
Instruments User Guide

[Tools > Performance](#)



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Introduction to Instruments User Guide

Instruments is an application for dynamically tracing and profiling Mac OS X code. It is a flexible and powerful tool that lets you track one or more processes and examine the collected data. In this way, Instruments helps you understand the behavior of both user programs and the operating system.

With the Instruments application, you use special tools (known as "instruments") to trace different aspects of a process' behavior. You can also use the application to record a sequence of user interface actions and replay them, using one or more instruments to gather data.

The Instruments application includes the ability to:

- Examine the behavior of one or more processes
- Record a sequence of user actions and replay them, reliably reproducing those events and collecting data over multiple runs
- Create your own custom DTrace instruments to analyze aspects of system and application behavior
- Save user interface recordings and instrument configurations as templates, accessible from Xcode

Using Instruments, you can:

- Track down difficult-to-reproduce problems in your code
- Do performance analysis on your program
- Automate testing of your code
- Stress-test parts of your application
- Perform general system-level troubleshooting
- Gain a deeper understanding of how your code works

Instruments is available with Xcode 3.0 and Mac OS X 10.5 and later.

This document describes the Instruments user interface and gives an overview of how to use the Instruments application to trace processes and view data. It is intended for developers and system administrators who want to use Instruments to better understand the behavior of their programs or of the system as a whole.

Organization of This Document

The following chapters describe how to use the Instruments application:

- “[Instruments Quick Start](#)” (page 11) gives a brief overview of the Instruments application and introduces the main window.

- “[Adding and Configuring Instruments](#)” (page 19) describes how to add and configure instruments and run them to collect data on one or more processes. This chapter also shows how to choose the program to trace.
- “[Recording Trace Data](#)” (page 31) describes the ways you can initiate traces and gather trace data.
- “[Working with a User Interface Track](#)” (page 39) describes how to record and replay a sequence of user actions.
- “[Viewing and Analyzing Trace Data](#)” (page 43) describes the tools you use to view the data returned by the instruments.
- “[Saving and Importing Trace Data](#)” (page 61) describes how you save trace documents and data and how you import data from other sources.
- “[Creating Custom Instruments with DTrace](#)” (page 63) shows how to create and configure your own DTrace-based custom instrument.
- “[Built-in Instruments](#)” (page 75) describes the instruments that ship with Instruments.

Getting the Xcode Tools

Instruments is part of the Xcode Tools, a comprehensive suite of developer tools for creating Mac OS X software. The Xcode Tools include applications to help you design, create, debug, and optimize your software. This tools suite also includes header files, sample code, and documentation for Apple technologies. You can download the Xcode Tools from the members area of the Apple Developer Connection (ADC) website (<http://connect.apple.com/>). Registration is required but free.

Instruments Quick Start

Instruments is a powerful tool you can use to collect data about the performance and behavior of one or more processes on the system and track that data over time. Unlike most other performance and debugging tools, Instruments lets you gather widely disparate types of data and view them side by side. In this way you can spot trends that might otherwise be hard to spot with other tools. For example, previously you had to sample a program and analyze its memory behavior during two separate execution runs. In Instruments, you can perform these tasks at the same time. You can then use the resulting data to spot trends between the code being run by your program and its corresponding memory usage.

The Instruments application uses **instruments** to collect data about a process over time. Each instrument collects and displays a different type of information, such as file access, memory use, and so forth. Instruments includes a library of standard instruments, which you can use as-is to examine various aspects of your code. You can configure instruments to gather data about the same process or about different processes on the system. You can build new instruments using the custom instrument builder interface, which uses the DTrace program to gather the data you want.

Note: Several Apple applications—namely iTunes, DVD Player, and Front Row, and applications that use QuickTime—prevent the collection of data through DTrace (either temporarily or permanently) in order to protect sensitive data. Therefore, you should not run those applications when performing systemwide data collection.

All work in Instruments is done in a trace document. A **trace document** collects the data gathered by the instruments associated with that document. Each trace document typically holds a single session's worth of data, which is also referred to as a single **trace**. You can save a trace document to preserve the trace data you have gathered and open them again later to view that data.

Although most instruments are geared towards gathering trace data, one of the most sophisticated instruments helps automate the collection of data. Using the User Interface instrument, you can record user events while you gather your trace data. You can use this recording to reliably reproduce the same sequence of events over and over again. Each time you run through this sequence, your trace document gathers a new set of trace data from the other instruments in the document and presents that data side by side with previous runs. This feature lets you compare trace data as you make improvements to your code and verify that the changes you make are having the desired impact.

Launching Instruments

Instruments is available as part of the Xcode Tools installation. There are several ways to launch Instruments:

- You can launch Instruments by double-clicking its application icon in the Finder. The Instruments application is located in `<Xcode>/Applications`, where `<Xcode>` is the root directory of your Xcode installation. (The default root directory for an Xcode installation is the `/Developer` directory.)

- You can use Xcode to launch Instruments and target an executable in your project. Choose an Instruments template from the Run > Start with Performance Tool menu in Xcode. Instruments launches with the specified template ready to run the current executable, as configured in Xcode.

Note: When launching your program from an Instruments template in this manner, you must explicitly stop your executable—either from the program or from Instruments—after tracing is complete. This does not close the Instruments trace document. Instead, if you relaunch the executable, Instruments displays the new session alongside the previous one, as shown in [Figure 4-2](#) (page 41). This lets you change your code in Xcode, rebuild, run, and compare the resulting trace data to the data generated before the change.

- You can launch Instruments by double-clicking an Instruments template or trace document. See “[Saving and Importing Trace Data](#)” (page 61) to learn how to save an instrument configuration or user interface recording as a trace template document.

Creating a Trace Document

When you launch Instruments, the application automatically creates a new document for you. You can also create new documents by choosing File > New.

For each new document you create, Instruments prompts you to select a starting template. These templates define the initial set of instruments you plan to use in your trace document. Instruments provides several different templates, listed in Table 1-1, each geared toward different goals. You can use the Blank template if you want to add a specific set of instruments to your trace document manually. For any of the templates, you can also remove instruments you do not want.

Table 1-1 Instruments starting templates

Template	Description
Blank	Creates an empty trace document to which you can add your own combination of instruments. To learn how to select and add instruments, see “ Adding and Configuring Instruments ” (page 19). For descriptions of the individual built-in instruments, see “ Built-in Instruments ” (page 75).
Activity Monitor	Adds the Activity Monitor instrument to your document. Use this template if you want to correlate the system workload with the virtual memory size.
CPU Sampler	Adds the Sampler and CPU Monitor instruments to your document. Use this template if you want to correlate the overall system workload with the work being done specifically by your application.
File Activity	Adds the File Activity, Reads/Writes, File Attributes, and Directory I/O instruments to your document. Use this template if you want to examine file usage patterns in the system. This combination of instruments monitors open, close, read, and write operations on files and also monitors changes the file system itself, including permission and owner changes.

Template	Description
Leaks	Adds the ObjectAlloc and Leaks instruments to your document. Use this template to monitor memory usage in your application and to detect memory leaks. (To use this template, you must launch your process from Instruments.)
Object Allocations	Adds the ObjectAlloc instrument to your document. Use this template to monitor memory and object-allocation patterns in your program. (To use this template, you must launch your process from Instruments.)
UI Recorder	Adds the User Interface instrument to your document. Use this template as a starting point for recording a series of user interactions with your application. You can use this feature to reproduce a series of events multiple times, gathering a new set of data during each successive run. You can then compare the sets of data knowing that the behavior that generated them was identical. Typically, you would start with this template and add additional instruments to your document to gather data.
Core Data	Adds the Core Data Fetches, Core Data Cache Misses, and Core Data Saves instruments to your document. Use this template to monitor data store interactions in a Core Data application.

If you do not want Instruments to ask you for a template when you create a new document, you can enable the Suppress template chooser option in the Instruments General preferences. For more information about adding and configuring the instruments in a document, see [“Adding and Configuring Instruments”](#) (page 19).

A Tour of the Trace Document Window

A trace document is a self-contained space for collecting and analyzing trace data. You use the document to organize and configure the instruments needed to collect data, and you use the document to view the data that you’ve gathered at both a high and low level.

Figure 1-1 shows a typical trace document. A trace document window presents a lot of information and therefore has to be well organized. As you work with trace documents, information generally flows from left to right. The farther right you are in the document window, the more detailed the information becomes. [Table 1-2](#) (page 14) provides descriptions for the key areas of this window.

Instruments Quick Start

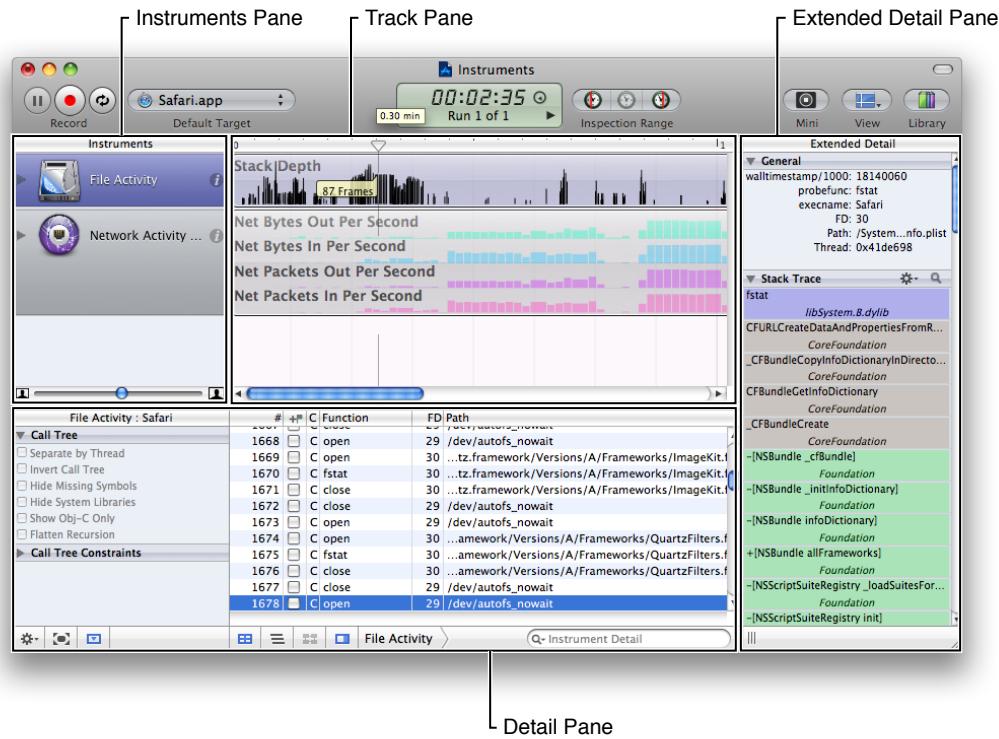
Figure 1-1 The Instruments window while tracing

Table 1-2 lists some of the key features that are called out in [Figure 1-1](#) (page 14) and provides a more in-depth discussion of how you use that feature.

Table 1-2 Trace document key features

Feature	Description
Instruments pane	This pane holds the instruments you want to run. You can drag instruments into this pane or delete them. You can click the inspector button in an instrument to configure its data display and gathering parameters. To learn more about instruments, see “ Adding and Configuring Instruments ” (page 19).
Track pane	The track pane displays a graphical summary of the data returned by the current instruments. Each instrument has its own “track,” which provides a chart of the data collected by that instrument. The information in this pane is read-only. You do use this pane to select specific data points you want to examine more closely, however. The track pane is described in more detail in “ The Track Pane ” (page 43).
Detail pane	The Detail pane shows the details of the data collected by each instrument. Typically, this pane displays the explicit set of “events” that were gathered and used to create the graphical view in the track pane. If the current instrument allows you to customize the way detailed data is displayed, those options are also listed in this pane. For more information about this pane, see “ The Detail Pane ” (page 47).

Feature	Description
Extended Detail pane	The Extended Detail pane shows even more detailed information about the item currently selected in the Detail pane. Most commonly, this pane displays the complete stack trace, timestamp, and other instrument-specific data gathered for the given event. The Extended Detail pane is described in “The Extended Detail Pane” (page 50).

The trace document’s toolbar lets you add and control instruments, open views, and configure the track pane. Figure 1-2 identifies the different controls on the toolbar, and [Table 1-3](#) (page 15) provides detailed information about how you use those controls.

Figure 1-2 The Instruments toolbar



Table 1-3 Trace document toolbar controls

Control	Description
Pause/Resume button	Pauses the gathering of data during a recording. This button does not actually stop recording, it simply stops Instruments from gathering data while a recording is under way. In the track pane, pauses show up as a gap in the trace data.
Record/Stop button	Starts and stops the recording process. You use this button to begin gathering trace data. For more information, see “Recording Trace Data” (page 34).
Loop button	Sets whether the user interface recorder should loop during play back to repeat the recorded steps continuously. Use this to gather multiple runs of a given set of steps. For information about playing tracks, see “Replaying a User Interface Track” (page 41).
Default Target menu	Selects the trace target for the document. The trace target is the process (or processes) for which data is gathered. For more information on choosing a trace target, see “Choosing Which Process to Trace” (page 31).
Time/Run control	Shows the elapsed time of the current trace. If your trace document has multiple data runs associated with it, you can use the arrow controls to choose the run whose data you want to display in the track pane. For information about trace runs, see “Viewing Trace Runs” (page 44).
Inspection Range control	Selects a time range in the track pane. When set, Instruments displays only data collected within the specified time period. Use the buttons of this control to set the start and end points of the inspection range and to clear the inspection range. For more information, see “Viewing Data for a Range of Time” (page 50).
Mini button	Replaces the visible Instruments trace documents with a smaller, more unobtrusive form. Use this control in situations where you want to focus on using your application. For more information, see “Running in Mini Mode” (page 36).

Control	Description
View button	Displays a menu with controls for hiding or showing the Detail pane and Extended pane. For more information, see “ The Detail Pane ” (page 47) and “ The Extended Detail Pane ” (page 50).
Library button	Hides or shows the instrument library. For information on using the Library window, see “ Using the Instrument Library ” (page 19).

Example: Performing a Quick Trace

To record trace data, specify the target from which you want to gather that data and press the Record button. Most instruments allow you to target a specific process on the system and some allow you to gather information for multiple processes.

The following steps show you how to create a new trace document, configure it, and record some data. The Instruments application should not be running prior to performing these steps.

1. Launch Instruments. The application automatically creates a new trace document and prompts you to select a template.
2. Select the Activity Monitor template and click the Choose button. Instruments adds the Activity Monitor instrument to the trace document.
3. In the Default Target menu of the trace document, select All Processes.
4. Click the Record button.
5. Wait a few seconds so that Instruments can gather some data.
6. Click the Stop button.

Congratulations! You have just used Instruments to gather some trace data. Instruments displays several graphs related to the system load and virtual memory size in the track pane. The Detail pane shows the list of processes that were running during the data-gathering period. You can select the different view modes in the Detail pane to see the same data organized in different ways.

What's Next?

Now that you have been introduced to the basic concepts associated with Instruments, you can start exploring the application in more detail. The remaining chapters provide more in-depth coverage of Instruments features, including how to add and configure instruments, how to record a user interface track, how to analyze the data that you gather, and how to save the data you gather for later use.

Remember that program analysis is both an art and a science. On the scientific side, there are some guidelines that can be followed to find problems. For example, if your application has a large memory footprint, it is likely that the application will experience paging at some point, which leads to poor performance. The art comes in determining how to reduce the memory footprint because the answer for every application is

CHAPTER 1

Instruments Quick Start

different. Is the application caching too much data? Is it loading too many libraries at launch time and then not using them? Is it leaking memory? These are the questions you need to ask yourself, and Instruments is the tool you can use to find the answers.

CHAPTER 1

Instruments Quick Start

Adding and Configuring Instruments

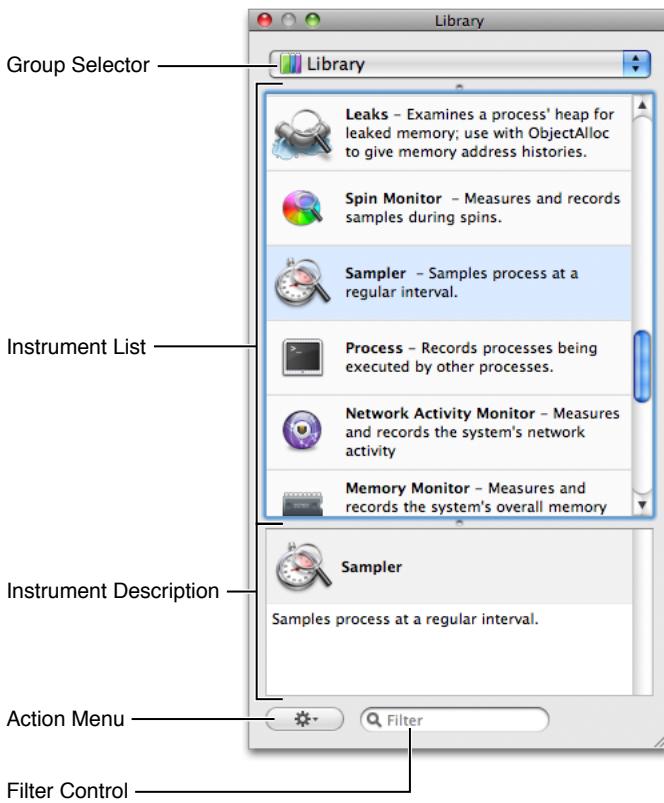
The Instruments application uses instruments to collect data and display that data to the user. Although there is no theoretical limit to the number of instruments you can include in a document, most documents contain fewer than ten for performance reasons. You can even include the same instrument multiple times, with each instrument configured to gather data from a different process on the system.

Instruments comes with a wide range of built-in instruments whose job is to gather specific data from one or more processes. Most of these instruments require little or no configuration to use. You simply add them to your trace document and begin gathering trace data. You can also create custom instruments, however, which provide you with a wide range of options for gathering data.

This chapter focuses on how to add existing instruments to your trace document and configure them for use. For information on how to create custom instruments, see “[Creating Custom Instruments with DTrace](#)” (page 63).

Using the Instrument Library

The instrument library (shown in Figure 2-1) displays all of the instruments that you can add to your trace document. The library includes all of the built-in instruments plus any custom instruments you have already defined. To open this window, click the Library button in your trace document or choose Window > Library.

Figure 2-1 The instrument library

Because the list of instruments in the Library window can get fairly long, especially if you add your own custom-built instruments, the instrument library provides several options for organizing and finding instruments. The following sections discuss these options and show how you use them to organize the available instruments.

Changing the Library View Mode

The library provides different view modes to help you organize the available instruments. View modes let you choose the amount of information you want displayed for each instrument and the amount of space you want that instrument to occupy. Instruments supports the following view modes:

- **View Icons.** Displays only the icon representing each instrument.
- **View Icons And Labels.** Displays the icon and name of each instrument.
- **View Icons and Descriptions.** Displays the icon, name, and full description of each instrument.
- **View Small Icons And Labels.** Displays the name of the instrument and a small version of its icon.

Note: Regardless of which view mode you choose, the Library window always displays detailed information about the selected instrument in the detail pane.

To change the library's view mode, select the desired mode from the action menu at the bottom of the Library window.

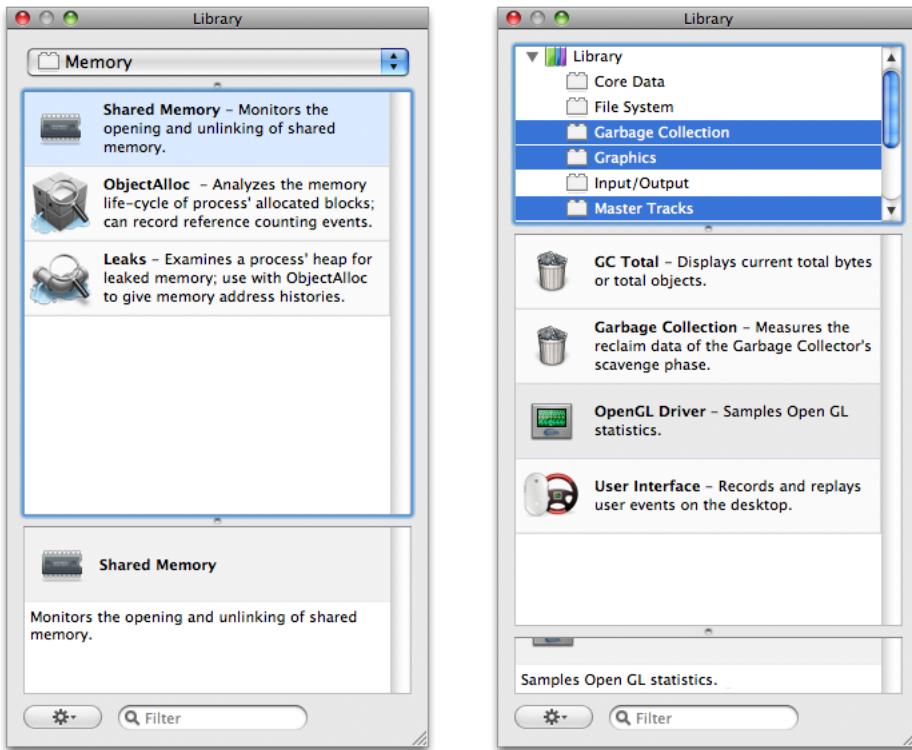
In addition to changing the library's view mode, you can display the parent group of a set of instruments by selecting Show Group Banners from the Action menu. The Library window organizes instruments into groups for convenience and to help you narrow down the list of instruments you want. By default, this group information is not displayed in the main pane of the Library window. Enabling the show Group Banners option adds it, making it easier to identify the general behavior of instruments in some view modes.

Finding an Instrument in the Library

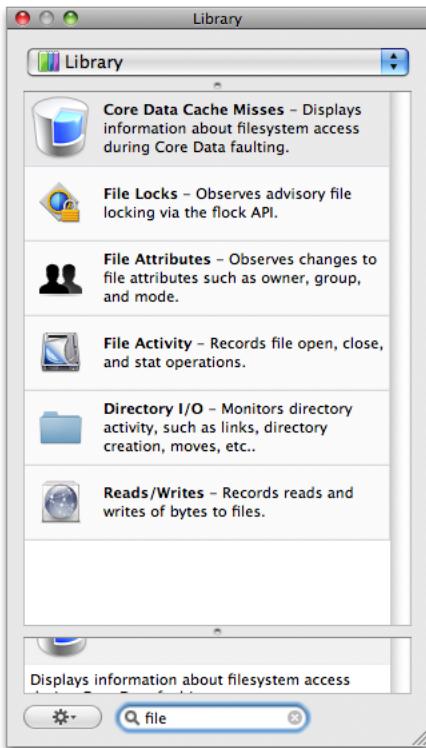
By default, the Library window shows all of the available instruments. Each instrument, however, belongs to a larger group, which identifies the purpose of instrument and the type of data it collects. You can use the group selection controls at the top of the Library window to select one or more groups and thereby limit the number of instruments displayed by the Library window. When there are many instruments in the library, this feature makes it easier to find the instruments you want.

The group selection controls have two different configurations. In one configuration, the Library window displays a pop-up menu, from which you can select a single group. If you drag the split bar between the pop-up menu and the instrument pane downward, however, the pop-up menu changes to an outline view. In this configuration, you can select multiple groups by holding down the Command or Shift key and selecting the desired groups.

Figure 2-2 shows both standard mode and outline mode in the Library window. The window on the left shows standard mode, in which you select a single group using the pop-up menu. The window on the right shows the outline view, in which you can select multiple groups and manage your own custom groups.

Figure 2-2 Viewing an instrument group

Another way to filter the contents of the Library window is to use the search field at the bottom of the Library window. Using the search field, you can quickly narrow down the contents of the Library to find the instrument or instruments whose name, description, category, or list of keywords matches the search text. For example, Figure 2-3 shows instruments that match the search string `file`.

Figure 2-3 Searching for an instrument

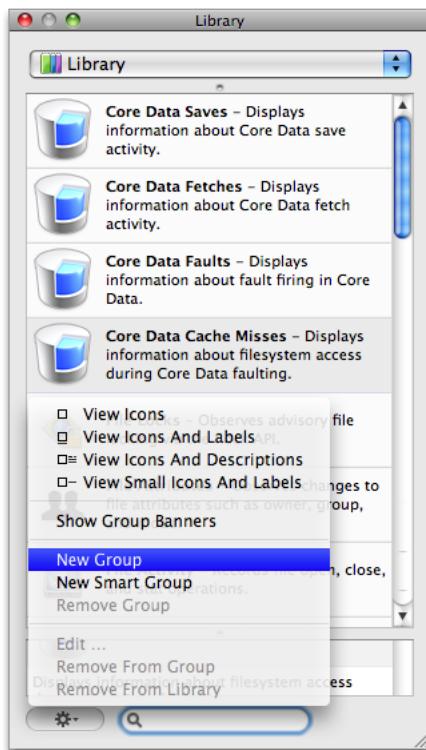
When the pop-up menu is displayed at the top of the Library window, the search field filters the contents based on the currently selected instrument group. If the outline view is displayed, the search field filters the contents based on the entire library of instruments, regardless of which groups are selected.

Creating Custom Instrument Groups

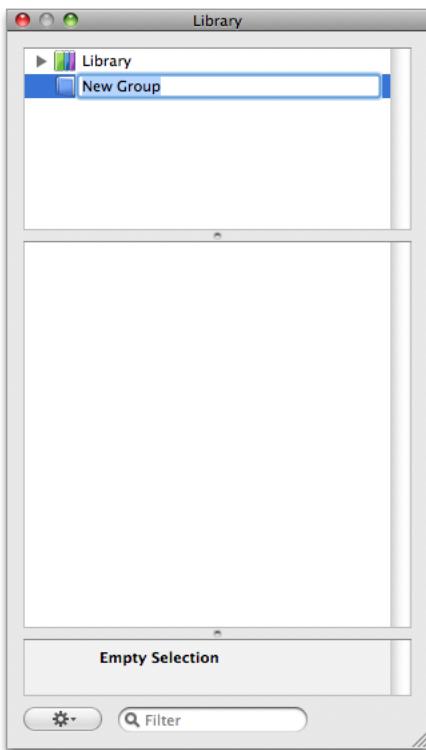
In addition to using the built-in instrument groups, you can create custom groups to organize instruments in a way that better suits your own use patterns. Instruments supports two different types of custom groups: static groups and smart groups. Static groups are just that—static. Instruments does not change their contents at all, leaving you free to configure the group however you want. Smart groups, on the other hand, are dynamic groups whose contents change automatically based on the criteria you specify for the group. You can use smart groups to show the list of recently used instruments or instruments whose name or description contains a specific keyword.

Creating a Static Group

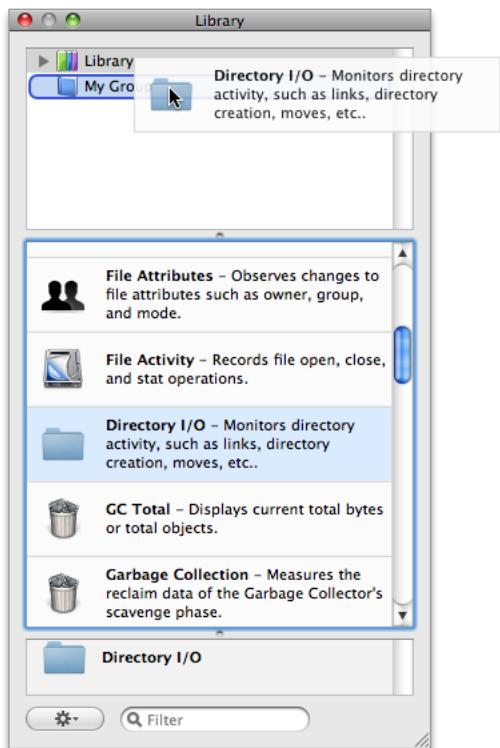
To create a static group, select New Group from the Library window's action menu, as shown in Figure 2-4.

Figure 2-4 Creating a group

Instruments creates a new group and adds it to the Library window. To see the new group and edit its name and contents, drag the separator bar beneath the pop-up menu to open an upper pane showing the group structure of the Library, as shown in Figure 2-5. Click on the group and give it a new name.

Figure 2-5 Editing the name of a group

To add an instrument to a static group, click Library to display the list of instruments, select the instrument, and drag it to the group in the upper pane as illustrated in Figure 2-6.

Figure 2-6 Adding an instrument to a custom group

You can create hierarchical organizations of instruments using static groups. Static groups can include other static groups and they can also include smart groups. Smart groups cannot contain other groups, however. To create a hierarchical set of groups, you can do one of the following:

- Drag an existing group to the parent static group.
- Select a static group and choose New Group or New Smart Group to create a new item as a child of the selected group.

A group that contains other groups displays its own instruments plus the instruments contained in all of its child groups. If the same instrument is present in multiple groups and the Show Group Banners option is enabled, then the same instrument is listed under each group that contains it. If the Show Group Banners option is disabled, however, the Library window coalesces identical copies of an instrument into a single entry.

To remove an instrument from a static group, do the following:

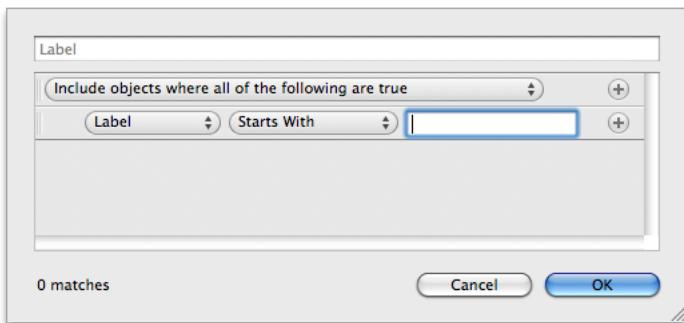
1. Select the group.
2. In the group, select the instrument you want to remove.
3. Choose Remove From Group from the action menu or simply press the Delete key.

To remove a static group from the Library window, select the group and choose Remove Group from the action menu. If you are currently viewing groups using the outline view, you can also select the group and press the Delete key. Removing a static group removes the group and any nested groups it contains. This operation does not, however, delete the instruments contained in the group from the library. You can always find the instruments again by looking in the Library group.

Creating a Smart Group

To create a new smart group, choose New Smart Group from the Library window's action menu. Instruments displays the rule editor shown in Figure 2-7. The Label field identifies the name of the group as it appears in the Library window. The rest of the sheet is dedicated to configuring the rules that determine which instruments reside in the group.

Figure 2-7 The smart group rule editor



Every smart group must have at least one rule. You can add additional rules, as needed, using the controls in the rule editor and configure the group to apply all or some of the rules. Table 2-1 lists the criteria you can use to match instruments.

Table 2-1 Smart group criteria

Criteria	Description
Label	Matches instruments based on their title. This criterion supports the Starts With, Ends With, and Contains comparison operators.
Used Within	Matches instruments based on when they were used. You can use this criterion to match only instruments that were used within the last few minutes, hours, days, or weeks.
Search Criteria Matches	Matches instruments whose title, description, category, or keywords include the specified string.
Category	Matches instruments whose library group name matches the specified string. This criterion does not match against custom groups.

To edit an existing smart group, select the group in the Library window and choose Edit <Group Name> from the action menu, where <Group Name> is the name of your smart group. Instruments displays the rule editor again so that you can modify the existing rules.

To remove a smart group from the Library window, select the group and choose Remove Group from the action menu. If you are currently viewing groups using the outline view, you can also select the group and press the Delete key.

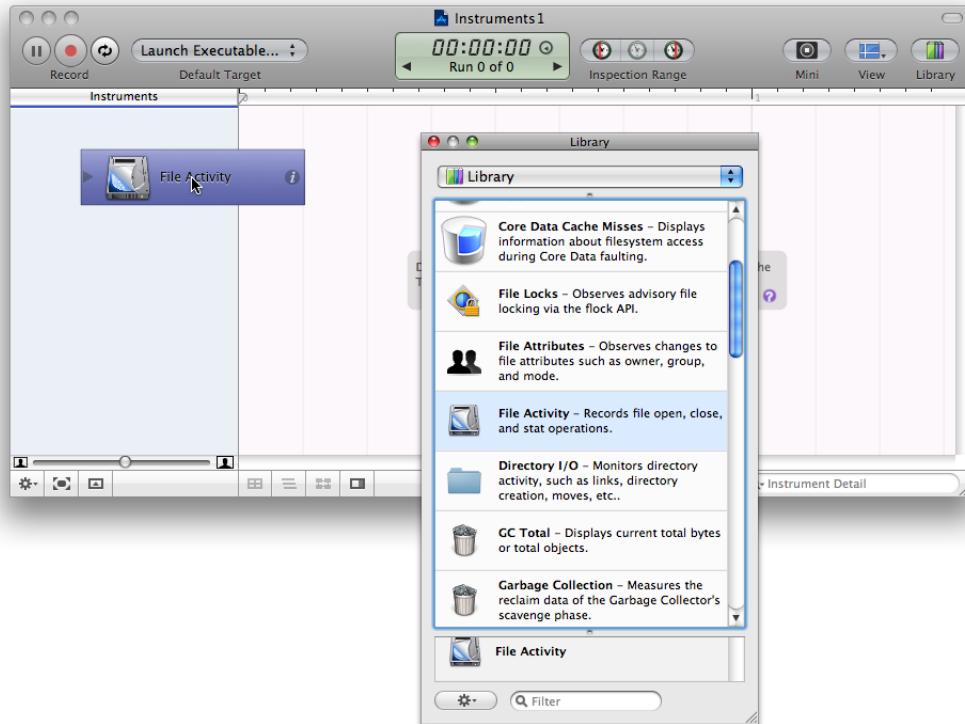
Adding and Removing Instruments

There are two ways to add an instrument to a trace document:

- You can drag an instrument from the library and drop it onto your trace document.
- You can add an instrument using the action menu of a trace document.

To add an instrument from the library, find the instrument you want and drag it from the Library window to the Instruments pane of your trace document, as shown in Figure 2-8.

Figure 2-8 Adding an instrument



The action menu in the bottom-left corner of a trace document includes an Add Instrument submenu that lists all of the available instruments. Selecting an instrument from this submenu adds it to your trace document.

You can add as many instruments as you like to the Instruments pane. Although some instruments can track all system processes, many track only a single process. For those instruments, you can use multiple instances of the instrument and assign each one to a different process if you like. In this way, you gather similar information for multiple programs simultaneously. For example, you might do this to sample a server process and one of its corresponding client processes and examine the overall interaction pattern.

To remove an instrument from the Instruments pane, select the instrument and press Delete.

Configuring an Instrument

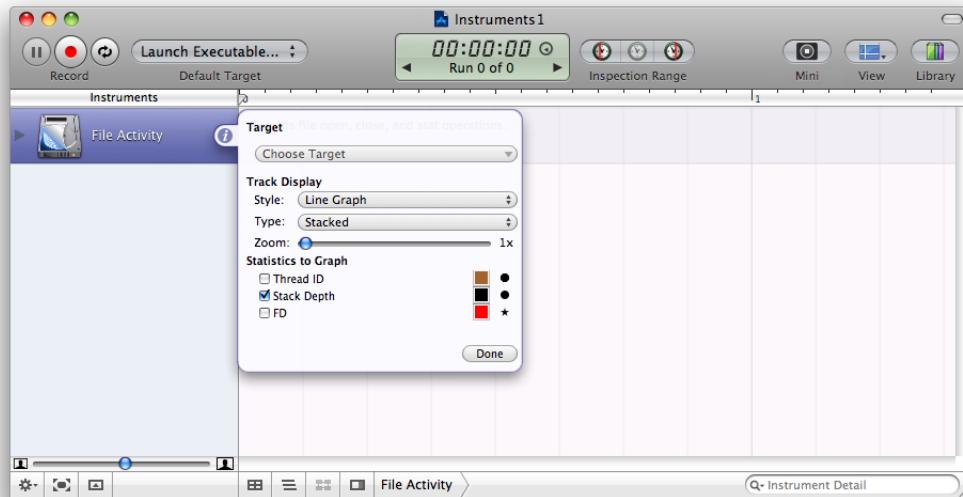
Most instruments are ready to use as soon as you add them to the Instruments pane. Some instruments can be also be configured using the instrument inspector. The content of the inspector varies from instrument to instrument. Most instruments contain options for configuring the contents of the track pane and a few contain additional controls for determining what type of information is gathered by the instrument itself.

To open the inspector for a given instrument, select the instrument and do one of the following:

- Click the inspector icon to the right of the instrument name.
- Choose File > Get Info.
- Press Command-I.

The inspector panel appears next to the instrument name, as shown in Figure 2-9. To dismiss the inspector, click the Done button. (The commands you used to open the inspector can also be used to close it.)

Figure 2-9 Inspector for the ObjectAlloc instrument



Controls related to displaying information in the track pane can be configured before, during, or after your record data for the track. Instruments automatically gathers the data it needs for each display option regardless of whether that option is currently displayed in the track pane.

The Zoom control found in most inspectors controls the vertical magnification of the trace data in the track pane. Changing the zoom value changes the height of the instrument in the track pane. The View > Decrease Deck Size and View > Increase Deck Size commands do a similar job of decreasing and increasing the track pane magnification for the selected instrument.

For a list of instruments, including their configurable options, see “[Built-in Instruments](#)” (page 75).

CHAPTER 2

Adding and Configuring Instruments

Recording Trace Data

After you decide which instruments you want to use to gather data, the next step is to choose the process you want to trace and begin recording data. How you select a process is dependent on the instruments in your trace document. Some instruments allow tracing of all system processes, others require you to record data for a single process. Some instruments even expect you to launch the process from Instruments so that they can gather data from the beginning of its execution.

Instruments provides several options for initiating a trace that make it easier to integrate Instruments into your development cycle. In this chapter, you learn how to select a process for your trace document and begin recording data using the available options in Instruments.

Choosing Which Process to Trace

Before you can start collecting data, you must tell Instruments which process you want to trace. You do this by designating a target process (or processes) using the the Default Target menu in the Instruments toolbar. This menu provides the following options:

- **All Processes.** Configures your document to trace all processes on the system.
- **Attach to Process.** Configures your document to trace an already running process.
- **Launch Executable.** Configures your document to launch and trace a process. (If the process is already running, Instruments launches a new copy and traces it.)
- **Instrument Specific.** Select this item to assign different trace targets to individual instruments.

The following sections describe each of these options in more detail.

Tracing All Processes

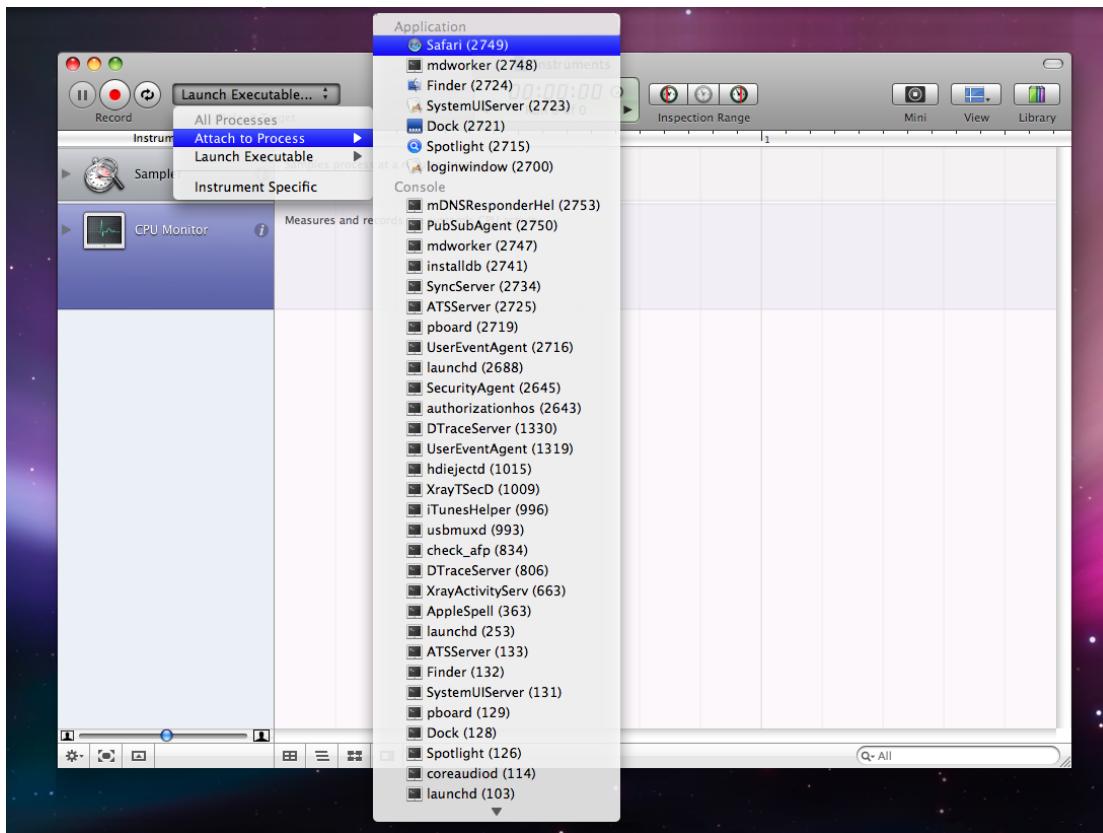
Some instruments are capable of collecting data for all processes currently running on the computer. You can use this ability to profile a type of event or activity across the entire system. For example, you can use the Disk Activity instrument to trace all read and write operations that occur on your computer over a particular time period. To trace all running processes, choose All Processes from the Default Target menu.

Note: The All Processes item is available only if all instruments in the Instruments pane support it.

Attaching to an Existing Process

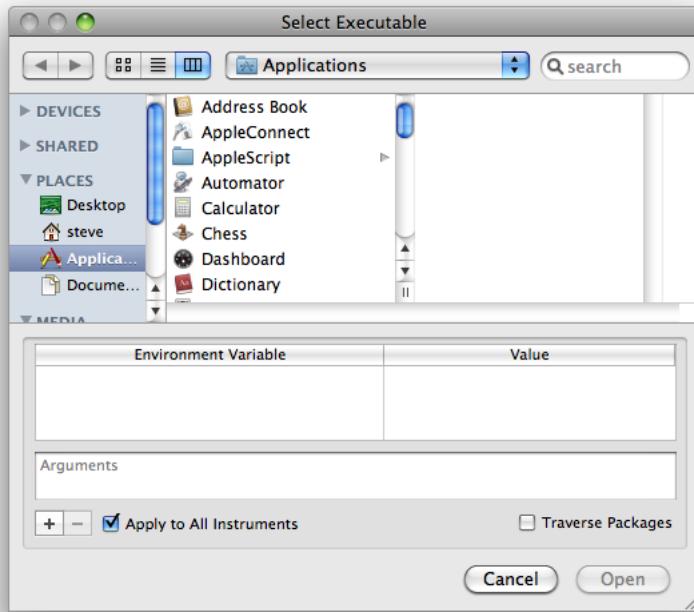
If the process you want to trace is already running on the computer, most instruments can attach to that process and start collecting data. To trace an existing process, choose Attach to Process from the Default Target menu and select the process to trace, as shown in Figure 3-1.

Figure 3-1 Tracing an existing process



Launching an Executable from Instruments

If the process that you want to trace is not already running on the computer, or if you want to control the conditions under which that process is launched, choose Launch Executable from the Default Target menu. Instruments remembers any recently launched processes and adds them to the Launch Executable menu for quick access. If the process you want to launch is not in that menu, select Choose Executable to display the panel shown in Figure 3-2

Figure 3-2 Choosing an executable to launch

The Choose Executable panel not only lets you select the program to launch but it also lets you specify how to launch the selected program. Table 3-1 lists the additional controls in this panel and explains how you use them.

Table 3-1 Options for launching an executable

Control	Description
Environment Variable	Identifies environment variables you want to set before running the process. You might use this option if your program has debugging options that are enabled using an environment variable. Use the plus (+) and minus (-) buttons to add or remove environment variables.
Arguments	Use this field to specify any launch arguments for the application. The arguments you specify are the same ones you would use from the command line when launching the application there.
Apply to All Instruments	Sets the specified application as the target for all instruments in the trace document. This option is enabled by default. Disabling it lets you assign different targets to different instruments in your trace document. You might use this feature when you have two copies of the same instrument or when you want to trace the behavior of two processes running side by side.
Traverse Packages	Displays bundles (such as applications and plug-ins) as a navigable directory structure. Use this feature if the executable you want to run is inside a bundle.

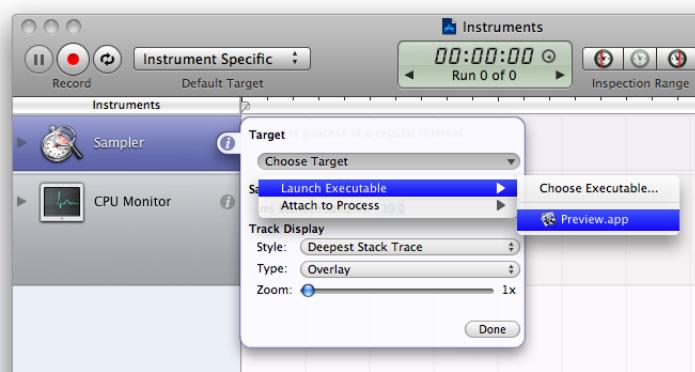
Specifying a Different Target for Each Instrument

When you choose All Processes, Attach to Process, or Launch Executable from the Default Target menu, Instruments sets the default target for all instruments to the program you choose. There are occasions, however, when you might want to set a different target for each instrument. You might want to sample two different programs at the same time, for example, using the Sampler instrument. If you have some instruments that are capable of tracing all processes, you might want them to do just that while single-process instruments sample just one process.

To assign trace targets on a per-instrument basis, do the following:

1. In the Default Target menu, select the Instrument Specific option.
2. Select one of your instruments.
3. Open the instrument inspector by clicking its information icon.
4. In the inspector window, use the pop-up menu in the Target section to set the target for the instrument, as shown in Figure 3-3.

Figure 3-3 Choosing per-instrument trace targets



5. Repeat steps 2 through 4 for each of your other instruments.

Recording Trace Data

After you've selected a process to trace, you are ready to start collecting data. Click the Record button (or choose File > Record Trace) to begin gathering the trace data. When you click Record, Instruments launches the specified executable or attaches to the specified processes and starts gathering data.

Note: When you click the Record button, Instruments may display one or more authentication panels. Many instruments require you to authenticate as an administrative user before they will record any data. Instruments is a powerful tool that enables you to see into running applications, and as such, it should be used only by authorized users.

When recording begins, the instruments start collecting data. Instruments displays the collected data in the track and Detail panes immediately. The Time control in the Instruments toolbar also shows you how much time has elapsed since you began recording. To stop collecting data, click the Stop button or choose File > Stop Trace.

During recording, if you want your program to continue running, but do not want Instruments to gather data, press the Pause button in your trace document. Instruments stops gathering data temporarily but does not stop the current recording run. Pressing the Resume button causes Instruments to continue gathering data at the current recording time. Thus, pausing and resuming leaves a data gap in the Track pane.

Launching Instruments Using Quick Start Keys

Quick Start keys are global key combinations that let you launch the Instruments application and begin collecting trace data immediately using a specific document template. You can use this feature if you are running an application and see something—such as a bug or unresponsive behavior—that you want to capture right away. You can associate different key combinations with different Instruments templates to capture different types of behavior.

To assign a Quick Start key combination, open the Instruments preferences and navigate to the Quick Start pane. This pane displays the list of Instruments templates that you can assign to key combinations. All templates start without a key combination. To assign one, find the row containing the desired template and double-click its Key column to create an editable cell. While the cell is in edit mode, press the key combination you want to use. For example, to assign the key combination Command-Option-1, press the Command, Option, and number 1 key all at the same time.

To remove a key combination from a template, select a row and press Delete.

Note: Quick Start key combinations should use at least two key modifiers (Command, Option, Control, Shift). You should avoid choosing key combinations that are commonly used by other applications.

To gather data for an application using a Quick Start Key, do the following:

1. Place the cursor over a window belonging to the application you want to trace.
2. Press the appropriate key combination to begin tracing.
3. Exercise the application.
4. When you want to stop tracing, you have two options:
 - Place the cursor over one of the application's windows and press the key combination again.
 - Find the trace document that was opened and press the Stop button.

Because Quick Start Keys require you to move the cursor over one of the application's windows, you can initiate multiple trace sessions for different applications using the same Quick Start Key without stopping any of the previous traces. You could also start different types of traces for the same application using different key combinations and have them all gathering data at the same time.

Running in Mini Mode

Mini mode provides a way for you to minimize the visual footprint of the Instruments application while gathering your data. When you are gathering data from certain types of applications, particularly graphics-oriented applications, there may be times when you want to gather data while remaining focused on your own application. Mini mode hides all open trace documents and in their place displays a small floating window that you can use to start and stop tracing. An added advantage of mini mode is that the Instruments application itself requires less drawing and therefore has less of an impact on system performance.

Figure 3-4 shows the mini Instruments window with several trace documents open. Instruments shows only three trace documents at a time in Mini mode, but you can use the up and down arrows to find the document you want.

Figure 3-4 The Mini Instruments window



Clicking the record button next to a trace document begins recording data for that document. The document must already have its instrument and target process configured before tracing can begin. During tracing, Instruments displays the elapsed time since tracing began but displays no other instruments, controls, or data.

To enable Mini mode, click the Mini button in the toolbar of any open trace document. To disable Mini mode, click the close box in the mini Instruments window. You can also toggle between standard and mini modes by choosing View > Mini Instruments from the menus.

Running Instruments from Xcode

During development, you can launch your programs in Instruments directly from the Xcode user interface. This integration lets you quickly launch Instruments and gather trace data in much the same way that you would launch your program and debug it using GDB.

The Run > Start with Performance Tool menu in Xcode provides several options for launching your program using the available performance tools, including Instruments. When launching your program in Instruments, you tell Xcode which Instruments template you want to use by selecting the appropriate menu item. Xcode launches Instruments, creates a trace document using the specified template, sets the target to your program, and tells Instruments to launch your program and start recording.

In addition to the existing templates in the Start with Performance Tool menu, Xcode lets you add custom trace templates to this menu as well. For information on how to save a trace template and add it to this menu, see “[Saving an Instruments Trace Template](#)” (page 61).

CHAPTER 3

Recording Trace Data

Working with a User Interface Track

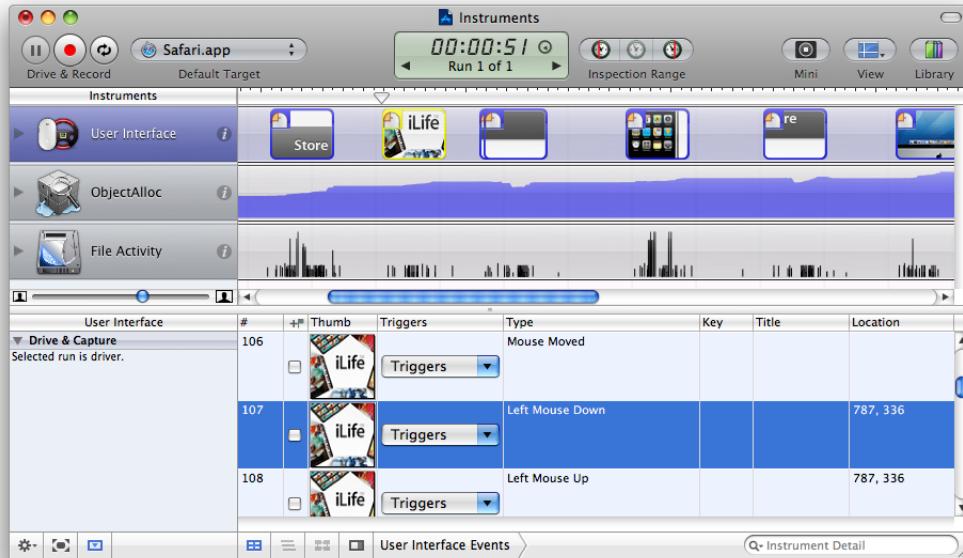
A user interface track records a series of events or operations in a running program. After the events are recorded, you can replay that track multiple times to reproduce the same sequence of events over and over. Each time you replay a user interface track, you can collect data using other instruments in your trace document. The benefit of doing so is that you can then compare the data you gather on each successful run and use it to measure the changes in your application's performance or behavior.

Recording a User Interface Track

You record a user interface track with the User Interface instrument. You add this instrument to your trace document just as you would any other instrument. When you click the Record button in your document, the User Interface instrument gathers events related to user input, such as mouse and keyboard events. It collects these events and displays them in the track pane for you to see and examine.

Note: If you create a new trace document using the UI Recorder template, Instruments automatically adds the User Interface instrument to the document for you.

After you have gathered a set of events for the user interface track, the title of the Record button changes to Drive & Record. Pushing this button again causes Instruments to drive the user interface, replaying the sequence of events you recorded previously. While it does this, the other instruments in your trace document gather data as usual. Upon completion of the event stream, you should have a new run of data to examine. Figure 4-1 shows a trace document with a User Interface track and several other instruments. Here, the user interface track already contains a sequence of events that are ready to be replayed.

Figure 4-1 Recording a user interface track

Important: User interface recording takes advantage of accessibility features normally used by screen readers and other assistive devices for disabled persons. To ensure that your computer supports this feature, open the Universal Access pane of System Preferences and make sure the “Enable access for assistive devices” setting is enabled.

The Detail pane for the User Interface instrument lists the events that were recorded, the location of the event, and the key that was pressed, if any. The instrument can also capture a screen shot of the area affected by the user action. A thumbnail version of the screen shot is shown in both the track pane and the detail pane. Each event is color-coded according to its type:

- Mouse events are blue.
- Key events are green.
- System events are yellow.

Rerecording a User Interface Track

If, after capturing a sequence of events, you decide that you did not get the sequence right, you can go back and recapture the sequence as needed until you get it right. Before you recapture the sequence, though, you must tell Instruments not to drive the user interface using the old event sequence. The Action section of the User Interface inspector contains a pop-up menu that lets you specify how you want that instrument to run. Normally, after you capture a sequence of events, the Action setting is automatically set to Drive. To recapture, you must change the setting to Capture. After you have done that, you can begin recording the new sequence. Because the Action setting switches back to Drive after each recording, recapturing a sequence several times requires that you change the Action setting back to Capture every time you record.

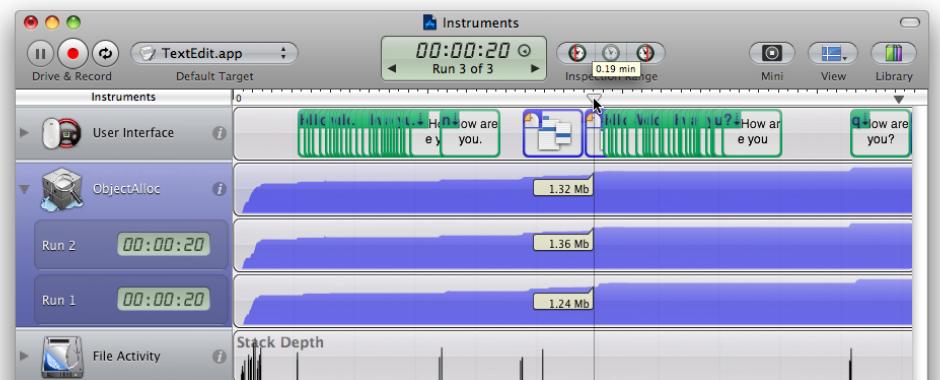
Replaying a User Interface Track

After you have recorded a user interface track, you can replay that track to reproduce the sequence of user events that you recorded. After recording a sequence of events, Instruments automatically changes the title of the Record button to Drive & Record. Clicking this button launches the selected application and performs each of the actions recorded in the user interface track. At the same time, Instruments begins collecting data for any active instruments in the Instruments pane.

After each successful run of the user interface track, Instruments displays the results of that run in the track pane. To change the active set of results in the track pane, you can use the arrows in the Time control. Clicking these arrows cycles through each of the available data sets, updating the display for each of the available instruments.

You can also view all of the runs for an instrument at the same time so that you can compare them. Each instrument includes a disclosure triangle on its left side. Clicking this control expands the instrument and displays the data from all of the previous runs side by side, as shown in Figure 4-2.

Figure 4-2 Viewing multiple runs



While collecting trace data, you can have Instruments repeat the events in the user interface track multiple times in succession by clicking the Loop button in the document toolbar. The state of the button is sticky, so clicking it enables looping and clicking it again disables it. When looping is enabled, Instruments runs the event sequence in a continuous loop, gathering a new set of trace data each time through the loop. You might use this feature to repeat a sequence of events that exhibits undesirable behavior after a number of tries. You can also use looping to stress-test your application by keeping it constantly busy.

CHAPTER 4

Working with a User Interface Track

Viewing and Analyzing Trace Data

Because Instruments lets you gather data from multiple instruments simultaneously, the amount of data available to you can quickly get overwhelming. Fortunately, Instruments devotes much of its interface to organizing and displaying data in ways that help you analyze and navigate that data. Understanding the different areas of your trace document window is essential to spotting trends and finding potential problem areas.

Every trace document includes the following interface elements:

- The Track pane
- The Detail pane
- The Extended Detail pane
- The Run Browser

Each of these elements show you the exact same data in your trace document; they just show it in very different ways, ranging from high-level overviews to detailed information about each data point. The idea is to give you different ways to visualize your data. You can view the high-level data to look for general trends, and then look at the detailed data to find out exactly what is happening in your code and formulate ideas on how to fix potential issues.

In addition to the user interface options, many instruments can be configured to present their data in several different ways. You can use these configuration options during the analysis phase to get fresh perspectives on the gathered data.

In this chapter, you learn how to use the information provided to you by Instruments and how you can modify the way that information is presented to suit your workflow needs.

Tools for Viewing Data

The following sections describe key elements of the Instruments user interface and how you use those elements to view trace data.

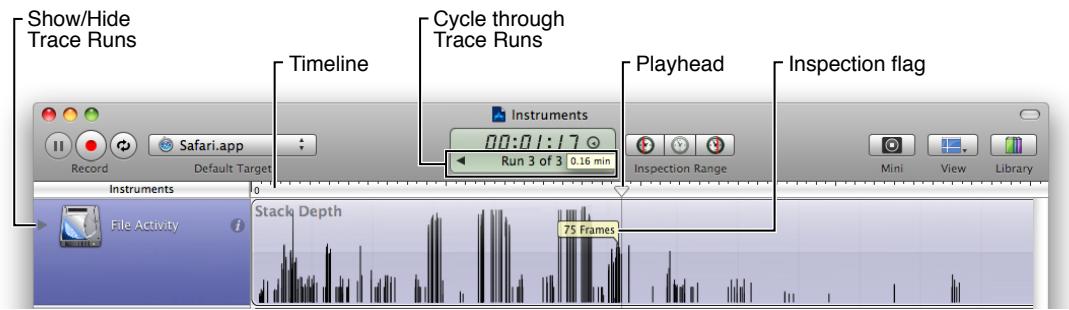
The Track Pane

The most prominent portion of a trace document window is the track pane. The track pane occupies the area immediately to the right of the instruments pane. This pane presents a high-level, graphical view of the data gathered by each instrument. You use this pane to examine the data from each instrument and to select the areas you want to investigate further.

The graphical nature of the track pane makes it easier to spot trends and potential problem areas in your program. For example, a spike in a memory usage graph indicates a place where your program is allocating more memory than usual. This spike might be normal, or it might indicate that your code is creating more objects or memory buffers than you had anticipated in this location. An instrument such as the Spin Monitor instrument can also point out places where your application becomes unresponsive. If the graph for the Spin Monitor is relatively empty, you know that your application is being responsive, but if the graph is not empty, you might want to examine why that is.

Figure 5-1 shows a sample trace document and calls out the basic features of the track pane. You use the timeline at the top of the pane to select where you want to investigate. Clicking in the timeline moves the playhead to that location and displays a set of inspection flags, which summarize the information for each instrument at that location. Clicking in the timeline also focuses the information in the Detail pane on the surrounding data points; see “[The Detail Pane](#)” (page 47).

Figure 5-1 The track pane



Although each instrument is different, nearly all of them offer options for changing the way data in the track pane is displayed. In addition, many instruments can be configured to display multiple sets of data in their track pane. Both features give you the option to display the data in a way that makes sense for your program.

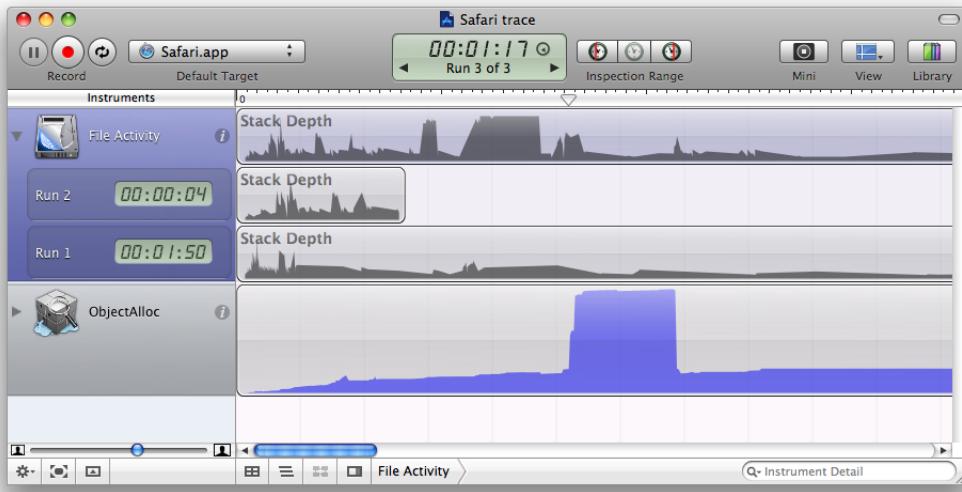
The sections that follow provide more information about the track pane and how you configure it.

Viewing Trace Runs

Each time you click the Record button in a trace document, Instruments starts gathering data for the target processes. Rather than append the new data to any existing data, Instruments creates a new trace run to store that data. A **trace run** constitutes all of the data gathered between the time you clicked the Record button and stopped gathering data by clicking the Stop button. By default, Instruments displays only the most recent trace run in the track pane, but you can view data from previous trace runs in one of two ways:

- Use the Time/Run control in the toolbar to select which trace run you want to view.
- Click the disclosure triangle next to an instrument to display the data for all trace runs for that instrument.

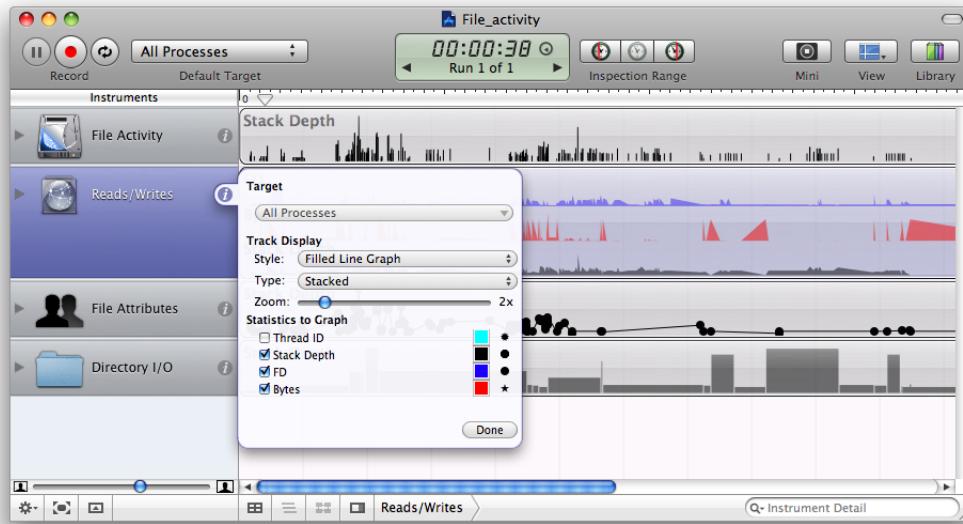
Figure 5-2 shows an instrument that has been expanded to show multiple trace runs. In this example, several trace runs have been collected, each of which was generated from a slightly different set of events. You might gather multiple trace runs when you are trying to reproduce a problem that does not occur every time, creating new trace runs until the problem surfaces. If you want to compare multiple trace runs using the exact same set of events, however, you need to create a user interface track, a process that is described in “[Working with a User Interface Track](#)” (page 39).

Figure 5-2 Viewing multiple runs of an instrument

When you save a trace document, Instruments normally discards the data from all runs except the one that is currently selected. It does this to keep the size of your trace documents from becoming too large. If you want to save all trace runs for your documents, go to the General tab of the Instruments preferences and uncheck the Save Current Run Only option.

Displaying Multiple Data Sets for an Instrument

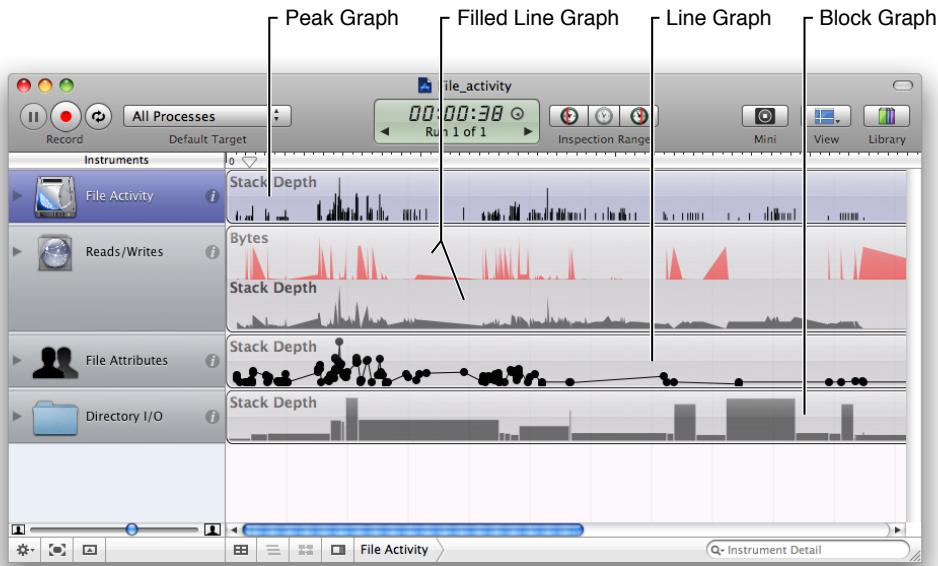
Some instruments are capable of displaying multiple streams of data inside their corresponding track pane. You can configure which streams of data are displayed using the instrument inspector, as shown in Figure 5-3. The Statistics to Graph section lists all of the integer-based data values gathered by the instrument. Selecting the checkboxes in that section adds the corresponding statistics to the track pane.

Figure 5-3 Configuring the statistics to graph

For information about the data gathered by each instrument, see “[Built-in Instruments](#)” (page 75).

Changing the Display Style of a Track

Instruments provides several different styles for graphing data in the track pane. Most instruments choose a style that makes the most sense for the type of data they are displaying. You can change the selected style for an instrument using the Style pop-up menu in the instrument’s inspector. Figure 5-4 shows several of the styles.

Figure 5-4 Track styles

Note: The style option you choose affects all of the data streams displayed by the instrument.

Zooming in the Track Pane

Instruments supports zooming in and out on track pane data along both the vertical and the horizontal axes.

- To change the horizontal (time) scale, use the slider control below the instruments pane.
- To change the vertical (amplitude or volume) scale, select an instrument and do one of the following:
 - Open the instrument's inspector and use the Zoom slider there.
 - Select the View > Increase Deck Size menu item to increase the zoom factor.
 - Select the View > Decrease Deck Size menu item to decrease the zoom factor.

For horizontal zooming, Instruments expands or contracts the track pane around the current playhead position. If you set the playhead to a particular point before zooming, you can zoom in or out on the data under that point.

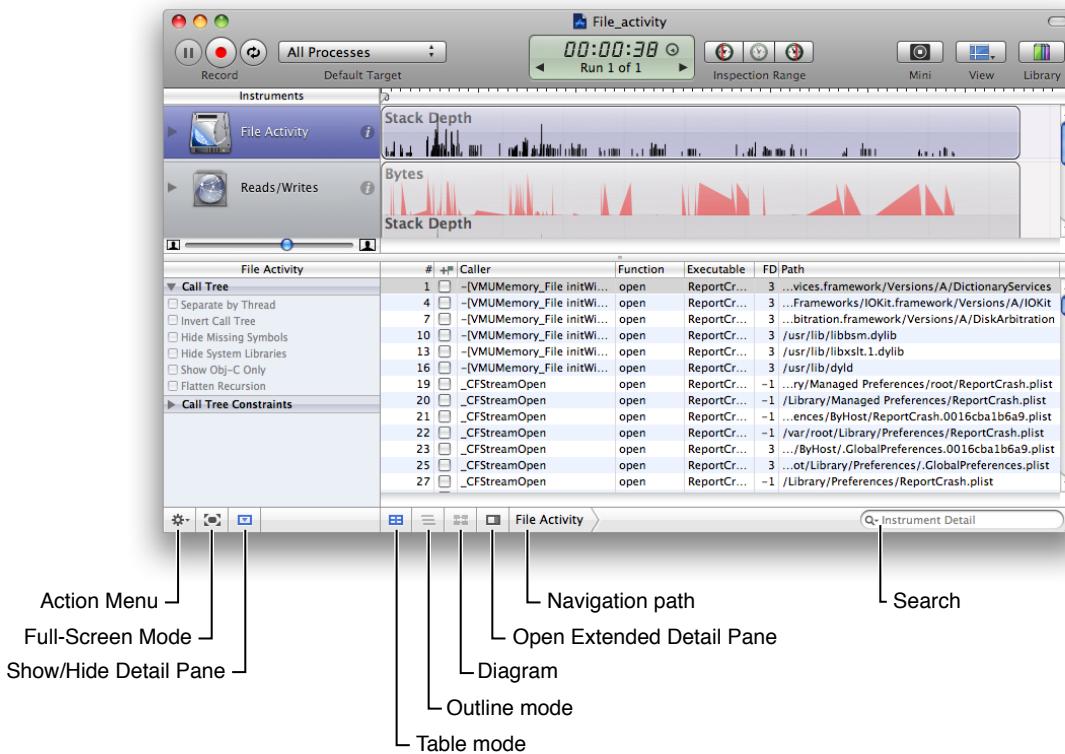
The Detail Pane

After you identify a potential problem area in the track pane, you use the Detail pane to examine the data in that area. The Detail pane displays the data associated with the current trace run for the selected instrument. Instruments displays only one instrument at a time in the Detail pane, so you must select different instruments to see different sets of details.

Viewing and Analyzing Trace Data

Different instruments display different types of data in the Detail pane. Figure 5-5 shows the Detail pane associated with the File Activity instrument, which records information related to specific file system routines. The Detail pane in this case displays the function or method that called the file system routine, the file descriptor that was used, and the path to the file that was accessed. For information about what each instrument displays in the Detail pane, see “[Built-in Instruments](#)” (page 75).

Figure 5-5 The Detail pane



To open or close the Detail pane, do one of the following:

- Choose View > Detail.
- Click the View button in the toolbar and select Detail from the pull-down menu.
- Click the Toggle Detail Pane button at the bottom left of the trace document window, next to the Full Screen mode button.
- Select Detail from the Action menu at the bottom of the Instruments window.

Changing the Display Style of the Detail Pane

For some instruments, you can display the data in the Detail pane using more than one format. The Detail pane supports the following formatting modes:

- **Table mode** displays a flat list of aggregated sample data.
- **Outline mode** displays a hierarchical list of samples, typically organized using stack trace or process information.

Viewing and Analyzing Trace Data

- **Diagram mode** displays a list of the individual samples

To view an instrument's data using one of these formats, click the appropriate mode button along the bottom of the Detail pane (see [Figure 5-5](#) (page 48)). Which modes an instrument supports depends on the type of data gathered by that instrument. For example, the Sample instrument supports only table and outline modes, but the Network Activity instrument supports all three modes.

When displaying data in Outline mode, you can use disclosure triangles in the appropriate rows to dive further down into the corresponding hierarchy. Clicking a disclosure triangle expands or closes just the given row. To expand both the row and all of its children, hold down the Option key while clicking on a disclosure triangle.

Sorting in the Detail Pane

You can sort the information displayed in the Detail pane according to the data in a particular column. To do so, click the appropriate column header. The columns in the Detail pane differ with each instrument.

Searching in the Detail Pane

You can type a string in the search field in the lower-right corner below the Detail pane to narrow down the list of information displayed in the Detail pane. By default, Instruments applies the specified search string against all of the data recorded by the instrument. With some instruments, however, you can refine the scope of your search even further. For example, use the ObjectAlloc instrument to apply the search string against specific subsets of the instrument data, such as the library or routine that created the memory block. You can even search for objects at a specific memory address.

The filter scoping criteria varies from instrument to instrument. To specify the desired scope, click the magnifying glass in the search field and choose from the available options. Figure 5-6 shows the search options for the ObjectAlloc instrument.

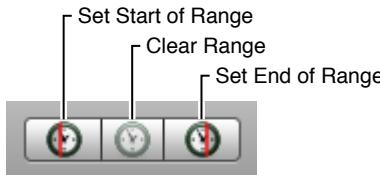
Figure 5-6 Filtering the Detail pane

#	Object Address	Category	Creation Time	Size	Responsible Library	Responsible Caller
0	0x20ea00	GeneralBlock-128	00:00.410	128	dyld	_dyld_start
1	0x20ea80	GeneralBlock-16	00:00.410	16	dyld	_dyld_start
2	0x20ea90	GeneralBlock-16	00:00.410	16	dyld	_dyld_start
3	0x20ea0	GeneralBlock-32	00:00.410	32	dyld	_dyld_start
4	0x20ea0	GeneralBlock-32	00:00.410	32	dyld	_dyld_start
5	0x20ea0	NSRecursiveLock	00:00.410	80	dyld	_dyld_start
6	0x20ea00	GeneralBlock-128	00:00.411	128	dyld	_dyld_start
7	0x20ea00	GeneralBlock-32	00:00.411	32	libGLProgrammabi...	std::Rb_tree<long, std::pair<long, long>, std::less<long>, std::allocator<std::pair<long, long>>::iterator
8	0x20ea20	GeneralBlock-32	00:00.411	32	libGLProgrammabi...	std::Rb_tree<long, std::pair<long, long>, std::less<long>, std::allocator<std::pair<long, long>>::iterator
9	0x20ea40	GeneralBlock-32	00:00.411	32	libGLProgrammabi...	std::Rb_tree<long, std::pair<long, long>, std::less<long>, std::allocator<std::pair<long, long>>::iterator
10	0x20ea60	GeneralBlock-32	00:00.411	32	libGLProgrammabi...	std::Rb_tree<long, std::pair<long, long>, std::less<long>, std::allocator<std::pair<long, long>>::iterator
11	0x220ea0	GeneralBlock-32	00:00.480	32	AppKit	+[NSApplication initialize]
12	0xfa20ea0	CFArray (store-deque)	00:41.057	144	Foundation	-[NSCFArray insertObject:atIndex:]
13	0xfa20ea0	CFArray (store-deque)	00:41.057	80	Foundation	-[NSCFArray insertObject:atIndex:]
14	0xfa20ea0	CFString	00:41.057	32	Foundation	-[NSCFString substringWithRange:]
15	0xfa20ea0	CFDictionary (key-st...)	00:48.667	16	SystemConfiguration	SCDynamicStoreCopyValue
16	0xfa20ea0	CFDictionary (key-st...)	00:48.667	16	SystemConfiguration	SCDynamicStoreCopyProxies

Viewing Data for a Range of Time

Although zooming in on a particular event in the track pane lets you see what happened at a specific time, you may also be interested in seeing the data collected over a range of time. You use the Inspection Range control (shown in Figure 5-7) to focus on the data collected in a specific time range.

Figure 5-7 Inspection Range control



To mark a time range for inspection, do the following:

1. Set the start of the range.
 - a. Drag the playhead to the desired starting point in the track pane.
 - b. Click the leftmost button in the Inspection Range control.

2. Set the end of the range.
 - a. Drag the playhead to the desired endpoint in the track pane.
 - b. Click the rightmost button in the Inspection Range control.

Instruments highlights the contents of the track pane that fall within the range that you specified. When you set the starting point for a range, Instruments automatically selects everything from the starting point to the end of the current trace run. If you set the endpoint first, Instruments selects everything from the beginning of the trace run to the specified endpoint.

You can also set an inspection range by holding the Option key and clicking and dragging in the track pane of the desired instrument. Clicking and dragging makes the instrument under the mouse the active instrument (if it is not already) and sets the range using the mouse-down and mouse-up points.

When you set a time range, Instruments filters the contents of the Detail pane, showing data collected only within the specified range. You can quickly narrow down the large amount of information collected by Instruments and see only the events that occurred over a certain period of time.

To clear an inspection range, click the button in the center of the Inspection Range control.

The Extended Detail Pane

For some instruments, the Extended Detail pane shows additional information about the item currently selected in the Detail pane. To open or close the Extended Detail pane, do one of the following:

- Choose View > Extended Detail.

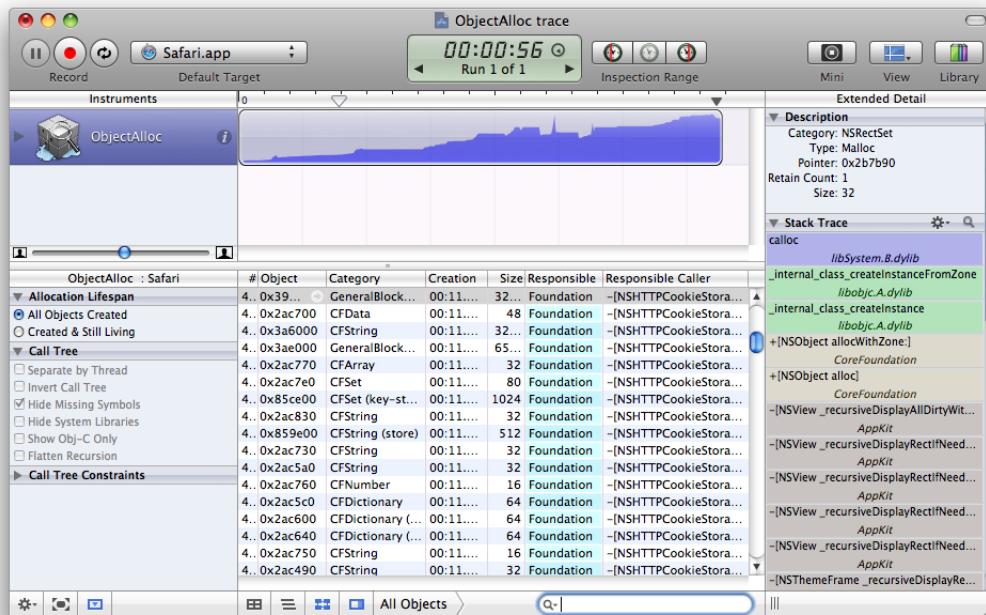
Viewing and Analyzing Trace Data

- Click the Toggle Extended Detail Pane button at the bottom of the Instruments window, next to the navigation bar.
- Click the View button and choose Extended Detail from the pull-down menu.
- Select Extended Detail from the action menu at the bottom of the Instruments window.

The Extended Detail pane usually includes a description of the probe or event that was recorded, a stack trace, and the time when the information was recorded. Not all instruments display this information, however. Some instruments may not provide any extended details, and others may provide other information in this pane. For information about what a particular instrument displays in this pane, see the instrument descriptions in “[Built-in Instruments](#)” (page 75).

Figure 5-8 shows the Extended Detail pane for the ObjectAlloc instrument. In this example, the instrument displays information about the type of memory that was allocated, including its type, pointer information, and size.

Figure 5-8 Extended Detail pane



For instruments that display stack trace information in the Extended Detail pane, double-clicking an entry for which you have source code opens the source file in Xcode. You can also configure the information shown in the stack trace using the Action menu at the top of that section. Clicking and holding the Action menu icon displays a menu from which you can enable or disable the options in Table 5-1.

Table 5-1 Action menu options

Para	Para
Invert Stack	Toggles the order in which calls are listed in the stack trace.

Para	Para
Color by Library	Highlights each symbol according to the library to which it belongs.
Source Location	Displays the source file that defines each symbol whose source you own.
Library Name	Displays the name of the library containing each symbol.
Frame #	Displays the number associated with each frame in the stack trace.
File Icon	Displays an icon representing the file in which each symbol is defined.
Trace Call Duration	Creates a new Instruments instrument that traces the selected symbol and places that instrument in the Instruments pane.
Look up API Documentation	Opens the Xcode Documentation window and brings up documentation, if available, for the selected symbol.
Copy Selected Frames	Copies the stack trace information for the selected frames to the pasteboard so that you can paste it into other applications.

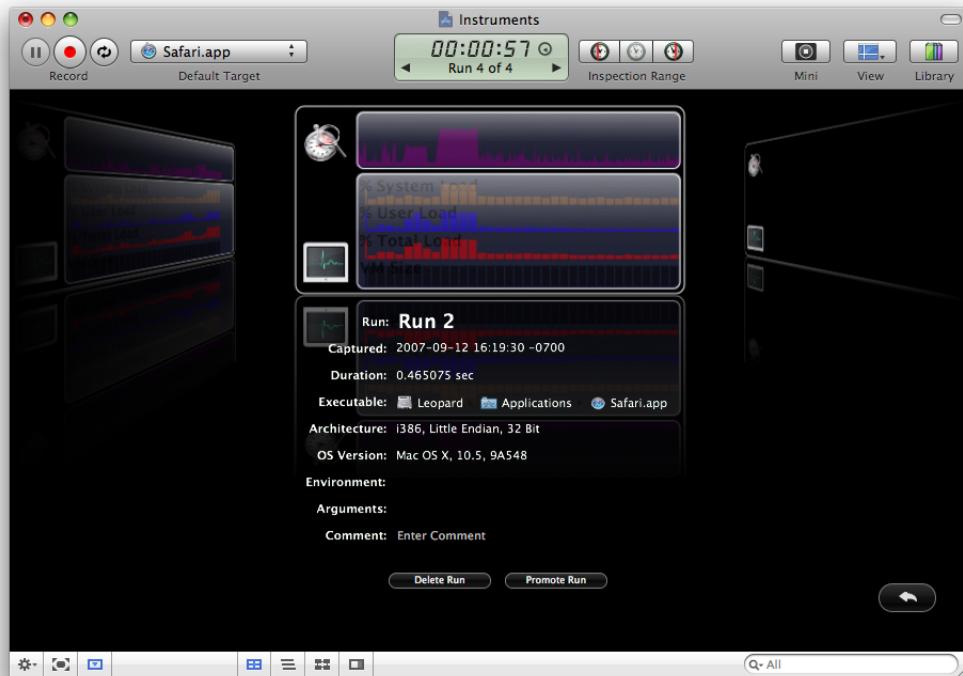
In addition, if you have an Xcode project with the source code for the symbols listed in a stack trace, you can double-click a symbol name in the Extended Detail pane to launch Xcode and jump to the relevant source code.

The Run Browser

The Run Browser is a way to view and manage previous runs quickly. If your trace document contains numerous runs, you can use this mode to scan those runs for the one you want and promote it to the top of the list. You can also delete runs and add comments to runs from this view.

To open the Run Browser, select View > Run Browser.

“The Run Browser” shows the Run Browser view in Instruments. Clicking views on either side of the selected view scrolls the new view into focus. To enter a comment for a view, double click the text in the Comment field to make it editable. To exit the Run Browser view, click the return arrow button in the bottom-right portion of the window.

Figure 5-9 The Run Browser

Analysis Techniques

Gathering and viewing trace data is easy. Analyzing that data and locating potential problems is hard. It is this latter task where the art of performance tuning and debugging comes into play. Recognizing patterns in the massive amounts of data gathered by performance tools can be daunting, even for experienced developers. This is where having the right tools (and knowing how to use them) makes all the difference. The instruments that come with the Instruments application provide many different options for organizing and filtering trace data. The following sections describe some of the behaviors and options available for specific instruments and how you use those instruments to identify issues in your code.

Analyzing Data with the Sampler Instrument

The Sampler instrument is a tool for performing a statistical analysis on a running application. Performing a statistical analysis involves stopping an application at regular intervals and recording information about what was executing at that moment in time. For each thread, the Sampler instrument records information about the functions and methods currently on the stack, including the name of the function or method and the module that owns it. After gathering the data, it coalesces the call stack information from the individual samples to form a master call tree for the application. This tree shows all of the execution paths that were seen during sampling and how many times each one was seen.

The advantage of statistical sampling is that it is a lightweight and convenient way to find out what your application is doing over a period of time. The technique can be used on any application without specially instrumenting the code, and it usually offers a reasonably accurate picture of your application's runtime behavior.

The disadvantage of statistical sampling, however, is that it does not give you a 100% accurate picture of what your application is doing. Because it only takes snapshots of the call stack at periodic intervals, the Sampler instrument does not record an exact history of all of the functions and methods that were executed. With typical sampling intervals on the order of 1 to 10 milliseconds, it is possible for a lot of functions and methods to be called between samples. Despite this seemingly inaccurate picture, statistical sampling does work for most applications when enough samples are gathered. Over time, the distortions caused by the sampling interval tend to smooth out as more samples are gathered. As a result, statistical sampling is still a good way to gather information about your application quickly and without too much effort.

Note: The Sampler instrument replaces the Sampler application, which is not available in Mac OS X v10.5 and later.

Analyzing the Call Stack Data

The purpose of the Sampler instrument is to show you where your application is spending its time. It does this by showing you which functions were called and how often they were called.

The place to start in the Sampler tool is the Track pane. By default, the track pane graphs the maximum call stack depth for all the threads of the application. (You can also change this graph to show the CPU load instead.) Because it offers a visual approach, the Track pane can help you spot trends in your code. Repeated patterns can indicate similar code paths being executed. The shape of different sections can also give some indication as to what they were doing. By clicking in an interesting area, you can then begin analyzing the data at that area using the Detail pane.

The Detail pane is where you do a more in-depth analysis of your code. The Detail pane supports both the Table and Outline viewing modes. Table mode presents you with the time-ordered list of samples. You can use this list to see what code was executing at a given point in your application. In Outline mode, you are presented with the sample data organized by call stack. From this view, you can look at each execution branch of each thread and see which ones have unusually large numbers of samples. Expanding each thread lets you see the individual methods and functions and the number of samples gathered for each one. To expand an entire hierarchy all at once, hold down the Option key while clicking the disclosure triangle.

In addition to starting at a thread's main routine and searching for heavy branches, you can also invert the call tree to start at the leaf nodes and see which methods and functions were called most often. Inverting the call tree can help quickly identify methods and functions that are perhaps being used too frequently. You can then expand the tree from these leaf nodes to find out who called that method or function and how often. While doing this, it is often helpful to display the number of milliseconds the given method or function spent running so that you can correlate the number of samples with the actual amount of time that function used.

Note: Although the Sampler instrument reports the amount of time spent in a given branch, these times are only approximations. You can use these values to determine roughly where your application spent its time but should not use them as performance metrics to determine how fast your code is.

The Extended Detail pane provides you with additional views of the sample data. In Table mode, the pane displays the data gathered by the selected sample, which includes the stack traces for all threads running when the sample was taken. In Outline mode, it shows the deepest stack trace containing the selected method or function.

Filtering the Contents of the Detail Pane

Table 5-2 lists the high-level configuration options you can apply to samples gathered with the Sampler instrument. You use these options to focus your analysis on the events that occurred at a particular time or that involve a particular portion of your code.

Table 5-2 Configuration options for the Sampler instrument

Configuration section	Description
Sample Perspective	Choose between displaying all samples that were captured or only those that were captured while the specified thread (or threads) were running. Viewing all samples can give you a complete picture of the behavior of a thread over a period of time, including how much time was spent blocked or waiting for data. Viewing only the running samples provides an approximate picture of how much time was spent actually executing your code. (The actual running time may differ somewhat from the time reported by Instruments so you should use the reported values only as a rough guide.)
Call Tree	Choose these options to flatten or hide uninteresting parts of the call tree. You can separate out symbols that were gathered from different threads of execution, hide missing symbols or libraries, flatten branches of the call tree that contain recursive calls, and more. These options help you trim irrelevant portions of the call tree and organize the remaining data in ways that make it easier to spot trends.
Call Tree Constraints	Choose the constraints for the data you want to view. You can use these configuration fields to prune the current data set. The Sampler instrument supports constraining data based on the number of samples gathered in a branch or the number of milliseconds spent executing a branch.
Active Thread	Choose the thread you want to analyze. Focusing on a specific thread displays only the samples for that thread, making it easier to see what the thread was doing. Viewing all threads lets you see all of the work being performed by your application.

The Call Tree configuration options offer several ways to trim down the call tree without removing any sample data. When you hide or flatten a set of symbols, Sampler applies the samples for those symbols to the calling function or method. This lets you remove any symbols that you cannot control and focus on your own code and how much time it took to execute.

Alternatively, the Call Tree Constraints actually remove sets of samples from the view to let you focus on code paths that meet specific criteria. For example, you might use a time-based constraint to focus on code paths that took at least 100 milliseconds to run.

When applying an instrument's configuration options, do not forget that you can also constrain the sample data based on when those samples were gathered. The Inspection Range control in each trace document lets you view the data from a specific set of sample points. This feature works in combination with all of the instrument's other configuration options. For more information on how to use the Inspection Range control, see "Viewing Data for a Range of Time" (page 50).

Analyzing Data with the ObjectAlloc Instrument

The ObjectAlloc instrument is a tool for tracking all of the memory allocations made by an application. You can then use that information to identify memory allocation patterns in your application and identify places where your application is using memory inefficiently. The ObjectAlloc instrument provides data trimming and pruning facilities that are equal to or better than the former ObjectAlloc application. Because it is integrated with the Instruments environment, you can also use the instrument to correlate your application's memory behavior with other types of behavior.

Because it tracks memory allocations over the life of an application, you must launch your application from Instruments so that the ObjectAlloc instrument can gather the data it needs. At launch time, the ObjectAlloc instrument uses existing hooks in the system to record information about allocation and deallocation events in your application, whether those events originated with the standard system malloc routines or your own custom malloc library. As data flows in, the instrument updates its displays in real time to show you how memory is being allocated.

The ObjectAlloc instrument works with applications that use the standard malloc functions (such as `malloc`, `calloc`, and `free`) but also works with garbage collected applications. In the latter case, the collector still issues `free` calls for GC-aware memory. The ObjectAlloc instrument also works with routines built on top of malloc, including the memory allocation routines in both Core Foundation and Cocoa.

Note: The ObjectAlloc instrument replaces the ObjectAlloc application, which is not available in Mac OS X v10.5 and later.

Analyzing the Object Allocation Data

The purpose of the ObjectAlloc instrument is to show you how your application is using memory. Memory is an important system resource that you should use wisely. Each memory allocation has both an immediate cost and a potential long-term cost. The immediate cost is the time it takes to allocate the memory, which could involve creating new virtual memory pages and mapping them into physical memory. It could also involve writing out stale memory pages to disk. Long term, keeping blocks resident in physical memory can trigger additional paging in the system, which as with all paging operations can seriously hamper performance.

Like all tools, the place to start in the ObjectAlloc tool is the Track pane. In its default configuration, the Track pane graphs the net amount of memory currently in use by your application. Using the instrument's inspector, you can change this view to show the allocation density, which shows you where the memory allocations occurred, or you can display the stack depth. The allocation density graph lets you see how frequently memory allocations occurred throughout your program. Spikes in the allocation density can indicate potential bottlenecks that you might want to mitigate by preallocating some blocks or being more lazy about other blocks.

Regardless of which display options you set using the inspector, the Track pane displays the allocations for all types of objects by default. To focus on a specific subset of memory allocations, you can use the Detail pane to configure which objects you want to include in the Track pane's graph. To focus on a particular object type or block size, open the Detail pane and set it to Table mode. In this mode, the Detail pane sorts

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memory allocations by object type or size. The Graph column contains checkboxes for selecting which objects you want to graph. Disabling the All Allocations checkbox (which is enabled by default) and enabling the checkbox for another object type updates the Track pane accordingly. If you enable multiple checkboxes, the ObjectAlloc instrument layers the graphs on top of each other using different colors.

The Detail pane (while it is in Table mode) displays other useful information to help you spot potential allocation issues. The net versus overall allocations column of the table shows a histogram of the currently active objects and the total number that were ever created. As the ratio of net allocations to overall allocations shrinks, the color of the histogram bar changes. Blue histogram bars represent a reasonable ratio while colors shifted towards the red spectrum represent lower ratios that might warrant some investigation.

Although Table mode is very useful for getting an overall picture of your allocations, the Detail pane takes advantage of all three viewing modes. Table 5-3 describes the information presented in each mode and how you might use that mode to look for problems.

Table 5-3 Analyzing data in the Detail pane

Mode	Description
Table	Use this mode to see the summary of net versus overall allocations and to choose which objects you want to graph in the Track pane. Allocations in this mode are grouped by size or object type initially. Clicking the follow link button next to an object type takes you a level deeper by showing you the individual allocation events for that object. Clicking the follow link button again shows you the history of events that occurred at the same memory address.
Outline	Use this mode to see the call trees associated with allocated objects. Clicking the follow link button next to an object type focuses on the call trees associated solely with that object type.
Diagram	Use this mode to see all objects in the order in which they were allocated. Clicking the follow link button next to the object address shows the allocation events associated with that memory address.

The Extended Detail pane for the ObjectAlloc instrument primarily displays stack trace information for the selected allocation event. For some allocation events, this pane also displays descriptive information about the event, including the type and size of the event and the object retain count (if any). This information is there to help you locate the allocation event in your code.

Tracking Reference Counting Events

When you add the ObjectAlloc instrument to your document, the instrument is initially configured to record only memory allocation and deallocation events. By default, it does not record reference counting events, such as `CFRetain` and `CFRelease` calls. The reason is that recording reference counting events adds significant overhead to the data gathering process and is not needed in all situations. If your code is leaking memory, however, you might want to configure the ObjectAlloc instrument to record these events as part of your effort to track down the leaks. In particular, you can look for any mismatched retain and release events to see if an object is still retained when the last reference to it is removed.

To enable the gathering of reference counting events, open the inspector for the ObjectAlloc instrument and enable the “Record reference counts” option.

Note: The ObjectAlloc instrument found in the Leaks template document comes preconfigured with the “Record reference counts” option already enabled to help you track down memory leaks.

Filtering the Contents of the Detail Pane

Table 5-4 lists the high-level configuration options you can apply to memory events recorded by the ObjectAlloc instrument. You use these options to focus your analysis on the events that occurred at a particular time or that involve a particular portion of your code. All of these options apply only when viewing data in Outline and Diagram modes. In Table mode, the ObjectAlloc instrument displays the history of all allocations.

Table 5-4 Configuration options for the ObjectAlloc instrument

Configuration section	Description
Allocation Lifespan	Choose between displaying all allocation events and those associated with objects that still exist.
Call Tree	Choose these options to flatten or hide uninteresting parts of the call tree. You can separate out memory blocks based on which thread allocated them, hide allocations made by system libraries, show allocations made from Objective-C calls only, and more. These options help you trim irrelevant portions of the call tree and organize the remaining data in ways that make it easier to spot trends.
Call Tree Constraints	Choose the constraints for the data you want to view. You can use these configuration fields to prune the current data set. The ObjectAlloc instrument supports constraining data based on the number of allocations made for a given type or the size (in bytes) of the allocations.

When applying an instrument’s configuration options, do not forget that you can also constrain the sample data based on when those samples were gathered. The Inspection Range control in each trace document lets you view the data from a specific set of sample points. This feature works in combination with all of the instrument’s other configuration options. For more information on how to use the Inspection Range control, see [“Viewing Data for a Range of Time”](#) (page 50).

Looking for Memory Leaks

The Leaks instrument provides leak-detection capabilities identical to those in the `Leaks` command-line tool. This instrument analyzes the in-use memory blocks of your application looking for blocks that are no longer referenced by your code. Unreferenced blocks are deemed “leaks” because they cannot be freed by your application and continue to occupy memory space until the user quits the application.

Eliminating memory leaks from your application is an important step toward improving your application’s reliability. This is especially true for applications that are designed to run for long periods of time. Leaks increase your application’s overall memory footprint, which can lead to paging. Applications that continue to leak memory may even find themselves unable to complete an operation because they cannot allocate the necessary memory. In extreme cases, the application may become so impaired that it crashes.

The Leaks instrument records all allocation events that occur in your application and then periodically searches the application's writable memory, registers, and stack for references to any active memory blocks. If it does not find a reference to a block in one of these places, it reports the buffer as a leak and displays the relevant information in the Detail pane.

In the Detail pane, you can view leaked memory blocks using Table and Outline modes. In Table mode, Instruments displays the complete list of leaked blocks, sorted by size. Clicking the follow link button next to a memory address shows the allocation history for memory blocks at that address, ultimately culminating in an allocation event without a matching free event. Selecting one of these allocation events displays the stack trace for that event in the Extended Detail pane along with general information about the memory block. In Outline mode, the Leaks instrument displays leaks organized by call tree. You can use this mode to find out how many leaks are in a specific branch of your code and how much memory was leaked by that branch. Selecting a branch displays the deepest code path for that branch in the Extended Detail pane.

Table 5-5 lists the configuration options for the Leaks instrument. Many of these options affect how leaks looks for information, but some affect how leaked buffers are reported.

Table 5-5 Configuration options for the Leaks instrument

Configuration option	Description
Leaks Configuration	Use the available option to enable automatic leak detection and to gather the contents of leaked memory blocks when a leak occurs.
Sampling Options	Use the specified field to set the frequency of automatic leak-detection checks.
Leaks Status	Displays the time until the next automatic leak-detection pass.
Check Manually	Use the provided button to initiate a check for memory leaks.
Call Tree	Choose these options to flatten or hide uninteresting parts of the call tree. You can hide allocations made by system libraries, show allocations made from Objective-C calls only, and more. These options help you manage the size of the call tree and organize it in ways that make it easier to spot trends.

For information about the `leaks` command-line tool, see `leaks` man page.

Analyzing Core Data Applications

For applications that use Core Data to manage their underlying data model, Instruments provides several Core Data-related instruments to analyze potential performance issues. These instruments give you insight into the events happening behind the scenes in Core Data and may help you identify places where your application is not fetching or saving data efficiently. Table 5-6 lists the provided instruments and how you might use each one.

Table 5-6 Core Data instrument usage

Instrument	Description
Core Data Saves	Use this instrument to find a balance between saving data too often and not saving it enough. Saving too often can lead to I/O overhead as your program writes data frequently to the disk. Conversely, saving infrequently can increase the application's memory overhead and lead to paging.
Core Data Fetches	Use this instrument to optimize the data your application reads from disk. Fetch operations that take a long time might be improved by adding more specific predicates to retrieve only the data needed at that moment. Alternatively, if you notice gaps of inactivity followed by a large number of fetch requests, you might want to use those gaps to prefetch data that you know will be needed later.
Core Data Faulting	Use this instrument to track the lazy initialization of an <code>NSManagedObject</code> or its to-many relationship. Object faults can be mitigated by prefetching the object itself or the objects to which it is related.
Core Data Cache Misses	Use this instrument to locate potential performance issues caused by cache misses. Data not found in the caches must be fetched from the disk. Prefetching objects during relatively quiet periods can help mitigate cache misses by ensuring the required objects are already in memory.

The Core Data template creates a new trace document containing the Core Data Fetches, Core Data Cache Misses, and Core Data Saves instruments. This template is the recommended starting point for analyzing your Core Data applications.

For more information about tuning a Core Data application, see *Core Data Programming Guide*.

Saving and Importing Trace Data

Instruments provides a number of ways for you to save instrument and trace data. For a given Instruments document window, you can save the trace data you've recorded with that document or you can save the instrument configuration of that document. Saving the trace data lets you maintain a record of your application's performance over time. Saving the document configuration avoids the need to recreate a commonly used configuration each time you run Instruments.

The following sections explain how to save your trace documents and also how to export trace data to formats that other applications can read.

Saving a Trace Document

To save a set of instruments together with the data that they have collected over one or more trace sessions, choose File > Save. Instruments saves the current document as an Instruments trace file, with the .trace extension.

By default, Instruments saves only the trace data collected on the most recent run. If you have recorded multiple runs and want Instruments to save all of that data, you must deselect the Save Current Run Only option in the General pane of Instruments Preferences before saving the document.

Saving an Instruments Trace Template

During your development cycle, you may want to gather data at several points by running Instruments on your application using a fixed set of instruments. Rather than reconfigure the same set of instruments in your trace document each time you run Instruments, you can configure the trace document once and save it as a trace template. Choose File > Save As Template to save your document's current instruments and configuration (including any user interface tracks) as a template.

Trace template documents are not the same as the Instruments templates that appear when you create a new document. You open a trace template in the same way that you open other Instruments documents, by choosing File > Open. When you open a trace template, Instruments creates a new trace document with the template configuration but without any data.

Xcode supports launching your applications using your custom trace templates. To add your trace template to the Run menu in Xcode, drop the template in the /Users/<username>/Library/Application Support/Instruments/Templates directory on your local system. To open it, choose it from the Run > Start with Performance Tool menu.

Exporting Track Data

Instruments lets you export trace data to a comma-separated value (CSV) file format. This simple data file format is supported by many applications. For example, you might save your trace data in this format so that you can import it into a spreadsheet application.

To save your trace data to a CSV file, select the instrument whose data you want to export and choose **Instrument > Export Data for: <Instrument Name>**. Instruments exports the data for the most recent run of that instrument.

Note: Not all instruments support exporting to the CSV file format.

Importing Data from the Sample Tool

If you use the `sample` command-line tool to do a statistical analysis of your program's execution, you can import your sample data and view it using Instruments. Importing data from the `sample` tool creates a new trace document with the Sampler instrument and loads the sample data into the Detail pane. Because the samples do not contain time stamp information, you can only view the data using Outline mode in the Detail pane. And although you can use the Call Tree configuration options of the Sampler instrument to trim the sample data, you cannot prune data using the Call Tree Constraints or Inspection Range controls.

To import data, choose **File > Import Data**. Instruments prompts you to select the text file containing the sample data. It then creates a new trace document based on the file you select.

Working With DTrace Data

If your trace document contains custom instruments, you can export the underlying scripts for those instruments and run them using the `dtrace` command-line tool. After running the scripts, you can then reimport the resulting data back into Instruments. For information on how to do this, see ["Exporting DTrace Scripts"](#) (page 73).

Creating Custom Instruments with DTrace

The built-in instruments of the Instruments application can provide a great deal of information about the inner workings of your program. Sometimes, though, you may want to tailor the information being gathered more closely to your own code. For example, instead of gathering data every time a function is called, you might want to set conditions on when data is gathered. Alternatively, you might want to dig deeper into your own code than the built-in instruments allow. For these situations, Instruments lets you create custom instruments.

Custom instruments use DTrace for their implementation. DTrace is a dynamic tracing facility originally created by Sun and ported to Mac OS X v10.5. Because DTrace taps into the operating system kernel, you have access to low-level operation about the kernel itself and about the user processes running on your computer. Many of the built-in instruments are already based on DTrace. And even though DTrace is itself a very powerful and complex tool, Instruments provides a simple interface that gives you access to the power of DTrace without the complexity.

Important: Although the custom instrument builder simplifies the process of creating DTrace probes, you should still be familiar with DTrace and how it works before creating new instruments. Many of the more powerful debugging and data gathering actions require you to write DTrace scripts. To learn about DTrace and the D scripting language, see the *Solaris Dynamic Tracing Guide*, available from the [OpenSolaris website](#). For information about the `dtrace` command-line tool, see `dtrace` man page.

Note: Several Apple applications—namely iTunes, DVD Player, and Front Row, and applications that use QuickTime—prevent the collection of data through DTrace (either temporarily or permanently) in order to protect sensitive data. Therefore, you should not run those applications when performing systemwide data collection.

The following sections show you how to create a custom instrument and how to use that instrument both with the Instruments application and the `dtrace` command-line tool.

About Custom Instruments

Custom instruments are built using DTrace probes. A **probe** is like a sensor that you place in your code. It corresponds to a location or event, such as a function entry point, to which DTrace can bind. When the function executes or the event is generated, the associated probe fires and DTrace runs whatever **actions** are associated with the probe. Most DTrace actions simply collect data about the operating system and user program behavior at that moment. It is possible, however, to run custom scripts as part of an action. Scripts let you use the features of DTrace to fine tune the data you gather.

Probes fire each time they are encountered, but the action associated with the probe need not be run every time the probe fires. A **predicate** is a conditional statement that lets you restrict when the probe's action is run. For example, you can restrict a probe to a specific process or user, or you can run the action when a

specific condition in your instrument is true. By default, probes do not have any predicates, meaning that the associated action runs every time the probe fires. You can add any number of predicates to a probe, however, and link them together using AND and OR operators to create complex decision trees.

An instrument consists of the following blocks:

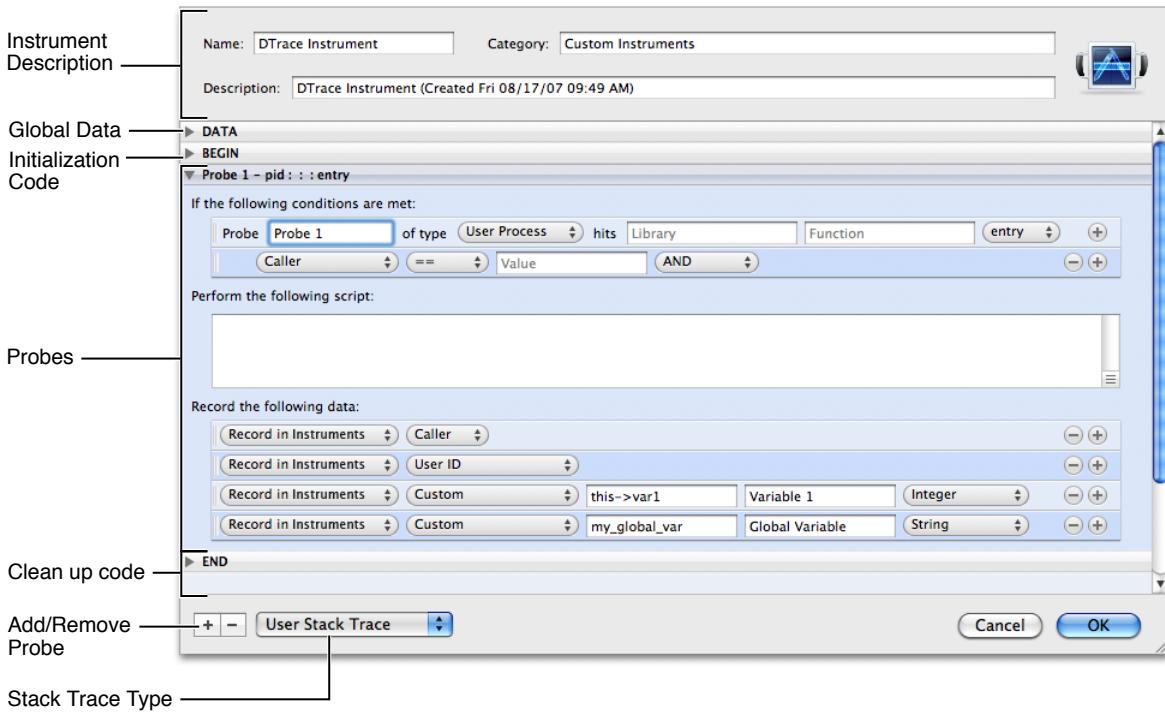
- A description block, which contains the name, category, and description of the instrument
- One or more probes, each containing its associated actions and predicates
- A DATA declaration area, which you use to declare global variables shared by all probes
- A BEGIN script, which initializes any global variables and performs any startup tasks required by the instrument
- An END script, which performs any final clean up actions

All instruments must have at least one probe with its associated actions. Similarly, all instruments should have an appropriate name and description to identify them to Instruments users. Instruments displays your instrument's descriptive information in the library window. Providing good information makes it easier to remember what the instrument does and how it should be used.

Probes are not required to have global data or begin and end scripts. Those elements are used in advanced instrument design when you want to share data among probes or provide some sort of initial configuration for your instrument. The creation of DATA, BEGIN, and END blocks is described in [“Tips for Writing Custom Scripts”](#) (page 71).

Creating a Custom Instrument

To create a custom DTrace instrument, select Instrument > Build New Instrument. (You can also choose Add Instrument > DTrace Instrument from the action menu of your trace document to perform the same action.) This command displays the instrument configuration sheet, which is shown in Figure 7-1. You use this sheet to specify your instrument information, including any probes and custom scripts.

Figure 7-1 The instrument configuration sheet

At a minimum, you should provide the following information for every instrument you create:

- **Name.** The name associated with your custom instrument in the library.
- **Category.** The category in which your instrument appears in the library. You can specify the name of an existing category—such as Memory—or create your own.
- **Description.** The instrument description and is used in both the library window and in the instrument’s help tag.
- **Probe provider.** The probe type and the details of when it should fire. Typically, this involves specifying the method or function to which the probe applies. For more information, see “[Specifying the Probe Provider](#)” (page 66)
- **Probe action.** The data to record or the script to execute when your probe fires; see “[Adding Actions to a Probe](#)” (page 70).

An instrument should contain at least one probe and may contain more than one. The probe definition consists of the provider information, predicate information, and action. All probes must specify the provider information at a minimum, and nearly all probes define some sort of action. The predicate portion of a probe definition is optional but can be a very useful tool for focusing your instrument on the correct data.

Adding and Deleting Probes

Every new instrument comes with one probe that you can configure. To add more probes, click the plus (+) button at the bottom of the instrument configuration sheet.

To remove a probe from your instrument, click the probe to select it and press the minus (-) button.

When adding probes, it is a good idea to provide a descriptive name for the probe. By default, Instruments enumerates probes with names like “Probe 1” and “Probe 2”.

Specifying the Probe Provider

To specify the location point or event that triggers a probe, you must associate the appropriate provider with the probe. **Providers** are kernel modules that act as agents for DTrace, providing the instrumentation necessary to create probes. You do not need to know how providers operate to create an instrument, but you do need to know the basic capabilities of each provider. Table 7-1 lists the providers that are supported by the Instruments application and available for use in your custom instruments. The Provider column lists the name displayed in the instrument configuration sheet while the DTrace provider column lists the actual name of the provider used in the corresponding DTrace script.

Table 7-1 DTrace providers

Provider	DTrace provider	Description
User Process	pid	The probe fires on entry (or return) of the specified function in your code. You must provide the function name and the name of the library that contains it.
Objective-C	objc	The probe fires on entry (or return) of the specified Objective-C method. You must provide the method name and the class to which it belongs.
System Call	syscall	The probe fires on entry (or return) of the specified system library function.
DTrace	DTrace	The probe fires when DTrace itself enters a BEGIN, END, or ERROR block.
Kernel Function Boundaries	fbt	The probe fires on entry (or return) of the specified kernel function in your code. You must provide the kernel function name and the name of the library that contains it.
Mach	mach_trap	The probe fires on entry (or return) of the specified Mach library function.
Profile	profile	The probe fires regularly at the specified time interval on each core of the machine. Profile probes can fire with a granularity that ranges from microseconds to days.
Tick	tick	The probe fires at periodic intervals on one core of the machine. Tick probes can fire with a granularity that ranges from microseconds to days. You might use this provider to perform periodic tasks that are not required to be on a particular core.
I/O	io	The probe fires at the start of the specified kernel routine. For a list of functions monitored by this probe, use the <code>dtrace -l</code> command from Terminal to get a list of probe points. You can then search this list for probes monitored by the <code>io</code> module.

Provider	DTrace provider	Description
Kernel Process	proc	The probe fires on the initiation of one of several kernel-level routines. For a list of functions monitored by this probe, use the <code>dtrace -l</code> command from Terminal to get a list of probe points. You can then search this list for functions monitored by the <code>proc</code> module.
User-Level Synchronization	plockstat	The probe fires at one of several synchronization points. You can use this provider to monitor mutex and read-write lock events.
Core Data	CoreData	The probe fires at one of several Core Data-specific events. For a list of methods monitored by this probe, use the <code>dtrace -l</code> command from Terminal to get a list of probe points. You can then search this list for methods monitored by the <code>CoreData</code> module.
Ruby	ruby	The probe fires at one of several Ruby-specific events.

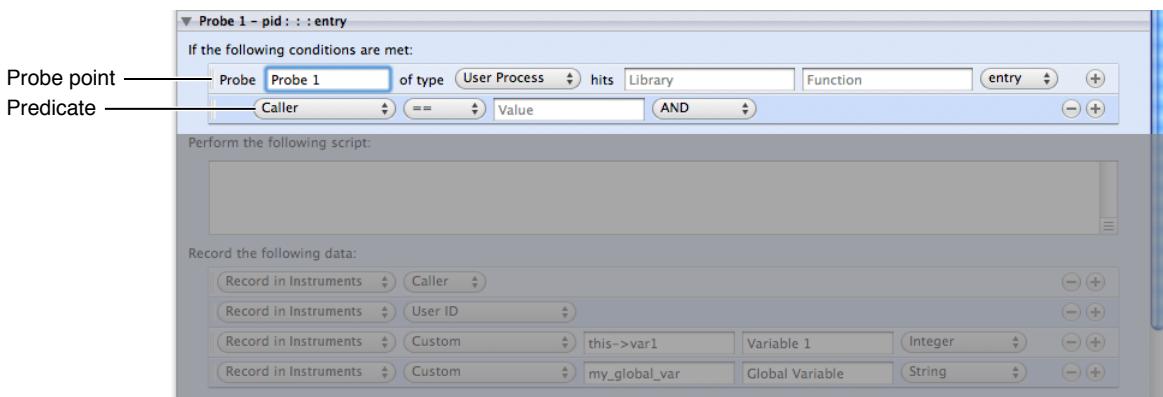
After selecting the provider for your probe, you need to specify the information needed by the probe. For function-level probes, this may require entering function or method name along with the code module or class containing it. Some providers may simply involve selecting the appropriate events from a pop-up menu.

After you have configured a probe, you can proceed to add additional predicates to it (to determine when it should fire) or you can go ahead and define the action for that probe.

Adding Predicates to a Probe

Predicates let you control when a probe's action is executed by Instruments. You can use them to prevent Instruments from gathering data in situations you do not care about or that might provide erroneous information. For example, if your code exhibits unusual behavior only when the stack reaches a certain depth, you could use a predicate to specify the minimum target stack depth. Every time a probe fires, Instruments evaluates the associated predicates. Only if they evaluate to true does DTrace perform the associated actions.

To add a predicate to a probe, click the plus (+) button at the end of the Probe line. Instruments adds a new predicate to the probe, as shown in Figure 7-2. You can add subsequent predicates using the plus (+) buttons of either the probe or the predicate. To remove a predicate, click the minus (-) button next to the predicate. To rearrange predicates, click the handle along the left side of the predicate line and drag it to a new location.

Figure 7-2 Adding a predicate

Instruments evaluates predicates from top to bottom in the order they appear. You can link predicates using the AND and OR operators but you cannot group them to create nested condition blocks. Instead, you must order your predicates carefully to ensure all of the appropriate conditions are checked.

The first pop-up menu in a predicate line lets you choose the data to inspect as part of the condition. Table 7-2 lists the standard variables defined by DTrace that you can use in your predicates or script code. The Variable column lists the name as it appears in the instrument configuration panel, while the DTrace variable column lists the actual name of the variable used in corresponding DTrace scripts. In addition to the standard variables, you can test against custom variables and constants from your script code by specifying the Custom variable type in the predicate field.

Table 7-2 DTrace variables

Variable	DTrace variable	Description
Caller	caller	The value of the current thread's program counter just before entering the probe. This variable contains an integer value.
Chip	chip	The identifier for the physical chip executing the probe. This is a 0-based integer indicating the index of the current core. For example, a four core machine has cores 0 through 3.
CPU	cpu	The identifier for the CPU executing the probe. This is a 0-based integer indicating the index of the current core. For example, a four core machine has cores 0 through 3.
Current Working Directory	cwd	The current working directory of the current process. This variable contains a string value.
Last Error #	errno	The error value returned by the last system call made on the current thread. This variable contains an integer value.
Executable	execname	The name that was passed to exec to execute the current process. This variable contains a string value.
User ID	uid	The real user ID of the current process. This variable contains an integer value.

Variable	DTrace variable	Description
Group ID	gid	The real group ID of the current process. This variable contains an integer value.
Process ID	pid	The process ID of the current process. This variable contains an integer value.
Parent ID	ppid	The process ID of the parent process. This variable contains an integer value.
Thread ID	tid	The thread ID of the current thread. This is the same value returned by the <code>pthread_self</code> function.
Interrupt Priority Level	ipl	The interrupt priority level on the current CPU at the time the probe fired. This variable contains an unsigned integer value.
Function	probefunc	The function name part of the probe's description. This variable contains a string value.
Module	probemod	The module name part of the probe's description. This variable contains a string value.
Name	probename	The name portion of the probe's description. This variable contains a string value.
Provider	probeprov	The provider name part of the probe's description. This variable contains a string value.
Root Directory	root	The root directory of the process. This variable contains a string value.
Stack Depth	stackdepth	The stack frame depth of the current thread at the time the thread fired. This variable contains an unsigned integer value.
Relative Timestamp	timestamp	The current value of the system's timestamp counter, measured in nanoseconds. Because this counter increments from an arbitrary point in the past, you should use it to calculate only relative time differences. This variable contains an unsigned 64-bit integer value.
Virtual Timestamp	vtimestamp	The amount of time the current thread has been running, measured in nanoseconds. This value does not include time spent in DTrace predicates and actions. This variable contains an unsigned 64-bit integer value.
Timestamp	walltimestamp/1000	The current number of nanoseconds that have elapsed since 00:00 Universal coordinated Time, January 1, 1970. This variable contains an unsigned 64-bit integer value.
arg0 through arg9	arg0 through arg9	The first 10 arguments to the probe represented as raw 64-bit integers. If fewer than ten arguments were passed to the probe, the remaining variables contain the value 0.

Variable	DTrace variable	Description
Custom	The name of your variable	Use this option to specify a variable or constant from one of your scripts.

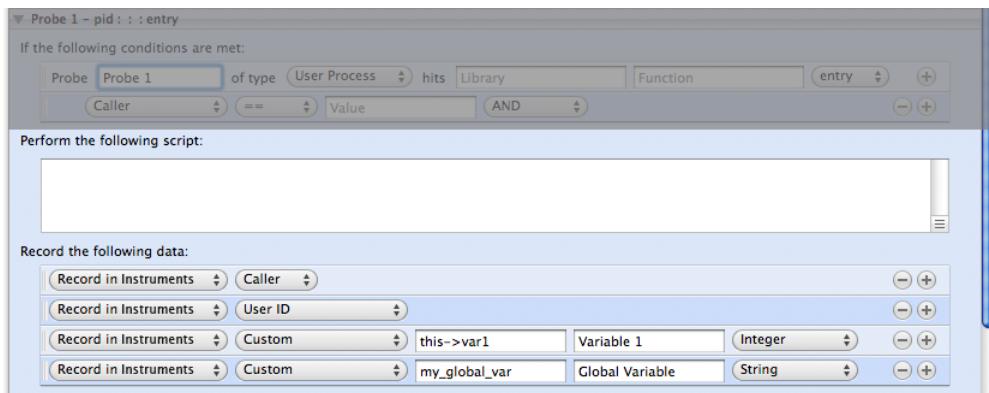
In addition to the condition variable, you must specify the comparison operator and the target value.

Adding Actions to a Probe

When a probe point defined by your instrument is hit, and the probe's predicate conditions evaluate to true, DTrace runs the actions associated with the probe. You use your probe's actions to gather data or to perform some additional processing. For example, if your probe monitors a specific function or method, you could have it return the caller of that function and any stack trace information to Instruments. If you wanted a slightly more advanced action, you could use a script variable to track the number of times the function was called and report that information as well. And if you wanted an even more advanced action, you could write a script that uses kernel-level DTrace functions to determine the status of a lock used by your function. In this latter case, your script code might also return the current owner of the lock (if there is one) to help you determine the interactions among your code's different threads.

Figure 7-3 shows the portion of the instrument configuration sheet where you specify your probe's actions. The script portion simply contains a text field for you to type in your script code. (Instruments does not validate your code before passing it to DTrace, so check your code carefully.) The bottom section contains controls for specifying the data you want DTrace to return to Instruments. You can use the pop-up menus to configure the built-in DTrace variables you want to return. You can also select Custom from this pop-up menu and return one of your script variables.

Figure 7-3 Configuring a probe's action



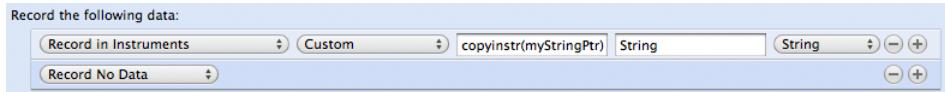
When you configure your instrument to return a custom variable, Instruments asks you to provide the following information:

- The script variable containing the data
- The name to apply to the variable in your instrument interface
- The type of the variable

Any data your probe returns to Instruments is collected and displayed in your instrument's Detail pane. The Detail pane displays all data variables regardless of type. If stack trace information is available for a specific probe, Instruments displays that information in your instrument's Extended Detail pane. In addition, Instruments automatically looks for integer data types returned by your instrument and adds those types to the list of statistics your instrument can display in the track pane.

Because DTrace scripts run in kernel space and the Instruments application runs in user space, if you want to return the value of a custom pointer-based script variable to Instruments, you must create a buffer to hold the variable's data. The simplest way to create a buffer is to use the `copyin` or `copyinstr` subroutines found in DTrace. The `copyinstr` subroutine takes a pointer to a C string and returns the contents of the string in a form you can return to Instruments. Similarly, the `copyin` subroutine takes a pointer and size value and returns a buffer to the data, which you can later format into a string using the `stringof` keyword. Both of these subroutines are part of the DTrace environment and can be used from any part of your probe's action definition. For example, to return the string from a C-style string pointer, you would simply wrap the variable name with the `copyinstr` subroutine as shown in Figure 7-4.

Figure 7-4 Returning a string pointer



Important: Instruments automatically wraps built-in variables (such as the `arg0` through `arg9` function arguments) with a call to `copyinstr` if the variable type is set to string. It does not do this with your script's custom variables, however. You are responsible for ensuring that the data in a custom variable actually matches the type specified for that variable.

For a list of the built-in variables supported by Instruments, see [Table 7-2](#) (page 68). For more information on scripts and script variables, see ["Tips for Writing Custom Scripts"](#) (page 71). For more information on DTrace subroutines, including the `copyin` and `copyinstr` subroutines, see the *Solaris Dynamic Tracing Guide* available from the [OpenSolaris website](#).

Tips for Writing Custom Scripts

You write DTrace scripts using the D scripting language, whose syntax is derived from a large subset of the C programming language. The D language combines the programming constructs of the C language with a special set of functions and variables to help you trace information in your program.

The following sections describe some of the common ways to use scripts in your custom instruments. These sections do not provide a comprehensive overview of the D language or the process for writing DTrace scripts, however. For information about scripting and the D language, see the *Solaris Dynamic Tracing Guide*, available on the [OpenSolaris website](#).

Writing BEGIN and END Scripts

If you want to do more than return the information in DTrace's built-in variables to Instruments whenever your action fires, you need to write custom scripts. Scripts interact directly with DTrace at the kernel level, providing access to low-level information about the kernel and the active process. Most instruments use scripts to gather information not readily available from DTrace. You can also use scripts to manipulate raw data before returning it to Instruments. For example, you could use a script to normalize a data value to a specific range if you wanted to make it easier to compare that value graphically with other values in your instrument's track pane.

In Instruments, the custom instrument configuration sheet provides several areas where you can write DTrace scripts:

- The DATA section contains definitions of any global variables you want to use in your instrument.
- The BEGIN section contains any initialization code for your instrument.
- Each probe contains script code as part of its action.
- The END section contains any clean up code for your instrument.

All script sections are optional. You are not required to have initialization scripts or clean up scripts if your instrument does not need them. If your instrument defines global variables in its DATA section, however, it is recommended that you also provide an initialization script to set those variables to a known value. The D language does not allow you to assign values inline with your global variable declarations, so you must put those assignments in your BEGIN section. For example, a simple DATA section might consist of a single variable declaration, such as the following:

```
int myVariable;
```

The corresponding BEGIN section would then contain the following code to initialize that variable:

```
myVariable = 0;
```

If your corresponding probe actions change the value of `myVariable`, you might use the END section of your probe to format and print out the final value of the variable.

Most of your script code is likely to be associated with individual probes. Each probe can have a script associated with its action. When it comes time to execute a probe's action, DTrace runs your script code first and then returns any requested data back to Instruments. Because passing data back to Instruments involves copying data from the kernel space back to the Instruments program space, you should always pass data back to Instruments by configuring the appropriate entries in the "Record the following data:" section of the instrument configuration sheet. Variables returned manually from your script code may not be returned correctly to Instruments.

Accessing Kernel Data from Custom Scripts

Because DTrace scripts execute inside the system kernel, they have access to kernel symbols. If you want to look at global kernel variables and data structures from your custom instruments, you can do so in your DTrace scripts. To access a kernel variable, you must precede the name of the variable with a single back quote character (`). The back quote character tells DTrace to look for the specified variable outside of the current script.

Listing 7-1 shows a sample action script that retrieves the current load information from the `avenrun` kernel variable and uses that variable to calculate one-minute average load of the system. If you were to create a probe using the Profile provider, you could have this script gather load data periodically and then graph that information in Instruments.

Listing 7-1 Accessing kernel variables from a DTrace script

```
this->load1a = `avenrun[0]/1000;
this->load1b = ((`avenrun[0] % 1000) * 100) / 1000;
this->load1 = (100 * this->load1a) + this->load1b;
```

Scoping Variables Appropriately

DTrace scripts have an essentially flat structure, due to a lack of flow control statements and the desire to keep probe execution time to a minimum. Variables in DTrace scripts, however, can be scoped to different levels depending on your need. Table 7-3 lists the scoping levels for variables and the syntax for using variables at each level.

Table 7-3 Variable scope in DTrace scripts

Scope	Syntax example	Description
Global	<code>myGlobal = 1;</code>	Global variables are identified simply using the variable name. All probe actions on all system threads have access to variables in this space.
Thread	<code>self->myThreadVar = 1;</code>	Thread-local variables are dereferenced from the <code>self</code> keyword. All probe actions running on the same thread have access to variables in this space. You might use this scope to collect data over the course of several runs of a probe's action on the current thread.
Probe	<code>this->myLocalVar = 1;</code>	Probe-local variables are dereferenced using the <code>this</code> keyword. Only the current running probe has access to variables in this space. Typically, you use this scope to define temporary variables that you want the kernel to clean up when the current action ends.

Finding Script Errors

If the script code for one of your custom instruments contains an error, Instruments displays an error message in the track pane when the script is compiled by DTrace. Instruments reports the error after you press the Record button in your trace document but before tracing actually begins. Inside the error message bubble is an Edit button. Clicking this button opens the instrument configuration sheet, which now identifies the probe with the error.

Exporting DTrace Scripts

Although Instruments provides a convenient interface for gathering trace data, there are still times when it is more convenient to gather trace data directly using DTrace. If you are a system administrator or are writing automated test scripts, for example, you might prefer to use the DTrace command-line interface to launch

a process and gather the data. Using the command-line tool requires you to write your own DTrace scripts, however, which can be time consuming and can lead to errors. If you already have a trace document with one or more DTrace-based instruments, you can use the Instruments application to generate a DTrace script that provides the same behavior as the instruments in your trace document.

Instruments supports exporting DTrace scripts only for documents where all of the instruments are based on DTrace. This means that your document can include custom instruments and a handful of the built-in instruments, such as the instruments in the File System and CoreData groups in the Library window. Information about whether an instrument is DTrace-based is included with the instrument description in “[Built-in Instruments](#)” (page 75).

To export a DTrace script, select the trace document containing the instruments and choose File > DTrace Script Export. This command places the script commands for your instruments in a text file that you can then pass to the `dtrace` command-line tool using the `-s` option. For example, if you exported a script named `MyInstrumentsScript.d`, you would run it from Terminal using the following command:

```
sudo dtrace -s MyInstrumentsScript.d
```

Note: You must have superuser privileges to run `dtrace` in most instances, which is why the `sudo` command is used to run `dtrace` in the preceding example.

Another advantage of exporting your scripts from Instruments (as opposed to writing it manually) is that after running the script, you can import the resulting data back into Instruments and review it there. Scripts exported from Instruments print a start marker (with the text `<dtrace_output_begin>`) at the beginning of the `dtrace` output. To gather the data, simply copy all of the DTrace output (including the start marker) from Terminal and paste it into a text file, or just redirect the output from the `dtrace` tool directly to a file. To import the data in Instruments, select the trace document from which you generated the original script and choose File > DTrace Data Import.

Built-in Instruments

A number of instruments come built into the Instruments application. Each instrument has its own configuration options and way of displaying information, appropriate to the type of data that instrument collects. The built-in instruments are grouped into a handful of categories, based on the type of information that the instrument gathers. The following sections describe the built-in instruments in greater detail.

Core Data

The following instruments gather data related to events in Core Data applications. You can use the information returned by these instruments to assess the performance implications of various events and to identify potential courses of action to correct issues.

Core Data Saves

The Core Data Saves instrument records save operations in Core Data applications. This instrument can operate on a single process or on all processes currently running on the system. It records data only for those processes that use Core Data. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

This instrument captures the following information:

- The method that initiated the save operation (including the stack trace information)
- The duration of the save operation (specified in microseconds)

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Save duration

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as the time at which the event occurred.

Core Data Fetches

The Core Data Fetches instrument records data store fetch operations in Core Data applications. This instrument can operate on a single process or on all processes currently running on the system. It records data only for those processes that use Core Data. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

This instrument captures the following information:

- The name of the entity that was fetched
- The caller of the function (including the stack trace information)
- The fetch count for that entity
- The duration of the fetch operation (specified in microseconds)

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Fetch count
- Fetch duration

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as the time at which the event occurred.

Core Data Faults

The Core Data Faults instrument records fault events that occur during the lazy initialization of an `NSManagedObject` or its to-many relationship. This instrument can operate on a single process or on all processes currently running on the system. It records data only for those processes that use Core Data. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

This instrument captures the following information:

- The name of the object that caused the fault
- The name of the method that triggered the fault (including the stack trace information)
- The execution duration for the fault handler (specified in microseconds)
- The relationship fault source
- The relationship name
- The relationship fault duration (specified in microseconds)

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Fault duration
- Relationship fault duration

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as the time at which the event occurred.

Core Data Cache Misses

The Core Data Cache Misses instrument records fault events that result in cache misses. This instrument can operate on a single process or on all processes currently running on the system. It records data only for those processes that use Core Data. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

Note: This instrument provides a subset of the behavior offered by the Core Data Faults instrument but is more useful for analyzing your application's overall performance.

This instrument captures the following information:

- The name of the object that caused the cache miss
- The name of the method that triggered the cache miss (including the stack trace information)
- The execution duration for the fault handler (specified in microseconds)
- The relationship cache miss source
- The relationship name
- The relationship cache miss duration (specified in microseconds)

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Cache miss duration
- Relationship cache miss duration

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as the time at which the event occurred.

File System

The instruments in this section analyze file system information and activity, such as read and write operations, permissions, and so forth.

File Locks

The File Locks instrument records advisory file-locking operations that use the `flock` function call. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

This instrument captures the following information:

- The name of the function

- The caller of the function (including the executable name and stack trace information)
- The path to the file being locked
- The operation type, which is an integer value corresponding to one of the following values (or a combination of values):
 - 1 - shared lock
 - 2 - exclusive lock
 - 4 - don't block when locking
 - 8 - unlock

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Timestamp

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

File Attributes

The File Attributes instrument records changes to ownership and access permissions for files in the file system. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script. This instrument captures information about calls to each of the following functions:

- Changes to file permission bits of a file made by the `chmod` and `fchmod` functions
- Changes to the file owner and group of a file made by the `chown` and `fchown` functions

For each function call, this instrument captures the following information:

- The name of the function
- The caller of the function (including the executable name and stack trace information)
- The path to the file on which the executable performed the operation
- The file descriptor of the file that was modified
- The mode flags, which indicate the permissions being applied to the file (This value is captured only for calls to `chmod` or `fchmod`.)
- The user ID of the new file owner (This value is captured only for calls to `chown` or `fchown`.)
- The group ID of the new group (This value is captured only for calls to `chown` or `fchown`.)

Note: For information about how to interpret the mode flags, see the `chmod` man page.

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- File descriptor
- Mode
- User ID
- Group ID

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

File Activity

The File Activity instrument lets you monitor file system access. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script. This instrument captures information about calls to each of the following functions:

- Open or create a file for reading or writing (`open`)
- Delete a descriptor from the per-process reference table(`close`)
- Get information about a file (`fstat`)

For each function call, this instrument captures the following information:

- The name of the function
- The caller of the function (including the executable name and stack trace information)
- The path to the file on which the executable performed the operation
- The file descriptor of the file

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- File descriptor

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

Directory I/O

The Directory I/O instrument records directory operations, such as moving directories, creating symbolic links, and so forth. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script. This instrument captures information about calls to each of the following functions:

- `delete` - delete files and directories
- `link` - create a hard or symbolic link
- `mkdir` - create a directory
- `mount` - mount a file system
- `rename` - change the name of a file or directory
- `rmdir` - remove a directory
- `symlink` - create a symbolic link
- `unlink` - remove a link
- `umount` - dismount a file system

For each function call, this instrument captures the following information:

- The name of the function
- The caller of the function (including the executable name and stack trace information)
- The path to the file or directory on which the executable performed the operation
- The new file or directory name (where appropriate)

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

Garbage Collection

The instruments in this section collect information on memory reclaimed by the garbage collector. To use these instruments, the program must be built for garbage collection and must be run with garbage collection enabled. See *Garbage Collection Programming Guide* for information about writing and building a program for garbage collection.

GC Total

The GC Total instrument tracks the total number of objects and bytes allocated and reclaimed by the garbage collector. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script. It records data only for those processes that have garbage collection enabled.

This instrument captures the following information:

- The function that initiated the reclamation of objects (including the stack trace information)
- The number of objects reclaimed by the garbage collector
- The total number of bytes reclaimed by the garbage collector
- The total number of allocated bytes still in use
- The total number of bytes, both reclaimed and in use

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Objects reclaimed
- Bytes reclaimed
- Bytes in use
- Total bytes

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

Garbage Collection

The Garbage Collection instrument measures the reclaim data of the Garbage Collector's scavenge phase. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script. It records data only for those processes that have garbage collection enabled.

This instrument captures the following information:

- The function that initiated the reclamation of objects (including the stack trace information)
- The zone in which the memory is allocated
- Whether the event is generational (1 for yes, 0 for no)
- The number of objects reclaimed by the garbage collector
- The number of bytes reclaimed by the garbage collector
- The duration of the scavenge event (specified in microseconds)

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Zone
- Is generational (the generational collector finds older objects no longer in use that are missed by the non-generational collector, but takes longer to run and is therefore run less frequently)
- Objects reclaimed
- Bytes reclaimed
- Duration

For entries in the Detail pane, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

Graphics

The following instruments gather graphics-related data.

OpenGL Driver

The OpenGL Driver instrument samples OpenGL statistics. This instrument can operate on a single process or on all processes currently running on the system.

This instrument captures the following information:

- Buffer swap count
- Client GLWait time
- Command2 DBytes per sample
- Context2 DCount
- Context GLCount
- Free Context Buffer2 DWait time
- Gart size bytes
- Surface count
- Texture count
- Vram free bytes
- and much more...

To see the full list of captured data, install the instrument and open the Extended Detail pane.

The Track pane indicates when the data was gathered. The Extended Detail pane shows the statistics at each sample point.

Input/Output

The following instruments gather data related to I/O operations.

Reads/Writes

The Reads/Writes instrument records reads from and writes to files. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script. It gathers information about each call to read and write functions, including `read`, `write`, `pread`, and `pwrite`.

This instrument captures the following information:

- The name of the function
- The caller of the function (including the executable name and stack trace information)
- The path to the file on which the executable performed the operation
- The file descriptor of the file that was modified
- The number of bytes read or written

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- File descriptor
- Bytes

For any of these calls, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

Master Tracks

The Master Tracks section contains the User Interface recorder, which lets you record and play back a series of user actions in an application.

User Interface

The User Interface instrument can launch an application or attach to a process and record your interaction with the user interface. You can then play back this recording as many times as you want, and run any other instruments you choose as you do so. You can use this instrument to create repeatable tests of the user interface as part of your quality assurance program and to capture errors that occur only sporadically. The use of the User Interface instrument is described in detail in [“Working with a User Interface Track”](#) (page 39).

Memory

The instruments in this section track memory use.

Shared Memory

The Shared Memory instrument records the opening and unlinking of shared memory. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script. It gathers information about each shared memory access, including `shm_open` and `shm_unlink`.

This instrument captures the following information:

- The name of the function
- The caller of the function (including the executable name and stack trace information)
- The name of the shared memory region
- The flags used to open the shared memory region (see the `shm_open` man page)
- The mode flags, indicating the access permissions for the region (see the `chmod` man page)

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Flags
- mode_t

For any of these calls, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

ObjectAlloc

The ObjectAlloc instrument tracks memory allocation for an application. This instrument requires that you launch a single process so that it can gather data from the start of the process.

This instrument captures the following information:

- Category - typically a Core Foundation object, an Objective-C class, or a raw block of memory.
- Net Bytes - the number of bytes of this type currently allocated but not yet released.
- # Net - the number of objects or memory blocks of this type currently allocated but not yet released.
- Overall Bytes - the total number of bytes of this type that have been allocated, including those that have been released.
- # Overall - the total number of objects or memory blocks of this type that have been allocated, including those that have been released.

- # Allocations (Net / Overall) - A histogram of the current and total counts. The bars are normally shades of blue. They are colored shades of yellow when the ratio between the total number of objects and the peak, or the ratio between the peak and the current number, is 1/3 or less. The bars are shades of red when the ratio is 1/10 or less.

Although the ratios displayed aren't necessarily bad (often, they're normal over the long run of an application), Instruments colors them to point out allocation patterns that may deserve a further look. If you see categories where the color is red or yellow, you might try to eliminate unnecessary temporary allocations of the given type in your application. Similarly, you might simply try to eliminate the high-water mark in the number of objects.

The data table in the details pane contains a Graph column, which contains a checkbox for each row in the table. When the checkbox for a given category is enabled, the instrument displays the graph for that particular category type in the Track pane. Instruments automatically assigns a color to each graphed category.

When you mouse over category names in the details pane, a more Info button appears next to the category name. Clicking this button displays detailed information about the objects in that category, including the following attributes:

- The address of the block.
- The function call or class that generated the allocation event. For example, you can see which method in a class retained an object.
- The creation time of the object.
- The library responsible for creating the object.

For any of these events, you can open the Extended Detail pane to see the stack trace for each object allocation, including the type of allocation and the time at which the event occurred.

For specific instances of an object (or memory block), you can click the more info button in the Object Address column to see the allocation events associated with that object. For each allocation event, this instrument displays the following information:

- The category of the object (its type)
- The event type.
- The timestamp for each event.
- The address of the block
- The size of the block
- The library responsible for allocating the block.
- The function that caused the allocation event.

For any allocation event, you can open the Extended Detail pane to see the stack trace, as well as any available event information and the time at which the event occurred.

To further filter information in the Detail pane, you can configure the Allocation Lifespan options. These options let you filter the allocation events based on the following criteria:

- All Objects Created - display all objects, regardless of whether they have been deallocated.
- Created & Still Living - display only objects that existed in memory when you stopped recording data..

The inspector for the ObjectAlloc instrument lets you configure the way the instrument tracks information. From the inspector, you can set the following options:

- Record reference counts. Use this option to track the reference count of each object.
- Discard unrecorded data on stop. Use this option to discard any data that has been gathered but not yet processed by the ObjectAlloc instrument.

For additional information about the ObjectAlloc instrument, see “[Analyzing Data with the ObjectAlloc Instrument](#)” (page 56).

Leaks

The Leaks instrument examines a process’s heap for leaked memory. You can use this instrument together with the ObjectAlloc instrument to get memory address histories. This instrument requires that you launch a single process so that it can gather data from the start of the process.

This instrument captures the following information:

- The number of leaks
- The size of each leak
- Address of the leaked block
- Type of the leaked object

Each view mode in the Detail pane shows the leak data in a slightly different way. In table mode, this instrument shows the individual leaks along with the percentage that each individual leak contributes to the total amount of leaked memory discovered. In outline mode, the data is reorganized so that you can see how much memory is leaked from within a given symbol. For entries in either mode, the Extended Detail pane displays a heavy stack trace showing from where the leak originated.

For additional information about the Leaks instrument, see “[Looking for Memory Leaks](#)” (page 58).

System

The instruments in this section gather data about system activity and resources.

Spin Monitor

The Spin Monitor instrument automatically samples any applications that become unresponsive on the system. An application becomes unresponsive when it does not retrieve events from the window server for 3 or more seconds. Applications that are unresponsive during this time may actually be doing useful work or they may be hung. You can use the sample information generated by this instrument to adjust your code so as to ensure your application keeps processing events in a timely manner. This instrument can operate on a single process or on all processes currently running on the system.

During sampling, this instrument captures the following information:

- The time at which sampling began
- The sampling duration
- Stack trace information (including the library and caller information)
- The maximum stack depth encountered during sampling
- The function encountered most frequently during sampling (the hot frame)

Each view mode in the Detail pane shows the sample data in a slightly different way. Both table and outline mode start by showing you the sessions during which a given application was sampled. Each session corresponds to a period of time where the application was deemed unresponsive and you can expand a given session to see what the application was doing during this time. In table mode, the instrument shows data about the functions that occurred most often during sampling. In outline mode, the instrument shows the number of samples that were gathered during each session. You can also show the running time for the samples that were gathered using the Sample Perspective options.

The inspector for this instrument lets you set the sample rate at which to gather samples. By default, this instrument gathers a sample once every 10 milliseconds.

Sampler

The Sampler instrument stops a program at prescribed intervals and records the stack trace information for each of the program's threads. You can use this information to determine where execution time is being spent in your program and improve your code to reduce running time. Unlike many instruments, Sampler does not require DTrace probes in order to function. This instrument operates on a single process.

The Sampler instrument records the following types of data for each sample:

- The function being executed
- The stack trace for each of the program's threads
- The time the sample was taken

The Sampler instrument lets you view this information in different ways. In table mode, you can view the samples in the order they were gathered, which shows the execution order of your code. In outline mode, Sampler provides a tree view of your program's call stack and shows the number of samples that occurred in each function in that call stack.

In studying the performance of a running program you should compare the impact of a function to the cost of executing that function. If your program spends a lot of time in a low-impact function, this instrument can show you that behavior. You can then use the sample data to find out why your program is spending its time there and who is calling the function, which can lead you to fixing your code so that the function is called less frequently.

To display a detailed call stack for a function, you can disclose items in the outline mode or select a function and open the Extended Detail pane. In outline mode, you can expand the entire call stack below a given entry by pressing the Option key and clicking the disclosure triangle for the entry.

The Track pane displays the stack depth at each sample time by default. This view is useful for identifying patterns of what is going on in your code. Because it is unlikely that two different execution paths will result in the same pattern of stack depths, when you see repeated structures in the graph, it is likely that the same code is being executed repetitively. If this code also takes a long time to execute, it is a good target for optimization.

For additional information about the Sampler instrument, see “[Analyzing Data with the Sampler Instrument](#)” (page 53).

Process

The Process instrument records processes forked by another process. This instrument can operate on a single process or on all processes currently running on the system. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

This instrument captures the following information:

- Execute a process (`execve`)
- Process exit (`exit`)

The Process instrument returns information about each call made to these functions, including:

- The name of the function (`execve` or `exit`)
- The caller of the function (including the executable name, path, and stack trace information)
- The process ID
- The exit status of the process

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- Process ID
- Exit status

For any of these calls, you can open the Extended Detail pane to see the stack trace for that call, as well as any available probe information and the time at which the event occurred.

Network Activity Monitor

The Network Activity Monitor instrument records network traffic through the computer. This instrument can operate on a single process or on all processes currently running on the system.

The Track pane is set to display the following network-related data by default, but you can configure it to display other types of data as well. By default, it displays the following information:

- The number of bytes sent each second

- The number of bytes received each second
- The number of packets sent each second
- The number of packets received each second

Memory Monitor

The Memory Monitor instrument records the amount of real and virtual memory used by processes. This instrument can operate on a single process or on all processes currently running on the system.

The Track pane is set to display the following memory-related data by default, but you can configure it to display other types of data as well. By default, it displays the following information:

- The number of virtual memory page ins
- The number of virtual memory page outs
- The total amount of virtual memory space in use
- The total amount of free physical memory
- The total amount of used physical memory

Disk Monitor

The Disk Monitor instrument records disk read and write operations. This instrument can operate on a single process or on all processes currently running on the system.

The Track pane is set to display the following disk-related data by default, but you can configure it to display other types of data as well. By default, it displays the following information:

- The number of bytes per second written to disk
- The number of bytes per second read from disk
- The number of write operations processed per second
- The number of read operations processed per second

CPU Monitor

The CPU Monitor instrument records the load on the system. This instrument can operate on a single process or on all processes currently running on the system.

The Track pane is set to display the following load values by default, but you can configure it to display other types of data as well. By default, it displays the following information:

- The amount of load generated by the system
- The amount of load generated by the user
- The total load on the system

Activity Monitor

The Activity Monitor instrument records the load on the system measured against the virtual memory size. This instrument can operate on a single process or on all processes currently running on the system.

The Track pane is set to display the following load values by default, but you can configure it to display other types of data as well. By default, it displays the following information:

- The total amount of virtual memory space in use
- The amount of load generated by the system
- The amount of load generated by the user
- The total load on the system

Threads/Locks

The following instruments gather thread-related data.

Java Thread

The Java Thread instrument records the initialization and destruction of Java threads. It displays:

- The time each measurement was taken
- Total threads

You can specify the colors to use when charting the running, waiting, and blocked threads.

User Interface

The following instruments gather data for application-level events.

Cocoa Events

The Cocoa Events instrument records events sent through the `sendEvent:` method of the `NSApplication` class. This is the main method for dispatching events to a Cocoa application. You can use this instrument to correlate application events with other application behavior, such as memory and CPU usage. This instrument operates on a single process. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

This instrument captures the type of event that was sent (both as an `NSEventType` code and spelled out).

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- The event kind

For any of these calls, you can open the Extended Detail pane to see the stack trace for that call, as well as the time at which the event occurred.

Carbon Events

The Carbon Events instrument records events returned by the `WaitNextEvent` function in the Carbon Event Manager. You can use this instrument to correlate application events with other application behavior, such as memory and CPU usage. This instrument operates on a single process. This instrument uses DTrace in its implementation and can be exported to a DTrace script.

This instrument captures the type of event that was sent.

The Track pane can be set to display any of the following data:

- Stack depth
- Thread ID
- The event kind

For any of these calls, you can open the Extended Detail pane to see the stack trace for that call, as well as the time at which the event occurred.

CHAPTER 8

Built-in Instruments

Document Revision History

This table describes the changes to *Instruments User Guide*.

Date	Notes
2008-10-15	Made minor editorial corrections.
2008-02-08	Explained how playing protected content affects systemwide data collection.
2007-10-31	New document that describes how to use the Instruments application.

REVISION HISTORY

Document Revision History