reimplement the method and leave the rest up to the framework. In fact, the more likely you are to write an application-specific version of a method, the less likely you are to invoke it in your own code. There's a good reason for this. In a general sense, a framework class declares public methods so that you, the developer, can do one of two things:

- Invoke them to avail yourself of the services the class provides
- Override them to introduce your own code into the program model defined by the framework

Sometimes a method falls into both these categories; it renders a valuable service upon invocation, and it can be strategically overridden. But generally, if a method is one that you can invoke, it's fully defined by the framework and doesn't need to be redefined in your code. If the method is one that you need to reimplement in a subclass, the framework has a particular job for it to do and so will invoke the method itself at the appropriate times. Figure 3-2 illustrates the two general types of framework methods.

Figure 3-2 Invoking a framework method that invokes an overridden method



Much of the work of object-oriented programming with a Cocoa framework is implementing methods that your program uses only indirectly, through messages arranged by the framework.

Types of Overridden Methods

You may choose to define several different types of methods in a subclass:

- Some framework methods are fully implemented and are meant to be invoked by other framework methods. In other words, even though you may reimplement these methods, you often don't invoke them elsewhere in your code. They provide some service—data or behavior—required by some other code at some point during program execution. These methods exist in the public interface for just one reason—so that you can override them if you want to. They give you an opportunity either to substitute your own algorithm for the one used by the framework or to modify or extend the framework algorithm.

An example of this type of method is `trackWithEvent:`, defined in the `NSMenuView` class of the AppKit framework. `NSMenuView` implements this method to satisfy the immediate requirement—handling menu tracking and item selection—but you may override it if you want different behavior.

- Another type of method is one that makes an object-specific decision, such as whether an attribute is turned on or whether a certain policy is in effect. The framework implements a default version of this method that makes the decision one way, and you must implement your own version if you want a different decision. In most cases, implementation is simply a matter of returning `YES` or `NO`, or of calculating a value other than the default.

  The `acceptsFirstResponder` method of `NSResponder` is typical of this sort of method. Views are sent `acceptsFirstResponder` messages asking, among other things, if they respond to keystrokes or mouse clicks. By default, `NSView` objects return `NO` for this method—most views don't accept typed input. But some do, and they should override `acceptsFirstResponder` to return `YES`. A UIKit example is the `layerClass` class method of `UIView`; if you do not want the default layer class for the view, you can override the method and substitute your own.

- Some methods must be overridden, but only to add something, not to replace what the framework implementation of the method does. The subclass version of the method augments the behavior of the superclass version. When your program implements one of these methods, it's important that it incorporate the very method it overrides. It does this by sending a message to `super` (the superclass), invoking the framework-defined version of the method.

  Often this kind of method is one that every class in a chain of inheritance is expected to contribute to. For example, objects that archive themselves must conform to the `NSCoding` protocol and implement the `initWithCoder:` and `encodeWithCoder:` methods. But before a class performs the encoding or decoding that is specific to its instance variables, it must invoke the superclass version of the method.

  Sometimes a subclass version of a method wants to reuse the superclass behavior and then add something, however small, to the final result. In the `NSView` method `drawRect:`, for example, a subclass of a view class that performs some complicated drawing might want to draw a border around the drawing, so it would invoke `super` first.

- Some framework methods do nothing at all or merely return some trivial default value (such as `self`) to prevent runtime or compile-time errors. These methods are meant to be overridden. The framework cannot define these methods even in rudimentary form because they carry out tasks that are entirely program-specific. There's no need to incorporate the framework implementation of the method with a message to `super`.

  Most methods that a subclass overrides belong in this group. For example, the `NSDocument` methods `dataOfType:error:` and `readFromData:ofType:error:` (among others) must be overridden when you create a document-based application.

Overriding a method does not have to be a formidable task. You can often make significant change in superclass behavior by a careful reimplementation of the method that entails no more than one or two lines of code. And you are not entirely on your own when you implement your own version of a method. You can draw on the classes, methods, functions, and types already provided by the Cocoa frameworks.

When to Make a Subclass

Just as important as knowing which methods of a class to override—and indeed preceding that decision—is identifying those classes to inherit from. Sometimes these decisions can be obvious, and sometimes they can be far from simple. A few design considerations can guide your choices.

First, know the framework. You should become familiar with the purpose and capabilities of each class in the framework. Maybe there is a class that already does what you want to do. And if you find a class that does *almost* what you want done, you're in luck. That class is a promising superclass for your custom class. Subclassing is a process of reusing an existing class and specializing it for your needs. Sometimes all a subclass needs to do is override a single inherited method and have the method do something slightly different from the original behavior. Other subclasses might add one or two attributes to their superclass (as instance variables), and then define the methods that access and operate on these attributes, integrating them into the superclass behavior.

There are other considerations that can help you decide where your subclass best fits into the class hierarchy. What is the nature of the application, or of the part of the application you're trying to craft? Some Cocoa architectures impose their own subclassing requirements. For example, if yours is a multiple-document application in OS X, the document-based architecture defined by AppKit requires you to subclass `NSDocument` and perhaps other classes as well. To make your Mac app scriptable (that is, responsive to AppleScript commands), you might have to subclass one of the scripting classes of AppKit, such as `NSScriptCommand`.

Another factor is the role that instances of the subclass will play in the application. The Model-View-Control design pattern, a major one in Cocoa, assigns roles to objects: They're view objects that appear on the user interface; model objects holding application data (and the algorithms that act on that data); or controller objects, which mediate between view and model objects. (For details, see "The Model-View-Controller Design Pattern" (page 193).) Knowing what role an object plays can narrow the decision for which superclass to use. If instances of your class are view objects that do their own custom drawing and event-handling, your class should probably inherit from `NSView` (if you are using AppKit) or from `UIView` (if you are using UIKit). If your application needs a controller object, you can either use one of the off-the-shelf controller classes of AppKit (such as `NSObjectController`) or, if you want a different behavior, subclass `NSController` or `NSObject`. If your class is a typical model class—say, one whose objects represent rows of corporate data in a spreadsheet—you probably should subclass `NSObject` or use the Core Data framework.

iOS Note The controller classes of the AppKit framework, including `NSController`, have no counterparts in UIKit. There are controller classes in UIKit—`UIViewController`, `UITableViewController`, `UINavigationController`, and `UITabBarController`—but these classes are based on a different design and have a different purpose—application navigation and mode selection (see "View Controllers in UIKit" (page 181) for a summary).

Subclassing is sometimes not the best way to solve a problem. There may be a better approach you could take. If you just want to add a few convenience methods to a class, you might create a category instead of a subclass. Or you could employ one of the many other design-pattern–based resources of the Cocoa development toolbox, such as delegation, notification, and target-action (described in "Communicating with Objects" (page 209)). When deciding on a candidate superclass, scan the header file of the class (or scan the reference documentation) to see if there is a delegation method, a notification, or some other mechanism that will enable you to do what you want without subclassing.

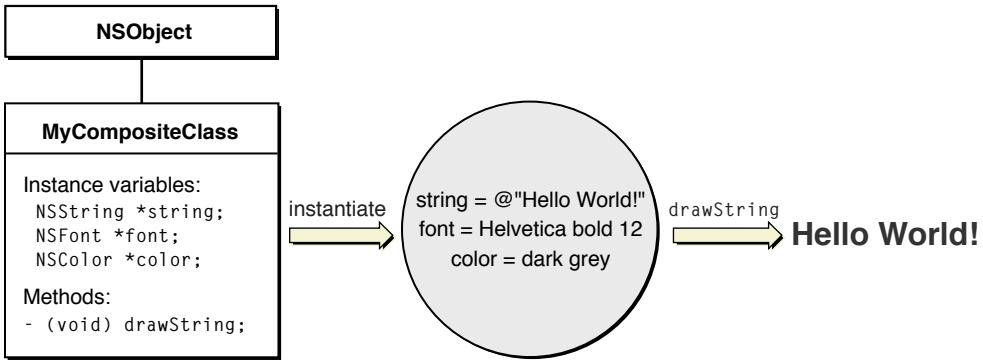
In a similar vein, you can also examine the header files or documentation for the framework's protocols. By adopting a protocol, you might be able to accomplish your goal while avoiding the difficulties of a complex subclass. For example, if you want to manage the enabled states of menu items, you can adopt the `NSMenuValidation` protocol in a custom controller class; you don't have to subclass `NSMenuItem` or `NSMenu` to get this behavior.

Just as some framework methods are not intended to be overridden, some framework classes (such as `NSFileManager` in AppKit and `UIWebView` in UIKit) are not intended to be subclassed. If you do attempt such a subclass, you should proceed with caution. The implementations of certain framework classes are complicated and tightly integrated into the implementations of other classes and even different parts of the operating system. Often it is difficult to duplicate correctly what a framework method does or to anticipate interdependencies or effects the method might have. Changes that you make in some method implementations could have far-reaching, unforeseen, and unpleasant consequences.

In some cases, you can get around these difficulties by using object composition, a general technique of assembling objects in a "host" object, which manages them to get complex and highly customized behavior (see Figure 3-3). Instead of inheriting directly from a complex framework superclass, you might create a custom class that holds an instance of that superclass as an instance variable. The custom class itself could be fairly simple, perhaps inheriting directly from the root class, `NSObject`; although simple in terms of inheritance, the class manipulates, extends, and augments the embedded instance. To client objects it can appear in some respects to be a subclass of the complex superclass, although it probably won't share the interface of the superclass. The Foundation framework class `NSAttributedString` gives an example of object composition. `NSAttributedString` holds an `NSString` object as an instance variable, and exposes it through the `string` method. `NSString` is a class with complex behaviors, including string encoding, string searching, and path

manipulation. `NSAttributedString` augments these behaviors with the capability for attaching attributes such as font, color, alignment, and paragraph style to a range of characters. And it does so without subclassing `NSString`.

Figure 3-3 Object composition



Basic Subclass Design

All subclasses, regardless of ancestor or role, share certain characteristics when they are well designed. A poorly designed subclass is susceptible to error, hard to use, difficult to extend, and a drag on performance. A well-designed subclass is quite the opposite. This section offers suggestions for designing subclasses that are efficient, robust, and both usable and reusable.

> **Further Reading** Although this document describes some of the mechanics of crafting a subclass, it focuses primarily on basic design. It does not describe how you can use the development applications Xcode and Interface Builder to automate part of class definition. To start learning about these applications, read *A Tour of Xcode* . The design information presented in this section is particularly applicable to model objects. *Model Object Implementation Guide* discusses the proper design and implementation of model objects at length.

The Form of a Subclass Definition

An Objective-C class consists of an interface and an implementation. By convention, these two parts of a class definition go in separate files. The name of the interface file (as with ANSI C header files) has an extension of `.h`; the name of the implementation file has an extension of `.m`. The name of the file up to the extension is typically the name of the class. Thus for a class named `Controller`, the files would be:

```
Controller.h
Controller.m
```

The interface file contains a list of property, method, and function declarations that establish the public interface of the class. It also holds declarations of instance variables, constants, string globals, and other data types. The directive `@interface` introduces the essential declarations of the interface, and the `@end` directive terminates the declarations. The `@interface` directive is particularly important because it identifies the name of the class and the class directly inherited from, using the form:

`@interface` *ClassName* `:` *Superclass*

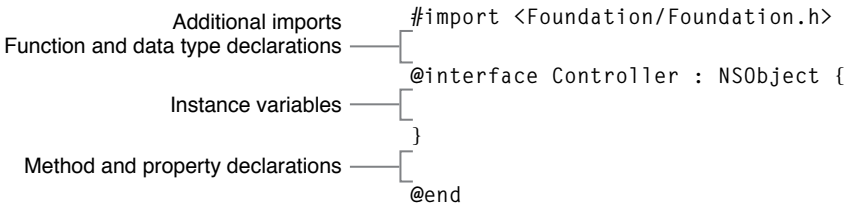
Listing 3-2 gives an example of the interface file for the hypothetical `Controller` class, before any declarations are made.

Listing 3-2 The basic structure of an interface file

```
#import <Foundation/Foundation.h>


@interface Controller : NSObject {

}

@end
```

To complete the class interface, you must make the necessary declarations in the appropriate places in this interface structure, as shown in Figure 3-4.

Figure 3-4 Where to put declarations in the interface file



See "Instance Variables" (page 141) and "Functions, Constants, and Other C Types" (page 158) for more information about these types of declarations.

You begin the class interface by importing the appropriate Cocoa frameworks as well as the header files for any types that appear in the interface. The `#import` preprocessor command is similar to `#include` in that it incorporates the specified header file. However, `#import` improves on efficiency by including the file only if

it was not previously included, directly or indirectly, for compilation. The angle brackets (`<...>`) following the command identify the framework the header file is from and, after a slash character, the header file itself. Thus the syntax for an `#import` line takes the form:

`#import <`*Framework*`/`*File*`.h>`

The framework must be in one of the standard system locations for frameworks. In the example in Listing 3-2 (page 139), the class interface file imports the file `Foundation.h` from the Foundation framework. As in this case, the Cocoa convention is that the header file having the same name as the framework contains a list of `#import` commands that include all the public interfaces (and other public headers) of the framework. Incidentally, if the class you're defining is part of an application, all you need to do is import the `Cocoa.h` file of the Cocoa umbrella framework.

If you must import a header file that is part of your project, use quotation marks rather than angle brackets as delimiters; for example:

```
#import "MyDataTypes.h"
```

The class implementation file has a simpler structure, as shown by Listing 3-3. It is important that the class implementation file begin by importing the class interface file.

Listing 3-3 The basic structure of an implementation file

```
#import "Controller.h"



@implementation Controller



@end
```

You must write all method and property implementations between the `@implementation` and `@end` directives. The implementations of functions related to the class can go anywhere in the file, although by convention they are also put between the two directives. Declarations of private types (functions, structures, and so on) typically go between the `#import` commands and the `@implementation` directive.

Overriding Superclass Methods

Custom classes, by definition, modify the behavior of their superclass in some program-specific way. Overriding superclass methods is usually the way to effect this change. When you design a subclass, an essential step is identifying the methods you are going to override and thinking about how you are going to reimplement them.

Although "When to Override a Method" (page 133) offers some general guidelines, identifying which superclass methods to override requires you to investigate the class. Peruse the header files and documentation of the class. Also locate the designated initializer of the superclass because, for initialization to succeed, you must invoke the superclass version of this method in your class's designated initializer. (See "Object Creation" (page 89) for details.)

Once you have identified the methods, you can start—from a purely practical standpoint—by copying the declarations of the methods to be overridden into your interface file. Then copy those same declarations into your `.m` file as skeletal method implementations by replacing the terminating semicolon with enclosing braces.

Remember, as discussed in "When to Override a Method" (page 133), a Cocoa framework (and not your own code) usually invokes the framework methods that you override. In some situations you need to let the framework know that it should invoke your overridden version of a method and not the original method. Cocoa gives you various ways to accomplish this. The Interface Builder application, for example, allows you to substitute your class for a (compatible) framework class in its Info (inspector) window. If you create a custom `NSCell` class, you can associate it with a particular control using the `setCell:` method of the `NSControl` class.

Instance Variables

The reason for creating a custom class, aside from modifying the behavior of the superclass, is to add properties to it. (The word *properties* here is intended in a general sense, indicating both the attributes of an instance of the subclass and the relationships that instance has to other objects.) Given a hypothetical `Circle` class, if you are going to make a subclass that adds color to the shape, the subclass must somehow carry the attribute of color. To accomplish this, you might add a `color` instance variable (most likely typed as an `NSColor` object for a Mac app, or a `UIColor` object for an iOS application) to the class interface. Instances of your custom class encapsulate the new attribute, holding it as a persistent, characterizing piece of data.

Instance variables in Objective-C are declarations of objects, structures, and other data types that are part of the class definition. If they are objects, the declaration can either dynamically type (using `id`) or statically type the object. The following example shows both styles:

```
id delegate;
NSColor *color;
```

Generally, you dynamically type an object instance variable when the class membership of the object is indeterminate or unimportant. Objects held as instance variables should be created, copied, or explicitly retained—unless they are already retained by a parent object. If an instance is unarchived, it should retain its object instance variables as it decodes and assigns them in `initWithCoder:`. (For more on object archiving and unarchiving, see "Entry and Exit Points" (page 143).)

The convention for naming instance variables is to make them a lowercase string containing no punctuation marks or special characters. If the name contains multiple words, run them together, but make the first letter of the second and each succeeding word uppercase. For example:

```
NSString *title;
UIColor *backgroundColor;
NSRange currentSelectedRange;
```

When the tag `IBOutlet` precedes the declarations of instance variables, it identifies an outlet with (presumably) a connection archived in a nib file. The tag also enables Interface Builder and Xcode to synchronize their activities. When outlets are unarchived from an Interface Builder nib file, the connections are automatically reestablished. ("Communicating with Objects" (page 209) discusses outlets in more detail.)

Instance variables can hold more than an object's attributes, vendable to clients of the object. Sometimes instance variables can hold private data that is used as the basis for some task performed by the object; a backing store or a cache are examples. (If data is not per-instance, but is to be shared among instances of a class, use global variables instead of instance variables.)

When you add instance variables to a subclass, follow these guidelines:

- Add only instance variables that are absolutely necessary. The more instance variables you add, the more the instance size swells. And the more instances of your class that are created, the more of a concern this becomes. If it's possible, compute a critical value from existing instance variables rather than add another instance variable to hold that value.
- Again, for economy represent the instance data of the class efficiently. For example, if you want to specify a number of flags as instance variables, use a bit field instead of a series of Boolean declarations. (Be aware, however, that there are archiving complications with bit fields). You might use an `NSDictionary` object to consolidate a number of related attributes as key-value pairs; if you do this, make sure that the keys are adequately documented.
- Give the proper scope to your instance variables. Never scope a variable as `@public` as this violates the principle of encapsulation. Use `@protected` for instance variables if you know which are the likely subclasses of your class (such as the classes of your application) and you require efficient access of data. Otherwise, `@private` is a reasonable choice for the high degree of implementation hiding it provides.

This implementation hiding is especially important for classes exposed by a framework and used by applications or other frameworks; it permits the modification of the class implementation without the need to recompile all clients.

- Make sure there are declared properties or accessor methods for those instance variables that are essential attributes or relationships of the class. Accessor methods and declared properties preserve encapsulation by enabling the values of instance variables to be set and retrieved. See "Storing and Accessing Properties" (page 146) for more information on this subject.
- If you intend your subclass to be public—that is, you anticipate that others might subclass it—pad the end of the instance variable list with a reserved field, usually typed as `id`. This reserved field helps to ensure binary compatibility if, at any time in the future, you need to add another instance variable to the class. See "When the Class Is Public (OS X)" (page 159) for more information on preparing public classes.

Entry and Exit Points

The Cocoa frameworks send messages to an object at various points in the object's life. Almost all objects (including classes, which are really objects themselves) receive certain messages at the beginning of their runtime life and just before their destruction. The methods invoked by these messages (if implemented) are hooks that allow the object to perform tasks relevant to the moment. These methods are (in the order of invocation):

1. `initialize`—This class method enables a class to initialize itself before it or its instances receive any other messages. Superclasses receive this message before subclasses. Classes that use the old archiving mechanism can implement `initialize` to set their class version. Other possible uses of `initialize` are registering a class for some service and initializing some global state that is used by all instances. However, sometimes it's better to do these kinds of tasks lazily (that is, the first time they're needed) in an instance method rather than in `initialize`.
2. `init` (or other initializer)—You must implement `init` or some other primary initializer to initialize the state of the instance unless the work done by the superclass's designated initializer is sufficient for your class. See "Object Creation" (page 89) for information on initializers, including designated initializers.
3. `initWithCoder:`—If you expect objects of your class to be archived—for example, yours is a model class— you should adopt (if necessary) the `NSCoding` protocol and implement its two methods, `initWithCoder:` and `encodeWithCoder:`. In these methods you must decode and encode, respectively, the instance variables of the object in a form suitable for an archive. You can use the decoding and encoding methods of `NSCoder` for this purpose or the key-archiving facilities of `NSKeyedArchiver` and `NSKeyedUnarchiver`. When the object is being unarchived instead of being explicitly created, the `initWithCoder:` method is invoked instead of the initializer. In this method, after decoding the instance-variable values, you assign them to the appropriate variables, retaining or copying them if necessary. For more on this subject, see *Archives and Serializations Programming Guide*.

4. `awakeFromNib`—When an application loads a nib file, an `awakeFromNib` message is sent to each object loaded from the archive, but only if it can respond to the message, and only after all the objects in the archive have been loaded and initialized. When an object receives an `awakeFromNib` message, it's guaranteed to have all its outlet instance variables set. Typically, the object that owns the nib file (File's Owner) implements `awakeFromNib` to perform programmatic initializations that require outlet and target-action connections to be set.
5. `encodeWithCoder:`—Implement this method if instances of your class should be archived. This method is invoked just prior to the destruction of the object. See the description of `initWithCoder:` above.
6. `dealloc` or `finalize`—In memory-managed programs, implement the `dealloc` method to release instance variables and deallocate any other memory claimed by an instance of your class. The instance is destroyed soon after this method returns. In garbage-collected code, you may need to implement the `finalize` method instead. See "The dealloc and finalize Methods" (page 98) for further information.

An application's singleton application object (stored by AppKit in the global variable `NSApp`) also sends messages to an object—if it's the application object's delegate and it implements the appropriate methods—at the beginning and end of the application's life. Just after the application launches, the application object sends its delegate the following messages, depending on the framework and platform:

- In AppKit, the application object sends `applicationWillFinishLaunching:` and `applicationDidFinishLaunching:` to the delegate. The former is sent just before any double-clicked document is opened, the latter just afterward.
- In UIKit, the application object sends `application:didFinishLaunchingWithOptions:` to the delegate.

In these methods the delegate can restore application state and specify global application logic that needs to happen just once early in the application's runtime existence. Just before it terminates, the application object for both frameworks sends `applicationWillTerminate:` to its delegate, which can implement the method to gracefully handle program termination by saving documents and (particularly in iOS) application state.

The Cocoa frameworks give you numerous other hooks for events ranging from view loading to application activation and deactivation. Sometimes these are implemented as delegation messages and require your object to be the delegate of the framework object and to implement the required method. Sometimes the hooks are notifications. In iOS, they can be methods inherited from the `UIViewController` that controllers override. (See "Communicating with Objects" (page 209) for more on delegation and notification.)

Initialize or Decode?

If you want objects of your class to be archived and unarchived, the class must conform to the `NSCoding` protocol; it must implement the methods that encode its objects (`encodeWithCoder:`) and decode them (`initWithCoder:`). Instead of an initializer method or methods, the `initWithCoder:` method is invoked to initialize an object being created from an archive.

Because the class's initializer method and `initWithCoder:` might be doing much of the same work, it makes sense to centralize that common work in a helper method called by both the initializer and `initWithCoder:`. For example, if as part of its set-up routine, an object specifies drag types and dragging source, it might implement something such as shown in Listing 3-4.

Listing 3-4 Initialization helper method

```
 (id)initWithFrame:(NSRect)frame {
    self = [super initWithFrame:frame];
    if (self) {
        [self setTitleColor:[NSColor lightGrayColor]];
        [self registerForDragging];
    }
    return self;
}
- (id)initWithCoder:(NSCoder *)aCoder {
    self = [super initWithCoder:aCoder];
    titleColor = [[aCoder decodeObject] copy];
    [self registerForDragging];
    return self;
}

- (void)registerForDragging {
    [theView registerForDraggedTypes:
        [NSArray arrayWithObjects:DragDropSimplePboardType, NSStringPboardType,
        NSFilenamesPboardType, nil]];
    [theView setDraggingSourceOperationMask:NSDragOperationEvery forLocal:YES];
}
```

An exception to the parallel roles of a class initializer and `initWithCoder:` is when you create a custom subclass of a framework class whose instances appear on an Interface Builder palette. The general procedure is to define the class in your project, drag the object from the Interface Builder palette into your interface, and then associate that object with your custom subclass using the Custom Class pane of the Interface Builder Info window. However, in this case the `initWithCoder:` method for the subclass is not invoked during unarchiving; an `init` message is sent instead. You should perform any special set-up tasks for your custom object in `awakeFromNib`, which is invoked after all objects in a nib file have been unarchived.

Storing and Accessing Properties

The word *property* has both a general and a language-specific meaning in Cocoa. The general notion comes from the design pattern of object modeling. The language-specific meaning relates to the language feature of declared properties.

As described in "Object Modeling" (page 202), a property is a defining characteristic of an object (called in the object modeling pattern an *entity*) and is part of its encapsulated data. A property can be of two sorts: an attribute, such as title and location, or a relationship. Relationships can be to-one or to-many, and can take many forms, such as an outlet, a delegate, or a collection of other objects. Properties are usually, but not always, stored as instance variables.

Part of the overall strategy for a well-designed class is to enforce encapsulation. Client objects should not be able to directly access properties where they are stored, but instead access them through the interface of the class. The methods that grant access to the properties of an object are called *accessor methods*. Accessor methods (or, simply, accessors) get and set the values of an object's properties. They function as the gates to those properties, regulating access to them and enforcing the encapsulation of the object's instance data. The accessor method that gets a value is, by convention, called a *getter* method and the method that sets a property's value is called a *setter* method.

The declared properties feature (introduced in Objective-C 2.0) has brought changes, some subtle, to how you control access to properties. A declared property is a syntactical shorthand for declaring the getter and setter methods of a class's property. In the implementation block you can then request the compiler to synthesize those methods. As summarized in "Declared Properties" (page 69), you declare a property, using the `@property` directive, in the `@interface` block of a class definition. The declaration specifies the name and type of the property and may include qualifiers that tell the compiler *how* to implement the accessor methods.

When you design a class, several factors affect how you might store and access the properties of the class. You may choose to use the declared properties feature and have the compiler synthesize accessor methods for you. Or you may elect to implement the class's accessor methods yourself; this is an option even if you do use declared properties. Another important factor is whether your code operates in a garbage-collected environment.

If the garbage collector is enabled, the implementation of accessor methods is much simpler than it is in memory-managed code. The following sections describe the various alternatives for storing and accessing properties.

Taking Advantage of Declared Properties

Unless you have a compelling reason to do otherwise, it is recommended that you use the declared properties feature of Objective-C 2.0 in new projects rather than manually writing all of your own accessor methods. First, declared properties relieve you of the tedious burden of accessor-method implementation. Second, by having the compiler synthesize accessor methods for you, you reduce the possibility of programming errors and ensure more consistent behavior in your class implementation. And finally, the declarative style of declared properties makes your intent clear to other developers.

You might declare some properties with `@property` but still need to implement your own accessor methods for them. The typical reason for doing this is wanting the method to do something more than simply get or set the value of the property. For example, the resource for an attribute—say, a large image file—has to be loaded from the file system, and for performance reasons you want your getter method to load the resource lazily (that is, the first time it is requested). If you have to implement an accessor method for such a reason, see "Implementing Accessor Methods" (page 150) for tips and guidelines. You tell the compiler not to synthesize accessor methods for a property either by designating that property with a `@dynamic` directive in the class's `@implementation` block or by simply not specifying a `@synthesize` directive for the property (`@dynamic` is the default); the compiler refrains from synthesizing an accessor method if it sees that such a method already exists in the implementation and there is no `@synthesize` directive for it.

If garbage collection is disabled for your program, the attribute you use to qualify your property declarations is important. By default (the `assign` attribute), a synthesized setter method performs simple assignment, which is appropriate for garbage-collected code. But in memory-managed code, simple assignment is not appropriate for properties with object values. You must either retain or copy the assigned object in your setter method; you tell the compiler to do this when you qualify a property declaration with a `retain` or `copy` attribute. Note that you should *always* specify the `copy` attribute for an object property whose class conforms to the `NSCopying` protocol, even if garbage collection is enabled.

The following examples illustrate a variety of behaviors you can achieve with property declarations (with different sets of qualifying attributes) in the `@interface` block and `@synthesize` and `@dynamic` directives in the `@implementation` block. The following code instructs the compiler to synthesize accessor methods for the declared `name` and `accountID` properties; because the `accountID` property is read-only, the compiler synthesizes only a getter method. In this case, garbage collection is assumed to be enabled.

```
@interface MyClass : NSObject {
    NSString *name;
    NSNumber *accountID;
```

```
}
@property (copy) NSString *name;
@property (readonly) NSNumber *accountID;
// ...
@end
@implementation MyClass
@synthesize name, accountID;
// ...
@end
```

Note As shown in this and subsequent code examples, a property in a 32-bit process must be backed by an instance variable. In a program with a 64-bit address space, properties do not have to be backed by instance variables.

The following code illustrates another aspect of declared properties. The assumption is that garbage collection is not enabled, so the declaration for the `currentHost` property has a `retain` attribute, which instructs the compiler to retain the new value in its synthesized getter method. In addition, the declaration for the `hidden` property includes a qualifying attribute that instructs the compiler to synthesize a getter method named `isHidden`. (Because the value of this property is a non-object value, simple assignment is sufficient in the setter method.)

```
@interface MyClass : NSObject {
    NSHost *currentHost;
    Boolean *hidden;
}
@property (retain, nonatomic) NSHost *currentHost;
@property (getter=isHidden, nonatomic) Boolean *hidden;
// ...
@end
@implementation MyClass
@synthesize currentHost, hidden;
// ...
@end
```

Note This example specifies the `nonatomic` attribute for the properties, a change from the default `atomic`. When a property is `atomic`, its synthesized getter method is guaranteed to return a valid value, even when other threads are executing simultaneously. See the discussion of properties in *The Objective-C Programming Language* for a discussion of atomic versus nonatomic properties, especially with regard to performance. For more on thread-safety issues, see *Threading Programming Guide*.

The property declaration in the following example tells the compiler that the `previewImage` property is read-only so that it won't expect to find a setter method. By using the `@dynamic` directive in the `@implementation` block, it also instructs the compiler not to synthesize the getter method, and then provides an implementation of that method.

```
@interface MyClass : NSObject {
    NSImage *previewImage;
}
@property (readonly) NSImage *previewImage;
// ...
@end
@implementation MyClass
@dynamic previewImage;
// ...
- (NSImage *)previewImage {
    if (previewImage == nil) {
        // lazily load image and assign to ivar
    }
   return previewImage;
}
// ...
@end
```

Further Reading Read "Declared Properties" in *The Objective-C Programming Language* for the definitive description of declared properties and for guidelines on using them in your code.

Implementing Accessor Methods

For reasons of convention—and because it enables classes to be compliant with key-value coding (see "Key-Value Mechanisms" (page 153))—the names of accessor methods must have a specific form. For a method that returns the value of an instance variable (sometimes called the *getter*), the name of the method is simply the name of the instance variable. For a method that sets the value of an instance variable (the *setter*), the name begins with "set" and is immediately followed by the name of the instance variable (with the first letter uppercase). For example, if you had an instance variable named "color," the declarations of the getter and setter accessors would be:

```
- (NSColor *)color;
- (void)setColor:(NSColor *)aColor;
```

With Boolean attributes a variation of the form for getter methods is acceptable. The syntax in this case would take the form `is`*Attribute*. For example, a Boolean instance variable named `hidden` would have a `isHidden` getter method and a `setHidden:` setter method.

If an instance variable is a scalar C type, such as `int` or `float`, the implementations of accessor methods tend to be very simple. Assuming an instance variable named `currentRate`, of type `float`, Listing 3-5 shows how to implement the accessor methods.

Listing 3-5 Implementing accessors for a scalar instance variable

```
- (float)currentRate {
    return currentRate;
}

- (void)setCurrentRate:(float)newRate {
    currentRate = newRate;
}
```

If garbage collection is enabled, implementation of the setter accessor method for properties with object values is also a matter of simple assignment. Listing 3-6 shows how you would implement such methods.

Listing 3-6 Implementing accessors for an object instance variable (garbage collection enabled)

```
- (NSString *)jobTitle {
    return jobTitle;
}

- (void)setJobTitle:(NSString *)newTitle {
    jobTitle = newTitle;
}
```

When instance variables hold objects and garbage collection is not enabled, the situation becomes more nuanced. Because they are instance variables, these objects must be persistent and so must be created, copied, or retained when they are assigned. When a setter accessor changes the value of an instance variable, it is responsible not only for ensuring persistence but for properly disposing of the old value. The getter accessor vends the value of the instance variable to the object requesting it. The operations of both types of accessors have implications for memory management given two assumptions from the Cocoa object-ownership policy:

- Objects returned from methods (such as from getter accessors) are valid in the scope of the invoking object. In other words, it is guaranteed that the object will not be released or change value within that scope (unless documented otherwise).
- When an invoking object receives an object from a method such as an accessor, it should not release the object unless it has explicitly retained (or copied) it first.

With these two assumptions in mind, let's look at two possible implementations of a getter and setter accessor for an `NSString` instance variable named `title`. Listing 3-7 shows the first.

Listing 3-7 Implementing accessors for an object instance variable—good technique

```
- (NSString *)title {
    return title;
 }
 - (void)setTitle:(NSString *)newTitle {
    if (title != newTitle) {
        [title autorelease];
        title = [newTitle copy];
    }
 }
```

Note that the getter accessor simply returns a reference to the instance variable. The setter accessor, on the other hand, is busier. After verifying that the passed-in value for the instance variable isn't the same as the current value, it autoreleases the current value before copying the new value to the instance variable. (Sending `autorelease` to the object is "more thread-safe" than sending it `release`.) However, there is still a potential danger with this approach. What if a client is using the object returned by the getter accessor and meanwhile the setter accessor autoreleases the old `NSString` object and then, soon after, that object is released and destroyed? The client object's reference to the instance variable would no longer be valid.

Listing 3-8 shows another implementation of the accessor methods that works around this problem by retaining and then autoreleasing the instance variable value in the getter method.

Listing 3-8 Implementing accessors for an object instance variable—better technique

```
- (NSString *)title {
    return [[title retain] autorelease];
}
- (void)setTitle:(NSString *)newTitle {
    if (title != newTitle) {
        [title release];
        title = [newTitle copy];
    }
}
```

In both examples of the setter method above (Listing 3-5 and Listing 3-7), the new `NSString` instance variable is copied rather than retained. Why isn't it retained? The general rule is this: When the object assigned to an instance variable is a value object—that is, an object that represents an attribute such as a string, date, number, or corporate record—you should copy it. You are interested in preserving the attribute value, and don't want to risk having it mutate from under you. In other words, you want your own copy of the object.

However, if the object to be stored and accessed is an entity object, such as an `NSView` or an `NSWindow` object, you should retain it. Entity objects are more aggregate and relational, and copying them can be expensive. One way to determine whether an object is a value object or entity object is to decide whether you're interested in the value of the object or in the object itself. If you're interested in the value, it's probably a value object and you should copy it (assuming, of course, the object conforms to the `NSCopying` protocol).

Another way to decide whether to retain or copy an instance variable in a setter method is to determine whether the instance variable is an attribute or a relationship. This is especially true for model objects, which are objects that represent the data of an application. An attribute is essentially the same thing as a value object: an object that is a defining characteristic of the object that encapsulates it, such as a color (`NSColor` object)

or title (`NSString` object). A relationship on the other hand is just that: a relationship with (or a reference to) one or more other objects. Generally, in setter methods you copy the values of attributes and you retain relationships. However, relationships have a cardinality; they can be one-to-one or one-to-many. One-to-many relationships, which are typically represented by collection objects such as `NSArray` instances or `NSSet` instances, may require setter methods to do something other than simply retain the instance variable. See *Model Object Implementation Guide* for details. For more on object properties as either attributes or relationships, see "Key-Value Mechanisms" (page 153).

> **Important** If you are implementing a getter accessor method to load the value of an instance variable value lazily—that is, when it is first requested—do *not* call the corresponding setter method in your implementation. Instead, set the value of the instance variable directly in the getter method.

If the setter accessors of a class are implemented as shown in either Listing 3-5 (page 150) or Listing 3-7 (page 151), to deallocate an instance variable in the class's `dealloc` method, all you need to do is invoke the appropriate setter method, passing in `nil`.

Key-Value Mechanisms

Several mechanisms with "key-value" in their names are fundamental parts of Cocoa: key-value binding, key-value coding, and key-value observing. They are essential ingredients of Cocoa technologies such as bindings, which automatically communicate and synchronize values between objects. They also provide at least part of the infrastructure for making applications scriptable—that is, responsive to AppleScript commands. Key-value coding and key-value observing are especially important considerations in the design of a custom subclass.

> **iOS Note** The controller classes used in bindings (`NSController` and subclasses) and in application scriptability are defined only by AppKit and not by UIKit.

The term *key-value* refers to the technique of using the name of a property as the key to obtain its value. The term is part of the vocabulary of the object modeling pattern, which is briefly discussed in "Storing and Accessing Properties" (page 146). Object modeling derives from the entity-relationship modeling used for describing relational databases. In object modeling, objects—particularly the data-bearing model objects of the Model-View-Controller pattern—have properties, which usually (but not always) take the form of instance variables. A property can either be an attribute, such as name or color, or it can be a reference to one or more other objects. These references are known as *relationships*, and relationships can be one-to-one or one-to-many. The network of objects in a program form an object graph through their relationships with each other. In object modeling you can use key paths—strings of dot-separated keys—to traverse the relationships in an object graph and access the properties of objects.

> **Note** For a full description of object modeling, see "Object Modeling" (page 202).

Key-value binding, key-value coding, and key-value observing are enabling mechanisms for this traversal.

- Key-value binding (KVB) establishes bindings between objects and also removes and advertises those bindings. It makes use of several informal protocols. A binding for a property must specify the object and a key path to the property.
- Key-value coding (KVC), through an implementation of the `NSKeyValueCoding` informal protocol, makes it possible to get and set the values of an object's properties through keys without having to invoke that object's accessor methods directly. (Cocoa provides a default implementation of the protocol.) A key typically corresponds to the name of an instance variable or accessor method in the object being accessed.
- Key-value observing (KVO), through an implementation of the `NSKeyValueObserving` informal protocol, allows objects to register themselves as observers of other objects. The observed object directly notifies its observers when there are changes to one of its properties. Cocoa implements automatic observer notifications for each property of a KVO-compliant object.

To make each property of a subclass compliant with the requirements of key-value coding, do the following:

- For an attribute or a to-one relationship named *key*, implement accessor methods named *key* (getter) and `set`*Key*`:` (setter). For example, if you have a property named `salary`, you would have accessor methods `salary` and `setSalary:`. (If the compiler synthesizes a declared property, it follows this pattern, unless instructed otherwise.)
- For a to-many relationship, if the property is based on an instance variable that is a collection (for example, an `NSArray` object) or an accessor method that returns a collection, give the getter method the same name as the property (for example, `employees`). If the property is mutable, but the getter method doesn't return a mutable collection (such as `NSMutableArray`), you must implement `insertObject:in`*Key*`AtIndex:` and `removeObjectFrom`*Key*`AtIndex:`. If the instance variable is not a collection and the getter method does not return a collection, you must implement other `NSKeyValueCoding` methods.

To make your object KVO-compliant, simply ensure that your object is KVC-compliant if you are satisfied with automatic observer notification. However, you may choose to implement manual key-value observing, which requires additional work.

Further Reading Read *Key-Value Coding Programming Guide* and *Key-Value Observing Programming Guide* to learn more about these technologies. For a summary of the Cocoa bindings technology, which uses KVC, KVO, and KVB, see "Bindings (OS X)" (page 224) in "Communicating with Objects" (page 209).

Object Infrastructure

If a subclass is well-designed, instances of that class will behave in ways expected of Cocoa objects. Code using the object can compare it to other instances of the class, discover its contents (for example, in a debugger), and perform similar basic operations with the object.

Custom subclasses should implement most, if not all, of the following root-class and basic protocol methods:

- `isEqual:` and `hash`—Implement these `NSObject` methods to bring some object-specific logic to their comparison. For example, if what individuates instances of your class is their serial number, make that the basis for equality. For further information, see "Introspection" (page 101).
- `description`—Implement this `NSObject` method to return a string that concisely describes the properties or contents of the object. This information is returned by the `print object` command in the `gdb` debugger and is used by the `%@` specifier for objects in formatted strings. For example, say you have a hypothetical `Employee` class with attributes for name, date of hire, department, and position ID. The description method for this class might look like the following:

```
- (NSString *)description {
    return [NSString stringWithFormat:@"Employee:Name = %@,
        Hire Date = %@, Department = %@, Position = %i\n", [self name],
        [[self dateOfHire] description], [self department],
        [self position]];
}
```

- `copyWithZone:`—If you expect clients of your subclass to copy instances of it, you should implement this method of the `NSCopying` protocol. Value objects, including model objects, are typical candidates for copying; objects such as `UITableView` and `NSColorPanel` are not. If instances of your class are mutable, you should instead conform to the `NSMutableCopying` protocol.
- `initWithCoder:` and `encodeWithCoder:`—If you expect instances of your class to be archived (for example, as with a model class), you should adopt the `NSCoding` protocol (if necessary) and implement these two methods. See "Entry and Exit Points" (page 143) for more on the `NSCoding` methods.

If any of the ancestors of your class adopts a formal protocol, you must also ensure that your class properly conforms to the protocol. That is, if the superclass implementation of any of the protocol methods is inadequate for your class, your class should reimplement the methods.

Error Handling

It is axiomatic for any programming discipline that the programmer should properly handle errors. However, what is proper often varies by programming language, application environment, and other factors. Cocoa has its own set of conventions and prescriptions for handling errors in subclass code.

- If the error encountered in a method implementation is a system-level or Objective-C runtime error, create and raise an exception, if necessary, and handle it locally, if possible.

  In Cocoa, exceptions are typically reserved for programming or *unexpected* runtime errors such as out-of-bounds collection access, attempts to mutate immutable objects, sending an invalid message, and losing the connection to the window server. You usually take care of these errors with exceptions when an application is being created rather than at runtime. Cocoa predefines several exceptions that you can catch with an exception handler. For information on predefined exceptions and the procedure and API for raising and handling exceptions, see *Exception Programming Topics*.

- For other sorts of errors, including *expected* runtime errors, return `nil`, `NO`, `NULL`, or some other type-suitable form of zero to the caller. Examples of these errors include the inability to read or write a file, a failure to initialize an object, the inability to establish a network connection, or a failure to locate an object in a collection. Use an `NSError` object if you feel it necessary to return supplemental information about the error to the sender.

  An `NSError` object encapsulates information about an error, including an error code (which can be specific to the Mach, POSIX, or `OSStatus` domains) and a dictionary of program-specific information. The negative value that is directly returned (`nil`, `NO`, and so on) should be the principal indicator of error; if you do communicate more specific error information, return an `NSError` object indirectly in an parameter of the method.

- If the error requires a decision or action from the user, display an alert dialog.

  For OS X, use an instance of the `NSAlert` class (and related facilities) for displaying an alert dialog and handling the user's response. For iOS, use the facilities of the `UIActionSheet` or `UIAlertView` classes. See *Dialogs and Special Panels* for information.

For further information about `NSError` objects, handling errors, and displaying error alerts, see *Error Handling Programming Guide*.

Resource Management and Other Efficiencies

There are all sorts of things you can do to enhance the performance of your objects and, of course, the application that incorporates and manages those objects. These procedures and disciplines range from multithreading to drawing optimizations and techniques for reducing your code footprint. You can learn more about these things by reading *Cocoa Performance Guidelines* and other performance documents.

Yet you can, before even adopting a more advanced performance technique, improve the performance of your objects significantly by following three simple, common-sense guidelines:

- Don't load a resource or allocate memory until you really need it.

  If you load a resource of the program, such as a nib file or an image, and don't use it until much later, or don't use it at all, that is a gross inefficiency. Your program's memory footprint is bloated for no good reason. You should load resources or allocate memory only when there is an immediate need.

  For example, if your application's preferences window is in a separate nib file, don't load that file until the user first chooses Preferences from the application menu. The same caution goes for allocating memory for some task; hold off on allocation until the need for that memory arises. This technique of lazy-loading or lazy-allocation is easily implemented. For example, say your application has an image that it loads, upon the first user request, for displaying in the user interface. Listing 3-9 shows one approach: loading the image in the getter accessor for the image.

Listing 3-9 Lazy-loading of a resource

```
- (NSImage *)fooImage {
    if (!fooImage) { // fooImage is an instance variable
       NSString *imagePath = [[NSBundle mainBundle] pathForResource:@"Foo"
 ofType:@"jpg"];
        if (!imagePath) return nil;
        fooImage = [[NSImage alloc] initWithContentsOfFile:imagePath];
    }
    return fooImage;
}
```

- Use the Cocoa API; don't dig down into lower-level programming interfaces.

  Much effort has gone into making the implementations of the Cocoa frameworks as robust, secure, and efficient as possible. Moreover, these implementations manage interdependencies that you might not be aware of. If, instead of using the Cocoa API for a certain task, you decide to "roll your own" solution using lower-level interfaces, you'll probably end up writing more code, which introduces a greater risk of error

or inefficiency. Also, by leveraging Cocoa, you are better prepared to take advantage of future enhancements while at the same time you are more insulated from changes in the underlying implementations. So use the Cocoa alternative for a programming task if one exists and its capabilities answer your needs.

- Practice good memory-management techniques.

  If you decide not to enable garbage collection (which is disabled by default in iOS), perhaps the most important single thing you can do to improve the efficiency and robustness of your custom objects is to practice good memory-management techniques. Make sure every object allocation, `copy` message, or `retain` message is matched with a corresponding `release` message. Become familiar with the policies and techniques for proper memory management and practice, practice, practice them. See *Advanced Memory Management Programming Guide* for complete details.

Functions, Constants, and Other C Types

Because Objective-C is a superset of ANSI C, it permits any C type in your code, including functions, `typedef` structures, `enum` constants, and macros. An important design issue is when and how to use these types in the interface and implementation of custom classes.

The following list offers some guidance on using C types in the definition of a custom class:

- Define a function rather than a method for functionality that is often requested but doesn't need to be overridden by subclasses. The reason for doing this is performance. In these cases, it's best for the function to be private rather then being part of the class API. You can also implement functions for behavior that is not associated with any class (because it is global) or for operations on simple types (C primitives or structures). However, for global functionality it might be better—for reasons of extensibility—to create a class from which a singleton instance is generated.
- Define a structure type rather than a simple class when the following conditions apply:
  - You don't expect to augment the list of fields.
  - All the fields are public (for performance reasons).
  - None of the fields is dynamic (dynamic fields might require special handling, such as retaining or releasing).
  - You don't intend to make use of object-oriented techniques, such as subclassing.

  Even when all these conditions apply, the primary justification for structures in Objective-C code is performance. In other words, if there is no compelling performance reason, a simple class is preferable.
- Declare `enum` constants rather than `#define` constants. The former are more suitable for typing, and you can discover their values in the debugger.

When the Class Is Public (OS X)

When you are defining a custom class for your own use, such as a controller class for an application, you have great flexibility because you know the class well and can always redesign it if you have to. However, if your custom class will likely be a superclass for other developers—in other words, if it's a public class—the expectations others have of your class mean that you have to be more careful of your design.

Here are few guidelines for developers of public Cocoa classes:

- Make sure those instance variables that subclasses need to access are scoped as `@protected`.
- Add one or two reserved instance variables to help ensure binary compatibility with future versions of your class (see "Instance Variables" (page 141)).
- In memory-managed code, implement your accessor methods to properly handle memory management of vended objects (see "Storing and Accessing Properties" (page 146)). Clients of your class should get back autoreleased objects from your getter accessors.
- Observe the naming guidelines for public Cocoa interfaces as recommended in *Coding Guidelines for Cocoa*.
- Document the class, at least with comments in the header file.

Multithreaded Cocoa Programs

It has long been a standard programming technique to optimize program performance through multithreading. By having data processing and I/O operations run on their own secondary threads and dedicating the main thread to user-interface management, you can enhance the responsiveness of your applications. But in recent years, multithreading has assumed even greater importance with the emergence of multicore computers and symmetric multiprocessing (SMP). Concurrent processing on such systems involves synchronizing the execution of not only multiple threads on the same processor but multiple threads on multiple processors.

But making your program multithreaded is not without risk or costs. Although threads share the virtual address space of their process, they still add to the process's memory footprint; each thread requires an additional data structure, associated attributes, and its own stack space. Multithreading also requires greater complexity of program design to synchronize access to shared memory among multiple threads. Such designs make a program harder to maintain and debug. Moreover, multithreading designs that overuse locks can actually degrade performance (relative to a single-threaded program) because of the high contention for shared resources. Designing a program for multithreading often involves tradeoffs between performance and protection and requires careful consideration of your data structures and the intended usage pattern for extra threads. Indeed, in some situations the best approach is to avoid multithreading altogether and keep all program execution on the main thread.

Further Reading To get a solid understanding of issues and guidelines related to multithreading, read *Threading Programming Guide*.

Multithreading and Multiprocessing Resources

Cocoa provides several classes that are useful for multithreading programs.

Threads and Run Loops

In Cocoa threads are represented by objects of the `NSThread` class. The implementation of the class is based upon POSIX threads. Although the interface of `NSThread` does not provide as many options for thread management as do POSIX threads, it is sufficient for most multithreading needs.

Run loops are a key component of the architecture for the distribution of events. Run loops have input sources (typically ports or sockets) and timers; they also have input modes for specifying which input sources the run loop listens to. Objects of the `NSRunLoop` class represent run loops in Cocoa. Each thread has its own run loop, and the run loop of the main thread is set up and run automatically when a process begins execution. Secondary threads, however, must run their own run loops.

Operations and Operation Queues

With the `NSOperation` and `NSOperationQueue` classes, you can manage the execution of one or more encapsulated tasks that may be concurrent or nonconcurrent. (Note that the word *task* here does not necessarily imply an `NSTask` object; a task, or operation, for example, typically runs on a secondary thread within the same process.) An `NSOperation` object represents a discrete task that can be executed only once. Generally, you use `NSOperationQueue` objects to schedule operations in a sequence determined by priority and interoperation dependency. An operation object that has dependencies does not execute until all of its dependent operation objects finish executing. An operation object remains in a queue until it is explicitly removed or it finishes executing.

Note The `NSOperation` and `NSOperationQueue` classes were introduced in OS X v10.5 and in the initial public version of the iOS SDK. They are not available in earlier versions of OS X.

Locks and Conditions

Locks act as resource sentinels for contending threads; they prevent threads from simultaneously accessing a shared resource. Several classes in Cocoa provide lock objects of different types.

Table 3-1 Lock classes

Classes	Description
`NSLock`	Implements a mutex lock—a lock that enforces **mutually exclusive** access to a shared resource. Only one thread can acquire the lock and use the resource, thereby blocking other threads until it releases the lock.
`NSRecursiveLock`	Implements a recursive lock—a mutex lock that can be acquired multiple times by the thread that currently owns it. The lock remains in place until each recursive acquisition of the lock has been balanced with a call that releases the lock.
`NSConditionLock` `NSCondition`	Both of these classes implement condition locks. This type of lock combines a semaphore with a mutex lock to implement locking behavior that is effective based on a program-defined condition. A thread blocks and waits for another thread to signal the condition, at which point it (or another waiting thread) is unblocked and continues execution. You can signal multiple threads simultaneously, causing them to unblock and continue execution.

`NSConditionLock` and `NSCondition` are similar in purpose and implementation; both are object-oriented implementations of `pthread` condition locks. The implementation of `NSConditionLock` is more thorough but less flexible (although it does offer features such as locking timeouts); it implements both the semaphore signaling *and* the mutex locking for you. The implementation of `NSCondition`, on the other hand, wraps the `pthread` condition variables and mutex locks and requires you to do your own locking, signaling, and predicate state management. However, it is more flexible. This approach closely follows the implementation pattern for `pthread` conditions.

Interthread Communication

When your program has multiple threads, those threads often need a way to communicate with each other. The condition-lock classes use `pthread`-based condition signaling (semaphores) as a way to communicate between threads. But Cocoa offers several other resources for interthread communication.

Objects of the `NSMachPort` and `NSMessagePort` classes enable interthread communication over Mach ports. Objects of the `NSSocketPort` class enable interthread *and* interprocess communication over BSD sockets. In addition, the `NSObject` class provides the `performSelectorOnMainThread:withObject:waitUntilDone:` method, which allows secondary threads to communicate with and send data to the main thread.

Multithreading Guidelines for Cocoa Programs

Whether your program uses the Cocoa frameworks or something else, there are some common observations that can be made about the appropriateness and wisdom of having multiple threads in your program. You might start by asking yourself the following questions; if you answer "yes" to any of them, you should consider multithreading:

- Is there a CPU- or I/O-intensive task that could block your application's user interface?

  The main thread manages an application's user interface—the view part of the Model-View-Controller pattern. Thus the application can perform work that involves the application's data model on one or more secondary threads. In a Cocoa application, because controller objects are directly involved in the management of the user interface, you would run them on the main thread.
- Does your program have multiple sources of input or multiple outputs, and is it feasible to handle them simultaneously?
- Do you want to spread the work your program performs across multiple CPU cores?

Let's say one of these situations applies to your application. As noted earlier, multithreading can involve costs and risks as well as benefits, so it's worthwhile to consider alternatives to multithreading. For example, you might try asynchronous processing.

Just as there are situations that are appropriate for multithreading, there are situations where it's not:

- The work requires little processing time.
- The work requires steps that must be performed serially.
- Underlying subsystems are not thread safe.

The last item brings up the important issue of thread safety. There are some guidelines you should observe to ensure—as much as possible—that your multithreaded code is thread safe. Some of these guidelines are general and others are specific to Cocoa programs. The general guidelines are as follows:

- Avoid sharing data structures across threads if possible.

  Instead you can give each thread its own copy of an object (or other data) and then synchronize changes using a transaction-based model. Ideally you want to minimize resource contention as much as possible.
- Lock data at the right level.

  Locks are an essential component of multithreaded code, but they do impose a performance bottleneck and may not work as planned if used at the wrong level.
- Catch local exceptions in your thread.

Each thread has its own call stack and is therefore responsible for catching any local exceptions and cleaning things up. The exception cannot be thrown to the main thread or any other thread for handling. Failure to catch and handle an exception may result in the termination of the thread or the owning process.

- Avoid `volatile` variables in protected code.

The additional guidelines for Cocoa programs are few:

- Deal with immutable objects in your code as much as possible, especially across interface boundaries.

  Objects whose value or content cannot be modified—immutable objects—are usually thread safe. Mutable objects are often not. As a corollary to this guideline, respect the declared mutability status of objects returned from method calls; if you receive an object declared as immutable but it is mutable and you modify it, you can cause behavior that is catastrophic to the program.
- The main thread of a Cocoa application is responsible for receiving and dispatching events. Although your application can handle events on a secondary thread instead of the main thread, if it does it must keep all event-handling code on that thread. If you spin off the handling of events to different threads, user events (such as the letters typed on the keyboard) can occur out of sequence.
- If a secondary thread is to draw a view in a Cocoa application in OS X, ensure that all drawing code falls between calls to the `NSView` methods `lockFocusIfCanDraw` and `unlockFocus`.

Note You can learn more about these guidelines in *Threading Programming Guide*.

Are the Cocoa Frameworks Thread Safe?

Before you can make your program thread safe, it's essential to know the thread safety of the frameworks that your program relies on. The core Cocoa frameworks, Foundation and AppKit, have parts that are thread safe and parts that are not.

Generally, the classes of Foundation whose objects are immutable collections (`NSArray`, `NSDictionary`, and so on) as well as those whose immutable objects encapsulate primitive values or constructs (for example, `NSString`, `NSNumber`, `NSException`) are thread safe. Conversely, objects of the mutable versions of these collection and primitive-value classes are not thread safe. A number of classes whose objects represent system-level entities—`NSTask`, `NSRunLoop`, `NSPipe`, `NSHost`, and `NSPort`, among others—are not thread safe. (`NSThread` and the lock classes, on the other hand, are thread safe.)

In AppKit, windows (`NSWindow` objects) are generally thread safe in that you can create and manage them on a secondary thread. Events (`NSEvent` objects), however, are safely handled only on the same thread, whether that be the main thread or a secondary thread; otherwise you run the risk of having events get out of sequence. Drawing and views (`NSView` objects) are generally thread safe, although operations on views such as creating, resizing, and moving should happen on the main thread.

All UIKit objects should be used on the main thread only.

For more information on the thread safety of the Cocoa frameworks, see ""Thread Safety Summary"" in *Threading Programming Guide* .

Cocoa Design Patterns

Many of the architectures and mechanisms of the Cocoa environment make effective use of design patterns: abstract designs that solve recurring problems in a particular context. This chapter describes the major implementations of design patterns in Cocoa, focusing in particular on Model-View-Controller and object modeling. This chapter's main purpose is to give you a greater awareness of design patterns in Cocoa and encourage you to take advantage of these patterns in your own software projects.

What Is a Design Pattern?

A design pattern is a template for a design that solves a general, recurring problem in a particular context. It is a tool of abstraction that is useful in fields like architecture and engineering as well as software development. The following sections summarize what design patterns are, explains why they're important for object-oriented design, and looks at a sample design pattern.

A Solution to a Problem in a Context

As a developer, you might already be familiar with the notion of design patterns in object-oriented programming. They were first authoritatively described and cataloged in *Design Patterns: Elements of Reusable Object-Oriented Software*, by Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides (commonly referred to as the "Gang of Four"). That book, originally published in 1994, was soon followed by other books and articles that further explored and elaborated design patterns in object-oriented systems.

The succinct definition of a design pattern is "a solution to a problem in a context." Let's parse this by working backward through the phrase. The context is a recurring situation in which the pattern applies. The problem is the goal you are trying to achieve in this context as well as any constraints that come with the context. And the solution is what you're after: a general design for the context that achieves the goal and resolves the constraints.

A design pattern abstracts the key aspects of the structure of a concrete design that has proven to be effective over time. The pattern has a name and identifies the classes and objects that participate in the pattern along with their responsibilities and collaborations. It also spells out consequences (costs and benefits) and the situations in which the pattern can be applied. A design pattern is a kind of template or guide for a particular design; in a sense, a concrete design is an "instantiation" of a pattern. Design patterns are not absolute. There is some flexibility in how you can apply them, and often things such as programming language and existing architectures can determine how the pattern is applied.

Several themes or principles of design influence design patterns. These design principles are rules of thumb for constructing object-oriented systems, such as "encapsulate the aspects of system structure that vary" and "program to an interface, not an implementation." They express important insights. For example, if you isolate the parts of a system that vary, and encapsulate them, they can vary independently of other parts of the system, especially if you define interfaces for them that are not tied to implementation specifics. You can later alter or extend those variable parts without affecting the other parts of the system. You thus eliminate dependencies and reduce couplings between parts, and consequently the system becomes more flexible and easier to change.

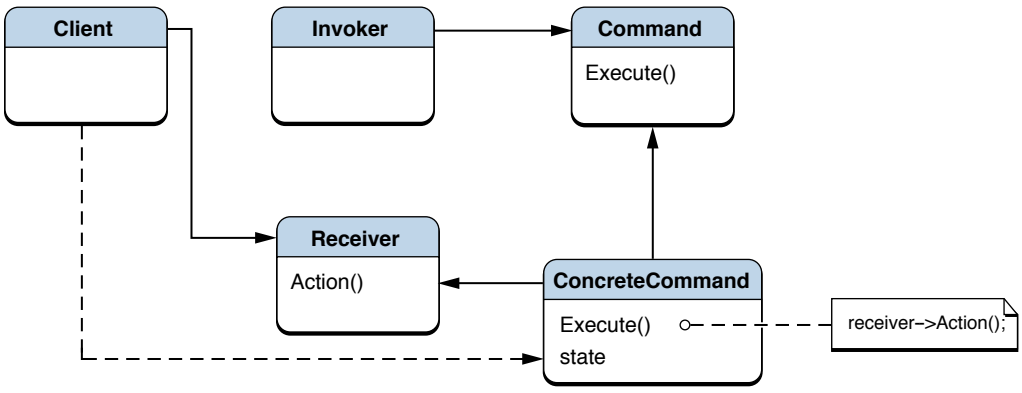
Benefits such as these make design patterns an important consideration when you're writing software. If you find, adapt, and use patterns in your program's design, that program—and the objects and classes that it comprises—will be more reusable, more extensible, and easier to change when future requirements demand it. Moreover, programs that are based on design patterns are generally more elegant and efficient than programs that aren't, as they require fewer lines of code to accomplish the same goal.

An Example: The Command Pattern

Most of the book by the Gang of Four consists of a catalog of design patterns. It categorizes the patterns in the catalog by scope (class or object) and by purpose (creational, structural, or behavioral). Each entry in the catalog discusses the intent, motivation, applicability, structure, participants, collaborations, consequences, and implementation of a design pattern. One of these entries is the Command pattern (an object-behavioral pattern).

The book states the intent of the Command pattern as "to encapsulate a request as an object, thereby letting you parameterize clients with different requests, queue or log requests, and support undoable operations." The pattern separates an object sending a message from the objects that receive and evaluate those messages. The originator of the message (the client) encapsulates a request by binding together one or more actions on a specific receiver. The encapsulated message can be passed around between objects, placed in queues or otherwise stored for later invocation, and dynamically modified to vary the receiver or message parameters. Figure 4-1 shows the structure diagram for the pattern.

Figure 4-1 Structure diagram for the Command pattern



For a developer familiar with Cocoa, this short overview of the Command pattern might ring a bell. The pattern perfectly describes a class in the Foundation framework whose purpose is to encapsulate messages: `NSInvocation`. As the pattern's intent states, one of its purposes is to make operations undoable. Invocation objects are used in the Cocoa designs for undo management as well as distributed objects, which is an architecture for interprocess communication. The Command pattern also describes (although less perfectly) the target-action mechanism of Cocoa in which user-interface control objects encapsulate the target and action of the messages they send when users activate them.

In its framework classes and in its languages and runtime, Cocoa has already implemented many of the cataloged design patterns for you. (These implementations are described in "How Cocoa Adapts Design Patterns" (page 167).) You can satisfy many of your development requirements by using one of these "off-the-shelf" adaptations of a design pattern. Or you may decide your problem and its context demands a brand new pattern-based design of your own. The important thing is to be aware of patterns when you are developing software and to use them in your designs when appropriate.

How Cocoa Adapts Design Patterns

You can find adaptations of design patterns throughout Cocoa, in both its OS X and iOS versions. Mechanisms and architectures based on patterns are common in Cocoa frameworks and in the Objective-C runtime and language. Cocoa often puts its own distinctive spin on a pattern because its designs are influenced by factors such as language capabilities or existing architectures.

This section contains summaries of most of the design patterns cataloged in *Design Patterns: Elements of Reusable Object-Oriented Software*. Each section not only summarizes the pattern but discusses the Cocoa implementations of it. Only patterns that Cocoa implements are listed, and each description of a pattern in the following sections pertains to a particular Cocoa context.

Implementations of design patterns in Cocoa come in various forms. Some of the designs described in the following sections—such as protocols and categories—are features of the Objective-C language. In other cases, the "instance of a pattern" is implemented in one class or a group of related classes (for example, class clusters and singleton classes). And in other cases the pattern adaptation is a major framework architecture, such as the responder chain. Some of the pattern-based mechanisms you get almost "for free" while others require some work on your part. And even if Cocoa does not implement a pattern, you are encouraged to do so yourself when the situation warrants it; for example, object composition (Decorator pattern) is often a better technique than subclassing for extending class behavior.

Two design patterns are reserved for later sections, Model-View-Controller (MVC) and object modeling. MVC is a compound, or aggregate pattern, meaning that it is based on several catalog patterns. Object modeling has no counterpart in the Gang of Four catalog, instead originating from the domain of relational databases. Yet MVC and object modeling are perhaps the most important and pervasive design patterns in Cocoa, and

to a large extent they are interrelated patterns. They play a crucial role in the design of several technologies, including bindings, undo management, scripting, and the document architecture. To learn more about these patterns, see "The Model-View-Controller Design Pattern" (page 193) and "Object Modeling" (page 202).

Abstract Factory

The Abstract Factory pattern provides an interface for creating families of related or dependent objects without specifying their concrete classes. The client is decoupled from any of the specifics of the concrete object obtained from the factory.

Class Cluster

A class cluster is an architecture that groups a number of private concrete subclasses under a public abstract superclass. The abstract superclass declares methods for creating instances of its private subclasses. The superclass dispenses an object of the proper concrete subclass based on the creation method invoked. Each object returned may belong to a different private concrete subclass.

Class clusters in Cocoa can generate only objects whose storage of data can vary depending on circumstances. The Foundation framework has class clusters for `NSString`, `NSData`, `NSDictionary`, `NSSet`, and `NSArray` objects. The public superclasses include these immutable classes as well as the complementary mutable classes `NSMutableString`, `NSMutableData`, `NSMutableDictionary`, `NSMutableSet`, and `NSMutableArray`.

Uses and Limitations

You use one of the public classes of a class cluster when you want to create immutable or mutable objects of the type represented by the cluster. With class clusters there is a trade-off between simplicity and extensibility. A class cluster simplifies the interface to a class and thus makes it easier to learn and use the class. However, it is generally more difficult to create custom subclasses of the abstract superclass of a class cluster.

> **Further Reading** "Class Clusters" (page 111) provides more information about class clusters in Cocoa.

Adapter

The Adapter design pattern converts the interface of a class into another interface that clients expect. Adapter lets classes work together that couldn't otherwise because of incompatible interfaces. It decouples the client from the class of the targeted object.

Protocols

A protocol is a language-level (Objective-C) feature that makes it possible to define interfaces that are instances of the Adapter pattern. A protocol is essentially a series of method declarations unassociated with a class. (In Java, *interface* is synonymous with *protocol*.) If you want a client object to communicate with another object, but the objects' incompatible interfaces make that difficult, you can define a protocol. The class of the other object then formally adopts the protocol and "conforms" to it by implementing one or more of the methods of the protocol. The protocol may require the conforming class to implement some of its methods and may leave the implementation of others optional. The client object can then send messages to the other object through the protocol interface.

Protocols make a set of method declarations independent of the class hierarchy. They make it possible to group objects on the basis of conformance to a protocol as well as class inheritance. The `NSObject` method `conformsToProtocol:` permits you to verify an object's protocol affiliation.

Cocoa has informal protocols as well as formal protocols. An informal protocol is a category on the `NSObject` class, thus making any object a potential implementer of any method in the category (see "Categories" (page 177)). The methods in an informal protocol can be selectively implemented. Informal protocols are part of the implementation of the delegation mechanism in OS X (see "Delegation" (page 175)).

Note that the design of protocols does not perfectly match the description of the Adapter pattern. But it achieves the goal of the pattern: allowing classes with otherwise incompatible interfaces to work together.

Uses and Limitations

You use a protocol primarily to declare an interface that hierarchically unrelated classes are expected to conform to if they want to communicate. But you can also use protocols to declare an interface of an object while concealing its class. The Cocoa frameworks include many formal protocols that enable custom subclasses to communicate with them for specific purposes. For example, the Foundation framework includes the `NSObject`, `NSCopying`, and `NSCoding` protocols, which are all very important ones. AppKit protocols include `NSDraggingInfo`, `NSTextInput`, and `NSChangeSpelling`. UIKit protocols include `UITextInputTraits`, `UIWebViewDelegate`, and `UITableViewDataSource`.

Formal protocols implicitly require the conforming class to implement *all* declared methods. However, they can mark single methods or groups of methods with the `@optional` directive, and the conforming class may choose to implement those. They are also fragile; once you define a protocol and make it available to other classes, future changes to it (except for additional optional methods) can break those classes.

Further Reading More more information on formal protocols, see "Protocols" in *The Objective-C Programming Language*.

Chain of Responsibility

The Chain of Responsibility design pattern decouples the sender of a request from its receiver by giving more than one object a chance to handle the request. The pattern chains the receiving objects together and passes the request along the chain until an object handles it. Each object in the chain either handles the request or passes it to the next object in the chain.

Responder Chain

The application frameworks include an architecture known as the responder chain. This chain consists of a series of responder objects (that is, objects inheriting from `NSResponder` or, in UIKit, `UIResponder`) along which an event (for example, a mouse click) or action message is passed and (usually) eventually handled. If a given responder object doesn't handle a particular message, it passes the message to the next responder in the chain. The order of responder objects in the chain is generally determined by the view hierarchy, with the progression from lower-level to higher-level responders in the hierarchy, culminating in the window object that manages the view hierarchy, the delegate of the window object, or the global application object. The paths of events and action messages up the responder chain is different. An application can have as many responder chains as it has windows (or even local hierarchies of views); but only one responder chain can be active at a time—the one associated with the currently active window.

The AppKit framework also implements a similar chain of responders for error handling.

iOS Note UIKit implements the responder chain differently than AppKit does. If a view is managed by a `UIViewController` object, the view controller becomes the next responder in the chain (and from there the event or action message passes to the view's superview). In addition, UIKit does not support a document architecture *per se*; therefore there are no document objects or window-controller objects in the responder chain. There is also no error-handling responder chain in iOS.

The design of the view hierarchy, which is closely related to the responder chain, adapts the Composite pattern ("Composite" (page 173)). Action messages—messages originating from control objects—are based on the target-action mechanism, which is an instance of the Command pattern ("Command" (page 171)).

Uses and Limitations

When you construct a user interface for a program either by using Interface Builder or programmatically, you get one or more responder chains "for free." The responder chain goes hand in hand with a view hierarchy, which you get automatically when you make a view object a subview of a window's content view. If you have a custom view added to a view hierarchy, it becomes part of the responder chain. If you implement the appropriate `NSResponder` or `UIResponder` methods, you can receive and handle events and action messages. A custom object that is a delegate of a window object or the global application object (`NSApp` in AppKit) can also receive and handle those messages.

You can also programmatically inject custom responders into the responder chain and you can programmatically manipulate the order of responders.

> **Further Reading** The AppKit responder chains for handling events and action messages and for handling errors are described in *Cocoa Event Handling Guide* and *Error Handling Programming Guide*. The UIKit responder chain is described in *Event Handling Guide for iOS*. The view hierarchy is a related design pattern that is summarized in "Composite" (page 173).

Command

The Command design pattern encapsulates a request as an object, thereby letting you parameterize clients with different requests, queue or log requests, and support undoable operations. The request object binds together one or more actions on a specific receiver. The Command pattern separates an object making a request from the objects that receive and execute that request.

Invocation Objects

An instance of the `NSInvocation` class encapsulates an Objective-C message. An invocation object contains a target object, method selector, and method parameters. You can dynamically change the target of the message dispatched by the invocation object as well as its parameters; once the invocation is executed, you can also obtain the return value from the object. With a single invocation object, you can repeatedly invoke a message with multiple variations in target and parameters.

The creation of an `NSInvocation` object requires an `NSMethodSignature` object, which is an object that encapsulates type information related to the parameters and return value of a method. An `NSMethodSignature` object, in turn, is created from a method selector. The implementation of `NSInvocation` also makes use of functions of the Objective-C runtime.

Uses and Limitations

`NSInvocation` objects are part of the programmatic interfaces of distributed objects, undo management, message forwarding, and timers. You can also use invocation objects in similar contexts where you need to decouple an object sending a message from the object that receives the message.

The distributed objects technology is for interprocess communication. See "Proxy" (page 186) for more on distributed objects.

> **Further Reading** See *NSInvocation Class Reference* for details on invocation objects. Also, consult the following documents for information about related technologies: *Undo Architecture*, *Timer Programming Topics*, and the "The Runtime System" in *The Objective-C Programming Language*.

The Target-Action Mechanism

The target-action mechanism enables a control object—that is, an object such as a button, slider, or text field—to send a message to another object that can interpret the message and handle it as an application-specific instruction. The receiving object, or the target, is usually a custom controller object. The message—named an action message—is determined by a selector, a unique runtime identifier of a method.

In the AppKit framework, the cell object that a control owns typically encapsulates the target and action. When the user clicks or otherwise activates the control, the control extracts the information from its cell and sends the message. (A menu item also encapsulates target and action, and sends an action message when the user chooses it.) The target-action mechanism can work on the basis of a selector (and not a method signature) because the signature of an action method in AppKit by convention is always the same.

In UIKit, the target-action mechanism does not rely on cells. Instead, a control maps a target and action to one or more multitouch events that can occur on the control.

Uses and Limitations

When creating a Cocoa application, you can set a control's action and target through the Interface Builder application. You thereby let the control initiate custom behavior without writing any code for the control itself. The action selector and target connection are archived in a nib file and are restored when the nib is unarchived. You can also change the target and action dynamically by sending the control or its cell `setTarget:` and `setAction:` messages.

A Cocoa application for OS X can use the target-action mechanism to instruct a custom controller object to transfer data from the user interface to a model object, or to display data in a model object. The Cocoa bindings technology obviates the need to use target-action for this purpose. See *Cocoa Bindings Programming Topics* for more about this technology.

Controls and cells do not retain their targets. See "Ownership of Delegates, Observers, and Targets" (page 235) for further information.

Further Reading See "The Target-Action Mechanism" (page 217) for further information.

Composite

The Composite design pattern composes related objects into tree structures to represent part-whole hierarchies. The pattern lets clients treat individual objects and compositions of objects uniformly.

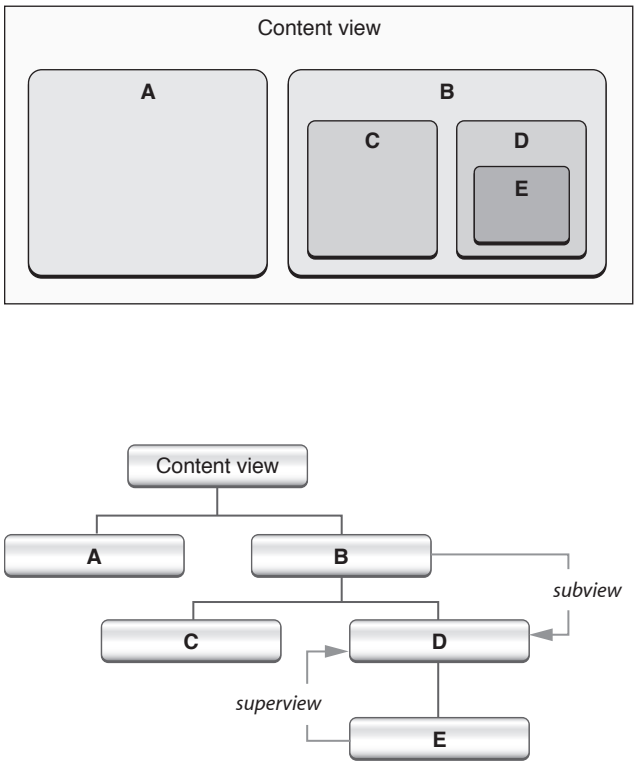
The Composite pattern is part of the Model-View-Controller aggregate pattern, which is describe in "The Model-View-Controller Design Pattern" (page 193).

View Hierarchy

The views (`NSView` or `UIView` objects) in a window are internally structured into a view hierarchy. At the root of the hierarchy is a window (`NSWindow` or `UIWindow` object) and its content view, a transparent view that fills the window's content rectangle. Views that are added to the content view become subviews of it, and

they become the superviews of any views added to them. Except for the content view, a view has one (and only one) superview and zero or any number of subviews. You perceive this structure as containment: a superview contains its subviews. Figure 4-2 shows the visual and structural aspects of the view hierarchy.

Figure 4-2 The view hierarchy, visual and structural



The view hierarchy is a structural architecture that plays a part in both drawing and event handling. A view has two bounding rectangles, its frame and its bounds, that affect how graphics operations with the view take place. The frame is the exterior boundary; it locates the view in its superview's coordinate system, defines its size, and clips drawing to the view's edges. The bounds, the interior bounding rectangle, defines the internal coordinate system of the surface where the view draws itself.

When a window is asked by the windowing system to prepare itself for display, superviews are asked to render themselves before their subviews. When you send some messages to a view—for example, a message that requests a view to redraw itself—the message is propagated to subviews. You can thus treat a branch of the view hierarchy as a unified view.

The view hierarchy is also used by the responder chain for handling events and action messages. See the summary of the responder chain in "Chain of Responsibility" (page 170).

Uses and Limitations

You create or modify a view hierarchy whenever you add a view to another view, either programmatically or using Interface Builder. The AppKit framework automatically handles all the relationships associated with the view hierarchy.

Further Reading *Cocoa Drawing Guide* discusses the view hierarchy in Mac apps.

Decorator

The Decorator design pattern attaches additional responsibilities to an object dynamically. Decorators provide a flexible alternative to subclassing for extending functionality. As does subclassing, adaptation of the Decorator pattern allows you to incorporate new behavior without modifying existing code. Decorators wrap an object of the class whose behavior they extend. They implement the same interface as the object they wrap and add their own behavior either before or after delegating a task to the wrapped object. The Decorator pattern expresses the design principle that classes should be open to extension but closed to modification.

General Comments

Decorator is a pattern for object composition, which is something that you are encouraged to do in your own code (see "When to Make a Subclass" (page 136)). Cocoa, however, provides some classes and mechanisms of its own (discussed in the following sections) that are based on the pattern. In these implementations, the extending object does not completely duplicate the interface of the object that it wraps, and the implementations use different techniques for interface sharing.

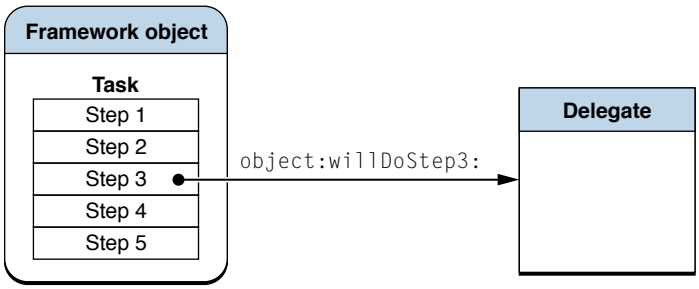
Cocoa uses the Decorator pattern in the implementation of several of its classes, including `NSAttributedString`, `NSScrollView`, and `UIDatePicker`. The latter two classes are examples of compound views, which group together simple objects of other view classes and coordinate their interaction.

Delegation

Delegation is a mechanism by which a host object embeds a weak reference (weak in the sense that it's a simple pointer reference, unretained) to another object—its delegate—and periodically sends messages to the delegate when it requires its input for a task. The host object is generally an "off-the-shelf" framework object (such as an `NSWindow` or `NSXMLParser` object) that is seeking to accomplish something, but can only do so in a generic fashion. The delegate, which is almost always an instance of a custom class, acts in coordination

with the host object, supplying program-specific behavior at certain points in the task (see Figure 4-3). Thus delegation makes it possible to modify or extend the behavior of another object without the need for subclassing.

Figure 4-3 Framework object sending a message to its delegate



Delegation, in the simple sense of one object delegating a task to another object, is a common technique in object-oriented programming. However, Cocoa implements delegation in a unique way. A host class uses a formal protocol or an informal protocol to define an interface that the delegate object may choose to implement. All the methods in the informal protocol are optional, and the formal protocol may declare optional methods, allowing the delegate to implement only some of the methods in the protocol. Before it attempts to send a message to its delegate, the host object determines whether it implements the method (via a `respondsToSelector:` message) to avoid runtime exceptions. For more on formal and informal protocols, see "Protocols" (page 169).

Some classes in the Cocoa frameworks also send messages to their data sources. A data source is identical in all respects to a delegate, except that the intent is to provide the host object with data to populate a browser, a table view, or similar user-interface view. A data source, unlike a delegate, may also be required to implement some methods of the protocol.

Delegation is not a strict implementation of the Decorator pattern. The host (delegating) object does not wrap an instance of the class it wants to extend; indeed, it's the other way around, in that the delegate is specializing the behavior of the delegating framework class. There is no sharing of interface either, other than the delegation methods declared by the framework class.

Delegation in Cocoa is also part of the Template Method pattern ("Template Method" (page 191)).

Uses and Limitations

Delegation is a common design in the Cocoa frameworks. Many classes in the AppKit and UIKit frameworks send messages to delegates, including `NSApplication`, `UIApplication`, `UITableView`, and several subclasses of `NSView`. Some classes in the Foundation framework, such as `NSXMLParser` and `NSStream`, also maintain delegates. You should always use a class's delegation mechanism instead of subclassing the class, unless the delegation methods do not allow you to accomplish your goal.

Although you can dynamically change the delegate, only one object can be a delegate at a time. Thus if you want multiple objects to be informed of a particular program event at the same time, you cannot use delegation. However, you can use the notification mechanism for this purpose. A delegate automatically receives notifications from its delegating framework object as long as the delegate implements one or more of the notification methods declared by the framework class. See the discussion of notifications in the Observer pattern ("Observer" (page 184)).

Delegating objects in AppKit do not retain their delegates or data sources. See "Ownership of Delegates, Observers, and Targets" (page 235) for further information.

> **Further Reading** For further information on delegation, see "Delegates and Data Sources" (page 211)".

Categories

A category is a feature of the Objective-C language that enables you to add methods (interface and implementation) to a class without having to make a subclass. There is no runtime difference—within the scope of your program—between the original methods of the class and the methods added by the category. The methods in the category become part of the class type and are inherited by all the class's subclasses.

As with delegation, categories are not a strict adaptation of the Decorator pattern, fulfilling the intent but taking a different path to implementing that intent. The behavior added by categories is a compile-time artifact, and is not something dynamically acquired. Moreover, categories do not encapsulate an instance of the class being extended.

Uses and Limitations

The Cocoa frameworks define numerous categories, most of them informal protocols (which are summarized in "Protocols" (page 169)). Often they use categories to group related methods. You may implement categories in your code to extend classes without subclassing or to group related methods. However, you should be aware of these caveats:

- You cannot add instance variables to the class.
- If you override existing methods of the class, your application may behave unpredictably.

Further Reading See "Defining a Class" in *The Objective-C Programming Language* for more information on categories.

Facade

The Facade design pattern provides a unified interface to a set of interfaces in a subsystem. The pattern defines a higher-level interface that makes the subsystem easier to use by reducing complexity and hiding the communication and dependencies between subsystems.

NSImage

The `NSImage` class of the AppKit framework provides a unified interface for loading and using images that can be bitmap-based (such as those in JPEG, PNG, or TIFF format) or vector-based (such as those in EPS or PDF format). `NSImage` can keep more than one representation of the same image; each representation is a kind of `NSImageRep` object. `NSImage` automates the choice of the representation that is appropriate for a particular type of data and for a given display device. It also hides the details of image manipulation and selection so that the client can use many different underlying representations interchangeably.

Uses and Limitations

Because `NSImage` supports several different representations of what an image is, some requested attributes might not apply. For example, asking an image for the color of a pixel does not work if the underlying image representation is vector-based and device-independent.

Note See *Cocoa Drawing Guide* for a discussion of `NSImage` and image representations.

Iterator

The Iterator design pattern provides a way to access the elements of an aggregate object (that is, a collection) sequentially without exposing its underlying representation. The Iterator pattern transfers the responsibility for accessing and traversing the elements of a collection from the collection itself to an iterator object. The Iterator defines an interface for accessing collection elements and keeps track of the current element. Different iterators can carry out different traversal policies.

Enumerators

The `NSEnumerator` class in the Foundation framework implements the Iterator pattern. The private, concrete subclass of the abstract `NSEnumerator` class returns enumerator objects that sequentially traverse collections of various types—arrays, sets, dictionaries (values and keys)—returning objects in the collection to clients.

`NSDirectoryEnumerator` is a distantly related class. Instances of this class recursively enumerate the contents of a directory in the file system.

Uses and Limitations

The collection classes such as `NSArray`, `NSSet`, and `NSDictionary` include methods that return an enumerator appropriate to the type of collection. All enumerators work in the same manner. You send a `nextObject` message to the enumerator object in a loop that exits when `nil` is returned instead of the next object in the collection.

You can also use fast enumeration to access the elements of a collection; this language feature is described in "Fast Enumeration" (page 72).

Mediator

The Mediator design pattern defines an object that encapsulates how a set of objects interact. Mediator promotes loose coupling by keeping objects from referring to each other explicitly, and it lets you vary their interaction independently. These objects can thus remain more reusable.

A "mediator object" in this pattern centralizes complex communication and control logic between objects in a system. These objects tell the mediator object when their state changes and, in turn, respond to requests from the mediator object.

Controller Classes in the AppKit Framework

The Model-View-Controller design pattern assigns roles to the objects in an object-oriented system such as an application. They can be model objects, which contain the data of the application and manipulate that data; they can be view objects, which present the data and respond to user actions; or they can be controller objects, which mediate between the model and view objects. Controller objects fit the Mediator pattern.

In Cocoa, controller objects can be of two general types: mediating controllers or coordinating controllers. Mediating controllers mediate the flow of data between view objects and model objects in an application. Mediating controllers are typically `NSController` objects. Coordinating controllers implement the centralized communication and control logic for an application, acting as delegates for framework objects and as targets for action messages. They are typically `NSWindowController` objects or instances of custom `NSObject` subclasses. Because they are so highly specialized for a particular program, coordinating controllers tend not to be reusable.

The abstract class `NSController` and its concrete subclasses in the AppKit framework are part of the Cocoa technology of bindings, which automatically synchronizes the data contained in model objects and displayed and edited in view objects. For example, if a user edits a string in a text field, the bindings technology

communicates that change—through a mediating controller—to the appropriate property of the bound model object. All programmers need to do is properly design their model objects and, using Interface Builder, establish bindings between the view, controller, and model objects of a program.

Instances of the concrete public controller classes are available from the Interface Builder library and hence are highly reusable. They provide services such as the management of selections and placeholder values. These objects perform the following specific functions:

- `NSObjectController` manages a single model object.
- `NSArrayController` manages an array of model objects and maintains a selection; it also allows you to add objects to and remove objects from the array.
- `NSTreeController` enables you to add, remove, and manage model objects in a hierarchical tree structure.
- `NSUserDefaultsController` provides a convenient interface to the preferences (user defaults) system.

Uses and Limitations

Generally you use `NSController` objects as mediating controllers because these objects are designed to communicate data between the view objects and model objects of an application. To use a mediating controller, you typically drag the object from the Interface Builder library, specify the model-object property keys, and establish the bindings between view and model objects using the Bindings pane of the Interface Builder Info window. You can also subclass `NSController` or one of its subclasses to get more specialized behavior.

You can potentially make bindings between almost any pair of objects as long as those objects comply with the `NSKeyValueCoding` and `NSKeyValueObserving` informal protocols. But to get all the benefits `NSController` and its subclasses give you, it is better to make bindings through mediating controllers.

Coordinating controllers centralize communication and control logic in an application by:

- Maintaining outlets to model and view objects (outlets are instance variables that hold connections or references to other objects)
- Responding to user manipulations of view objects through target-action (see "The Target-Action Mechanism" (page 172))
- Acting as a delegate for messages sent by framework objects (see "Delegation" (page 175))

You usually make all of the above connections—outlets, target-action, and delegates—in Interface Builder, which archives them in the application's nib file.

Further Reading See "The Model-View-Controller Design Pattern" (page 193) for a discussion of mediating controllers, coordinating controllers, and design decisions related to controllers. *Cocoa Bindings Programming Topics* describes the mediating controller classes in detail.

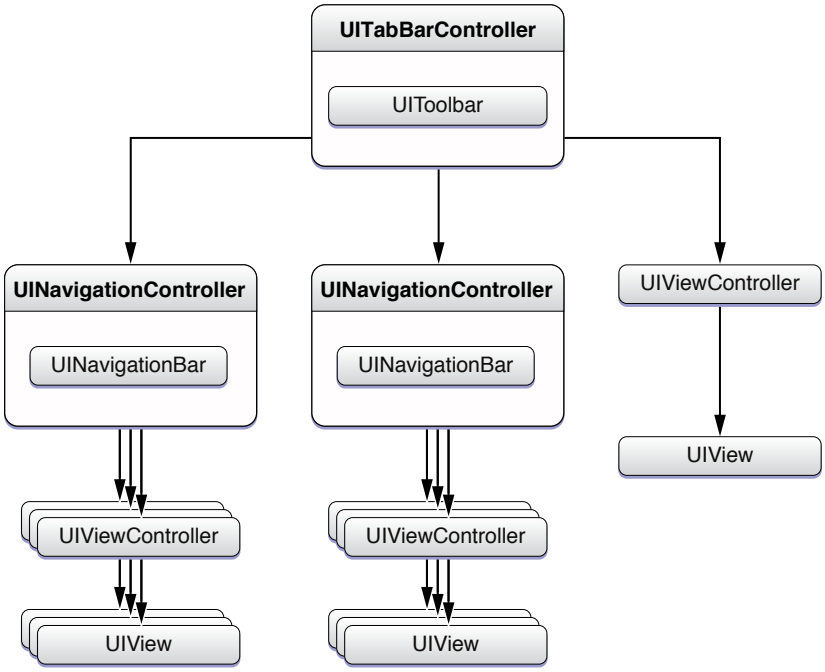
View Controllers in UIKit

Applications running in iOS frequently use a modal and navigational user-interface design for presenting screen-size chunks of the application's data model. An application may have a navigation bar and a toolbar, and between these objects is the current view of application data. Users can tap buttons on the toolbar to select a mode, tap buttons on the navigation bar, and tap controls in the current view to traverse a hierarchy of model (data) objects; at each level the central view presents more detail. At the end of this hierarchy is often an item that the user can inspect or edit. (An application, of course, is free to use just a navigation bar or just a toolbar.)

View controllers—that inherit from `UIViewController`—are central to this design. `UIViewController` is an abstract class that you can subclass to manage a particular view. The UIKit framework also provides `UIViewController` subclasses for managing navigation bar and toolbar objects: `UINavigationController` and `UITabBarController`. As depicted in Figure 4-4, a tab-bar controller can manage a number of navigation controllers, which in turn can manage one or more view controllers, each with its associated view object. In addition to managing views (including overlay views), a view controller specifies the buttons and titles that are displayed in the navigation bar.

To learn more about view controllers, see *View Controller Programming Guide for iOS*.

Figure 4-4 View controllers in UIKit



Memento

The Memento pattern captures and externalizes an object's internal state—without violating encapsulation—so that the object can be restored to this state later. The Memento pattern keeps the important state of a key object external from that object to maintain cohesion.

Archiving

Archiving converts the objects in a program, along with those objects' properties (attributes and relationships) into an archive that can be stored in the file system or transmitted between processes or across a network. The archive captures the object graph of a program as an architecture-independent stream of bytes that preserves the identity of the objects and the relationships among them. Because an object's type is stored along with its data, an object decoded from a stream of bytes is normally instantiated using the same class of the object that was originally encoded.

Uses and Limitations

Generally, you want to archive those objects in your program whose state you want to preserve. Model objects almost always fall into this category. You write an object to an archive by encoding it, and you read that object from an archive by decoding it. Encoding and decoding are operations that you perform using an `NSCoder`

object, preferably using the keyed archiving technique (requiring you to invoke methods of the `NSKeyedArchiver` and `NSKeyedUnarchiver` classes). The object being encoded and decoded must conform to the `NSCoding` protocol; the methods of this protocol are invoked during archiving.

> **Further Reading** See *Archives and Serializations Programming Guide* for further information about archiving.

Property List Serialization

A property list is a simple, structured serialization of an object graph that uses only objects of the following classes: `NSDictionary`, `NSArray`, `NSString`, `NSData`, `NSDate`, and `NSNumber`. These objects are commonly referred to as *property list objects*. Several Cocoa framework classes offer methods to serialize these property list objects and define special formats for the data stream recording the contents of the objects and their hierarchical relationship. The `NSPropertyListSerialization` class provides class methods that serialize property list objects to and from an XML format or an optimized binary format.

Uses and Limitations

If the objects in an object graph are simple, property list serialization is a flexible, portable, and adequate means to capture and externalize an object and its state. However, this form of serialization has its limitations. It does not preserve the full class identity of objects, only the general kind (array, dictionary, string, and so on). Thus an object restored from a property list might be of a different class than its original class. This is especially an issue when the mutability of an object can vary. Property list serialization also doesn't keep track of objects that are referenced multiple times in an object, potentially resulting in multiple instances upon deserialization that was a single instance in the original object graph.

> **Further Reading** See *Archives and Serializations Programming Guide* for further information on property list serialization.

Core Data

Core Data is a Cocoa framework that defines an architecture for managing object graphs and making them persistent. It is this second capability—object persistence—that makes Core Data an adaptation of the Memento pattern.

In the Core Data architecture, a central object called the *managed object context* manages the various model objects in an application's object graph. Below the managed object context is the persistence stack for that object graph—a collection of framework objects that mediate between the model objects and external data

stores, such as XML files or relational databases. The persistence-stack objects map between data in the store and corresponding objects in the managed data context and, when there are multiple data stores, present them to the managed object context as a single aggregate store.

The design of Core Data is also heavily influenced by the Model-View-Controller and object modeling patterns.

Uses and Limitations

Core Data is particularly useful in the development of enterprise applications where complex graphs of model objects must be defined, managed, and transparently archived and unarchived to and from data stores. The Xcode development environment includes project templates and design tools that reduce the programming effort required to create the two general types of Core Data applications, those that are document-based and those that are not document-based. The Interface Builder application also includes configurable Core Data framework objects in its library.

> **Further Reading** To learn more about Core Data, read *Core Data Programming Guide*. The tutorials *NSPersistentDocument Core Data Tutorial* and *Core Data Utility Tutorial* step you through the basic procedure for creating document-based and non–document-based Core Data applications.

Observer

The Observer design pattern defines a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically. The Observer pattern is essentially a publish-and-subscribe model in which the subject and its observers are loosely coupled. Communication can take place between the observing and observed objects without either needing to know much about the other.

Notifications

The notification mechanism of Cocoa implements one-to-many broadcast of messages based on the Observer pattern. Objects in a program add themselves or other objects to a list of observers of one or more notifications, each of which is identified by a global string (the notification name). The object that wants to notify other objects—the observed object—creates a notification object and posts it to a notification center. The notification center determines the observers of a particular notification and sends the notification to them via a message. The methods invoked by the notification message must conform to a certain single-parameter signature. The parameter of the method is the notification object, which contains the notification name, the observed object, and a dictionary containing any supplemental information.

Posting a notification is a synchronous procedure. The posting object doesn't regain control until the notification center has broadcast the notification to all observers. For asynchronous behavior, you can put the notification in a notification queue; control returns immediately to the posting object and the notification center broadcasts the notification when it reaches the top of the queue.

Regular notifications—that is, those broadcast by the notification center—are intraprocess only. If you want to broadcast notifications to other processes, you can use the distributed notification center and its related API.

Uses and Limitations

You can use notifications for a variety of reasons. For example, you could broadcast a notification to change how user-interface elements display information based on a certain event elsewhere in the program. Or you could use notifications as a way to ensure that objects in a document save their state before the document window is closed. The general purpose of notifications is to inform other objects of program events so they can respond appropriately.

But objects receiving notifications can react only after the event has occurred. This is a significant difference from delegation. The delegate is given a chance to reject or modify the operation proposed by the delegating object. Observing objects, on the other hand, cannot directly affect an impending operation.

The notification classes are `NSNotification` (for notification objects), `NSNotificationCenter` (to post notifications and add observers), `NSNotificationQueue` (to enqueue notifications), and `NSDistributedNotificationCenter`. Many Cocoa framework classes publish and post notifications that any object can observe.

> **Further Reading** "Notifications" (page 227) describes the notification mechanism in greater detail and offers guidelines for its use.

Key-Value Observing

Key-value observing is a mechanism that allows objects to be notified of changes to specific properties of other objects. It is based on the `NSKeyValueObserving` informal protocol. Observed properties can be simple attributes, to-one relationships, or to-many relationships. In the context of the Model-View-Controller pattern, key-value observing is especially important because it enables view objects to observe—via the controller layer—changes in model objects. It is thus an essential component of the Cocoa bindings technology (see "Controller Classes in the AppKit Framework" (page 179)).

Cocoa provides a default "automatic" implementation of many `NSKeyValueObserving` methods that gives all complying objects a property-observing capability.

Uses and Limitations

Key-value observing is similar to the notification mechanism but is different in important respects. In key-value observing there is no central object that provides change notification for all observers. Instead, notifications of changes are directly transmitted to observing objects. Key-value observing is also directly tied to the values of specific object properties. The notification mechanism, on the other hand, is more broadly concerned with program events.

Objects that participate in key-value observing (KVO) must be KVO-compliant—that is, comply with certain requirements. For automatic observing, this requires compliance with the requirements of key-value coding (KVC-compliance) and using the KVC-compliance methods (that is, accessor methods). Key-value coding is a related mechanism (based on a related informal protocol) for automatically getting and setting the values of object properties.

You can refine KVO notifications by disabling automatic observer notifications and implementing manual notifications using the methods of the `NSKeyValueObserving` informal protocol and associated categories.

> **Further Reading** See *Key-Value Observing Programming Guide* to learn more about the mechanism and underlying protocol. Also see the related documents *Key-Value Coding Programming Guide* and *Cocoa Bindings Programming Topics*.

Proxy

The Proxy design pattern provides a surrogate, or placeholder, for another object in order to control access to that other object. You use this pattern to create a representative, or proxy, object that controls access to another object, which may be remote, expensive to create, or in need of securing. This pattern is structurally similar to the Decorator pattern but it serves a different purpose; Decorator adds behavior to an object whereas Proxy controls access to an object.

NSProxy

The `NSProxy` class defines the interface for objects that act as surrogates for other objects, even for objects that don't yet exist. A proxy object typically forwards a message sent to it to the object that it represents, but it can also respond to the message by loading the represented object or transforming itself into it. Although `NSProxy` is an abstract class, it implements the `NSObject` protocol and other fundamental methods expected of a root object; it is, in fact, the root class of a hierarchy just as the `NSObject` class is.

Concrete subclasses of `NSProxy` can accomplish the stated goals of the Proxy pattern, such as lazy instantiation of expensive objects or acting as sentry objects for security. `NSDistantObject`, a concrete subclass of `NSProxy` in the Foundation framework, implements a remote proxy for transparent distributed messaging. `NSDistantObject` objects are part of the architecture for distributed objects. By acting as proxies for objects in other processes or threads, they help to enable communication between objects in those threads or processes.

`NSInvocation` objects, which are an adaptation of the Command pattern, are also part of the distributed objects architecture (see "Invocation Objects" (page 171)).

Uses and Limitations

Cocoa employs `NSProxy` objects only in distributed objects. The `NSProxy` objects are specifically instances of the concrete subclasses `NSDistantObject` and `NSProtocolChecker`. You can use distributed objects not only for interprocess messaging (on the same or different computers) but you can also use it to implement distributed computing or parallel processing. If you want to use proxy objects for other purposes, such as the creation of expensive resources or security, you have to implement your own concrete subclass of `NSProxy`.

> **Further Reading** To learn more about Cocoa proxy objects and the role they play in distributed messaging, read *Distributed Objects Programming Topics*.

Receptionist

The Receptionist design pattern addresses the general problem of redirecting an event occurring in one execution context of an application to another execution context for handling. It is a hybrid pattern. Although it doesn't appear in the "Gang of Four" book, it combines elements of the Command, Memo, and Proxy design patterns described in that book. It is also a variant of the Trampoline pattern (which also doesn't appear in the book); in this pattern, an event initially is received by a trampoline object, so-called because it immediately bounces, or redirects, the event to a target object for handling.

You can adopt the Receptionist design pattern whenever you need to bounce off work to another execution context for handling. When you observe a notification, or implement a block handler, or respond to an action message and you want to ensure that your code executes in the appropriate execution context, you can implement the Receptionist pattern to redirect the work that must be done to that execution context. With the Receptionist pattern, you might even perform some filtering or coalescing of the incoming data before you bounce off a task to process the data. For example, you could collect data into batches, and then at intervals dispatch those batches elsewhere for processing.

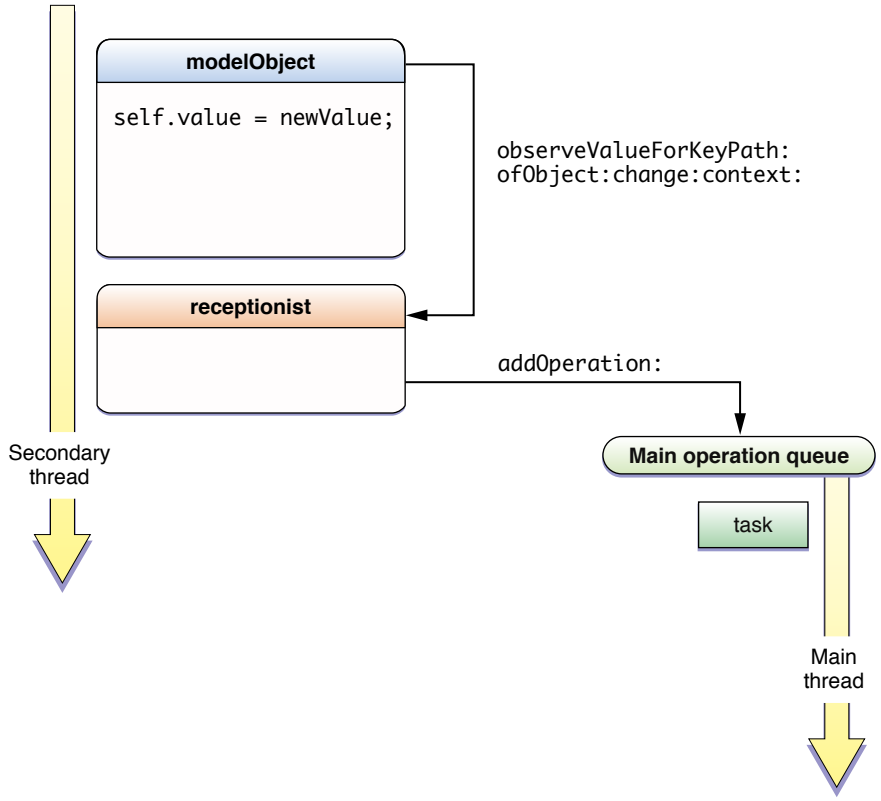
One common situation where the Receptionist pattern is useful is key-value observing. In key-value observing, changes to the value of an model object's property are communicated to observers via KVO notifications. However, changes to a model object can occur on a background thread. This results in a thread mismatch,

because changes to a model object's state typically result in updates to the user interface, and these must occur on the main thread. In this case, you want to redirect the KVO notifications to the main thread. where the updates to an application's user interface can occur.

The Receptionist Design Pattern in Practice

A KVO notification invokes the `observeValueForKeyPath:ofObject:change:context:` method implemented by an observer. If the change to the property occurs on a secondary thread, the `observeValueForKeyPath:ofObject:change:context:` code executes on that same thread. There the central object in this pattern, the receptionist, acts as a thread intermediary. As Figure 4-5 illustrates, a receptionist object is assigned as the observer of a model object's property. The receptionist implements `observeValueForKeyPath:ofObject:change:context:` to redirect the notification received on a secondary thread to another execution context—the main operation queue, in this case. When the property changes, the receptionist receives a KVO notification. The receptionist immediately adds a block operation to the main operation queue; the block contains code—specified by the client—that updates the user interface appropriately.

Figure 4-5 Bouncing KVO updates to the main operation queue



You define a receptionist class so that it has the elements it needs to add itself as an observer of a property and then convert a KVO notification into an update task. Thus it must know what object it's observing, the property of the object that it's observing, what update task to execute, and what queue to execute it on. Listing 4-1 shows the initial declaration of the `RCReceptionist` class and its instance variables.

Listing 4-1 Declaring the receptionist class

```
@interface RCReceptionist : NSObject {
    id observedObject;
    NSString *observedKeyPath;
    RCTaskBlock task;
    NSOperationQueue *queue;
}
```

The `RCTaskBlock` instance variable is a block object of the following declared type:

```
typedef void (^RCTaskBlock)(NSString *keyPath, id object, NSDictionary *change);
```

These parameters are similar to those of the `observeValueForKeyPath:ofObject:change:context:` method. Next, the parameter class declares a single class factory method in which an `RCTaskBlock` object is a parameter:

```
+ (id)receptionistForKeyPath:(NSString *)path
        object:(id)obj
         queue:(NSOperationQueue *)queue
          task:(RCTaskBlock)task;
```

It implements this method to assign the passed-in value to instance variables of the created receptionist object and to add that object as an observer of the model object's property, as shown in Listing 4-2.

Listing 4-2 The class factory method for creating a receptionist object

```
+ (id)receptionistForKeyPath:(NSString *)path object:(id)obj queue:(NSOperationQueue
 *)queue task:(RCTaskBlock)task {
    RCReceptionist *receptionist = [RCReceptionist new];
    receptionist->task = [task copy];
    receptionist->observedKeyPath = [path copy];
    receptionist->observedObject = [obj retain];
```

```
    receptionist->queue = [queue retain];
    [obj addObserver:receptionist forKeyPath:path
             options:NSKeyValueObservingOptionNew | NSKeyValueObservingOptionOld
context:0];
    return [receptionist autorelease];
}
```

Note that the code copies the block object instead of retaining it. Because the block was probably created on the stack, it must be copied to the heap so it exists in memory when the KVO notification is delivered.

Finally, the parameter class implements the `observeValueForKeyPath:ofObject:change:context:` method. The implementation (see Listing 4-3) is simple.

Listing 4-3 Handling the KVO notification

```
- (void)observeValueForKeyPath:(NSString *)keyPath ofObject:(id)object
        change:(NSDictionary *)change context:(void *)context {
    [queue addOperationWithBlock:^{
        task(keyPath, object, change);
    }];
}
```

This code simply enqueues the task onto the given operation queue, passing the task block the observed object, the key path for the changed property, and the dictionary containing the new value. The task is encapsulated in an `NSBlockOperation` object that executes the task on the queue.

The client object supplies the block code that updates the user interface when it creates a receptionist object, as shown in Listing 4-4. Note that when it creates the receptionist object, the client passes in the operation queue on which the block is to be executed, in this case the main operation queue.

Listing 4-4 Creating a receptionist object

```
        RCReceptionist *receptionist = [RCReceptionist
receptionistForKeyPath:@"value" object:model queue:mainQueue task:^(NSString
*keyPath, id object, NSDictionary *change) {
            NSView *viewForModel = [modelToViewMap objectForKey:model];
            NSColor *newColor = [change objectForKey:NSKeyValueChangeNewKey];
            [[[viewForModel subviews] objectAtIndex:0] setFillColor:newColor];
```

```
        }];
```

Singleton

The Singleton design pattern ensures a class only has one instance, and provides a global point of access to it. The class keeps track of its sole instance and ensures that no other instance can be created. Singleton classes are appropriate for situations where it makes sense for a single object to provide access to a global resource.

Framework Classes

Several Cocoa framework classes are singletons. They include `NSFileManager`, `NSWorkspace`, `NSApplication`, and, in UIKit, `UIApplication`. A process is limited to one instance of these classes. When a client asks the class for an instance, it gets a shared instance, which is lazily created upon the first request.

Uses and Limitations

Using the shared instance returned by a singleton class is no different from using an instance of a nonsingleton class, except that you are prevented from copying, retaining, or releasing it (the related methods are reimplemented as null operations). You can create your own singleton classes if the situation warrants it.

> **Further Reading** "Cocoa Objects" (page 61) explains how to create a singleton class.

Template Method

The Template Method design pattern defines the skeleton of an algorithm in an operation, deferring some steps to subclasses. The Template Method pattern lets subclasses redefine certain steps of an algorithm without changing the algorithm's structure.

Overridden Framework Methods

The Template Method pattern is a fundamental design of Cocoa, and indeed of object-oriented frameworks in general. The pattern in Cocoa lets custom components of a program hook themselves into an algorithm, but the framework components determine when and how they are needed. The programmatic interfaces of Cocoa classes often include methods that are meant to be overridden by subclasses. At runtime, the framework invokes these so-called generic methods at certain points in the task it is carrying out. The generic methods provide a structure for custom code to contribute program-specific behavior and data to the task being executed and coordinated by framework classes.

Uses and Limitations

To make use of the Cocoa adaptation of the Template Method pattern, you must create a subclass and override those methods that the framework invokes to insert application-specific input into the algorithm it is executing. If you are writing your own framework, you should probably include the pattern in the design.

> **Note** "Adding Behavior to a Cocoa Program" (page 126) discusses the Cocoa adaptation of the Template Method pattern, especially in "Inheriting from a Cocoa Class" (page 133).

The Document Architecture in OS X

The document architecture defined by the AppKit framework is a particular—and important—instance of the general design of overridden framework methods as an adaptation of the Template Method pattern. Cocoa applications that can create and manage multiple documents, each in its own window, are almost always based on the document architecture. In this architecture there are cooperating objects of three framework classes: `NSDocument`, `NSWindowController`, and `NSDocumentController`. `NSDocument` objects manage the model objects that represent the data of a document; upon user requests, they write that data to files and reload the data, recreating the model objects with it. `NSWindowController` objects manage the user interface of particular documents. The `NSDocumentController` object of a document-based application tracks and manages all open documents and otherwise coordinates the activities of the application. At runtime, each of these objects receives messages from AppKit requesting it to perform specific operations. The application developer must override many of the methods invoked by these messages to add application-specific behavior.

The design of the document architecture of Cocoa is also heavily influenced by the Model-View-Controller pattern.

Uses and Limitations

You can create a project for a document-based Cocoa application by choosing the Cocoa Document-based Application template from the New Project dialog in Xcode. Then you must implement a custom subclass of `NSDocument` and may choose to implement custom subclasses of `NSWindowController` and `NSDocumentController`. The AppKit framework provides much of the document-management logic of the application for you.

Note For the definitive documentation for this adaptation of the Template Method pattern, see *Document-Based Applications Overview*.

The Model-View-Controller Design Pattern

The Model-View-Controller design pattern (MVC) is quite old. Variations of it have been around at least since the early days of Smalltalk. It is a high-level pattern in that it concerns itself with the global architecture of an application and classifies objects according to the general roles they play in an application. It is also a compound pattern in that it comprises several, more elemental patterns.

Object-oriented programs benefit in several ways by adapting the MVC design pattern for their designs. Many objects in these programs tend to be more reusable and their interfaces tend to be better defined. The programs overall are more adaptable to changing requirements—in other words, they are more easily extensible than programs that are not based on MVC. Moreover, many technologies and architectures in Cocoa—such as bindings, the document architecture, and scriptability—are based on MVC and require that your custom objects play one of the roles defined by MVC.

Roles and Relationships of MVC Objects

The MVC design pattern considers there to be three types of objects: model objects, view objects, and controller objects. The MVC pattern defines the roles that these types of objects play in the application and their lines of communication. When designing an application, a major step is choosing—or creating custom classes for—objects that fall into one of these three groups. Each of the three types of objects is separated from the others by abstract boundaries and communicates with objects of the other types across those boundaries.

Model Objects Encapsulate Data and Basic Behaviors

Model objects represent special knowledge and expertise. They hold an application's data and define the logic that manipulates that data. A well-designed MVC application has all its important data encapsulated in model objects. Any data that is part of the persistent state of the application (whether that persistent state is stored in files or databases) should reside in the model objects once the data is loaded into the application. Because they represent knowledge and expertise related to a specific problem domain, they tend to be reusable.

Ideally, a model object has no explicit connection to the user interface used to present and edit it. For example, if you have a model object that represents a person (say you are writing an address book), you might want to store a birthdate. That's a good thing to store in your Person model object. However, storing a date format string or other information on how that date is to be presented is probably better off somewhere else.

In practice, this separation is not always the best thing, and there is some room for flexibility here, but in general a model object should not be concerned with interface and presentation issues. One example where a bit of an exception is reasonable is a drawing application that has model objects that represent the graphics displayed. It makes sense for the graphic objects to know how to draw themselves because the main reason for their existence is to define a visual thing. But even in this case, the graphic objects should not rely on living in a particular view or any view at all, and they should not be in charge of knowing when to draw themselves. They should be asked to draw themselves by the view object that wants to present them.

> **Further Reading** *Model Object Implementation Guide* discusses the proper design and implementation of model objects.

View Objects Present Information to the User

A view object knows how to display, and might allow users to edit, the data from the application's model. The view should not be responsible for storing the data it is displaying. (This does not mean the view never actually stores data it's displaying, of course. A view can cache data or do similar tricks for performance reasons). A view object can be in charge of displaying just one part of a model object, or a whole model object, or even many different model objects. Views come in many different varieties.

View objects tend to be reusable and configurable, and they provide consistency between applications. In Cocoa, the AppKit framework defines a large number of view objects and provides many of them in the Interface Builder library. By reusing the AppKit's view objects, such as `NSButton` objects, you guarantee that buttons in your application behave just like buttons in any other Cocoa application, assuring a high level of consistency in appearance and behavior across applications.

A view should ensure it is displaying the model correctly. Consequently, it usually needs to know about changes to the model. Because model objects should not be tied to specific view objects, they need a generic way of indicating that they have changed.

Controller Objects Tie the Model to the View

A controller object acts as the intermediary between the application's view objects and its model objects. Controllers are often in charge of making sure the views have access to the model objects they need to display and act as the conduit through which views learn about changes to the model. Controller objects can also perform set-up and coordinating tasks for an application and manage the life cycles of other objects.

In a typical Cocoa MVC design, when users enter a value or indicate a choice through a view object, that value or choice is communicated to a controller object. The controller object might interpret the user input in some application-specific way and then either may tell a model object what to do with this input—for example, "add a new value" or "delete the current record"—or it may have the model object reflect a changed value in one of its properties. Based on this same user input, some controller objects might also tell a view object to change

an aspect of its appearance or behavior, such as telling a button to disable itself. Conversely, when a model object changes—say, a new data source is accessed—the model object usually communicates that change to a controller object, which then requests one or more view objects to update themselves accordingly.

Controller objects can be either reusable or nonreusable, depending on their general type. "Types of Cocoa Controller Objects" (page 195) describes the different types of controller objects in Cocoa.

Combining Roles

One can merge the MVC roles played by an object, making an object, for example, fulfill both the controller and view roles—in which case, it would be called a *view controller*. In the same way, you can also have model-controller objects. For some applications, combining roles like this is an acceptable design.

A *model controller* is a controller that concerns itself mostly with the model layer. It "owns" the model; its primary responsibilities are to manage the model and communicate with view objects. Action methods that apply to the model as a whole are typically implemented in a model controller. The document architecture provides a number of these methods for you; for example, an `NSDocument` object (which is a central part of the document architecture) automatically handles action methods related to saving files.

A view controller is a controller that concerns itself mostly with the view layer. It "owns" the interface (the views); its primary responsibilities are to manage the interface and communicate with the model. Action methods concerned with data displayed in a view are typically implemented in a view controller. An `NSWindowController` object (also part of the document architecture) is an example of a view controller.

"Design Guidelines for MVC Applications" (page 200) offers some design advice concerning objects with merged MVC roles.

> **Further Reading** *Document-Based Applications Overview* discusses the distinction between a model controller and a view controller from another perspective.

Types of Cocoa Controller Objects

The section "Controller Objects Tie the Model to the View" (page 194) sketches the abstract outline of a controller object, but in practice the picture is far more complex. In Cocoa there are two general kinds of controller objects: mediating controllers and coordinating controllers. Each kind of controller object is associated with a different set of classes and each provides a different range of behaviors.

A *mediating controller* is typically an object that inherits from the `NSController` class. Mediating controller objects are used in the Cocoa bindings technology. They facilitate—or mediate—the flow of data between view objects and model objects.

> **iOS Note** AppKit implements the `NSController` class and its subclasses. These classes and the bindings technology are not available in iOS.

Mediating controllers are typically ready-made objects that you drag from the Interface Builder library. You can configure these objects to establish the bindings between properties of view objects and properties of the controller object, and then between those controller properties and specific properties of a model object. As a result, when users change a value displayed in a view object, the new value is automatically communicated to a model object for storage—via the mediating controller; and when a property of a model changes its value, that change is communicated to a view for display. The abstract `NSController` class and its concrete subclasses—`NSObjectController`, `NSArrayController`, `NSUserDefaultsController`, and `NSTreeController`—provide supporting features such as the ability to commit and discard changes and the management of selections and placeholder values.

A *coordinating controller* is typically an `NSWindowController` or `NSDocumentController` object (available only in AppKit), or an instance of a custom subclass of `NSObject`. Its role in an application is to oversee—or coordinate—the functioning of the entire application or of part of the application, such as the objects unarchived from a nib file. A coordinating controller provides services such as:

- Responding to delegation messages and observing notifications
- Responding to action messages
- Managing the life cycle of owned objects (for example, releasing them at the proper time)
- Establishing connections between objects and performing other set-up tasks

`NSWindowController` and `NSDocumentController` are classes that are part of the Cocoa architecture for document-based applications. Instances of these classes provide default implementations for several of the services listed above, and you can create subclasses of them to implement more application-specific behavior. You can even use `NSWindowController` objects to manage windows in an application that is not based on the document architecture.

A coordinating controller frequently owns the objects archived in a nib file. As File's Owner, the coordinating controller is external to the objects in the nib file and manages those objects. These owned objects include mediating controllers as well as window objects and view objects. See "MVC as a Compound Design Pattern" (page 197) for more on coordinating controllers as File's Owner.

Instances of custom `NSObject` subclasses can be entirely suitable as coordinating controllers. These kinds of controller objects combine both mediating and coordinating functions. For their mediating behavior, they make use of mechanisms such as target-action, outlets, delegation, and notifications to facilitate the movement of data between view objects and model objects. They tend to contain a lot of glue code and, because that code is exclusively application-specific, they are the least reusable kind of object in an application.

Further Reading For more on controller objects in their role as mediators, see the information on the Mediator design pattern in "Mediator" (page 179). For more on the Cocoa bindings technology, see *Cocoa Bindings Programming Topics*.

MVC as a Compound Design Pattern

Model-View-Controller is a design pattern that is composed of several more basic design patterns. These basic patterns work together to define the functional separation and paths of communication that are characteristic of an MVC application. However, the traditional notion of MVC assigns a set of basic patterns different from those that Cocoa assigns. The difference primarily lies in the roles given to the controller and view objects of an application.

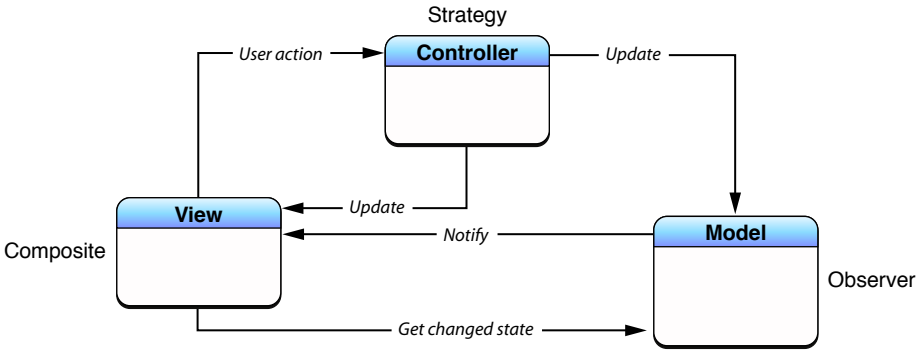
In the original (Smalltalk) conception, MVC is made up of the Composite, Strategy, and Observer patterns.

- Composite—The view objects in an application are actually a composite of nested views that work together in a coordinated fashion (that is, the view hierarchy). These display components range from a window to compound views, such as a table view, to individual views, such as buttons. User input and display can take place at any level of the composite structure.
- Strategy—A controller object implements the strategy for one or more view objects. The view object confines itself to maintaining its visual aspects, and it delegates to the controller all decisions about the application-specific meaning of the interface behavior.
- Observer—A model object keeps interested objects in an application—usually view objects—advised of changes in its state.

The traditional way the Composite, Strategy, and Observer patterns work together is depicted by Figure 4-6: The user manipulates a view at some level of the composite structure and, as a result, an event is generated. A controller object receives the event and interprets it in an application-specific way—that is, it applies a strategy. This strategy can be to request (via message) a model object to change its state or to request a view

object (at some level of the composite structure) to change its behavior or appearance. The model object, in turn, notifies all objects who have registered as observers when its state changes; if the observer is a view object, it may update its appearance accordingly.

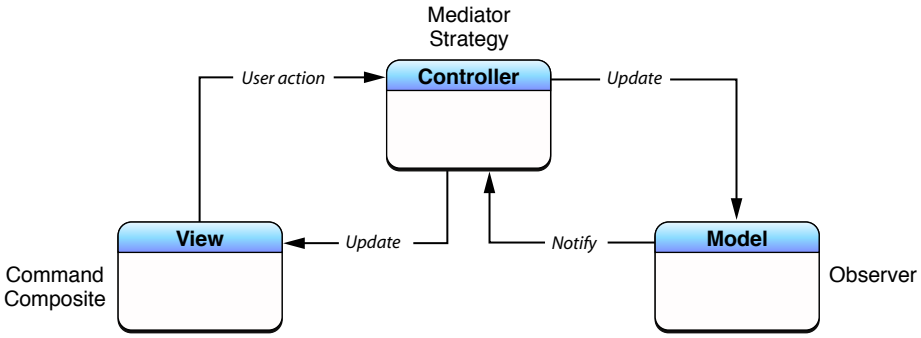
Figure 4-6 Traditional version of MVC as a compound pattern



The Cocoa version of MVC as a compound pattern has some similarities to the traditional version, and in fact it is quite possible to construct a working application based on the diagram in Figure 4-6. By using the bindings technology, you can easily create a Cocoa MVC application whose views directly observe model objects to receive notifications of state changes. However, there is a theoretical problem with this design. View objects and model objects should be the most reusable objects in an application. View objects represent the "look and feel" of an operating system and the applications that system supports; consistency in appearance and behavior is essential, and that requires highly reusable objects. Model objects by definition encapsulate the data associated with a problem domain and perform operations on that data. Design-wise, it's best to keep model and view objects separate from each other, because that enhances their reusability.

In most Cocoa applications, notifications of state changes in model objects are communicated to view objects *through* controller objects. Figure 4-7 shows this different configuration, which appears much cleaner despite the involvement of two more basic design patterns.

Figure 4-7 Cocoa version of MVC as a compound design pattern



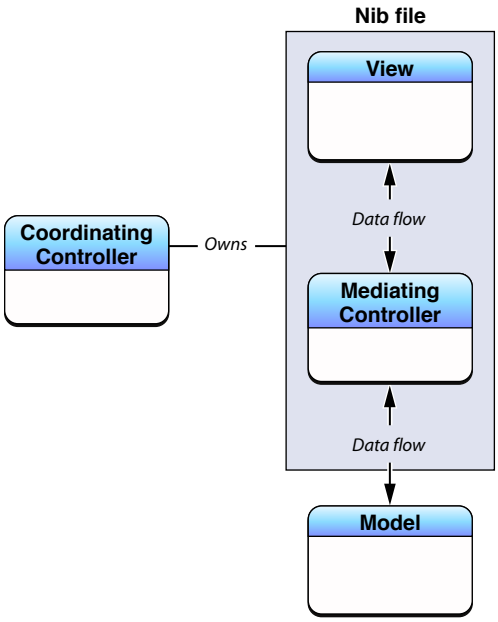
The controller object in this compound design pattern incorporates the Mediator pattern as well as the Strategy pattern; it mediates the flow of data between model and view objects in both directions. Changes in model state are communicated to view objects through the controller objects of an application. In addition, view objects incorporate the Command pattern through their implementation of the target-action mechanism.

> **Note** The target-action mechanism, which enables view objects to communicate user input and choices, can be implemented in both coordinating and mediating controller objects. However, the design of the mechanism differs in each controller type. For coordinating controllers, you connect the view object to its target (the controller object) in Interface Builder and specify an action selector that must conform to a certain signature. Coordinating controllers, by virtue of being delegates of windows and the global application object, can also be in the responder chain. The bindings mechanism used by mediating controllers also connects view objects to targets and allows action signatures with a variable number of parameters of arbitrary types. Mediating controllers, however, aren't in the responder chain.

There are practical reasons as well as theoretical ones for the revised compound design pattern depicted in Figure 4-7, especially when it comes to the Mediator design pattern. Mediating controllers derive from concrete subclasses of `NSController`, and these classes, besides implementing the Mediator pattern, offer many features that applications should take advantage of, such as the management of selections and placeholder values. And if you opt not to use the bindings technology, your view object could use a mechanism such as the Cocoa notification center to receive notifications from a model object. But this would require you to create a custom view subclass to add the knowledge of the notifications posted by the model object.

In a well-designed Cocoa MVC application, coordinating controller objects often own mediating controllers, which are archived in nib files. Figure 4-8 shows the relationships between the two types of controller objects.

Figure 4-8 Coordinating controller as the owner of a nib file



Design Guidelines for MVC Applications

The following guidelines apply to Model-View-Controller considerations in the design of applications:

- Although you can use an instance of a custom subclass of `NSObject` as a mediating controller, there's no reason to go through all the work required to make it one. Use instead one of the ready-made `NSController` objects designed for the Cocoa bindings technology; that is, use an instance of `NSObjectController`, `NSArrayController`, `NSUserDefaultsController`, or `NSTreeController`—or a custom subclass of one of these concrete `NSController` subclasses.

  However, if the application is very simple and you feel more comfortable writing the glue code needed to implement mediating behavior using outlets and target-action, feel free to use an instance of a custom `NSObject` subclass as a mediating controller. In a custom `NSObject` subclass, you can also implement a mediating controller in the `NSController` sense, using key-value coding, key-value observing, and the editor protocols.

- Although you can combine MVC roles in an object, the best overall strategy is to keep the separation between roles. This separation enhances the reusability of objects and the extensibility of the program they're used in. If you are going to merge MVC roles in a class, pick a predominant role for that class and then (for maintenance purposes) use categories in the same implementation file to extend the class to play other roles.

- A goal of a well-designed MVC application should be to use as many objects as possible that are (theoretically, at least) reusable. In particular, view objects and model objects should be highly reusable. (The ready-made mediating controller objects, of course, are reusable.) Application-specific behavior is frequently concentrated as much as possible in controller objects.
- Although it is possible to have views directly observe models to detect changes in state, it is best not to do so. A view object should always go through a mediating controller object to learn about changes in an model object. The reason is two-fold:
    - If you use the bindings mechanism to have view objects directly observe the properties of model objects, you bypass all the advantages that `NSController` and its subclasses give your application: selection and placeholder management as well as the ability to commit and discard changes.
    - If you don't use the bindings mechanism, you have to subclass an existing view class to add the ability to observe change notifications posted by a model object.
- Strive to limit code dependency in the classes of your application. The greater the dependency a class has on another class, the less reusable it is. Specific recommendations vary by the MVC roles of the two classes involved:
    - A view class shouldn't depend on a model class (although this may be unavoidable with some custom views).
    - A view class shouldn't have to depend on a mediating controller class.
    - A model class shouldn't depend on anything other than other model classes.
    - A mediating controller class shouldn’t depend on a model class (although, like views, this may be necessary if it's a custom controller class).
    - A mediating controller class shouldn't depend on view classes or on coordinating controller classes.
    - A coordinating controller class depends on classes of all MVC role types.
- If Cocoa offers an architecture that solves a programming problem, and this architecture assigns MVC roles to objects of specific types, use that architecture. It will be much easier to put your project together if you do. The document architecture, for example, includes an Xcode project template that configures an `NSDocument` object (per-nib model controller) as File's Owner.

Model-View-Controller in Cocoa (OS X)

The Model-View-Controller design pattern is fundamental to many Cocoa mechanisms and technologies. As a consequence, the importance of using MVC in object-oriented design goes beyond attaining greater reusability and extensibility for your own applications. If your application is to incorporate a Cocoa technology that is MVC-based, your application will work best if its design also follows the MVC pattern. It should be relatively painless to use these technologies if your application has a good MVC separation, but it will take more effort to use such a technology if you don’t have a good separation.

Cocoa in OS X includes the following architectures, mechanisms, and technologies that are based on Model-View-Controller:

- **Document architecture**. In this architecture, a document-based application consists of a controller object for the entire application (`NSDocumentController`), a controller object for each document window (`NSWindowController`), and an object that combines controller and model roles for each document (`NSDocument`).
- **Bindings**. MVC is central to the bindings technology of Cocoa. The concrete subclasses of the abstract `NSController` provide ready-made controller objects that you can configure to establish bindings between view objects and properly designed model objects.
- **Application scriptability**. When designing an application to make it scriptable, it is essential not only that it follow the MVC design pattern but that your application's model objects are properly designed. Scripting commands that access application state and request application behavior should usually be sent to model objects or controller objects.
- **Core Data**. The Core Data framework manages graphs of model objects and ensures the persistence of those objects by saving them to (and retrieving them from) a persistent store. Core Data is tightly integrated with the Cocoa bindings technology. The MVC and object modeling design patterns are essential determinants of the Core Data architecture.
- **Undo**. In the undo architecture, model objects once again play a central role. The primitive methods of model objects (which are usually its accessor methods) are often where you implement undo and redo operations. The view and controller objects of an action may also be involved in these operations; for example, you might have such objects give specific titles to the undo and redo menu items, or you might have them undo selections in a text view.

Object Modeling

This section defines terms and presents examples of object modeling and key-value coding that are specific to Cocoa bindings and the Core Data framework. Understanding terms such as key paths is fundamental to using these technologies effectively. This section is recommended reading if you are new to object-oriented design or key-value coding.

When using the Core Data framework, you need a way to describe your model objects that does not depend on views and controllers. In a good reusable design, views and controllers need a way to access model properties without imposing dependencies between them. The Core Data framework solves this problem by borrowing concepts and terms from database technology—specifically, the entity-relationship model.

Entity-relationship modeling is a way of representing objects typically used to describe a data source's data structures in a way that allows those data structures to be mapped to objects in an object-oriented system. Note that entity-relationship modeling isn't unique to Cocoa; it's a popular discipline with a set of rules and terms that are documented in database literature. It is a representation that facilitates storage and retrieval of objects in a data source. A data source can be a database, a file, a web service, or any other persistent store. Because it is not dependent on any type of data source it can also be used to represent any kind of object and its relationship to other objects.

In the entity-relationship model, the objects that hold data are called *entities*, the components of an entity are called *attributes*, and the references to other data-bearing objects are called *relationships*. Together, attributes and relationships are known as *properties*. With these three simple components (entities, attributes, and relationships), you can model systems of any complexity.

Cocoa uses a modified version of the traditional rules of entity-relationship modeling referred to in this document as *object modeling*. Object modeling is particularly useful in representing model objects in the Model-View-Controller (MVC) design pattern. This is not surprising because even in a simple Cocoa application, models are typically persistent—that is, they are stored in a data container such as a file.

Entities

Entities are model objects. In the MVC design pattern, model objects are the objects in your application that encapsulate specified data and provide methods that operate on that data. They are usually persistent but more importantly, model objects are not dependent on how the data is displayed to the user.

For example, a structured collection of model objects (an object model) can be used to represent a company's customer base, a library of books, or a network of computers. A library book has attributes—such as the book title, ISBN number, and copyright date—and relationships to other objects—such as the author and library member. In theory, if the parts of a system can be identified, the system can be expressed as an object model.

Figure 4-9 shows an example object model used in an employee management application. In this model, Department models a department and Employee models an employee.

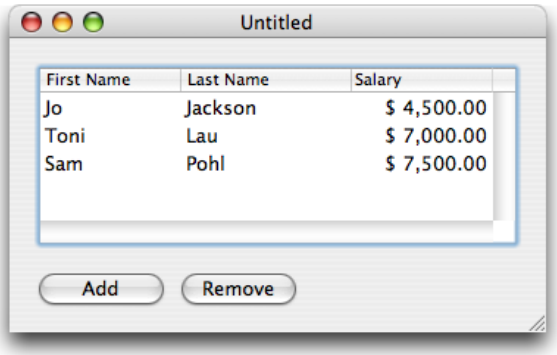
Figure 4-9 Employee management application object diagram

Attributes

Attributes represent structures that contain data. An attribute of an object may be a simple value, such as a scalar (for example, an `integer`, `float`, or `double` value), but can also be a C structure (for example an array of `char` values or an `NSPoint` structure) or an instance of a primitive class (such as, `NSNumber`, `NSData`, or `NSColor` in Cocoa). Immutable objects such as `NSColor` are usually considered attributes too. (Note that Core Data natively supports only a specific set of attribute types, as described in *NSAttributeDescription Class Reference*. You can, however, use additional attribute types, as described in "Non-Standard Persistent Attributes" in *Core Data Programming Guide*.)

In Cocoa, an attribute typically corresponds to a model's instance variable or accessor method. For example, Employee has `firstName`, `lastName`, and `salary` instance variables. In an employee management application, you might implement a table view to display a collection of Employee objects and some of their attributes, as shown in Figure 4-10. Each row in the table corresponds to an instance of Employee, and each column corresponds to an attribute of Employee.

Figure 4-10 Employees table view



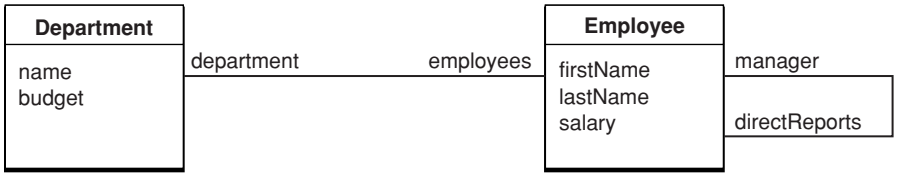
Relationships

Not all properties of a model are attributes—some properties are relationships to other objects. Your application is typically modeled by multiple classes. At runtime, your object model is a collection of related objects that make up an object graph. These are typically the persistent objects that your users create and save to some data container or file before terminating the application (as in a document-based application). The relationships between these model objects can be traversed at runtime to access the properties of the related objects.

For example, in the employee management application, there are relationships between an employee and the department in which the employee works, and between an employee and the employee's manager. Because a manage is also an employee. the employee–manager relationship is an example of a reflexive relationship—a relationship from an entity to itself.

Relationships are inherently bidirectional, so conceptually at least there are also relationships between a department and the employees that work in the department, and an employee and the employee's direct reports. Figure 4-11 (page 205) illustrates the relationships between a Department and an Employee entity, and the Employee reflexive relationship. In this example, the Department entity's "employees" relationship is the inverse of the Employee entity's "department" relationship. It is possible, however, for relationships to be navigable in only one direction—for there to be no inverse relationship. If, for example, you are never interested in finding out from a department object what employees are associated with it, then you do not have to model that relationship. (Note that although this is true in the general case, Core Data may impose additional constraints over general Cocoa object modeling—not modeling the inverse should be considered an extremely advanced option.)

Figure 4-11 Relationships in the employee management application



Relationship Cardinality and Ownership

Every relationship has a *cardinality*; the cardinality tells you how many destination objects can (potentially) resolve the relationship. If the destination object is a single object, then the relationship is called a *to-one relationship*. If there may be more than one object in the destination, then the relationship is called a *to-many relationship*.

Relationships can be mandatory or optional. A mandatory relationship is one where the destination is required—for example, every employee must be associated with a department. An optional relationship is, as the name suggests, optional—for example, not every employee has direct reports. So the `directReports` relationship depicted in Figure 4-12 is optional.

It is also possible to specify a range for the cardinality. An optional to-one relationship has a range 0-1. An employee may have any number of direct reports, or a range that specifies a minimum and a maximum, for example, 0-15, which also illustrates an optional to-many relationship.

Figure 4-12 illustrates the cardinalities in the employee management application. The relationship between an Employee object and a Department object is a mandatory to-one relationship—an employee must belong to one, and only one, department. The relationship between a Department and its Employee objects is an optional to-many relationship (represented by a "*"). The relationship between an employee and a manager is an optional to-one relationship (denoted by the range 0-1)—top-ranking employees do not have managers.

Figure 4-12 Relationship cardinality

Note also that destination objects of relationships are sometimes owned and sometimes shared.

Accessing Properties

In order for models, views, and controllers to be independent of each other, you need to be able to access properties in a way that is independent of a model's implementation. This is accomplished by using key-value pairs.

Keys

You specify properties of a model using a simple key, often a string. The corresponding view or controller uses the key to look up the corresponding attribute value. This design enforces the notion that the attribute itself doesn't necessarily contain the data—the value can be indirectly obtained or derived.

Key-value coding is used to perform this lookup; it is a mechanism for accessing an object's properties indirectly and, in certain contexts, automatically. Key-value coding works by using the names of the object's properties—typically its instance variables or accessor methods—as keys to access the values of those properties.

For example, you might obtain the name of a Department object using a `name` key. If the Department object either has an instance variable or a method called `name` then a value for the key can be returned (if it doesn't have either, an error is returned). Similarly, you might obtain Employee attributes using the `firstName`, `lastName`, and `salary` keys.

Values

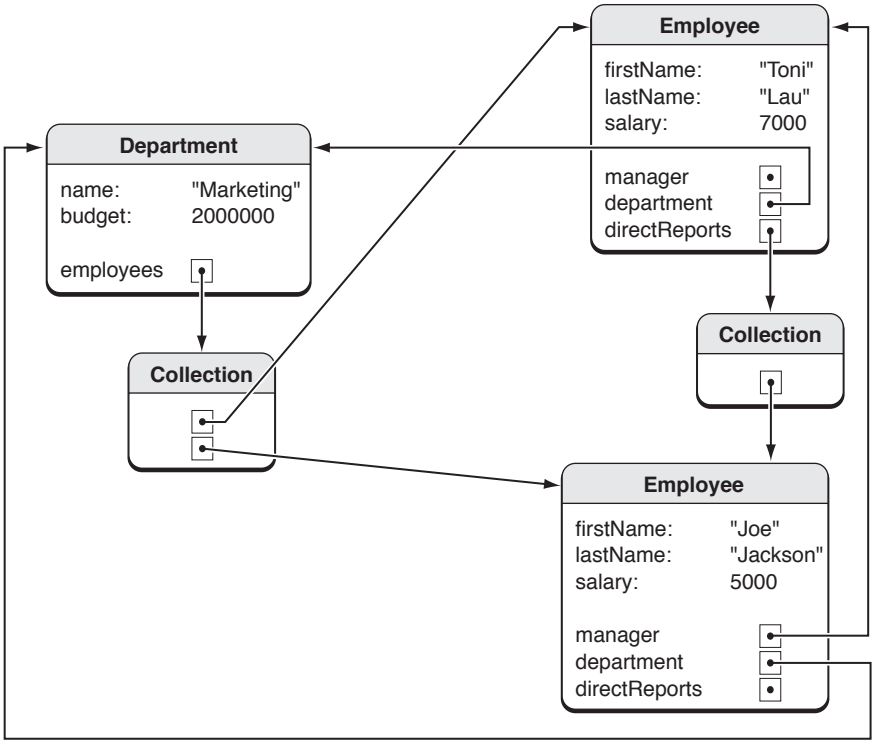
All values for a particular attribute of a given entity are of the same data type. The data type of an attribute is specified in the declaration of its corresponding instance variable or in the return value of its accessor method. For example, the data type of the Department object `name` attribute may be an `NSString` object in Objective-C.

Note that key-value coding returns only object values. If the return type or the data type for the specific accessor method or instance variable used to supply the value for a specified key is not an object, then an `NSNumber` or `NSValue` object is created for that value and returned in its place. If the `name` attribute of Department is of type `NSString`, then, using key-value coding, the value returned for the `name` key of a Department object is an `NSString` object. If the `budget` attribute of Department is of type `float`, then, using key-value coding, the value returned for the `budget` key of a Department object is an `NSNumber` object.

Similarly, when you set a value using key-value coding, if the data type required by the appropriate accessor or instance variable for the specified key is not an object, then the value is extracted from the passed object using the appropriate *–type*`Value` method.

The value of a to-one relationship is simply the destination object of that relationship. For example, the value of the `department` property of an Employee object is a Department object. The value of a to-many relationship is the collection object. The collection can be a set or an array. If you use Core Data it is a set; otherwise, it is typically an array) that contains the destination objects of that relationship. For example, the value of the `employees` property of an Department object is a collection containing Employee objects. Figure 4-13 shows an example object graph for the employee management application.

Figure 4-13 Object graph for the employee management application

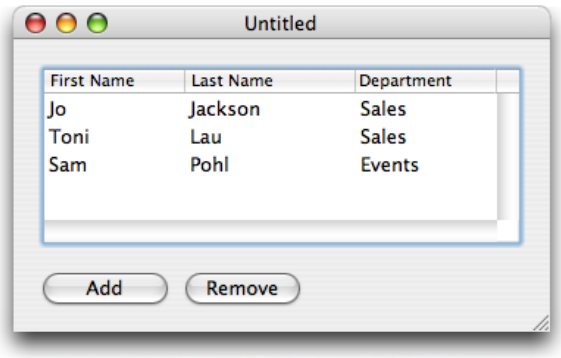


Key Paths

A *key path* is a string of dot-separated keys that specify a sequence of object properties to traverse. The property of the first key is determined by, and each subsequent key is evaluated relative to, the previous property. Key paths allow you to specify the properties of related objects in a way that is independent of the model implementation. Using key paths you can specify the path through an object graph, of whatever depth, to a specific attribute of a related object.

The key-value coding mechanism implements the lookup of a value given a key path similar to key-value pairs. For example, in the employee-management application you might access the name of a Department via an Employee object using the `department.name` key path where `department` is a relationship of Employee and `name` is an attribute of Department. Key paths are useful if you want to display an attribute of a destination entity. For example, the employee table view in Figure 4-14 is configured to display the name of the employee's department object, not the department object itself. Using Cocoa bindings, the value of the Department column is bound to `department.name` of the Employee objects in the displayed array.

Figure 4-14 Employees table view showing department name



Not every relationship in a key path necessarily has a value. For example, the `manager` relationship can be `nil` if the employee is the CEO. In this case, the key-value coding mechanism does not break—it simply stops traversing the path and returns an appropriate value, such as `nil`.

Communicating with Objects

Several of the Cocoa adaptations of design patterns assist communication between objects in an application. These mechanisms and paradigms include delegation, notification, target-action, and the bindings technology. This chapter describes those mechanisms and paradigms.

Communication in Object-Oriented Programs

With Cocoa and Objective-C, the object-oriented language for Cocoa, one way of adding the behavior that is specific to your program is through inheritance. You create a subclass of an existing class that either augments the attributes and behavior of an instance of that class or modifies them in some way. But there are other ways of adding the special logic that characterizes your program. There are other mechanisms for reusing and extending the capabilities of Cocoa objects.

The relationships between objects in a program exist in more than one dimension. There is the hierarchical structure of inheritance, but objects in a program also exist dynamically, in a network of other objects that must communicate with one another at runtime to get the work of the program done. In a fashion similar to a musician in an orchestra, each object in a program has a role, a limited set of behaviors it contributes to the program. It displays an oval surface that responds to mouse clicks, or it manages a collection of objects, or it coordinates the major events in the life of a window. It does what it is designed to do, and nothing more. But for its contributions to be realized in the program, it must be able to communicate them to other objects. It must be able to send messages to other objects or be able to receive messages from other objects.

Before your object can send a message to another object, it must either have a reference to it or have some delivery mechanism it can rely on. Cocoa gives objects many ways to communicate with each other. These mechanisms and techniques, which are based on design patterns described in "Cocoa Design Patterns" (page 165), make it possible to construct robust applications efficiently. They range from the simple to the slightly more elaborate, and often are a preferable alternative to subclassing. You can configure them programmatically and sometimes graphically in Interface Builder.

Outlets

An outlet is an object instance variable—that is, an instance variable of an object that references another object. With outlets, the reference is configured and archived through Interface Builder. The connections between the containing object and its outlets are reestablished every time the containing object is unarchived from its nib file. The containing object holds an outlet as an instance variable with the type qualifier of `IBOutlet`. For example:

```
@interface AppController : NSObject
{
    IBOutlet NSArray *keywords;
}
```

Because it is an instance variable, an outlet becomes part of an object's encapsulated data. But an outlet is more than a simple instance variable. The connection between an object and its outlets is archived in a nib file; when the nib file is loaded, each connection is unarchived and reestablished, and is thus always available whenever it becomes necessary to send messages to the other object. The type qualifier `IBOutlet` is a tag applied to an instance-variable declaration so that the Interface Builder application can recognize the instance variable as an outlet and synchronize the display and connection of it with Xcode.

You connect an outlet in Interface Builder, but you must first declare an outlet in the header file of your custom class by tagging the instance variable with the `IBOutlet` qualifier.

An application typically sets outlet connections between its custom controller objects and objects on the user interface, but they can be made between any objects that can be represented as instances in Interface Builder, even between two custom objects. As with any instance variable, you should be able to justify its inclusion in a class; the more instance variables an object has, the more memory it takes up. If there are other ways to obtain a reference to an object, such as finding it through its index position in a matrix, or through its inclusion as a function parameter, or through use of a tag (an assigned numeric identifier), you should do that instead.

Outlets are a form of object composition, which is a dynamic pattern that requires an object to somehow acquire references to its constituent objects so that it can send messages to them. It typically holds these other objects as instance variables. These variables must be initialized with the appropriate references at some point during the execution of the program.

Delegates and Data Sources

A delegate is an object that acts on behalf of, or in coordination with, another object when that object encounters an event in a program. The delegating object is often a responder object—that is, an object inheriting from `NSResponder` in AppKit or `UIResponder` in UIKit—that is responding to a user event. The delegate is an object that is delegated control of the user interface for that event, or is at least asked to interpret the event in an application-specific manner.

To better appreciate the value of delegation, it helps to consider an off-the-shelf Cocoa object such as a text field (an instance of `NSTextField` or `UITextField`) or a table view (an instance of `NSTableView` or `UITableView`). These objects are designed to fulfill a specific role in a generic fashion; a window object in the AppKit framework, for example, responds to mouse manipulations of its controls and handles such things as closing, resizing, and moving the physical window. This restricted and generic behavior necessarily limits what the object can know about how an event affects (or will affect) something elsewhere in the application, especially when the affected behavior is specific to your application. Delegation provides a way for your custom object to communicate application-specific behavior to the off-the-shelf object.

The programming mechanism of delegation gives objects a chance to coordinate their appearance and state with changes occurring elsewhere in a program, changes usually brought about by user actions. More importantly, delegation makes it possible for one object to alter the behavior of another object without the need to inherit from it. The delegate is almost always one of your custom objects, and by definition it incorporates application-specific logic that the generic and delegating object cannot possibly know itself.

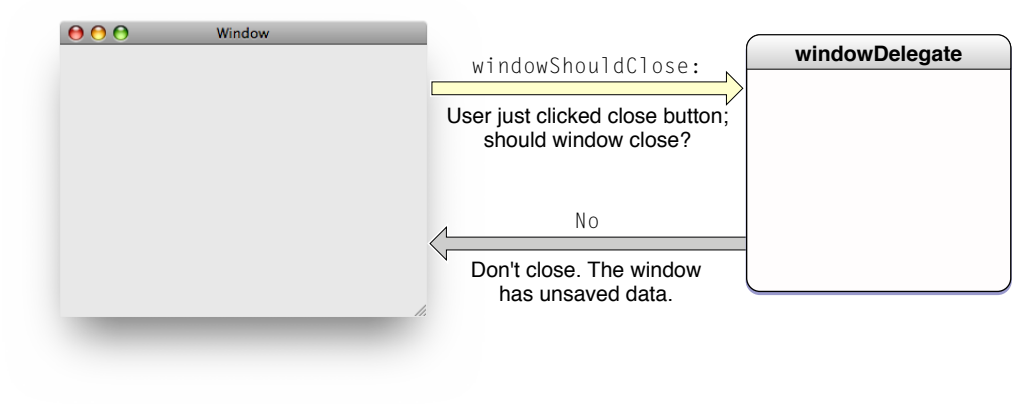
How Delegation Works

The design of the delegation mechanism is simple (Figure 5-1). The delegating class has an outlet or property, usually one that is named `delegate`; if it is an outlet, it includes methods for setting and accessing the value of the outlet. It also declares, without implementing, one or more methods that constitute a formal protocol or an informal protocol. A formal protocol that uses optional methods—a feature of Objective-C 2.0—is the preferred approach, but both kinds of protocols are used by the Cocoa frameworks for delegation.

In the informal protocol approach, the delegating class declares methods on a category of `NSObject`, and the delegate implements only those methods in which it has an interest in coordinating itself with the delegating object or affecting that object's default behavior. If the delegating class declares a formal protocol, the delegate may choose to implement those methods marked optional, but it must implement the required ones.

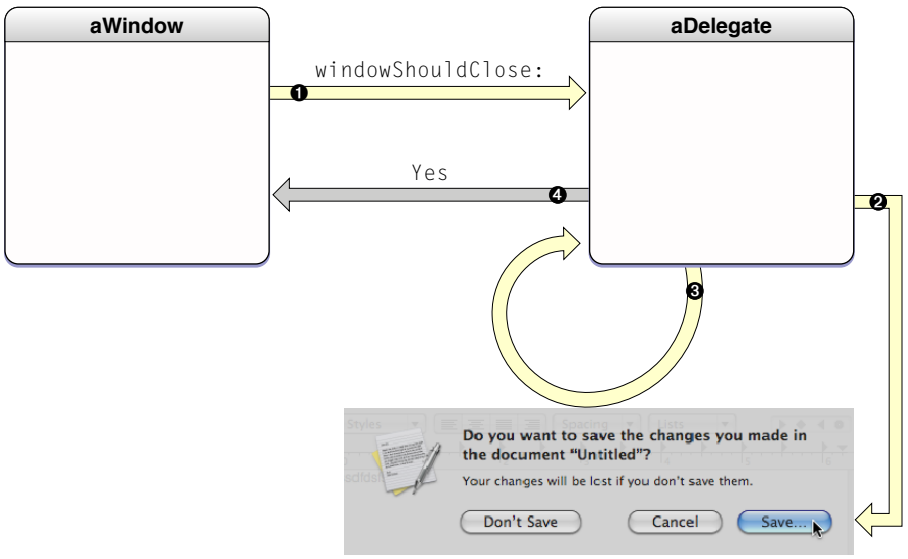
Delegation follows a common design, illustrated by Figure 5-1.

Figure 5-1 The mechanism of delegation



The methods of the protocol mark significant events handled or anticipated by the delegating object. This object wants either to communicate these events to the delegate or, for impending events, to request input or approval from the delegate. For example, when a user clicks the close button of a window in OS X, the window object sends the `windowShouldClose:` message to its delegate; this gives the delegate the opportunity to veto or defer the closing of the window if, for example, the window has associated data that must be saved (see Figure 5-2).

Figure 5-2 A more realistic sequence involving a delegate



The delegating object sends a message only if the delegate implements the method. It makes this discovery by invoking the `NSObject` method `respondsToSelector:` in the delegate first.

The Form of Delegation Messages

Delegation methods have a conventional form. They begin with the name of the AppKit or UIKit object doing the delegating—application, window, control, and so on; this name is in lower-case and without the "NS" or "UI" prefix. Usually (but not always) this object name is followed by an auxiliary verb indicative of the temporal status of the reported event. This verb, in other words, indicates whether the event is about to occur ("Should" or "Will") or whether it has just occurred ("Did" or "Has"). This temporal distinction helps to categorize those messages that expect a return value and those that don't. Listing 5-1 includes a few AppKit delegation methods that expect a return value.

Listing 5-1 Sample delegation methods with return values

```
- (BOOL)application:(NSApplication *)sender
    openFile:(NSString *)filename;                          // NSApplication
- (BOOL)application:(UIApplication *)application
    handleOpenURL:(NSURL *)url;                            // UIApplicationDelegate
- (UITableRowIndexSet *)tableView:(NSTableView *)tableView
    willSelectRows:(UITableRowIndexSet *)selection;        // UITableViewDelegate
- (NSRect)windowWillUseStandardFrame:(NSWindow *)window
    defaultFrame:(NSRect)newFrame;                          // NSWindow
```

The delegate that implements these methods can block the impending event (by returning `NO` in the first two methods) or alter a suggested value (the index set and the frame rectangle in the last two methods). It can even defer an impending event; for example, the delegate implementing the `applicationShouldTerminate:` method can delay application termination by returning `NSTerminateLater`.

Other delegation methods are invoked by messages that don't expect a return value and so are typed to return `void`. These messages are purely informational, and the method names often contain "Did", "Will", or some other indication of a transpired or impending event. Listing 5-2 shows a few examples of these kinds of delegation method.

Listing 5-2 Sample delegation methods returning `void`

```
- (void) tableView:(NSTableView*)tableView
    mouseDownInHeaderOfTableColumn:(NSTableColumn *)tableColumn;     // NSTableView
- (void)windowDidMove:(NSNotification *)notification;                  // NSWindow
- (void)application:(UIApplication *)application
    willChangeStatusBarFrame:(CGRect)newStatusBarFrame;                //
UIApplication
```

```
- (void)applicationWillBecomeActive:(NSNotification *)notification;   //
NSApplication
```

There are a couple of things to note about this last group of methods. The first is that an auxiliary verb of "Will" (as in the third method) does not necessarily mean that a return value is expected. In this case, the event is imminent and cannot be blocked, but the message gives the delegate an opportunity to prepare the program for the event.

The other point of interest concerns the second and last method declarations in Listing 5-2 . The sole parameter of each of these methods is an `NSNotification` object, which means that these methods are invoked as the result of the posting of a particular notification. For example, the `windowDidMove:` method is associated with the `NSWindow` notification `NSWindowDidMoveNotification`. The section "Notifications" (page 227) discusses notifications in detail, but here it's important to understand the relationship of notifications to delegation messages in AppKit. The delegating object automatically makes its delegate an observer of all notifications it posts. All the delegate needs to do is implement the associated method to get the notification.

To make an instance of your custom class the delegate of an AppKit object, simply connect the instance to the `delegate` outlet or property in Interface Builder. Or you can set it programmatically through the delegating object's `setDelegate:` method or `delegate` property, preferably early on, such as in the `awakeFromNib` or `applicationDidFinishLaunching:` method.

Delegation and the Cocoa Application Frameworks

The delegating object in a Cocoa application is often a responder object such as a `UIApplication`, `NSWindow`, or `NSTableView` object. The delegate object itself is typically, but not necessarily, an object, often a custom object, that controls some part of the application (that is, a coordinating controller object). The following AppKit classes define a delegate:

- `NSApplication`
- `NSBrowser`
- `NSControl`
- `NSDrawer`
- `NSFontManager`
- `NSFontPanel`
- `NSMatrix`
- `NSOutlineView`
- `NSSplitView`

- `NSTableView`
- `NSTabView`
- `NSText`
- `NSTextField`
- `NSTextView`
- `NSWindow`

The UIKit framework also uses delegation extensively and always implements it using formal protocols. The application delegate is extremely important in an application running in iOS because it must respond to application-launch, application-quit, low-memory, and other messages from the application object. The application delegate must adopt the `UIApplicationDelegate` protocol.

Delegating objects do not (and should not) retain their delegates. However, clients of delegating objects (applications, usually) are responsible for ensuring that their delegates are around to receive delegation messages. To do this, they may have to retain the delegate in memory-managed code. This precaution applies equally to data sources, notification observers, and targets of action messages. Note that in a garbage-collection environment, the reference to the delegate is strong because the retain-cycle problem does not apply.

Some AppKit classes have a more restricted type of delegate called a *modal delegate*. Objects of these classes (`NSOpenPanel`, for example) run modal dialogs that invoke a handler method in the designated delegate when the user clicks the dialog's OK button. Modal delegates are limited in scope to the operation of the modal dialog.

The existence of delegates has other programmatic uses. For example, with delegates it is easy for two coordinating controllers in the same program to find and communicate with each other. For example, the object controlling the application overall can find the controller of the application's inspector window (assuming it's the current key window) using code similar to the following:

```
id winController = [[NSApp keyWindow] delegate];
```

And your code can find the application-controller object—by definition, the delegate of the global application instance—by doing something similar to the following:

```
id appController = [NSApp delegate];
```

Data Sources

A data source is like a delegate except that, instead of being delegated control of the user interface, it is delegated control of data. A data source is an outlet held by `NSView` and `UIView` objects such as table views and outline views that require a source from which to populate their rows of visible data. The data source for a view is usually the same object that acts as its delegate, but it can be any object. As with the delegate, the data source must implement one or more methods of an informal protocol to supply the view with the data it needs and, in more advanced implementations, to handle data that users directly edit in such views.

As with delegates, data sources are objects that must be present to receive messages from the objects requesting data. The application that uses them must ensure their persistence, retaining them if necessary in memory-managed code.

Data sources are responsible for the persistence of the objects they hand out to user-interface objects. In other words, they are responsible for the memory management of those objects. However, whenever a view object such as an outline view or table view accesses the data from a data source, it retains the objects as long as it uses the data. But it does not use the data for very long. Typically it holds on to the data only long enough to display it.

Implementing a Delegate for a Custom Class

To implement a delegate for your custom class, complete the following steps:

- Declare the delegate accessor methods in your class header file.

```
- (id)delegate;
- (void)setDelegate:(id)newDelegate;
```

- Implement the accessor methods. In a memory-managed program, to avoid retain cycles, the setter method should not retain or copy your delegate.

```
- (id)delegate {
    return delegate;
}

- (void)setDelegate:(id)newDelegate {
    delegate = newDelegate;
}
```

In a garbage-collected environment, where retain cycles are not a problem, you should not make the delegate a weak reference (by using the `__weak` type modifier). For more on retain cycles, see "Object Ownership and Disposal" in *Advanced Memory Management Programming Guide*. For more on weak references in garbage collection, see "Garbage Collection for Cocoa Essentials" in *Garbage Collection Programming Guide*.

- Declare a formal or informal protocol containing the programmatic interface for the delegate. Informal protocols are categories on the `NSObject` class. If you declare a formal protocol for your delegate, make sure you mark groups of optional methods with the `@optional` directive.

  "The Form of Delegation Messages" (page 213) gives advice for naming your own delegation methods.

- Before invoking a delegation method, make sure the delegate implements it by sending it a `respondsToSelector:` message.

```
- (void)someMethod {
    if ( [delegate respondsToSelector:@selector(operationShouldProceed)]
 ) {
        if ( [delegate operationShouldProceed] ) {
            // do something appropriate
        }
    }
}
```

The precaution is necessary only for optional methods in a formal protocol or methods of an informal protocol.

The Target-Action Mechanism

Although delegation, bindings, and notification are useful for handling certain forms of communication between objects in a program, they are not particularly suitable for the most visible sort of communication. A typical application's user interface consists of a number of graphical objects, and perhaps the most common of these objects are controls. A control is a graphical analog of a real-world or logical device (button, slider, checkboxes, and so on); as with a real-world control, such as a radio tuner, you use it to convey your intent to some system of which it is a part—that is, an application.

The role of a control on a user interface is simple: It interprets the intent of the user and instructs some other object to carry out that request. When a user acts on the control by, say, clicking it or pressing the Return key, the hardware device generates a raw event. The control accepts the event (as appropriately packaged for Cocoa) and translates it into an instruction that is specific to the application. However, events by themselves

don't give much information about the user's intent; they merely tell you that the user clicked a mouse button or pressed a key. So some mechanism must be called upon to provide the translation between event and instruction. This mechanism is called *target-action*.

Cocoa uses the target-action mechanism for communication between a control and another object. This mechanism allows the control and, in OS X its cell or cells, to encapsulate the information necessary to send an application-specific instruction to the appropriate object. The receiving object—typically an instance of a custom class—is called the *target*. The *action* is the message that the control sends to the target. The object that is interested in the user event—the target—is the one that imparts significance to it, and this significance is usually reflected in the name it gives to the action.

The Target

A target is a receiver of an action message. A control or, more frequently, its cell holds the target of its action message as an outlet (see "Outlets" (page 210)). The target usually is an instance of one of your custom classes, although it can be any Cocoa object whose class implements the appropriate action method.

You can also set a cell's or control's target outlet to `nil` and let the target object be determined at runtime. When the target is `nil`, the application object (`NSApplication` or `UIApplication`) searches for an appropriate receiver in a prescribed order:

1. It begins with the first responder in the key window and follows `nextResponder` links up the responder chain to the window object's (`NSWindow` or `UIWindow`) content view.

   Note A key window in OS X responds to key presses for an application and is the receiver of messages from menus and dialogs. An application's main window is the principal focus of user actions and often has key status as well.

2. It tries the window object and then the window object's delegate.
3. If the main window is different from the key window, it then starts over with the first responder in the main window and works its way up the main window's responder chain to the window object and its delegate.
4. Next, the application object tries to respond. If it can't respond, it tries its delegate. The application object and its delegate are the receivers of last resort.

Control objects do not (and should not) retain their targets. However, clients of controls sending action messages (applications, usually) are responsible for ensuring that their targets are available to receive action messages. To do this, they may have to retain their targets in memory-managed environments. This precaution applies equally to delegates and data sources.

The Action

An action is the message a control sends to the target or, from the perspective of the target, the method the target implements to respond to the action message. A control or—as is frequently the case in AppKit—a control's cell stores an action as an instance variable of type `SEL`. `SEL` is an Objective-C data type used to specify the signature of a message. An action message must have a simple, distinct signature. The method it invokes returns nothing and usually has a sole parameter of type `id`. This parameter, by convention, is named `sender`. Here is an example from the `NSResponder` class, which defines a number of action methods:

```
- (void)capitalizeWord:(id)sender;
```

Action methods declared by some Cocoa classes can also have the equivalent signature:

```
- (IBAction) deleteRecord:(id)sender;
```

In this case, `IBAction` does not designate a data type for a return value; no value is returned. `IBAction` is a type qualifier that Interface Builder notices during application development to synchronize actions added programmatically with its internal list of action methods defined for a project.

> **iOS Note** In UIKit, action selectors can also take two other forms. See "Target-Action in UIKit" (page 223) for details.

The `sender` parameter usually identifies the control sending the action message (although it can be another object substituted by the actual sender). The idea behind this is similar to a return address on a postcard. The target can query the sender for more information if it needs to. If the actual sending object substitutes another object as sender, you should treat that object in the same way. For example, say you have a text field and when the user enters text, the action method `nameEntered:` is invoked in the target:

```
- (void)nameEntered:(id) sender {
    NSString *name = [sender stringValue];
    if (![name isEqualToString:@""]) {
        NSMutableArray *names = [self nameList];
        [names addObject:name];
        [sender setStringValue:@""];
    }
}
```

Here the responding method extracts the contents of the text field, adds the string to an array cached as an instance variable, and clears the field. Other possible queries to the sender would be asking an `NSMatrix` object for its selected row (`[sender selectedRow]`), asking an `NSButton` object for its state (`[sender state]`), and asking any cell associated with a control for its tag (`[[sender cell] tag]`), a tag being a numeric identifier.

Target-Action in the AppKit Framework

The AppKit framework uses specific architectures and conventions in implementing target-action.

Controls, Cells, and Menu Items

Most controls in AppKit are objects that inherit from the `NSControl` class. Although a control has the initial responsibility for sending an action message to its target, it rarely carries the information needed to send the message. For this, it usually relies on its cell or cells.

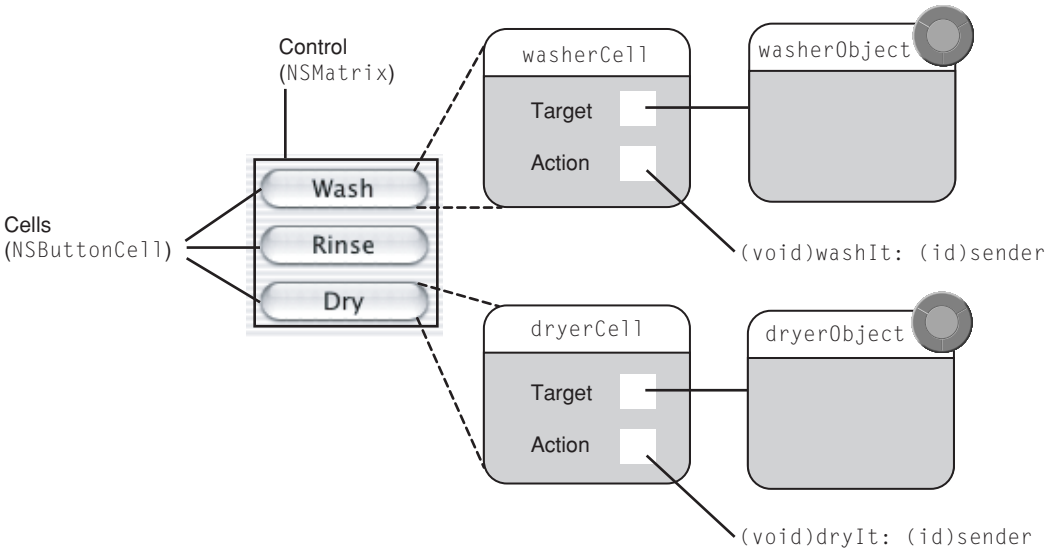
A control almost always has one or more cells—objects that inherit from `NSCell`—associated with it. Why is there this association? A control is a relatively "heavy" object because it inherits all the combined instance variables of its ancestors, which include the `NSView` and `NSResponder` classes. Because controls are expensive, cells are used to subdivide the screen real estate of a control into various functional areas. Cells are lightweight objects that can be thought of as overlaying all or part of the control. But it's not only a division of area, it's a division of labor. Cells do some of the drawing that controls would otherwise have to do, and cells hold some of the data that controls would otherwise have to carry. Two items of this data are the instance variables for target and action. Figure 5-3 (page 221) depicts the control-cell architecture.

Being abstract classes, `NSControl` and `NSCell` both incompletely handle the setting of the target and action instance variables. By default, `NSControl` simply sets the information in its associated cell, if one exists. (`NSControl` itself supports only a one-to-one mapping between itself and a cell; subclasses of `NSControl` such as `NSMatrix` support multiple cells.) In its default implementation, `NSCell` simply raises an exception. You must go one step further down the inheritance chain to find the class that really implements the setting of target and action: `NSActionCell`.

Objects derived from `NSActionCell` provide target and action values to their controls so the controls can compose and send an action message to the proper receiver. An `NSActionCell` object handles mouse (cursor) tracking by highlighting its area and assisting its control in sending action messages to the specified target.

In most cases, the responsibility for an `NSControl` object's appearance and behavior is completely given over to a corresponding `NSActionCell` object. (`NSMatrix`, and its subclass `NSForm`, are subclasses of `NSControl` that don't follow this rule.)

Figure 5-3 How the target-action mechanism works in the control-cell architecture



When users choose an item from a menu, an action is sent to a target. Yet menus (`NSMenu` objects) and their items (`NSMenuItem` objects) are completely separate, in an architectural sense, from controls and cells. The `NSMenuItem` class implements the target-action mechanism for its own instances; an `NSMenuItem` object has both target and action instance variables (and related accessor methods) and sends the action message to the target when a user chooses it.

> **Note** See *Control and Cell Programming Topics* and *Application Menu and Pop-up List Programming Topics* for more information about the control-cell architecture.

Setting the Target and Action

You can set the targets and actions of cells and controls programmatically or by using Interface Builder. For most developers and most situations, Interface Builder is the preferred approach. When you use it to set controls and targets, Interface Builder provides visual confirmation, allows you to lock the connections, and archives the connections to a nib file. The procedure is simple:

1. Declare an action method in the header file of your custom class that has the `IBAction` qualifier.
2. In Interface Builder, connect the control sending the message to the action method of the target.

If the action is handled by a superclass of your custom class or by an off-the-shelf AppKit or UIKit class, you can make the connection without declaring any action method. Of course, if you declare an action method yourself, you must be sure to implement it.

To set the action and the target programmatically, use the following methods to send messages to a control or cell object:

```
- (void)setTarget:(id)anObject;
- (void)setAction:(SEL)aSelector;
```

The following example shows how you might use these methods:

```
[aCell setTarget:myController];
[aControl setAction:@selector(deleteRecord:)];
[aMenuItem setAction:@selector(showGuides:)];
```

Programmatically setting the target and action does have its advantages and in certain situations it is the only possible approach. For example, you might want the target or action to vary according to some runtime condition, such as whether a network connection exists or whether an inspector window has been loaded. Another example is when you are dynamically populating the items of a pop-up menu, and you want each pop-up item to have its own action.

Actions Defined by AppKit

The AppKit framework not only includes many `NSActionCell`-based controls for sending action messages, it defines action methods in many of its classes. Some of these actions are connected to default targets when you create a Cocoa application project. For example, the Quit command in the application menu is connected to the `terminate:` method in the global application object (`NSApp`).

The `NSResponder` class also defines many default action messages (also known as *standard commands*) for common operations on text. This allows the Cocoa text system to send these action messages up an application's responder chain—a hierarchical sequence of event-handling objects—where it can be handled by the first `NSView`, `NSWindow`, or `NSApplication` object that implements the corresponding method.

Target-Action in UIKit

The UIKit framework also declares and implements a suite of control classes; the control classes in this framework inherit from the `UIControl` class, which defines most of the target-action mechanism for iOS. However there are some fundamental differences in how the AppKit and UIKit frameworks implement target-action. One of these differences is that UIKit does not have any true cell classes. Controls in UIKit do not rely upon their cells for target and action information.

A larger difference in how the two frameworks implement target-action lies in the nature of the event model. In the AppKit framework, the user typically uses a mouse and keyboard to register events for handling by the system. These events—such as clicking on a button—are limited and discrete. Consequently, a control object in AppKit usually recognizes a single physical event as the trigger for the action it sends to its target. (In the case of buttons, this is a mouse-up event.) In iOS, the user's fingers are what originate events instead of mouse clicks, mouse drags, or physical keystrokes. There can be more than one finger touching an object on the screen at one time, and these touches can even be going in different directions.

To account for this multitouch event model, UIKit declares a set of control-event constants in `UIControl.h` that specify various physical gestures that users can make on controls, such as lifting a finger from a control, dragging a finger into a control, and touching down within a text field. You can configure a control object so that it responds to one or more of these touch events by sending an action message to a target. Many of the control classes in UIKit are implemented to generate certain control events; for example, instances of the `UISlider` class generate a `UIControlEventValueChanged` control event, which you can use to send an action message to a target object.

You set up a control so that it sends an action message to a target object by associating both target and action with one or more control events. To do this, send `addTarget:action:forControlEvents:` to the control for each target-action pair you want to specify. When the user touches the control in a designated fashion, the control forwards the action message to the global `UIApplication` object in a `sendAction:to:from:forEvent:` message. As in AppKit, the global application object is the centralized dispatch point for action messages. If the control specifies a `nil` target for an action message, the application queries objects in the responder chain until it finds one that is willing to handle the action message—that is, one implementing a method corresponding to the action selector.

In contrast to the AppKit framework, where an action method may have only one or perhaps two valid signatures, the UIKit framework allows three different forms of action selector:

```
- (void)action
- (void)action:(id)sender
- (void)action:(id)sender forEvent:(UIEvent *)event
```

To learn more about the target-action mechanism in UIKit, read *UIControl Class Reference*.

Bindings (OS X)

Bindings are a Cocoa technology that you can use to synchronize the display and storage of data in a Cocoa application created for OS X. They are an important tool in the Cocoa toolbox for enabling communication between objects. The technology is an adaptation of both the Model-View-Controller and object modeling design patterns. ("The Model-View-Controller Design Pattern" (page 193) introduced bindings in its discussion of controller objects.) It allows you to establish a mediated connection—a binding—between the attribute of a view object that displays a value and a model-object property that stores that value; when a change occurs in the value in one side of the connection, it is automatically reflected in the other. The controller object that mediates the connection provides additional support, including selection management, placeholder values, and sortable tables.

How Bindings Work

Bindings arise from the conceptual space defined by the Model-View-Controller (MVC) and object modeling design patterns. An MVC application assigns objects general roles and maintains separation between objects based on these roles. Objects can be view objects, model objects, or controller objects whose roles can be briefly stated as follows:

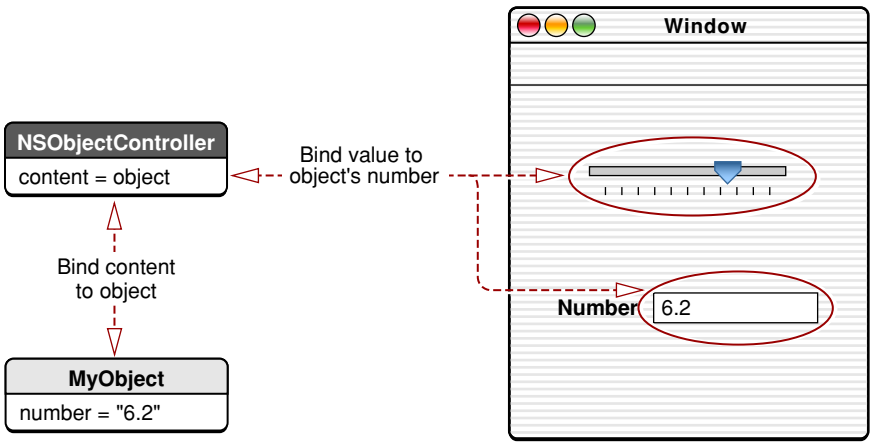
- View objects display the data of the application.
- Model objects encapsulate and operate on application data. They are typically the persistent objects that your users create and save while an application is running.
- Controller objects mediate the exchange of data between view and model objects and also perform command-and-control services for the application.

All objects, but most importantly model objects, have defining components or characteristics called *properties*. Properties can be of two sorts: attributes—values such as strings, scalars, and data structures—and relationships to other objects. Relationships can be of two sorts: one-to-one and one-to-many. They can also be bidirectional and reflexive. The objects of an application thus have various relationships with each other, and this web of objects is called an *object graph*. A property has an identifying name called a *key*. Using key paths—period-separated sequences of keys—one can traverse the relationships in an object graph to access the attributes of related objects.

The bindings technology makes use of an object graph to establish bindings among the view, model, and controller objects of an application. With bindings you can extend the web of relationships from the object graph of model objects to the controller and view objects of an application. You can establish a binding between an attribute of a view object and a property of a model object (typically through a mediating property of a controller object). Any change in the displayed attribute value is automatically propagated through the binding to the property where the value is stored. And any internal change in the value of the property is communicated back to the view for display.

For example, Figure 5-4 shows a simplified set of bindings between the displayed values of a slider and a text field (attributes of those view objects) and the `number` attribute of a model object (`MyObject`) through the `content` property of a controller object. With these bindings established, if a user moves the slider, the change in value is applied to the `number` attribute and communicated back to the text field for display.

Figure 5-4 Bindings between view, controller, and model objects



The implementation of bindings rests on the enabling mechanisms of key-value coding, key-value observing, and key-value binding. See "Key-Value Mechanisms" (page 153) for overviews of these mechanisms and their associated informal protocols. The discussion of the Observer pattern in "Observer" (page 184) also describes key-value observing.

You can establish a binding between any two objects. The only requirement is that the objects comply with the conventions of key-value coding and key-value observing. However, you generally want to establish the binding *through* a mediating controller because such controller objects offer bindings-related services such as selection management, placeholder values, and the ability to commit or discard pending changes. Mediating controllers are instances of several `NSController` subclasses; they are available in the Objects & Controllers section of the Interface Builder library (see "How You Establish Bindings" (page 226)). You can also create custom mediating-controller classes to acquire more specialized behavior.

Further Reading To learn more about the design patterns summarized above (including a discussion of mediating controllers and `NSController` objects), see "The Model-View-Controller Design Pattern" (page 193), "Object Modeling" (page 202), and "Mediator" (page 179).

How You Establish Bindings

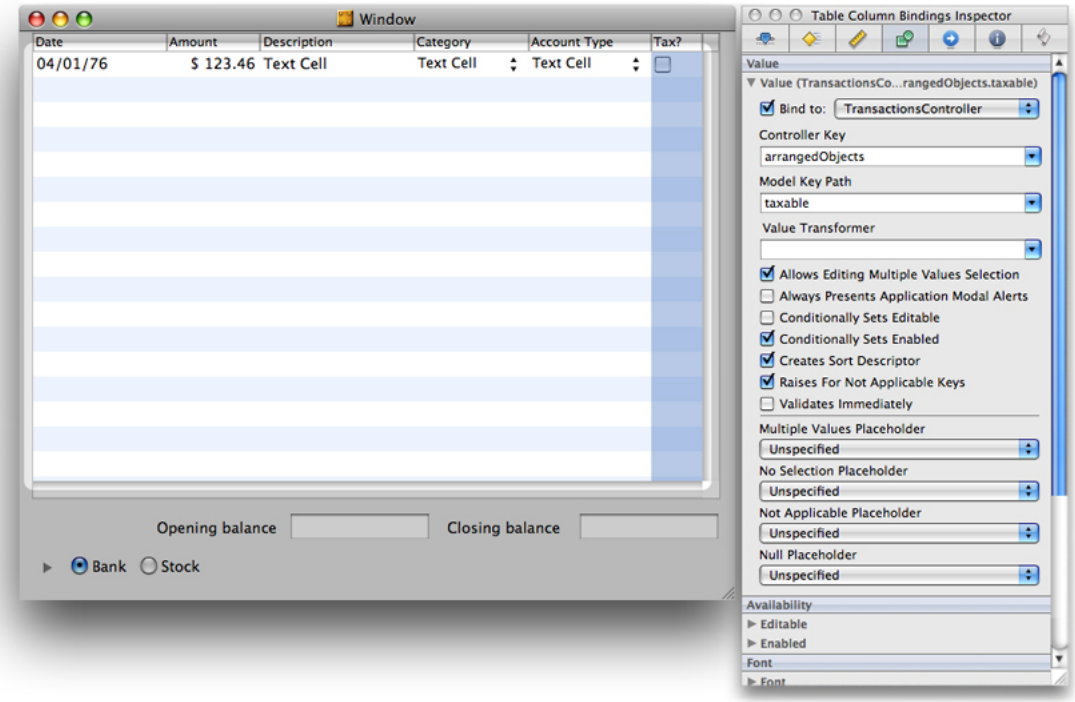
If the only custom classes of your application are model classes, the only requirement for establishing bindings is that those classes be compliant with key-value coding conventions for any properties you want to bind. If you are using a custom view or custom controller, you should also ensure that it is compliant with key-value observing. See "Key-Value Mechanisms" (page 153) for a summary of the requirements for compliance with both key-value coding and key-value observing.

Note Most of the classes of the Cocoa frameworks are compliant with key-value coding. Some are compliant with key-value observing; check the reference documentation for details.

You can also establish bindings programmatically but for most situations you use the Interface Builder application to establish bindings. In Interface Builder, you start by dragging `NSController` objects from the library into your nib file. Then you use the Bindings pane of the Info window to specify the relationships between the properties of the view, controller, and model objects of your application and the attributes you want bound.

Figure 5-5 gives an example of a binding. It shows the "Tax?" column of the top table view bound to the model attribute `taxable`, where the controller is `TransactionsController` (an `NSArrayController` object); this controller is itself bound to an array of model objects (not shown).

Figure 5-5 Establishing a binding in Interface Builder



Further Reading Read *Cocoa Bindings Programming Topics* to learn more about the bindings technology and how to use Interface Builder to establish bindings. Also see *Key-Value Coding Programming Guide* and *Key-Value Observing Programming Guide* for complete descriptions of these mechanisms.

Notifications

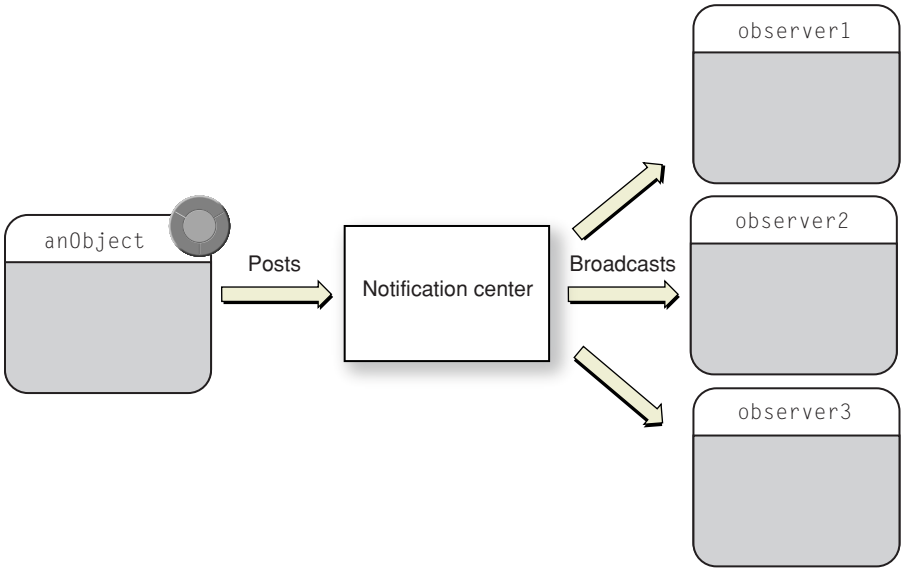
The standard way to pass information between objects is message passing—in which one object invokes the method of another object. However, message passing requires that the object sending the message know who the receiver is and what messages it responds to. This requirement is true of delegation messages as well as other types of messages. At times, this tight coupling of two objects is undesirable—most notably because it would join together what might be two otherwise independent subsystems. And it is impractical because it would require hard-coded connections between many disparate objects in an application.

For cases where standard message passing just won't do, Cocoa offers the broadcast model of notification. By using the notification mechanism, one object can keep other objects informed of what it is doing. In this sense, it is similar to delegation, but the differences are important. The key distinction between delegation and notification is that the former is a one-to-one communication path (between the delegating object and its delegate). But notification is a potentially one-to-many form of communication—it is a broadcast. An object can have only one delegate, but it can have many *observers*, as the recipients of notification are known. And the object doesn't have to know what those observers are. Any object can observe an event indirectly via notification and adjust its own appearance, behavior, and state in response to the event. Notification is a powerful mechanism for attaining coordination and cohesion in a program.

How the notification mechanism works is conceptually straightforward. A process has an object called a *notification center*, which acts as a clearing house and broadcast center for notifications. Objects that need to know about an event elsewhere in the application register with the notification center to let it know they want to be notified when that event happens. An example of this is a controller object that needs to know when a pop-up menu choice is made so it can reflect this change in the user interface. When the event does happen, the object that is handling the event posts a notification to the notification center, which then dispatches the notification to all of its observers. Figure 5-6 depicts this mechanism.

> **Note** The notification center delivers a notification to its observers synchronously. The posting object does not get back control until all notifications are sent. To post notifications asynchronously, you must use a notification queue (see "Notification Queues" (page 232)). A notification queue posts notifications to the notification center after it delays specified notifications and coalesces notifications that are similar according to some specified criteria.

Figure 5-6 Posting and broadcasting a notification



Any object can post a notification and any object can register itself with the notification center as an observer of a notification. The object posting the notification, the object that the posting object includes in the notification, and the observer of the notification may all be different objects or the same object. (Having the posting and observing object be the same does have its uses, such as in idle-time processing.) Objects that post notifications need not know anything about the observers. On the other hand, observers need to know at least the notification name and the keys to any dictionary encapsulated by the notification object. ("The Notification Object" (page 231) describes what a notification object consists of.)

> **Further Reading** For a thorough discussion of the notification mechanism, see *Notification Programming Topics*.

When and How to Use Notifications

As with delegation, the notification mechanism is a great tool for enabling communication between objects in an application. Notifications allow objects within an application to learn about changes that occur elsewhere in that application. Generally, an object registers to be an observer of a notification because it wants to make adjustments when a certain event occurs or is about to occur. For example, if a custom view wants to change its appearance when its window is resized, it can observe the `NSWindowDidResizeNotification` posted by that window object. Notifications also permit information to be passed between objects because a notification can include a dictionary of data related to the event.

But there are differences between notification and delegation, and these differences dictate what these mechanisms should be used for. As noted earlier, the main difference between the notification model and the delegation model is that the former is a broadcast mechanism whereas delegation is a one-to-one relationship. Each model has its advantages; with notifications they include the following:

- The posting object does not have to know the identity of the observing objects.
- An application is not limited to the notifications declared by the Cocoa frameworks; any class can declare notifications for its instances to post.
- Notifications are not limited to intra-application communication; with distributed notifications, one process can notify another process about events that occur.

> **iOS Note** Distributed notifications are not available in iOS.

But the one-to-one model of delegation has its advantages too. A delegate is given the opportunity to affect an event by returning a value to the delegating object. A notification observer, on the other hand, must play a more passive role; it can affect only itself and its environment in response to the event. Notification methods must have the following signature:

```
- (void)notificationHandlerName:(NSNotification *);
```

This requirement precludes the observing object from affecting the original event in any direct way. A delegate, however, can often affect how the delegating object will handle an event. Moreover, the delegate of an AppKit object is automatically registered as an observer of its notifications. All it need do is implement the notification methods defined by the framework class for its notifications.

The notification mechanism is not the only Cocoa alternative for observing changes in object state, and indeed for many situations should not be the preferred one. The Cocoa bindings technology, and specifically its enabling key-value observing (KVO) and key-value binding (KVB) protocols, also allow objects in an application to observe changes in the properties of other objects. The bindings mechanism accomplishes this function more efficiently than do notifications. In bindings, the communication between observed and observing object is direct, and does not require an intermediary object such as the notification center. Moreover, the bindings mechanism imposes no performance penalty for unobserved changes, as do regular notifications.

However, there can be situations where it makes sense to prefer notifications over bindings. You may want to observe events other than a change in object properties. Or it might be impractical to implement KVO and KVB compliance, especially when the notifications to be posted and observed are few.

Even if the situation warrants the use of notifications, you should be aware of the performance implications. When you post a notification, it is eventually dispatched to observing objects synchronously by the local notification center. This occurs regardless of whether the posting was done synchronously or asynchronously. If there are many observers or each observer does a lot of work while handling the notification, your program could experience a significant delay. Therefore you should be careful about overusing notifications or using them inefficiently. The following guidelines for notification usage should help toward this end:

- Be selective about which notifications your application should observe.
- Be specific about notification names and posting objects when you register for notifications.
- Implement the methods that then handle notifications to do so as efficiently as possible.
- Refrain from adding and removing numerous observers; it is much better to have a few intermediary observers that can communicate the results of notifications to the objects they have access to.

Further Reading For detailed information about the efficient use of notifications, see "Notifications" in *Cocoa Performance Guidelines*.

The Notification Object

A notification is an object, an instance of `NSNotification`. This object encapsulates information about an event, such as a window gaining focus or a network connection closing. When the event does happen, the object handling the event posts the notification to the notification center, which immediately broadcasts the notification to all registered objects.

An `NSNotification` object contains a name, an object, and an optional dictionary. The name is a tag identifying the notification. The object is any object that the poster of the notification wants to send to observers of that notification (typically it is the object that posted the notification). It is similar to the sender object in delegation messages, allowing the receiver to query the object for more information. The dictionary stores any information related to the event.

Notification Centers

A notification center manages the sending and receiving of notifications. It notifies all observers of notifications meeting specific criteria. The notification information is encapsulated in `NSNotification` objects. Client objects register themselves with the notification center as observers of specific notifications posted by other objects. When an event occurs, an object posts an appropriate notification to the notification center. The notification center dispatches a message to each registered observer, passing the notification as the sole parameter. It is possible for the posting object and the observing object to be the same.

Cocoa includes two types of notification centers:

- A notification center (an instance of `NSNotificationCenter`) manages notifications within a single task.
- A distributed notification center (an instance of `NSDistributedNotificationCenter`) manages notifications across multiple tasks on a single computer.

Note that in contrast to many other Foundation classes, `NSNotificationCenter` is not toll-free bridged to its Core Foundation counterpart (`CFNotificationCenterRef`).

NSNotificationCenter

Each task has a default notification center that you access with the `NSNotificationCenter` class method `defaultCenter`. The notification center handles notifications within a single task. For communication between tasks on the same computer, use a distributed notification center (see "NSDistributedNotificationCenter" (page 232)).

A notification center delivers notifications to observers synchronously. In other words, the poster of the notification doesn't regain control until all observers have received and processed the notification. To send notifications asynchronously, use a notification queue, which is described in "Notification Queues" (page 232).

In a multithreaded application, notifications are always delivered in the thread in which the notification was posted, which may not be the same thread in which an observer registered itself.

NSDistributedNotificationCenter

Each task has a default distributed notification center that you access with the `NSDistributedNotificationCenter` class method `defaultCenter`. This distributed notification center handles notifications that can be sent between tasks on a single computer. For communication between tasks on different computers, use distributed objects (see *Distributed Objects Programming Topics*).

Posting a distributed notification is an expensive operation. The notification gets sent to a systemwide server that then distributes it to all the tasks that have objects registered for distributed notifications. The latency between posting the notification and the notification's arrival in another task is unbounded. In fact, if too many notifications are being posted and the server's queue fills up, notifications might be dropped.

Distributed notifications are delivered via a task's run loop. A task must be running a run loop in one of the common modes, such as `NSDefaultRunLoopMode`, to receive a distributed notification. If the receiving task is multithreaded, do not depend on the notification arriving on the main thread. The notification is usually delivered to the main thread's run loop, but other threads could also receive the notification.

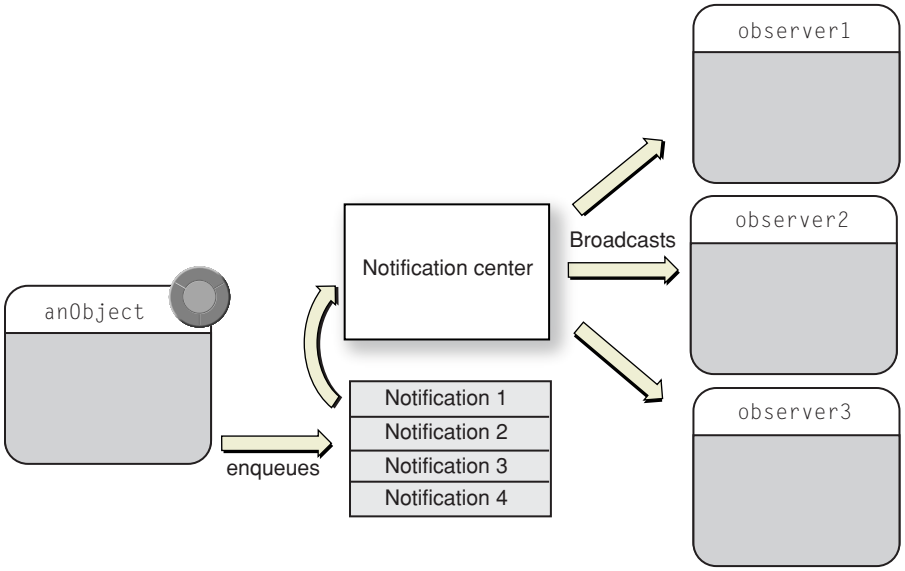
Whereas a regular notification center allows any object to be the notification object (that is, the object encapsulated by the notification), a distributed notification center is restricted to having an `NSString` object as its notification object. Because the posting object and the observer may be in different tasks, notifications cannot contain pointers to arbitrary objects. Therefore a distributed notification center requires notifications to use a string as the notification object. Notification-matching is done based on this string, rather than based on an object pointer.

Notification Queues

`NSNotificationQueue` objects (or simply, notification queues) act as buffers for notification centers (instances of `NSNotificationCenter`). A notification queue maintains notifications (instances of `NSNotification`) generally in a First In First Out (FIFO) order. When a notification rises to the front of the queue, the queue posts it to the notification center, which in turn dispatches the notification to all objects registered as observers.

Every thread has a default notification queue, which is associated with the default notification center for the task. Figure 5-7 illustrates this association. You can create your own notification queues and have multiple queues per center and thread.

Figure 5-7 A notification queue and notification center



Coalescing Notifications

The `NSNotificationQueue` class contributes two important features to the Foundation framework's notification mechanism: the coalescing of notifications and asynchronous posting. Coalescing is a process that removes notifications in the queue that are similar to the notification just queued. If the new item is similar to a notification already queued, the new one isn't queued and all similar notifications (except the first one in the queue) are removed. However, you should not depend on this particular coalescing behavior.

You indicate the criteria for similarity in notifications by specifying one or more of the following constants in the third parameter of the `enqueueNotification:postingStyle:coalesceMask:forModes:` method.

```
NSNotificationNoCoalescing
NSNotificationCoalescingOnName
NSNotificationCoalescingOnSender
```

You can perform a bitwise-OR operation with the `NSNotificationCoalescingOnName` and `NSNotificationCoalescingOnSender` constants to specify coalescing using both the notification name and notification object. In this case, all notifications having the same name and sender as the one enqueued are coalesced.

Asynchronously Posting Notifications

With the `NSNotificationCenter` method `postNotification:` and its variants, you can post a notification immediately to a notification center. However, the invocation of the method is synchronous: Before the posting object can resume its thread of execution, it must wait until the notification center dispatches the notification to all observers and returns. With the `NSNotificationQueue` methods `enqueueNotification:postingStyle:` and `enqueueNotification:postingStyle:coalesceMask:forModes:`, however, you can post a notification asynchronously by putting it in a queue. These methods immediately return to the invoking object after putting the notification in the queue.

The notification queue is emptied and its notifications are posted based on the posting style and run-loop mode specified in the enqueuing method. The mode parameter specifies the run loop mode in which the queue is emptied. For example, if you specify `NSModalPanelRunLoopMode`, the notifications is posted only when the run loop is in this mode. If the run loop is not currently in this mode, the notifications wait until the next time that mode is entered.

Posting to a notification queue can occur in one of three different styles: `NSPostASAP`, `NSPostWhenIdle`, and `NSPostNow`. These styles are described in the following sections.

Posting as Soon as Possible

Any notification queued with the `NSPostASAP` style is posted to the notification center when the current iteration of the run loop completes, assuming the current run-loop mode matches the requested mode. (If the requested and current modes are different, the notification is posted when the requested mode is entered.) Because the run loop can make multiple callouts during each iteration, the notification may or may not get delivered as soon as the current callout exits and control returns to the run loop. Other callouts may take place first, such as a timer or source firing or the delivery of other asynchronous notifications.

You typically use the `NSPostASAP` posting style for an expensive resource, such as the display server. When many clients draw on the window buffer during a callout from the run loop, it is expensive to flush the buffer to the display server after every draw operation. In this situation, each `draw...` method enqueues some notification such as “FlushTheServer” with coalescing on name and object specified and with a posting style of `NSPostASAP`. As a result, only one of those notifications is dispatched at the end of the run loop and the window buffer is flushed only once.

Posting When Idle

A notification queued with the `NSPostWhenIdle` style is posted only when the run loop is in a wait state. In this state, there’s nothing in the run loop’s input channels, including timers or other asynchronous events. Note that a run loop that is about to exit (which occurs when all of the input channels have expired) is not in a wait state and thus does not post a notification.

Posting Immediately

A notification queued with `NSPostNow` is posted immediately after coalescing to the notification center. You queue a notification with `NSPostNow` (or post one with the NSNotificationCenter method `postNotification:`) when you do not require asynchronous calling behavior. For many programming situations, synchronous behavior is not only allowable but desirable: You want the notification center to return after dispatching so you can be sure that observing objects have received and processed the notification. Of course, you should use `enqueueNotification...` with `NSPostNow` rather than use `postNotification:` when there are similar notifications in the queue that you want to remove through coalescing.

Ownership of Delegates, Observers, and Targets

Delegating objects are not considered to own their delegates or data sources. Similarly, controls and cells are not considered to own their targets, and the notification center does not own the observers of notifications. Consequently, for memory-managed code these framework objects follow the convention of *not* retaining their targets, observers, delegates, and data sources; instead, they simply store a pointer to the object.

> **Note** In memory management, a nonretained object reference is known as a *weak reference*, which is something different from a weak reference in a garbage-collected environment. In the latter, all references to objects are considered strong by default and are thus visible to the garbage collector; weak references, which must be marked with the `__weak` type modifier, are not visible. In garbage collection, retain cycles are not a problem.

The object-ownership policy in memory management recommends that owned objects should be retained and archived unconditionally, and that referenced (but not owned) objects should not be retained and should be archived conditionally. The practical intent of this ownership policy is to avoid circular references, a situation where two objects retain each other. (This is often called a *retain cycle*.) Retaining an object creates a strong reference, and an object cannot be deallocated until all of its strong references are released. If two objects retain each other, neither object ever gets deallocated because the connection between them cannot be broken.

You must ensure that an object that acts as a delegate remains a valid reference or your application can crash. When that object is deallocated, you need to remove the delegate link by sending a `setDelegate:` message with a `nil` parameter to the other object. You normally send these messages from the object's `dealloc` method.

If you create a subclass from a Cocoa framework class with a delegate, data source, observer, or target, you should never explicitly retain the object in your subclass. You should create a nonretained reference to it and archive it conditionally.

Further Reading For more on the ownership policy, weak references, and circular references in memory management, see "Object Ownership and Disposal" in *Advanced Memory Management Programming Guide*. For a summary of strong references and weak references in garbage collection, see "Garbage Collection for Cocoa Essentials" in *Garbage Collection Programming Guide* (available only in the OS X Developer Library).

Document Revision History

This table describes the changes to *Cocoa Fundamentals Guide*.

Date	Notes
2010-12-13	Replaced the layer diagrams with a single diagram and adjusted surrounding text. Removed the appendixes "Core Application Architecture" and "Other Cocoa Architectures." Made minor corrections throughout.
2010-11-15	Added information related to versions of iOS up to iOS 4.2, including updated diagrams. Added information on toll-free bridging. Also made several minor corrections.
2010-06-25	Changed "iPhone OS" to "iOS" throughout.
2010-05-26	Made several minor corrections.
2010-03-24	Added cautionary advice about UIKit classes and secondary threads.
2009-10-19	Fixed some issues with the discussion of singleton implementation.
2009-08-20	Modified the illustration showing iOS architecture.
2009-07-14	Updated to describe Core Data as a technology supported by both OS X and iOS (as of iOS 3.0). Added description of value objects. Updated class-hierarchy diagrams for iOS 3.0 and OS X v10.6.
2009-05-28	Added link to iPhone tutorial in the See Also section of the introduction and made minor corrections.
2008-11-19	Made various small corrections.
2008-10-15	Updated obsolete references to the iOS Programming Guide.
2008-07-08	Updated for iOS.

Date	Notes
2007-10-31	Updated to describe new and enhanced features, including garbage collection, properties, fast enumeration, and development tools. Also added section on multithreading.
2006-12-20	Added a "Cocoa API Conventions" section to "Adding Behavior to Your Cocoa Program."
2006-10-03	Clarified the statement about reinitialization of objects and made minor corrections.
2006-08-07	Corrected several minor errors.
2006-05-23	Added description of represented objects and updated examples and descriptions of singleton objects and object copying.
2006-03-08	A new document that gives developers an orientation to the basic concepts, terminology, architectures, and design patterns of Cocoa. The now-retired documents consolidated as chapters in this document are "What Is Cocoa?," "Cocoa Objects," "Adding Behavior to a Cocoa Program," "Cocoa Design Patterns," and "Communicating With Objects." Two new chapters have been added: “The Core Application Architecture on OS X” and “Other Cocoa Architectures on OS X”. In addition, the discussion of the Model-View-Controller design pattern in “Cocoa Design Patterns” (page 165) has been greatly expanded.

Apple Inc.
1 Infinite Loop
Cupertino, CA 95014
408-996-1010