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DTrace Reference Guide

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Preface

> **WARNING:**
>
> Oracle Linux 7 is now in Extended Support. See Oracle Linux Extended Support and Oracle Open Source Support Policies for more information.
>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

Oracle Linux: DTrace Reference Guide describes how to use DTrace. The guide also describes some DTrace providers in detail. Most of the information in this document is generic and applies to all releases of Oracle Linux 6 and Oracle Linux 7, with support for the Unbreakable Enterprise Kernel Release 4 (UEK R4) and Unbreakable Enterprise Kernel Release 5 (UEK R5) kernels. Note that UEK R5 is not supported on Oracle Linux 6.

> **Note:**
>
> This release of DTrace supports systems that use the x86_64 processor architecture, but not systems that use 32-bit x86 processors.
>
> DTrace support has also been extended to the 64-bit Arm architecture in this release. However, note that some providers might not be supported on this architecture.

Documentation License

Conventions

The following text conventions are used in this document:

Convention	Meaning
boldface	Boldface type indicates graphical user interface elements associated with an action, or terms defined in text or the glossary.

Convention	Meaning
italic	Italic type indicates book titles, emphasis, or placeholder variables for which you supply particular values.
`monospace`	Monospace type indicates commands within a paragraph, URLs, code in examples, text that appears on the screen, or text that you enter.

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Diversity and Inclusion

Oracle is fully committed to diversity and inclusion. Oracle respects and values having a diverse workforce that increases thought leadership and innovation. As part of our initiative to build a more inclusive culture that positively impacts our employees, customers, and partners, we are working to remove insensitive terms from our products and documentation. We are also mindful of the necessity to maintain compatibility with our customers' existing technologies and the need to ensure continuity of service as Oracle's offerings and industry standards evolve. Because of these technical constraints, our effort to remove insensitive terms is ongoing and will take time and external cooperation.

1

About DTrace

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DTrace provides dynamic tracing, which is the ability to instrument a running operating system kernel.

DTrace enables you to associate actions, such as collecting or printing stack traces, function arguments, timestamps, and statistical aggregates, with probes, which can be runtime events or source-code locations. The D language is powerful, yet simple. DTrace is dynamic, has low overhead, and is safe to use on production systems. It enables you to examine the behavior of user programs and the operating system, to understand how your system works, to track down performance problems, and to locate the causes of aberrant behavior.

DTrace is a kernel framework that dynamically traces data into buffers that are read by *consumers*. On Oracle Linux, you will probably only use one consumer, the `dtrace` command-line utility, which contains the D language that grants you full access to the framework's power.

This guide is largely a reference manual. For information about how to use DTrace and step-by-step examples, see Oracle Linux: DTrace Tutorial.

Getting Started With DTrace

> **Note:**
>
> Most uses of DTrace require `root` privileges.

Prior to installing the `dtrace_utils` package, ensure that you are subscribed to the ULN channel that corresponds to the UEK kernel that you are running. For example, if you are running Oracle Linux 7 with UEK R5, the `dtrace_utils` package is available in the `ol7_UEKR5` channel. For more information about subscribing to channels on ULN, see Oracle Linux: Unbreakable Linux Network User's Guide for Oracle Linux 6 and Oracle Linux 7.

For information about updating your Oracle Linux or UEK release, see the documentation at https://docs.oracle.com/en/operating-systems/linux.html.

Install the `dtrace-utils` package:

```
# yum install dtrace-utils
```

If you want to implement a `libdtrace` consumer:

```
# yum install dtrace-utils-devel
```

If you want to develop a DTrace provider:

```
# yum install dtrace-modules-provider-headers
```

To confirm that `dtrace` is properly installed on your system and that you have all of the required privileges, use the `dtrace -l` command. Running this command should load any of the required kernel modules and the output should indicate any available probes.

> **Note:**
>
> The `dtrace-utils` package installs `dtrace` in `/usr/sbin/dtrace`. Make sure your path detects this path instead of the similarly named utility that is located in `/usr/bin/dtrace`, which is installed by the `systemtap-sdt-devel` package.

A *provider* is a set of probes with a particular kind of instrumentation.

Note:

To use a provider's probes, the kernel module that supports that provider must be loaded. Typically, `dtrace` automatically handles this for you. Upon first use, it will load the `dtrace` module and all of the modules that are listed in `/etc/dtrace-modules`, which the system administrator can edit.

In some cases, the kernel module that supports the desired provider must be loaded manually, for example:

```
# more /etc/dtrace-modules
sdt
systrace
profile
fasttrap
# modprobe sdt
# modprobe systrace
# modprobe profile
# modprobe fasttrap
```

These required modules are different from the modules, if any, that are instrumented by the provider's probes and are found in the `dtrace -l` output. For example, while the module that is required to support `proc` probes is `sdt`, the module that these probes instrument is `vmlinux`, as shown in the following output:

```
# dtrace -l -P proc
   ID   PROVIDER    MODULE          FUNCTION NAME
  197       proc   vmlinux          _do_fork lwp-create
  198       proc   vmlinux          _do_fork create
  225       proc   vmlinux           do_exit lwp-exit
  226       proc   vmlinux           do_exit exit
  275       proc   vmlinux   do_sigtimedwait signal-clear
...
```

You dynamically assign actions to be taken at probes, which can be runtime events or source-code locations. Every probe in DTrace has two names: a unique integer ID, which is assigned as the probes are loaded, and a human-readable string name. You can start learning about DTrace by building some very simple requests that use the probe named `BEGIN`. The `BEGIN` probe fires once each time you start a new tracing request.

Use the `dtrace` command with the `-n` option to enable a probe by specifying its name:

```
# dtrace -n BEGIN
dtrace: description 'BEGIN' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0      1                           :BEGIN
^C
#
```

The default output of the previous example displays the following information: the probes that were matched, column headers, and then one row each time a probe fires. The default per row is the CPU where the probe fired and information about which probe fired. DTrace remains paused, waiting for other probes to fire. To exit, press `Ctrl-C`.

You can construct DTrace requests by using arbitrary numbers of probes and actions. For example, create a simple request using two probes by adding the `END` probe to the command shown in the previous example. The `END` probe fires once when tracing is completed.

Type the following command, and then press `Ctrl-C` in your shell again, after you see the line of output for the `BEGIN` probe:

```
# dtrace -n BEGIN -n END
dtrace: description 'BEGIN' matched 1 probe
dtrace: description 'END' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0      1                           :BEGIN
^C
  1      2                             :END
```

Pressing `Ctrl-C` to exit `dtrace` triggers the `END` probe. The `dtrace` command reports this probe firing before exiting.

In addition to constructing DTrace experiments on the command line, you can also write DTrace experiments in text files by using the D programming language.

In a text editor, create a new file named `hello.d` and type your first D program:

```
BEGIN
{
  trace("hello, world");
  exit(0);
}
```

After you save the program, you can run it by using the `dtrace -s` command, as shown in the following example:

```
# dtrace -s hello.d
dtrace: script 'hello.d' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0      1                           :BEGIN   hello, world
#
```

The `dtrace` command printed the same output as the previous example, followed by the text, ”hello, world”. However, unlike the previous example, you did not have to wait and then press `Ctrl-C`. These changes were the result of the actions that you specified for the `BEGIN` probe in `hello.d`.

To understand what happened, let us explore the structure of your D program in more detail.

- Each D program consists of a series of clauses, and each clause describes one or more probes to enable, as well as an optional set of actions to perform when the probes fires.
- The actions are listed as a series of statements that are enclosed in braces (`{}`) that follow the probe name. Each statement ends with a semicolon (`;`).
- The first statement uses the `trace()` function to indicate that DTrace should record the specified argument, the string, ”hello, world”, when the `BEGIN` probe fires and then print it out.
- The second statement uses the `exit()` function to indicate that DTrace should cease tracing and exit the `dtrace` command.

DTrace provides a set of useful functions such as `trace()` and `exit()` for you to call in your D programs.

To call a function, you specify its name, followed by a parenthesized list of arguments. See Actions and Subroutines for the complete set of D functions.

If you are familiar with the C programming language, you probably have noticed that DTrace's D programming language is very similar to C. Indeed, D is derived from a large subset of C, combined with a special set of functions and variables to help make tracing easy. These features are described in more detail in subsequent chapters. If you have written a C program previously, you should be able to immediately transfer most of your knowledge to building tracing programs in D. If you have never written a C program, learning D is still relatively easy. By the end of this chapter, you will understand all of the syntax. First, let us take a step back from language rules and learn more about how DTrace works. Then, later in this guide, you will learn how to build more interesting D programs.

Providers and Probes

In the preceding examples, you learned how to use two simple probes named `BEGIN` and `END`. DTrace probes come in sets that are called *providers*, each of which performs a particular kind of instrumentation to create probes. When you use DTrace, each provider is given an opportunity to publish the probes that it can provide to the DTrace framework. You can then enable and bind your tracing actions to any of the probes that have been published.

You can list all of the available probes on your system by typing the following command:

```
# dtrace -l
   ID   PROVIDER            MODULE                          FUNCTION NAME
    1     dtrace                                                     BEGIN
    2     dtrace                                                     END
    3     dtrace                                                     ERROR
    4    syscall          vmlinux                               read entry
    5    syscall          vmlinux                               read return
    6    syscall          vmlinux                              write entry
    7    syscall          vmlinux                              write return
    ...
```

Note that it might take some time for all of the output to be displayed.

To count all of the probes, type the following command:

```
# dtrace -l | wc -l
4097
```

Note that you might observe a different total on your system, as the number of probes can vary, depending on the following: your operating platform, the software you have installed, and the provider modules you have loaded. Note also that this output is not the complete list. As will be described later, some providers offer the ability to create new probes on-the-fly, based on your tracing requests, which makes the actual number of DTrace probes virtually unlimited. Notice that each probe has the two names previously mentioned: an integer ID and a human-readable name. The human-readable name is composed of four parts that are displayed as separate columns in the `dtrace` output and are as follows:

provider
A name of the DTrace provider that is publishing this probe.

module
If this probe corresponds to a specific program location, the name of the kernel module, library, or user-space program in which the probe is located.

function
If this probe corresponds to a specific program location, the name of the program function in which the probe is located.

name
A name that provides some idea of the probe's semantic meaning, such as `BEGIN` or `END`.

When writing the full human-readable name of a probe, write all four parts of the name separated by colons like this:

provider:*module*:*function*:*name*

Notice that some of the probes in the list do not have a module and function, such as the `BEGIN` and `END` probes that were used previously. Some probes leave these two fields blank because these probes do not correspond to any specific instrumented program function or location. Instead, these probes refer to a more abstract concept, such as the idea of the end of your tracing request.

By convention, if you do not specify all of the fields of a probe name, DTrace matches your request to all of the probes with matching values in the parts of the name that you do specify. In other words, when you used the probe name `BEGIN` in the previous exercise, you were actually directing DTrace to match any probe with the name field `BEGIN`, regardless of the value of the provider, module, and function fields. Because there is only one probe matching that description, the result is the same. You now know that the true name of the `BEGIN` probe is `dtrace:::BEGIN`, which indicates that this probe is provided by the DTrace framework itself and is not specific to any function. Therefore, the `hello.d` program could be written as follows and would produce the same result:

```
dtrace:::BEGIN
{
  trace("hello, world");
  exit(0);
}
```

2
The D Programming Language

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The D systems programming language enables you to interface with operating system APIs and with the hardware. This chapter formally describes the overall structure of a D program and the various features for constructing probe descriptions that match more than one probe. The chapter also discusses the use of the C preprocessor, `cpp`, with D programs.

D Program Structure

A *D program*, also known as a *script*, consists of a set of clauses that describe the probes to enable and the predicates and actions to bind to these probes. D programs can also contain declarations of variables and definitions of new types. See Variables and Type and Constant Definitions for more details.

Probe Clauses and Declarations

As shown in the examples in this guide thus far, a D program source file consists of one or more probe clauses that describe the instrumentation to be enabled by DTrace. Each probe clause uses the following general form:

```
probe descriptions
/ predicate /
{
  action statements
}
```

Note that the predicate and list of action statements may be omitted. Any directives that are found outside of probe clauses are referred to as *declarations*. Declarations may only be used outside of probe clauses. No declarations are permitted inside of the enclosing braces (`{}`). Also, declarations may not be interspersed between the elements of the probe clause in previous example. You can use white space to separate any D program elements and to indent action statements.

Declarations can be used to declare D variables and external C symbols or to define new types for use in D. For more details, see Variables and Type and Constant Definitions. Special D compiler directives, called *pragmas*, may also appear anywhere in a D program, including outside of probe clauses. D pragmas are specified on lines beginning with a `#` character. For

example, D pragmas are used to set DTrace runtime options. See Options and Tunables for more details.

Probe Descriptions

Every program clause begins with a list of one or more probe descriptions, each taking the following usual form:

provider:*module*:*function*:*name*

If one or more fields of the probe description are omitted, the specified fields are interpreted from right to left by the D compiler. For example, the probe description `foo:bar` would match a probe with the function `foo` and name bar, regardless of the value of the probe's provider and module fields. Therefore, a probe description is really more accurately viewed as a *pattern* that can be used to match one or more probes based on their names.

You should write your D probe descriptions specifying all four field delimiters so that you can specify the desired *provider* on the left-hand side. If you don't specify the provider, you might obtain unexpected results if multiple providers publish probes with the same name. Similarly, subsequent versions of DTrace might include new providers with probes that unintentionally match your partially specified probe descriptions. You can specify a provider but match any of its probes by leaving any of the module, function, and name fields blank. For example, the description `syscall:::` can be used to match every probe that is published by the DTrace `syscall` provider.

Probe descriptions also support a pattern-matching syntax similar to the shell *globbing* pattern matching syntax that is described in the `sh(1)` manual page. Before matching a probe to a description, DTrace scans each description field for the characters `*`, `?`, and `[`. If one of these characters appears in a probe description field and is not preceded by a `\`, the field is regarded as a pattern. The description pattern must match the entire corresponding field of a given probe. To successfully match and enable a probe, the complete probe description must match on every field. A probe description field that is not a pattern must exactly match the corresponding field of the probe. Note that a description field that is empty matches any probe.

The special characters in the following table are recognized in probe name patterns.

Table 2-1 Probe Name Pattern Matching Characters

Symbol	Description
`*`	Matches any string, including the null string.
`?`	Matches any single character.
`[...]`	Matches any one of the enclosed characters. A pair of characters separated by - matches any character between the pair, inclusive. If the first character after the `[` is `!`, any character not enclosed in the set is matched.
`\`	Interpret the next character as itself, without any special meaning.

Pattern match characters can be used in any or all of the four fields of your probe descriptions. You can also use patterns to list matching probes by them on the command line by using the `dtrace -l` command. For example, the `dtrace -l -f kmem_*` command lists all of the DTrace probes in functions with names that begin with the prefix `kmem_`.

If you want to specify the same predicate and actions for more than one probe description, or description pattern, you can place the descriptions in a comma-separated list. For example, the following D program would trace a timestamp each time probes associated with entry to system calls containing the strings "`read`" or "`write`" fire:

```
syscall::*read*:entry, syscall::*write*:entry
{
  trace(timestamp);
}
```

A probe description can also specify a probe by using its integer probe ID, for example, the following clause could be used to enable probe ID `12345`, as reported by `dtrace -l -i 12345`:

```
12345
{
  trace(timestamp);
}
```

> **Note:**
>
> You should always write your D programs using human-readable probe descriptions. Integer probe IDs are not guaranteed to remain consistent as DTrace provider kernel modules are loaded and unloaded or following a reboot.

Clause Predicates

Predicates are expressions that are enclosed in a pair of slashes (`//`) that are then evaluated at probe firing time to determine whether the associated actions should be executed. Predicates are the primary conditional construct that are used for building more complex control flow in a D program. You can omit the predicate section of the probe clause entirely for any probe. In which case, the actions are always executed when the probe fires.

Predicate expressions can use any of the D operators and can refer to any D data objects such as variables and constants. The predicate expression must evaluate to a value of integer or pointer type so that it can be considered as true or false. As with all D expressions, a zero value is interpreted as false and any non-zero value is interpreted as true.

Probe Actions

Probe actions are described by a list of statements that are separated by semicolons (`;`) and enclosed in braces (`{}`). An empty set of braces with no statements included, leads to the default actions, which are to print the CPU and the probe.

Order of Execution

The actions for a probe are executed in program order, regardless of whether those actions are in the same clause or in different clauses.

No other ordering constraints are imposed. It is not uncommon for the output from two distinct probes to appear interspersed or in an opposite order from which the probes fired. Also, output might appear misordered if it came from different CPUs.

Use of the C Preprocessor

The C programming language that is used for defining Linux system interfaces includes a *preprocessor* that performs a set of initial steps in C program compilation. The C preprocessor is commonly used to define macro substitutions, where one token in a C program is replaced with another predefined set of tokens, or to include copies of system header files. You can use the C preprocessor in conjunction with your D programs by specifying the `dtrace` command with the `-c` option. This option causes the `dtrace` command to execute the `cpp` preprocessor on your program source file and then pass the results to the D compiler. The C preprocessor is described in more detail in The C Programming Language by Kernighan and Ritchie, details of which are referenced in Preface.

The D compiler automatically loads the set of C type descriptions that is associated with the operating system implementation. However, you can use the preprocessor to include other type definitions such as the types that are used in your own C programs. You can also use the preprocessor to perform other tasks such as creating macros that expand to chunks of D code and other program elements. If you use the preprocessor with your D program, you may only include files that contain valid D declarations. The D compiler can correctly interpret C header files that include only external declarations of types and symbols. However, the D compiler cannot parse C header files that include additional program elements, such as C function source code, which produces an appropriate error message.

Compilation and Instrumentation

When you write traditional programs, you often use a compiler to convert your program from source code into object code that you can execute. When you use the `dtrace` command you are invoking the compiler for the D language that was used in a previous example to write the `hello.d` program. When your program is compiled, it is sent into the operating system kernel for execution by DTrace. There, the probes named in your program are enabled and the corresponding provider performs whatever instrumentation is required in order to activate them.

All of the instrumentation in DTrace is completely dynamic: probes are enabled discretely only when you are using them. No instrumented code is present for inactive probes, so your system does not experience any kind of performance degradation when you are not using DTrace. After your experiment is complete and the `dtrace` command exits, all of the probes that you used are automatically disabled and their instrumentation is removed, returning your system to its exact original state. No effective difference exists between a system where DTrace is not active and a system where the DTrace software is not installed, other than a few megabytes of disk space that is required for type information and for DTrace itself.

The instrumentation for each probe is performed dynamically on the live, running operating system or on user processes that you select. The system is not quiesced or paused in any way and instrumentation code is added only for the probes that you enable. As a result, the probe effect of using DTrace is limited to exactly what you direct DTrace to do: no extraneous data is traced and no one, big “tracing switch” is turned on in the system. All of the DTrace instrumentation is designed to be as efficient as possible. These features enable you to use DTrace in production to solve real problems in real time.

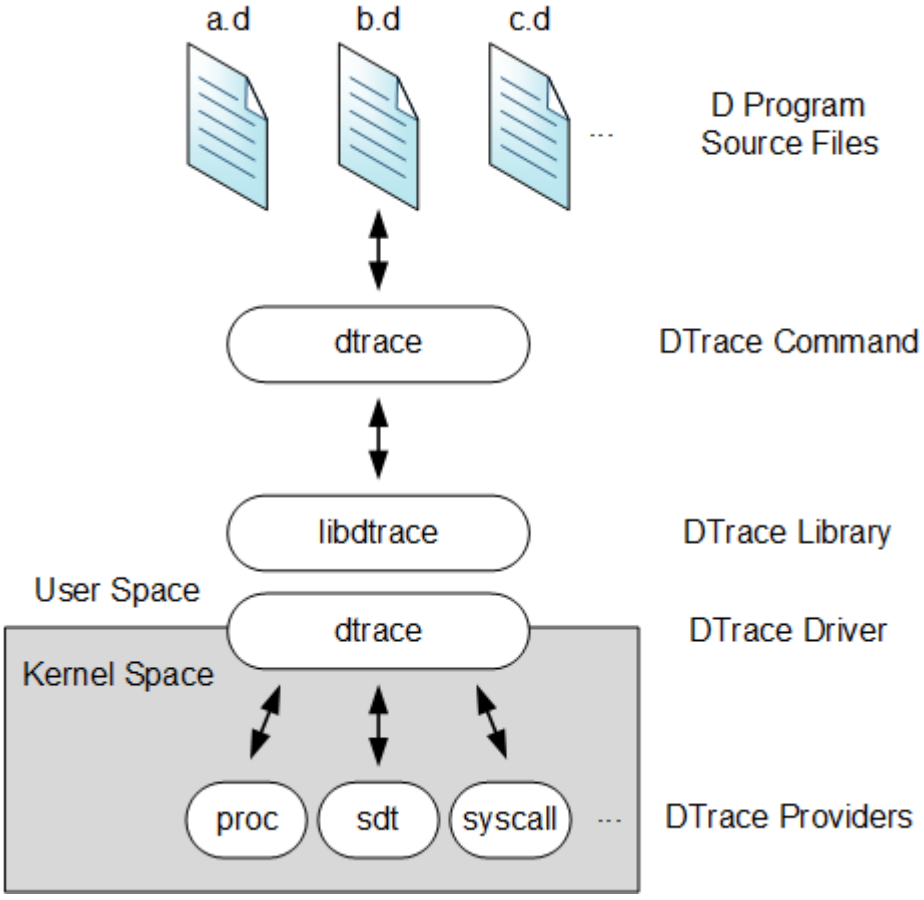
The DTrace framework also provides support for an arbitrary number of virtual clients. You can run as many simultaneous DTrace experiments and commands as you like, limited only by your system's memory capacity. The commands all operate independently using the same underlying instrumentation. This same capability also permits any number of distinct users on the system to take advantage of DTrace simultaneously: developers, administrators, and

service personnel can all work together, or on distinct problems, using DTrace on the same system without interfering with one another.

Unlike programs that are written in C and C++, and similar to programs that are written in the Java programming language, DTrace D programs are compiled into a safe, intermediate form that is used for execution when your probes fire. This intermediate form is validated for safety when your program is first examined by the DTrace kernel software. The DTrace execution environment also handles any runtime errors that might occur during your D program's execution, including dividing by zero, dereferencing invalid memory, and so on, and reports them to you. As a result, you can never construct an unsafe program that would cause DTrace to inadvertently damage the operating system kernel or one of the processes running on your system. These safety features enable you to use DTrace in a production environment without being concerned about crashing or corrupting your system. If you make a programming mistake, DTrace reports the error to you and disables your instrumentation, enabling you to correct the mistake and try again. The DTrace error reporting and debugging features are described later in this guide.

#unique_22/unique_22_Connect_42_dt_archfig_dlang shows the different components of the DTrace architecture.

Overview of the DTrace Architecture and Components



Now that you understand how DTrace works, let us return to the tour of the D programming language and start writing some more interesting programs.

Variables and Arithmetic Expressions

Our next example program makes use of the DTrace `profile` provider to implement a simple time-based counter. The profile provider is able to create new probes based on the descriptions found in your D program. If you create a probe named `profile:::tick-`*n* `sec` for some integer *n*, the profile provider creates a probe that fires every *n* seconds. Type the following source code and save it in a file named `counter.d`:

```
/*
 * Count off and report the number of seconds elapsed
 */

dtrace:::BEGIN
{
  i = 0;
}

profile:::tick-1sec
{
  i = i + 1;
  trace(i);
}

dtrace:::END
{
  trace(i);
}
```

When executed, the program counts off the number of elapsed seconds until you press `Ctrl-C`, and then prints the total at the end:

```
# dtrace -s counter.d
dtrace: script 'counter.d' matched 3 probes
CPU     ID                    FUNCTION:NAME
  1    638                       :tick-1sec         1
  1    638                       :tick-1sec         2
  1    638                       :tick-1sec         3
  1    638                       :tick-1sec         4
  1    638                       :tick-1sec         5
  1    638                       :tick-1sec         6
  1    638                       :tick-1sec         7
^C
  1    638                       :tick-1sec         8
  0      2                            :END         8
```

The first three lines of the program are a comment to explain what the program does. Similar to C, C++, and the Java programming language, the D compiler ignores any characters between the `/*` and `*/` symbols. Comments can be used anywhere in a D program, including both inside and outside your probe clauses.

The `BEGIN` probe clause defines a new variable named `i` and assigns it the integer value zero using the statement:

```
i = 0;
```

Unlike C, C++, and the Java programming language, D variables can be created by simply using them in a program statement; explicit variable declarations are not required. When a variable is used for the first time in a program, the type of the variable is set based on the type of its first assignment. Each variable has only one type over the lifetime of the program, so

subsequent references must conform to the same type as the initial assignment. In `counter.d`, the variable `i` is first assigned the integer constant zero, so its type is set to `int`. D provides the same basic integer data types as C, including those in the following table.

Data Type	Description
`char`	Character or single byte integer
`int`	Default integer
`short`	Short integer
`long`	Long integer
`long long`	Extended long integer

The sizes of these types are dependent on the operating system kernel's data model, described in Types, Operators, and Expressions. D also provides built-in friendly names for signed and unsigned integer types of various fixed sizes, as well as thousands of other types that are defined by the operating system.

The central part of `counter.d` is the probe clause that increments the counter `i`:

```
profile:::tick-1sec
{
  i = i + 1;
  trace(i);
}
```

This clause names the probe `profile:::tick-1sec`, which tells the `profile` provider to create a new probe that fires once per second on an available processor. The clause contains two statements, the first incrementing `i`, and the second tracing (printing) the new value of `i`. All the usual C arithmetic operators are available in D. For the complete list, see Types, Operators, and Expressions. The `trace` function takes any D expression as its argument, so you could write `counter.d` more concisely as follows:

```
profile:::tick-1sec
{
  trace(++i);
}
```

If you want to explicitly control the type of the variable `i`, you can surround the desired type in parentheses when you assign it in order to *cast* the integer zero to a specific type. For example, if you wanted to determine the maximum size of a `char` in D, you could change the `BEGIN` clause as follows:

```
dtrace:::BEGIN
{
  i = (char)0;
}
```

After running `counter.d` for a while, you should see the traced value grow and then wrap around back to zero. If you grow impatient waiting for the value to wrap, try changing the `profile` probe name to `profile:::tick-100msec` to make a counter that increments once every 100 milliseconds, or 10 times per second.

Predicate Examples

For runtime safety, one major difference between D and other programming languages such as C, C++, and the Java programming language is the absence of control-flow constructs such as `if`-statements and loops. D program clauses are written as single straight-line statement lists that trace an optional, fixed amount of data. D does provide the ability to conditionally trace data and modify control flow using logical expressions called *predicates*. A predicate expression is evaluated at probe firing time prior to executing any of the statements associated with the corresponding clause. If the predicate evaluates to true, represented by any non-zero value, the statement list is executed. If the predicate is false, represented by a zero value, none of the statements are executed and the probe firing is ignored.

Type the following source code for the next example and save it in a file named `countdown.d`:

```
dtrace:::BEGIN
{
  i = 10;
}

profile:::tick-1sec
/i > 0/
{
  trace(i--);
}

profile:::tick-1sec
/i == 0/
{
  trace("blastoff!");
  exit(0);
}
```

This D program implements a 10-second countdown timer using predicates. When executed, `countdown.d` counts down from 10 and then prints a message and exits:

```
# dtrace -s countdown.d
dtrace: script 'countdown.d' matched 3 probes
CPU     ID                    FUNCTION:NAME
  0    638                       :tick-1sec        10
  0    638                       :tick-1sec         9
  0    638                       :tick-1sec         8
  0    638                       :tick-1sec         7
  0    638                       :tick-1sec         6
  0    638                       :tick-1sec         5
  0    638                       :tick-1sec         4
  0    638                       :tick-1sec         3
  0    638                       :tick-1sec         2
  0    638                       :tick-1sec         1
  0    638                       :tick-1sec   blastoff!
#
```

This example uses the `BEGIN` probe to initialize an integer `i` to 10 to begin the countdown. Next, as in the previous example, the program uses the `tick-1sec` probe to implement a timer that fires once per second. Notice that in `countdown.d`, the `tick-1sec` probe description is used in two different clauses, each with a different predicate and action list. The predicate is a logical expression surrounded by enclosing slashes `//` that appears after the probe name and before the braces `{}` that surround the clause statement list.

The first predicate tests whether `i` is greater than zero, indicating that the timer is still running:

```
profile:::tick-1sec
/i > 0/
{
  trace(i--);
}
```

The relational operator `>` means *greater than* and returns the integer value zero for false and one for true. All of the C relational operators are supported in D. For the complete list, see Types, Operators, and Expressions. If `i` is not yet zero, the script traces `i` and then decrements it by one using the `--` operator.

The second predicate uses the `==` operator to return true when `i` is exactly equal to zero, indicating that the countdown is complete:

```
profile:::tick-1sec
/i == 0/
{
  trace("blastoff!");
  exit(0);
}
```

Similar to the first example, `hello.d`, `countdown.d` uses a sequence of characters enclosed in double quotes, called a *string constant*, to print a final message when the countdown is complete. The `exit` function is then used to exit `dtrace` and return to the shell prompt.

If you look back at the structure of `countdown.d`, you will see that by creating two clauses with the same probe description but different predicates and actions, we effectively created the logical flow:

```
i = 10
once per second,
  if i is greater than zero
    trace(i--);
  if i is equal to zero
    trace("blastoff!");
    exit(0);
```

When you wish to write complex programs using predicates, try to first visualize your algorithm in this manner, and then transform each path of your conditional constructs into a separate clause and predicate.

Now let us combine predicates with a new provider, the `syscall` provider, and create our first real D tracing program. The `syscall` provider permits you to enable probes on entry to or return from any Oracle Linux system call. The next example uses DTrace to observe every time your shell performs a `read()` or `write()` system call. First, open two windows, one to use for DTrace and the other containing the shell process that you are going to watch. In the second window, type the following command to obtain the process ID of this shell:

```
# echo $$
2860
```

Now go back to your first window and type the following D program and save it in a file named `rw.d`. As you type in the program, replace the integer constant `2860` with the process ID of the shell that was printed in response to your `echo` command.

```
syscall::read:entry,
syscall::write:entry
/pid == 2860/
```

```
{
}
```

Notice that the body of `rw.d`'s probe clause is left empty because the program is only intended to trace notification of probe firings and not to trace any additional data. Once you have typed in `rw.d`, use `dtrace` to start your experiment and then go to your second shell window and type a few commands, pressing return after each command. As you type, you should see `dtrace` report probe firings in your first window, similar to the following example:

```
# dtrace -s rw.d
dtrace: script 'rw.d' matched 2 probes
CPU     ID                    FUNCTION:NAME
  1      7                      write:entry
  1      5                       read:entry
  0      7                      write:entry
  0      5                       read:entry
  0      7                      write:entry
  0      5                       read:entry
  0      7                      write:entry
  0      5                       read:entry
  0      7                      write:entry
  1      7                      write:entry
  1      7                      write:entry
  1      5                       read:entry
...^C
```

You are now watching your shell perform `read()` and `write()` system calls to read a character from your terminal window and echo back the result. This example includes many of the concepts described so far and a few new ones as well. First, to instrument `read()` and `write()` in the same manner, the script uses a single probe clause with multiple probe descriptions by separating the descriptions with commas like this:

```
syscall::read:entry,
syscall::write:entry
```

For readability, each probe description appears on its own line. This arrangement is not strictly required, but it makes for a more readable script. Next the script defines a predicate that matches only those system calls that are executed by your shell process:

```
/pid == 2860/
```

The predicate uses the predefined DTrace variable `pid`, which always evaluates to the process ID associated with the thread that fired the corresponding probe. DTrace provides many built-in variable definitions for useful things like the process ID. The following table lists a few DTrace variables you can use to write your first D programs.

Variable Name	Data Type	Meaning
`errno`	`int`	Current `errno` value for system calls
`execname`	`string`	Name of the current process's executable file
`pid`	`pid_t`	Process ID of the current process
`tid`	`id_t`	Thread ID of the current thread
`probeprov`	`string`	Current probe description's provider field

Variable Name	Data Type	Meaning
probemod	string	Current probe description's module field
probefunc	string	Current probe description's function field
probename	string	Current probe description's name field

Now that you've written a real instrumentation program, try experimenting with it on different processes running on your system by changing the process ID and the system call probes that are instrumented. Then, you can make one more simple change and turn `rw.d` into a very simple version of a system call tracing tool like `strace`. An empty probe description field acts as a wildcard, matching any probe, so change your program to the following new source code to trace any system call executed by your shell:

```
syscall:::entry
/pid == 2860/
{
}
```

Try typing a few commands in the shell such as `cd`, `ls`, and `date` and see what your DTrace program reports.

Output Formatting Examples

System call tracing is a powerful way to observe the behavior of many user processes. The following example improves upon the earlier `rw.d` program by formatting its output so you can more easily understand the output. Type the following program and save it in a file called `stracerw.d`:

```
syscall::read:entry,
syscall::write:entry
/pid == $1/
{
  printf("%s(%d, 0x%x, %4d)", probefunc, arg0, arg1, arg2);
}

syscall::read:return,
syscall::write:return
/pid == $1/
{
  printf("\tt = %d\n", arg1);
}
```

In this example, the constant `2860` is replaced with the label `$1` in each predicate. This label enables you to specify the process of interest as an *argument* to the script: `$1` is replaced by the value of the first argument when the script is compiled. To execute `stracerw.d`, use the `dtrace` options `-q` and `-s`, followed by the process ID of your shell as the final argument. The `-q` option indicates that `dtrace` should be quiet and suppress the header line and the CPU and ID columns shown in the preceding examples. As a result, you only see the output for the data that you explicitly trace. Type the following command, replacing `2860` with the process ID of a shell process, and then press return a few times in the specified shell:

```
# dtrace -q -s stracerw.d 2860
        t = 1
```

```
write(2, 0x7fa621b9b000,    1)  t = 1
write(1, 0x7fa621b9c000,   22)  t = 22
write(2, 0x7fa621b9b000,   20)  t = 20
read(0, 0x7fff60f74b8f,    1)   t = 1
write(2, 0x7fa621b9b000,    1)  t = 1
write(1, 0x7fa621b9c000,   22)  t = 22
write(2, 0x7fa621b9b000,   20)  t = 20
read(0, 0x7fff60f74b8f,    1)   t = 1
write(2, 0x7fa621b9b000,    1)  t = 1
write(1, 0x7fa621b9c000,   22)  t = 22
write(2, 0x7fa621b9b000,   20)  t = 20
read(0, 0x7fff60f74b8f,    1)^C
#
```

Now let us examine your D program and its output in more detail. First, a clause similar to the earlier program instruments each of the shell's calls to `read()` and `write()`. But for this example, we use a new function, `printf`, to trace the data and print it out in a specific format:

```
syscall::read:entry,
syscall::write:entry
/pid == $1/
{
  printf("%s(%d, 0x%x, %4d)", probefunc, arg0, arg1, arg2);
}
```

The `printf` function combines the ability to trace data, as if by the `trace` function used earlier, with the ability to output the data and other text in a specific format that you describe. The `printf` function tells DTrace to trace the data associated with each argument after the first argument, and then to format the results using the rules described by the first `printf` argument, known as a *format string*.

The format string is a regular string that contains any number of format conversions, each beginning with the `%` character, that describe how to format the corresponding argument. The first conversion in the format string corresponds to the second `printf` argument, the second conversion to the third argument, and so on. All of the text between conversions is printed verbatim. The character following the `%` conversion character describes the format to use for the corresponding argument. Here are the meanings of the three format conversions used in `stracerw.d`.

Format Conversion	Description
`%d`	Print the corresponding value as a decimal integer
`%s`	Print the corresponding value as a string
`%x`	Print the corresponding value as a hexadecimal integer

DTrace `printf` works just like the C `printf()` library routine or the shell `printf` utility. If you have never seen `printf` before, the formats and options are explained in detail in Output Formatting. You should read this chapter carefully even if you are already familiar with `printf` from another language. In D, `printf` is provided as a built-in and some new format conversions are available to you designed specifically for DTrace.

To help you write correct programs, the D compiler validates each `printf` format string against its argument list. Try changing `probefunc` in the clause above to the integer `123`. If you run the modified program, you will see an error message telling you that the string format conversion `%s` is not appropriate for use with an integer argument:

```
# dtrace -q -s stracerw.d
dtrace: failed to compile script stracerw.d: line 5: printf( )
argument #2 is incompatible with conversion #1 prototype:
    conversion: %s
     prototype: char [] or string (or use stringof)
      argument: int
#
```

To print the name of the read or write system call and its arguments, use the `printf` statement:

```
printf("%s(%d, 0x%x, %4d)", probefunc, arg0, arg1, arg2);
```

to trace the name of the current probe function and the first three integer arguments to the system call, available in the DTrace variables `arg0`, `arg1`, and `arg2`. For more information about probe arguments, see Built-In Variables. The first argument to `read()` and `write()` is a file descriptor, printed in decimal. The second argument is a buffer address, formatted as a hexadecimal value. The final argument is the buffer size, formatted as a decimal value. The format specifier `%4d` is used for the third argument to indicate that the value should be printed using the `%d` format conversion with a minimum field width of 4 characters. If the integer is less than 4 characters wide, `printf` inserts extra blanks to align the output.

To print the result of the system call and complete each line of output, use the following clause:

```
syscall::read:return,
syscall::write:return
/pid == $1/
{
  printf("\tt = %d\n", arg1);
}
```

Notice that the `syscall` provider also publishes a probe named `return` for each system call in addition to `entry`. The DTrace variable `arg1` for the syscall `return` probes evaluates to the system call's return value. The return value is formatted as a decimal integer. The character sequences beginning with backwards slashes in the format string expand to tab (`\t`) and newline (`\n`) respectively. These *escape sequences* help you print or record characters that are difficult to type. D supports the same set of escape sequences as C, C++, and the Java programming language. For a complete list of escape sequences, see Constants.

Array Overview

D permits you to define variables that are integers, as well as other types to represent strings and composite types called *structs* and *unions*. If you are familiar with C programming, you will be happy to know you can use any type in D that you can in C. If you are not a C expert, do not worry: the different kinds of data types are all described in Types, Operators, and Expressions.

D also supports arrays. Linearly indexed scalar arrays, familiar to C programmers, are discussed in Array Declarations and Storage.

More powerful and commonly used are *associative arrays*, which are indexed with *tuples*. Each associative array has a particular type signature. That is, its tuples all have the same number of elements, those elements of consistent type and in the same order, and its values are all of the same type. D associative arrays are described further in Associative Arrays.

Associative Array Example

For example, the following D statements access an associative array, whose values must all be type `int` and whose tuples must all have signature `string,int`, setting an element to 456 and then incrementing it to 457:

```
a["hello", 123] = 456;
a["hello", 123]++;
```

Now let us use an associative array in a D program. Type the following program and save it in a file named `rwtime.d`:

```
syscall::read:entry,
syscall::write:entry
/pid == $1/
{
  ts[probefunc] = timestamp;
}
syscall::read:return,
syscall::write:return
/pid == $1 && ts[probefunc] != 0/
{
  printf("%d nsecs", timestamp - ts[probefunc]);
}
```

As with `stracerw.d`, specify the ID of the shell process when you execute `rwtime.d`. If you type a few shell commands, you will see the time elapsed during each system call. Type in the following command and then press return a few times in your other shell:

```
# dtrace -s rwtime.d `/usr/bin/pgrep -n bash`
dtrace: script 'rwtime.d' matched 4 probes
CPU     ID                    FUNCTION:NAME
  0      8                     write:return 51962 nsecs
  0      8                     write:return 45257 nsecs
  0      8                     write:return 40787 nsecs
  1      6                      read:return 925959305 nsecs
  1      8                     write:return 46934 nsecs
  1      8                     write:return 41626 nsecs
  1      8                     write:return 176839 nsecs
...
^C
#
```

To trace the elapsed time for each system call, you must instrument both the entry to and return from `read()` and `write()` and measure the time at each point. Then, on return from a given system call, you must compute the difference between our first and second timestamp. You could use separate variables for each system call, but this would make the program annoying to extend to additional system calls. Instead, it is easier to use an associative array indexed by the probe function name. The following is the first probe clause:

```
syscall::read:entry,
syscall::write:entry
/pid == $1/
{
  ts[probefunc] = timestamp;
}
```

This clause defines an array named `ts` and assigns the appropriate member the value of the DTrace variable `timestamp`. This variable returns the value of an always-incrementing

nanosecond counter. When the entry timestamp is saved, the corresponding return probe samples `timestamp` again and reports the difference between the current time and the saved value:

```
syscall::read:return,
syscall::write:return
/pid == $1 && ts[probefunc] != 0/
{
  printf("%d nsecs", timestamp - ts[probefunc]);
}
```

The predicate on the return probe requires that DTrace is tracing the appropriate process and that the corresponding `entry` probe has already fired and assigned `ts[probefunc]` a non-zero value. This trick eliminates invalid output when DTrace first starts. If your shell is already waiting in a `read()` system call for input when you execute `dtrace`, the `read:return` probe fires without a preceding `read:entry` for this first `read()` and `ts[probefunc]` will evaluate to zero because it has not yet been assigned.

External Symbols and Types

DTrace instrumentation executes inside the Oracle Linux operating system kernel. So, in addition to accessing special DTrace variables and probe arguments, you can also access kernel data structures, symbols, and types. These capabilities enable advanced DTrace users, administrators, service personnel, and driver developers to examine low-level behavior of the operating system kernel and device drivers. The reading list at the start of this guide includes books that can help you learn more about Oracle Linux operating system internals.

D uses the back quote character (`) as a special scoping operator for accessing symbols that are defined in the operating system and not in your D program. For example, the Oracle Linux kernel contains a C declaration of a system variable named `max_pfn`. This variable is declared in C in the kernel source code as follows:

```
unsigned long max_pfn
```

To trace the value of this variable in a D program, you can write the following D statement:

```
trace(`max_pfn);
```

DTrace associates each kernel symbol with the type that is used for the symbol in the corresponding operating system C code, which provides easy source-based access to the native operating system data structures.

To use external operating system variables, you will need access to the corresponding operating system source code.

Kernel symbol names are kept in a separate namespace from D variable and function identifiers, so you do not need to be concerned about these names conflicting with your D variables. When you prefix a variable with a back quote, the D compiler searches the known kernel symbols and uses the list of loaded modules to find a matching variable definition. Because the Oracle Linux kernel supports dynamically loaded modules with separate symbol namespaces, the same variable name might be used more than once in the active operating system kernel. You can resolve these name conflicts by specifying the name of the kernel module that contains the variable to be accessed prior to the back quote in the symbol name. For example, you would refer to the address of the `_bar` function that is provided by a kernel module named `foo` as follows:

```
foo`_bar
```

You can apply any of the D operators to external variables, except for those that modify values, subject to the usual rules for operand types. When required, the D compiler loads the variable names that correspond to active kernel modules, so you do not need to declare these variables. You may not apply any operator to an external variable that modifies its value, such as = or +=. For safety reasons, DTrace prevents you from damaging or corrupting the state of the software that you are observing.

When you access external variables from a D program, you are accessing the internal implementation details of another program, such as the operating system kernel or its device drivers. These implementation details do not form a stable interface upon which you can rely. Any D programs you write that depend on these details might cease to work when you next upgrade the corresponding piece of software. For this reason, external variables are typically used to debug performance or functionality problems by using DTrace. To learn more about the stability of your D programs, see DTrace Stability Features.

You have now completed a whirlwind tour of DTrace and have learned many of the basic DTrace building blocks that are necessary to build larger and more complex D programs. The remaining portions of this chapter describe the complete set of rules for D and demonstrate how DTrace can make complex performance measurements and functional analysis of the system easy. Later, you will learn how to use DTrace to connect user application behavior to system behavior, which provides you with the capability to analyze your entire software stack.

Types, Operators, and Expressions

D provides the ability to access and manipulate a variety of data objects: variables and data structures can be created and modified, data objects that are defined in the operating system kernel and user processes can be accessed, and integer, floating-point, and string constants can be declared. D provides a superset of the ANSI C operators that are used to manipulate objects and create complex expressions. This section describes the detailed set of rules for types, operators, and expressions.

Identifier Names and Keywords

D identifier names are composed of uppercase and lowercase letters, digits, and underscores, where the first character must be a letter or underscore. All identifier names beginning with an underscore (_) are reserved for use by the D system libraries. You should avoid using these names in your D programs. By convention, D programmers typically use mixed-case names for variables and all uppercase names for constants.

D language keywords are special identifiers that are reserved for use in the programming language syntax itself. These names are always specified in lowercase and must not be used for the names of D variables. The following table lists the keywords that are reserved for use by the D language.

Table 2-2 D Keywords

auto*	do*	if*	register*	string+	unsigned
break*	double	import*+	restrict*	stringof+	void
case*	else*	inline	return*	struct	volatile
char	enum	int	self+	switch*	while*
const	extern	long	short	this+	xlate+
continue*	float	offsetof+	signed	translator+	

Table 2-2 (Cont.) D Keywords

counter*+	for*	probe*+	sizeof	typedef
default*	goto*	provider*+	static*	union

D reserves for use as keywords a superset of the ANSI C keywords. The keywords reserved for future use by the D language are marked with "*". The D compiler produces a syntax error if you attempt to use a keyword that is reserved for future use. The keywords that are defined by D but not defined by ANSI C are marked with "+". D provides the complete set of types and operators found in ANSI C. The major difference in D programming is the absence of control-flow constructs. Note that keywords associated with control-flow in ANSI C are reserved for future use in D.

Data Types and Sizes

D provides fundamental data types for integers and floating-point constants. Arithmetic may only be performed on integers in D programs. Floating-point constants may be used to initialize data structures, but floating-point arithmetic is not permitted in D. In Oracle Linux, D provides a 64-bit data model for use in writing programs. However, a 32-bit data model is not supported. The data model used when executing your program is the native data model that is associated with the active operating system kernel, which must also be 64-bit.

The names of the integer types and their sizes in the 64-bit data model are shown in the following table. Integers are always represented in twos-complement form in the native byte-encoding order of your system.

Table 2-3 D Integer Data Types

Type Name	64-bit Size
char	1 byte
short	2 bytes
int	4 bytes
long	8 bytes
long long	8 bytes

Integer types can be prefixed with the signed or unsigned qualifier. If no sign qualifier is present, it is assumed that the type is signed. The D compiler also provides the type aliases that are listed in the following table.

Table 2-4 D Integer Type Aliases

Type Name	Description
int8_t	1-byte signed integer
int16_t	2-byte signed integer
int32_t	4-byte signed integer
int64_t	8-byte signed integer
intptr_t	Signed integer of size equal to a pointer

Table 2-4 (Cont.) D Integer Type Aliases

Type Name	Description
`uint8_t`	1-byte unsigned integer
`uint16_t`	2-byte unsigned integer
`uint32_t`	4-byte unsigned integer
`uint64_t`	8-byte unsigned integer
`uintptr_t`	Unsigned integer of size equal to a pointer

These type aliases are equivalent to using the name of the corresponding base type listed in the previous table and are appropriately defined for each data model. For example, the `uint8_t` type name is an alias for the type unsigned `char`. See Type and Constant Definitions for information about how to define your own type aliases for use in D programs.

> **Note:**
>
> The predefined type aliases cannot be used in files that are included by the preprocessor.

D provides floating-point types for compatibility with ANSI C declarations and types. Floating-point operators are not supported in D, but floating-point data objects can be traced and formatted with the `printf` function. You can use the floating-point types that are listed in the following table.

Table 2-5 D Floating-Point Data Types

Type Name	64-bit Size
`float`	4 bytes
`double`	8 bytes
`long double`	16 bytes

D also provides the special type `string` to represent ASCII strings. Strings are discussed in more detail in DTrace Support for Strings.

Constants

Integer constants can be written in decimal (`12345`), octal (`012345`), or hexadecimal (`0x12345`) format. Octal (base 8) constants must be prefixed with a leading zero. Hexadecimal (base 16) constants must be prefixed with either `0x` or `0X`. Integer constants are assigned the smallest type among `int`, `long`, and `long long` that can represent their value. If the value is negative, the signed version of the type is used. If the value is positive and too large to fit in the signed type representation, the unsigned type representation is used. You can apply one of the suffixes listed in the following table to any integer constant to explicitly specify its D type.

Suffix	D type
`u` or `U`	`unsigned` version of the type selected by the compiler
`l` or `L`	`long`
`ul` or `UL`	`unsigned long`
`ll` or `LL`	`long long`
`ull` or `ULL`	`unsigned long long`

Floating-point constants are always written in decimal format and must contain either a decimal point (`12.345`), an exponent (`123e45`), or both (`123.34e-5`). Floating-point constants are assigned the type `double` by default. You can apply one of the suffixes listed in the following table to any floating-point constant to explicitly specify its D type.

Suffix	D type
`f` or `F`	`float`
`l` or `L`	`long double`

Character constants are written as a single character or escape sequence that is enclosed in a pair of single quotes (`'a'`). Character constants are assigned the `int` type rather than `char` and are equivalent to an integer constant with a value that is determined by that character's value in the ASCII character set. See the `ascii(7)` manual page for a list of characters and their values. You can also use any of the special escape sequences that are listed in the following table in your character constants. D supports the same escape sequences as those found in ANSI C.

Table 2-6 Character Escape Sequences

Escape Sequence	Represents	Escape Sequence	Represents
`\a`	alert	`\\`	backslash
`\b`	backspace	`\?`	question mark
`\f`	form feed	`\'`	single quote
`\n`	newline	`\"`	double quote
`\r`	carriage return	`\0`*oo*	octal value 0*oo*
`\t`	horizontal tab	`\x`*hh*	hexadecimal value 0x*hh*
`\v`	vertical tab	`\0`	null character

You can include more than one character specifier inside single quotes to create integers with individual bytes that are initialized according to the corresponding character specifiers. The bytes are read left-to-right from your character constant and assigned to the resulting integer in the order corresponding to the native endianness of your operating environment. Up to eight character specifiers can be included in a single character constant.

Strings constants of any length can be composed by enclosing them in a pair of double quotes (`"hello"`). A string constant may not contain a literal newline character. To create strings containing newlines, use the `\n` escape sequence instead of a literal newline. String constants

can contain any of the special character escape sequences that are shown for character constants previously. Similar to ANSI C, strings are represented as arrays of characters terminated by a null character (`\0`) that is implicitly added to each string constant you declare. String constants are assigned the special D type `string`. The D compiler provides a set of special features for comparing and tracing character arrays that are declared as strings. See DTrace Support for Strings for more information.

Arithmetic Operators

D provides the binary arithmetic operators that are described in the following table for use in your programs. These operators all have the same meaning for integers that they do in ANSI C.

Table 2-7 Binary Arithmetic Operators

Operator	Description
+	Integer addition
-	Integer subtraction
*	Integer multiplication
/	Integer division
%	Integer modulus

Arithmetic in D may only be performed on integer operands or on pointers. See Pointers and Scalar Arrays. Arithmetic may not be performed on floating-point operands in D programs. The DTrace execution environment does not take any action on integer overflow or underflow. You must specifically check for these conditions in situations where overflow and underflow can occur.

However, the DTrace execution environment does automatically check for and report division by zero errors resulting from improper use of the `/` and `%` operators. If a D program executes an invalid division operation, DTrace automatically disables the affected instrumentation and reports the error. Errors that are detected by DTrace have no effect on other DTrace users or on the operating system kernel. You therefore do not need to be concerned about causing any damage if your D program inadvertently contains one of these errors.

In addition to these binary operators, the `+` and `-` operators can also be used as unary operators as well, and these operators have higher precedence than any of the binary arithmetic operators. The order of precedence and associativity properties for all of the D operators is presented in Table 2-12. You can control precedence by grouping expressions in parentheses (`()`).

Relational Operators

D provides the binary relational operators that are described in the following table for use in your programs. These operators all have the same meaning that they do in ANSI C.

Table 2-8 D Relational Operators

Operator	Description
<	Left-hand operand is less than right-operand

Table 2-8 (Cont.) D Relational Operators

Operator	Description
<=	Left-hand operand is less than or equal to right-hand operand
>	Left-hand operand is greater than right-hand operand
>=	Left-hand operand is greater than or equal to right-hand operand
==	Left-hand operand is equal to right-hand operand
!=	Left-hand operand is not equal to right-hand operand

Relational operators are most frequently used to write D predicates. Each operator evaluates to a value of type `int`, which is equal to one if the condition is `true`, or zero if it is `false`.

Relational operators can be applied to pairs of integers, pointers, or strings. If pointers are compared, the result is equivalent to an integer comparison of the two pointers interpreted as unsigned integers. If strings are compared, the result is determined as if by performing a `strcmp()` on the two operands. The following table shows some example D string comparisons and their results.

D string comparison	Result
`"coffee" < "espresso"`	Returns 1 (`true`)
`"coffee" == "coffee"`	Returns 1 (`true`)
`"coffee"" >= "mocha"`	Returns 0 (`false`)

Relational operators can also be used to compare a data object associated with an enumeration type with any of the enumerator tags defined by the enumeration. Enumerations are a facility for creating named integer constants and are described in more detail in Type and Constant Definitions.

Logical Operators

D provides the binary logical operators that are listed in the following table for use in your programs. The first two operators are equivalent to the corresponding ANSI C operators.

Table 2-9 D Logical Operators

Operator	Description
&&	Logical `AND`: true if both operands are true
||	Logical `OR`: true if one or both operands are true
^^	Logical `XOR`: true if exactly one operand is true

Logical operators are most frequently used in writing D predicates. The logical `AND` operator performs the following short-circuit evaluation: if the left-hand operand is false, the right-hand expression is not evaluated. The logical `OR` operator also performs the following short-circuit

evaluation: if the left-hand operand is true, the right-hand expression is not evaluated. The logical `XOR` operator does not short-circuit. Both expression operands are always evaluated.

In addition to the binary logical operators, the unary `!` operator can be used to perform a logical negation of a single operand: it converts a zero operand into a one and a non-zero operand into a zero. By convention, D programmers use `!` when working with integers that are meant to represent boolean values and `== 0` when working with non-boolean integers, although the expressions are equivalent.

The logical operators may be applied to operands of integer or pointer types. The logical operators interpret pointer operands as unsigned integer values. As with all logical and relational operators in D, operands are true if they have a non-zero integer value and false if they have a zero integer value.

Bitwise Operators

D provides the binary operators that are listed in the following table for manipulating individual bits inside of integer operands. These operators all have the same meaning as in ANSI C.

Table 2-10 D Bitwise Operators

Operator	Description
`&`	Bitwise `AND`
`|`	Bitwise `OR`
`^`	Bitwise `XOR`
`<<`	Shift the left-hand operand left by the number of bits specified by the right-hand operand
`>>`	Shift the left-hand operand right by the number of bits specified by the right-hand operand

The binary `&` operator is used to clear bits from an integer operand. The binary `|` operator is used to set bits in an integer operand. The binary `^` operator returns one in each bit position, exactly where one of the corresponding operand bits is set.

The shift operators are used to move bits left or right in a given integer operand. Shifting left fills empty bit positions on the right-hand side of the result with zeroes. Shifting right using an unsigned integer operand fills empty bit positions on the left-hand side of the result with zeroes. Shifting right using a signed integer operand fills empty bit positions on the left-hand side with the value of the sign bit, also known as an *arithmetic shift* operation.

Shifting an integer value by a negative number of bits or by a number of bits larger than the number of bits in the left-hand operand itself produces an undefined result. The D compiler produces an error message if the compiler can detect this condition when you compile your D program.

In addition to the binary logical operators, the unary `~` operator may be used to perform a bitwise negation of a single operand: it converts each zero bit in the operand into a one bit, and each one bit in the operand into a zero bit.

Assignment Operators

D provides the binary assignment operators that are listed in the folloiwng table for modifying D variables. You can only modify D variables and arrays. Kernel data objects and constants may

not be modified using the D assignment operators. The assignment operators have the same meaning as they do in ANSI C.

Table 2-11 D Assignment Operators

Operator	Description
=	Set the left-hand operand equal to the right-hand expression value.
+=	Increment the left-hand operand by the right-hand expression value
-=	Decrement the left-hand operand by the right-hand expression value.
*=	Multiply the left-hand operand by the right-hand expression value.
/=	Divide the left-hand operand by the right-hand expression value.
%=	Modulo the left-hand operand by the right-hand expression value.
|=	Bitwise OR the left-hand operand with the right-hand expression value.
&=	Bitwise AND the left-hand operand with the right-hand expression value.
^=	Bitwise XOR the left-hand operand with the right-hand expression value.
<<=	Shift the left-hand operand left by the number of bits specified by the right-hand expression value.
>>=	Shift the left-hand operand right by the number of bits specified by the right-hand expression value.

Aside from the assignment operator `=`, the other assignment operators are provided as shorthand for using the `=` operator with one of the other operators that were described earlier. For example, the expression `x = x + 1` is equivalent to the expression `x += 1`, except that the expression `x` is evaluated one time. These assignment operators adhere to the same rules for operand types as the binary forms described earlier.

The result of any assignment operator is an expression equal to the new value of the left-hand expression. You can use the assignment operators or any of the operators described thus far in combination to form expressions of arbitrary complexity. You can use parentheses `()` to group terms in complex expressions.

Increment and Decrement Operators

D provides the special unary `++` and `--` operators for incrementing and decrementing pointers and integers. These operators have the same meaning as they do in ANSI C. These operators can only be applied to variables and they may be applied either before or after the variable name. If the operator appears before the variable name, the variable is first modified and then the resulting expression is equal to the new value of the variable. For example, the following two code fragments produce identical results:

```
x += 1; y = x;

y = ++x;
```

If the operator appears after the variable name, then the variable is modified after its current value is returned for use in the expression. For example, the following two code fragments produce identical results:

```
y = x; x -= 1;

y = x--;
```

You can use the increment and decrement operators to create new variables without declaring them. If a variable declaration is omitted and the increment or decrement operator is applied to a variable, the variable is implicitly declared to be of type `int64_t`.

The increment and decrement operators can be applied to integer or pointer variables. When applied to integer variables, the operators increment or decrement the corresponding value by one. When applied to pointer variables, the operators increment or decrement the pointer address by the size of the data type that is referenced by the pointer. Pointers and pointer arithmetic in D are discussed in Pointers and Scalar Arrays.

Conditional Expressions

Although D does not provide support for `if-then-else` constructs, it does provide support for simple conditional expressions by using the `?` and `:` operators. These operators enable a triplet of expressions to be associated, where the first expression is used to conditionally evaluate one of the other two.

For example, the following D statement could be used to set a variable `x` to one of two strings, depending on the value of `i`:

```
x = i == 0 ? "zero" : "non-zero";
```

In the previous example, the expression `i == 0` is first evaluated to determine whether it is true or false. If the expression is true, the second expression is evaluated and its value is returned. If the expression is false, the third expression is evaluated and its value is returned.

As with any D operator, you can use multiple `?:` operators in a single expression to create more complex expressions. For example, the following expression would take a `char` variable `c` containing one of the characters `0-9`, `a-f`, or `A-F`, and return the value of this character when interpreted as a digit in a hexadecimal (base 16) integer:

```
hexval = (c >= '0' && c <= '9') ? c - '0' : (c >= 'a' && c <= 'f') ? c + 10 - 'a' : c +
10 - 'A';
```

To be evaluated for its truth value, the first expression that is used with `?:` must be a pointer or integer. The second and third expressions can be of any compatible types. You may not construct a conditional expression where, for example, one path returns a string and another path returns an integer. The second and third expressions also may not invoke a tracing function such as `trace` or `printf`. If you want to conditionally trace data, use a predicate instead. See Predicate Examples for more information.

Type Conversions

When expressions are constructed by using operands of different but compatible types, type conversions are performed to determine the type of the resulting expression. The D rules for

type conversions are the same as the arithmetic conversion rules for integers in ANSI C. These rules are sometimes referred to as the *usual arithmetic conversions*.

A simple way to describe the conversion rules is as follows: each integer type is ranked in the order `char`, `short`, `int`, `long`, `long long`, with the corresponding unsigned types assigned a rank higher than its signed equivalent, but below the next integer type. When you construct an expression using two integer operands such as `x + y` and the operands are of different integer types, the operand type with the highest rank is used as the result type.

If a conversion is required, the operand with the lower rank is first *promoted* to the type of the higher rank. Promotion does not actually change the value of the operand: it simply extends the value to a larger container according to its sign. If an unsigned operand is promoted, the unused high-order bits of the resulting integer are filled with zeroes. If a signed operand is promoted, the unused high-order bits are filled by performing sign extension. If a signed type is converted to an unsigned type, the signed type is first sign-extended and then assigned the new, unsigned type that is determined by the conversion.

Integers and other types can also be explicitly *cast* from one type to another. In D, pointers and integers can be cast to any integer or pointer types, but not to other types. Rules for casting and promoting strings and character arrays are discussed in DTrace Support for Strings.

An integer or pointer cast is formed using an expression such as the following:

```
y = (int)x;
```

In this example, the destination type is enclosed in parentheses and used to prefix the source expression. Integers are cast to types of higher rank by performing promotion. Integers are cast to types of lower rank by zeroing the excess high-order bits of the integer.

Because D does not permit floating-point arithmetic, no floating-point operand conversion or casting is permitted and no rules for implicit floating-point conversion are defined.

Operator Precedence

Table 2-12 lists the D rules for operator precedence and associativity. These rules are somewhat complex, but they are necessary to provide precise compatibility with the ANSI C operator precedence rules. The following entries in the following table are in order from highest precedence to lowest precedence.

Table 2-12 D Operator Precedence and Associativity

Operators	Associativity
`() [] -> .`	Left to right
`! ~ ++ -- + - * & (`*type*`) sizeof stringof offsetof xlate`	Right to left
`* / %`	Left to right
`+ -`	Left to right
`<< >>`	Left to right
`< <= > >=`	Left to right
`== !=`	Left to right
`&`	Left to right
`^`	Left to right

Table 2-12 (Cont.) D Operator Precedence and Associativity

Operators	Associativity
`|`	Left to right
`&&`	Left to right
`^^`	Left to right
`||`	Left to right
`?:`	Right to left
`= += -= *= /= %= &= ^= ?= <<= >>=`	Right to left
`,`	Left to right

Several operators listed in the previous table that have not been discussed yet. These operators are described in subsequent chapters. The following table lists several miscellaneous operators that are provided by the D language.

Operators	Description	For More Information
`sizeof`	Computes the size of an object.	Structs and Unions
`offsetof`	Computes the offset of a type member.	Structs and Unions
`stringof`	Converts the operand to a string.	DTrace Support for Strings
`xlate`	Translates a data type.	Translators
unary `&`	Computes the address of an object.	Pointers and Scalar Arrays
unary `*`	Dereferences a pointer to an object.	Pointers and Scalar Arrays
`->` and `.`	Accesses a member of a structure or union type.	Structs and Unions

The comma (`,`) operator that is listed in the table is for compatibility with the ANSI C comma operator. It can be used to evaluate a set of expressions in left-to-right order and return the value of the right most expression. This operator is provided strictly for compatibility with C and should generally not be used.

The `()` entry listed in the table of operator precedence represents a function call. For examples of calls to functions, such as `printf` and `trace`, see Output Formatting. A comma is also used in D to list arguments to functions and to form lists of associative array keys. Note that this comma is not the same as the comma operator and does not guarantee left-to-right evaluation. The D compiler provides no guarantee regarding the order of evaluation of arguments to a function or keys to an associative array. Note that you should be careful of using expressions with interacting side-effects, such as the pair of expressions `i` and `i++`, in these contexts.

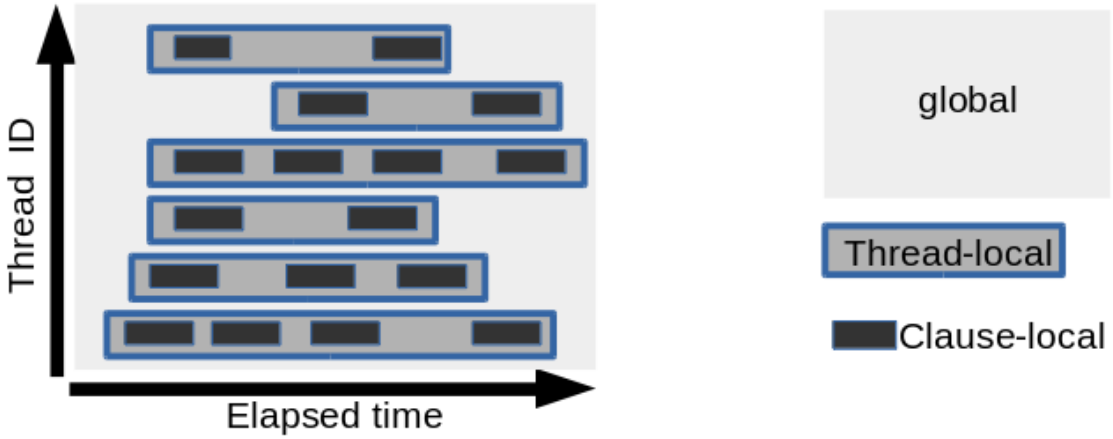
The `[]` entry listed in the table of operator precedence represents an array or associative array reference. Examples of associative arrays are presented in Associative Arrays. A special kind of associative array, called an *aggregation*, is described in Aggregations. The `[]` operator can also be used to index into fixed-size C arrays as well. See Pointers and Scalar Arrays.

Variables

D provides two basic types of variables for use in your tracing programs: scalar variables and associative arrays. An *aggregation* is a special kind of array variable. See Aggregations for more information about aggregations.

To understand the scope of variables, consider the following figure.

Scope of Variables



In the figure, system execution is illustrated, showing elapsed time along the horizontal axis and thread number along the vertical axis. D probes fire at different times on different threads, and each time a probe fires, the D script is run. Any D variable would have one of the scopes that are described in the following table.

Scope	Syntax	Initial Value	Thread-safe?	Description
global	*myname*	0	No	Any probe that fires on any thread accesses the same instance of the variable.
Thread-local	`self->`*myname*	0	Yes	Any probe that fires on a thread accesses the thread-specific instance of the variable.
Clause-local	`this->`*myname*	Not defined	Yes	Any probe that fires accesses an instance of the variable specific to that particular firing of the probe.

> **Note:**
>
> Note the following additional information:
>
> - Scalar variables and associative arrays have a global scope and are not multi-processor safe (MP-safe). Because the value of such variables can be changed by more than one processor, there is a chance that a variable can become corrupted if more than one probe modifies it.
> - Aggregations are MP-safe even though they have a global scope because independent copies are updated locally before a final aggregation produces the global result.

Scalar Variables

Scalar variables are used to represent individual, fixed-size data objects, such as integers and pointers. Scalar variables can also be used for fixed-size objects that are composed of one or more primitive or composite types. D provides the ability to create arrays of objects, as well as composite structures. DTrace also represents strings as fixed-size scalars by permitting them to grow to a predefined maximum length. Control over string length in your D program is discussed further in DTrace Support for Strings.

Scalar variables are created automatically the first time you assign a value to a previously undefined identifier in your D program. For example, to create a scalar variable named `x` of type `int`, you can simply assign it a value of type `int` in any probe clause, for example:

```
BEGIN
{
  x = 123;
}
```

Scalar variables that are created in this manner are *global variables*: each one is defined once and is visible in every clause of your D program. Any time that you reference the `x` identifier, you are referring to a single storage location associated with this variable.

Unlike ANSI C, D does not require explicit variable declarations. If you do want to declare a global variable and assign its name and type explicitly before using it, you can place a declaration outside of the probe clauses in your program, as shown in the following example:

```
int x; /* declare an integer x for later use */
BEGIN
{
  x = 123;
  ...
}
```

Explicit variable declarations are not necessary in most D programs, but sometimes are useful when you want to carefully control your variable types or when you want to begin your program with a set of declarations and comments documenting your program's variables and their meanings.

Unlike ANSI C declarations, D variable declarations may not assign initial values. You must use a `BEGIN` probe clause to assign any initial values. All global variable storage is filled with zeroes by DTrace before you first reference the variable.

The D language definition places no limit on the size and number of D variables. Limits are defined by the DTrace implementation and by the memory that is available on your system.

The D compiler enforces any of the limitations that can be applied at the time you compile your program. See Options and Tunables for more about how to tune options related to program limits.

Associative Arrays

Associative arrays are used to represent collections of data elements that can be retrieved by specifying a name, which is called a *key*. D associative array keys are formed by a list of scalar expression values, called a *tuple*. You can think of the array tuple as an imaginary parameter list to a function that is called to retrieve the corresponding array value when you reference the array. Each D associative array has a fixed *key signature* consisting of a fixed number of tuple elements, where each element has a given, fixed type. You can define different key signatures for each array in your D program.

Associative arrays differ from normal, fixed-size arrays in that they have no predefined limit on the number of elements: the elements can be indexed by any tuple, as opposed to just using integers as keys, and the elements are not stored in preallocated, consecutive storage locations. Associative arrays are useful in situations where you would use a hash table or other simple dictionary data structure in a C, C++, or Java language program. Associative arrays provide the ability to create a dynamic history of events and state captured in your D program, which you can use to create more complex control flows.

To define an associative array, you write an assignment expression of the following form:

```
name [ key ] = expression ;
```

where *name* is any valid D identifier and *key* is a comma-separated list of one or more expressions.

For example, the following statement defines an associative array a with key signature [`int, string`] and stores the integer value `456` in a location named by the tuple `[123, "hello"]`:

```
a[123, "hello"] = 456;
```

The type of each object that is contained in the array is also fixed for all elements in a given array. Because it was first assigned by using the integer `456`, every subsequent value that is stored in the array will also be of type `int`. You can use any of the assignment operators that are defined in Types, Operators, and Expressions to modify associative array elements, subject to the operand rules defined for each operator. The D compiler produces an appropriate error message if you attempt an incompatible assignment. You can use any type with an associative array key or value that can be used with a scalar variable.

You can reference an associative array by using any tuple that is compatible with the array key signature. The rules for tuple compatibility are similar to those for function calls and variable assignments. That is, the tuple must be of the same length and each type in the list of actual parameters and must be compatible with the corresponding type in the formal key signature. For example, for an associative array `x` that is defined as follows:

```
x[123ull] = 0;
```

The key signature is of type unsigned `long long` and the values are of type `int`. This array can also be referenced by using the expression `x['a']` because the tuple consisting of the character constant `'a'`, of type `int` and length one, is compatible with the key signature unsigned `long long`, according to the arithmetic conversion rules. These rules are described in Type Conversions.

If you need to explicitly declare a D associative array before using it, you can create a declaration of the array name and key signature outside of the probe clauses in your program source code, for example:

```
int x[unsigned long long, char];
BEGIN
{
  x[123ull, 'a'] = 456;
}
```

Storage is allocated only for array elements with a nonzero value.

> **Note:**
>
> When an associative array is defined, references to any tuple of a compatible key signature are permitted, even if the tuple in question has not been previously assigned. Accessing an unassigned associative array element is defined to return a zero-filled object. A consequence of this definition is that underlying storage is not allocated for an associative array element until a non-zero value is assigned to that element. Conversely, assigning an associative array element to zero causes DTrace to deallocate the underlying storage.
>
> This behavior is important because the dynamic variable space out of which associative array elements are allocated is finite; if it is exhausted when an allocation is attempted, the allocation fails and an error message indicating a dynamic variable drop is generated. Always assign zero to associative array elements that are no longer in use. See Options and Tunables for information about techniques that you can use to eliminate dynamic variable drops.

Thread-Local Variables

DTrace provides the ability to declare variable storage that is local to each operating system thread, as opposed to the global variables demonstrated earlier in this chapter. Thread-local variables are useful in situations where you want to enable a probe and mark every thread that fires the probe with some tag or other data. Creating a program to solve this problem is easy in D because thread-local variables share a common name in your D code, but refer to separate data storage that is associated with each thread.

Thread-local variables are referenced by applying the `->` operator to the special identifier `self`, for example:

```
syscall::read:entry
{
  self->read = 1;
}
```

This D fragment example enables the probe on the `read()` system call and associates a thread-local variable named `read` with each thread that fires the probe. Similar to global variables, thread-local variables are created automatically on their first assignment and assume the type that is used on the right-hand side of the first assignment statement, which is `int` in this example.

Each time the `self->read` variable is referenced in your D program, the data object that is referenced is the one associated with the operating system thread that was executing when the corresponding DTrace probe fired. You can think of a thread-local variable as an

associative array that is implicitly indexed by a tuple that describes the thread's identity in the system. A thread's identity is unique over the lifetime of the system: if the thread exits and the same operating system data structure is used to create a new thread, this thread does not reuse the same DTrace thread-local storage identity.

When you have defined a thread-local variable, you can reference it for any thread in the system, even if the variable in question has not been previously assigned for that particular thread. If a thread's copy of the thread-local variable has not yet been assigned, the data storage for the copy is defined to be filled with zeroes. As with associative array elements, underlying storage is not allocated for a thread-local variable until a non-zero value is assigned to it. Also, as with associative array elements, assigning zero to a thread-local variable causes DTrace to deallocate the underlying storage. Always assign zero to thread-local variables that are no longer in use. For other techniques to fine-tune the dynamic variable space from which thread-local variables are allocated, see Options and Tunables.

Thread-local variables of any type can be defined in your D program, including associative arrays. The following are some example thread-local variable definitions:

```
self->x = 123; /* integer value */

self->s = "hello"; /* string value */

self->a[123, 'a'] = 456; /* associative array */
```

Like any D variable, you do not need to explicitly declare thread-local variables prior to using them. If you want to create a declaration anyway, you can place one outside of your program clauses by pre-pending the keyword `self`, for example:

```
self int x; /* declare int x as a thread-local variable */
syscall::read:entry
{
  self->x = 123;
}
```

Thread-local variables are kept in a separate namespace from global variables so that you can reuse names. Remember that `x` and `self->x` are not the same variable if you overload names in your program.

The following example shows how to use thread-local variables. In an editor, type the following program and save it in a file named `rtime.d`:

```
syscall::read:entry
{
  self->t = timestamp;
}

syscall::read:return
/self->t != 0/
{
  printf("%d/%d spent %d nsecs in read()\n", pid, tid, timestamp - self->t);
  /*
   * We are done with this thread-local variable; assign zero to it
   * to allow the DTrace runtime to reclaim the underlying storage.
   */
  self->t = 0;
}
```

Next, in your shell, start the program running. Wait a few seconds and you should begin to see some output. If no output appears, try running a few commands:

```
# dtrace -q -s rtime.d
3987/3987 spent 12786263 nsecs in read()
2183/2183 spent 13410 nsecs in read()
2183/2183 spent 12850 nsecs in read()
2183/2183 spent 10057 nsecs in read()
3583/3583 spent 14527 nsecs in read()
3583/3583 spent 12571 nsecs in read()
3583/3583 spent 9778 nsecs in read()
3583/3583 spent 9498 nsecs in read()
3583/3583 spent 9778 nsecs in read()
2183/2183 spent 13968 nsecs in read()
2183/2183 spent 72076 nsecs in read()
...
^C
#
```

The `rtime.d` program uses a thread-local variable that is named to capture a timestamp on entry to `read()` by any thread. Then, in the return clause, the program prints the amount of time spent in `read()` by subtracting `self->t` from the current timestamp. The built-in D variables `pid` and `tid` report the process ID and thread ID of the thread that is performing the `read()`. Because `self->t` is no longer needed after this information is reported, it is then assigned `0` to enable DTrace to reuse the underlying storage that is associated with `t` for the current thread.

Typically, you see many lines of output without doing anything because server processes and daemons are executing `read()` all the time behind the scenes. Try changing the second clause of `rtime.d` to use the `execname` variable to print out the name of the process performing a `read()`, for example:

```
printf("%s/%d spent %d nsecs in read()\n", execname, tid, timestamp - self->t);
```

If you find a process that is of particular interest, add a predicate to learn more about its `read()` behavior, as shown in the following example:

```
syscall::read:entry
/execname == "Xorg"/
{
  self->t = timestamp;
}
```

Clause-Local Variables

The value of a D variable can be accessed whenever a probe fires. Variables describes how variables could have a different *scope*. For a global variable, the same instance of the variable is accessed from every thread. For thread-local, the instance of the variable is thread-specific.

Meanwhile, for a clause-local variable, the instance of the variable is specific to that particular firing of the probe. Clause-local is the narrowest scope. When a probe fires on a CPU, the D script is executed in program order. Each clause-local variable is instantiated with an undefined value the first time it is used in the script. The same instance of the variable is used in all clauses until the D script has completed execution for that particular firing of the probe.

Clause-local variables can be referenced and assigned by prefixing with `this->`:

```
BEGIN
{
  this->secs = timestamp / 1000000000;
  ...
}
```

If you want to declare a clause-local variable explicitly before using it, you can do so by using the `this` keyword:

```
this int x;  /* an integer clause-local variable */
this char c; /* a character clause-local variable */

BEGIN
{
  this->x = 123;
  this->c = 'D';
}
```

Note that if your program contains multiple clauses for a single probe, any clause-local variables remain intact as the clauses are executed, as shown in the following example. Type the following source code and save it in a file named `clause.d`:

```
int me;       /* an integer global variable */
this int foo; /* an integer clause-local variable */

tick-1sec
{
  /*
   * Set foo to be 10 if and only if this is the first clause executed.
   */
  this->foo = (me % 3 == 0) ? 10 : this->foo;
  printf("Clause 1 is number %d; foo is %d\n", me++ % 3, this->foo++);
}

tick-1sec
{
  /*
   * Set foo to be 20 if and only if this is the first clause executed.
   */
  this->foo = (me % 3 == 0) ? 20 : this->foo;
  printf("Clause 2 is number %d; foo is %d\n", me++ % 3, this->foo++);
}

tick-1sec
{
  /*
   * Set foo to be 30 if and only if this is the first clause executed.
   */
  this->foo = (me % 3 == 0) ? 30 : this->foo;
  printf("Clause 3 is number %d; foo is %d\n", me++ % 3, this->foo++);
}
```

Because the clauses are always executed in program order, and because clause-local variables are persistent across different clauses that are enabling the same probe, running the preceding program always produces the same output:

```
# dtrace -q -s clause.d
Clause 1 is number 0; foo is 10
Clause 2 is number 1; foo is 11
Clause 3 is number 2; foo is 12
Clause 1 is number 0; foo is 10
Clause 2 is number 1; foo is 11
Clause 3 is number 2; foo is 12
Clause 1 is number 0; foo is 10
Clause 2 is number 1; foo is 11
Clause 3 is number 2; foo is 12
Clause 1 is number 0; foo is 10
Clause 2 is number 1; foo is 11
```

```
Clause 3 is number 2; foo is 12
^C
```

While clause-local variables are persistent across clauses that are enabling the same probe, their values are undefined in the first clause executed for a given probe. Be sure to assign each clause-local variable an appropriate value before using it or your program might have unexpected results.

Clause-local variables can be defined using any scalar variable type, but associative arrays may not be defined using clause-local scope. The scope of clause-local variables only applies to the corresponding variable data, not to the name and type identity defined for the variable. When a clause-local variable is defined, this name and type signature can be used in any subsequent D program clause.

You can use clause-local variables to accumulate intermediate results of calculations or as temporary copies of other variables. Access to a clause-local variable is much faster than access to an associative array. Therefore, if you need to reference an associative array value multiple times in the same D program clause, it is more efficient to copy it into a clause-local variable first and then reference the local variable repeatedly.

Built-In Variables

The following table provides a complete list of built-in D variables. All of these variables are scalar global variables.

Table 2-13 DTrace Built-In Variables

Variable	Description
`args[]`	The typed arguments, if any, to the current probe. The `args[]` array is accessed using an integer index, but each element is defined to be the type corresponding to the given probe argument. For information about any typed arguments, use `dtrace -l` with the verbose option `-v` and check `Argument Types`.
`int64_t arg0, ..., arg9`	The first ten input arguments to a probe, represented as raw 64-bit integers. Values are meaningful only for arguments defined for the current probe.
`uintptr_t caller`	The program counter location of the current kernel thread at the time the probe fired.
`chipid_t chip`	The CPU chip identifier for the current physical chip.
`processorid_t cpu`	The CPU identifier for the current CPU. See sched Provider for more information.
`cpuinfo_t *curcpu`	The CPU information for the current CPU. See sched Provider.
`lwpsinfo_t *curlwpsinfo`	The process state of the current thread. See proc Provider.
`psinfo_t *curpsinfo`	The process state of the process associated with the current thread. See proc Provider.

Table 2-13 (Cont.) DTrace Built-In Variables

Variable	Description
`task_struct *curthread`	Is a `vmlinux` data type, for which members can be found by searching for "task_struct" on the Internet.
`string cwd`	The name of the current working directory of the process associated with the current thread.
`uint_t epid`	The enabled probe ID (EPID) for the current probe. This integer uniquely identifies a particular probe that is enabled with a specific predicate and set of actions.
`int errno`	The error value returned by the last system call executed by this thread.
`string execname`	The name that was passed to `execve()` to execute the current process.
`fileinfo_t fds[]`	The files that the current process has opened in an `fileinfo_t` array, indexed by file descriptor number. See fileinfo_t. **Note:** You must load the `sdt` kernel module for `fds[]` to be available.
`gid_t gid`	The real group ID of the current process.
`uint_t id`	The probe ID for the current probe. This ID is the system-wide unique identifier for the probe, as published by DTrace and listed in the output of `dtrace -l`.

Table 2-13 (Cont.) DTrace Built-In Variables

Variable	Description
`uint_t ipl`	The interrupt priority level (IPL) on the current CPU at probe firing time. **Note:** This value is non-zero if interrupts are firing and zero otherwise. The non-zero value depends on whether preemption is active, as well as other factors, and can vary between kernel releases and kernel configurations.
`lgrp_id_t lgrp`	The latency group ID for the latency group of which the current CPU is a member. This value is always zero.
`pid_t pid`	The process ID of the current process.
`pid_t ppid`	The parent process ID of the current process.
`string probefunc`	The function name portion of the current probe's description.
`string probemod`	The module name portion of the current probe's description.
`string probename`	The name portion of the current probe's description.
`string probeprov`	The provider name portion of the current probe's description.
`psetid_t pset`	The processor set ID for the processor set containing the current CPU. This value is always zero.
`string root`	The name of the `root` directory of the process that is associated with the current thread.
`uint_t stackdepth`	The current thread's stack frame depth at probe firing time.
`id_t tid`	The task ID of the current thread.
`uint64_t timestamp`	The current value of a nanosecond timestamp counter. This counter increments from an arbitrary point in the past and should only be used for relative computations.
`uintptr_t ucaller`	The program counter location of the current user thread at the time the probe fired.

Table 2-13 (Cont.) DTrace Built-In Variables

Variable	Description
`uid_t uid`	The real user ID of the current process.
`uint64_t uregs[]`	The current thread's saved user-mode register values at probe firing time. Use of the `uregs[]` array is discussed in uregs[] Array.
`uint64_t vtimestamp`	The current value of a nanosecond timestamp counter that is virtualized to the amount of time that the current thread has been running on a CPU, minus the time spent in DTrace predicates and actions. This counter increments from an arbitrary point in the past and should only be used for relative time computations.
`int64_t walltimestamp`	The current number of nanoseconds since 00:00 Universal Coordinated Time, January 1, 1970.

Functions that are built into the D language such as `trace` are discussed in Actions and Subroutines.

External Variables

The D language uses the back quote character (`) as a special scoping operator for accessing variables that are defined in the operating system and not in your D program. For more information, see External Symbols and Types.

Pointers and Scalar Arrays

Pointers are memory addresses of data objects in the operating system kernel or in the address space of a user process. D provides the ability to create and manipulate pointers and store them in variables and associative arrays. This section describes the D syntax for pointers, operators that can be applied to create or access pointers, and the relationship between pointers and fixed-size scalar arrays. Also discussed are issues relating to the use of pointers in different address spaces.

> **Note:**
>
> If you are an experienced C or C++ programmer, you can skim most of this section as the D pointer syntax is the same as the corresponding ANSI C syntax. Howevver, you should read Pointers and Addresses and Pointers to DTrace Objects, as these sections describe features and issues that are specific to DTrace.

Pointers and Addresses

The Linux operating system uses a technique called *virtual memory* to provide each user process with its own virtual view of the memory resources on your system. A virtual view of memory resources is referred to as an *address space*. An address space associates a range of

address values, either `[0 ... 0xffffffff]` for a 32-bit address space or `[0 ... 0xffffffffffffffff]` for a 64-bit address space, with a set of translations that the operating system and hardware use to convert each virtual address to a corresponding physical memory location. Pointers in D are data objects that store an integer virtual address value and associate it with a D type that describes the format of the data stored at the corresponding memory location.

You can explicitly declare a D variable to be of pointer type by first specifying the type of the referenced data and then appending an asterisk (`*`) to the type name. Doing so indicates you want to declare a pointer type, as shown in the following statement:

```
int *p;
```

This statement declares a D global variable named `p` that is a pointer to an integer. The declaration means that `p` is a 64-bit integer with a value that is the address of another integer located somewhere in memory. Because the compiled form of your D code is executed at probe firing time inside the operating system kernel itself, D pointers are typically pointers associated with the kernel's address space. You can use the `arch` command to determine the number of bits that are used for pointers by the active operating system kernel.

If you want to create a pointer to a data object inside of the kernel, you can compute its address by using the `&` operator. For example, the operating system kernel source code declares an `unsigned long max_pfn` variable. You could trace the address of this variable by tracing the result of applying the `&` operator to the name of that object in D:

```
trace(&`max_pfn);
```

The `*` operator can be used to refer to the object addressed by the pointer, and acts as the inverse of the `&` operator. For example, the following two D code fragments are equivalent in meaning:

```
q = &`max_pfn; trace(*q);
```

```
trace(`max_pfn);
```

In this example, the first fragment creates a D global variable pointer `q`. Because the `max_pfn` object is of type `unsigned long`, the type of `&`max_pfn` is `unsigned long *` (that is, pointer to `unsigned long`), implicitly setting the type of `q`. Tracing the value of `*q`follows the pointer back to the data object `max_pfn`. This fragment is therefore the same as the second fragment, which directly traces the value of the data object by using its name.

Pointer Safety

If you are a C or C++ programmer, you might be a bit apprehensive after reading the previous section because you know that misuse of pointers in your programs can cause your programs to crash. DTrace, however, is a robust, safe environment for executing your D programs. Take note that these types of mistakes cannot cause program crashes. You might write a buggy D program, but invalid D pointer accesses do not cause DTrace or the operating system kernel to fail or crash in any way. Instead, the DTrace software detects any invalid pointer accesses, disables your instrumentation, and reports the problem back to you for debugging.

If you have previously programmed in the Java programming language, you are probably aware that the Java language does not support pointers for precisely the same reasons of safety. Pointers are needed in D because they are an intrinsic part of the operating system's implementation in C, but DTrace implements the same kind of safety mechanisms that are found in the Java programming language to prevent buggy programs from damaging

themselves or each other. DTrace's error reporting is similar to the runtime environment for the Java programming language that detects a programming error and reports an exception.

To observe DTrace's error handling and reporting, you could write a deliberately bad D program using pointers. For example, in an editor, type the following D program and save it in a file named `badptr.d`:

```
BEGIN
{
  x = (int *)NULL;
  y = *x;
  trace(y);
}
```

The `badptr.d` program creates a D pointer named `x` that is a pointer to `int`. The program assigns this pointer the special invalid pointer value `NULL`, which is a built-in alias for address 0. By convention, address `0` is always defined as invalid so that `NULL` can be used as a sentinel value in C and D programs. The program uses a cast expression to convert `NULL` to be a pointer to an integer. The program then dereferences the pointer by using the expression `*x`, assigns the result to another variable `y`, and then attempts to trace `y`. When the D program is executed, DTrace detects an invalid pointer access when the statement `y = *x` is executed and reports the following error:

```
# dtrace -s badptr.d
dtrace: script 'badptr.d' matched 1 probe
dtrace: error on enabled probe ID 1 (ID 1: dtrace:::BEGIN):
invalid address (0x0) in action #2 at DIF offset 4
^C
#
```

Notice that the D program moves past the error and continues to execute; the system and all observed processes remain unperturbed. You can also add an `ERROR` probe to your script to handle D errors. For details about the DTrace error mechanism, see ERROR Probe.

Array Declarations and Storage

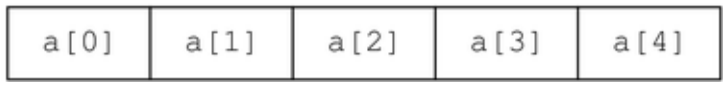
In addition to the dynamic associative arrays that are described in Variables, D supports *scalar arrays*. Scalar arrays are a fixed-length group of consecutive memory locations that each store a value of the same type. Scalar arrays are accessed by referring to each location with an integer, starting from zero. Scalar arrays correspond directly in concept and syntax with arrays in C and C++. Scalar arrays are not used as frequently in D as associative arrays and their more advanced counterparts *aggregations*. You might, however, need to use scalar arrays to access existing operating system array data structures that are declared in C. Aggregations are described in Aggregations.

A D scalar array of 5 integers is declared by using the type `int` and suffixing the declaration with the number of elements in square brackets, for example:

```
int a[5];
```

#unique_31/unique_31_Connect_42_dt_arrayfig_dlang shows a visual representation of the array storage:

Scalar Array Representation



The D expression `a[0]` refers to the first array element, `a[1]` refers to the second, and so on. From a syntactic perspective, scalar arrays and associative arrays are very similar. You can declare an associative array of integers referenced by an integer key as follows:

```
int a[int];
```

You can also reference this array using the expression `a[0]`. But, from a storage and implementation perspective, the two arrays are very different. The static array `a` consists of five consecutive memory locations numbered from zero, and the index refers to an offset in the storage that is allocated for the array. On the other hand, an associative array has no predefined size and does not store elements in consecutive memory locations. In addition, associative array keys have no relationship to the corresponding value storage location. You can access associative array elements `a[0]` and `a[-5]` and only two words of storage are allocated by DTrace, and these might or might not be consecutive. Associative array keys are abstract names for the corresponding values and have no relationship to the value storage locations.

If you create an array using an initial assignment and use a single integer expression as the array index , for example, `a[0] = 2`, the D compiler always creates a new associative array, even though in this expression `a` could also be interpreted as an assignment to a scalar array. Scalar arrays must be predeclared in this situation so that the D compiler can recognize the definition of the array size and infer that the array is a scalar array.

Pointer and Array Relationship

Pointers and scalar arrays have a special relationship in D, just as they do in ANSI C. A scalar array is represented by a variable that is associated with the address of its first storage location. A pointer is also the address of a storage location with a defined type. Thus, D permits the use of the array `[]` index notation with both pointer variables and array variables. For example, the following two D fragments are equivalent in meaning:

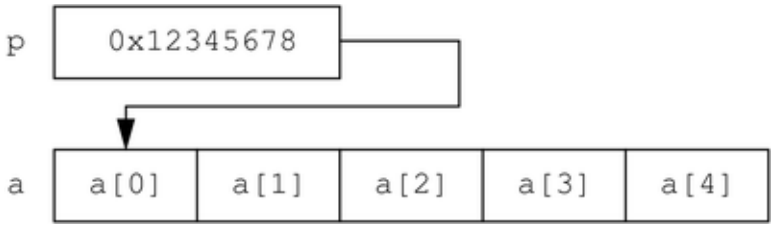
```
p = &a[0]; trace(p[2]);
```

```
trace(a[2]);
```

In the first fragment, the pointer `p` is assigned to the address of the first element in scalar array `a` by applying the `&` operator to the expression `a[0]`. The expression `p[2]` traces the value of the third array element (index 2). Because `p` now contains the same address associated with `a`, this expression yields the same value as `a[2]`, shown in the second fragment. One consequence of this equivalence is that C and D permit you to access any index of any pointer or array. Array bounds checking is not performed for you by the compiler or the DTrace runtime environment. If you access memory beyond the end of a scalar array's predefined size, you either get an unexpected result or DTrace reports an invalid address error, as shown in the previous example. As always, you cannot damage DTrace itself or your operating system, but you do need to debug your D program.

The difference between pointers and arrays is that a pointer variable refers to a separate piece of storage that contains the integer address of some other storage. Whereas, an array variable names the array storage itself, not the location of an integer that in turn contains the location of the array. #unique_64/unique_64_Connect_42_dt_arrptrfig_dlang illustrates this difference.

Pointer and Array Storage



This difference is manifested in the D syntax if you attempt to assign pointers and scalar arrays. If `x` and `y` are pointer variables, the expression `x = y` is legal; it copies the pointer address in `y` to the storage location that is named by `x`. If `x` and `y` are scalar array variables, the expression `x = y` is not legal. Arrays may not be assigned as a whole in D. However, an array variable or symbol name can be used in any context where a pointer is permitted. If `p` is a pointer and `a` is a scalar array, the statement `p = a` is permitted. This statement is equivalent to the statement `p = &a[0]`.

Pointer Arithmetic

Because pointers are just integers that are used as addresses of other objects in memory, D provides a set of features for performing arithmetic on pointers. However, pointer arithmetic is not identical to integer arithmetic. Pointer arithmetic implicitly adjusts the underlying address by multiplying or dividing the operands by the size of the type referenced by the pointer.

The following D fragment illustrates this property:

```
int *x;

BEGIN
{
  trace(x);
  trace(x + 1);
  trace(x + 2);
}
```

This fragment creates an integer pointer `x` and then traces its value, its value incremented by one, and its value incremented by two. If you create and execute this program, DTrace reports the integer values `0`, `4`, and `8`.

Since `x` is a pointer to an `int` (size 4 bytes), incrementing `x` adds 4 to the underlying pointer value. This property is useful when using pointers to refer to consecutive storage locations such as arrays. For example, if `x` was assigned to the address of an array `a`, similar to what is shown in #unique_64/unique_64_Connect_42_dt_arrptrfig_dlang, the expression `x + 1` would be equivalent to the expression `&a[1]`. Similarly, the expression `*(x + 1)` would refer to the value `a[1]`. Pointer arithmetic is implemented by the D compiler whenever a pointer value is incremented by using the `+`, `++`, or `=+` operators. Pointer arithmetic is also applied as follows; when an integer is subtracted from a pointer on the left-hand side, when a pointer is subtracted from another pointer, or when the `--` operator is applied to a pointer.

For example, the following D program would trace the result `2`:

```
int *x, *y;
int a[5];

BEGIN
{
  x = &a[0];
  y = &a[2];
```

```
  trace(y - x);
}
```

Generic Pointers

Sometimes it is useful to represent or manipulate a generic pointer address in a D program without specifying the type of data referred to by the pointer. Generic pointers can be specified by using the type `void *`, where the keyword `void` represents the absence of specific type information, or by using the built-in type alias `uintptr_t`, which is aliased to an unsigned integer type of size that is appropriate for a pointer in the current data model. You may not apply pointer arithmetic to an object of type `void *`, and these pointers cannot be dereferenced without casting them to another type first. You can cast a pointer to the `uintptr_t` type when you need to perform integer arithmetic on the pointer value.

Pointers to `void` can be used in any context where a pointer to another data type is required, such as an associative array tuple expression or the right-hand side of an assignment statement. Similarly, a pointer to any data type can be used in a context where a pointer to `void` is required. To use a pointer to a non-`void` type in place of another non-`void` pointer type, an explicit cast is required. You must always use explicit casts to convert pointers to integer types, such as `uintptr_t`, or to convert these integers back to the appropriate pointer type.

Multi-Dimensional Arrays

Multi-dimensional scalar arrays are used infrequently in D, but are provided for compatibility with ANSI C and are for observing and accessing operating system data structures that are created by using this capability in C. A multi-dimensional array is declared as a consecutive series of scalar array sizes enclosed in square brackets `[]` following the base type. For example, to declare a fixed-size, two-dimensional rectangular array of integers of dimensions that is 12 rows by 34 columns, you would write the following declaration:

```
int a[12][34];
```

A multi-dimensional scalar array is accessed by using similar notation. For example, to access the value stored at row `0` and column `1`, you would write the D expression as follows:

```
a[0][1]
```

Storage locations for multi-dimensional scalar array values are computed by multiplying the row number by the total number of columns declared and then adding the column number.

Be careful not to confuse the multi-dimensional array syntax with the D syntax for associative array accesses, that is, `a[0][1]`, is not the same as `a[0,1]`). If you use an incompatible tuple with an associative array or attempt an associative array access of a scalar array, the D compiler reports an appropriate error message and refuses to compile your program.

Pointers to DTrace Objects

The D compiler prohibits you from using the `&` operator to obtain pointers to DTrace objects such as associative arrays, built-in functions, and variables. You are prohibited from obtaining the address of these variables so that the DTrace runtime environment is free to relocate them as needed between probe firings . In this way, DTrace can more efficiently manage the memory required for your programs. If you create composite structures, it is possible to construct expressions that do retrieve the kernel address of your DTrace object storage. You should avoid creating such expressions in your D programs. If you need to use such an expression, do not rely on the address being the same across probe firings.

In ANSI C, pointers can also be used to perform indirect function calls or to perform assignments, such as placing an expression using the unary `*` dereference operator on the left-hand side of an assignment operator. In D, these types of expressions using pointers are not permitted. You may only assign values directly to D variables by specifying their name or by applying the array index operator `[]` to a D scalar or associative array. You may only call functions that are defined by the DTrace environment by name, as specified in Actions and Subroutines. Indirect function calls using pointers are not permitted in D.

Pointers and Address Spaces

A pointer is an address that provides a translation within some *virtual address space* to a piece of physical memory. DTrace executes your D programs within the address space of the operating system kernel itself. The Linux system manages many address spaces: one for the operating system kernel and one for each user process. Because each address space provides the illusion that it can access all of the memory on the system, the same virtual address pointer value can be reused across address spaces, but translate to different physical memory. Therefore, when writing D programs that use pointers, you must be aware of the address space corresponding to the pointers you intend to use.

For example, if you use the `syscall` provider to instrument entry to a system call that takes a pointer to an integer or array of integers as an argument, for example, `pipe()`, it would not be valid to dereference that pointer or array using the `*` or `[]` operators because the address in question is an address in the address space of the user process that performed the system call. Applying the `*` or `[]` operators to this address in D would result in kernel address space access, which would result in an invalid address error or in returning unexpected data to your D program, depending on whether the address happened to match a valid kernel address.

To access user-process memory from a DTrace probe, you must apply one of the `copyin`, `copyinstr`, or `copyinto` functions that are described in Actions and Subroutines to the user address space pointer. To avoid confusion, take care when writing your D programs to name and comment variables storing user addresses appropriately. You can also store user addresses as `uintptr_t` so that you do not accidentally compile D code that dereferences them. Techniques for using DTrace on user processes are described in User Process Tracing.

DTrace Support for Strings

DTrace provides support for tracing and manipulating strings. This section describes the complete set of D language features for declaring and manipulating strings. Unlike ANSI C, strings in D have their own built-in type and operator support to enable you to easily and unambiguously use them in your tracing programs.

String Representation

In DTrace, strings are represented as an array of characters terminated by a null byte (that is, a byte whose value is zero, usually written as `'\0'`). The visible part of the string is of variable length, depending on the location of the null byte, but DTrace stores each string in a fixed-size array so that each probe traces a consistent amount of data. Strings cannot exceed the length of the predefined string limit. However, the limit can be modified in your D program or on the `dtrace` command line by tuning the `strsize` option. See Options and Tunables for more information about tunable DTrace options. The default string limit is 256 bytes.

The D language provides an explicit `string` type rather than using the type `char *` to refer to strings. The string type is equivalent to `char *`, in that it is the address of a sequence of characters, but the D compiler and D functions such as `trace` provide enhanced capabilities

when applied to expressions of type string. For example, the string type removes the ambiguity of type `char *` when you need to trace the actual bytes of a string.

In the following D statement, if `s` is of type `char *`, DTrace traces the value of the pointer `s`, which means it traces an integer address value:

```
trace(s);
```

In the following D statement, by the definition of the `*` operator, the D compiler dereferences the pointer `s` and traces the single character at that location:

```
trace(*s);
```

These behaviors enable you to manipulate character pointers that refer to either single characters, or to arrays of byte-sized integers that are not strings and do not end with a null byte.

In the next D statement, if `s` is of type `string`, the string type indicates to the D compiler that you want DTrace to trace a null terminated string of characters whose address is stored in the variable `s`:

```
trace(s);
```

You can also perform lexical comparison of expressions of type string. See String Comparison.

String Constants

String constants are enclosed in pairs of double quotes ("") and are automatically assigned the type `string` by the D compiler. You can define string constants of any length, limited only by the amount of memory DTrace is permitted to consume on your system. The terminating null byte (`\0`) is added automatically by the D compiler to any string constants that you declare. The size of a string constant object is the number of bytes associated with the string, plus one additional byte for the terminating null byte.

A string constant may not contain a literal newline character. To create strings containing newlines, use the `\n` escape sequence instead of a literal newline. String constants can also contain any of the special character escape sequences that are defined for character constants. See Table 2-6.

String Assignment

Unlike the assignment of `char *` variables, strings are copied by value and not by reference. The string assignment operator `=` copies the actual bytes of the string from the source operand up to and including the null byte to the variable on the left-hand side, which must be of type `string`. You can create a new string variable by assigning it an expression of type `string`.

For example, the D statement:

```
s = "hello";
```

would create a new variable `s` of type `string` and copy the six bytes of the string `"hello"` into it (five printable characters, plus the null byte). String assignment is analogous to the C library function `strcpy()`, with the exception that if the source string exceeds the limit of the storage of the destination string, the resulting string is automatically truncated by a null byte at this limit.

You can also assign to a string variable an expression of a type that is compatible with strings. In this case, the D compiler automatically promotes the source expression to the string type

and performs a string assignment. The D compiler permits any expression of type `char *` or of type `char[n]`, that is, a scalar array of `char` of any size, to be promoted to a string.

String Conversion

Expressions of other types can be explicitly converted to type `string` by using a cast expression or by applying the special `stringof` operator, which are equivalent in the following meaning:

```
s = (string) expression;

s = stringof (expression);
```

The expression is interpreted as an address to the string.

The `stringof` operator binds very tightly to the operand on its right-hand side. Typically, parentheses are used to surround the expression for clarity. Although, they are not strictly necessary.

Any expression that is a scalar type, such as a pointer or integer, or a scalar array address may be converted to string. Expressions of other types such as `void` may not be converted to `string`. If you erroneously convert an invalid address to a string, the DTrace safety features prevents you from damaging the system or DTrace, but you might end up tracing a sequence of undecipherable characters.

String Comparison

D overloads the binary relational operators and permits them to be used for string comparisons, as well as integer comparisons. The relational operators perform string comparison whenever both operands are of type `string` or when one operand is of type `string` and the other operand can be promoted to type `string`. See String Assignment for a detailed description. See also Table 2-14, which lists the relational operators that can be used to compare strings.

Table 2-14 D Relational Operators for Strings

Operator	Description
<	Left-hand operand is less than right-operand.
<=	Left-hand operand is less than or equal to right-hand operand.
>	Left-hand operand is greater than right-hand operand.
>=	Left-hand operand is greater than or equal to right-hand operand.
==	Left-hand operand is equal to right-hand operand.
!=	Left-hand operand is not equal to right-hand operand.

As with integers, each operator evaluates to a value of type `int`, which is equal to one if the condition is true or zero if it is false.

The relational operators compare the two input strings byte-by-byte, similarly to the C library routine `strcmp()`. Each byte is compared by using its corresponding integer value in the ASCII

character set until a null byte is read or the maximum string length is reached. See the `ascii(7)` manual page for more information. Some example D string comparisons and their results are shown in the following table.

D string comparison	Result
`"coffee" < "espresso"`	Returns 1 (true)
`"coffee" == "coffee"`	Returns 1 (true)
`"coffee"" >= "mocha"`	Returns 0 (false)

> **Note:**
>
> Seemingly identical Unicode strings might compare as being different if one or the other of the strings is not normalized.

Structs and Unions

Collections of related variables can be grouped together into composite data objects called *structs* and *unions*. You define these objects in D by creating new type definitions for them. You can use your new types for any D variables, including associative array values. This section explores the syntax and semantics for creating and manipulating these composite types and the D operators that interact with them.

Structs

The D keyword `struct`, short for *structure*, is used to introduce a new type that is composed of a group of other types. The new `struct` type can be used as the type for D variables and arrays, enabling you to define groups of related variables under a single name. D structs are the same as the corresponding construct in C and C++. If you have programmed in the Java programming language previously, think of a D struct as a class that contains only data members and no methods.

Suppose you want to create a more sophisticated system call tracing program in D that records a number of things about each `read()` and `write()` system call that is executed by your shell, for example, the elapsed time, number of calls, and the largest byte count passed as an argument.

You could write a D clause to record these properties in three separate associative arrays, as shown in the following example:

```
int maxbytes[string]; /* declare maxbytes */
syscall::read:entry, syscall::write:entry
/pid == 12345/
{
  ts[probefunc] = timestamp;
  calls[probefunc]++;
  maxbytes[probefunc] = arg2 > maxbytes[probefunc] ?
        arg2 : maxbytes[probefunc];
}
```

This clause, however, is inefficient because DTrace must create three separate associative arrays and store separate copies of the identical tuple values corresponding to `probefunc` for

each one. Instead, you can conserve space and make your program easier to read and maintain by using a struct.

First, declare a new `struct` type at the top of the D program source file:

```
struct callinfo {
  uint64_t ts;       /* timestamp of last syscall entry */
  uint64_t elapsed;  /* total elapsed time in nanoseconds */
  uint64_t calls;    /* number of calls made */
  size_t maxbytes;   /* maximum byte count argument */
};
```

The `struct` keyword is followed by an optional identifier that is used to refer back to the new type, which is now known as `struct callinfo`. The struct members are then enclosed in a set of braces `{}` and the entire declaration is terminated by a semicolon (`;`). Each struct member is defined by using the same syntax as a D variable declaration, with the type of the member listed first followed by an identifier naming the member and another semicolon (`;`).

The `struct` declaration simply defines the new type. It does not create any variables or allocate any storage in DTrace. When declared, you can use `struct callinfo` as a type throughout the remainder of your D program. Each variable of type `struct callinfo` stores a copy of the four variables that are described by our structure template. The members are arranged in memory in order, according to the member list, with padding space introduced between members, as required for data object alignment purposes.

You can use the member identifier names to access the individual member values using the "`.`" operator by writing an expression of the following form:

variable-name.member-name

The following example is an improved program that uses the new structure type. In a text editor, type the following D program and save it in a file named `rwinfo.d`:

```
struct callinfo {
  uint64_t ts; /* timestamp of last syscall entry */
  uint64_t elapsed; /* total elapsed time in nanoseconds */
  uint64_t calls; /* number of calls made */
  size_t maxbytes; /* maximum byte count argument */
};

struct callinfo i[string]; /* declare i as an associative array */

syscall::read:entry, syscall::write:entry
/pid == $1/
{
  i[probefunc].ts = timestamp;
  i[probefunc].calls++;
  i[probefunc].maxbytes = arg2 > i[probefunc].maxbytes ?
        arg2 : i[probefunc].maxbytes;
}

syscall::read:return, syscall::write:return
/i[probefunc].ts != 0 && pid == $1/
{
  i[probefunc].elapsed += timestamp - i[probefunc].ts;
}

END
{
```

```
  printf("       calls max bytes elapsed nsecs\n");
  printf("------ ----- --------- -------------\n");
  printf("  read %5d %9d %d\n",
  i["read"].calls, i["read"].maxbytes, i["read"].elapsed);
  printf(" write %5d %9d %d\n",
  i["write"].calls, i["write"].maxbytes, i["write"].elapsed);
}
```

When you have typed the program, run the `dtrace -q -s rwinfo.d` command, specifying one of your shell processes. Then, type a few commands in your shell. When you have finished typing the shell commands, type `Ctrl-C` to fire the `END` probe and print the results:

```
# dtrace -q -s rwinfo.d `pgrep -n bash`
 ^C
       calls max bytes elapsed nsecs
------ ----- --------- -------------
  read    25      1024 8775036488
 write    33        22 1859173
```

Pointers to Structs

Referring to structs by using pointers is very common in C and D. You can use the operator `->` to access struct members through a pointer. If `struct s` has a member `m`, and you have a pointer to this struct named `sp`, where `sp` is a variable of type `struct s *`, you can either use the `*` operator to first dereference the `sp` pointer to access the member:

```
struct s *sp;
(*sp).m
```

Or, you can use the `->` operator as shorthand for this notation. The following two D fragments are equivalent if `sp` is a pointer to a struct:

```
(*sp).m
sp->m
```

DTrace provides several built-in variables that are pointers to structs. For example, the pointer `curpsinfo` refers to `struct psinfo` and its content provides a snapshot of information about the state of the process associated with the thread that fired the current probe. The following table lists a few example expressions that use `curpsinfo`, including their types and their meanings.

Example Expression	Type	Meaning
`curpsinfo->pr_pid`	`pid_t`	Current process ID
`curpsinfo->pr_fname`	`char []`	Executable file name
`curpsinfo->pr_psargs`	`char []`	Initial command-line arguments

For more information, see psinfo_t.

The next example uses the `pr_fname` member to identify a process of interest. In an editor, type the following script and save it in a file named `procfs.d`:

```
syscall::write:entry
/ curpsinfo->pr_fname == "date" /
{
  printf("%s run by UID %d\n", curpsinfo->pr_psargs, curpsinfo->pr_uid);
}
```

This clause uses the expression `curpsinfo->pr_fname` to access and match the command name so that the script selects the correct `write()` requests before tracing the arguments. Notice that by using operator `==` with a left-hand argument that is an array of `char` and a right-hand argument that is a string, the D compiler infers that the left-hand argument should be promoted to a string and a string comparison should be performed. Type the command `dtrace -q -s procs.d` in one shell and then type the `date` command several times in another shell. The output that is displayed by DTrace is similar to the following:

```
# dtrace -q -s procfs.d
date  run by UID 500
/bin/date  run by UID 500
date -R  run by UID 500
...
^C
#
```

Complex data structures are used frequently in C programs, so the ability to describe and reference structs from D also provides a powerful capability for observing the inner workings of the Oracle Linux operating system kernel and its system interfaces.

Unions

Unions are another kind of composite type that is supported by ANSI C and D and are closely related to structs. A union is a composite type where a set of members of different types are defined and the member objects all occupy the same region of storage. A union is therefore an object of variant type, where only one member is valid at any given time, depending on how the union has been assigned. Typically, some other variable or piece of state is used to indicate which union member is currently valid. The size of a union is the size of its largest member. The memory alignment that is used for the union is the maximum alignment required by the union members.

Member Sizes and Offsets

You can determine the size in bytes of any D type or expression, including a `struct` or `union`, by using the `sizeof` operator. The `sizeof` operator can be applied either to an expression or to the name of a type surrounded by parentheses, as illustrated in the following two examples:

```
sizeof expression
sizeof (type-name)
```

For example, the expression `sizeof (uint64_t)` would return the value `8`, and the expression `sizeof (callinfo.ts)` would also return `8`, if inserted into the source code of the previous example program. The formal return type of the `sizeof` operator is the type alias `size_t`, which is defined as an unsigned integer that is the same size as a pointer in the current data model and is used to represent byte counts. When the `sizeof` operator is applied to an expression, the expression is validated by the D compiler, but the resulting object size is computed at compile time and no code for the expression is generated. You can use `sizeof` anywhere an integer constant is required.

You can use the companion operator `offsetof` to determine the offset in bytes of a struct or union member from the start of the storage that is associated with any object of the `struct` or `union` type. The `offsetof` operator is used in an expression of the following form:

```
offsetof (type-name, member-name)
```

Here, *type-name* is the name of any `struct` or `union` type or type alias, and *member-name* is the identifier naming a member of that struct or union. Similar to `sizeof`, `offsetof` returns a `size_t` and you can use it anywhere in a D program that an integer constant can be used.

Bit-Fields

D also permits the definition of integer struct and union members of arbitrary numbers of bits, known as *bit-fields*. A bit-field is declared by specifying a signed or unsigned integer base type, a member name, and a suffix indicating the number of bits to be assigned for the field, as shown in the following example:

```
struct s
{
  int a : 1;
  int b : 3;
  int c : 12;
};
```

The bit-field width is an integer constant that is separated from the member name by a trailing colon. The bit-field width must be positive and must be of a number of bits not larger than the width of the corresponding integer base type. Bit-fields that are larger than 64 bits may not be declared in D. D bit-fields provide compatibility with and access to the corresponding ANSI C capability. Bit-fields are typically used in situations when memory storage is at a premium or when a struct layout must match a hardware register layout.

A bit-field is a compiler construct that automates the layout of an integer and a set of masks to extract the member values. The same result can be achieved by simply defining the masks yourself and using the `&` operator. The C and D compilers attempt to pack bits as efficiently as possible, but they are free to do so in any order or fashion they desire. Therefore, bit-fields are not guaranteed to produce identical bit layouts across differing compilers or architectures. If you require stable bit layout, you should construct the bit masks yourself and extract the values by using the `&` operator.

A bit-field member is accessed by simply specifying its name in combination with the "`.`" or `->` operators, like any other struct or union member. The bit-field is automatically promoted to the next largest integer type for use in any expressions. Because bit-field storage cannot be aligned on a byte boundary or be a round number of bytes in size, you may not apply the `sizeof` or `offsetof` operators to a bit-field member. The D compiler also prohibits you from taking the address of a bit-field member by using the `&` operator.

Type and Constant Definitions

This section describes how to declare type aliases and named constants in D. It also discusses D type and namespace management for program and operating system types and identifiers.

typedefs

The `typedef` keyword is used to declare an identifier as an alias for an existing type. Like all D type declarations, `typedef` is used outside of probe clauses in a declaration of the following form:

```
typedef existing-type new-type ;
```

where *existing-type* is any type declaration and *new-type* is an identifier to be used as the alias for this type. For example, the D compiler uses the following declaration internally to create the `uint8_t` type alias:

```
typedef unsigned char uint8_t;
```

You can use type aliases anywhere that a normal type can be used, such as the type of a variable or associative array value or tuple member. You can also combine `typedef` with more elaborate declarations such as the definition of a new `struct`, as shown in the following example:

```
typedef struct foo {
  int x;
  int y;
} foo_t;
```

In the previous example, `struct foo` is defined using the same type as its alias, `foo_t`. Linux C system headers often use the suffix `_t` to denote a `typedef` alias.

Enumerations

Defining symbolic names for constants in a program eases readability and simplifies the process of maintaining the program in the future. One method is to define an *enumeration*, which associates a set of integers with a set of identifiers called enumerators that the compiler recognizes and replaces with the corresponding integer value. An enumeration is defined by using a declaration such as the following:

```
enum colors {
  RED,
  GREEN,
  BLUE
};
```

The first enumerator in the enumeration, `RED`, is assigned the value zero and each subsequent identifier is assigned the next integer value.

You can also specify an explicit integer value for any enumerator by suffixing it with an equal sign and an integer constant, as shown in the following example:

```
enum colors {
  RED = 7,
  GREEN = 9,
  BLUE
};
```

The enumerator `BLUE` is assigned the value `10` by the compiler because it has no value specified and the previous enumerator is set to `9`. When an enumeration is defined, the enumerators can be used anywhere in a D program that an integer constant is used. In addition, the enumeration `enum colors` is also defined as a type that is equivalent to an `int`. The D compiler allows a variable of `enum` type to be used anywhere an `int` can be used and will allow any integer value to be assigned to a variable of `enum` type. You can also omit the `enum` name in the declaration, if the type name is not needed.

Enumerators are visible in all subsequent clauses and declarations in your program. Therefore, you cannot define the same enumerator identifier in more than one enumeration. However, you can define more than one enumerator with the same value in either the same or different enumerations. You may also assign integers that have no corresponding enumerator to a variable of the enumeration type.

The D enumeration syntax is the same as the corresponding syntax in ANSI C. D also provides access to enumerations that are defined in the operating system kernel and its loadable modules. Note that these enumerators are not globally visible in your D program. Kernel enumerators are only visible if you specify one as an argument in a comparison with an object

of the corresponding enumeration type. This feature protects your D programs against inadvertent identifier name conflicts, with the large collection of enumerations that are defined in the operating system kernel.

The following example D program displays information about I/O requests. The program uses the enumerators `B_READ` and `B_WRITE` to differentiate between read and write operations:

```
io:::done,
io:::start,
io:::wait-done,
io:::wait-start
{
    printf("%8s %10s: %d %16s (%s size %d @ sect %d)\n",
        args[1]->dev_statname, probename,
        timestamp, execname,
    args[0]->b_flags & B_READ ? "R" :
    args[0]->b_flags & B_WRITE ? "W" : "?",
    args[0]->b_bcount, args[0]->b_blkno);
}
```

Inlines

D named constants can also be defined by using `inline` directives, which provide a more general means of creating identifiers that are replaced by predefined values or expressions during compilation. Inline directives are a more powerful form of lexical replacement than the `#define` directive provided by the C preprocessor because the replacement is assigned an actual type and is performed by using the compiled syntax tree and not simply a set of lexical tokens. An `inline` directive is specified by using a declaration of the following form:

```
inline type name = expression;
```

where *type* is a type declaration of an existing type, *name* is any valid D identifier that is not previously defined as an inline or global variable, and *expression* is any valid D expression. After the inline directive is processed, the D compiler substitutes the compiled form of *expression* for each subsequent instance of *name* in the program source.

For example, the following D program would trace the string "`hello`" and integer value `123`:

```
inline string hello = "hello";
inline int number = 100 + 23;

BEGIN
{
  trace(hello);
  trace(number);
}
```

An inline name can be used anywhere a global variable of the corresponding type is used. If the inline expression can be evaluated to an integer or string constant at compile time, then the inline name can also be used in contexts that require constant expressions, such as scalar array dimensions.

The inline expression is validated for syntax errors as part of evaluating the directive. The expression result type must be compatible with the type that is defined by the `inline`, according to the same rules used for the D assignment operator (`=`). An inline expression may not reference the `inline` identifier itself: recursive definitions are not permitted.

The DTrace software packages install a number of D source files in the system directory `/usr/lib64/dtrace/`*`installed-version`* , which contain inline directives that you can use in your D programs.

For example, the `signal.d` library includes directives of the following form:

```
inline int SIGHUP = 1;
inline int SIGINT = 2;
inline int SIGQUIT = 3;
...
```

These inline definitions provide you with access to the current set of Oracle Linux signal names, as described in the `sigaction(2)` manual page. Similarly, the `errno.d` library contains inline directives for the C `errno` constants that are described in the `errno(3)` manual page.

By default, the D compiler includes all of the provided D library files automatically so that you can use these definitions in any D program.

Type Namespaces

In traditional languages such as ANSI C, type visibility is determined by whether a type is nested inside of a function or other declaration. Types declared at the outer scope of a C program are associated with a single global namespace and are visible throughout the entire program. Types that are defined in C header files are typically included in this outer scope. Unlike these languages, D provides access to types from multiple outer scopes.

D is a language that facilitates dynamic observability across multiple layers of a software stack, including the operating system kernel, an associated set of loadable kernel modules, and user processes that are running on the system. A single D program can instantiate probes to gather data from multiple kernel modules or other software entities that are compiled into independent binary objects. Therefore, more than one data type of the same name, perhaps with different definitions, might be present in the universe of types that are available to DTrace and the D compiler. To manage this situation, the D compiler associates each type with a namespace, which is identified by the containing program object. Types from a particular program object can be accessed by specifying the object name and the back quote (`) scoping operator in any type name.

For example, for a kernel module named `foo` that contains the following C type declaration:

```
typedef struct bar {
  int x;
} bar_t;
```

The types `struct bar` and `bar_t` could be accessed from D using the following type names:

```
struct foo`bar
foo`bar_t
```

The back quote operator can be used in any context where a type name is appropriate, including when specifying the type for D variable declarations or cast expressions in D probe clauses.

The D compiler also provides two special, built-in type namespaces that use the names C and D, respectively. The C type namespace is initially populated with the standard ANSI C intrinsic types, such as `int`. In addition, type definitions that are acquired by using the C preprocessor (`cpp`), by running the `dtrace -C` command, are processed by and added to the C scope. As a result, you can include C header files containing type declarations that are already visible in another type namespace without causing a compilation error.

The D type namespace is initially populated with the D type intrinsics, such as `int` and `string`, as well as the built-in D type aliases, such as `uint64_t`. Any new type declarations that appear in the D program source are automatically added to the D type namespace. If you create a

complex type such as a `struct` in a D program consisting of member types from other namespaces, the member types are copied into the D namespace by the declaration.

When the D compiler encounters a type declaration that does not specify an explicit namespace using the back quote operator, the compiler searches the set of active type namespaces to find a match by using the specified type name. The C namespace is always searched first, followed by the D namespace. If the type name is not found in either the C or D namespace, the type namespaces of the active kernel modules are searched in load address order, which does not guarantee any ordering properties among the loadable modules. To avoid type name conflicts with other kernel modules, you should use the scoping operator when accessing types that are defined in loadable kernel modules.

The D compiler uses the compressed ANSI C debugging information that is provided with the core Linux kernel modules to automatically access the types that are associated with the operating system source code, without the need to access the corresponding C include files. Note that this symbolic debugging information might not be available for all kernel modules on your system. The D compiler reports an error if you attempt to access a type within the namespace of a module that lacks the compressed C debugging information that is intended for use with DTrace.

3
Aggregations

> **WARNING:**
>
> Oracle Linux 7 is now in Extended Support. See Oracle Linux Extended Support and Oracle Open Source Support Policies for more information.
>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

When instrumenting the system to answer performance-related questions, it is useful to consider how data can be aggregated to answer a specific question, rather than thinking in terms of data gathered by individual probes. For example, if you want to know the number of system calls by user ID, you would not necessarily care about the datum collected at *each* system call. In this cae, you simply want to see a table of user IDs and system calls. Historically, you would answer this question by gathering data at each system call and post-processing the data using a tool like `awk` or `perl`. Whereas, in DTrace, the aggregating of data is a first-class operation. This chapter describes the DTrace facilities for manipulating aggregations.

Aggregation Concepts

An aggregating function is one that has the following property:

$$func(func(x_0)\ U\ func(x_1)\ U\ \ldots\ U\ func(x_n)) = func(x_0\ U\ x_1\ U\ \ldots\ U\ x_n)$$

where x_n is a set of arbitrary data, which is to say, applying an aggregating function to subsets of the whole and then applying it again to the results yields the same result as applying it to the whole itself. For example, consider the `SUM` function, which yields the summation of a given data set. If the raw data consists of {2, 1, 2, 5, 4, 3, 6, 4, 2}, the result of applying `SUM` to the entire set is {29}. Similarly, the result of applying `SUM` to the subset consisting of the first three elements is {5}, the result of applying `SUM` to the set consisting of the subsequent three elements is {12}, and the result of applying `SUM` to the remaining three elements is also {12}. `SUM` is an aggregating function because applying it to the set of these results, {5, 12, 12}, yields the same result, {29}, as though applying `SUM` to the original data.

Not all functions are aggregating functions. An example of a non-aggregating function is the `MEDIAN` function. This function determines the median element of the set. The median is defined to be that element of a set for which as many elements in the set are greater than the element, as those that are less than it. The `MEDIAN` is derived by sorting the set and selecting the middle element. Returning to the original raw data, if `MEDIAN` is applied to the set consisting of the first three elements, the result is {2}. The sorted set is {1, 2, 2}; {2} is the set consisting of the middle element. Likewise, applying `MEDIAN` to the next three elements yields {4} and applying `MEDIAN` to the final three elements yields {4}. Thus, applying `MEDIAN` to each of the subsets yields the set {2, 4, 4}. Applying `MEDIAN` to this set yields the result {4}. Note that

sorting the original set yields {1, 2, 2, 2, 3, 4, 4, 5, 6}. Thus, applying `MEDIAN` to this set yields {3}. Because these results do not match, `MEDIAN` is not an aggregating function. Nor is `MODE`, the most common element of a set.

Many common functions that are used to understand a set of data are aggregating functions. These functions include the following:

- Counting the number of elements in the set.
- Computing the minimum value of the set.
- Computing the maximum value of the set.
- Summing all of the elements in the set.
- Histogramming the values in the set, as quantized into certain bins.

Moreover, some functions, which strictly speaking are not aggregating functions themselves, can nonetheless be constructed as such. For example, average (arithmetic mean) can be constructed by aggregating the count of the number of elements in the set and the sum of all elements in the set, reporting the ratio of the two aggregates as the final result. Another important example is standard deviation.

Applying aggregating functions to data as it is traced has a number of advantages, including the following:

- The entire data set need not be stored. Whenever a new element is to be added to the set, the aggregating function is calculated, given the set consisting of the current intermediate result and the new element. When the new result is calculated, the new element can be discarded. This process reduces the amount of storage that is required by a factor of the number of data points, which is often quite large.
- Data collection does not induce pathological scalability problems. Aggregating functions enable intermediate results to be kept per-CPU instead of in a shared data structure. DTrace then applies the aggregating function to the set consisting of the per-CPU intermediate results to produce the final system-wide result.

Basic Aggregation Statement

DTrace stores the results of aggregating functions in objects called *aggregations*. In D, the syntax for an aggregation is as follows:

```
@name[ keys ] = aggfunc( args );
```

The aggregation *name* is a D identifier that is prefixed with the special character `@`. All aggregations that are named in your D programs are global variables. There are no thread-local or clause-local aggregations. The aggregation names are kept in an identifier namespace that is separate from other D global variables. If you reuse names, remember that `a` and `@a` are *not* the same variable. The special aggregation name `@` can be used to name an anonymous aggregation in simple D programs. The D compiler treats this name as an alias for the aggregation name `@_`.

Aggregations are indexed with keys, where *keys* are a comma-separated list of D expressions, similar to the tuples of expressions used for associative arrays. Keys can also be actions with non-`void` return values, such as `stack`, `func`, `sym`, `mod`, `ustack`, `uaddr`, and `usym`.

The *aggfunc* is one of the DTrace aggregating functions, and *args* is a comma-separated list of arguments that is appropriate to that function. The DTrace aggregating functions are described in the following table. Most aggregating functions take just a single argument that represents the new datum.

Table 3-1 DTrace Aggregating Functions

Function Name	Arguments	Result
`count`	None	Number of times called.
`sum`	Scalar expression	Total value of the specified expressions.
`avg`	Scalar expression	Arithmetic average of the specified expressions.
`min`	Scalar expression	Smallest value among the specified expressions.
`max`	Scalar expression	Largest value among the specified expressions.
`stddev`	Scalar expression	Standard deviation of the specified expressions.
`quantize`	Scalar expression [, increment]	Power-of-two frequency distribution (histogram) of the values of the specified expressions. An optional increment (weight) can be specified.
`lquantize`	Scalar expression, lower bound, upper bound [, step value [, increment]]	Lnear frequency distribution of the values of the specified expressions, sized by the specified range. Note that the default step value is `1`.
`llquantize`	Scalar expression, base, lower exponent, upper exponent, number of steps per order of magnitude [, increment]	Log-linear frequency distribution. The logarithmic base is specified, along with lower and upper exponents and the number of steps per order of magnitude.

Aggregation Examples

The following is a series of examples that illustrate aggregations.

Basic Aggregation

To count the number of `write()` system calls in the system, you could use an informative string as a key and the `count` aggregating function and save it to file named `writes.d`:

```
syscall::write:entry
{
  @counts["write system calls"] = count();
}
```

The `dtrace` command prints aggregation results by default when the process terminates, either as the result of an explicit `END` action or when you press `Ctrl-C`. The following example shows the result of running this command, waiting a few seconds, and then pressing `Ctrl-C`:

```
# dtrace -s writes.d
dtrace: script './writes.d' matched 1 probe
^C
write system calls                                179
#
```

Using Keys

You can count system calls per process name by specifying the `execname` variable as the key to an aggregation and saving it in a file named `writesbycmd.d`:

```
syscall::write:entry
{
  @counts[execname] = count();
}
```

The following example output shows the result of running this command, waiting a few seconds, and then pressing `Ctrl-C`:

```
# dtrace -s writesbycmd.d
dtrace: script 'writesbycmd.d' matched 1 probe
^C
  dirname                                                   1
  dtrace                                                    1
  gnome-panel                                               1
  mozilla-xremote                                           1
  ps                                                        1
  avahi-daemon                                              2
  basename                                                  2
  gconfd-2                                                  2
  java                                                      2
  pickup                                                    2
  qmgr                                                      2
  sed                                                       2
  dbus-daemon                                               3
  rtkit-daemon                                              3
  uname                                                     3
  w                                                         5
  bash                                                      9
  cat                                                       9
  gnome-session                                             9
  Xorg                                                     21
  firefox                                                 149
  gnome-terminal                                         9421
#
```

Alternatively, you might want to further examine writes that are organized by both executable name and file descriptor. The file descriptor is the first argument to `write()`. The following example uses a key that is a tuple, which consists of both `execname` and `arg0`:

```
syscall::write:entry
{
  @counts[execname, arg0] = count();
}
```

Running this command results in a table with both executable name and file descriptor, as shown in the following example:

```
# dtrace -s writesbycmdfd.d
dtrace: script 'writesbycmdfd.d' matched 1 probe
^C
```

```
  basename                                                  1        1
  dbus-daemon                                              70        1
  dircolors                                                 1        1
  dtrace                                                    1        1
  gnome-panel                                              35        1
  gnome-terminal                                           16        1
  gnome-terminal                                           18        1
  init                                                      4        1
  ps                                                        1        1
  pulseaudio                                               20        1
  tput                                                      1        1
  Xorg                                                      2        2
#
```

A limited set of actions can be used as aggregation keys. Consider the following use of the `mod()` and `stack()` actions:

```
profile-10
{
  @hotmod[mod(arg0)] = count();
  @hotstack[stack()] = count();
}
```

Here, the `hotmod` aggregation counts probe firings by module, using the `profile` probe's `arg0` to determine the kernel program counter. The `hotstack` aggregation counts probe firings by stack. The aggregation output reveals which modules and kernel call stacks are the hottest.

Using the avg Function

The following example displays the average time spent in the `write()` system call, organized by process name. This example uses the `avg` aggregating function, specifying the expression to average as the argument. The example averages the wall clock time spent in the system call and is saved in a file named `writetime.d`:

```
syscall::write:entry
{
  self->ts = timestamp;
}

syscall::write:return
/self->ts/
{
  @time[execname] = avg(timestamp - self->ts);
  self->ts = 0;
}
```

The following output shows the result of running this command, waiting a few seconds, and then pressing `Ctrl-C`:

```
# dtrace -s writetime.d
dtrace: script 'writetime.d' matched 2 probes
^C

  gnome-session                                          8260
  udisks-part-id                                         9279
  gnome-terminal                                         9378
  mozilla-xremote                                       10061
  abrt-handle-eve                                       13414
  vgdisplay                                             13459
```

```
  avahi-daemon                                              14043
  vgscan                                                    14190
  uptime                                                    14533
  lsof                                                      14903
  ip                                                        15075
  date                                                      15371
  ...
  ps                                                        91792
  sestatus                                                  98374
  pstree                                                   102566
  sysctl                                                   175427
  iptables                                                 192835
  udisks-daemon                                            250405
  python                                                   282544
  dbus-daemon                                              491069
  lsblk                                                    582138
  Xorg                                                    2337328
  gconfd-2                                               17880523
  cat                                                    59752284
#
```

Using the stddev Function

Meanwhile, you can use the `stddev` aggregating function to characterize the distribution of data points. The following example shows the average and standard deviation of the time that it takes to `exec` processes. Save it in a file named `stddev.d`:

```
syscall::execve:entry
{
 self->ts = timestamp;
}

syscall::execve:return
/ self->ts /
{
  t = timestamp - self->ts;
  @execavg[probefunc] = avg(t);
  @execsd[probefunc] = stddev(t);
  self->ts = 0;
}

END
{
  printf("AVERAGE:");
  printa(@execavg);
  printf("\nSTDDEV:");
  printa(@execsd);
}
```

The sample output is as follows:

```
# dtrace -q -s stddev.d
^C
AVERAGE:
  execve                                                  253839

STDDEV:
  execve                                                  260226
```

> **Note:**
>
> The standard deviation is approximated as $\sqrt{((\Sigma(x^2)/N)-(\Sigma x/N)^2)}$, which is an imprecise approximation, but should suffice for most purposes to which DTrace is put.

Using the quantize Function

The average and standard deviation can be useful for crude characterization, but often do not provide sufficient detail to understand the distribution of data points. To understand the distribution in further detail, use the `quantize` aggregating function, as shown in the following example, which is saved in a file named `wrquantize.d`:

```
syscall::write:entry
{
  self->ts = timestamp;
}

syscall::write:return
/self->ts/
{
  @time[execname] = quantize(timestamp - self->ts);
  self->ts = 0;
}
```

Because each line of output becomes a frequency distribution diagram, the output of this script is substantially longer than previous scripts. The following example shows a selection of sample output:

```
# dtrace -s wrquantize.d
dtrace: script 'wrquantize.d' matched 2 probes
^C
...
  bash
           value  ------------- Distribution ------------- count
            8192 |                                         0
           16384 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 4
           32768 |                                         0
           65536 |                                         0
          131072 |@@@@@@@@@                                1
          262144 |                                         0

  gnome-terminal
           value  ------------- Distribution ------------- count
            4096 |                                         0
            8192 |@@@@@@@@@@@@@@@                          5
           16384 |@@@@@@@@@@@@@@@                          5
           32768 |@@@@@@@@@@@@                             4
           65536 |@@@                                      1
          131072 |                                         0

  Xorg
           value  ------------- Distribution ------------- count
            2048 |                                         0
            4096 |@@@@@@@@                                 4
            8192 |@@@@@@@@@@@@@@@@                         8
           16384 |@@@@@@@@@@@@@@                           7
           32768 |@@@                                      2
```

```
          65536 |@@                                       1
         131072 |                                         0
         262144 |                                         0
         524288 |                                         0
        1048576 |                                         0
        2097152 |@@@                                      2
        4194304 |                                         0

  firefox
           value  ------------- Distribution ------------- count
            2048 |                                         0
            4096 |@@@                                      22
            8192 |@@@@@@@@@@@                              90
           16384 |@@@@@@@@@@@@@@                           107
           32768 |@@@@@@@@@                                72
           65536 |@@@                                      28
          131072 |                                         3
          262144 |                                         0
          524288 |                                         1
         1048576 |                                         1
         2097152 |                                         0
```

The rows for the frequency distribution are always power-of-two values. Each row indicates a count of the number of elements that are greater than or equal to the corresponding value, but less than the next larger row's value. For example, the previous output shows that `firefox` had 107 writes, taking between 16,384 nanoseconds and 32,767 nanoseconds, inclusive.

The previous example shows the distribution of numbers of write times. You might also be interested in knowing which write times are contributing to the overall run time the most. You can optionally use the `increment` argument with the `quantize` function for this purpose. Note that the default value is `1`, but this argument can be a D expression, as well as have negative values.

The following example shows a modified script:

```
 syscall::write:entry
{
  self->ts = timestamp;
}

syscall::write:return
/self->ts/
{
  self->delta = timestamp - self->ts;
  @time[execname] = quantize(self->delta, self->delta);
  self->ts = 0;
}
```

Using the lquantize Function

While `quantize` is useful for getting quick insight into data, you might want to examine a distribution across linear values instead. To display a linear value distribution, use the `lquantize` aggregating function. The `lquantize` function takes three arguments in addition to a D expression: a lower bound, an upper bound, and an optional step. Note that the default step value is `1`.

For example, if you wanted to look at the distribution of writes by file descriptor, a power-of-two quantization would not be effective. Instead, as shown in the following example, you could use a linear quantization with a small range, which is saved in a file named `wrlquantize.d`:

```
syscall::write:entry
{
  @fds[execname] = lquantize(arg0, 0, 100, 1);
}
```

Note that you could also omit the last argument because `1` is the default step value.

Running this script for several seconds yields a large amount of information. The following example shows a selection of the typical output:

```
# dtrace -s wrlquantize.d
dtrace: script 'wrlquantize.d' matched 1 probe
^C
 ...
  gnome-session
           value  ------------- Distribution ------------- count
              25 |                                         0
              26 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 9
              27 |                                         0

  gnome-terminal
           value  ------------- Distribution ------------- count
              15 |                                         0
              16 |@@                                       1
              17 |                                         0
              18 |                                         0
              19 |                                         0
              20 |                                         0
              21 |@@@@@@@@@                                4
              22 |@@                                       1
              23 |@@                                       1
              24 |                                         0
              25 |                                         0
              26 |                                         0
              27 |                                         0
              28 |                                         0
              29 |@@@@@@@@@@@@@@                           6
              30 |@@@@@@@@@@@@@@                           6
              31 |                                         0
 ...
```

You can also use the `lquantize` aggregating function to aggregate on time, starting with some point of time in the past. This technique enables you to observe a change in behavior over time.

The following example displays the change in system call behavior over the lifetime of a process that is executing the `date` command. Save it in a file named `dateprof.d`:

```
syscall::execve:return
/execname == "date"/
{
  self->start = timestamp;
}

syscall:::entry
/self->start/
{
  /*
   * We linearly quantize on the current virtual time minus our
   * process's start time. We divide by 1000 to yield microseconds
   * rather than nanoseconds. The range runs from 0 to 10 milliseconds
   * in steps of 100 microseconds; we expect that no date(1) process
```

```
   * will take longer than 10 milliseconds to complete.
   */
  @a["system calls over time"] =
  lquantize((timestamp - self->start) / 1000, 0, 10000, 100);
}

syscall::exit:entry
/self->start/
{
  self->start = 0;
}
```

This script provides greater insight into system call behavior when many `date` processes are being executed. To see this result, run `sh -c 'while true; do date >/dev/null; done'` in one window, while executing the D script in another window. The script produces a profile of the system call behavior of the `date` command that is similar to the following:

```
# dtrace -s dateprof.d
dtrace: script 'dateprof.d' matched 298 probes
^C

  system calls over time
           value  ------------- Distribution ------------- count
             < 0 |                                         0
               0 |@@                                       23428
             100 |@@@@@                                    56263
             200 |@@@@@                                    61271
             300 |@@@@@                                    58132
             400 |@@@@@                                    54617
             500 |@@@@                                     45545
             600 |@@                                       26049
             700 |@@@                                      38859
             800 |@@@@                                     51569
             900 |@@@@                                     42553
            1000 |@                                        11339
            1100 |                                         4020
            1200 |                                         2236
            1300 |                                         1264
            1400 |                                         812
            1500 |                                         706
            1600 |                                         764
            1700 |                                         586
            1800 |                                         266
            1900 |                                         155
            2000 |                                         118
            2100 |                                         86
            2200 |                                         93
            2300 |                                         66
            2400 |                                         32
            2500 |                                         32
            2600 |                                         18
            2700 |                                         23
            2800 |                                         26
            2900 |                                         30
            3000 |                                         26
            3100 |                                         1
            3200 |                                         7
            3300 |                                         9
            3400 |                                         3
            3500 |                                         5
            3600 |                                         1
            3700 |                                         6
```

```
3800 |                                         8
3900 |                                         8
4000 |                                         8
4100 |                                         1
4200 |                                         1
4300 |                                         6
4400 |                                         0
```

The previous output provides a rough idea of the different phases of the `date` command, with respect to the services that are required of the kernel. To better understand these phases, you might want to understand which system calls are being called and when they are called. In this case, you could change the D script to aggregate on the `probefunc` variable instead of a constant string.

The log-linear `llquantize` aggregating function combines the capabilities of both the log and linear functions. While the simple `quantize` function uses base 2 logarithms, with `llquantize`, you specify the base, as well as the minimum and maximum exponents. Further, each logarithmic range is subdivided linearly with a number of steps, as specified.

Printing Aggregations

By default, multiple aggregations are displayed in the order in which they are introduced in the D program. You can override this behavior by using the `printa` function to print the aggregations. The `printa` function also enables you to precisely format the aggregation data by using a format string, as described in Output Formatting.

If an aggregation is not formatted with a `printa` statement in your D program, the `dtrace` command snapshots the aggregation data and prints the results after tracing has completed, using the default aggregation format. If a given aggregation is formatted with a `printa` statement, the default behavior is disabled. You can achieve equivalent results by adding the `printa(@`*`aggregation-name`*`)` statement to an `END` probe clause in your program. The default output format for the `avg`, `count`, `min`, `max`, and `sum` aggregating functions displays an integer decimal value corresponding to the aggregated value for each tuple. The default output format for the `quantize`, `lquantize`, and `llquantize` aggregating functions displays an ASCII table with the results. Aggregation tuples are printed as though `trace` had been applied to each tuple element.

Data Normalization

When aggregating data over some period of time, you might want to normalize the data, with respect to some constant factor. This technique enables you to compare disjointed data more easily. For example, when aggregating system calls, you might want to output system calls as a per-second rate instead of as an absolute value over the course of the run. The DTrace `normalize` action enables you to normalize data in this way. The parameters to `normalize` are an aggregation and a normalization factor. The output of the aggregation shows each value divided by the normalization factor.

The following example shows how to aggregate data by system call:

```
#pragma D option quiet

BEGIN
{
  /*
   * Get the start time, in nanoseconds.
   */
  start = timestamp;
```

```
}

syscall::entry
{
  @func[execname] = count();
}

END
{
  /*
   * Normalize the aggregation based on the number of seconds we have
   * been running. (There are 1,000,000,000 nanoseconds in one second.)
   */
  normalize(@func, (timestamp - start) / 1000000000);
}
```

Running the previous script for a brief period of time results in the following output:

```
# dtrace -s normalize.d
^C
  memballoon                                                      1
  udisks-daemon                                                   1
  vmstats                                                         1
  rtkit-daemon                                                    2
  automount                                                       2
  gnome-panel                                                     3
  gnome-settings-                                                 5
  NetworkManager                                                  6
  gvfs-afc-volume                                                 6
  metacity                                                        6
  qpidd                                                           9
  hald-addon-inpu                                                14
  gnome-terminal                                                 19
  Xorg                                                           35
  VBoxClient                                                     52
  X11-NOTIFY                                                    104
  java                                                          143
  dtrace                                                        309
  sh                                                          36467
  date                                                        68142
```

The normalize action sets the normalization factor for the specified aggregation, but this action does not modify the underlying data. The denormalize action takes only an aggregation. Adding the denormalize action to the preceding example returns both raw system call counts and per-second rates. Type the following source code and save it in a file named `denorm.d`:

```
#pragma D option quiet

BEGIN
{
  start = timestamp;
}

syscall::entry
{
  @func[execname] = count();
}

END
{
  this->seconds = (timestamp - start) / 1000000000;
  printf("Ran for %d seconds.\n", this->seconds);
```

```
  printf("Per-second rate:\n");
  normalize(@func, this->seconds);
  printa(@func);
  printf("\nRaw counts:\n");
  denormalize(@func);
  printa(@func);
}
```

Running the previous script for a brief period of time produces output similar to the following:

```
# dtrace -s denorm.d
^C
Ran for 7 seconds.
Per-second rate:

  audispd                                                 0
  auditd                                                  0
  memballoon                                              0
  rtkit-daemon                                            0
  timesync                                                1
  gnome-power-man                                         1
  vmstats                                                 1
  automount                                               2
  udisks-daemon                                           2
  gnome-panel                                             2
  metacity                                                2
  gnome-settings-                                         3
  qpidd                                                   4
  clock-applet                                            4
  gvfs-afc-volume                                         5
  crond                                                   6
  gnome-terminal                                          7
  vminfo                                                 15
  hald-addon-inpu                                        32
  VBoxClient                                             45
  Xorg                                                   63
  X11-NOTIFY                                             90
  java                                                  126
  dtrace                                                315
  sh                                                  31430
  date                                                58724

Raw counts:

  audispd                                                 1
  auditd                                                  4
  memballoon                                              4
  rtkit-daemon                                            6
  timesync                                                8
  gnome-power-man                                         9
  vmstats                                                12
  automount                                              16
  udisks-daemon                                          16
  gnome-panel                                            20
  metacity                                               20
  gnome-settings-                                        22
  qpidd                                                  28
  clock-applet                                           34
  gvfs-afc-volume                                        40
  crond                                                  42
  gnome-terminal                                         54
  vminfo                                                105
```

```
  hald-addon-inpu                                             225
  VBoxClient                                                  318
  Xorg                                                        444
  X11-NOTIFY                                                  634
  java                                                        883
  dtrace                                                     2207
  sh                                                       220016
  date                                                     411073
```

Aggregations can also be renormalized. If `normalize` is called more than once for the same aggregation, the normalization factor is the factor specified in the most recent call. The following example displays only the per-second system call rates of the top ten system-calling applications in a ten-second period. Type the following source code and save it in a file named `truncagg.d`:

```
#pragma D option quiet

BEGIN
{
  start = timestamp;
}

syscall::::entry
{
  @func[execname] = count();
}

tick-10sec
{
  normalize(@func, (timestamp - start) / 1000000000);
  printa(@func);
}
```

Clearing Aggregations

When using DTrace to build simple monitoring scripts, you can periodically clear the values in an aggregation by using the `clear` function. This function takes an aggregation as its only parameter. The `clear` function clears only the aggregation's values, while the aggregation's keys are retained. Therefore, the presence of a key in an aggregation that has an associated value of zero indicates that the key had a non-zero value that was subsequently set to zero as part of a `clear`. To discard both an aggregation's values and its keys, use the `trunc` function. See Truncating Aggregations.

The following example uses `clear` to show the system call rate only for the most recent ten-second period:

```
#pragma D option quiet

BEGIN
{
  last = timestamp;
}

syscall::::entry
{
  @func[execname] = count();
}

tick-10sec
{
```

```
  normalize(@func, (timestamp - last) / 1000000000);
  printa(@func);
  clear(@func);
  last = timestamp;
}
```

Truncating Aggregations

When looking at aggregation results, you often care only about the top several results. The keys and values that are associated with anything other than the highest values are not of interest. You might also choose to discard an entire aggregation result, removing both the keys and values. The DTrace `trunc` function is used in both of these situations.

The parameters to `trunc` are an aggregation and an optional truncation value. Without the truncation value, `trunc` discards both the aggregation values and the aggregation keys for the entire aggregation. When a truncation value *n* is present, `trunc` discards the aggregation values and keys, except for those values and keys that are associated with the highest *n* values. That is to say, `trunc(@foo, 10)` truncates the aggregation named `foo` after the top ten values, where `trunc(@foo)` discards the entire aggregation. The entire aggregation is also discarded if `0` is specified as the truncation value.

To see the bottom *n* values instead of the top *n* values, specify a negative truncation value to `trunc`. For example, `trunc(@foo, -10)` truncates the aggregation named `foo` after the bottom ten values.

The following example displays only the per-second system call rates of the top ten system-calling applications in a ten-second period:

```
#pragma D option quiet

BEGIN
{
  last = timestamp;
}

syscall:::entry
{
  @func[execname] = count();
}

tick-10sec
{
  trunc(@func, 10);
  normalize(@func, (timestamp - last) / 1000000000);
  printa(@func);
  clear(@func);
  last = timestamp;
}
```

The following example shows the output from running the previous script on a lightly loaded system:

```
# dtrace -s truncagg.d

  dbus-daemon                                                   0
  NetworkManager                                                1
  gmain                                                         1
  systemd-logind                                                1
  sendmail                                                      1
  systemd                                                       1
```

```
  httpd                                                         2
  tuned                                                         5
  dtrace                                                       44

  rpcbind                                                       0
  dbus-daemon                                                   0
  gmain                                                         0
  sshd                                                          1
  systemd-logind                                                1
  sendmail                                                      1
  systemd                                                       1
  httpd                                                         2
  tuned                                                         5
  dtrace                                                       41

  dbus-daemon                                                   0
  gmain                                                         1
  sshd                                                          1
  systemd-logind                                                1
  sendmail                                                      1
  systemd                                                       1
  httpd                                                         2
  tuned                                                         5
  automount                                                     7
  dtrace                                                       41
^C

#
```

Minimizing Drops

Because DTrace buffers some aggregation data in the kernel, space might not be available when a new key is added to an aggregation. In this case, the data is dropped, the counter is incremented, and `dtrace` generates a message indicating an aggregation drop. You should note that this situation rarely occurs because DTrace keeps state information consisting of the aggregation's key and intermediate results at user level, where space can grow dynamically. In the unlikely event that an aggregation drop occurs, you can increase the aggregation buffer size by using the `aggsize` option, which reduces the likelihood of drops.

You can also use this option to minimize the memory footprint of DTrace. As with any size option, `aggsize` can be specified with any size suffix. The resizing policy of this buffer is dictated by the `bufresize` option. For more information about buffering, see Buffers and Buffering.

An alternative method to eliminate aggregation drops is to increase the rate at which aggregation data is consumed at the user level. This rate defaults to once per second, and may be explicitly tuned with the `aggrate` option. As with any rate option, `aggrate` can be specified with any time suffix, but defaults to rate-per-second. For more information about the `aggsize` option, see Options and Tunables.

4

Actions and Subroutines

> **WARNING:**
>
> Oracle Linux 7 is now in Extended Support. See Oracle Linux Extended Support and Oracle Open Source Support Policies for more information.
>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

You use D function calls such as `trace` and `printf` to invoke two different kinds of services that are provided by DTrace: *actions* and *subroutines*. Actions trace data or modify a state that is external to DTrace, while *subroutines* affect only the internal DTrace state.

This chapter defines DTrace actions and subroutines and also describes their syntax and semantics.

Action Functions

Action functions enable your DTrace programs to interact with the system outside of DTrace. The most common actions record data to a DTrace buffer. Other actions are available, such as stopping the current process, raising a specific signal on the current process, and ceasing tracing altogether. Some of these actions are *destructive*, in that they change the system, albeit in a well-defined way. These actions may only be used if destructive actions have been explicitly enabled. By default, data recording actions record data to the *principal buffer*. For more information about the principal buffer and buffer policies, see Buffers and Buffering.

Default Action

A clause can contain any number of actions and variable manipulations. If a clause is left empty, the *default action* is taken. The default action is to trace the enabled probe identifier (EPID) to the principal buffer. For more information about `epid`, see Built-In Variables. From the EPID, the `dtrace` command outputs the following information: CPU, probe ID, probe function, and probe name.

The default action facilitates a simple use of the `dtrace` command. For example, running the following command enables all of the probes in the `vmlinux` module with the default action:

```
# dtrace -m vmlinux
```

The preceding command might produce output similar to the following:

```
# dtrace -m vmlinux
dtrace: description 'vmlinux' matched 35 probes
CPU     ID                    FUNCTION:NAME
  0     42                  __schedule:sleep
```

```
  0     34             dequeue_task:dequeue
  0     40               __schedule:off-cpu
  0     23        finish_task_switch:on-cpu
  0     24             enqueue_task:enqueue
  0     41               __schedule:preempt
  0     40               __schedule:off-cpu
  0     23        finish_task_switch:on-cpu
  0     11        update_process_times:tick
  0     42                 __schedule:sleep
  0     34             dequeue_task:dequeue
  0     40               __schedule:off-cpu
  0     23        finish_task_switch:on-cpu
  0     24             enqueue_task:enqueue
  0     41               __schedule:preempt
  0     40               __schedule:off-cpu
  0     23        finish_task_switch:on-cpu
  0     11        update_process_times:tick
  0     12            try_to_wake_up:wakeup
  0     42                 __schedule:sleep
...
```

Data Recording Actions

Data recording actions are the core DTrace actions. Each of these actions records data to the principal buffer by default, but each action can also be used to record data to speculative buffers. See Buffers and Buffering and Speculative Tracing for more details on the principal buffer and speculative buffers.

The following descriptions refer only to the *directed buffer*, indicating that data is recorded either to the principal buffer or to a speculative buffer if the action follows a `speculate`.

freopen

```
void freopen(string format, ...)
```

The `freopen` action changes the file that is associated with `stdout` to the file that is specified by the arguments in `printf` fashion.

If the `""` string is used, the output is again restored to `stdout`.

> **Caution:**
>
> The `freopen` action is not only data-recording but also destructive, because you can use it to overwrite arbitrary files.

ftruncate

```
void ftruncate(void)
```

The `ftruncate` action truncates the output stream on `stdout`.

func

```
_symaddr func(uintptr_t address)
```

The `func` action prints the symbol that corresponds to a specified kernel-space address. For example, `func((uintptr_t) (&vmlinux`max_pfn))` causes `vmlinux`max_pfn` to be printed. The `func` action is an alias for `sym`.

mod

```
_symaddr mod(uintptr_t address)
```

The `mod` action prints the name of the module that corresponds to a specified kernel-space address. For example, `mod((uintptr_t) (&vmlinux`max_pfn))` prints `vmlinux`.

printa

```
void printa(aggregation)
void printa(string format, aggregation)
```

The `printa` action enables you to display and format aggregations. See Aggregations for more details. If *format* is not specified, `printa` traces only a directive to the DTrace consumer for which the specified aggregation should be processed and is displayed using the default format. If *format* is specified, the aggregation is formatted. See printa Action for a detailed description of the `printa` format string.

When `printa` traces only a *directive* that the aggregation should be processed by the DTrace consumer, it does not process the aggregation in the kernel. Therefore, the time between the tracing of the `printa` directive and the actual processing of the directive depends on factors that affect buffer processing, which include the following: the aggregation rate, the buffering policy (and if the buffering policy is `switching`), and the rate at which buffers are switched. See Aggregations and Buffers and Buffering for detailed descriptions.

printf

```
void printf(string format, ...)
```

Like `trace`, the `printf` action traces D expressions, but `printf` enables elaborate `printf`-style formatting. The parameters consist of a *format* string, followed by a variable number of arguments. By default, the arguments are traced to the directed buffer. The arguments are later formatted for output by the `dtrace` command, according to the specified format string, for example:

```
printf("execname is %s; priority is %d", execname, curlwpsinfo->pr_pri);
```

For more information, see printf Action.

stack

```
stack stack(int nframes)
stack stack(void)
```

The `stack` action records a kernel stack trace to the directed buffer. The kernel stack is *nframes* in depth. If *nframes* is not specified, the number of stack frames recorded is the number that is specified by the `stackframes` option. The `dtrace` command reports frames, either up to the root frame or until the *nframes* limit has been reached, whichever comes first:

```
# dtrace -n gettimeofday:entry'{stack()}'
dtrace: description 'gettimeofday:entry' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0    196              gettimeofday:entry
```

```
              vmlinux`pollwake
              vmlinux`dtrace_stacktrace+0x30
              vmlinux`__brk_limit+0x1e1832d7
              vmlinux`__brk_limit+0x1e1913a1
              vmlinux`pollwake
              vmlinux`do_gettimeofday+0x1a
              vmlinux`ktime_get_ts+0xad
              vmlinux`systrace_syscall+0xde
              vmlinux`audit_syscall_entry+0x1d7
              vmlinux`system_call_fastpath+0x16

  0    196              gettimeofday:entry
              vmlinux`dtrace_stacktrace+0x30
              vmlinux`__brk_limit+0x1e1832d7
              vmlinux`__brk_limit+0x1e1913a1
              vmlinux`security_file_permission+0x8b
              vmlinux`systrace_syscall+0xde
              vmlinux`audit_syscall_entry+0x1d7
              vmlinux`system_call_fastpath+0x16

...
```

The `stack` action, having a non-`void` return value, can also be used as the key to an aggregation, for example:

```
# dtrace -n execve:entry'{@[stack()] = count()}'
dtrace: description 'execve:entry' matched 1 probe
^C


              vmlinux`dtrace_stacktrace+0x30
              vmlinux`__brk_limit+0x1e1832d7
              vmlinux`__brk_limit+0x1e1913a1
              vmlinux`dtrace_execve+0xcd
              vmlinux`audit_syscall_entry+0x1d7
              vmlinux`dtrace_stub_execve+0x6c
                2

              vmlinux`dtrace_stacktrace+0x30
              vmlinux`__brk_limit+0x1e1832d7
              vmlinux`__brk_limit+0x1e1913a1
              vmlinux`do_sigaction+0x13a
              vmlinux`dtrace_execve+0xcd
              vmlinux`audit_syscall_entry+0x1d7
              vmlinux`dtrace_stub_execve+0x6c
               13

...
```

sym

```
_symaddr sym(uintptr_t address)
```

The `sym` action prints the symbol that corresponds to a specified kernel-space address. For example, `sym((uintptr_t) (&vmlinux`max_pfn))` causes `vmlinux`max_pfn` to be printed. The `sym` action is an alias for `func`.

trace

```
void trace(expression)
```

The `trace` action is the most basic action. This action takes a D expression as its argument and then traces the result to the directed buffer. The following statements are examples of `trace` actions:

```
trace(execname);
trace(curlwpsinfo->pr_pri);
trace(timestamp / 1000);
trace('lbolt);
trace("somehow managed to get here");
```

If the `trace` action is used on a buffer, the output format depends on the data type. If the `dtrace` command determines that the data is like an ASCII string, it prints it as text and terminates the output with a null character (`0`). When `dtrace` decides that the data is most likely binary, it prints it in hexadecimal format, for example:

```
0      342                       write:entry
             0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f  0123456789abcdef
           0: c0 de 09 c2 4a e8 27 54 dc f8 9f f1 9a 20 4b d1  ....J.'T..... K.
          10: 9c 7a 7a 85 1b 03 0a fb 3a 81 8a 1b 25 35 b3 9a  .zz.....:...%5..
          20: f1 7d e6 2b 66 6d 1c 11 f8 eb 40 7f 65 9a 25 f8  .}.+fm....@.e.%.
          30: c8 68 87 b2 6f 48 a2 a5 f3 a2 1f 46 ab 3d f9 d2  .h..oH.....F.=..
          40: 3d b8 4c c0 41 3c f7 3c cd 18 ad 0d 0d d3 1a 90  =.L.A<.<........
```

You can force the `trace` action to always use the binary format by specifying the `rawbytes` option.

tracemem

```
void tracemem(address, size_t nbytes)
void tracemem(address, size_t nbytes, size_t dbytes)
```

The `tracemem` action takes a D expression as its first argument, *address*, and a constant as its second argument, *nbytes*. The `tracemem` action copies the memory from the address specified by *address* into the directed buffer for the length specified by *nbytes*. If only two arguments are provided, `dtrace` dumps the entire contents of the buffer.

In the second format, the `tracemem` action takes an additional, third argument, *dbytes*, which is a D expression that is computed dynamically. The result is used to limit the number of bytes that are displayed. If the result is less than zero or greater than *nbytes*, the result is ignored and `tracemem` behaves as though it is called by using the two-argument form. Otherwise, `dtrace` dumps only the *dbytes* bytes of the directed buffer.

ustack

> **Note:**
>
> If you want to perform symbol lookup in a stripped executable, you must specify the `--export-dynamic` option when linking the program. This option causes the linker to add all symbols to the dynamic symbol table, which is the set of symbols that is visible from dynamic objects at run time. If you use `gcc` to link the objects, specify the option as `-Wl,--export-dynamic` to pass the correct option to the linker.
>
> Note also that f you want to look up symbols in shared libraries or unstripped executables, the `--export-dynamic` option is not required.

DTrace supports the use of the `ustack` action with both 32-bit and 64-bit binaries, for example:

```
stack ustack(int nframes, int strsize)
stack ustack(int nframes)
stack ustack(void)
```

The `ustack` action records a user stack trace to the directed buffer. The user stack is *nframes* in depth. If *nframes* is not specified, the number of stack frames that is recorded is the number specified by the `ustackframes` option. While `ustack` is able to determine the address of the calling frames when the probe fires, the stack frames are not translated into symbols until the `ustack` action is processed at user level by the DTrace consumer. If *strsize* is specified and is non-zero, `ustack` allocates the specified amount of string space and then uses it to perform address-to-symbol translation directly from the kernel. Such direct user symbol translation is used only with stacktrace helpers that support this usage with DTrace. If such frames cannot be translated, the frames appear only as hexadecimal addresses.

The following example traces a stack with no address-to-symbol translation:

```
# dtrace -n syscall::write:entry'/pid == $target/{ustack(); exit(0)}' -c "./
mytestprog -v"
dtrace: description 'syscall::write:entry' matched 1 probe
mytestprog (Version 1.0)
CPU     ID                    FUNCTION:NAME
  2      6                      write:entry
              mytestprog`printver+0x2f
              mytestprog`0x401338
              mytestprog`main+0xc7
              mytestprog`0x401338
              libc.so.6`__libc_start_main+0xfd
              mytestprog`main
              mytestprog`0x400ad0
              mytestprog`__libc_csu_init
              mytestprog`0x400ad0
              mytestprog`0x400af9
```

The `ustack` symbol translation occurs after the stack data is recorded. Therefore, the corresponding user process might exit before symbol translation can be performed, making stack frame translation impossible. If the user process exits before symbol translation is performed, `dtrace` outputs a warning message, followed by the hexadecimal stack frames.

uaddr

DTrace supports the use of the `uaddr` action with both 32-bit and 64-bit binaries.

```
_usymaddr uaddr(uintptr_t address)
```

The `uaddr` action prints the symbol for a specified address, including hexadecimal offset, which enables the same symbol resolution that `ustack` provides.

usym

DTrace supports the use of the `usym` action with both 32-bit and 64-bit binaries.

```
_usymaddr usym(uintptr_t address)
```

The `usym` action prints the symbol for a specified address, which is analogous to how `uaddr` works, but without the hexadecimal offsets.

Destructive Actions

Some DTrace actions are destructive, in that they change the state of the system in some well-defined way. Destructive actions may not be used unless they have been explicitly enabled. When using `dtrace`, you enable destructive actions by using the `-w` option. If you attempt to perform destructive actions without explicitly enabling them, `dtrace` fails with a message similar to the following:

```
dtrace: failed to enable 'syscall': destructive actions not allowed
```

Process-destructive actions are destructive only to a particular process. Whereas, kernel-destructive actions are destructive to the entire system. Therefore, these actions must be used extremely carefully, as such actions affect every process on the system and any other system, implicitly or explicitly, depending upon the affected system's network services.

The following information pertains to both process-destructive and kernel-destructive actions.

copyout (Process-Destructive)

```
void copyout(void *buf, uintptr_t addr, size_t nbytes)
```

The `copyout` action copies *nbytes* from the buffer that is specified by *buf* to the address that is specified by *addr*, in the address space of the process that associated with the current thread. If the user-space address does not correspond to a valid, faulted-in page in the current address space, an error is generated.

copyoutstr (Process-Destructive)

```
void copyoutstr(string str, uintptr_t addr, size_t maxlen)
```

The `copyoutstr` action copies the string tha tis specified by *str* to the address that is specified by *addr* in the address space of the process associated with the current thread. If the user-space address does not correspond to a valid, faulted-in page in the current address space, an error is generated. Note that the string length is limited to the value that is set by the *strsize* option. See Options and Tunables.

raise (Process-Destructive)

```
void raise(int signal)
```

The `raise` action sends the specified signal to the currently running process. This action is similar to using the `kill` command to send a signal to a process. The `raise` action can be used to send a signal at a precise point in the execution of a process.

stop (Process-Destructive)

```
void stop(void)
```

The `stop` action forces the process that is firing the enabled probe to stop when it next leaves the kernel, as if stopped by a `proc` action. The `stop` action can be used to stop a process at any DTrace probe point. This action can be used to capture a program in a particular state that would be difficult to achieve with a simple breakpoint and then attach a traditional debugger such as `gdb` to the process. You can also use the `gcore` utility to save the state of a stopped process in a core file for later analysis.

system (Process-Destructive)

```
void system(string program, ...)
```

The `system` action causes the specified *program* to be executed as though given to the shell as input. The *program* string can contain any of the `printf` or `printa` format conversions. Arguments that match the format conversions must be specified. See Output Formatting for details on valid format conversions.

The following example runs the `date` command once per second:

```
# dtrace -wqn tick-1sec'{system("date")}'
Tue Oct 16 10:21:34 BST 2012
Tue Oct 16 10:21:35 BST 2012
Tue Oct 16 10:21:36 BST 2012
^C
#
```

The following example shows a more elaborate use of the action by using `printf` conversions in the program string, along with traditional filtering tools such as pipes. Type the following source code and save it in a file named `whosend.d`:

```
#pragma D option destructive
#pragma D option quiet

proc:::signal-send
/args[2] == SIGINT/
{
  printf("SIGINT sent to %s by ", args[1]->pr_fname);
  system("getent passwd %d | cut -d: -f5", uid);
}
```

Running the previous script results in output similar to the following:

```
# dtrace -s whosend.d
SIGINT sent to top by root
SIGINT sent to bash by root
SIGINT sent to bash by A Nother
^C
SIGINT sent to dtrace by root
```

The execution of the specified command does not occur in the context of the firing probe. Rather, it occurs when the buffer containing the details of the `system` action are processed at user level. How and when this processing occurs depends on the buffering policy, as described in Buffers and Buffering. With the default buffering policy, the buffer processing rate is specified by the `switchrate` option.

You can see the delay that is inherent in system if you explicitly tune the `switchrate` higher than its one-second default, as shown in the following example. Save it in a file named `time.d`:

```
#pragma D option quiet
#pragma D option destructive
#pragma D option switchrate=5sec

tick-1sec
/n++ < 5/
{
  printf("walltime : %Y\n", walltimestamp);
  printf("date : ");
  system("date");
```

```
  printf("\n");
}

tick-1sec
/n == 5/
{
  exit(0);
}
```

Running the previous script results in output similar to the following:

```
# dtrace -s time.d
walltime : 2012 Oct 16 10:26:07
date : Tue Oct 16 10:26:11 BST 2012

walltime : 2012 Oct 16 10:26:08
date : Tue Oct 16 10:26:11 BST 2012

walltime : 2012 Oct 16 10:26:09
date : Tue Oct 16 10:26:11 BST 2012

walltime : 2012 Oct 16 10:26:10
date : Tue Oct 16 10:26:11 BST 2012

walltime : 2012 Oct 16 10:26:11
date : Tue Oct 16 10:26:11 BST 2012
```

In the previous output, notice that the `walltime` values differ, but the `date` values are identical. This result reflects the fact that the execution of the `date` command occurred when the buffer was processed, not when the `system` action was recorded.

chill (Kernel-Destructive)

```
void chill(int nanoseconds)
```

The `chill` action causes DTrace to spin for the specified number of nanoseconds. This action is primarily useful for exploring problems that might be timing related. For example, you can use this action to open race condition windows or bring periodic events into or out of phase with one another. Because interrupts are disabled while in DTrace probe context, any use of the `chill` action results in an interrupt, scheduling, or dispatch latency. Therefore, `chill` can cause unexpected systemic effects and therefore should not be used indiscriminately. Because system activity relies on periodic interrupt handling, DTrace refuses to execute the `chill` action for more than 500 milliseconds out of each one-second interval on any given CPU. If the maximum `chill` interval is exceeded, DTrace reports an illegal operation error:

```
# dtrace -w -n syscall::openat:entry'{chill(500000001)}'
dtrace: allowing destructive actions
dtrace: description 'syscall::openat:entry' matched 1 probe
dtrace: 57 errors
CPU     ID                    FUNCTION:NAME
dtrace: error on enabled probe ID 1 (ID 14: syscall::openat:entry): \
illegal operation in action #1
```

This limit is enforced even if the time is spread across multiple calls to `chill` or multiple DTrace consumers of a single probe. For example, the same error would be generated by running the following command:

```
# dtrace -w -n syscall::openat:entry'{chill(250000000); chill(250000001);}'
```

panic (Kernel-Destructive)

```
void panic(void)
```

When triggered, the `panic` action causes a kernel panic. This action should be used to force a system crash dump at a time of interest. You can use this action along with ring buffering to understand a problem. For more information, see Buffers and Buffering . When the `panic` action is used, a panic message appears denoting the probe that is causing the panic. `rsyslogd` also emits a message upon reboot. The message buffer of the crash dump contains the probe and event control block (ECB) that is responsible for the `panic` action.

Special Actions

The following are special actions that are not data recording actions or destructive actions.

Speculative Actions

The actions associated with speculative tracing are `speculate`, `commit`, and `discard`. These actions are described in more detail in Speculative Tracing.

exit

```
void exit(int status)
```

The `exit` action is used to immediately stop tracing and inform the DTrace consumer that it should do the following: cease tracing, perform any final processing, and call `exit()` with the specified *status* value. Because `exit` returns a status to user level, it is considered a data recording action, However, unlike other data storing actions, `exit` cannot be speculatively traced. The `exit` action causes the DTrace consumer to exit regardless of buffer policy. Note that because `exit` is a data recording action, it can be dropped.

When `exit` is called, only those DTrace actions that are already in progress on other CPUs are completed. No new actions occur on any CPU. The only exception to this rule is the processing of the `END` probe, which is called after the DTrace consumer has processed the `exit` action, and indicates that tracing should stop.

setopt

```
void setopt(const char *opt_name)
void setopt(const char *opt_name, const char *opt_value)
```

The `setopt` action enables you to specify a DTrace option dynamically, for example:

```
setopt("quiet");
setopt("bufsize", "50m");
setopt("aggrate", "2hz");
```

Subroutine Functions

Subroutine functions differ from actions because they generally only affect the internal DTrace state. Therefore, no destructive subroutines exist. Also, subroutines never trace data into buffers. Many subroutines have analogs in the application programming interfaces. See the Section 3 manual pages for more details.

A number of these subroutines require temporary buffers, which persist only for duration of the clause. Pre-allocated scratch memory is used for such buffers.

alloca

```
void *alloca(size_t size)
```

The `alloca` function allocates *size* bytes out of scratch memory, and returns a pointer to the allocated memory. The returned pointer is guaranteed to have 8–byte alignment. Scratch memory is only valid for the duration of a clause. Memory that is allocated with `alloca` is deallocated when the clause completes. If insufficient scratch memory is available, no memory is allocated and an error is generated.

basename

```
string basename(char *str)
```

The `basename` function creates a string that consists of a copy of the specified string, but excludes any prefix that ends in `/`, such as a directory path. The returned string is allocated out of scratch memory, and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `basename` does not execute and an error is generated.

bcopy

```
void bcopy(void *src, void *dest, size_t size)
```

The `bcopy` function copies *size* bytes from the memory that is pointed to by *src* to the memory that is pointed to by *dest*. All of the source memory must lie outside of scratch memory, and all of the destination memory must lie within it. If these conditions are not met, no copying takes place and an error is generated.

cleanpath

```
string cleanpath(char *str)
```

The `cleanpath` function creates a string consisting of a copy of the path indicated by *str*, but with certain redundant elements eliminated. In particular, `/./` elements in the path are removed, and `/../` elements are collapsed. The collapsing of `/../` elements in the path occurs without regard to symbolic links. Therefore, it is possible that `cleanpath` could take a valid path and return a shorter, invalid path.

For example, if *str* were "`/foo/../bar`" and `/foo` were a symbolic link to `/net/foo/export`, `cleanpath` would return the string "`/bar`", even though `bar` might only exist in `/net/foo` and not in `/`. This limitation is due to the fact that `cleanpath` is called in the context of a firing probe, where full symbolic link resolution of arbitrary names is not possible. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `cleanpath` does not execute and an error is generated.

copyin

```
void *copyin(uintptr_t addr, size_t size)
```

The `copyin` function copies the specified size in bytes from the specified user address (*addr*) into a DTrace scratch buffer and returns the address of this buffer. The user address is interpreted as an address in the space of the process that is associated with the current thread. The resulting buffer pointer is guaranteed to have 8-byte alignment. The address in question must correspond to a faulted-in page in the current process. If the address does not correspond to a faulted-in page, or if insufficient scratch memory is available, `NULL` is returned and an error is generated.

copyinstr

```
string copyinstr(uintptr_t addr)
string copyinstr(uintptr_t addr, size_t maxlen)
```

The `copyinstr` function copies a null-terminated C string from the specified user address (*addr*) into a DTrace scratch buffer and returns the address of this buffer. The user address is interpreted as an address in the space of the process that is associated with the current thread. The *maxlen* parameter, if specified, sets a limit on the number of bytes past *addr* that are examined (the resulting string is always null-terminated). The resulting string's length is limited to the value set by the `strsize` option. See Options and Tunables for details. As with the `copyin` function, the specified address must correspond to a faulted-in page in the current process. If the address does not correspond to a faulted-in page, or if insufficient scratch memory is available, `NULL` is returned and an error is generated.

copyinto

```
void copyinto(uintptr_t addr, size_t size, void *dest)
```

The `copyinto` function copies the specified size in bytes from the specified user address (*addr*) into the DTrace scratch buffer that is specified by *dest*. The user address is interpreted as an address in the space of the process that is associated with the current thread. The address in question must correspond to a faulted-in page in the current process. If the address does not correspond to a faulted-in page, or if any of the destination memory lies outside of scratch memory, no copying takes place and an error is generated.

d_path

```
string d_path(struct path *ptr)
```

The `d_path` function creates a string containing the absolute pathname of the `struct path` that is pointed to by *ptr*. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `d_path` does not execute and an error is generated.

dirname

```
string dirname(char *str)
```

The `dirname` function creates a string that consists of all but the last level of the pathname that is specified by *str*. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `dirname` does not execute and an error is generated.

getmajor

```
dev_t getmajor(dev_t dev)
```

The `getmajor` function returns the major device number for the device that is specified by *dev*.

getminor

```
dev_t getminor(dev_t dev)
```

The `getminor` function returns the minor device number for the device that is specified by *dev*.

htonl

```
uint32_t htonl(uint32_t hostlong)
```

The `htonl` function converts *hostlong* from host-byte order to network-byte order.

htonll

```
uint64_t htonll(uint64_t hostlonglong)
```

The `htonll` function converts *hostlonglong* from host-byte order to network-byte order.

htons

```
uint16_t htons(uint16_t hostshort)
```

The `htons` function converts *hostshort* from host-byte order to network-byte order.

index

```
int index(const char *s, const char *subs)
int index(const char *s, const char *subs, int start)
```

The `index` function locates the position of the first occurrence of the substring (*subs*) in the *s* string, starting at the optional position *start*. If the specified value of *start* is less than `0`, it is implicitly set to `0`. If *s* is an empty string, `index` returns `0`. If no match is found for *subs* in *s*, `index` returns `1`.

inet_ntoa

```
string inet_ntoa(ipaddr_t *addr)
```

The `inet_ntoa` function takes a pointer *addr* to an IPv4 address and returns it as a dotted, quad decimal string. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `inet_ntoa` does not execute and an error is generated.

inet_ntoa6

```
string inet_ntoa6(in6_addr_t *addr)
```

The `inet_ntoa6` function takes a pointer *addr* to an IPv6 address and returns it as an RFC 1884 convention 2 string, with lowercase hexadecimal digits. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `inet_ntoa6` does not execute and an error is generated.

inet_ntop

```
string inet_ntop(int af, void *addr)
```

The `inet_ntop` function takes a pointer *addr* to an IP address and returns a string version that depends on the provided address family. Supported address families are `AF_INET` and `AF_INET6`, both of which are defined for use in D programs. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `inet_ntop` does not execute and an error is generated.

lltostr

```
string lltostr(int64_t longlong)
```

The `lltostr` function converts *longlong* to a string. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `lltostr` does not execute and an error is generated.

mutex_owned

```
int mutex_owned(kmutex_t *mutex)
```

The `mutex_owned` function returns non-zero if the calling thread currently holds the specified kernel mutex, or zero otherwise.

mutex_owner

```
kthread_t *mutex_owner(kmutex_t *mutex)
```

The `mutex_owner` function returns the thread pointer of the current owner of the specified adaptive kernel mutex. `mutex_owner` returns `NULL` if the specified adaptive mutex is currently unowned or if the specified mutex is a spin mutex.

mutex_type_adaptive

```
int mutex_type_adaptive(kmutex_t *mutex)
```

All mutexes in the Oracle Linux kernel are adaptive, so the `mutex_type_adaptive` function always returns `1`.

mutex_type_spin

```
int mutex_type_spin(kmutex_t *mutex)
```

All mutexes in the Oracle Linux kernel are adaptive, so the `mutex_type_spin` function always returns `0`.

ntohl

```
uint32_t ntohl(uint32_t netlong)
```

The `ntohl` function converts *netlong* from network-byte order to host-byte order.

ntohll

```
uint64_t ntohll(uint64_t netlonglong)
```

The `ntohll` function converts *netlonglong* from network-byte order to host-byte order.

ntohs

```
uint16_t ntohs(uint16_t netshort)
```

The `ntohs` function converts *netshort* from network-byte order to host-byte order.

progenyof

```
int progenyof(pid_t pid)
```

The `progenyof` function returns non-zero if the calling process (the process associated with the thread that is currently triggering the matched probe) is among the progeny of the specified process ID *pid*.

rand

```
int rand(void)
```

The `rand` function returns a pseudo-random integer. Because the number that is returned is a weak pseudo-random number, it therefore should not be used for any cryptographic application.

rindex

```
int rindex(const char *s, const char *subs)
int rindex(const char *s, const char *subs, int start)
```

The `rindex` function locates the position of the last occurrence of the substring *subs* in the string *s*, starting at the optional position, *start*. If the specified value of *start* is less than `0`, it is implicitly set to `0`. If *s* is an empty string, `rindex` returns `0`. If no match is found for *subs* in *s*, `rindex` returns `-1`.

rw_iswriter

```
int rw_iswriter(krwlock_t *rwlock)
```

The `rw_iswriter` function returns non-zero if the specified reader-writer lock (*rwlock*) is either held or desired by a writer. If the lock is held only by readers and no writer is blocked, or if the lock is not held at all, `rw_iswriter` returns zero.

rw_read_held

```
int rw_read_held(krwlock_t *rwlock)
```

The `rw_read_held` function returns non-zero if the specified reader-writer lock (*rwlock*) is currently held by a reader. If the lock is held only by writers or is not held at all, `rw_read_held` returns zero.

rw_write_held

```
int rw_write_held(krwlock_t *rwlock)
```

The `rw_write_held` function returns non-zero if the specified reader-writer lock (*rwlock*) is currently held by a writer. If the lock is held only by readers or is not held at all, `rw_write_held` returns zero.

speculation

```
int speculation(void)
```

The `speculation` function reserves a speculative trace buffer for use with `speculate` and returns an identifier for this buffer. See Speculative Tracing for details.

strchr

```
string strchr(const char *s, char c)
```

The `strchr` function returns a pointer to the first occurrence of the character *c* in the string *s*. If no match is found, `strstr` returns `0`. Note that this function does not work with wide characters or multi-byte characters.

strjoin

```
string strjoin(char *str1, char *str2)
```

The `strjoin` functon creates a string that consists of *str1* concatenated with *str2*. The returned string is allocated out of scratch memory and is therefore valid only for the duration of the clause. If insufficient scratch memory is available, `strjoin` does not execute and an error is generated.

strlen

```
size_t strlen(string str)
```

The `strlen` function returns the length of the specified string *str* in bytes, excluding the terminating null byte.

strrchr

```
string strrchr(const char *s, char c)
```

The `strrchr` function returns a pointer to the last occurrence of the character *c* in the string *s*. If no match is found, `strrstr` returns `0`. This function does not work with wide characters or multi-byte characters.

strstr

```
string strstr(const char *s, const char *subs)
```

The `strstr` function returns a pointer to the first occurrence of the substring *subs* in the string *s*. If *s* is an empty string, `strstr` returns a pointer to an empty string. If no match is found, `strstr` returns `0`.

strtok

```
string strtok(const char *str, const char *delim)
```

The `strtok` function parses a string into a sequence of tokens by using *delim* as the delimiting string . When you initially call `strtok`, specify the string to be parsed in *str*. In each subsequent call to obtain the next token, specify *str* as `NULL`. You can specify a different delimiter for each call. The internal pointer that `strtok` uses to traverse *str* is only valid within multiple enablings of the same probe, meaning it behaves like an implicit clause-local variable. The `strtok` function returns `NULL` if there are no more tokens.

substr

```
string substr(const char *s, int index)
string substr(const char *s, int index, int length)
```

The `substr` function returns the substring of the *s*, string, starting at the *index* position. If *length* is specified, `substr` limits the substring to that length.

5

Buffers and Buffering

> **WARNING:**
>
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>
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>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

Data buffering and management is an essential service that is provided by the DTrace framework for it clients, for example, the `dtrace` command. This chapter explores data buffering in detail and describes options that you can use to change DTrace's buffer management policies.

Principal Buffers

By default, the *principal buffer* is present in every DTrace invocation and is the buffer to which tracing actions record their data. These actions include the following: `printa`, `printf`, `stack`, `trace`, and `tracemem`.

The principal buffers are always allocated on a per-CPU basis. This policy is not tunable, but you can restrict tracing and buffer allocation to a single CPU by using the `cpu` option.

Principal Buffer Policies

DTrace permits tracing in highly constrained contexts in the kernel. In particular, DTrace permits tracing in contexts in which kernel software might not reliably allocate memory. One consequence of this flexibility of context is that there always exists a possibility that DTrace might attempt to trace data when there is no space available. DTrace must have a policy to deal with such situations as they arise. However, you might choose to tune the policy based on the needs of a given experiment. Sometimes the appropriate policy might be to discard the new data. Other times, it might be desirable to reuse the space containing the oldest recorded data to enable the tracing of new data. Most often, the desired policy is to minimize the likelihood of running out of available space in the first place. To accommodate these varying demands, DTrace supports several different buffer policies. This support is implemented with the `bufpolicy` option and can be set on a per-consumer basis. See Options and Tunables for more details.

switch Policy

By default, the principal buffer has a `switch` buffer policy. Under this policy, per-CPU buffers are allocated in pairs, where one buffer is active and the other buffer is inactive. When a DTrace consumer attempts to read a buffer, the kernel first switches the inactive and active

buffers. Buffer switching is done in such a manner that there is no window in which tracing data can be lost. When the buffers are switched, the newly inactive buffer is copied out to the DTrace consumer. This policy assures that the consumer always sees a self-consistent buffer. Note that a buffer is never simultaneously traced to and copied out. This technique also avoids introducing a window of time in which tracing is paused or otherwise prevented. The rate at which the buffer is switched and read out is controlled by the consumer with the `switchrate` option. As with any rate option, `switchrate` can be specified with the any time suffix, but defaults to rate-per-second. For more information about `switchrate` and other options, see Options and Tunables.

Under the `switch` policy, if a given enabled probe would trace more data than there is space available in the active principal buffer, the data is *dropped* and a per-CPU drop count is incremented. In the event of one or more drops, `dtrace` displays a message similar to the following:

```
dtrace: 11 drops on CPU 0
```

If a given record is larger than the total buffer size, the record is dropped, regardless of buffer policy. You can reduce or eliminate drops, either by increasing the size of the principal buffer with the `bufsize` option, or by increasing the switching rate with the `switchrate` option.

Under the `switch` policy, scratch memory for DTrace subroutines is allocated out of the active buffer.

fill Policy

For some problems, you might want to use a single, in-kernel buffer. While this approach can be implemented with the `switch` policy and appropriate D constructs by incrementing a variable in D and predicating an `exit` action appropriately, such an implementation does not eliminate the possibility of drops. To request a single, large in-kernel buffer and continue tracing until one or more of the per-CPU buffers has filled, use the `fill` buffer policy. Under this policy, tracing continues until an enabled probe attempts to trace more data than can fit in the remaining principal buffer space. When insufficient space remains, the buffer is marked as filled and the consumer is notified that at least one of its per-CPU buffers is filled. When `dtrace` detects a single filled buffer, tracing is stopped, all buffers are processed, and `dtrace` exits. No further data is traced to a filled buffer even if the data would fit in the buffer.

To use the `fill` policy, set the `bufpolicy` option to `fill`. For example, the following command traces every system call entry into a per-CPU 2 KB buffer with the buffer policy set to `fill`:

```
# dtrace -n syscall:::entry -b 2k -x bufpolicy=fill
```

fill Policy and END Probes

`END` probes usually do not fire until tracing has been explicitly stopped by the DTrace consumer. `END` probes are guaranteed to fire only on one CPU, but the CPU on which the probe fires is undefined. With `fill` buffers, tracing is explicitly stopped when at least one of the per-CPU principal buffers has been marked as filled. If the `fill` policy is selected, the `END` probe might fire on a CPU that has a filled buffer. To accommodate `END` tracing in `fill` buffers, DTrace calculates the amount of space that is potentially consumed by `END` probes and subtracts this space from the size of the principal buffer. If the net size is negative, DTrace does not start and `dtrace` outputs the following error message:

```
dtrace: END enablings exceed size of principal buffer
```

The reservation mechanism ensures that a full buffer always has sufficient space for any `END` probes.

ring Policy

The DTrace `ring` buffer policy assists with tracing the events leading up to a failure. If reproducing the failure takes hours or days, you might want to keep only the most recent data. When a principal buffer has filled, tracing wraps around to the first entry, overwriting older tracing data. You establish the ring buffer by specifying `bufpolicy=ring` as follows:

```
# dtrace -s foo.d -x bufpolicy=ring
```

When used to create a ring buffer, `dtrace` does not display any output until the process is terminated. At that time, the ring buffer is consumed and processed. The `dtrace` command processes each ring buffer in CPU order. Within a CPU's buffer, trace records are displayed in order from oldest to youngest. Just as with the `switch` buffering policy, no ordering exists between records from different CPUs. If such an ordering is required, you should trace the `timestamp` variable as part of your tracing request.

The following example demonstrates the use of a `#pragma option` directive to enable ring buffering:

```
#pragma D option bufpolicy=ring
#pragma D option bufsize=16k

syscall:::entry
/execname == $1/
{
  trace(timestamp);
}

syscall::exit:entry
{
  exit(0);
}
```

Other Buffers

Principal buffers exist in every DTrace enabling. Beyond principal buffers, some DTrace consumers might have additional in-kernel data buffers, such as an aggregation buffer, and one or more speculative buffers. See Aggregations and Speculative Tracing for more details.

Buffer Sizes

The size of each buffer can be tuned on a per-consumer basis. Separate options are provided to tune each buffer size, as shown in the following table.

Buffer	Size Option
Aggregation	`aggsize`
Principal	`bufsize`
Speculative	`specsize`

Each of these options is set with a value that denotes the size. As with any size option, the value might have an optional size suffix. See Options and Tunables for more details.

For example, you would set the buffer size to 10 megabytes on the `dtrace` command line as follows:

```
# dtrace -P syscall -x bufsize=10m
```

Alternatively, you can use the `-b` option with the `dtrace` command:

```
# dtrace -P syscall -b 10m
```

Finally, you can set `bufsize` by using a pragma, for example:

```
#pragma D option bufsize=10m
```

The buffer size that you select denotes the size of the buffer on each CPU. Moreover, for the `switch` buffer policy, `bufsize` denotes the size of each buffer on each CPU. The default buffer size is four megabytes.

Buffer Resizing Policy

Occasionally, the system might not have adequate free kernel memory to allocate a buffer of the desired size, either because not enough memory is available or because the DTrace consumer has exceeded one of the tunable limits that are described in Options and Tunables. You can configure the policy for buffer allocation failure by using the `bufresize` option, which defaults to `auto`. Under the `auto` buffer resize policy, the size of a buffer is halved until a successful allocation occurs. `dtrace` generates a message if a buffer, as allocated, is smaller than the requested size, as shown in the following example:

```
# dtrace -P syscall -b 4g
dtrace: description 'syscall' matched 430 probes
dtrace: buffer size lowered to 128m ...
```

Or, a message similar to the following is generated:

```
# dtrace -P syscall'{@a[probefunc] = count()}' -x aggsize=1g
dtrace: description 'syscall' matched 430 probes
dtrace: aggregation size lowered to 128m ...
```

Alternatively, you can require manual intervention after buffer allocation failure by setting `bufresize` to `manual`. Under this policy, an allocation failure prevents DTrace from starting:

```
# dtrace -P syscall -x bufsize=1g -x bufresize=manual
dtrace: description 'syscall' matched 430 probes
dtrace: could not enable tracing: Not enough space
#
```

The buffer resizing policy for all buffers (principal, speculative and aggregation) is dictated by the `bufresize` option.

6
Output Formatting

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DTrace provides the built-in `printf` and `printa`formatting functions, which you can use from your D programs to format output. The D compiler provides features that are not found in the C library's `printf()` routine, so be sure to read this chapter even if you are already familiar with `printf`.

This chapter also discusses the formatting behavior of the `trace` function and the default output format that is used by the `dtrace` command to display aggregations.

printf Action

The `printf` action combines the ability to trace data, as if by the `trace` function, but with the ability to output the data and other text in a specific format that you describe. The `printf` function directs DTrace to trace the data associated with each argument after the first argument and then format the results using the rules described by the first `printf` argument, known as a *format string*. The format string is a regular string that contains any number of format conversions, each beginning with a `%` character, that describe how to format the corresponding argument. The first conversion in the format string corresponds to the second `printf` argument, the second conversion to the third argument, and so on. All of the text between conversions is printed verbatim. The character following the `%` conversion character describes the format to use for the corresponding argument.

Unlike the C library's `printf()` function, DTrace's `printf` function is a built-in function that is recognized by the D compiler. The D compiler provides several useful services for the DTrace `printf` function that are not found in `printf()`, including the following:

- The D compiler compares the arguments to the conversions in the format string. If an argument's type is incompatible with the format conversion, the D compiler provides an error message explaining the problem.
- The D compiler does not require the use of size prefixes with `printf` format conversions. The C `printf` routine requires that you indicate the size of arguments by adding prefixes such as `%ld` for `long`, or `%lld` for `long long`. The D compiler is aware of the size and type of your arguments, so these prefixes are not required in your D `printf` statements.

- DTrace provides additional format characters that are useful for debugging and observability. For example, the `%a` format conversion can be used to print a pointer as a symbol name and offset.

To implement these features, you must specify the format string in the DTrace `printf` function as a string constant in your D program. Format strings cannot be dynamic variables of type `string`.

Conversion Specifications

Each conversion specification in the format string is introduced by the `%` character, after which the following information appears in sequence:

- Zero or more *flags* (in any order), that modify the meaning of the conversion specification, as described in Flag Specifiers.
- An optional minimum *field width*. If the converted value has fewer bytes than the field width, the value is padded with spaces on the left, by default, or on the right, if the left-adjustment flag (`-`) is specified. The field width can also be specified as an asterisk (`*`), in which case the field width is set dynamically, based on the value of an additional argument of type `int`.
- An optional *precision* specifier that indicates the following:
  - The minimum number of digits to appear for the `d`, `i`, `o`, `u`, `x`, and `X` conversions— the field is padded with leading zeroes—the number of digits to appear after the radix character for the `e`, `E`, and `f` conversions.
  - The maximum number of significant digits for the `g` and `G` conversions.
  - Or the maximum number of bytes to be printed from a string by the `s` conversion.

  The precision specifier takes the form of a period (`.`), followed by either an asterisk (`*`), as described in Width and Precision Specifiers, or a decimal digit string.
- An optional sequence of *size prefixes* that indicate the size of the corresponding argument. Size prefixes are not required in D, but are provided for compatibility with the C `printf()` function.
- A *conversion specifier* that indicates the type of conversion to be applied to the argument.

The C `printf()` function also supports conversion specifications of the form `%`*n*`$`, where *n* is a decimal integer. Note that the DTrace `printf` function does not support this type of conversion specification.

Flag Specifiers

The `printf` conversion flags are enabled by specifying one or more of the following characters, which can appear in any order, as described in the following table.

Flag Specifier	Description
'	The integer portion of the result of a decimal conversion (%d, %f, %g, %G, %i, or %u) is formatted with thousands of grouping characters by using the non-monetary grouping character. Some locales, including the POSIX C locale, do not provide non-monetary grouping characters for use with this flag. (The relevant locale is the locale in which dtrace is running.)
-	The result of the conversion is left-justified within the field. The conversion is right-justified if this flag is not specified.
+	The result of signed conversion always begins with a sign (+ or -). If this flag is not specified, the conversion begins with a sign *only* when a negative value is converted.
space	If the first character of a signed conversion is not a sign or if a signed conversion results in no characters, a space is placed before the result. If the space and + flags both appear, the space flag is ignored.
#	The value is converted to an alternate form if an alternate form is defined for the selected conversion. The alternate formats for conversions are described along with the corresponding conversion.
0	For d, e, E, f, g, G, i, o, u, x, and X conversions, leading zeroes (following any indication of sign or base) are used to pad the field width and no space padding is performed. If the 0 and - flags both appear, the 0 flag is ignored. For d, i, o, u, x and X conversions, if a precision is specified, the 0 flag is ignored. If the 0 and ' flags both appear, the grouping characters are inserted before the zero padding.

Width and Precision Specifiers

The minimum field width can be specified as a decimal-digit string following any flag specifier, in which case the field width is set to the specified number of columns. The field width can also be specified as asterisk (*) in which case an additional argument of type int is accessed to determine the field width.

For example, to print an integer x in a field width determined by the value of the int variable w, you would write the following D statement:

```
printf("%*d", w, x);
```

The field width can also be specified with a ? character to indicate that the field width should be set based on the number of characters required to format an address (in hexadecimal) in the data model of the operating system kernel. The width is set to 8, if the kernel is using the 32-bit data model, or to 16, if the kernel is using the 64-bit data model. The precision for the conversion can be specified as a decimal digit string following a period (.), or by an asterisk (*)

following a period. If an asterisk is used to specify the precision, an additional argument of type `int` before the conversion argument provides the precision. If both width and precision are specified as asterisks, the order of arguments to `printf` for the conversion should appear in the following order: width, precision, value.

Size Prefixes

Size prefixes are required in ANSI C programs that use `printf()` to indicate the size and type of the conversion argument. The D compiler performs this processing for your `printf` calls automatically, so size prefixes are not required. Although size prefixes are provided for C compatibility, their use is explicitly discouraged in D programs because they bind your code to a particular data model when using derived types.

For example, if a `typedef` is redefined to different integer base types depending on the data model, it is not possible to use a single C conversion that works in both data models without explicitly knowing the two underlying types and including a cast expression or defining multiple format strings. The D compiler solves this problem automatically by enabling you to omit size prefixes and automatically determining the argument size.

Size prefixes can be placed just prior to the format conversion name and after any flags, widths, and precision specifiers and are as follows:

- An optional `h` specifies that a following `d`, `i`, `o`, `u`, `x`, or `X` conversion applies to a `short` or unsigned `short`.
- An optional `l` specifies that a following `d`, `i`, `o`, `u`, `x`, or `X` conversion applies to a `long` or unsigned `long`.
- An optional `ll` specifies that a following `d`, `i`, `o`, `u`, `x`, or `X` conversion applies to a `long long` or unsigned `long long`.
- An optional `L` specifies that a following `e`, `E`, `f`, `g`, or `G` conversion applies to a `long` double.
- An optional `l` specifies that a following `c` conversion applies to a `wint_t` argument, and that a following `s` conversion character applies to a pointer to a `wchar_t` argument.

Conversion Formats

Each conversion character sequence results in fetching zero or more arguments. If insufficient arguments are provided for the format string, if the format string is exhausted and arguments remain, or if an undefined conversion format is specified, then the D compiler issues an appropriate error message. The following table describes the conversion character sequences.

Conversion Characters	Description
`a`	The pointer or `uintptr_t` argument is printed as a kernel symbol name in the form *`module'symbol-name`*, plus an optional hexadecimal byte offset. If the value does not fall within the range that is defined by a known kernel symbol, the value is printed as a hexadecimal integer.
`A`	Identical to `%a`, but is used for user symbols.
`c`	The `char`, `short`, or `int` argument is printed as an ASCII character.

Conversion Characters	Description
`C`	The `char`, `short`, or `int` argument is printed as an ASCII character if the character is a printable ASCII character. If the character is not a printable character, it is printed by using the corresponding escape sequence, as shown in Table 2-6.
`d`	The `char`, `int`, `long`, `long long`, or `short` argument is printed as a decimal (base 10) integer. If the argument is `signed`, it is printed as a signed value. If the argument is `unsigned`, it is printed as an unsigned value. This conversion has the same meaning as `i`.
`e`, `E`	The `double`, `float`, or `long double` argument is converted to the style `[-]`*`d`*`.`*`ddde`*`[+-]`*`dd`* , where there is one digit before the radix character and the number of digits that follow is equal to the precision. The radix character is non-zero if the argument is non-zero. If the precision is not specified, the default precision value is `6`. If the precision is `0` and the `#` flag is not specified, no radix character appears. The `E` conversion format produces a number with `E` introducing the exponent, instead of `e`. The exponent always contains at least two digits. The value is rounded up to the appropriate number of digits.
`f`	The `double`, `float`, or `long double` argument is converted to the style `[-]`*`ddd`*`.`*`ddd`* , where the number of digits after the radix character is equal to the precision specification. If the precision is not specified, the default precision value is `6`. If the precision is `0` and the `#` flag is not specified, no radix character appears. If a radix character appears, at least one digit appears before it. The value is rounded up to the appropriate number of digits.
`g`, `G`	The `double`, `float`, or `long double` argument is printed in the style `f` or `e` (or in style `E` in the case of a `G` conversion character), with the precision specifying the number of significant digits. If an explicit precision is `0`, it is taken as `1`. The style that is used depends on the value converted: style `e` (or `E`) is used only if the exponent resulting from the conversion is less than `-4`, or greater than or equal to the precision. Trailing zeroes are removed from the fractional part of the result. A radix character appears only if it is followed by a digit. If the `#` flag is specified, trailing zeroes are not removed from the result.

Conversion Characters	Description
i	The char, int, long, long long, or short argument is printed as a decimal (base 10) integer. If the argument is signed, it is printed as a signed value. If the argument is unsigned, it is printed as an unsigned value. This conversion has the same meaning as d.
k	The stack argument is printed as if by a call to trace() and handles kernel-level stacks. This argument is valid only with printa because stack cannot be called from a D expression, as a D program context is required.
o	The char, int, long, long long, and short argument is printed as an unsigned octal (base 8) integer. Arguments that are signed or unsigned may be used with this conversion. If the # flag is specified, the precision of the result is increased to force the first digit of the result to be a zero, if necessary.
p	The pointer or uintptr_t argument is printed as a hexadecimal (base 16) integer. D accepts pointer arguments of any type. If the # flag is specified, a non-zero result has 0x prepended to it.
s	The argument must be an array of char or a string. Bytes from the array or string are read up to a terminating null character or the end of the data and interpreted and printed as ASCII characters. If the precision is not specified, it is taken to be infinite so that all characters up to the first null character are printed. If the precision is specified, only the portion of the character array that is displayed in the corresponding number of screen columns is printed. If an argument of type char * is to be formatted, it should be cast to string or prefixed with the D stringof operator to indicate that DTrace should trace the bytes of the string and format them.
S	The argument must be an array of char or string. The argument is processed as if by the %s conversion, but any ASCII characters that are not printable are replaced by the corresponding escape sequence, as described in Table 2-6.
u	The char, int, long, long long, or short argument is printed as an unsigned decimal (base 10) integer. Arguments that are signed or unsigned can be used with this conversion. The result is always formatted as unsigned.

Conversion Characters	Description
wc	The int argument is converted to a wide character (wchar_t) and the resulting wide character is printed.
ws	The argument must be an array of wchar_t. Bytes from the array are read up to a terminating null character or the end of the data and interpreted and printed as wide characters. If the precision is not specified, it is taken to be infinite, so all wide characters up to the first null character are printed. If the precision is specified, only that portion of the wide character array that is displayed in the corresponding number of screen columns is printed.
x, X	The char, int, long, long long, or short argument is printed as an unsigned hexadecimal (base 16) integer. Arguments that are signed or unsigned may be used with this conversion. If the x form of the conversion is used, the letter digits abcdef are used. If the X form of the conversion is used, the letter digits ABCDEF are used. If the # flag is specified, a non-zero result has 0x (for %x) or 0X (for %X) that is prepended to it.
Y	The uint64_t argument is interpreted to be the number of nanoseconds, since 00:00 Universal Coordinated Time, January 1, 1970, and is printed in the following format: "%Y %a %b %e %T %Z". The current number of nanoseconds since 00:00 UTC, January 1, 1970 is available as the walltimestamp variable.
%	Print a literal % character. No argument is converted. The entire conversion specification must be %%.

printa Action

The printa action enables you to format the results of aggregations in a D program. The function is invoked by using one of following two forms:

```
printa(@aggregation-name);
printa(format-string, @aggregation-name);
```

If the first form of the function is used, the dtrace command takes a consistent snapshot of the aggregation data and produces output that is equivalent to the default output format used for aggregations. See Aggregations. If the second form of the function is used, the dtrace command takes a consistent snapshot of the aggregation data and produces output according to the conversions that are specified in the format string, according to the following rules:

- The format conversions must match the tuple signature that is used to create the aggregation. Each tuple element can only appear once. For example, if you aggregate a count by using the following D statements:

```
@a["hello", 123] = count();
@a["goodbye", 456] = count();
```

Then, you add the D statement `printa(format-string, @a)` to a probe clause, `dtrace` takes a snapshot of the aggregation data and produces output as though you entered these statements:

```
printf(format-string, "hello", 123);
printf(format-string, "goodbye", 456);
```

Then, continue similarly on for each tuple defined in the aggregation.

- Unlike `printf`, the format string that you use for `printa` does not need to include all elements of the tuple: you can have a tuple of length 3 and only one format conversion. Therefore, you can omit any tuple keys from your `printa` output by changing your aggregation declaration to move the keys you want to omit to the end of the tuple and then omit any corresponding conversion specifiers for them in the `printa` format string.
- The aggregation result is included in the output by using the additional `@` format flag character, which is only valid when used with `printa`. The `@` flag can be combined with any appropriate format conversion specifier. Also, the flag can appear more than once in a format string so that your tuple result can appear anywhere in the output, as well as appear more than once. The set of conversion specifiers that can be used with each aggregating function are implied by the aggregating function's result type. The aggregation result types are listed in the following table.

Aggregation	Result Type
avg	uint64_t
count	uint64_t
llquantize	int64_t
lquantize	int64_t
max	uint64_t
min	uint64_t
quantize	int64_t
sum	uint64_t

For example, to format the results of `avg`, you can apply the `%d`, `%i`, `%o`, `%u`, or `%x` format conversions. The `quantize`, `lquantize`, and `llquantize` functions format their results as an ASCII table rather than as a single value.

The following D program shows an example of `printa` using the profile provider to sample the value of caller, then formatting the results as a simple table. Type the following source code and save it in a file named `printa.d`:

```
profile:::tick-1000
{
  @myagg[caller] = count();
}

END
{
  printa("%@8u %a\n", @myagg);
}
```

If you use the `dtrace` command to execute this program, wait a few seconds, then press `Ctrl-C`. You should see output similar to the following:

```
# dtrace -qs printa.d
                ^C
       1 vmlinux`do_syscall_64+0x2f
       1 vmlinux`__bpf_prog_run+0x528
       1 vmlinux`page_frag_free+0x3e
       1 vmlinux`__legitimize_mnt
       1 vmlinux`seq_printf+0x1b
       1 vmlinux`selinux_sb_show_options+0x39
       1 vmlinux`strchr+0x1f
       1 ip6_tables`ip6t_do_table+0xbb
       2 vmlinux`__raw_callee_save___pv_queued_spin_unlock+0x10
      14 libata`__dta_ata_sff_pio_task_1036+0x9e
   12975 vmlinux`native_safe_halt+0x6
```

trace Default Format

If you use `trace` rather than `printf` to capture data, the `dtrace` command formats the results by using a default output format. If the data is 1, 2, 4, or 8 bytes in size, the result is formatted as a decimal integer value. If the data is any other size, and is a sequence of printable characters if interpreted as a sequence of bytes, it is printed as an ASCII string. If the data is any other size, and is not a sequence of printable characters, it is printed as a series of byte values that is formatted as hexadecimal integers.

7

Speculative Tracing

> **WARNING:**
>
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>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

This chapter describes how to use the DTrace facility for *speculative tracing*, which includes the ability to tentatively trace data and then later decide whether to commit the data to a tracing buffer or discard it.

About Speculative Tracing

In DTrace, the primary mechanism for filtering out uninteresting events is the *predicate mechanism*, which is described in more detail in D Program Structure. Predicates are useful when you know whether a probe event is of interest at the time that it fires. For example, if you are only interested in activity that is associated with a certain process or a certain file descriptor, you know when the probe fires if it is associated with the process or file descriptor of interest. Note that in other situations, you might not know whether a given probe event is of interest until some time after the probe fires.

Take the example of a system call that is occasionally failing with a common error code such as `EIO` or `EINVAL`. In this instance, you might want to examine the code path leading to the error condition. To capture the code path, you could enable every probe, but only if the failing call can be isolated in such a way that a meaningful predicate can be constructed. If the failures are sporadic or non-deterministic, you would be forced to trace all of the events that might be interesting, then later post-process the data to filter out the events that were not associated with the failing code path. In this case, even though the number of interesting events might be reasonably small, the number of events that must be traced is very large, making post-processing difficult.

In such situations, you can use speculative tracing facility to tentatively trace data at one or more probe locations. You can then decide to commit the data to the principal buffer at another probe location. The result is that your trace data only contains the output that is of interest; no post-processing is required and the DTrace overhead is minimized.

Speculation Interfaces

The following table describes DTrace speculation functions.

Table 7-1 DTrace Speculation Functions

Function	Args	Description
`speculation`	None	Returns an identifier for a new speculative buffer.
`speculate`	ID	Denotes that the remainder of the clause should be traced to the speculative buffer specified by ID.
`commit`	ID	Commits the speculative buffer that is associated with ID.
`discard`	ID	Discards the speculative buffer that is associated with ID.

Creating a Speculation

The `speculation` function allocates a speculative buffer and returns a speculation identifier. The speculation identifier should be used in subsequent calls to the `speculate` function. Speculative buffers are a finite resource. If no speculative buffer is available when `speculation` is called, an ID of zero is returned and a corresponding DTrace error counter is incremented. An ID of zero is always invalid, but it can be passed to the `speculate`, `commit` and `discard` functions. If a call to `speculation` fails, `dtrace` generates a message similar to the following:

```
dtrace: 2 failed speculations (no speculative buffer space available)
```

The number of speculative buffers defaults to one but can be optionally tuned higher. See Speculation Options and Tuning.

Using a Speculation

To use a speculation, an identifier that is returned from `speculation` must be passed to the `speculate` function in a clause prior to any data-recording actions. All subsequent data-recording actions in a clause containing a `speculate` are speculatively traced. The D compiler generates a compile-time error if a call to `speculate` follows data-recording actions in a D probe clause. Therefore, clauses might contain speculative tracing or non-speculative tracing requests, but not both.

Aggregating actions, destructive actions, and the `exit` action may never be speculative. Any attempt to take one of these actions in a clause containing a `speculate` results in a compile-time error. Also, a `speculate` may not follow a `speculate`. Only one speculation is permitted per clause. A clause that contains only a `speculate` speculatively traces the default action, which is defined to trace only the enabled probe ID. See Actions and Subroutines for a description of the default action.

Typically, you assign the result of `speculation` to a thread-local variable and then use that variable as a subsequent predicate to other probes, as well as an argument to `speculate`, as shown in the following example:

```
syscall::openat:entry
{
  self->spec = speculation();
}
```

```
syscall::: 
/self->spec/
{
  speculate(self->spec);
  printf("this is speculative");
}
```

Committing a Speculation

You commit speculations by using the `commit` function. When a speculative buffer is committed, its data is copied into the principal buffer. If there is more data in the specified speculative buffer than there is available space in the principal buffer, no data is copied and the drop count for the buffer is incremented. If the buffer has been speculatively traced on more than one CPU, the speculative data on the committing CPU is copied immediately, while speculative data on other CPUs is copied some time after the `commit`. Thus, some time might elapse between a `commit` that begins on one CPU, while the data is being copied from speculative buffers to principal buffers on all CPUs. This length of time is guaranteed to be no longer than the time dictated by the cleaning rate. See Speculation Options and Tuning.

A committing speculative buffer is not made available to subsequent `speculation` calls until each per-CPU speculative buffer has been completely copied into its corresponding per-CPU principal buffer. Similarly, subsequent calls to `speculate` to the committing buffer are silently discarded, and subsequent calls to `commit` or `discard` silently fail. Finally, a clause containing a `commit` cannot contain a data recording action. However, a clause can contain multiple `commit` calls to commit disjoint buffers.

Discarding a Speculation

You discard speculations by using the `discard` function. When a speculative buffer is discarded, its contents are also discarded. If the speculation has only been active on the CPU calling `discard`, the buffer is immediately available for subsequent calls to `speculation`. If the speculation has been active on more than one CPU, the discarded buffer will be available for subsequent `speculation` some time after the call to `discard`. The length of time between a `discard` on one CPU and the buffer being made available for subsequent speculations is guaranteed to be no longer than the time that is dictated by the cleaning rate. If, at the time `speculation` is called, no buffer is available because all speculative buffers are currently being discarded or committed, `dtrace` generates a message similar to the following:

```
dtrace: 905 failed speculations (available buffer(s) still busy)
```

You can reduce the likelihood of all buffers being unavailable by tuning the number of speculation buffers or the cleaning rate. See Speculation Options and Tuning.

Example of a Speculation

One potential use for speculations is to highlight a particular code path. The following example shows the entire code path under the `open()` system call when the call fails. Type the following source code and save it in a file named `specopen.d`:

```
#!/usr/sbin/dtrace -Fs

syscall::open:entry
{
  /*
   * The call to speculation() creates a new speculation. If this fails,
```

```
   * dtrace will generate an error message indicating the reason for
   * the failed speculation(), but subsequent speculative tracing will be
   * silently discarded.
   */
  self->spec = speculation();
  speculate(self->spec);

  /*
   * Because this printf() follows the speculate(), it is being
   * speculatively traced; it will only appear in the data buffer if the
   * speculation is subsequently committed.
   */
  printf("%s", copyinstr(arg0));
}

syscall::open:return
/self->spec/
{
  /*
   * To balance the output with the -F option, we want to be sure that
   * every entry has a matching return. Because we speculated the
   * open entry above, we want to also speculate the open return.
   * This is also a convenient time to trace the errno value.
   */
  speculate(self->spec);
  trace(errno);
}

syscall::open:return
/self->spec && errno != 0/
{
  /*
   * If errno is non-zero, we want to commit the speculation.
   */
  commit(self->spec);
  self->spec = 0;
}

syscall::open:return
/self->spec && errno == 0/
{
  /*
   * If errno is not set, we discard the speculation.
   */
  discard(self->spec);
  self->spec = 0;
}
```

Running the previous script produces output similar to the following:

```
# ./specopen.d
dtrace: script ’./specopen.d’ matched 4 probes
CPU FUNCTION
  1  => open                                  /var/ld/ld.config
  1  <= open                                          2
  1  => open                                  /images/UnorderedList16.gif
  1  <= open                                          4
...
```

Speculation Options and Tuning

If a speculative buffer is full when a speculative tracing action is attempted, no data is stored in the buffer and a drop count is incremented. In this situation, `dtrace` generates a message similar to the following:

```
dtrace: 38 speculative drops
```

Speculative drops do not prevent the full speculative buffer from being copied into the principal buffer when it is committed. Similarly, speculative drops can occur even if drops were experienced on a speculative buffer that were ultimately discarded. Speculative drops can be reduced by increasing the speculative buffer size, which is tuned by using the `specsize` option. The `specsize` option can be specified with any size suffix. The resizing policy of this buffer is dictated by the `bufresize` option.

Speculative buffers might be unavailable when `speculation` is called. If buffers that have not yet been committed or discards exist, `dtrace` generates a message similar to the following:

```
dtrace: 1 failed speculation (no speculative buffer available)
```

You can reduce the likelihood of failed speculations of this nature by increasing the number of speculative buffers by specifying the `nspec` option. The value of `nspec` defaults to `1`.

Also, `speculation` can fail if all speculative buffers are busy. In this case, an error message similar to the following is displayed:

```
dtrace: 1 failed speculation (available buffer(s) still busy)
```

This error message indicates that `speculation` was called after `commit` was called for a speculative buffer, but before that buffer was actually committed on all CPUs. You can reduce the likelihood of failed speculations of this nature by increasing the rate at which CPUs are cleaned by using the `cleanrate` option. The value of `cleanrate` defaults to `101`.

8
dtrace Command Reference

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>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

The `dtrace` command is a generic front-end utility for the DTrace facility. The command implements a simple interface to invoke the D language compiler. The `dtrace` command also has the ability to retrieve buffered trace data from the DTrace kernel facility and a includes a set of basic routines to format and print traced data. This chapter provides a complete reference for the `dtrace` command.

dtrace Command Description

The `dtrace` command provides a generic interface to all of the essential services that are provided by the DTrace facility, including options to do the following:

- List the set of probes and providers currently published by DTrace.
- Enable probes directly by using any of the probe description specifiers (provider, module, function, name).
- Run the D compiler and compile one or more D program files or programs written directly on the command line.
- Generate program stability reports. See DTrace Stability Features.
- Modify DTrace tracing and buffering behavior and enable additional D compiler features. See Options and Tunables.

You can also use the `dtrace` command to create D scripts by using the command in a `#!` declaration to create an interpreter file. See Scripting. Finally, you can use the `-e` option to `dtrace` to compile D programs and determine their properties without actually enabling any tracing.

dtrace Command Options

The `dtrace` command accepts the following options:

```
dtrace [-CeFGhHlqSvVwZ]
[-b bufsz] [-c command] [-D name[=value]] [-I pathname] [-L pathname]
[-o pathname] [-p PID] [-s source_pathname]
[-U name] [-x option[=value]] [-X a|c|s|t]
```

```
[-P provider[[predicate]action]]
[-m [[provider:]module[[predicate]action]]]
[-f [[provider:]module:]function[[predicate]action]]
[-n [[[provider:]module:]function:]name[[predicate]action]]
[-i probe-id[[predicate]action]]
```

where *predicate* is any D predicate enclosed in slashes `//` and *action* is any D statement list enclosed in braces `{}`, according to the D language syntax.

If D program code is provided as an argument to the `-P`, `-m`, `-f`, `-n`, or `-i` options, this text must be appropriately quoted to avoid interpretation by the shell.

The options are as follows:

`-b bufsize`
Set the principal trace buffer size, which can include any of the size suffixes `k` (kilobyte), `m` (megabyte), `g` (gigabyte), or `t` (terabyte). If the buffer space cannot be allocated, `dtrace` attempts to reduce the buffer size or exits, depending on the setting of the `bufresize` property.

`-c command`
Run the specified command and exit upon its completion. If you specify more than one `-c` option, `dtrace` exits when all of the commands have exited, and then reports the exit status for each child process as it terminates. The `dtrace` command makes the process ID of the first command available to D programs as the *$target* macro variable.

`-C`
Run the C preprocessor (`cpp`) on D programs before compiling them. You can pass options to the C preprocessor by using the `-D`, `-H`, `-I`, and `-U` options. Use the `-X` option to select the degree of conformance with the C standard.

`-D name[=value]`
Define the specified macro name and optional value when invoking `cpp` with the `-C` option. You can specify the `-D` option to the command multiple times.

`-e`
Exit after compiling any requests and before enabling any probes. You can combine this option with the `-D` option to verify that your D programs compile without executing them or enabling the corresponding instrumentation.

`-f [[provider:]module:] function [[predicate]action]`
Specify a function (optionally specifying the provider and module) that you want to trace or list. You can append an optional D-probe clause. You can specify the `-f` option multiple times to the command.

`-F`
Reduce trace output by combining the output for function and system call entry and return points. The `dtrace` command indents entry probe reports and leaves return probe reports unindented. The command prefixes the output from function entry probe reports with `->` and the output from function return probe reports with `<-`. The `dtrace` command prefixes the output from system call entry probe reports with `=>` and the output from system call return probe reports with `<=`.

`-G`
Generate an ELF file that contains an embedded D program. The command saves the DTrace probes that are specified in the program by using a relocatable ELF object that can be linked with another program. If you specify the `-o` option, `dtrace`

saves the ELF file to the specified path name. If you do not specify the `-o` option, the ELF file is assigned the same name as the source file for the D program, except with a `.o` extension rather than the `.s` extension. Otherwise, the ELF file is saved with the name `d.out`.

`-h`
Create a header file based on probe definitions in the file that is specified as the argument to the `-s` option. If you specify the `-o` option, the command saves the header file to the specified path name. If you do not specify the `-o` option, the header file is assigned the same name as the source file for the D program, except with a `.h` extension rather than a `.d` extension. You should amend the source file of the program to be traced so that it includes this header file.

`-H`
Print the path names of included files on `stderr` when you invoke `cpp` with the `-C` option.

`-i` *`probe_ID`* `[[`*`predicate`*`]`*`action`*`]`
Specify a probe identifier that you want to trace or list. You must specify the probe ID as a decimal integer, as displayed by `dtrace -l`. You can append an optional D-probe clause. You can specify the `-i` option multiple times to the command.

`-I` *`pathname`*
Add the specified directory path to the search path for `#include` files when you invoke `cpp` with the `-C` option. The specified directory is inserted at the head of the default directory list.

`-l`
List probes instead of enabling them. The `dtrace` command filters the list of probes based on the arguments to the `-f`, `-i`, `-m`, `-n`, `-P`, and `-s` options. If no options are specified, the command lists all of the probes.

`-L` *`pathname`*
Add the specified directory path to the end of the library search path. Use this option to specify the path to DTrace libraries, which contain common definitions for D programs.

`-m [[`*`provider`*`:]`*`module`* `[[`*`predicate`*`]`*`action`*`]]`
Specify a module that you want to trace or list. You can optionally specify the provider. You can append an optional D-probe clause. You can specify the `-m` option multiple times to the command.

`-n [[[`*`provider`*`:]`*`module`*`:] `*`function`*`:]`*`name`* `[[`*`predicate`*`]`*`action`*`]`
Specify a probe name that you want to trace or list. You can append an optional D-probe clause. You can optionally specify the provider, module, and function. You can specify the `-n` option multiple times to the command.

`-o` *`pathname`*
Specify the output file for the `-G` and `-l` options, or for traced data.

`-p` *`PID`*
Grab a process by specifying its process ID, cache its symbol tables, and exit upon its completion. If you specify more than one `-p` option, `dtrace` exits when all of the processes have exited. In addition, the command reports the exit status for each process as it terminates. The `dtrace` command makes the first process ID that is specified available to D programs as the macro variable *$target*.

`-P` *`provider`*`['`*`D-probe_clause`*`']`
Specify a provider that you want to trace or list. You can append an optional D-probe clause. You can specify the `-P` option multiple times to the command.

-q
Set quiet mode. The `dtrace` command suppresses informational messages, column headers, CPU ID, probe ID, and additional newlines. Only the data that is traced and formatted by the `printa()`, `printf()`, and `trace()` D program statements is displayed on `stdout`. This option is equivalent to specifying `#pragma D option quiet` in a D program.

-s *source_pathname*
Specify the name of a D program source file to be compiled by the `dtrace` command, as follows:

- If you specify the `-h` option, `dtrace` creates a header file using the probe definitions in the file.
- If you specify the `-G` option, `dtrace` generates a relocatable ELF object that can be linked with another program.
- If you specify the `-e` option, `dtrace` compiles the program, but does not enable any instrumentation.
- If you specify the `-l` option, `dtrace` compiles the program and lists the set of matching probes, but it does not enable any instrumentation.
- If you do not specify an option, `dtrace` enables the instrumentation that is specified by the D program and begins tracing.

-S
Show the D compiler intermediate code. The D compiler writes a report of the intermediate code that was generated for each D program to `stderr`.

-U *name*
Undefine the specified name when invoking `cpp` with the `-C` option. You can specify the `-U` option multiple times to the command.

-v
Set verbose mode. The `dtrace` command produces a program stability report showing the minimum interface stability and dependency level for any specified D programs.

-V
Write the highest D programming interface version that is supported by `dtrace` to `stdout`. The combination `-vV` adds other version information, such as the version of the user-space binaries from the `dtrace-utils` package.

-w
Permit destructive actions by D programs. Note that if you do not specify this option, the command does not compile or enable a D program that contains destructive actions. This option is equivalent to specifying `#pragma D option destructive` in a D program.

-x *option*[=*value*]
Enable or modify a DTrace runtime option or D compiler option.

-X a|c|t
Include the option `-std=gnu99` (conformance with 1999 C standard including GNU extensions) when invoking `cpp` with the `-C` option.

-Xs
Include the option `-traditional-cpp` (conformance with K&R C) when invoking `cpp` with the `-C` option.
Regardless of the `-X` mode, the following additional C preprocessor definitions are always specified and valid in all modes:

- `__linux`
- `__unix`
- `__SVR4`
- `__`\`uname -s\` (for example, `__Linux`)
- `__SUNW_D=1`
- `__SUNW_D_64`
- `__SUNW_D_VERSION=0x`*MMmmmuuu*

  where *MM* is the Major release value in hexadecimal, *mmm* is the Minor release value in hexadecimal, and *uuu* is the Micro release value in hexadecimal. See DTrace Versioning for more information about DTrace versioning.

-z
Permit probe descriptions that do not match any probes. If you do not specify this option, the `dtrace` command reports an error and exits if a probe description
does not match a known probe.

dtrace Command Operands

You can specify zero or more additional arguments on the `dtrace` command line to define a set of macro variables, such as `$1`, `$2`, and so on, to be used in any D programs that are specified with the `-s` option or on the command line. The use of macro variables is described further in Scripting.

dtrace Command Exit Status

The following exit values are returned by the `dtrace` command:

0
Indicates that the specified requests were completed successfully. For D program requests, the `0` exit status indicates that programs were successfully compiled, probes were successfully enabled, or an anonymous state was successfully retrieved. The `dtrace` command returns `0` even if the specified tracing requests encountered errors or drops.

1
Indicates that a fatal error occurred. For D program requests, the `1` exit status indicates that program compilation failed or that the specified request could not be satisfied.

2
Indicates that invalid command-line options or arguments were specified.

9
Scripting

> **WARNING:**
>
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>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

You can use the `dtrace` command to create interpreter files from D programs, which are similar to shell scripts that can be installed as reusable interactive DTrace tools. The D compiler and the `dtrace` command provide a set of macro variables that are expanded by the D compiler to make it easy to create DTrace scripts. This chapter provides a reference for the macro variable facility and tips for creating persistent scripts.

Interpreter Files

Similar to your shell and utilities such as `awk` and `perl`, you can use the `dtrace` command to create executable interpreter files.

An interpreter file begins with a line of the following form:

```
#!pathname [arg]
```

where *pathname* is the path of the interpreter and *arg* is a single, optional argument. When an interpreter file is executed, the system invokes the specified interpreter. If *arg* was specified in the interpreter file, it is passed as an argument to the interpreter. The path to the interpreter file and any additional arguments that were specified when it was executed are then appended to the interpreter argument list. Therefore, you always need to create DTrace interpreter files with at least the following arguments:

```
#!/usr/sbin/dtrace -s
```

When your interpreter file is executed, the argument to the `-s` option is the pathname of the interpreter file. The `dtrace` command then reads, compiles, and executes this file as if you had typed the following command in your shell:

```
# dtrace -s interpreter-file
```

The following example shows how you would create and execute a `dtrace` interpreter file. First, type the following D source code and save it in a file named `interp.d`:

```
#!/usr/sbin/dtrace -s
BEGIN
{
  trace("hello");
```

```
  exit(0);
}
```

Then, make the `interp.d` file executable and execute it as follows:

```
# chmod a+rx interp.d
# ./interp.d
dtrace: script './interp.d' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0      1                           :BEGIN   hello
#
```

Remember that the `#!` directive must comprise the first two characters of your file with no intervening or preceding white space. The D compiler automatically ignores this line when it processes the interpreter file.

The `dtrace` command uses `getopt()` to process command-line options so that you can combine multiple options in your single interpreter argument. For example, to add the `-q` option to the previous example you could change the interpreter directive to the following:

```
#!/usr/sbin/dtrace -qs
```

> **Note:**
>
> If you specify multiple options, the `-s` option must always end the list of options so that the next argument, the interpreter file name, is correctly processed as the argument to the `-s` option.

If you need to specify more than one option that requires an argument in your interpreter file, use the `#pragma D option` directive to set your options. Several `dtrace` command-line options have `#pragma` equivalents that you can use. See Options and Tunables.

Macro Variables

The D compiler defines a set of built-in macro variables that you can use when writing D programs or interpreter files. Macro variables are identifiers that are prefixed with a dollar sign (`$`) and are expanded once by the D compiler when processing your input file. The following table describes the macro variables that the D compiler provides.

Table 9-1 D Macro Variables

Name	Description	Reference
`$[0-9]+`	Macro arguments	Macro Arguments
`$egid`	Effective group ID	See the `getegid(2)` manual page.
`$euid`	Effective user ID	See the `geteuid(2)` manual page.
`$gid`	Real group ID	See the `getgid(2)` manual page.
`$pid`	Process ID	See the `getpid(2)` manual page.

Table 9-1 (Cont.) D Macro Variables

Name	Description	Reference
`$pgid`	Process group ID	See the `getpgid(2)` manual page.
`$ppid`	Parent process ID	See the `getppid(2)` manual page.
`$sid`	Session ID	See the `getsid(2)` manual page.
`$target`	Target process ID	Target Process ID
`$uid`	Real user ID	See the `getuid(2)` manual page

With the exception of the `$[0-9]+` macro arguments and the `$target` macro variable, all of the macro variables expand to integers that correspond to system attributes, such as the process ID and the user ID. The variables expand to the attribute value associated with the current `dtrace` process or whatever process is running the D compiler.

Using macro variables in interpreter files enables you to create persistent D programs that you do not need to edit every time you want to use them. For example, to count all system calls, except those that are executed by the `dtrace` command, you would use the following D program clause containing `$pid`:

```
syscall:::entry
/pid != $pid/
{
  @calls = count();
}
```

This clause always produces the desired result, even though each invocation of the `dtrace` command has a different process ID. Macro variables can be used in a D program anywhere that an integer, identifier, or string can be used.

Macro variables are expanded only one time when the input file is parsed, not recursively.

Except in probe descriptions, each macro variable is expanded to form a separate input token and cannot be concatenated with other text to yield a single token.

For example, if `$pid` expands to the value `456`, the D code in the following example would expand to the two adjacent tokens `123` and `456`, resulting in a syntax error, rather than the single integer token `123456`:

```
123$pid
```

However, in probe descriptions, macro variables are expanded and concatenated with adjacent text. For example, the following clause uses the DTrace `pid` provider to instrument the `dtrace` command:

```
# dtrace -c ./a.out -n 'pid$target:libc.so::entry'
```

Macro variables are only expanded one time within each probe description field and they may not contain probe description delimiters (`:`).

Macro Arguments

The D compiler also provides a set of macro variables corresponding to any additional argument operands that are specified as part of the `dtrace` command invocation. These *macro arguments* are accessed by using the built-in names `$0`, for the name of the D program file or `dtrace` command, `$1`, for the first additional operand, `$2` for the second operand, and so on. If you use the `-s` option, `$0` expands to the value of the name of the input file that is used with this option. For D programs that are specified on the command line, `$0` expands to the value of `argv[0]`, which is used to execute the `dtrace` command itself.

Macro arguments can expand to integers, identifiers, or strings, depending on the form of the corresponding text. As with all macro variables, macro arguments can be used anywhere integer, identifier, and string tokens can be used in a D program.

All of the following examples could form valid D expressions assuming appropriate macro argument values:

```
execname == $1  /* with a string macro argument */

x += $1         /* with an integer macro argument */

trace(x->$1)    /* with an identifier macro argument */
```

Macro arguments can be used to create DTrace interpreter files that act like real Linux commands and use information that is specified by a user or by another tool to modify their behavior.

For example, the following D interpreter file traces `write()` system calls that are executed by a particular process ID and saved in a file named `tracewrite`:

```
#!/usr/sbin/dtrace -s
syscall::write:entry
/pid == $1/
{
}
```

If you make this interpreter file executable, you can specify the value of `$1` by using an additional command-line argument to your interpreter file, for example:

```
# chmod a+rx ./tracewrite
# ./tracewrite 12345
```

The resulting command invocation counts each `write()` system call that is executed by the process ID 12345.

If your D program references a macro argument that is not provided on the command line, an appropriate error message is printed and your program fails to compile, as shown in the following example:

```
# ./tracewrite
dtrace: failed to compile script ./tracewrite: line 4:
  macro argument $1 is not defined
```

D programs can reference unspecified macro arguments if you set the `defaultargs` option. If `defaultargs` is set, unspecified arguments have the value `0`. See Options and Tunables for more information about D compiler options. The D compiler also produces an error message if additional arguments that are not referenced by your D program are specified on the command line.

The macro argument values must match the form of an integer, identifier, or string. If the argument does not match any of these forms, the D compiler reports an appropriate error message. When specifying string macro arguments to a DTrace interpreter file, you should surround the argument in an extra pair of single quotes to avoid interpretation of the double quotes and string contents by your shell:

```
# ./foo '"a string argument"'
```

If you want your D macro arguments to be interpreted as string tokens, even if they match the form of an integer or identifier, prefix the macro variable or argument name with two leading dollar signs, for example, `$$1`, which forces the D compiler to interpret the argument value as if it were a string surrounded by double quotes. All of the usual D string escape sequences, per Table 2-6, are expanded inside of any string macro arguments, regardless of whether they are referenced by using the `$arg` or `$$arg` form of the macro. If the `defaultargs` option is set, unspecified arguments that are referenced with the `$$arg` form have the value of the empty string ("").

Target Process ID

Use the `$target` macro variable to create scripts to be applied to the user process of interest that you specify with the `-p` option or that you create by using the `dtrace` command with the `-c` option. The D programs that you specify on the command line or by using the `-s` option are compiled after processes are created or grabbed, and the `$target` variable expands to the integer process ID of the first such process.

For example, you could use the following D script to determine the distribution of system calls that are executed by a particular subject process. Save it in a file named `syscall.d`:

```
syscall:::entry
/pid == $target/
{
  @[probefunc] = count();
}
```

To determine the number of system calls executed by the `date` command, save the script in the file named `syscall.d`, then run the following command:

```
# dtrace -s syscall.d -c date
dtrace: script 'syscall.d' matched 296 probes
Tue Oct 16 15:12:07 BST 2012

  access                                                    1
  arch_prctl                                                1
  clock_gettime                                             1
  exit_group                                                1
  getrlimit                                                 1
  lseek                                                     1
  rt_sigprocmask                                            1
  set_robust_list                                           1
  set_tid_address                                           1
  write                                                     1
  futex                                                     2
  rt_sigaction                                              2
  brk                                                       3
  munmap                                                    3
  read                                                      5
  open                                                      6
  mprotect                                                  7
  close                                                     8
```

```
newfstat                                    8
mmap                                       16
```

10

Options and Tunables

> **WARNING:**
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>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

To enable customization, DTrace affords its consumers several important degrees of freedom. To minimize the likelihood of requiring specific tuning, DTrace is implemented with reasonable default values and flexible default policies, but situations might arise that require tuning the behavior of DTrace on a consumer-by-consumer basis. This chapter describes DTrace options and tunables and the interfaces that you can use to modify them.

Consumer Options

DTrace is tuned by setting or enabling options. The available options for tuning DTrace are described in the following table. For some options, a corresponding `dtrace` command-line option is also provided.

Table 10-1 DTrace Consumer Options

Option Name	Type	Value	Description
`aggpercpu`	Compile-time		Aggregate per CPU. See Aggregations.
`aggrate`	Dynamic runtime	time	Rate of aggregation reading. See Aggregations.
`aggsize`	Runtime	size	Aggregation buffer size/ See Aggregations.
`aggsortkey`	Dynamic runtime	`false` or `true`	Sort aggregations by key. See Aggregations.
`aggsortkeypos`	Dynamic runtime	scalar	Number of the aggregation key on which to sort. See Aggregations.

Table 10-1 (Cont.) DTrace Consumer Options

Option Name	Type	Value	Description
`aggsortpos`	Dynamic runtime	scalar	Number of the aggregation variable on which to sort See Aggregations.
`aggsortrev`	Dynamic runtime	`false` or `true`	Sort aggregations in reverse order. See Aggregations.
`amin`	Compile-time	string	Stability attribute minimum. See Stability Enforcement
`argref`	Compile-time		Do not require all macro arguments to be used.
`bufpolicy`	Runtime	`fill`, `ring`, or `switch`	Buffer policy. See Buffers and Buffering .
`bufresize`	Runtime	`auto` or `manual`	Buffer resizing policy. See Buffers and Buffering .
`bufsize`	Runtime	size	Principal buffer size (equivalent to the `dtrace -b`). See Buffers and Buffering .
`cleanrate`	Runtime	time	Cleaning rate. See Speculative Tracing.
`core`	Compile-time		Enable core dumping by `dtrace`.
`cpp`	Compile-time		Use `cpp` to pre-process the input file.
`cpphdrs`	Compile-time		Specify the `-H` option to `cpp` to print the name of each header file that is used.
`cpppath`	Compile-time	string	Specify the path name of `cpp`.
`cpu`	Runtime	scalar	CPU on which to enable tracing. See Buffers and Buffering.

Table 10-1 (Cont.) DTrace Consumer Options

Option Name	Type	Value	Description
`ctypes`	Compile-time	string	Write out Compact Type Format (CTF) definitions of all C types used in a program at the end of a D compilation run.
`debug`	Compile-time		Enable DTrace debugging mode (equivalent to setting the environment variable `DTRACE_DEBUG`).
`defaultargs`	Compile-time		Allow references to unspecified macro arguments. Use `0` as the value for an unspecified argument. See Scripting.
`define`	Compile-time	string	Define a macro name and optional value in the form *name*[=*value*]. (equivalent to `dtrace -D`).
`destructive`	Runtime		Allow destructive actions (equivalent to `dtrace -w`). See Actions and Subroutines.
`droptags`	Compile-time		Specifies that drop tags are used.
`dtypes`	Compile-time	string	Write out CTF definitions of all D types that are used in a program at the end of a D compilation run.
`dynvarsize`	Runtime	size	Dynamic variable space size. See Variables.
`empty`	Compile-time		Permit compilation of empty D source files.
`errtags`	Compile-time		Prefix default error message with error tags.

Table 10-1 (Cont.) DTrace Consumer Options

Option Name	Type	Value	Description
`evaltime`	Compile-time	`exec`, `main`, `postinit`, or `preinit`	Control when DTrace starts tracing a new process. For dynamically linked binaries, tracing starts: **`exec`** After `exec()`. **`preinit`** After initialization of the dynamic linker to load the binary. **`postinit` (default)** After constructor execution. **`main`** Before `main()` starts. Same as `postinit`. For statically linked binaries, `preinit` is equivalent to `exec`. For stripped, statically linked binaries, `postinit` and `main` are equivalent to `preinit`.
`flowindent`	Dynamic runtime		Indent function entry and prefix with `->`. Unindent function return and prefix with `<-`. Indent system call entry and prefix with `=>`. Unindent system call return and prefix with `<=`. Equivalent to `dtrace -F`. See dtrace Command Reference.
`incdir`	Compile-time	string	Add a `#include` directory to the preprocessor search path (equivalent to `dtrace -I`).

Table 10-1 (Cont.) DTrace Consumer Options

Option Name	Type	Value	Description
`iregs`	Compile-time	scalar	Size of the DTrace Intermediate Format (DIF) integer register set. The default value is `8`.
`kdefs`	Compile-time		Do not permit unresolved kernel symbols.
`knodefs`	Compile-time		Permit unresolved kernel symbols.
`late`	Compile-time	`dynamic` or `static`	Specify whether references to dynamic translators are permitted: **dynamic** Allow references to dynamic translators. **static** Require translators to be statically defined.
`lazyload`	Compile-time	`false` or `true`	Specify that the DTrace Object Format (DOF) should be lazily loaded rather than actively loaded.
`ldpath`	Compile-time	string	Specify the path of the dynamic linker loader (`ld`).
`libdir`	Compile-time	string	Add a library directory to the library search path.

Table 10-1 (Cont.) DTrace Consumer Options

Option Name	Type	Value	Description
`linkmode`	Compile-time	`dynamic`, `kernel`, or `static`	Specify the symbol linking mode that is used by the assembler when processing external symbol references: **dynamic** All symbols are treated as dynamic. **kernel** Kernel symbols are treated as static and user symbols are treated as dynamic. **static** All symbols are treated as static.
`linktype`	Compile-time	`dof` or `elf`	Specify the output file type: **dof** Produce a standalone DOF file. **elf** Produce an ELF file that contains DOF.
`modpath`	Compile-time	string	Module path. The default path is `/lib/modules/` *version*.
`nolibs`	Compile-time		Do not process D system libraries.
`nspec`	Runtime	scalar	Number of speculations. See Speculative Tracing.
`pgmax`	Compile-time	scalar	Limit on the number of threads that DTrace can grab for tracing. The default value is `8`.
`preallocate`	Compile-time	scalar	Amount of memory to preallocate.
`procfspath`	Compile-time	string	Path to the `procfs` file system. The default path is `/proc`.
`pspec`	Compile-time		Interpret ambiguous specifiers as probe names.

Table 10-1 (Cont.) DTrace Consumer Options

Option Name	Type	Value	Description
`quiet`	Dynamic runtime		Output only explicitly traced data (equivalent to `dtrace -q`). See dtrace Command Reference.
`quietresize`	Dynamic runtime		Suppress buffer-resize messages. See Buffers and Buffering.
`rawbytes`	Dynamic runtime		Always print `trace` output in hexadecimal. See Actions and Subroutines.
`specsize`	Runtime	size	Speculation buffer size. See Speculative Tracing.
`stackframes`	Runtime	scalar	Number of stack frames. See Actions and Subroutines.
`stackindent`	Dynamic runtime	scalar	Number of white space characters to use when indenting `stack` and `ustack` output. See Actions and Subroutines.
`statusrate`	Runtime	time	Rate of status checking.
`stdc`	Compile-time	`a`, `c`, `s`, or `t`	Specify ISO C conformance settings for the preprocessor when invoking `cpp` with the `-C` option. The `a`, `c`, and `t` settings include the `-std=gnu99` option (conformance with 1999 C standard including GNU extensions). The `s` setting includes the `-traditional-cpp` option (conformance with K&R C).

Table 10-1 (Cont.) DTrace Consumer Options

Option Name	Type	Value	Description
`strip`	Compile-time		Strip non-loadable sections from the program.
`strsize`	Runtime	size	String size. See DTrace Support for Strings.
`switchrate`	Dynamic runtime	time	Rate of buffer switching. See Buffers and Buffering .
`syslibdir`	Compile-time	string	Path name of system libraries.
`tree`	Compile-time	scalar	Value of the DTrace tree dump bitmap.
`tregs`	Compile-time	scalar	Size of the DIF tuple register set. The default value is `8`.
`udefs`	Compile-time		Do not permit unresolved user symbols.
`undef`	Compile-time	string	Undefine a symbol when invoking the preprocessor. Equivalent to `dtrace -U`.
`unodefs`	Compile-time		Permit unresolved user symbols.
`ustackframes`	Runtime	scalar	Number of user-land stack frames. See Actions and Subroutines.
`verbose`	Compile-time		DIF verbose mode, which shows each compiled DIF object (DIFO).
`version`	Compile-time	string	Request a specific version of the native DTrace library.
`zdefs`	Compile-time		Permit probe definitions that match zero probes.

Values that denote sizes can be given an optional suffix of `k`, `m`, `g`, or `t` to denote kilobytes, megabytes, gigabytes, and terabytes, respectively. Values that denote times can be given an optional suffix of `ns`, `us`, `ms`, `s` or `hz` to denote nanoseconds, microseconds, milliseconds, seconds, and number per second, respectively.

Modifying Options

You can set options in a D script by using `#pragma D` followed by the string `option` and the option name. If the option takes a value, the option name should be followed by an equal sign (=) and the option value. The following are examples of valid option settings:

```
#pragma D option nspec=4

#pragma D option bufsize=2g

#pragma D option switchrate=10hz

#pragma D option aggrate=100us

#pragma D option bufresize=manual
```

The `dtrace` command also accepts option settings on the command line as an argument to the `-x` option, for example:

```
# dtrace -x nspec=4 -x bufsize=2g \
-x switchrate=10hz -x aggrate=100us -x bufresize=manual
```

If an invalid option is specified, `dtrace` indicates that the option name is invalid and exits, as shown in the following example:

```
# dtrace -x wombats=25
dtrace: failed to set option -x wombats: Invalid option name
```

Similarly, if a value is not valid for the given option, `dtrace` indicates that the value is invalid, as shown here:

```
# dtrace -x bufsize=100wombats
dtrace: failed to set option -x bufsize: Invalid value for specified option
```

If an option is set more than once, subsequent settings overwrite earlier settings. Some options can only be set. The presence of such an option sets it, and you cannot subsequently unset it.

11
DTrace Providers

> **WARNING:**
>
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>
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>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

This chapter describes some of the existing DTrace providers. Note that the list of providers discussed in this chapter is not exhaustive. To display the providers that are available on your system, use the `dtrace -l` command. Detailed information about translators for important data structures can be found in `/usr/lib64/dtrace/version/*.d` files.

dtrace Provider

The `dtrace` provider includes several probes that are related to DTrace itself. You can use these probes to initialize state before tracing begins, process state after tracing has completed, and to handle unexpected execution errors in other probes.

BEGIN Probe

The `BEGIN` probe fires before any other probe. No other probe fires until all `BEGIN` clauses have completed. This probe can be used to initialize any state that is needed in other probes. The following example shows how to use the `BEGIN` probe to initialize an associative array to map between `mmap()` protection bits and a textual representation:

```
BEGIN
{
  prot[0] = "---";
  prot[1] = "r--";
  prot[2] = "-w-";
  prot[3] = "rw-";
  prot[4] = "--x";
  prot[5] = "r-x";
  prot[6] = "-wx";
  prot[7] = "rwx";
}

syscall::mmap:entry
{
  printf("mmap with prot = %s", prot[arg2 & 0x7]);
}
```

The BEGIN probe fires in an unspecified context, which means the output of stack or ustack, and the value of context-specific variables such as execname, are all arbitrary. These values should not be relied upon or interpreted to infer any meaningful information. No arguments are defined for the BEGIN probe.

END Probe

The END probe fires after all other probes. This probe will not fire until all other probe clauses have completed. This probe can be used to process state that has been gathered or to format the output. The printa action is therefore often used in the END probe. The BEGIN and END probes can be used together to measure the total time that is spent tracing, for example:

```
BEGIN
{
  start = timestamp;
}

/*
 * ... other tracing actions...
 */

END
{
  printf("total time: %d secs", (timestamp - start) / 1000000000);
}
```

See Data Normalization and printa Action for other common uses of the END probe.

As with the BEGIN probe, no arguments are defined for the END probe. The context in which the END probe fires is arbitrary and should not be depended upon.

When tracing with the bufpolicy option set to fill, adequate space is reserved to accommodate any records that are traced in the END probe. See fill Policy and END Probes for details.

> **Note:**
>
> The exit action causes tracing to stop and the END probe to fire. However, there is some delay between the invocation of the exit action and when the END probe fires. During this delay, no probes will fire. After a probe invokes the exit action, the END probe is not fired until the DTrace consumer determines that exit has been called and stops tracing. The rate at which the exit status is checked can be set by using statusrate option. For more information, see Options and Tunables.

ERROR Probe

The ERROR probe fires when a runtime error occurs during the execution of a clause for a DTrace probe. As shown in the following example, if a clause attempts to dereference a NULL pointer, the ERROR probe fires. Save it in a file named error.d:

```
BEGIN
{
  *(char *)NULL;
}
```

```
ERROR
{
  printf("Hit an error!");
}
```

When you run this program, output similar to the following is displayed:

```
# dtrace -s error.d
dtrace: script 'error.d' matched 2 probes
CPU     ID                    FUNCTION:NAME
  1      3                           :ERROR Hit an error!
dtrace: error on enabled probe ID 1 (ID 1: dtrace:::BEGIN):
invalid address (0x0) in action #1 at DIF offset 16
^C
```

The previous output indicates that the `ERROR` probe fired and that `dtrace` reported the error. `dtrace` has its own enabling of the `ERROR` probe so that it can report errors. Using the `ERROR` probe, you can create your own custom error handling.

The arguments to the `ERROR` probe are described in the following table.

Argument	Description
`arg1`	The enabled probe identifier (EPID) of the probe that caused the error.
`arg2`	The index of the action that caused the fault.
`arg3`	The DIF offset into the action or -1 if not applicable.
`arg4`	The fault type.
`arg5`	Value that is particular to the fault type.

The following table describes the various fault types that can be specified in `arg4` and the values that `arg5` can take for each fault type.

`arg4` Value	**Description**	**`arg5` Meaning**
`DTRACEFLT_UNKNOWN`	Unknown fault type	None
`DTRACEFLT_BADADDR`	Access to unmapped or invalid address	Address accessed
`DTRACEFLT_BADALIGN`	Unaligned memory access	Address accessed
`DTRACEFLT_ILLOP`	Illegal or invalid operation	None
`DTRACEFLT_DIVZERO`	Integer divide by zero	None
`DTRACEFLT_NOSCRATCH`	Insufficient scratch memory to satisfy scratch allocation	None
`DTRACEFLT_KPRIV`	Attempt to access a kernel address or property without sufficient privileges	Address accessed or 0 if not applicable
`DTRACEFLT_UPRIV`	Attempt to access a user address or property without sufficient privileges	Address accessed or 0 if not applicable
`DTRACEFLT_TUPOFLOW`	DTrace internal parameter stack overflow	None

arg4 Value	Description	arg5 Meaning
DTRACEFLT_BADSTACK	Invalid user process stack	Address of invalid stack pointer

If the actions that are taken in the ERROR probe cause an error, that error is silently dropped. The ERROR probe is not recursively invoked.

dtrace Stability

The dtrace provider uses DTrace's stability mechanism to describe its stabilities. These values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Stable	Stable	Common
Module	Private	Private	Unknown
Function	Private	Private	Unknown
Name	Stable	Stable	Common
Arguments	Stable	Stable	Common

For more information about the stability mechanism, see DTrace Stability Features.

profile Provider

The profile provider includes probes that are associated with an interrupt that fires at some regular, specified time interval. Such probes are not associated with any particular point of execution, but rather with the asynchronous interrupt event. You can use these probes to sample some aspect of the system state and then use the samples to infer system behavior. If the sampling rate is high or the sampling time is long, an accurate inference is possible. Using DTrace actions, you can use the profile provider to sample practically any aspect of the system. For example, you could sample the state of the current thread, the state of the CPU, or the current machine instruction.

profile-*n* Probes

The profile-*n* probes fire at a fixed interval, at a high-interrupt level on all active CPUs. The units of *n* default to a frequency that is expressed as a rate of firing per second, but the value can also have an optional suffix , as shown in Table 11-1, which specifies either a time interval or a frequency. The following table describes valid time suffixes for a tick-*n* probe.

Table 11-1 Valid Time Suffixes

Suffix	Time Units
nsec or ns	nanoseconds
usec or us	microseconds
msec or ms	milliseconds
sec or s	seconds

Table 11-1 (Cont.) Valid Time Suffixes

Suffix	Time Units
`min` or `m`	minutes
`hour` or `h`	hours
`day` or `d`	days
`hz`	hertz (frequency expressed as rate per second)

tick-*n* Probes

The `tick-n` probes fire at fixed intervals, at a high interrupt level on only one CPU per interval. Unlike `profile-n` probes, which fire on every CPU, `tick-n` probes fire on only one CPU per interval and the CPU on which they fire can change over time. The units of *n* default to a frequency expressed as a rate of firing per second, but the value can also have an optional time suffix as shown in Table 11-1, which specifies either a time interval or a frequency.

The `tick-n` probes have several uses, such as providing some periodic output or taking a periodic action.

> **Note:**
>
> By default, the highest supported tick frequency is 5000 Hz (`tick-5000`).

profile Probe Arguments

The following table describes the arguments for the `profile` probes.

Table 11-2 `profile` Probe Arguments

Probe	arg0	arg1	arg2
`profile-n`	`pc`	`upc`	`nsecs`
`tick-n`	`pc`	`upc`	—

The arguments are as follows:

- `pc`: kernel program counter
- `upc`: user-space program counter
- `nsecs`: elapsed number of nanoseconds

profile Probe Creation

Unlike other providers, the `profile` provider creates probes dynamically on an as-needed basis. Thus, the desired probe might not appear in a listing of all probes, for example, when using the `dtrace -l -P profile` command, but the probe is created when it is explicitly enabled.

A time interval that is too short causes the machine to continuously field time-based interrupts and denies service on the machine. The `profile` provider silently refuses to create a probe that would result in an interval of less than two hundred microseconds.

prof Stability

The `profile` provider uses DTrace's stability mechanism to describe its stabilities. These stability values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	Common
Module	Unstable	Unstable	Unknown
Function	Private	Private	Unknown
Name	Evolving	Evolving	Common
Arguments	Evolving	Evolving	Common

For more information, see DTrace Stability Features.

fbt Provider

The `fbt` (Function Boundary Tracing) provider includes probes that are associated with the entry to and return from most functions in the Oracle Linux kernel. Therefore, there could well be tens of thousands of `fbt` probes.

To confirm that the `fbt` provider is available on your processor's architecture, you should be able to load the module that provides `fbt` instrumentation and successfully list several probes. Note that this process could take several seconds due to the large number of such probes. For example, consider the following command, which is executed as `root`:

```
# dtrace -l -P fbt | wc -l
dtrace: failed to match fbt:::: No probe matches description
1
# modprobe fbt
# dtrace -l -P fbt | wc -l
88958
```

In the previous example, the first `dtrace` command automatically loads modules that are listed in `/etc/dtrace-modules`, but also confirms that `fbt` was not among them. After `fbt` is loaded manually, many `fbt` probes appear. For more information, see Module Loading and fbt.

Like other DTrace providers, Function Boundary Tracing (FBT) has no probe effect when not explicitly enabled. When enabled, FBT only induces a probe effect in probed functions. While the FBT implementation is highly specific to the instruction set architecture, FBT has been implemented on both x86 and 64-bit Arm platforms. For each instruction set, there are a small number of *leaf* functions that do not call other functions and are highly optimized by the compiler, which cannot be instrumented by FBT. Probes for these functions are not present in DTrace.

An effective use of FBT probes requires knowledge of the operating system implementation. It is therefore recommended that you use FBT only when developing kernel software or when other providers are not sufficient. You can use other DTrace providers such as `syscall`, `sched`, `proc`, and `io` to answer most system analysis questions without requiring operating system implementation knowledge.

fbt Probes

FBT provides a probe at the entry and return of most functions in the kernel, named `entry` and `return`, respectively. All FBT probes have a function name and module name.

fbt Probe Arguments

The arguments to `entry` probes are the same as the arguments to the corresponding operating system kernel function. These arguments can be accessed as `int64_t` values by using the `arg0`, `arg1`, `arg2`, ... variables.

If the function has a return value, the return value is stored in `arg1` of the `return` probe. If a function does not have a return value, `arg1` is not defined.

While a given function only has a single point of entry, it might have many different points where it returns to its caller. FBT collects a function's multiple return sites into a single `return` probe. If you want to know the exact return path, you can examine the `return` probe `arg0` value, which indicates the offset in bytes of the returning instruction in the function text.

fbt Examples

You can easily use the `fbt` provider to explore the kernel's implementation. The following example script records the first `gettimeofday` call from any `clock` process and then follows the subsequent code path through the kernel. Type the following D source code and save it in a file named `xgettimeofday.d`:

```
/*
 * To make the output more readable, indent every function entry
 * and unindent every function return.  This is done by setting the
 * "flowindent" option.
 */
#pragma D option flowindent

syscall::gettimeofday:entry
/execname == "clock" && guard++ == 0/
{
        self->traceme = 1;
        printf("start");
}

fbt:::
/self->traceme/
{}

syscall::gettimeofday:return
/self->traceme/
{
        self->traceme = 0;
        exit(0);
}
```

Running this script results in output that is similar to the following:

```
# dtrace -s ./xgettimeofday.d
dtrace: script './xgettimeofday.d' matched 92115 probes
CPU FUNCTION
  0  => gettimeofday                          start
```

```
0    -> SyS_gettimeofday
0      -> getnstimeofday64
0        -> __getnstimeofday64
0        <- __getnstimeofday64
0      <- getnstimeofday64
0      -> _copy_to_user
0      <- _copy_to_user
0    <- SyS_gettimeofday
0  <= gettimeofday
```

The previous output shows the internal kernel functions that are called when the `gettimeofday` system call is made.

Module Loading and fbt

While the Oracle Linux kernel can dynamically load and unload kernel modules, for `fbt` probes, the `fbt` kernel module must be loaded to support the instrumentation. For more information about loading kernel modules, see the note in Getting Started With DTrace. If `fbt` is not listed in `/etc/dtrace-modules`, or if the `dtrace -l` command lists no `fbt` probes, use the following command:

```
# modprobe fbt
```

Conversely, you can unload the `fbt` instrumentation with the following command:

```
# modprobe -r fbt
```

When the `fbt` module is loaded, FBT automatically provides probes to instrument all other loaded modules, including any new modules that are dynamically loaded. If a loaded module has no enabled FBT probes, the module might be unloaded and the corresponding probes are destroyed as the module is unloaded. If a loaded module has enabled FBT probes, the module is considered busy and cannot be unloaded.

fbt Stability

The `fbt` provider uses DTrace's stability mechanism to describe its stabilities. These stability values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	Common
Module	Private	Private	Unknown
Function	Private	Private	ISA
Name	Evolving	Evolving	Common
Arguments	Private	Private	ISA

For more information, see DTrace Stability Features.

syscall Provider

The `syscall` provider makes available a probe at the entry to and return from every system call in the system. Because system calls are the primary interface between user-level applications and the operating system kernel, the `syscall` provider can offer tremendous insight into application behavior with respect to the system.

syscall Probes

`syscall` provides a pair of probes for each system call: an `entry` probe that fires before the system call is entered, and a `return` probe that fires after the system call has completed, but before control has been transferred back to user-level. For all `syscall` probes, the function name is set as the name of the instrumented system call.

Often, the system call names that are provided by `syscall` correspond to names in the Section 2 manual pages. However, some `syscall` provider probes do not directly correspond to any documented system call. Some common reasons for this discrepancy are described in the following sections.

System Call Anachronisms

In some cases, the name of the system call, as provided by the `syscall` provider, might be a reflection of an ancient implementation detail.

Subcoded System Calls

Some system calls might be implemented as sub operations of another system call. For example, `socketcall()`, is the common kernel entry point for the socket system calls.

New System Calls

Oracle Linux implements `at`-suffixed system interfaces as individual system calls, for example:

- `faccessat()`
- `fchmodat()`
- `fchownat()`
- `fstatat64()`
- `futimensat()`
- `linkat()`
- `mkdirat()`
- `mknodat()`
- `name_to_handle_at()`
- `newfstatat()`
- `open_by_handle_at()`
- `openat()`
- `readlinkat()`
- `renameat()`
- `symlinkat()`
- `unlinkat()`
- `utimensat()`

These system calls implement a superset of the functionality of their old non-`at`-suffixed counterparts. They take an additional first argument that is either an open directory file descriptor. In which case, the operation on a relative pathname is taken relative to the specified directory, or is the reserved value `AT_FDCWD`, in which case the operation takes place relative to the current working directory.

Replaced System Calls

In Oracle Linux, the following older system calls have been replaced and are not called by the newer `glibc` interfaces. These legacy interfaces remain, but are reimplemented, not as system calls in their own right, but as calls to the newer system calls. The following table lists the legacy call and its new call equivalent.

Legacy System Call	New System Call
`access(p, m)`	`faccessat(AT_FDCWD, p, m, 0)`
`chmod(p, m)`	`fchmodat(AT_FDCWD, p, m, 0)`
`chown(p, u, g)`	`fchownat(AT_FDCWD, p, u, g, 0)`
`creat(p, m)`	`openat(AT_FDCWD, p, O_WRONLY|O_CREAT|O_TRUNC, m)`
`fchmod(fd, m)`	`fchmodat(fd, NULL, m, 0)`
`fchown(fd, u, g)`	`fchownat(fd, NULL, u, g, 0)`
`fstat(fd, s)`	`fstatat(fd, NULL, s, 0)`
`lchown(p, u, g)`	`fchownat(AT_FDCWD, p, u, g, AT_SYMLINK_NOFOLLOW)`
`link(p1, p2)`	`linkat(AT_FDCWD, p1, AT_FDCWD, p2, 0)`
`lstat(p, s)`	`fstatat(AT_FDCWD, p, s, AT_SYMLINK_NOFOLLOW)`
`mkdir(p, m)`	`mkdirat(AT_FDCWD, p, m)`
`mknod(p, m, d)`	`mknodat(AT_FDCWD, p, m, d)`
`open(p, o, m)`	`openat(AT_FDCWD, p, o, m)`
`readlink(p, b, s)`	`readlinkat(AT_FDCWD, p, b, s)`
`rename(p1, p2)`	`renameat(AT_FDCWD, p1, AT_FDCWD, p2)`
`rmdir(p)`	`unlinkat(AT_FDCWD, p, AT_REMOVEDIR)`
`stat(p, s)`	`fstatat(AT_FDCWD, p, s, 0)`
`symlink(p1, p2)`	`symlinkat(p1, AT_FDCWD, p2)`
`unlink(p)`	`unlinkat(AT_FDCWD, p, 0)`

Large File System Calls

A 32-bit program that supports *large files* that exceed two gigabytes in size must be able to process 64-bit file offsets. Because large files require the use of large offsets, large files are manipulated through a parallel set of system interfaces. The following table lists some of the `syscall` probes for the large file system call interfaces.

Table 11-3 syscall Large File Probes

Large File `syscall` Probe	System Call
`getdents64`	`getdents()`
`pread64` *	`pread()`
`pwrite64` *	`pwrite()`

Private System Calls

Some system calls are private implementation details of Oracle Linux subsystems that span the user-kernel boundary.

syscall Probe Arguments

For `entry` probes, the arguments, `arg0` ... `argn` , are arguments to the system call. For return probes, both `arg0` and `arg1` contain the return value. A non-zero value in the D variable `errno` indicates a system call failure.

syscall Stability

The `syscall` provider uses DTrace's stability mechanism to describe its stabilities. These stability values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	Common
Module	Private	Private	Unknown
Function	Private	Private	Instruction set architecture (ISA)
Name	Evolving	Evolving	Common
Arguments	Private	Private	ISA

For more information about the stability mechanism, see DTrace Stability Features.

sdt provider

The Statically Defined Tracing (SDT) provider (`sdt`) creates probes at sites that a software programmer has formally designated. The SDT mechanism enables programmers to consciously choose locations of interest to users of DTrace and to convey some semantic knowledge about each location through the probe name.

Importantly, SDT can act as a metaprovider by registering probes so that they appear to come from other providers, such as `io`, `proc`, and `sched`, which do not have dedicated modules of their own. Thus, the SDT provider is chiefly of interest only to developers of new providers. Most users will access SDT only indirectly by using other providers.

> **Note:**
>
> Because the `sdt` probes that are defined for the Oracle Linux kernel are likely to change over time, they are not listed here. Both the name stability and the data stability of the probes are Private, which reflects the kernel's implementation and should not be interpreted as a commitment to preserve these interfaces. For more information, see DTrace Stability Features.

Creating sdt Probes

If you are a device driver developer, you might be interested in creating your own `sdt` probes for your Oracle Linux driver. The disabled probe effect of SDT is essentially the cost of several no-operation machine instructions. You are therefore encouraged to add `sdt` probes to your device drivers as needed. Unless these probes negatively affect performance, you can leave them in your shipping code. See Statically Defined Tracing of Kernel Modules.

DTrace also provides a mechanism for application developers to define user-space static probes. See Statically Defined Tracing of User Applications.

Declaring Probes

The `sdt` probes are declared by using the `DTRACE_PROBE` macro from `<linux/sdt.h>`.

The module name and function name of an SDT-based probe correspond to the kernel module and function of the probe, respectively. DTrace includes the kernel module name and function name as part of the tuple identifying a probe, so you do not need to include this information in the probe name to prevent name space collisions. Use the `dtrace -l -m` *`module`* command to list the probes that your driver module has installed and the full names that are seen by DTrace users.

The name of the probe depends on the name that is provided in the `DTRACE_PROBE` macro. If the name does not contain two consecutive underscores (__), the name of the probe is as written in the macro. If the name contains two consecutive underscores, the probe name converts the consecutive underscores to a single dash (-). For example, if a `DTRACE_PROBE` macro specifies `transaction__start`, the SDT probe is named `transaction-start`. This substitution enables C code to provide macro names that are not valid C identifiers without specifying a string.

SDT can also act as a metaprovider by registering probes so that they appear to come from other providers, such as `io`, `proc`, and `sched`, which do not have dedicated modules of their own. For example, `kernel/exit.c` contains calls to the `DTRACE_PROC` macro, which are defined as follows in `<linux/sdt.h>`:

```
# define DTRACE_PROC(name) \
         DTRACE_PROBE(__proc_##name);
```

Probes that use such macros appear to come from a provider other than `sdt`. The leading double underscore, provider name, and trailing underscore in the `name` argument are used to match the provider and are not included in the probe name. Note that the functionality for creating probes for providers other than those that are hard-coded into DTrace is not currently available.

sdt Probe Arguments

The arguments for each `sdt` probe are the arguments that are specified in the kernel source code in the corresponding `DTRACE_PROBE` macro reference. When declaring your `sdt` probes, you can minimize their disabled probe effect by not dereferencing pointers and by not loading from global variables in the probe arguments. Both pointer dereferencing and global variable loading may be done safely in D actions that enable probes, so DTrace users can request these actions only when they are needed.

sdt Stability

The `sdt` provider uses DTrace's stability mechanism to describe its stabilities. These values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	ISA
Module	Private	Private	Unknown
Function	Private	Private	Unknown
Name	Private	Private	ISA
Arguments	Private	Private	ISA

For more information about the stability mechanism, refer to DTrace Stability Features.

pid Provider

The `pid` provider enables tracing of any user process, as specified by its `pid`.

The `pid` provider enables tracing function entry and return in user programs just like the `fbt` provider provides that capability for the kernel. Note that most of the examples in this guide that use the `fbt` provider to trace kernel function calls can be modified slightly to apply to user processes.

The `pid` provider also enables tracing of any instruction, as specified by an absolute address or function offset.

The `pid` provider has no probe effect when probes are not enabled. When probes are enabled, the probes only induce probe effect on those processes that are traced.

> **Note:**
>
> When the compiler inlines a function, the `pid` provider's probe does not fire. Use one of the following methods to compile a particular C function so that it will not be inlined.
>
> - Sun Studio: `#pragma no_inline (funcname[, funcname])`
> - gcc: `funcname __attribute__ ((noinline))`
>
> Consult your compiler documentation for updates.

Naming pid Probes

The `pid` provider actually defines a class of providers. Each process can potentially have its own associated `pid` provider. For example, a process with ID 123, would be traced by using the `pid123` provider.

The module portion of the probe description refers to an object loaded in the corresponding process's address space. To see which objects will be loaded for `my_exec` or are loaded for process ID 123, use the following commands:

```
# ldd my_exec
...
# pldd 123
123:  /tmp/my_exec
linux-vdso.so.1
/lib64/libc.so.6
/lib64/ld-linux-x86-64.so.2p
```

In the probe description, you name the object by the name of the file, not by its full path name. You can also omit the `.6` or `so.6` suffix. All of the following examples name the same probe:

```
pid123:libc.so.6:strcpy:entry
pid123:libc.so:strcpy:entry
pid123:libc:strcpy:entry
```

The first example is the actual name of the probe. The other examples are convenient aliases that are replaced with the full load object name internally.

For the load object of the executable, you can use the `a.out` alias. The following two probe descriptions name the same probe:

```
pid123:my_exec:main:return
pid123:a.out:main:return
```

The function field of the probe description names a function in the module. A user application binary might have several names for the same function. For example, `__gnu_get_libc_version` might be an alternate name for the function `gnu_get_libc_version` in `libc.so.6`. DTrace chooses one canonical name for such a function and uses that name internally.

The following example illustrates how DTrace internally remaps module and function names to a canonical form:

```
# dtrace -q -n 'pid123:libc:__gnu_get_libc_version:
    { printf("%s\n%s\n", probemod, probefunc)}'
libc.so.6
gnu_get_libc_version
```

For examples of how to use the `pid` provider effectively, see User Process Tracing.

pid Probe Arguments

An `entry` probe fires when the traced function is invoked. The arguments to entry probes are the values of the arguments to the traced function.

A `return` probe fires when the traced function returns or makes a tail call to another function. The `arg1` probe argument holds the function return value.

An *offset probe* fires whenever execution reaches the instruction at the specified offset in the function. For example, to trace the instruction at the address 4 bytes into function `main`, you can use `pid123:a.out:main:4`. The arguments for offset probes are undefined. The `uregs[]` array will help you when examining the process state at these probe sites. See uregs[] Array.

pid Stability

The `pid` provider uses DTrace's stability mechanism to describe its stabilities. These values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	ISA
Module	Private	Private	Unknown
Function	Private	Private	Unknown
Name	Evolving	Evolving	ISA
Arguments	Private	Private	Unknown

For more information about the stability mechanism, see DTrace Stability Features.

proc Provider

The `proc` provider makes available the probes that pertain to the following activities: process creation and termination, LWP creation and termination, execution of new program images, and signal sending and handling.

proc Probes

The probes for the `proc` provider are listed in the following table.

Table 11-4 proc Probes

Probe	Description
`create`	Fires when a process (or process thread) is created using `fork()` or `vfork()`, which both invoke `clone()`. The `psinfo_t` corresponding to the new child process is pointed to by `args[0]`.
`exec`	Fires whenever a process loads a new process image using a variant of the `execve()` system call. The `exec` probe fires before the process image is loaded. Process variables like `execname` and `curpsinfo` therefore contain the process state before the image is loaded. Some time after the `exec` probe fires, either the `exec-failure` or `exec-success` probe subsequently fires in the same thread. The path of the new process image is pointed to by `args[0]`.

Table 11-4 (Cont.) proc Probes

Probe	Description
exec-failure	Fires when an exec() variant has failed. The exec-failure probe fires only after the exec probe has fired in the same thread. The errno value is provided in args[0].
exec-success	Fires when an exec() variant has succeeded. Like the exec-failure probe, the exec-success probe fires only after the exec probe has fired in the same thread. By the time that the exec-success probe fires, process variables like execname and curpsinfo contain the process state after the new process image has been loaded.
exit	Fires when the current process is exiting. The reason for exit, which is expressed as one of the SIGCHLD <asm-generic/signal.h> codes, is contained in args[0].
lwp-create	Fires when a process thread is created, the latter typically as a result of pthread_create(). The lwpsinfo_t corresponding to the new thread is pointed to by args[0]. The psinfo_t of the process that created the thread is pointed to by args[1].
lwp-exit	Fires when a process or process thread is exiting, due either to a signal or to an explicit call to exit or pthread_exit().
lwp-start	Fires within the context of a newly created process or process thread. The lwp-start probe fires before any user-level instructions are executed. If the thread is the first created for the process, the start probe fires, followed by lwp-start.
signal-clear	Probes that fires when a pending signal is cleared because the target thread was waiting for the signal in sigwait(), sigwaitinfo(), or sigtimedwait(). Under these conditions, the pending signal is cleared and the signal number is returned to the caller. The signal number is in args[0]. signal-clear fires in the context of the formerly waiting thread.
signal-discard	Fires when a signal is sent to a single-threaded process and the signal is both unblocked and ignored by the process. Under these conditions, the signal is discarded on generation. The lwpsinfo_t and psinfo_t of the target process and thread are in args[0] and args[1], respectively. The signal number is in args[2].

Table 11-4 (Cont.) proc Probes

Probe	Description
signal-handle	Fires immediately before a thread handles a signal. The signal-handle probe fires in the context of the thread that will handle the signal. The signal number is in args[0]. A pointer to the siginfo_t structure that corresponds to the signal is in args[1]. The address of the signal handler in the process is in args[2].
signal-send	Fires when a signal is sent to a process or to a thread created by a process. The signal-send probe fires in the context of the sending process or thread. The lwpsinfo_t and psinfo_t of the receiving process and thread are in args[0] and args[1], respectively. The signal number is in args[2]. signal-send is always followed by signal-handle or signal-clear in the receiving process and thread.
start	Fires in the context of a newly created process. The start probe fires before any user-level instructions are executed in the process.

> **Note:**
>
> In Linux, there is no fundamental difference between a process and a thread that a process creates. The threads of a process are set up so that they can share resources, but each thread has its own entry in the process table with its own process ID.

proc Probe Arguments

The following table lists the argument types for the proc probes. See Table 11-4 for a description of the arguments.

Table 11-5 proc Probe Arguments

Probe	args[0]	args[1]	args[2]
create	psinfo_t *	—	—
exec	char *	—	—
exec-failure	int	—	—
exec-success	—	—	—
exit	int	—	—
lwp-create	lwpsinfo_t *	psinfo_t *	—

Table 11-5 (Cont.) proc Probe Arguments

Probe	args[0]	args[1]	args[2]
lwp-exit	—	—	—
lwp-start	—	—	—
signal-clear	int	—	—
signal-discard	lwpsinfo_t *	psinfo_t *	int
signal-handle	int	siginfo_t *	void (*)(void)
signal-send	lwpsinfo_t *	psinfo_t *	int
start	—	—	—

lwpsinfo_t

Several `proc` probes have arguments of type `lwpsinfo_t`. Detailed information about this data structure can be found in `/usr/lib64/dtrace/version/procfs.d`. The definition of the `lwpsinfo_t` structure, as available to DTrace consumers, is as follows:

```
typedef struct lwpsinfo {
  int pr_flag;                /* flags */
  id_t pr_lwpid;              /* thread id */
  uintptr_t pr_addr;          /* internal address of thread */
  uintptr_t pr_wchan;         /* wait addr for sleeping lwp (NULL on Linux) */
  char pr_stype;              /* sync event type (0 on Linux) */
  char pr_state;              /* numeric thread state */
  char pr_sname;              /* printable character for pr_state */
  int pr_pri;                 /* priority, high value = high priority */
  char pr_name[PRCLSZ];       /* scheduling class name */
  processorid_t pr_onpro;     /* processor which last ran this thread */
} lwpsinfo_t;
```

> **Note:**
>
> Lightweight processes do not exist in Linux. Rather, in Oracle Linux, processes and threads are represented by process descriptors of type `struct task_struct` in the task list. DTrace translates the members of `lwpsinfo_t` from the `task_struct` for the Oracle Linux process.

The `pr_flag` is set to `1` if the thread is stopped. Otherwise, it is set to `0`.

In Oracle Linux, the `pr_stype` field is unsupported, and hence is always `0`.

The following table describes the values that `pr_state` can take, as well as the corresponding character values for `pr_sname`.

Table 11-6 pr_state Values

pr_state Value	pr_sname Value	Description
SRUN (2)	R	The thread is runnable or is currently running on a CPU. The sched:::enqueue probe fires immediately before a thread's state is transitioned to SRUN. The sched:::on-cpu probe will fire a short time after the thread starts to run. The equivalent Oracle Linux task state is TASK_RUNNING.
SSLEEP (1)	S	The thread is sleeping. The sched:::sleep probe will fire immediately before a thread's state is transitioned to SSLEEP. The equivalent Oracle Linux task state is TASK_INTERRUPTABLE or TASK_UNINTERRUPTABLE.
SSTOP (4)	T	The thread is stopped, either due to an explicit proc directive or some other stopping mechanism. The equivalent Oracle Linux task state is __TASK_STOPPED or __TASK_TRACED.
SWAIT (7)	W	The thread is waiting on wait queue. The sched:::cpucaps-sleep probe will fire immediately before the thread's state transitions to SWAIT. The equivalent Oracle Linux task state is TASK_WAKEKILL or TASK_WAKING.
SZOMB (3)	Z	The thread is a zombie. The equivalent Oracle Linux task state is EXIT_ZOMBIE, EXIT_DEAD, or TASK_DEAD.

psinfo_t

Several proc probes have an argument of type psinfo_t. Detailed information about this data structure can be found in /usr/lib64/dtrace/*version*/procfs.d. The definition of the psinfo_t structure, as available to DTrace consumers, is as follows:

```
typedef struct psinfo {
        int pr_nlwp;                    /* not supported */
        pid_t pr_pid;                   /* unique process id */
        pid_t pr_ppid;                  /* process id of parent */
```

```
        pid_t pr_pgid;                  /* pid of process group leader */
        pid_t pr_sid;                   /* session id */
        uid_t pr_uid;                   /* real user id */
        uid_t pr_euid;                  /* effective user id */
        uid_t pr_gid;                   /* real group id */
        uid_t pr_egid;                  /* effective group id */
        uintptr_t pr_addr;              /* address of process */
        size_t pr_size;                 /* not supported */
        size_t pr_rssize;               /* not supported */
        struct tty_struct *pr_ttydev;   /* controlling tty (or -1) */
        ushort_t pr_pctcpu;             /* not supported */
        ushort_t pr_pctmem;             /* not supported */
        timestruc_t pr_start;           /* not supported */
        timestruc_t pr_time;            /* not supported */
        timestruc_t pr_ctime;           /* not supported */
        char pr_fname[16];              /* name of exec'ed file */
        char pr_psargs[80];             /* initial chars of arg list */
        int pr_wstat;                   /* not supported */
        int pr_argc;                    /* initial argument count */
        uintptr_t pr_argv;              /* address of initial arg vector */
        uintptr_t pr_envp;              /* address of initial env vector */
        char pr_dmodel;                 /* data model */
        taskid_t pr_taskid;             /* not supported */
        projid_t pr_projid;             /* not supported */
        int pr_nzomb;                   /* not supported */
        poolid_t pr_poolid;             /* not supported */
        zoneid_t pr_zoneid;             /* not supported */
        id_t pr_contract;               /* not supported */
        lwpsinfo_t pr_lwp;              /* not supported */
} psinfo_t;
```

> **Note:**
>
> Lightweight processes do not exist in Linux. In Oracle Linux, processes and threads are represented by process descriptors of type `struct task_struct` in the task list. DTrace translates the members of `psinfo_t` from the `task_struct` for the Oracle Linux process.

`pr_dmodel` is set to either `PR_MODEL_ILP32`, denoting a 32–bit process, or `PR_MODEL_LP64`, denoting a 64–bit process.

proc Examples

The following examples illustrate the use of the probes that are published by the `proc` provider.

exec

The following example shows how you can use the `exec` probe to easily determine which programs are being executed, and by whom. Type the following D source code and save it in a file named `whoexec.d`:

```
#pragma D option quiet

proc:::exec
{
  self->parent = execname;
```

```
}

proc:::exec-success
/self->parent != NULL/
{
  @[self->parent, execname] = count();
  self->parent = NULL;
}

proc:::exec-failure
/self->parent != NULL/
{
  self->parent = NULL;
}

END
{
  printf("%-20s %-20s %s\n", "WHO", "WHAT", "COUNT");
  printa("%-20s %-20s %@d\n", @);
}
```

Running the example script for a short period of time results in output similar to the following:

```
# dtrace -s ./whoexec.d
^C
WHO                  WHAT                 COUNT
abrtd                abrt-handle-eve      1
firefox              basename             1
firefox              mkdir                1
firefox              mozilla-plugin-      1
firefox              mozilla-xremote      1
firefox              run-mozilla.sh       1
firefox              uname                1
gnome-panel          firefox              1
kworker/u:1          modprobe             1
modprobe             modprobe.ksplic      1
mozilla-plugin-      plugin-config        1
mozilla-plugin-      uname                1
nice                 sosreport            1
run-mozilla.sh       basename             1
run-mozilla.sh       dirname              1
run-mozilla.sh       firefox              1
run-mozilla.sh       uname                1
sh                   abrt-action-sav      1
sh                   blkid                1
sh                   brctl                1
sh                   cut                  1
...
```

start and exit Probes

If you want to know how long programs are running, from creation to termination, you can enable the `start` and `exit` probes, as shown in the following example. Save it in a file named `progtime.d`:

```
proc:::start
{
  self->start = timestamp;
}

proc:::exit
```

```
/self->start/
{
  @[execname] = quantize(timestamp - self->start);
  self->start = 0;
}
```

Running the example script on a build server for several seconds results in output similar to the following:

```
# dtrace -s ./progtime.d
dtrace: script ’./progtime.d’ matched 2 probes
^C
...
cc
           value  ------------- Distribution ------------- count
        33554432 |                                         0
        67108864 |@@@                                      3
       134217728 |@                                        1
       268435456 |                                         0
       536870912 |@@@@                                     4
      1073741824 |@@@@@@@@@@@@@@                           13
      2147483648 |@@@@@@@@@@@@                             11
      4294967296 |@@@                                      3
      8589934592 |                                         0

sh
           value  ------------- Distribution ------------- count
          262144 |                                         0
          524288 |@                                        5
         1048576 |@@@@@@@@                                 29
         2097152 |                                         0
         4194304 |                                         0
         8388608 |@@@                                      12
        16777216 |@@                                       9
        33554432 |@@                                       9
        67108864 |@@                                       8
       134217728 |@                                        7
       268435456 |@@@@@                                    20
       536870912 |@@@@@@                                   26
      1073741824 |@@@                                      14
      2147483648 |@@                                       11
      4294967296 |                                         3
      8589934592 |                                         1
     17179869184 |                                         0
...
```

signal-send

The following example shows how you can use the `signal-send` probe to determine the sending and receiving of process associated with any signal. Type the following D source code and save it in a file named `sig.d`:

```
#pragma D option quiet

proc:::signal-send
{
  @[execname, stringof(args[1]->pr_fname), args[2]] = count();
}

END
{
```

```
  printf("%20s %20s %12s %s\n",
      "SENDER", "RECIPIENT", "SIG", "COUNT");
  printa("%20s %20s %12d %@d\n", @);
}
```

Running this script results in output similar to the following:

```
# dtrace -s sig.d
^C
              SENDER            RECIPIENT          SIG COUNT
        gnome-panel                 Xorg           29 1
        kworker/0:2               dtrace            2 1
               Xorg                 Xorg           29 3
               java                 Xorg           29 6
            firefox                 Xorg           29 14
        kworker/0:0                 Xorg           29 1135
```

proc Stability

The `proc` provider uses DTrace's stability mechanism to describe its stabilities. These values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	ISA
Module	Private	Private	Unknown
Function	Private	Private	Unknown
Name	Evolving	Evolving	ISA
Arguments	Evolving	Evolving	ISA

For more information about the stability mechanism, see DTrace Stability Features.

sched Provider

The `sched` provider makes available probes that are related to CPU scheduling. Because CPUs are the one resource that all threads must consume, the `sched` provider is very useful for understanding systemic behavior. For example, using the `sched` provider, you can understand when and why threads sleep, run, change priority, or wake other threads.

sched Probes

The following table describes the probes for the `sched` provider.

Table 11-7 sched Probes

Probe	*Description*
`change-pri`	Fires whenever a thread's priority is about to be changed. The `lwpsinfo_t` of the thread is pointed to by `args[0]`. The thread's current priority is in the `pr_pri` field of this structure. The `psinfo_t` of the process containing the thread is pointed to by `args[1]`. The thread's new priority is contained in `args[2]`.

Table 11-7 (Cont.) sched Probes

Probe	*Description*
dequeue	Fires immediately before a runnable thread is dequeued from a run queue. The lwpsinfo_t of the thread being dequeued is pointed to by args[0]. The psinfo_t of the process containing the thread is pointed to by args[1]. The cpuinfo_t of the CPU from which the thread is being dequeued is pointed to by args[2]. If the thread is being dequeued from a run queue that is not associated with a particular CPU, the cpu_id member of this structure will be -1.
enqueue	Fires immediately before a runnable thread is enqueued to a run queue. The lwpsinfo_t of the thread being enqueued is pointed to by args[0]. The psinfo_t of the process containing the thread is pointed to by args[1]. The cpuinfo_t of the CPU to which the thread is being enqueued is pointed to by args[2]. If the thread is being enqueued from a run queue that is not associated with a particular CPU, the cpu_id member of this structure will be -1. The value in args[3] is a boolean indicating whether the thread will be enqueued to the front of the run queue. The value is non-zero if the thread will be enqueued at the front of the run queue, and zero if the thread will be enqueued at the back of the run queue.
off-cpu	Fires when the current CPU is about to end execution of a thread. The curcpu variable indicates the current CPU. The curlwpsinfo variable indicates the thread that is ending execution. The lwpsinfo_t of the thread that the current CPU will next execute is pointed to by args[0]. The psinfo_t of the process containing the next thread is pointed to by args[1].
on-cpu	Fires when a CPU has just begun execution of a thread. The curcpu variable indicates the current CPU. The curlwpsinfo variable indicates the thread that is beginning execution. The curpsinfo variable describes the process containing the current thread.

Table 11-7 (Cont.) sched Probes

Probe	*Description*
`preempt`	Fires immediately before the current thread is preempted. After this probe fires, the current thread will select a thread to run and the `off-cpu` probe will fire for the current thread. In some cases, a thread on one CPU will be preempted, but the preempting thread will run on another CPU in the meantime. In this situation, the preempt probe will fire, but the dispatcher will be unable to find a higher priority thread to run and the `remain-cpu` probe will fire instead of the `off-cpu` probe.
`remain-cpu`	Fires when a scheduling decision has been made, but the dispatcher has elected to continue to run the current thread. The `curcpu` variable indicates the current CPU. The `curlwpsinfo` variable indicates the thread that is beginning execution. The `curpsinfo` variable describes the process containing the current thread.
`sleep`	Fires immediately before the current thread sleeps on a synchronization object. The type of the synchronization object is contained in the `pr_stype` member of the `lwpsinfo_t` pointed to by `curlwpsinfo`. The address of the synchronization object is contained in the `pr_wchan` member of the `lwpsinfo_t` pointed to by `curlwpsinfo`. The meaning of this address is a private implementation detail, but the address value may be treated as a token unique to the synchronization object.
`surrender`	Fires when a CPU has been instructed by another CPU to make a scheduling decision — often because a higher-priority thread has become runnable. The `lwpsinfo_t` of the current thread is pointed to by `args[0]`. The `psinfo_t` of the process containing the thread is pointed to by `args[1]`.
`tick`	Fires as a part of clock tick-based accounting. In clock tick-based accounting, CPU accounting is performed by examining which threads and processes are running when a fixed-interval interrupt fires. The `lwpsinfo_t` that corresponds to the thread that is being assigned CPU time is pointed to by `args[0]`. The `psinfo_t` that corresponds to the process that contains the thread is pointed to by `args[1]`.

Table 11-7 (Cont.) sched Probes

Probe	*Description*
wakeup	Fires immediately before the current thread wakes a thread sleeping on a synchronization object. The lwpsinfo_t of the sleeping thread is pointed to by args[0]. The psinfo_t of the process containing the sleeping thread is pointed to by args[1]. The type of the synchronization object is contained in the pr_stype member of the lwpsinfo_t of the sleeping thread. The address of the synchronization object is contained in the pr_wchan member of the lwpsinfo_t of the sleeping thread. The meaning of this address is a private implementation detail, but the address value may be treated as a token unique to the synchronization object.

sched Probe Arguments

The following table describes the argument types for the sched probes. See Table 11-7 for descriptions of the arguments.

Table 11-8 sched Probe Arguments

Probe	args[0]	args[1]	args[2]	args[3]
change-pri	lwpsinfo_t *	psinfo_t *	int	—
dequeue	lwpsinfo_t *	psinfo_t *	cpuinfo_t *	—
enqueue	lwpsinfo_t *	psinfo_t *	cpuinfo_t *	int
off-cpu	lwpsinfo_t *	psinfo_t *	—	—
on-cpu	—	—	—	—
preempt	—	—	—	—
remain-cpu	—	—	—	—
sleep	—	—	—	—
surrender	lwpsinfo_t *	psinfo_t *	—	—
tick	lwpsinfo_t *	psinfo_t *	—	—
wakeup	lwpsinfo_t *	psinfo_t *	—	—

cpuinfo_t

The cpuinfo_t structure defines a CPU. Per the information in Table 11-8, arguments to both the enqueue and dequeue probes include a pointer to a cpuinfo_t. Additionally, the cpuinfo_t that corresponds to the current CPU is pointed to by the curcpu variable.

The definition of the cpuinfo_t structure is as follows:

```
typedef struct cpuinfo {
  processorid_t cpu_id;      /* CPU identifier */
  psetid_t cpu_pset;         /* not supported */
  chipid_t cpu_chip;         /* chip identifier */
  lgrp_id_t cpu_lgrp;        /* not supported */
  cpuinfo_arch_t *cpu_info;  /* CPU information */
} cpuinfo_t;
```

`cpu_id`: Is the processor identifier.

`cpu_chip`: Is the identifier of the physical chip. Physical chips can contain several CPU cores.

`cpu_info`: Is a pointer to the `cpuinfo_arch_t` structure that is associated with the CPU.

sched Examples

The following examples show the use of `sched` probes.

on-cpu and off-cpu Probes

One common question that you might want answered is which CPUs are running threads and for how long? The following example shows how you can use the `on-cpu` and `off-cpu` probes to easily answer this question on a system-wide basis. Type the following D source code and save it in a file named `where.d`:

```
sched:::on-cpu
{
  self->ts = timestamp;
}

sched:::off-cpu
/self->ts/
{
  @[cpu] = quantize(timestamp - self->ts);
  self->ts = 0;
}
```

Running the previous script results in output that is similar to the following:

```
# dtrace -s ./where.d
dtrace: script ’./where.d’ matched 2 probes
^C
        0
          value  ------------- Distribution ------------- count
           2048 |                                         0
           4096 |@@                                       37
           8192 |@@@@@@@@@@@@@@                           212
          16384 |@                                        30
          32768 |                                         10
          65536 |@                                        17
         131072 |                                         12
         262144 |                                         9
         524288 |                                         6
        1048576 |                                         5
        2097152 |                                         1
        4194304 |                                         3
        8388608 |@@@@                                     75
       16777216 |@@@@@@@@@@@@@@                           201
       33554432 |                                         6
       67108864 |                                         0
```

```
  1
    value  ------------- Distribution ------------- count
     2048 |                                         0
     4096 |@                                        6
     8192 |@@@@                                     23
    16384 |@@@                                      18
    32768 |@@@@                                     22
    65536 |@@@@                                     22
   131072 |@                                        7
   262144 |                                         5
   524288 |                                         2
  1048576 |                                         3
  2097152 |@                                        9
  4194304 |                                         4
  8388608 |@@@                                      18
 16777216 |@@@                                      19
 33554432 |@@@                                      16
 67108864 |@@@@                                     21
134217728 |@@                                       14
268435456 |                                         0
```

The previous output shows that on CPU 1 threads tend to run for less than 131072 nanoseconds (on order of 100 microseconds) at a stretch, or for 8388608 to 134217728 nanoseconds (approximately 10 to 100 milliseconds). A noticeable gap between the two clusters of data is shown in the histogram. You also might be interested in knowing which CPUs are running a particular process.

You can also use the `on-cpu` and `off-cpu` probes for answering this question. The following script displays which CPUs run a specified application over a period of ten seconds. Save it in a file named `whererun.d`.:

```
#pragma D option quiet
dtrace:::BEGIN
{
  start = timestamp;
}

sched:::on-cpu
/execname == $$1/
{
  self->ts = timestamp;
}

sched:::off-cpu
/self->ts/
{
  @[cpu] = sum(timestamp - self->ts);
  self->ts = 0;
}

profile:::tick-1sec
/++x >= 10/
{
  exit(0);
}

dtrace:::END
{
  printf("CPU distribution over %d seconds:\n\n",
    (timestamp - start) / 1000000000);
  printf("CPU microseconds\n--- ------------\n");
```

```
  normalize(@, 1000);
  printa("%3d %@d\n", @);
}
```

Running the previous script on a large mail server and specifying the IMAP daemon results in output that is similar to the following:

```
# dtrace -s ./whererun.d imapd
CPU distribution of imapd over 10 seconds:

CPU microseconds
--- ------------
 15 10102
 12 16377
 21 25317
 19 25504
 17 35653
 13 41539
 14 46669
 20 57753
 22 70088
 16 115860
 23 127775
 18 160517
```

Oracle Linux takes into account the amount of time that a thread has been sleeping when selecting a CPU on which to run the thread, as a thread that has been sleeping for less time tends not to migrate. Use the `off-cpu` and `on-cpu` probes to observe this behavior. Type the following source code and save it in a file named `howlong.d`:

```
sched:::off-cpu
/curlwpsinfo->pr_state == SSLEEP/
{
 self->cpu = cpu;
 self->ts = timestamp;
}

sched:::on-cpu
/self->ts/
{
 @[self->cpu == cpu ?
   "sleep time, no CPU migration" : "sleep time, CPU migration"] =
   lquantize((timestamp - self->ts) / 1000000, 0, 500, 25);
 self->ts = 0;
 self->cpu = 0;
}
```

Running the previous script for approximately 30 seconds results in output that is similar to the following:

```
# dtrace -s ./howlong.d
dtrace: script ’./howlong.d’ matched 2 probes
^C
 sleep time, CPU migration
          value  ------------- Distribution ------------- count
            < 0 |                                         0
              0 |@@@@@@@                                  6838
             25 |@@@@@                                    4714
             50 |@@@                                      3108
             75 |@                                        1304
            100 |@                                        1557
            125 |@                                        1425
```

```
           150 |                                         894
           175 |@                                        1526
           200 |@@                                       2010
           225 |@@                                       1933
           250 |@@                                       1982
           275 |@@                                       2051
           300 |@@                                       2021
           325 |@                                        1708
           350 |@                                        1113
           375 |                                         502
           400 |                                         220
           425 |                                         106
           450 |                                         54
           475 |                                         40
         >= 500 |@                                        1716

 sleep time, no CPU migration
          value  ------------- Distribution ------------- count
            < 0 |                                         0
              0 |@@@@@@@@@@@@                             58413
             25 |@@@                                      14793
             50 |@@                                       10050
             75 |                                         3858
            100 |@                                        6242
            125 |@                                        6555
            150 |                                         3980
            175 |@                                        5987
            200 |@                                        9024
            225 |@                                        9070
            250 |@@                                       10745
            275 |@@                                       11898
            300 |@@                                       11704
            325 |@@                                       10846
            350 |@                                        6962
            375 |                                         3292
            400 |                                         1713
            425 |                                         585
            450 |                                         201
            475 |                                         96
         >= 500 |                                         3946
```

The previous output reveals that there are many more occurrences of non-migration than migration. Also, when sleep times are longer, migrations are more likely. The distributions are noticeably different in the sub-100 millisecond range, but look very similar as the sleep times get longer. This result would seem to indicate that sleep time is not factored into the scheduling decision when a certain threshold is exceeded.

enqueue and dequeue Probes

You might want to know on which CPUs processes and threads are waiting to run. You can use the `enqueue` probe along with the `dequeue` probe to answer this question. Type the following source code and save it in a file named `qtime.d`:

```
sched:::enqueue
{
  a[args[0]->pr_lwpid, args[1]->pr_pid, args[2]->cpu_id] =
  timestamp;
}

sched:::dequeue
/a[args[0]->pr_lwpid, args[1]->pr_pid, args[2]->cpu_id]/
```

```
{
  @[args[2]->cpu_id] = quantize(timestamp -
    a[args[0]->pr_lwpid, args[1]->pr_pid, args[2]->cpu_id]);
  a[args[0]->pr_lwpid, args[1]->pr_pid, args[2]->cpu_id] = 0;
}
```

Running the previous script for several seconds results in output that is similar to the following:

```
# dtrace -s qtime.d
dtrace: script 'qtime.d' matched 16 probes
^C

        1
           value  ------------- Distribution ------------- count
            8192 |                                         0
           16384 |                                         1
           32768 |@                                        47
           65536 |@@@@@@@                                  365
          131072 |@@@@@@@@@@@@                             572
          262144 |@@@@@@@@@@@@                             570
          524288 |@@@@@@@                                  354
         1048576 |@                                        57
         2097152 |                                         7
         4194304 |                                         1
         8388608 |                                         1
        16777216 |                                         0

        0
           value  ------------- Distribution ------------- count
            8192 |                                         0
           16384 |                                         6
           32768 |@                                        49
           65536 |@@@@@                                    261
          131072 |@@@@@@@@@@@@@                            753
          262144 |@@@@@@@@@@@@                             704
          524288 |@@@@@@@@                                 455
         1048576 |@                                        74
         2097152 |                                         9
         4194304 |                                         2
         8388608 |                                         0
```

Rather than looking at wait times, you might want to examine the length of the run queue over time. Using the `enqueue` and `dequeue` probes, you can set up an associative array to track the queue length. Type the following source code and save it in a file named `qlen.d`:

```
sched:::enqueue
{
  this->len = qlen[args[2]->cpu_id]++;
  @[args[2]->cpu_id] = lquantize(this->len, 0, 100);
}

sched:::dequeue
/qlen[args[2]->cpu_id]/
{
  qlen[args[2]->cpu_id]--;
}
```

Running the previous script on a largely idle dual-core processor system for approximately 30 seconds results in output that is similar to the following:

```
# dtrace -s qlen.d
dtrace: script 'qlen.d' matched 16 probes
```

```
^C

        1
           value  ------------- Distribution ------------- count
             < 0 |                                         0
               0 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 8124
               1 |@@@@@@@                                  1558
               2 |@                                        160
               3 |                                         51
               4 |                                         24
               5 |                                         13
               6 |                                         11
               7 |                                         9
               8 |                                         6
               9 |                                         0

        0
           value  ------------- Distribution ------------- count
             < 0 |                                         0
               0 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 8569
               1 |@@@@@@@@@@                               2429
               2 |@                                        292
               3 |                                         25
               4 |                                         8
               5 |                                         5
               6 |                                         4
               7 |                                         4
               8 |                                         1
               9 |                                         0
```

The output is roughly what you would expect for an idle system: the majority of the time that a runnable thread is enqueued, the run queues were very short (three or fewer threads in length). However, given that the system was largely idle, the exceptional data points at the bottom of each table might be unexpected. For example, why were the run queues as long as 8 runnable threads? To explore this question further, you could write a D script that displays the contents of the run queue when the length of the run queue is long. This problem is complicated because D enablings cannot iterate over data structures, and therefore cannot simply iterate over the entire run queue. Even if D enablings could do so, you should avoid dependencies on the kernel's internal data structures.

For this type of script, you would enable the `enqueue` and `dequeue` probes and then use both speculations and associative arrays. Whenever a thread is enqueued, the script increments the length of the queue and records the timestamp in an associative array keyed by the thread. You cannot use a thread-local variable in this case because a thread might be enqueued by another thread. The script then checks to see if the queue length exceeds the maximum, and if so, the script starts a new speculation, and records the timestamp and the new maximum. Then, when a thread is dequeued, the script compares the `enqueue` timestamp to the timestamp of the longest length: if the thread was enqueued before the timestamp of the longest length, the thread was in the queue when the longest length was recorded. In this case, the script speculatively traces the thread's information. When the kernel dequeues the last thread that was enqueued at the timestamp of the longest length, the script commits the speculation data. Type the following source code and save it in a file named `whoqueue.d`:

```
#pragma D option quiet
#pragma D option nspec=4
#pragma D option specsize=100k

int maxlen;
int spec[int];
sched:::enqueue
```

```
{
  this->len = ++qlen[this->cpu = args[2]->cpu_id];
  in[args[0]->pr_addr] = timestamp;
}

sched:::enqueue
/this->len > maxlen && spec[this->cpu]/
{
  /*
   * There is already a speculation for this CPU. We just set a new
   * record, so we'll discard the old one.
   */
  discard(spec[this->cpu]);
}

sched:::enqueue
/this->len > maxlen/
{
  /*
   * We have a winner. Set the new maximum length and set the timestamp
   * of the longest length.
   */
  maxlen = this->len;
  longtime[this->cpu] = timestamp;
  /*
   * Now start a new speculation, and speculatively trace the length.
   */
  this->spec = spec[this->cpu] = speculation();
  speculate(this->spec);
  printf("Run queue of length %d:\n", this->len);
}

sched:::dequeue
/(this->in = in[args[0]->pr_addr]) &&
  this->in <= longtime[this->cpu = args[2]->cpu_id]/
{
  speculate(spec[this->cpu]);
  printf(" %d/%d (%s)\n",
    args[1]->pr_pid, args[0]->pr_lwpid,
    stringof(args[1]->pr_fname));
}

sched:::dequeue
/qlen[args[2]->cpu_id]/
{
  in[args[0]->pr_addr] = 0;
  this->len = --qlen[args[2]->cpu_id];
}

sched:::dequeue
/this->len == 0 && spec[this->cpu]/
{
  /*
   * We just processed the last thread that was enqueued at the time
   * of longest length; commit the speculation, which by now contains
   * each thread that was enqueued when the queue was longest.
   */
  commit(spec[this->cpu]);
  spec[this->cpu] = 0;
}
```

Running the previous script on the same system results in output that is similar to the following:

```
# dtrace -s whoqueue.d
Run queue of length 1:
 2850/2850 (java)
Run queue of length 2:
 4034/4034 (kworker/0:1)
 16/16 (sync_supers)
Run queue of length 3:
 10/10 (ksoftirqd/1)
 1710/1710 (hald-addon-inpu)
 25350/25350 (dtrace)
Run queue of length 4:
 2852/2852 (java)
 2850/2850 (java)
 1710/1710 (hald-addon-inpu)
 2099/2099 (Xorg)
Run queue of length 5:
 3149/3149 (notification-da)
 2417/2417 (gnome-settings-)
 2437/2437 (gnome-panel)
 2461/2461 (wnck-applet)
 2432/2432 (metacity)
Run queue of length 9:
 3685/3685 (firefox)
 3149/3149 (notification-da)
 2417/2417 (gnome-settings-)
 2437/2437 (gnome-panel)
 2852/2852 (java)
 2452/2452 (nautilus)
 2461/2461 (wnck-applet)
 2432/2432 (metacity)
 2749/2749 (gnome-terminal)
^C
```

sleep and wakeup Probes

The following example shows how you might use the `wakeup` probe to determine what is waking a particular process, and when, over a given period. Type the following source code and save it in a file named `gterm.d`:

```
#pragma D option quiet

dtrace:::BEGIN
{
  start = timestamp;
}

sched:::wakeup
/stringof(args[1]->pr_fname) == "gnome-terminal"/
{
  @[execname] = lquantize((timestamp - start) / 1000000000, 0, 10);
}

profile:::tick-1sec
/++x == 10/
{
  exit(0);
}
```

The output from running this script is as follows:

```
# dtrace -s gterm.d

  Xorg
           value  ------------- Distribution ------------- count
             < 0 |                                         0
               0 |@@@@@@@@@@@@@@@@                       69
               1 |@@@@@@@@                               35
               2 |@@@@@@@@@@                             42
               3 |                                       2
               4 |                                       0
               5 |                                       0
               6 |                                       0
               7 |@@@@                                   16
               8 |                                       0
               9 |@@@                                    15
            >= 10 |                                       0
```

This output shows that the X server is waking the `gnome-terminal` process as you interact with the system.

Additionally, you could use the `sleep` probe with the `wakeup` probe to understand which applications are blocking on other applications, and for how long. Type the following source code and save it in a file named `whofor.d`:

```
#pragma D option quiet
sched:::sleep
{
  bedtime[curlwpsinfo->pr_addr] = timestamp;
}

sched:::wakeup
/bedtime[args[0]->pr_addr]/
{
  @[stringof(args[1]->pr_fname), execname] =
    quantize(timestamp - bedtime[args[0]->pr_addr]);
  bedtime[args[0]->pr_addr] = 0;
}

END
{
  printa("%s sleeping on %s:\n%@d\n", @);
}
```

The tail of the output from running the previous example script on a desktop system for several seconds is similar to the following:

```
# dtrace -s whofor.d
                      ^C
...
Xorg sleeping on metacity:

           value  ------------- Distribution ------------- count
           65536 |                                         0
          131072 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 2
          262144 |                                         0

gnome-power-man sleeping on Xorg:

           value  ------------- Distribution ------------- count
          131072 |                                         0
          262144 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 1
```

```
          524288 |                                       0
...
```

preempt and remain-cpu Probes

Because Oracle Linux is a preemptive system, higher priority threads preempt lower priority threads. Preemption can induce a significant latency bubble in the lower priority thread. Therefore, you might want to know which threads are being preempted by other threads.

The following example shows how you would use the `preempt` and `remain-cpu` probes to display this information. Type the following source code and save it in a file named `whopreempt.d`:

```
#pragma D option quiet

sched:::preempt
{
  self->preempt = 1;
}

sched:::remain-cpu
/self->preempt/
{
  self->preempt = 0;
}

sched:::off-cpu
/self->preempt/
{
  /*
   * If we were told to preempt ourselves, see who we ended up giving
   * the CPU to.
   */
  @[stringof(args[1]->pr_fname), args[0]->pr_pri, execname,
    curlwpsinfo->pr_pri] = count();
  self->preempt = 0;
}

END
{
  printf("%30s %3s %30s %3s %5s\n", "PREEMPTOR", "PRI",
    "PREEMPTED", "PRI", "#");
  printa("%30s %3d %30s %3d %5@d\n", @);
}
```

Running the previous script on a desktop system for several seconds results in output that is similar to the following:

```
# dtrace -s whopreempt.d
^C
                      PREEMPTOR PRI                      PREEMPTED PRI     #
                         firefox 120                    kworker/0:0 120     1
                    gnome-panel 120                        swapper 120     1
                    gnome-panel 120                    wnck-applet 120     1
                    jbd2/dm-0-8 120                        swapper 120     1
                     khugepaged 139                    kworker/0:0 120     1
                    ksoftirqd/1 120                    kworker/0:0 120     1
                    kworker/0:0 120                 gnome-terminal 120     1
                    kworker/0:2 120                           Xorg 120     1
                    kworker/0:2 120                           java 120     1
                    kworker/1:0 120                           Xorg 120     1
```

```
          nautilus 120
      rtkit-daemon   0
      rtkit-daemon 120
        watchdog/0   0
        watchdog/1   0
       wnck-applet 120
       wnck-applet 120
         automount 120
  gnome-power-man 120
      kworker/0:0 120
      kworker/1:0 120
          metacity 120
  notification-da 120
    udisks-daemon 120
         automount 120
      gnome-panel 120
  gnome-settings- 120
  gnome-settings- 120
   gnome-terminal 120
             java 120
      ksoftirqd/0 120
      kworker/0:2 120
          metacity 120
          nautilus 120
             qpidd 120
          metacity 120
  gvfs-afc-volume 120
             java 120
  notification-da 120
  notification-da 120
             Xorg 120
      wnck-applet 120
      VBoxService 120
           dtrace 120
      kworker/1:0 120
           dtrace 120
             Xorg 120
  hald-addon-inpu 120
             java 120
   gnome-terminal 120
             Xorg 120     1
      rtkit-daemon 120     1
           swapper 120     1
           swapper 120     1
       kworker/0:0 120     1
             Xorg 120     1
           swapper 120     1
       kworker/0:0 120     2
       kworker/0:0 120     2
           swapper 120     2
            dtrace 120     2
       kworker/0:0 120     2
           swapper 120     2
       kworker/0:0 120     2
           swapper 120     3
             Xorg 120     3
             Xorg 120     3
           swapper 120     3
           swapper 120     3
       kworker/0:0 120     3
           swapper 120     3
           swapper 120     3
             Xorg 120     3
       kworker/0:0 120     3
           swapper 120     3
           swapper 120     4
           swapper 120     5
             Xorg 120     5
             Xorg 120     5
       kworker/0:0 120     5
       kworker/0:0 120     6
       kworker/0:0 120    10
           swapper 120    13
           swapper 120    14
       kworker/0:0 120    16
       kworker/0:0 120    20
           swapper 120    90
           swapper 120   100
           swapper 120   108
       kworker/0:0 120   110
```

tick

If `NOHZ` is set to `off`, Oracle Linux uses *tick-based CPU accounting*, where a system clock interrupt fires at a fixed interval and attributes CPU utilization to the processes that are running at the time of the tick. The following example shows how you would use the `tick` probe to observe this attribution.

```
# dtrace -n sched:::tick'{ @[stringof(args[1]->pr_fname)] = count() }'
dtrace: description 'sched:::tick' matched 1 probe
^C

  VBoxService                                                     1
  gpk-update-icon                                                 1
  hald-addon-inpu                                                 1
  jbd2/dm-0-8                                                     1
  automount                                                       2
  gnome-session                                                   2
  hald                                                            2
  gnome-power-man                                                 3
  ksoftirqd/0                                                     3
```

```
  kworker/0:2                                                     3
  notification-da                                                 4
  devkit-power-da                                                 6
  nautilus                                                        9
  dbus-daemon                                                    11
  gnome-panel                                                    11
  gnome-settings-                                                11
  dtrace                                                         19
  khugepaged                                                     22
  metacity                                                       27
  kworker/0:0                                                    41
  swapper                                                        56
  firefox                                                        58
  wnck-applet                                                    61
  gnome-terminal                                                 67
  java                                                           84
  Xorg                                                          227
```

One deficiency of tick-based accounting is that the system clock that performs accounting is often also responsible for dispatching any time-related scheduling activity. As a result, if a thread is to perform some amount of work every clock tick (that is, every 10 milliseconds), the system either over-accounts or under-accounts for the thread, depending on whether the accounting is done before or after time-related dispatching scheduling activity. If accounting is performed before time-related dispatching, the system under-accounts for threads running at a regular interval. If such threads run for less than the clock tick interval, they can effectively hide behind the clock tick.

The following example examines whether a system has any such threads. Type the following source code and save it in a file named `tick.d`:

```
sched:::tick,
sched:::enqueue
{
  @[probename] = lquantize((timestamp / 1000000) % 10, 0, 10);
}
```

The output of the example script is two distributions of the millisecond offset within a ten millisecond interval, one for the `tick` probe and another for `enqueue`:

```
# dtrace -s tick.d
dtrace: script 'tick.d' matched 9 probes
^C

  tick
           value  ------------- Distribution ------------- count
             < 0 |                                         0
               0 |@@@@@                                    29
               1 |@@@@@@@@@@@@@@@@@@@@                     106
               2 |@@@@@                                    27
               3 |@                                        7
               4 |@@                                       10
               5 |@@                                       12
               6 |@                                        4
               7 |@                                        8
               8 |@@                                       9
               9 |@@@                                      17
           >= 10 |                                         0

  enqueue
           value  ------------- Distribution ------------- count
             < 0 |                                         0
```

```
           0 |@@@@                                     82
           1 |@@@@                                     86
           2 |@@@@                                     76
           3 |@@@                                      65
           4 |@@@@@                                    101
           5 |@@@@                                     79
           6 |@@@@                                     75
           7 |@@@@                                     76
           8 |@@@@                                     89
           9 |@@@@                                     75
      >= 10 |                                         0
```

The output histogram named `tick` shows that the clock tick is firing at a 1 millisecond offset. In this example, the output for `enqueue` is evenly spread across the ten millisecond interval and no spike is visible at 1 millisecond, so it appears that the threads are being not being scheduled on a time basis.

sched Stability

The `sched` provider uses DTrace's stability mechanism to describe its stabilities. These values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	ISA
Module	Private	Private	Unknown
Function	Private	Private	Unknown
Name	Evolving	Evolving	ISA
Arguments	Evolving	Evolving	ISA

For more information about the stability mechanism, see DTrace Stability Features.

io Provider

The `io` provider makes available probes that relate to data input and output. The `io` provider enables quick exploration of behavior that is observed through I/O monitoring tools such as `iostat`. For example, you can use the `io` provider to understand I/O by device, I/O type, I/O size, process, or application name .

io Probes

The following table describes the probes for the `io` provider.

Table 11-9 io Probes

Probe	Description
`start`	Fires when an I/O request is about to be made either to a peripheral device or to an NFS server.

Table 11-9 (Cont.) io Probes

Probe	Description
done	Fires after an I/O request has been fulfilled. The done probe fires after the I/O completes, but before completion processing has been performed on the buffer. As a result B_DONE is not set in b_flags at the time the done probe fires.
wait-start	Fires immediately before a thread begins to wait pending completion of a given I/O request. Some time after the wait-start probe fires, the wait-done probe fires in the same thread.
wait-done	Fires when a thread finishes waiting for the completion of a given I/O request. The wait-done probe fires only after the wait-start probe has fired in the same thread.

The io probes fire for all I/O requests to peripheral devices, and for all file read and file write requests to an NFS server. Requests for metadata from an NFS server, for example, do not trigger io probes due to a readdir() request.

io Probe Arguments

The following table describes the arguments for the io probes.

Table 11-10 io Probe Arguments

Argument	Type	Description
args[0]	bufinfo_t *	The bufinfo_t for the corresponding I/O request.
args[1]	devinfo_t *	The devinfo_t for the device for the corresponding I/O request.
args[2]	fileinfo_t *	The fileinfo_t for the file for the corresponding I/O request.

> **Note:**
>
> DTrace does not currently support the use of fileinfo_t with io probes. In Oracle Linux, no information is readily accessible at the level where the io probes fire about the file where an I/O request originated.

bufinfo_t

The bufinfo_t structure is the abstraction that describes an I/O request. The buffer that corresponds to an I/O request is pointed to by args[0] in the start, done, wait-start, and

`wait-done` probes. Detailed information about this data structure can be found in `/usr/lib64/dtrace/version/io.d`. The definition of `bufinfo_t` is as follows:

```
typedef struct bufinfo {
  int b_flags;          /* flags */
  size_t b_bcount;      /* number of bytes */
  caddr_t b_addr;       /* buffer address */
  uint64_t b_blkno;     /* expanded block # on device */
  uint64_t b_lblkno;    /* logical block # on device */
  size_t b_resid;       /* not supported */
  size_t b_bufsize;     /* size of allocated buffer */
  caddr_t b_iodone;     /* I/O completion routine */
  int b_error;          /* not supported */
  dev_t b_edev;         /* extended device */
} bufinfo_t;
```

> **Note:**
>
> DTrace translates the members of `bufinfo_t` from the `buffer_head` or `bio` for the Oracle Linux I/O request structure, depending on the kernel version.

`b_flags` indicates the state of the I/O buffer, and consists of a bitwise-or of different state values. The following table describes the values for the supported states.

Table 11-11 b_flags Values

b_flags	Value	Description
B_ASYNC	0x000400	Indicates that the I/O request is asynchronous and is not waited upon. The wait-start and wait-done probes do not fire for asynchronous I/O requests.

Note:

Some I/Os directed to be asynchronous might not set B_ASYNC. The asynchronous I/O subsystem could implement the asynchronous request by having

Table 11-11 (Cont.) b_flags Values

b_flags	Value	Description
		a separate worker thread perform asynchronous I/O operation.
B_PAGEIO	0x000010	Indicates that the buffer is being used in a paged I/O request.
B_PHYS	0x000020	Indicates that the buffer is being used for physical (direct) I/O to a user data area.
B_READ	0x000040	Indicates that data is to be read from the peripheral device into main memory.
B_WRITE	0x000100	Indicates that the data is to be transferred from main memory to the peripheral device.

`b_bcount`: Is the number of bytes to be transferred as part of the I/O request.

`b_addr`: Is the virtual address of the I/O request, when known.

`b_blkno`: Identifies which block on the device is to be accessed.

`b_lblkno`: Identifies which logical block on the device is to be accessed. The mapping from a logical block to a physical block (such as the cylinder, track, and so on) is defined by the device.

`b_bufsize`: Contains the size of the allocated buffer.

`b_iodone`: Identifies a specific routine in the kernel that is called when the I/O is complete.

`b_edev`: Contains the major and minor device numbers of the device accessed. You can use the D subroutines `getmajor` and `getminor` to extract the major and minor device numbers from the `b_edev` field.

devinfo_t

The `devinfo_t` structure provides information about a device. The `devinfo_t` structure that corresponds to the destination device of an I/O is pointed to by `args[1]` in the `start`, `done`, `wait-start`, and `wait-done` probes. Detailed information about this data structure can be found in `/usr/lib64/dtrace/version/io.d`. The definition of `devinfo_t` is as follows:

```
typedef struct devinfo {
  int dev_major;           /* major number */
  int dev_minor;           /* minor number */
  int dev_instance;        /* not supported */
  string dev_name;         /* name of device */
  string dev_statname;     /* name of device + instance/minor */
  string dev_pathname;     /* pathname of device */
} devinfo_t;
```

> **Note:**
>
> DTrace translates the members of `devinfo_t` from the `buffer_head` for the Oracle Linux I/O request structure.

`dev_major`: Is the major number of the device.

`dev_minor`: Is the minor number of the device.

`dev_name`: Is the name of the device driver that manages the device.

`dev_statname`: Is the name of the device as reported by `iostat`. This field is provided so that aberrant `iostat` output can be quickly correlated to actual I/O activity.

`dev_pathname`: Is the full path of the device. The path that is specified by `dev_pathname` includes components expressing the device node, the instance number, and the minor node. However, note that all three of these elements are not necessarily expressed in the statistics name. For some devices, the statistics name consists of the device name and the instance number. For other devices, the name consists of the device name and the number of the minor node. As a result, two devices that have the same `dev_statname` migh differ in their `dev_pathname`.

fileinfo_t

> **Note:**
>
> DTrace does not currently support the use of `fileinfo_t` with the `args[2]` argument of the `io` probes. You can use the `fileinfo_t` structure to obtain information about a process's open files by using the `fds[]` array. See Built-In Variables.

The `fileinfo_t` structure provides information about a file. `args[2]` in the `start`, `done`, `wait-start`, and `wait-done` probes points to the file to which an I/O request corresponds. The presence of file information is contingent upon the file system providing this information when dispatching I/O requests. Some file systems, especially third-party file systems, might not

provide this information. Also, I/O requests might emanate from a file system for which no file information exists. For example, any I/O from or to file system metadata is not associated with any one file. Finally, some highly optimized file systems might aggregate I/O from disjoint files into a single I/O request. In this case, the file system might provide the file information either for the file that represents the majority of the I/O or for the file that represents some of the I/O. Alternatively, the file system might provide no file information at all in this case.

Detailed information about this data structure can be found in `/usr/lib64/dtrace/version/io.d`. The definition of `fileinfo_t` is as follows:

```
typedef struct fileinfo {
  string fi_name;           /* name (basename of fi_pathname) */
  string fi_dirname;        /* directory (dirname of fi_pathname) */
  string fi_pathname;       /* full pathname */
  loff_t fi_offset;         /* offset within file */
  string fi_fs;             /* file system */
  string fi_mount;          /* not supported */
  int fi_oflags;            /* open() flags for file descriptor */
} fileinfo_t;
```

The `fi_name` field contains the name of the file but does not include any directory components. If no file information is associated with an I/O, the `fi_name` field is set to the string `<none>`. In some rare cases, the pathname that is associated with a file might be unknown. In this case, the `fi_name` field is set to the string `<unknown>`.

The `fi_dirname` field contains only the directory component of the file name. As with `fi_name`, this string can be set to `<none>`, if no file information is present, or `<unknown>` if the pathname that is associated with the file is not known.

The `fi_pathname` field contains the full pathname to the file. As with `fi_name`, this string can be set to `<none>`, if no file information is present, or `<unknown>` if the pathname that is associated with the file is not known.

The `fi_offset` field contains the offset within the file , or `-1`, if either file information is not present or if the offset is otherwise unspecified by the file system.

The `fi_fs` field contains the name of the file system type, or `<none>`, if no information is present.

The `fi_oflags` field contains the flags that were specified when opening the file.

io Examples

'The following example script displays information for every I/O as it is issued. Type the following source code and save it in a file named `iosnoop.d`.

```
#pragma D option quiet

BEGIN
{
  printf("%10s %2s\n", "DEVICE", "RW");
}

io:::start
{
  printf("%10s %2s\n", args[1]->dev_statname,
  args[0]->b_flags & B_READ ? "R" : "W");
}
```

The output from this script is similar to the following:

```
# dtrace -s ./iosnoop.d
    DEVICE RW
     dm-00  R
     dm-00  R
     dm-00  R
     dm-00  R
     dm-00  R
     dm-00  R
...
```

You can make the example script slightly more sophisticated by using an associative array to track the time (in milliseconds) spent on each I/O, as shown in the following example:

```
#pragma D option quiet

BEGIN
{
  printf("%10s %2s %7s\n", "DEVICE", "RW", "MS");
}

io:::start
{
  start[args[0]->b_edev, args[0]->b_blkno] = timestamp;
}

io:::done
/start[args[0]->b_edev, args[0]->b_blkno]/
{
  this->elapsed = timestamp - start[args[0]->b_edev, args[0]->b_blkno];
  printf("%10s %2s %3d.%03d\n", args[1]->dev_statname,
  args[0]->b_flags & B_READ ? "R" : "W",
  this->elapsed / 10000000, (this->elapsed / 1000) % 1000);
  start[args[0]->b_edev, args[0]->b_blkno] = 0;
}
```

The modified script adds a MS (milliseconds) column to the output.

You can aggregate on device, application, process ID and bytes transferred, then save it in a file named `whoio.d`, as shown in the following example:

```
#pragma D option quiet

io:::start
{
  @[args[1]->dev_statname, execname, pid] = sum(args[0]->b_bcount);
}

END
{
  printf("%10s %20s %10s %15s\n", "DEVICE", "APP", "PID", "BYTES");
  printa("%10s %20s %10d %15@d\n", @);
}
```

Running this script for a few seconds results in output that is similar to the following:

```
# dtrace -s whoio.d
                    ^C
    DEVICE                  APP        PID          BYTES
     dm-00               evince      14759          16384
     dm-00          flush-252:0       1367          45056
     dm-00                 bash      14758         131072
     dm-00       gvfsd-metadata       2787         135168
```

```
    dm-00              evince      14758          139264
    dm-00              evince      14338          151552
    dm-00         jbd2/dm-0-8        390          356352
```

If you are copying data from one device to another, you might want to know if one of the devices acts as a limiter on the copy. To answer this question, you need to know the effective throughput of each device, rather than the number of bytes per second that each device is transferring. For exampe, you can determine throughput by using the following script and saving it in a file named `copy.d`:

```
#pragma D option quiet

io:::start
{
  start[args[0]->b_edev, args[0]->b_blkno] = timestamp;
}

io:::done
/start[args[0]->b_edev, args[0]->b_blkno]/
{
  /*
   * We want to get an idea of our throughput to this device in KB/sec.
   * What we have, however, is nanoseconds and bytes. That is we want
   * to calculate:
   *
   * bytes / 1024
   * ------------------------
   * nanoseconds / 1000000000
   *
   * But we cannot calculate this using integer arithmetic without losing
   * precision (the denominator, for one, is between 0 and 1 for nearly
   * all I/Os). So we restate the fraction, and cancel:
   *
   * bytes       1000000000      bytes       976562
   * --------- * ------------- = --------- * -------------
   * 1024        nanoseconds     1           nanoseconds
   *
   * This is easy to calculate using integer arithmetic.
   */
  this->elapsed = timestamp - start[args[0]->b_edev, args[0]->b_blkno];
  @[args[1]->dev_statname, args[1]->dev_pathname] =
    quantize((args[0]->b_bcount * 976562) / this->elapsed);
  start[args[0]->b_edev, args[0]->b_blkno] = 0;
}

END
{
  printa(" %s (%s)\n%@d\n", @);
}
```

Running the previous script for several seconds while copying data from a hard disk to a USB drive yields the following output:

```
# dtrace -s copy.d
^C
sdc1 (/dev/sdc1)

           value  ------------- Distribution ------------- count
              32 |                                         0
              64 |                                         3
             128 |                                         1
             256 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  2257
```

```
           512 |                                         1
          1024 |                                         0

dm-00 (/dev/dm-00)

           value  ------------- Distribution ------------- count
             128 |                                         0
             256 |                                         1
             512 |                                         0
            1024 |                                         2
            2048 |                                         0
            4096 |                                         2
            8192 |@@@@@@@@@@@@@@@@@@@                      172
           16384 |@@@@@                                    52
           32768 |@@@@@@@@@@@                              108
           65536 |@@@                                      34
          131072 |                                         0
```

The previous output shows that the USB drive (`sdc1`) is clearly the limiting device. The throughput of `sdc1` is between 256K/sec and 512K/sec, while `dm-00` delivered I/O at anywhere from 8 MB/second to over 64 MB/second.

io Stability

The `io` provider uses DTrace's stability mechanism to describe its stabilities. These values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	ISA
Module	Private	Private	Unknown
Function	Private	Private	Unknown
Name	Evolving	Evolving	ISA
Arguments	Evolving	Evolving	ISA

For more information about the stability mechanism, see DTrace Stability Features

fasttrap Provider

The `fasttrap` provider performs dynamic instrumentation of arbitrary instructions in user-space threads. Unlike most other DTrace providers, the `fasttrap` provider is not designed for tracing system activity. Rather, this provider is intended as a way for DTrace consumers to inject information into the DTrace framework by activating the `fasttrap` probe.

For more information about enabling statically defined probes in user-space programs, see Statically Defined Tracing of User Applications.

fasttrap Probes

The `fasttrap` provider makes available a single probe that fires whenever a user-level process makes a certain DTrace call into the kernel. The DTrace call to activate the probe is not available

fasttrap Stability

The `fasttrap` provider uses DTrace's stability mechanism to describe its stabilities. These values are listed in the following table.

Element	Name Stability	Data Stability	Dependency Class
Provider	Evolving	Evolving	ISA
Module	Private	Private	Unknown
Function	Private	Private	Unknown
Name	Evolving	Evolving	ISA
Arguments	Private	Private	Unknown

For more information about the stability mechanism, see DTrace Stability Features.

12

User Process Tracing

> **WARNING:**
>
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>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

DTrace is a powerful tool for understanding the behavior of user processes. DTrace can be invaluable when debugging and analyzing performance problems, or for simply understanding the behavior of a complex application. This chapter focuses on the DTrace facilities that are relevant to tracing user process activity and provides examples that illustrate their use.

copyin and copyinstr Subroutines

DTrace's interaction with processes is slightly different than most traditional debuggers and observability tools. Many such tools appear to execute within the scope of the process, allowing users dereference pointers to program variables directly. Rather than appearing to execute within or as part of the process itself, DTrace probes execute in the Oracle Linux kernel. To access process data, a probe uses the `copyin` or `copyinstr` subroutines to copy user process data into the address space of the kernel.

For example, consider the following `write()` system call:

```
ssize_t write(int fd, const void *buf, size_t nbytes);
```

The following D program illustrates an incorrect attempt to print the contents of a string that is passed to the `write()` system call:

```
syscall::write:entry
{
  printf("%s", stringof(arg1)); /* incorrect use of arg1 */
}
```

If you attempt to run this script, DTrace produces error messages similar to the following:

```
dtrace: error on enabled probe ID 1 (ID 37: syscall::write:entry): \
invalid address (0x10038a000) in action #1
```

The `arg1` variable, which contains the value of the *buf* parameter, is an address that refers to memory in the process executing the system call. To read the string at that address, use the `copyinstr` subroutine and record its result with the `printf` action, for example:

```
syscall::write:entry
{
```

```
  printf("%s", copyinstr(arg1)); /* correct use of arg1 */
}
```

In the previous script, the output shows all of the strings that are being passed to the `write()` system call. Occasionally, however, you might see irregular output similar to the following:

```
 0         37                      write:entry mada&^%**&
```

The `copyinstr` subroutine acts on an input argument, which is the user address of a null-terminated ASCII string, but buffers that are passed to the `write()` system call might refer to binary data rather than ASCII strings or to ASCII strings that do not include a terminating null byte. To print only as much of the string as the caller intended, use the two parameter version of the `copyinstr` subroutine, which includes the size of the targeted string buffer:

```
syscall::write:entry { printf("%s", copyinstr(arg1, arg2)); }
```

Alternatively, you can use the `copyin` subroutine, which takes an address and size, for example:

```
syscall::write:entry
{
  printf("%s", stringof(copyin(arg1, arg2)));
}
```

Note that the `stringof` operator is necessary so that DTrace properly converts the user data that is retrieved by `copyin` to a string. The use of `stringof` is not necessary with the `copyinstr` subroutine because it always returns the type `string`.

Avoiding Errors

The `copyin` and `copyinstr` subroutines cannot read from user addresses that have not yet been touched, so even a valid address could cause an error if the page containing that address has not yet been faulted in by being accessed. Consider the following example:

```
# dtrace -n syscall::open:entry'{ trace(copyinstr(arg0)); }'
dtrace: description 'syscall::open:entry' matched 1 probe
CPU     ID                    FUNCTION:NAME
  1      8                       open:entry   /dev/sr0
  1      8                       open:entry   /var/run/utmp
  1      8                       open:entry   /dev/sr0
dtrace: error on enabled probe ID 2 (ID 8: syscall::open:entry): \
invalid address (0x9af1b) in action #1 at DIF offset 52
```

In the example output, the application was functioning properly, and the address in `arg0` was valid, but it referred to a page that had not yet been accessed by the corresponding process. To resolve this issue, you would need to wait for the kernel or an application to use the data before tracing it.

For example, you might wait until the system call returns to apply `copyinstr`, as shown here:

```
# dtrace -n syscall::open:entry'{ self->file = arg0; }' \
  -n syscall::open:return'{ trace(copyinstr(self->file)); self->file = 0; }'
dtrace: description 'syscall::open:entry' matched 1 probe
dtrace: description 'syscall::open:return' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0      9                      open:return   /dev/sr0
  1      9                      open:return   /usr/lib64/gconv/gconv-modules.cache
  0      9                      open:return   /dev/sr0
  0      9                      open:return   public/pickup
  1      9                      open:return   maildrop
```

```
  1      9                     open:return   /dev/sr0
  1      9                     open:return   /dev/sr0
  1      9                     open:return   /var/run/utmp
...
```

Eliminating dtrace Interference

If you trace every call to the `write()` system call, it causes a cascade of output because each call causes the `dtrace` command to call `write()` as it displays the output, and so on. This feedback loop is a good example of how the `dtrace` command can interfere with the desired data. To prevent this type of unwanted data from being traced, use a simple predicate like the one that is shown in the following example and save it in a file named `stringof.d`:

```
syscall::write:entry
/pid != $pid/
{
  printf("%s", stringof(copyin(arg1, arg2)));
}
```

In the previous example, the `$pid` macro variable expands to the process identifier of the process that enabled the probes. The `pid` variable contains the process identifier of the process whose thread was running on the CPU where the probe was fired. Therefore, the predicate `/pid != $pid/` ensures that the script does not trace any events related to itself.

Using the syscall Provider

The `syscall` provider enables you to trace every system call entry and return. System calls can be a good starting point for understanding the behavior of a process, especially if the process seems to be spending a large amount of time executing or blocked in the kernel, as shown in the output of commands such as `ps` and `top`.

For example, consider a process with a process ID of 31337 that is consuming a large amount of system time. One possible explanation for this behavior is that the process is executing a large number of system calls. You can specify a simple D program on the command line to see which system calls are happening most often:

```
# dtrace -n syscall:::entry'/pid == 31337/{ @syscalls[probefunc] = count(); }'
dtrace: description 'syscall:::entry' matched 215 probes
^C

  kill                                                            1
  clone                                                           4
  pipe                                                            4
  setpgid                                                         4
  rt_sigreturn                                                    6
  sendmsg                                                         7
  socket                                                          7
  access                                                          8
  getegid                                                         8
  geteuid                                                         8
  getgid                                                          8
  getuid                                                          8
  wait4                                                          12
  close                                                          15
  read                                                           23
  newstat                                                        25
  write                                                          42
  ioctl                                                          65
```

```
  rt_sigaction                                                168
  rt_sigprocmask                                              198
  write                                                      1092
```

The previous report shows the system calls that are being called most often, which in this case, is the `write()` system call.

You can use the `syscall` provider to further examine the source of all of the `write()` system calls, for example:

```
# dtrace -n syscall::write:entry'/pid == 31337/{ @writes = quantize(arg2); }'
dtrace: description 'syscall::write:entry' matched 1 probe
^C

           value  ------------- Distribution ------------- count
               0 |                                         0
               1 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@   1037
               2 |@                                        3
               4 |                                         0
               8 |                                         0
              16 |                                         0
              32 |@                                        3
              64 |                                         0
             128 |                                         0
             256 |                                         0
             512 |                                         0
            1024 |@                                        5
```

The previous output shows that the process is executing many `write()` system calls with a relatively small amount of data. The ratio could be the source of the performance problem for this particular process. This example illustrates a general methodology for investigating system call behavior.

ustack Action

> **Note:**
>
> If you want to perform symbol lookup in a stripped executable, you must specify the `--export-dynamic` option when linking the program. This option causes the linker to add all symbols to the dynamic symbol table (the set of symbols that are visible from dynamic objects at run time). If you use `gcc` to link the objects, specify the option as `-Wl,--export-dynamic` to pass the correct option to the linker.
>
> If you want to look up symbols in shared libraries or unstripped executables, the `--export-dynamic` option is not required.

Tracing a process thread's stack when a particular probe is activated is often useful for examining a problem in more detail. The `ustack` action traces the user thread's stack. For example, if a process that opens many files occasionally fails in the `open()` system call, you can use the `ustack` action to discover the code path that executes the failed open. Type the following source code and save it in a file named `badopen.d`:

```
syscall::open:entry
/pid == $1/
{
```

```
  self->path = copyinstr(arg0);
}

syscall::open:return
/self->path != NULL && errno != 0/
{
  printf("open for '%s' failed", self->path);
  ustack();
}
```

This script also illustrates the use of the `$1` macro variable, which takes the value of the first operand that is specified on the `dtrace` command line:

```
# dtrace -s ./badopen.d 3430
dtrace: script './badopen.d' matched 2 probes
CPU     ID                    FUNCTION:NAME
  1    489                    openat:return open for '/usr/lib/foo' failed
              libc.so.6`sleep+0xe0
              ld-linux-x86-64.so.2`do_lookup_x+0x847
              libc.so.6`0x3cb8003630
              libc.so.6`0x3cb8003c48
              libc.so.6`0x3cb800e2c8
              libc.so.6`0x3cb8003c48
              looper`0x400612
              libc.so.6`getenv+0x2a
              looper`0x4003c8
              looper`0x4009b0
              libc.so.6`0x3cb800e2c8
              looper`0x4009b0
              looper`doOpenLoop+0x33
              looper`0x400e9c
              looper`main+0x5f
              looper`0x400ea9
              libc.so.6`__libc_start_main+0xfd
              looper`main
              looper`0x4009b0
              looper`__libc_csu_init
```

The `ustack` action records program counter (PC) values for the stack and the `dtrace` command resolves the PC values to symbol names by looking though the process's symbol tables. If `dtrace` cannot resolve the PC value to a symbol, it prints out the value as a hexadecimal integer.

If a process exits or is killed before the `ustack` data is formatted for output, `dtrace` might be unable to convert the PC values in the stack trace to symbol names and the command displays them as hexadecimal integers.

uregs[] Array

The `uregs[]` array enables you to access individual user registers. See Table 12-1, which lists the index constants into the `uregs[]` array for each supported architecture.

The following table lists the index constants into the `uregs[]` array for each supported architecture.

Table 12-1 x86 uregs[] Constants

Constant	Register	Architecture
R_PC	program counter register	x86, AMD64
R_SP	stack pointer register	x86, AMD64
R_R0	first return code	x86, AMD64
R_R1	second return code	x86, AMD64
R_CS	%cs	x86, AMD64
R_GS	%gs	x86, AMD64
R_ES	%es	x86, AMD64
R_DS	%ds	x86, AMD64
R_EDI	%ed	x86, AMD64
R_ESI	%es	x86, AMD64
R_EBP	%ebp	x86, AMD64
R_EAX	%eax	x86, AMD64
R_ESP	%esp	x86, AMD64
R_EAX	%eax	x86, AMD64
R_EBX	%ebx	x86, AMD64
R_ECX	%ecx	x86, AMD64
R_EDX	%edx	x86, AMD64
R_TRAPNO	%trapno	x86, AMD64
R_ERR	%err	x86, AMD64
R_EIP	%eip	x86, AMD64
R_CS	%cs	x86, AMD64
R_EFL	%efl	x86, AMD64
R_UESP	%uesp	x86, AMD64
R_SS	%ss	x86, AMD64
R_RSP	%rsp	AMD64
R_RFL	%rfl	AMD64
R_RIP	%rip	AMD64
R_RAX	%rax	AMD64
R_RCX	%rcx	AMD64
R_RDX	%rdx	AMD64
R_RBP	%rbp	AMD64
R_RSI	%rsi	AMD64
R_RDI	%rdi	AMD64
R_R8	%r8	AMD64
R_R9	%r9	AMD64

Table 12-1 (Cont.) x86 uregs[] Constants

Constant	Register	Architecture
R_R10	%r10	AMD64
R_R11	%r11	AMD64
R_R12	%r12	AMD64
R_R13	%r13	AMD64
R_R14	%r14	AMD64
R_R15	%r15	AMD64

Using the pid Provider

The `pid` provider enables you to trace any instruction in a process. Unlike most other providers, `pid` probes are created on demand, based on the probe descriptions that are found in your D programs. As a result, no `pid` probes are listed in the output of the `dtrace -l` command until you enable them.

User Function Boundary Tracing

The simplest mode of operation for the `pid` provider is to provide function boundary tracing in user space. The following example program traces all of the function entries and returns that are made from a single function. The `$1` macro variable, the first operand on the command line, is the process ID for the process to trace. The `$2` macro variable, the second operand on the command line, is the name of the function from which to trace all function calls. Type the following source code and save it in a file named `userfunc.d`:

```
#!/usr/sbin/dtrace -s
#pragma D option flowindent

pid$1::$2:entry
{
  self->trace = 1;
}

pid$1:::entry,
pid$1:::return
/self->trace/
{
}

pid$1::$2:return
/self->trace/
{
  self->trace = 0;
}
```

Type the previous example script and save it in a file named `userfunc.d`, then use the `chmod` command to make the file executable. This script produces output with more details on the principal buffer:

```
# ./userfunc.d 123 execute
dtrace: script ’./userfunc.d’ matched 11594 probes
```

```
  0  -> execute
  0    -> execute
  0      -> Dfix
  0      <- Dfix
  0      -> s_strsave
  0        -> malloc
  0        <- malloc
  0      <- s_strsave
  0      -> set
  0        -> malloc
  0        <- malloc
  0      <- set
  0      -> set1
  0        -> tglob
  0        <- tglob
  0      <- set1
  0      -> setq
  0        -> s_strcmp
  0        <- s_strcmp
...
```

The `pid` provider can only be used on processes that are already running. You can use the `$target` macro variable (see Scripting) and the `dtrace` command with the `-c` and `-p` options to create and grab processes of interest and instrument them by using DTrace.

For example, you can use the following D script to determine the distribution of function calls that are made to `libc` by a particular subject process. Type the following source code and save it in a file named `libc.d`:

```
pid$target:libc.so::entry
{
  @[probefunc] = count();
}
```

To determine the distribution of such calls that are made by the `date` command, save the script in a file named `libc.d` and run the following command:

```
# dtrace -s libc.d -c date
dtrace: script 'libc.d' matched 2476 probes
Fri Jul 30 14:08:54 PDT 2004
dtrace: pid 109196 has exited

  pthread_rwlock_unlock                             1
  _fflush_u                                         1
  rwlock_lock                                       1
  rw_write_held                                     1
  strftime                                          1
  _close                                            1
  _read                                             1
  __open                                            1
  _open                                             1
  strstr                                            1
  load_zoneinfo                                     1
...
  _ti_bind_guard                                   47
  _ti_bind_clear                                   94
```

Tracing Arbitrary Instructions

You can use the `pid` provider to trace any instruction in any user function. Upon demand, the `pid` provider creates a probe for every instruction in a function. The name of each probe is the

offset of its corresponding instruction in the function and is expressed as a hexadecimal integer. For example, to enable a probe that is associated with the instruction at offset `0x1c` in the function `foo` of the module `bar.so` in the process with PID 123, you would use the following command:

```
# dtrace -n pid123:bar.so:foo:1c
```

To enable all of the probes in the function `foo`, including the probe for each instruction, you would use the following command:

```
# dtrace -n pid123:bar.so:foo:
```

Using the previous command demonstrates an extremely powerful technique for debugging and analyzing user applications. Infrequent errors can be difficult to debug because they can be difficult to reproduce. Often, you can identify a problem after the failure has occurred, which is too late to reconstruct the code path.

The following example demonstrates how to combine the `pid` provider with speculative tracing to solve this problem by tracing every instruction in a function. See Speculative Tracing for a description.

Type the following source code and save it in a file named `errorpath.d`:

```
pid$1::$2:entry
{
  self->spec = speculation();
  speculate(self->spec);
  printf("%x %x %x %x %x", arg0, arg1, arg2, arg3, arg4);
}

pid$1::$2:
/self->spec/
{
  speculate(self->spec);
}

pid$1::$2:return
/self->spec && arg1 == 0/
{
  discard(self->spec);
  self->spec = 0;
}

pid$1::$2:return
/self->spec && arg1 != 0/
{
  commit(self->spec);
  self->spec = 0;
}
```

Executing the `errorpath.d` script results in output similar to the following:

```
# ./errorpath.d 123 _chdir
dtrace: script './errorpath.d' matched 19 probes
CPU     ID                    FUNCTION:NAME
  0 25253                      _chdir:entry 81e08 6d140 ffbfcb20 656c73 0
  0 25253                      _chdir:entry
  0 25269                      _chdir:0
  0 25270                      _chdir:4
  0 25271                      _chdir:8
  0 25272                      _chdir:c
  0 25273                      _chdir:10
```

```
0 25274                  _chdir:14
0 25275                  _chdir:18
0 25276                  _chdir:1c
0 25277                  _chdir:20
0 25278                  _chdir:24
0 25279                  _chdir:28
0 25280                  _chdir:2c
0 25268                  _chdir:return
```

13

Statically Defined Tracing of User Applications

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>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

DTrace provides a facility for user application developers to define customized probes in application code to augment the capabilities of the `pid` provider. These static probes impose little to no overhead when disabled and are dynamically enabled like all other DTrace probes. You can use static probes to describe application semantics to users of DTrace without exposing or requiring implementation knowledge of your applications. This chapter describes how to define static probes in user applications and how to use DTrace to enable such probes in user processes.

> **Note:**
>
> DTrace supports statically defined tracing of user applications for both 32-bit and 64-bit binaries.

For information about using static probes with kernel modules, see Statically Defined Tracing of Kernel Modules.

Choosing the Probe Points

DTrace enables developers to embed static probe points in application code, including both complete applications and shared libraries. You can enable these probes wherever the application or library is running, either in development or production. You should define probes that have a semantic meaning that is readily understood by your DTrace user community. For example, you could define `query-receive` and `query-respond` probes for a web server that correspond to a client that is submitting a request and the web server that is responding to the request. These example probes are easily understood by most DTrace users and correspond to the highest level abstractions for the application, rather than lower-level implementation details. DTrace users can use these probes to understand the time distribution of requests. If your `query-receive` probe presented the URL request strings as an argument, a DTrace user could determine which requests were generating the most disk I/O by combining this probe with the `io` provider.

You should also consider the stability of the abstractions you describe when choosing probe names and locations. For example, will the probe persist in future releases of the application even if the implementation changes? Does the probe make sense on all system architectures or is it specific to a particular instruction set? This chapter discusses how these decisions can guide your static tracing definitions.

Adding Probes to an Application

DTrace probes for libraries and executables are defined in an ELF section in the corresponding application binary. The following topics are discussed in more detail in this section: defining probes, adding probes to your application source code, and augmenting your application's build process to include the DTrace probe definitions.

Defining Providers and Probes

You define DTrace probes in a `.d` source file, which is then used when compiling and linking your application. First, select an appropriate name for your user application provider. The provider name that you choose is appended with the process identifier for each process that is executing your application code. For example, if you chose the provider name `myserv` for a web server that was executing as process ID 1203, the DTrace provider name that corresponds to this process would be `myserv1203`. In a `.d` source file, you would add a provider definition similar to the one that is shown the following example:

```
provider myserv
{
  ...
};
```

Next, add a definition for each probe and the corresponding arguments. The following example defines the two probes that are discussed in Choosing the Probe Points. The first probe has two arguments, both of type `char *`. The second probe has no arguments. The D compiler converts two consecutive underscores (__) to a dash (-) in the probe name:

```
provider myserv
{
  probe query__receive(char *, char *);
  probe query__respond();
};
```

You can add stability attributes to your provider definition so that consumers of your probes understand the likelihood of change in future versions of your application. See DTrace Stability Features for more information on DTrace stability attributes.

The following example illustrates how stability attributes are defined:

```
#pragma D attributes Evolving/Evolving/Common provider myserv provider
#pragma D attributes Private/Private/Unknown provider myserv module
#pragma D attributes Private/Private/Unknown provider myserv function
#pragma D attributes Evolving/Evolving/Common provider myserv name
#pragma D attributes Evolving/Evolving/Common provider myserv args

provider myserv
{
  probe query__receive(char *, char *);
  probe query__respond();
};
```

Adding Probes to Application Code

After you have defined your probes in a `.d` file, you then need to augment your source code to indicate the locations that should trigger your probes. Consider the following example C application source code:

```
void main_look(void)
{
  ...
  query = wait_for_new_query();
  process_query(query);
  ...
}
```

To add probes to an application, use the `-h` option to the `dtrace` command, which generates a header file based on the probe definitions. For example, the following command generates the header file `myserv.h`, which contains macro definitions corresponding to the probe definitions in `myserv.d`:

```
# dtrace -h -s myserv.d
```

This method is recommended, as the coding is easier to implement and understand. The method is also compatible with both C and C++. In addition, because the generated macros depend on the types that you define in the provider definition, the compiler can perform type checking on them.

For example, you can add a probe site by using the `MYSERV_QUERY_RECEIVE` macro that `dtrace -h` defines in `myserv.h`:

```
#include "myserv.h"
...
void main_look(void)
{
  ...
  query = wait_for_new_query();
  MYSERV_QUERY_RECEIVE(query->clientname, query->msg);
  process_query(query);
  ...
}
```

In the previous example, the name of the macro encodes both the provider name and the probe name.

Testing if a Probe Is Enabled

The computational overhead of a DTrace probe is usually equivalent to a few no-op instructions. However, setting up probe arguments can be expensive, particularly in the case of dynamic languages, where the code has to determine the name of a class or the method at runtime.

In addition to the probe macro, the `dtrace -h` command creates an *is-enabled probe* macro for each probe that you specify in the provider definition. To ensure that your program computes the arguments to a DTrace probe only when required, you can use the is-enabled probe test to verify whether the probe is currently enabled, for example:

```
if (MYSERV_QUERY_RECEIVE_ENABLED())
  MYSERV_QUERY_RECEIVE(query->clientname, query->msg);
```

If the probe arguments are computationally expensive to calculate, the slight overhead that is incurred by performing the is-enabled probe test is more than offset when the probe is not enabled.

Building Applications With Probes

You must augment the build process for your application to include the DTrace provider and probe definitions. A typical build process takes each source file and compiles it to create a corresponding object file. The compiled object files are then linked to each other to create the finished application binary, as shown in the following example:

```
src1.o: src1.c
    gcc -c src1.c

src2.o: src2.c
    gcc -c src2.c

myserv: src1.o src2.o
    gcc -o myserv src1.o src2.o
```

If you included DTrace probe definitions in your application, you need to add appropriate `Makefile` rules to your build process to execute the `dtrace` command.

The `dtrace` command post-processes the object files that are created by the preceding compiler commands and generates the object file `myserv.o` from `myserv.d` and the other object files. The `-G` option is used to link provider and probe definitions with a user application.

The `-Wl,--export-dynamic` link options to `gcc` are required to support symbol lookup in a stripped executable at runtime, for example, by running `ustack()`.

If you inserted probes in the source code by using the macros that were defined in a header file created by `dtrace -h`, you need to include that command in the Makefile:

```
myserv.h: myserv.d
    dtrace -h -s myserv.d

src1.o: src1.c myserv.h
    gcc -c src1.c

src2.o: src2.c myserv.h
    gcc -c src2.c

myserv.o: myserv.d src1.o src2.o
    dtrace -G -s myserv.d src1.o src2.o

myserv: myserv.o
    gcc -Wl,--export-dynamic,--strip-all -o myserv myserv.o src1.o src2.o
```

The rules in the `Makefile` take into account the dependency of the header file on the probe definition.

Using Statically Defined Probes

The DTrace helper device (`/dev/dtrace/helper`) enables a user-space application that contains USDT probes to send probe provider information to DTrace.

If the program that is to be traced is run by a user other than `root`, change the mode of the DTrace helper device to allow the user to record tracing information:

```
# chmod 666 /dev/dtrace/helper
```

Alternatively, if the `acl` package is installed on your system, you can use an ACL rule to limit access to a specific user, as shown in the following example:

```
# setfacl -m u:guest:rw /dev/dtrace/helper
# ls -l /dev/dtrace
total 0
crw-rw----  1 root root 10, 16 Sep 26 10:38 dtrace
crw-rw----+ 1 root root 10, 17 Sep 26 10:38 helper
drwxr-xr-x  2 root root     80 Sep 26 10:38 provider
# getfacl /dev/dtrace/helper
getfacl: Removing leading '/' from absolute path names
# file: dev/dtrace/helper
# owner: root
# group: root
user::rw-
user:guest:rw-
group::rw-
mask::rw-
other::---
```

> **Note:**
>
> You must change the mode on the device before the user runs the program.

The full name of a probe in a user application takes the usual *provider PID* : *module* : *function* : *name* form, where:

provider
Is the name of the provider, as defined in the provider definition file.

PID
Is the process ID of the running executable.

module
Is the name of the executable.

function
Is the name of the function where the probe is located.

name
Is the name of the probe, as defined in the provider definition file with any two consecutive underscores (__) replaced by a dash (-).

For example, for a `myserv` process with a PID of 1173, the full name of the `query-receive` probe would be `myserv1173:myserv:main_look:query-receive`.

The following simple example shows how to invoke a traced process from `dtrace`:

```
# dtrace -c ./myserv -qs /dev/stdin <<EOF
                    $target:::query-receive
    {
      printf("%s:%s:%s:%s %s %s\n", probeprov, probemod, probefunc, probename,
                                    stringof(args[0]), stringof(args[1]));
    }
```

```
  $target:::query-respond
    {
      printf("%s:%s:%s:%s\n", probeprov, probemod, probefunc, probename);
    }
EOF

myserv1173:myserv:main_look:query-receive foo1 msg1
myserv1173:myserv:process_query:query-respond
myserv1173:myserv:main_look:query-receive bar2 msg1
myserv1173:myserv:process_query:query-respond
...
```

> **Note:**
>
> For the `query-receive` probe, `stringof()` is used to cast `args[0]` and `args[1]` to type `string`. Otherwise, a DTrace compilation error similar to the following is displayed:
>
> ```
> dtrace: failed to compile script /dev/stdin: line 7:
> printf( ) argument #5 is incompatible with conversion #4 prototype:
>     conversion: %s
>      prototype: char [] or string (or use stringof)
>       argument: char *
> ```
>
> If the probe arguments were defined as type `string` instead of `char *` in the probe definition file, a compilation warning similar to the following would be displayed:
>
> ```
> In file included from src1.c:5:
> myserv.h:39: warning: parameter names (without types) in function declaration
> ```
>
> In this case, casting the probe arguments to the type `string` would no longer be required.

The following script illustrates the complete process of instrumenting, compiling and tracing a simple user-space program. Save it in a file named `testscript`:

```
#!/bin/bash

# Define the probes
cat > prov.d <<EOF
provider myprog
{
  probe dbquery__entry(char *);
  probe dbquery__result(int);
};
EOF

# Create the C program
cat > test.c <<EOF
#include <stdio.h>
#include "prov.h"

int
main(void)
{
        char *query = "select value from table where name = 'foo'";
        /* If the dbquery-entry probe is enabled, trigger it */
        if (MYPROG_DBQUERY_ENTRY_ENABLED())
```

```
                MYPROG_DBQUERY_ENTRY(query);
        /* Pretend to run query and obtain result */
        sleep(1);
        int result = 42;
        /* If the dbquery-result probe is enabled, trigger it */
        if (MYPROG_DBQUERY_RESULT_ENABLED())
                MYPROG_DBQUERY_RESULT(result);
        return (0);
}
EOF



test.o: test.c prov.h
  gcc -c test.c

prov.o: prov.d test.o
  dtrace -G -s prov.d test.o

test: prov.o
  gcc -o test prov.o test.o
EOF

# Make the executable
make test

# Trace the program
dtrace -c ./test -qs /dev/stdin <<EOF
myprog\$target:::dbquery-entry
{
        self->ts = timestamp;
        printf("Query = %s\n", stringof(args[0]));
}

myprog\$target:::dbquery-result
{
        printf("Query time = %d microseconds; Result = %d\n",
            (timestamp - self->ts) / 1000, args[0]);
}
EOF
```

The output from running this script shows the compilation steps, as well as the results of tracing the program:

```
# chmod +x testscript
# ./testscript
dtrace -h -s prov.d
gcc -c test.c
dtrace -G -s prov.d test.o
gcc -o test prov.o test.o
Query = select value from table where name = 'foo'
Query time = 1000481 microseconds; Result = 42
```

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Statically Defined Tracing of Kernel Modules

> **WARNING:**
>
> Oracle Linux 7 is now in Extended Support. See Oracle Linux Extended Support and Oracle Open Source Support Policies for more information.
>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

DTrace provides a facility for developers to define customized probes in kernel modules. These static probes appear as additional probes of the `sdt` provider and impose little to no overhead if the `sdt` module is not loaded. For example, for x86_64, the overhead is a single-byte NOP, followed by a 4-byte NOP. This chapter provides a full example of how to define and use static probes in a kernel module.

The general principles for naming probes and choosing insertion points are the same for kernel modules as they are for user-space applications. You should define probes that have a semantic meaning that is readily understood by your DTrace user community. Typically, you might name probes for the routine in which you place them and their position in that routine. For example, if your probes provide information about data values on entry to or return from a routine named `foo`, you might name them `foo-entry` and `foo-return`. The data values that are returned by such probes could present the routine as a *black box*, rather than return intermediate values from the internal implementation of the module. To gather data from deeper within a module, you might insert additional probes with names such as `foo-stage1` or `foo-post-hardware-init`.

In one respect, using static probes with kernel modules can be simpler than for user-space applications. You do not need to modify the build files unless you want to conditionally compile a module to include the probes. Inserting the probes in the source code is slightly more complex, as you cannot use the `dtrace -h` command to generate the probe macros. However, using a `DTRACE_PROBE` macro to insert a probe is a relatively simple change to make to the source code.

You can insert `sdt` static probes in any Oracle Linux kernel module for which you have the source files and the necessary build infrastructure, but note that DTrace supports statically defined tracing of 64-bit kernel modules only.

For more information about the `sdt` provider, see sdt provider.

For an introduction to the concepts of statically defined tracing as applied to user-space applications, see Statically Defined Tracing of User Applications.

Inserting Static Probe Points

You can embed static probes within the source code for which you want to capture the current state of a module and its data.

The following example pseudo character device driver consists of three source files:

revdev.h
Is the header file for the module.

rev_mod.c
Defines the module's properties and its `init` and `exit` routines.

rev_dev.c
Defines the driver's `open`, `read`, `release`, `unlocked_ioctl`, and `write` routines. The static probes are inserted in the `read`, `unlocked_ioctl`, and `write` routines, although probes could also be inserted in the other routines, if required.

revdev.h Example

The module header file `revdev.h` must be prepared, as indicated in bold font in the following example, by adding lines to include `linux/sdt.h` and to define probe macros.

```
#include <asm/uaccess.h>
#include <linux/cdev.h>
#include <linux/fs.h>
#include <linux/kernel.h>
#include <linux/miscdevice.h>
#include <linux/module.h>
#include <linux/mutex.h>
#include <linux/types.h>
#include <linux/sdt.h>

#define DEVICE "revdev"

#define REVDEV_IOCTL_ENTRY_PROBE(name, file, cmd, arg) \
         DTRACE_PROBE3(ioctl__##name, struct file *, file, \
                       unsigned int, cmd, unsigned long, arg)
#define REVDEV_IOCTL_RETURN_PROBE(name, str) \
        DTRACE_PROBE1(ioctl__##name, struct char *, str)
#define REVDEV_READ_ENTRY_PROBE(name,fp,buf) \
        DTRACE_PROBE2(read__##name, file *, fp, char *, buf)
#define REVDEV_READ_RETURN_PROBE(name,buf,n) \
        DTRACE_PROBE2(read__##name, char *, buf, size_t, n)
#define REVDEV_WRITE_ENTRY_PROBE(name,fp,buf,n) \
        DTRACE_PROBE3(write__##name, file *, fp, char *, buf, size_t, n)
#define REVDEV_WRITE_RETURN_PROBE(name,buf,n) \
        DTRACE_PROBE2(write__##name, char *, buf, size_t, n)
```

The `DTRACE_PROBE` macros that are defined in `/lib/modules/`uname -r`/build/include/linux/sdt.h` support from zero to eight arguments.

You can define your own macros for the inserted probes, as shown in the preceding example. Unlike user-space static probes, you cannot use the `dtrace -h` command to create a header file that includes suitable probe definitions. You do not need to create a provider definition file for the probes.

The probes are named according to the first argument of the `DTRACE_PROBE` macro. The suffix *N* in the macro name `DTRACE_PROBEN` refers the number of arguments that are passed to the probe. The first argument to the probe macro is the probe name. As described in Declaring Probes, two consecutive underscores are converted to a single dash. The remaining macro arguments are pairs of arguments that define the DTrace `argn` variables that are assigned when the probe fires. Each pair of arguments defines the variable type and a variable name, for example:

```
#define REVDEV_WRITE_ENTRY_PROBE(name, fp, buf, n) \
        DTRACE_PROBE3(write__##name, file *, fp, char *, buf, size_t, n)
```

The values of `fp`, `buf`, and `n` are made available by the `arg0`, `arg1`, and `arg2` variables in DTrace when the probe fires.

The provider, module, and function elements of the complete probe are named for `sdt`, the driver module name (without the `.ko`), and the driver routine.

The probes inherit the stability attributes of the `sdt` provider.

rev_mod.c Example

No changes are made in the following example, which does not insert any probes in the module's `init` and `exit` routines. Note that there is no restriction on inserting probes in these routines.

```
#include "revdev.h"

MODULE_AUTHOR("DTrace Example");
MODULE_DESCRIPTION("Using DTrace SDT probes with a device driver");
MODULE_VERSION("v1.0");
MODULE_LICENSE("GPL");

extern const struct file_operations revdev_fops;

static struct miscdevice revdev = {
    .minor = 0,
    .name = DEVICE,
    .fops = &revdev_fops,
};

DEFINE_MUTEX(revdev_mutex);

static int revdev_entry(void){ /* Register device */
    int retval;
    retval = misc_register(&revdev);
    if (retval < 0) {
        printk(KERN_ERR "revdev: Could not register device");
        return retval;
    }
    mutex_init(&revdev_mutex);
    return 0;
}

static void revdev_exit(void){
    misc_deregister(&revdev);
}

/* Define module init and exit calls */
module_init(revdev_entry);
module_exit(revdev_exit);
```

rev_dev.c Example

No existing lines of code are modified in this example. Only line insertions are required for the `entry` and `return` probes in each of the `read`, `unlocked_ioctl`, and `write` routines.

The changes in this example appear in bold font.

```
#include "revdev.h"

static struct device_buffer {
    char data[80];
} devbuf;

static char *oddeven[] = { "Even", "Odd" };

extern struct mutex revdev_mutex;

static long revdev_ioctl(struct file *file, unsigned int cmd,
                         unsigned long arg) {
    char *cp;
    REVDEV_IOCTL_ENTRY_PROBE(entry, file, cmd, arg);
    cp = oddeven[arg%2];
    REVDEV_IOCTL_RETURN_PROBE(return, cp);
    return -EAGAIN;
}

static int revdev_open(struct inode *inode, struct file *fp){
    if (!mutex_trylock(&revdev_mutex)){
        printk(KERN_INFO "revdev: Device already in use");
        return -EBUSY;
    }
    return 0;
}

static void revstr(char *s) { /* After Kernighan and Ritchie */
    int i, j, t;
    for (i = 0, j = strlen(s)-1; i < j; i++, j--)
        t = s[i], s[i] = s[j], s[j] = t;
}

static ssize_t revdev_read(struct file *fp, char* buf, size_t n, loff_t *o){
    int retval;
    REVDEV_READ_ENTRY_PROBE(entry, fp, devbuf.data);
    revstr(devbuf.data);
    n = strlen(devbuf.data);
    retval = copy_to_user(buf, devbuf.data, n);
    REVDEV_READ_RETURN_PROBE(return, buf, n);
    if (retval != 0) return -EINVAL;
    return 0;
}

static ssize_t revdev_write(struct file *fp, const char* buf, size_t n, loff_t *o){
    int retval;
    REVDEV_WRITE_ENTRY_PROBE(entry, fp, buf, n);
    retval = copy_from_user(devbuf.data, buf, n);
    devbuf.data[n-retval] = '\0';
    REVDEV_WRITE_RETURN_PROBE(return, devbuf.data, n);
    if (retval != 0) return -EINVAL;
    return 0;
}
```

```
static int revdev_close(struct inode *inode, struct file *fp){
    mutex_unlock(&revdev_mutex);
    return 0;
}

const struct file_operations revdev_fops = {
    .owner = THIS_MODULE,
    .read = revdev_read,
    .write = revdev_write,
    .unlocked_ioctl = revdev_ioctl,
    .open = revdev_open,
    .release = revdev_close,
};
```

Building Modules With Static Probes

> **Note:**
>
> The following example requires that you link the module against a UEK version that supports the DTrace modules, which can be either UEK R5 or UEK R4 for Oracle Linux 7 or UEK R4 for Oracle Linux 6.
>
> A bug in the current implementation means that a module containing SDT probes must be built from two or more source files.

The following `Kbuild` and `Makefile` are used to build the example pseudo driver module `revdev.ko` and a test program named `testrevdev`.

Kbuild Example

```
bj-m            += revdev.o

revdev-y        := rev_dev.o rev_mod.o
```

Makefile Example

> **Note:**
>
> All of the command lines in the Makefile, such as those beginning with `gcc` in the following example, *must* start with tabs.

```
KERNEL_DIR = /lib/modules/`uname -r`/build

modules:: testrevdev

install:: modules_install

testrevdev: testrevdev.c
  gcc -o testrevdev testrevdev.c
```

```
%::
        $(MAKE) -C $(KERNEL_DIR) M=`pwd` $@
```

The source file for `testrevdev` is `testrevdev.c`.

testrevdev.c Example

```
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#define DEVICE_FILE "/dev/revdev"

int main() {
    char buf[81];
    int i, fd, n;

    if ((fd = open(DEVICE_FILE, O_RDWR)) != 0) {
        perror("open");
        exit(1);
    }

    i=0;
    while (1) {
        (i++)%20;
        printf("Write: ");
        scanf(" %80[^\n]", buf);
        n = strlen(buf);
    if (!strncmp(buf, "exit", 4))
            break;
    else if (!strncmp(buf, "ioctl", 5))
            ioctl(fd,128,i);
        else {
            write(fd, buf, n);
            read(fd, buf, n);
            buf[n]='\0';
            printf(" Read: %s\n", buf);
        }
    }

    close(fd);
    exit(0);
}
```

When run, `testrevdev` reads a string that you enter, writes the string to the `revdev` device, and then reads the reversed string from the device.

If the input string begins with `ioctl`, the program calls `ioctl` on the open file descriptor, which invokes the device's `unlocked_ioctl` routine. An input string that begins with `exit` terminates the program.

To build the module and test program, use the `make` command:

```
# make
make -C /lib/modules/`uname -r`/build M=`pwd` modules
make[1]: Entering directory `/usr/src/kernels/4.1.12-version.el6uek.x86_64'
  CC [M]  /root/revdev/rev_dev.o
  CC [M]  /root/revdev/rev_mod.o
  SDTSTB  /root/revdev/revdev.sdtstub.S
  AS [M]  /root/revdev/revdev.sdtstub.o
  LD [M]  /root/revdev/revdev.o
```

```
  Building modules, stage 2.
  MODPOST 1 modules
  SDTINF  /root/revdev/revdev.sdtinfo.c
  CC      /root/revdev/revdev.mod.o
  CTF
  LD [M]  /root/revdev/revdev.ko
make[1]: Leaving directory `/usr/src/kernels/4.1.12-version.el6uek.x86_64'
```

Using DTrace to Test Modules With Static Probes

You can use DTrace to display information when one of the embedded static probes in a module fires.

To test the example module `revdev.ko`:

1. Set up a `udev` rule to create the `/dev/revdev` device file:

   ```
   # echo "KERNEL==\"revdev\", MODE=\"0660\"" > /etc/udev/rules.d/10-
   revdev.rules
   ```

2. Load the `revdev.ko` module:

   ```
   # insmod revdev.ko
   ```

   You can use `dtrace` to test that the probes are now available:

   ```
   # dtrace -l -m revdev
      ID   PROVIDER            MODULE                          FUNCTION NAME
       4        sdt            revdev                     revdev_ioctl ioctl-return
       5        sdt            revdev                     revdev_ioctl ioctl-entry
       6        sdt            revdev                     revdev_write write-return
       7        sdt            revdev                     revdev_write write-entry
       8        sdt            revdev                      revdev_read read-return
       9        sdt            revdev                      revdev_read read-entry
   ```

3. Enter the following DTrace script (`traceflow`):

   ```
   #!/usr/sbin/dtrace -qs
   #pragma D option nspec=10

   self int indent;

   syscall:::entry
   /execname == "testrevdev"/
   {
     self->specflag = 0;
     self->spec = speculation();
     self->indent += 2;
     speculate(self->spec);
   }

   syscall:::entry
   /self->spec/
   {
     speculate(self->spec);
     printf("%*s ", self->indent, "->");
     printf("%s() entry\n",probefunc);
     self->indent += 2;
   }

   syscall:::return
   /self->spec/
   ```

```
{
  speculate(self->spec);
  self->indent -= 2;
  printf("%*s ", self->indent, "<-");
  printf("%s() return\n",probefunc);
}

syscall:::return
/self->spec && self->specflag == 0/
{
  discard(self->spec);
  self->indent -= 2;
  self->spec = 0;
}

syscall:::return
/self->spec && self->specflag == 1/
{
  commit(self->spec);
  self->indent -= 2;
  self->spec = 0;
}

sdt:revdev::ioctl-entry
/self->spec/
{
  speculate(self->spec);
  self->specflag = 1;
  printf("%*s ", self->indent, "=>");
  printf("%s() entry file: %s cmd: %d arg: %d\n",
         probefunc, d_path(&(((struct file *)arg0)->f_path)), arg1, arg2);
}

sdt:revdev::ioctl-return
/self->spec/
{
  speculate(self->spec);
  printf("%*s ", self->indent, "<=");
  printf("%s() return cpstr: %s\n", probefunc, stringof((char*)arg0));
}

sdt:revdev::read-entry
/self->spec/
{
  speculate(self->spec);
  self->specflag = 1;
  printf("%*s ", self->indent, "=>");
  printf("%s() entry file: %s devbuf: %s\n",
         probefunc, d_path(&(((struct file *)arg0)->f_path)),
         stringof((char *)arg1));
}

sdt:revdev::read-return
/self->spec/
{
  speculate(self->spec);
  printf("%*s ", self->indent, "<=");
  printf("%s() return string: %s len: %d\n",
         probefunc, stringof((char *)arg0), arg1);
}

sdt:revdev::write-entry
```

```
/self->spec/
{
  speculate(self->spec);
  self->specflag = 1;
  printf("%*s ", self->indent, "=>");
  printf("%s() entry file: %s string: %s len: %d\n",
         probefunc, d_path(&(((struct file *)arg0)->f_path)),
         stringof((char *)arg1), arg2);
}

sdt:revdev::write-return
/self->spec/
{
  speculate(self->spec);
  printf("%*s ", self->indent, "<=");
  printf("%s() return string: %s len: %d\n",
         probefunc, stringof((char *)arg0), arg1);
}
```

When one of the inserted probes fires, `traceflow` displays information about data values in the module by using the probe argument variables (`arg0`, `arg1`, `arg2`,...).

> **Note:**
>
> Argument variables that return pointer types, such as `file *` and `char *`, must be explicitly cast.

The script uses `d_path` and `stringof` to create printable file paths and strings. For example, `(struct file *)arg0` casts the value of `arg0` to a file pointer (`struct file *`). The `f_path` member of the `struct file` contains the path structure (`struct path`) for a file. As `d_path` takes a path pointer (`struct path *`) as its argument, the `&` operator is used to return a pointer to the `struct path`.

See d_path and String Conversion for more information.

4. Make `traceflow` executable:

```
# chmod +x traceflow
```

5. In one window, run `traceflow`:

```
# ./traceflow
```

6. In another window, run `testrevdev` and enter input, for example:

```
# ./testrevdev
Write: hello
 Read: olleh
Write: world
 Read: dlrow
Write: ioctl
Write: ioctl
Write: exit
```

In the window that `traceflow` is running, you should see output similar to the following , as DTrace responds to the probes in `revdev.ko` that are firing:

```
# ./traceflow
-> write() entry
```

```
  => revdev_write() entry file: /dev/revdev string: hello len: 5
  <= revdev_write() return string: hello len: 5
<- write() return
-> read() entry
  => revdev_read() entry file: /dev/revdev devbuf: hello
  <= revdev_read() return string: olleh len: 5
<- read() return
-> write() entry
  => revdev_write() entry file: /dev/revdev string: world len: 5
  <= revdev_write() return string: world len: 5
<- write() return
-> read() entry
  => revdev_read() entry file: /dev/revdev devbuf: world
  <= revdev_read() return string: dlrow len: 5
<- read() return
-> ioctl() entry
  => revdev_ioctl() entry file: /dev/revdev cmd: 128 arg: 3
  <= revdev_ioctl() return cpstr: Odd
<- ioctl() return
-> ioctl() entry
  => revdev_ioctl() entry file: /dev/revdev cmd: 128 arg: 4
  <= revdev_ioctl() return cpstr: Even
<- ioctl() return
```

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Performance Considerations

> **WARNING:**
>
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>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

DTrace creates additional work in the system. Therefore, enabling DTrace always affects system performance in some way. Often, this effect is negligible, but it can become substantial if many probes with significant enablings are enabled. This chapter describes some techniques for minimizing the performance effect of DTrace.

Limit Enabled Probes

Dynamic instrumentation techniques enable DTrace to provide unparalleled tracing coverage of the kernel and arbitrary user processes. While this coverage provides revolutionary new insight into system behavior, it also can cause enormous probe effect. If tens of thousands or hundreds of thousands of probes are enabled, the effect on the system can easily be substantial. Therefore, you should only enable as many probes as you need to solve a problem. For example, you should not enable all `syscall` probes if a more concise enabling can answer your question. Your question might require that you concentrate on a specific module of interest or a specific function.

> **Caution:**
>
> When using the `pid` provider, be especially careful. Because the `pid` provider can instrument every instruction, you could enable millions of probes in an application and therefore slow the target process to a crawl.

You can also use DTrace in situations where large numbers of probes must be enabled to answer a question. Enabling a large number of probes might slow down the system significantly, but it never induces fatal failure on the system. You should therefore not hesitate to enable many probes, if so required.

Using Aggregations

As discussed in Aggregations, DTrace aggregations provide a scalable way to aggregate data. Associative arrays might appear to offer functionality that is similar to aggregations, but

because general-purpose variables are global by nature, associative arrays cannot offer the linear scalability of aggregations. Therefore, the preference is to use aggregations over associative arrays whenever possible. For example, the following D program uses an associative array to aggregate data:

```
syscall:::entry
{
  totals[execname]++;
}

syscall::rexit:entry
{
  printf("%40s %d\n", execname, totals[execname]);
  totals[execname] = 0;
}
```

Whereas, the following D program is preferred, as it uses an aggregation to achieve the same result:

```
syscall:::entry
{
  @totals[execname] = count();
}

END
{
  printa("%40s %@d\n", @totals);
}
```

Using Cacheable Predicates

You use DTrace predicates to filter unwanted data from the experiment by tracing data only if a specified condition is found to be true. When enabling many probes, you generally use predicates of a form that identifies a specific thread, or threads of interest, such as `/self->traceme/` or `/pid == 12345/`. Although many of these predicates evaluate to a false value for most threads in most probes, the evaluation itself can become costly when done for many thousands of probes. To reduce this cost, DTrace caches the evaluation of a predicate if it includes only thread-local variables, such as `/self->traceme/`, or for immutable variables, such as `/pid == 12345/`. The cost of evaluating a cached predicate is much less than the cost of evaluating a non-cached predicate, especially if the predicate involves thread-local variables, string comparisons, or other relatively costly operations. While predicate caching is transparent to the user, it does require some guidelines for constructing optimal predicates. Some guidelines for constructing optimal predicates are outlined in the following table.

Cacheable	Uncacheable
`self->mumble`	`mumblecurthread`
	`mumblepid`
	`tid`
`execname`	`curpsinfo->pr_fname`
	`((struct task_struct *)curthread)->comm`
`pid`	`curpsinfo->pr_pid`
	`((struct task_struct *)curthread)->pid`

Cacheable	Uncacheable
`tid`	`curlwpsinfo->pr_lwpid` `((struct task_struct *)curthread)->pid`
`curthread`	`curthread->`*`any_member`* `curlwpsinfo->`*`any_member`* `curpsinfo->`*`any_member`*

The following example uses an associative array in the predicate and is not cacheable:

```
syscall::read:entry
{
  follow[pid, tid] = 1;
}

lockstat:::
/follow[pid, tid]/
{}

syscall::read:return
/follow[pid, tid]/
{
  follow[pid, tid] = 0;
}
```

Using a cacheable, thread-local variable, per the following example, is preferable:

```
syscall::read:entry
{
  self->follow = 1;
}

lockstat:::
/self->follow/
{}

syscall::read:return
/self->follow/
{
  self->follow = 0;
}
```

For a predicate to be cacheable, it must consist exclusively of cacheable expressions. All of the following predicates all cacheable:

```
/execname == "myprogram"/

/execname == $$1/

/pid == 12345/

/pid == $1/

/self->traceme == 1/
```

The following examples, which use global variables, are not cacheable:

```
/execname == one_to_watch/
```

```
/traceme[execname]/

/pid == pid_i_care_about/

/self->traceme == my_global/
```

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DTrace Stability Features

> **WARNING:**
>
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>
> Migrate applications and data to Oracle Linux 8 or Oracle Linux 9 as soon as possible.
>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

Developers are provided with early access to new technologies, as well as observability tools that enable them peer into the internal implementation details of user and kernel software. Unfortunately, new technologies and internal implementation details are prone to changes because interfaces and implementations evolve and mature when software is upgraded or patched.

Application and interface stability levels are documented using a set of labels to help set user expectations for the kinds of changes that might occur in different types of future releases. No individual stability attribute appropriately describes the arbitrary set of entities and services that can be accessed from a D program. Therefore, DTrace and the D compiler include features to dynamically compute and describe the stability levels of the D programs that you create.

This chapter discusses the DTrace features for determining program stability to help you design stable D programs. You can use these DTrace stability features to inform you of the stability attributes of your D programs or to produce compile-time errors when your program has undesirable interface dependencies.

Stability Levels

DTrace provides two types of stability attributes for entities like built-in variables, functions and probes: a *stability level* and an architectural *dependency class*. The DTrace stability level assists you in making risk assessments when developing scripts and tools that are based on DTrace by indicating how likely it is for an interface or DTrace entity to change in a future release or patch. The DTrace dependency class indicates whether an interface is common to all Oracle Linux platforms and processors or whether it is associated with a particular architecture. The two types of attributes that are used to describe interfaces can vary independently.

The stability values that are used by DTrace are described in the following table and are listed in order, from the lowest stability to the highest stability. Applications that depend only on Stable interfaces should reliably continue to function on future minor releases and will not be broken by interim patches. The less stable interfaces allow for experimentation, prototyping, tuning, and debugging on your current system. These less stable interfaces should be used with the understanding that they might change and become incompatible or even be dropped or replaced with alternatives in future minor releases.

DTrace stability values also help you understand the stability of the software entities that you are observing, in addition to the stability of the DTrace interfaces themselves. Therefore, DTrace stability values also indicate how likely your D programs and layered tools are to require corresponding changes when you upgrade or change the software stack that you are observing.

Stability Value	Description
Internal	The interface is private to DTrace and represents an implementation detail of DTrace. Internal interfaces might change in minor or micro releases.
Private	The interface is private to Oracle and represents an interface developed for use by other Oracle products that are not yet publicly documented for use by customers and ISVs (independent software vendors). Private interfaces might change in minor or micro releases.
Obsolete	The interface is supported in the current release but is scheduled to be removed, most likely in a future minor release. The D compiler might produce warning messages if you attempt to use an Obsolete interface.
External	The interface is controlled by an entity other than Oracle. Oracle makes no claims regarding either source or binary compatibility for External interfaces between any two releases. Applications based on these interfaces might not work in future releases, including patches that contain External interfaces.
Unstable	The interface provides developers early access to new or rapidly changing technology or to an implementation artifact that is essential for observing or debugging system behavior for which a more stable solution is anticipated in the future. Oracle makes no claims about either source or binary compatibility for Unstable interfaces from one minor release to another.
Evolving	The interface might eventually become Standard or Stable but is still in transition. When non-upward, compatible changes become necessary, they occur in minor and major releases. These changes will be avoided in micro releases whenever possible. If such a change is necessary, it will be documented in the release notes for the affected release. Also, when feasible, migration aids are provided for binary compatibility and continued D program development.
Stable	The interface is a mature interface.

Stability Value	Description
Standard	The interface complies with an industry standard. The corresponding documentation for the interface describes the standard to which the interface conforms. Standards are typically controlled by a standards development organization. Changes can be made to the interface in accordance with approved changes to the standard. This stability level can also apply to interfaces that have been adopted (without a formal standard) by an industry convention. Support is provided for only the specified versions of a standard; support for later versions is not guaranteed.

Dependency Classes

Because Oracle Linux and DTrace support a variety of operating platforms and processors, DTrace also labels interfaces with a *dependency class*, which indicates whether an interface is common to all Oracle Linux platforms and processors or whether the interface is associated with a particular system architecture. The dependency class is orthogonal to the stability levels previously described in this document. For example, a DTrace interface can be Stable, but only supported on x86_64 microprocessors. Or, the interface can be Unstable, but common to all Oracle Linux platforms. The DTrace dependency classes are described in the following table and listed in order, from least common (most specific to a particular architecture), to most common (common to all architectures).

Dependency Class	Description
Unknown	The interface has an unknown set of architectural dependencies. DTrace does not necessarily know the architectural dependencies of all entities, such as the data types defined in the operating system implementation. The Unknown label is typically applied to interfaces of very low stability for which dependencies cannot be computed. The interface might not be available when using DTrace on *any* architecture other than what you are currently using.
CPU	The interface is specific to the CPU model of the current system. Interfaces with CPU model dependencies might not be available on other CPU implementations, even if those CPUs export the same instruction set architecture (ISA).
Platform	The interface is specific to the hardware platform for the current system. A platform typically associates a set of system components and architectural characteristics. To display the current platform name, use the `uname -i` command. The interface might not be available on other hardware platforms.

Dependency Class	Description
Group	The interface is specific to the hardware platform group for the current system. A platform group typically associates a set of platforms with related characteristics together under a single name. To display the current platform group name, use the `uname -m` command. The interface is available on other platforms in the platform group, but it might not be available on hardware platforms that are not members of the group.
ISA	The interface is specific to the ISA that is supported by the microprocessors on the current system. The ISA describes a specification for software that can be executed on the microprocessor, including details such as assembly language instructions and registers. To display the native instruction sets that are supported by the system, use the `isainfo` command. The interface might not be supported on systems that do not export any of the same instruction sets.
Common	The interface is common to all Oracle Linux platforms, regardless of the underlying hardware. DTrace programs and layered applications that depend only on Common interfaces can be executed and deployed on other Oracle Linux platforms with the same Oracle Linux and DTrace revisions. The majority of DTrace interfaces are Common, so you can use them wherever you use Oracle Linux.

Interface Attributes

DTrace describes interfaces by using a triplet of attributes consisting of two stability levels and one dependency class. By convention, the interface attributes are written in the following order and are separated by slashes:

name_stability / *data_stability* / *dependency_class*

The *name stability* of an interface describes the stability level that is associated with its name, as it appears in your D program or on the `dtrace` command line. For example, the `execname` D variable is a Stable name.

The *data stability* of an interface is distinct from the stability that is associated with the interface name. This stability level describes the commitment to maintain the data formats that are used by the interface and any associated data semantics.

The *dependency class* of an interface is distinct from its name and data stability and describes whether the interface is specific to the current operating platform or microprocessor.

DTrace and the D compiler track the stability attributes for all of the following DTrace interface entities: providers, probe descriptions, D variables, D functions, types, and program statements. These interface entities are described later in this chapter. Note that all three

values can vary independently. For example, the `curthread` D variable has Stable/Private/Common attributes: the variable name is Stable and is Common to all Oracle Linux platforms. Note that this variable provides access to a Private data format that is an artifact of the Oracle Linux kernel implementation. Most D variables are provided with Stable/Stable/Common attributes, as are the variables you define.

Stability Computations and Reports

The D compiler performs stability computations for each of the probe descriptions and action statements in your D programs. You can use the `dtrace` command with the `-v` option to display a report of your program's stability, as shown in the follow example that uses a program written on the command line:

```
# dtrace -v -n dtrace:::BEGIN'{exit(0);}'
dtrace: description 'dtrace:::BEGIN' matched 1 probe

Stability attributes for description dtrace:::BEGIN:

    Minimum Probe Description Attributes
        Identifier Names: Stable
        Data Semantics:   Stable
        Dependency Class: Common

    Minimum Statement Attributes
        Identifier Names: Stable
        Data Semantics:   Stable
        Dependency Class: Common

CPU     ID                    FUNCTION:NAME
  0      1                           :BEGIN
```

You can also choose to combine the `-v` option with the `-e` option, which directs the `dtrace` command to compile, but not execute your D program, so that you can determine program stability without enabling any probes and executing your program, as shown in the following stability report:

```
# dtrace -ev -n dtrace:::BEGIN'{trace(curthread->parent);}'

Stability data for description dtrace:::BEGIN:

    Minimum probe description attributes
        Identifier Names: Evolving
        Data Semantics: Evolving
        Dependency Class: Common

    Minimum probe statement attributes
        Identifier Names: Stable
        Data Semantics: Private
        Dependency Class: Common
```

In this example, notice that in the new program, the D `curthread` variable is referenced. This variable has a Stable name, but Private data semantics: if you look at it, you are accessing Private implementation details of the kernel. This status is now reflected in the program's stability report. Stability attributes in the program report are computed by selecting the minimum stability level and class from the corresponding values for each interface attributes triplet.

Stability attributes are computed for a probe description by taking the minimum stability attributes of all of the specified probe description fields, according to the attributes that are

published by the provider. The attributes of the available DTrace providers are shown in the section corresponding to each provider. DTrace providers export a stability attributes triplet for each of the four description fields for all of the probes published by that provider. Therefore, a provider's name can have a greater stability than the individual probes that it exports. For simplicity, most providers use a single set of attributes for all of the individual module function name values they publish. Providers also specify attributes for the `args[]` array because the stability of any probe arguments varies by provider.

If the provider field is not specified in a probe description, then the description is assigned the Unstable/Unstable/Common stability attributes because the description might end up matching probes of providers that do not yet exist when used on a future Oracle Linux release. As such, Oracle does not provide guarantees about the future stability and behavior of this program. You should always explicitly specify the provider when writing your D program clauses. In addition, any probe description fields that contain pattern matching characters or macro variables, such as `$1`, are treated as unspecified because these description patterns might expand to match providers or probes to be released in future versions of DTrace and Oracle Linux. For more details on pattern matching characters and macro variables, see D Program Structureand Scripting.

Stability attributes are computed for most D language statements by taking the minimum stability and class of the entities in the statement. The D language entities and their stability attributes are listed in the following table.

Entity	Attributes
D built-in variable `curthread`	Stable/Private/Common
D user-defined variable `x`	Stable/Stable/Common

For example, if you write the following D program statement, the resulting attributes of the statement are Stable/Private/Common and the minimum attributes are associated with the `curthread` and `x` operands:

```
x += curthread->prio;
```

The stability of an expression is computed by taking the minimum stability attributes of each of the operands.

Any D variables that you define in your program are automatically assigned the Stable/Stable/Common attributes. In addition, the D language grammar and D operators are implicitly assigned these three attributes. References to kernel symbols by using the back quote (`) operator are always assigned the Private/Private/Unknown attributes because they reflect implementation artifacts. Types that you define in your D program source code, specifically those that are associated with the C and D type namespace, are assigned the Stable/Stable/Common attributes. Types that are defined in the operating system implementation and provided by other type namespaces are assigned the Private/Private/Unknown attributes. The D type cast operator yields an expression with stability attributes that are the minimum of the input expression's attributes and the attributes of the cast output type.

If you use the C preprocessor to include C system header files, these types are associated with the C type namespace and are assigned the Stable/Stable/Common attributes, as the D compiler automatically assumes you are taking responsibility for these declarations. It is therefore possible to be misled about your program's stability if you use the C preprocessor to include a header file containing implementation artifacts. You should always consult the documentation corresponding to the header files that you are including so that you can determine the correct stability levels.

Stability Enforcement

When developing a DTrace script or layered tool, you might want to identify the specific source of stability issues or ensure that your program has a desired set of stability attributes. You can use the `-x amin=_attributes_` option with the `dtrace` command to force the D compiler to produce an error whenever any attributes computation results in a triplet of attributes less than the minimum values that you specify on the command line.

The following example demonstrates the use of the `-x amin` option using a snippet of D program source. Note that attributes are specified with three labels that are delimited `/`, in the usual order:

```
# dtrace -x amin=Evolving/Evolving/Common \
  -ev -n dtrace:::BEGIN'{trace(curthread->parent);}'
dtrace: invalid probe specifier dtrace:::BEGIN{trace(curthread->parent);}: \
    in action list: attributes for scalar curthread (Stable/Private/Common) \
    are less than predefined minimum
```

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Translators

> **WARNING:**
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DTrace Stability Features describes how DTrace computes and reports program stability attributes. Ideally, you should construct your DTrace programs by consuming only Stable or Evolving interfaces. Unfortunately, when debugging a low-level problem or measuring system performance, you might need to enable probes that are associated with internal operating system routines, such as functions in the kernel, rather than probes that are associated with more stable interfaces, such as system calls. The available data at probe locations deep within the software stack is often a collection of implementation artifacts rather than more stable data structures, such as those associated with Oracle Linux system call interfaces. To assist you with writing stable D programs, DTrace provides a facility for translating implementation artifacts into stable data structures that are accessible from your D program statements.

Translator Declarations

A *translator* is a collection of D assignment statements provided by the supplier of an interface. Translators can be used to translate an input expression into an object of the `struct` type. To understand the need for using translators, consider as an example the ANSI C standard library routines that are defined in `stdio.h`. These routines operate on a data structure named `FILE`, which contains implementation artifacts that are abstracted away from C programmers. A standard technique for creating a data structure abstraction is to provide only a forward declaration of a data structure in public header files, while keeping the corresponding `struct` definition in a separate and private header file.

If you are writing a C program and want to know the file descriptor corresponding to a `FILE struct`, use the `fileno()` function to obtain the descriptor rather than dereferencing a member of the `FILE struct` directly. The Oracle Linux header files enforce this rule by defining `FILE` as an opaque forward declaration tag so that it cannot be dereferenced directly by C programs that include `<stdio.h>`.

Inside the `/lib/libc.so.6` library, consider the following hypothetical example where `fileno` is implemented in C, noting that a real-life implementation would not be at all similar to this example:

```
int
fileno(FILE *fp)
{
  struct file_impl *ip = (struct file_impl *)fp;
```

```
  return (ip->fd);
}
```

In the example, the hypothetical `fileno` takes a `FILE` pointer as an argument and casts it to a pointer that corresponds to the internal `libc` structure, `struct file_impl`, then returns the value of the `fd` member of the implementation structure.

Unfortunately, observability software like DTrace requires the ability to peer inside the implementation in order to provide useful results. DTrace cannot call arbitrary C functions that are defined in Oracle Linux libraries or in the kernel. You could declare a copy of `struct file_impl` in your D program to instrument the routines that are declared in `stdio.h`, but then your D program would rely on Private implementation artifacts of the library that might break in a future micro or minor release, or even in a patch. Ideally, you want to provide a construct for use in D programs that is bound to the implementation of the library and is updated accordingly, yet still provides an additional layer of abstraction associated with greater stability.

A new translator is created by using a declaration of the following form:

```
translator output-type < input-type
                  input-identifier > {
  member-name = expression ;
  member-name = expression ;
  ...
};
```

The *output-type* names a `struct` that will be the result type for the translation. The *input-type* specifies the type of the input expression, is surrounded in angle brackets `<>`, and followed by an *input-identifier* that can be used in the translator expressions as an alias for the input expression. The body of the translator is surrounded in braces `{}` and terminated with a semicolon (`;`), and consists of a list of *member-name*s and identifiers that correspond to translation expressions. Each member declaration must name a unique member of the *output-type* and must be assigned an expression of a type that is compatible with the member type, according to the rules for the D assignment (`=`) operator.

For example, you could define a `struct` of stable information about `stdio` files based on some of the available `libc` interfaces:

```
struct file_info {
  int file_fd;   /* file descriptor from fileno() */
  int file_eof;  /* eof flag from feof() */
};
```

Then, you could define a hypothetical D translator from `FILE` to `file_info`:

```
translator struct file_info < FILE *F > {
  file_fd = ((struct file_impl *)F)->fd;
  file_eof = ((struct file_impl *)F)->eof;
};
```

In this hypothetical translator, the input expression is of type `FILE *` and is assigned the *input-identifier* `F`. The identifier `F` can then be used in the translator member expressions as a variable of type `FILE *` that is only visible within the body of the translator declaration. To determine the value of the output `file_fd` member, the translator performs a cast and dereference similar to the hypothetical implementation of `fileno()` shown in the previous example. A similar translation is performed to obtain the value of the `EOF` indicator.

xlate D Operator

The `xlate` D operator is used to perform a translation from an input expression to one of the defined translation output structures. The `xlate` operator is used in an expression of the following form:

```
xlate <output-type> ( input-expression )
```

For example, to invoke the hypothetical translator for `FILE` `struct`s that are defined previously and access the `file_fd` member, you would write the expression as follows:

```
xlate <struct file_info *>(f)->file_fd;
```

where `f` is a D variable of type `FILE *`. The `xlate` expression itself is assigned the type that is defined by the *output-type*. When a translator is defined, it can be used to translate input expressions to either the translator output `struct` type or to a pointer to that `struct`.

If you translate an input expression to a `struct`, you can either dereference a particular member of the output immediately by using the "`.`" operator, or you can assign the entire translated `struct` to another D variable to make a copy of the values of all the members. If you dereference a single member, the D compiler only generates code that corresponds to the expression for that member. You may not apply the `&` operator to a translated `struct` to obtain its address, as the data object itself does not exist until it is copied or one of its members is referenced.

If you translate an input expression to a pointer to a `struct`, you can either dereference a particular member of the output immediately by using the `->` operator, or you can dereference the pointer by using the unary `*` operator. In the latter case, the result behaves as though you translated the expression to a `struct`. If you dereference a single member, the D compiler only generates code corresponding to the expression for that member. You may not assign a translated pointer to another D variable, as the data object does not exist until it is copied or one of its members is referenced, and therefore cannot be addressed.

A translator declaration may omit expressions for one or more members of the output type. If an `xlate` expression is used to access a member for which no translation expression is defined, the D compiler produces an appropriate error message and aborts the program compilation. If the entire output type is copied by means of a structure assignment, any members for which no translation expressions are defined are filled with zeroes.

To find a matching translator for an `xlate` operation, the D compiler examines the set of available translators in the following order:

- The compiler checks for a translation from the exact input expression type to the exact output type.
- The compiler resolves the input and output types by following any `typedef` aliases to the underlying type names, and then checks for a translation from the resolved input type to the resolved output type.
- The compiler checks for a translation from a compatible input type to the resolved output type. The compiler uses the same rules as those used for determining compatibility of function call arguments with function prototypes in order to determine if an input expression type is compatible with a translator's input type.

If no matching translator can be found according to these rules, the D compiler produces an appropriate error message and the program compilation fails.

Process Model Translators

The DTrace library file, `/usr/lib64/dtrace/version/procfs.d`, provides a set of translators for use in your D programs to translate from the operating system kernel implementation structure for a process descriptor (`struct task_struct`), to the stable structures, `psinfo` and `lwpsinfo`. These structures define useful Stable information about processes and threads, such as the process ID, process priority, command name, initial arguments, and other data that is displayed by the `ps` command. The following table describes `procfs.d` translators.

Table 17-1 procfs.d Translators

Input Type	Input Type Attributes	Output Type	Output Type Attributes
`struct task_struct *`	Private/Private/ Common	`psinfo_t *`	Stable/Stable/Common
`struct task_struct *`	Private/Private/ Common	`lwpsinfo_t *`	Stable/Stable/Common

Stable Translations

Although a translator provides the ability to convert information into a stable data structure, it does not necessarily resolve all stability issues that can arise in translating data. For example, if the input expression for an `xlate` operation references Unstable data, the resulting D program is also Unstable because program stability is always computed as the minimum stability of the accumulated D program statements and expressions. Therefore, it is sometimes necessary to define a specific stable input expression for a translator to permit stable programs to be constructed. To facilitate such *stable translations*, you can use the D inline mechanism.

The DTrace `procfs.d` library provides the `curlwpsinfo` and `curpsinfo` variables, which were previously described as stable translations. For example, the `curpsinfo` and `curlwpsinfo` variables are actually `inline` and declared as follows:

```
inline psinfo_t *curpsinfo = xlate <psinfo_t *> (curthread);
#pragma D attributes Stable/Stable/Common curpsinfo

inline lwpsinfo_t *curlwpsinfo = xlate <lwpsinfo_t *> (curthread);
#pragma D attributes Stable/Stable/Common curlwpsinfo
```

The `curpsinfo` and `curlwpsinfo` are both defined as inline translations from the `curthread` variable, a pointer to the kernel's Private data structure representing a process descriptor, to the Stable `lwpsinfo_t` type. The D compiler processes this library file and caches the `inline` declarations, making `curpsinfo` and `curlwpsinfo` appear as any other D variable. The `#pragma` statement following the declaration is used to explicitly reset the attributes of the `curpsinfo` and `curlwpsinfo` identifiers to Stable/Stable/Common, masking the reference to `curthread` in the inline expressions.

18
DTrace Versioning

> **WARNING:**
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>
> For more information about DTrace, see *Oracle Linux: DTrace Release Notes* and Oracle Linux: Using DTrace for System Tracing.

In the chapter, DTrace Stability Features, the DTrace features for determining the stability attributes of D programs that you create are described. When you have created a D program with the appropriate stability attributes, you might also choose to bind this program to a particular *version* of the D programming interface.

The D interface version is a label that is applied to a particular set of types, variables, functions, constants, and translators that are made available to you by the D compiler. If you specify a binding to a specific version of the D programming interface, you ensure that you can recompile your program on future versions of DTrace without encountering conflicts between program identifiers that you define, as well as identifiers that are defined in future versions of the D programming interface. You should establish version bindings for any D programs that you want to install as persistent scripts or use in layered tools. See Scripting for more information about using DTrace scripts.

> **Note:**
>
> DTrace versioning in Oracle Linux is not currently interoperable with DTrace versioning on other operating system platforms.

Versions and Releases

The D compiler labels sets of types, variables, functions, constants, and translators that correspond to a particular software release by using a *version string*. A version string is a period-delimited sequence of decimal integers that takes one of the following forms:

x
Major release

x.y
Minor release

x.y.z
Micro release

Version comparisons are made by comparing the integers from left to right. If the leftmost integers are not equal, the string with the greater integer is the greater, and therefore more recent version. If the leftmost integers are equal, the comparison proceeds to the next integer, in order, from left to right, to determine the result. All unspecified integers in a version string are interpreted as having the value zero during a version comparison.

The DTrace version strings correspond to the standard nomenclature for interface versions. A change in the D programming interface is accompanied by a new version string. The following table summarizes the version strings that are used by DTrace and the likely significance of the corresponding DTrace software release.

Table 18-1 DTrace Release Versions

Release	Version	Significance
Major	*x*.0	A Major release is likely to contain major feature additions; adhere to different, possibly incompatible Standard revisions; and though unlikely, could change, drop, or replace Standard or Stable interfaces (see DTrace Stability Features). The initial version of the D programming interface is labeled as version 1.0.
Minor	*x.y*	Compared to an *x*.0 or earlier version (where *y* is not equal to zero), a new Minor release is likely to contain minor feature additions, compatible Standard and Stable interfaces, possibly incompatible Evolving interfaces, or likely incompatible Unstable interfaces. These changes may include new built-in D types, variables, functions, constants, and translators. In addition, a Minor release may remove support for interfaces previously labeled as Obsolete (see DTrace Stability Features).
Micro	*x.y.z*	Micro releases are intended to be interface compatible with the previous release (where *z* is not equal to zero), but are likely to include bug fixes, performance enhancements, and support for additional hardware.

In general, each new version of the D programming interface provides a superset of the capabilities that are offered by the previous version, with the exception of any obsolete interfaces that have been removed.

Versioning Options

By default, any D programs that you compile by using the `dtrace -s` command or that you specify by using the `dtrace -P`, `-m`, `-f`, `-n`, or `-i` command options, are bound to the most recent D programming interface version offered by the D compiler.

You can determine the current D programming interface version by using the `-V` option:

```
# dtrace -V
dtrace: Sun D 1.6.4
```

> **Note:**
>
> Specifying the `-Vv` combination displays other version information, such as the version of the user-space binaries from the `dtrace-utils` package.
>
> ```
> # dtrace -Vv
> dtrace: Sun D 1.6.4
> This is DTrace 1.0.4.
> dtrace(1) version-control ID: 364a014be59b349d6222991d651d38422f170e7e
> libdtrace version-control ID: 364a014be59b349d6222991d651d38422f170e7e
> ```

If you want to establish a binding to a specific version of the D programming interface, you can set the `version` option to an appropriate version string. Similar to other DTrace options that are described in Options and Tunables, you can set the version option as follows:

```
# dtrace -x version=1.6 -n 'BEGIN{trace("hello");}'
```

Alternatively, you can use the `#pragma D option` syntax to set the option in your D program source file, for example:

```
#pragma D option version=1.6

BEGIN
{
  trace("hello");
}
```

If you use the `#pragma D option` syntax to request a version binding, you must place this directive at the top of your D program file, prior to any other declarations and probe clauses. If the version binding argument is not a valid version string or refers to a version that is not offered by the D compiler, an appropriate error message is produced and compilation fails. You can also use the version binding facility to cause the execution of a D script on an older version of DTrace to fail with an obvious error message.

Before compiling your program declarations and clauses, the D compiler loads the set of D types, functions, constants, and translators for the appropriate interface version into the compiler namespaces. Therefore, any version binding options that you specify simply control the set of identifiers, types, and translators that are visible to your program, in addition to the variables, types, and translators that your program defines. Version binding prevents the D compiler from loading newer interfaces that might define identifiers or translators that conflict with declarations in your program source code and would therefore cause a compilation error. See Identifier Names and Keywords for tips on selecting identifier names that are unlikely to conflict with interfaces offered by future versions of DTrace.

Provider Versioning

Unlike interfaces that are offered by the D compiler, interfaces that are offered by DTrace providers, that is, probes and probe arguments, are not affected by or associated with the D programming interface or the version binding options previously described. The available provider interfaces are established as part of loading your compiled instrumentation into the DTrace software in the operating system kernel. These interfaces vary, depending on the following: your instruction set architecture, operating platform, processor, the software that is installed on your Oracle Linux system, and your current security privileges. The D compiler and DTrace runtime examine the probes that are described in your D program clauses and report appropriate error messages whenever probes requested by your D program are not available. These features are orthogonal to the D programming interface version because DTrace providers do not export interfaces that can conflict with definitions in your D programs, which means you can only enable probes in D; you cannot define them. Also, probe names are kept in a separate namespace from other D program identifiers.

Use the `dtrace -l` command, optionally adding the `-v` option, to explore the set of providers and probes that are available on your Oracle Linux system. See DTrace Providers for more information about common providers and probes.