The illumos

Dynamic Tracing Guide
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Preface

DTrace is a comprehensive dynamic tracing framework for the illumos™ Operating System. DTrace provides a powerful infrastructure to permit administrators, developers, and service personnel to concisely answer arbitrary questions about the behavior of the operating system and user programs. The illumos Dynamic Tracing Guide describes how to use DTrace to observe, debug, and tune system behavior. This book also includes a complete reference for bundled DTrace observability tools and the D programming language.

Note
This illumos release supports systems that use the SPARC® and x86 families of processor architectures: UltraSPARC®, SPARC64, AMD64, Pentium, and Xeon EM64T. The supported systems appear in the illumos Hardware Compatibility List. This document cites any implementation differences between the platform types.
In this document the term “x86” refers to 64–bit and 32–bit systems manufactured using processors compatible with the AMD64 or Intel Xeon/Pentium product families. For supported systems, see the illumos Hardware Compatibility List.

Who Should Use This Book

If you have ever wanted to understand the behavior of your system, DTrace is the tool for you. DTrace is a comprehensive dynamic tracing facility that is built into illumos. The DTrace facility can be used to examine the behavior of user programs. The DTrace facility can also be used to examine the behavior of the operating system. DTrace can be used by system administrators or application developers, and is suitable for use with live production systems. DTrace will allow you to explore your system to understand how it works, track down performance problems across many layers of software, or locate the cause of aberrant behavior. As you’ll see, DTrace lets you create your own custom programs to dynamically instrument the system and provide immediate, concise answers to arbitrary questions you can formulate using the DTrace D programming language.

DTrace allows all illumos users to:

- Dynamically enable and manage thousands of probes
- Dynamically associate logical predicates and actions with probes
- Dynamically manage trace buffers and buffer policies
- Display and examine trace data from the live system or a crash dump
DTrace allows illumos developers and administrators to:

- Implement custom scripts that use the DTrace facility
- Implement layered tools that use DTrace to retrieve trace data

This guide will teach you everything you need to know about using DTrace. Basic familiarity with a programming language such as C or a scripting language such as awk(1) or perl(1) will help you learn DTrace and the D programming language faster, but you need not be an expert in any of these areas. If you have never written a program or script before in any language, the section called “Related Information” provides references to other documents you might find useful.

How This Book Is Organized

Chapter 1 provides a whirlwind tour of the entire DTrace facility and introduces readers to the D programming language. Chapter 2, Chapter 3, and Chapter 4 then discuss the fundamentals of D in greater detail, and explain how D programs are converted into dynamic instrumentation. This initial group of chapters should be read first by all readers.

Chapter 5, Chapter 6, Chapter 7, and Chapter 8 discuss the remaining D language features, most of which will be familiar already to C, C++, and Java™ programmers. Readers who are unfamiliar with any of these languages should read these chapters; more experienced programmers may wish to proceed directly to later chapters.

Chapter 9 and Chapter 10 discuss DTrace’s powerful primitive for aggregating data and the set of built-in actions that can be used to build tracing experiments. All readers should carefully read these chapters.

Chapter 11 describes the DTrace policies for buffering data and how these can be configured. This chapter should be read by users once they are familiar with constructing and running D programs.

Chapter 12 describes the D output formatting actions as well as the default policy for formatting trace data. Readers who are familiar with the C printf function can rapidly skim this chapter. Readers who have never seen printf before should read this chapter carefully.

Chapter 13 discusses the DTrace facility for speculatively committing data to a trace buffer. This chapter should be read by users who need to use DTrace in a situation where data must be traced prior to understanding whether it is relevant to the question at hand.

Chapter 14 provides a complete reference for the dtrace command-line utility, similar to the corresponding on-line manual page. Readers may wish to refer to this chapter when various command-line options are presented elsewhere in the book. Chapter 15 then discusses how the dtrace utility can be used to construct executable D scripts and process their command-line arguments, and Chapter 16 describes the options that can be tuned on the command-line or from within a D program itself.

The group of chapters beginning with Chapter 17 and ending with Chapter 32 discuss the various DTrace providers that can be used to instrument various aspects of the illumos system. All readers should skim these chapters to familiarize themselves with the various providers, and then return back to read particular chapters in detail as needed.

Chapter 33 discusses examples of using DTrace to instrument user processes. Chapter 34 describes how application programmers can add customized DTrace providers and probes to user applications. Readers who are user program developers or administrators and wish to use DTrace to investigate user process behavior should read these chapters.
Chapter 35 and the remaining chapters discuss advanced topics such as security, versioning, and stability attributes of DTrace, and how to perform boot-time and post-mortem tracing with DTrace. These chapters are intended for advanced DTrace users.

Related Information

These books and papers are recommended and related to the tasks that you need to perform with DTrace:


You can share your DTrace experiences and scripts with the rest of the DTrace community on the DTrace discussion mailing list.

Additional Documentation

Additional resources can be found on the illumos website, including the manual pages referenced throughout this book, and additional books and guides for using illumos and its tools.

We Welcome Your Comments

The DTrace and illumos communities are interested in improving this documentation and welcome your comments and suggestions. To share your comments, either join and e-mail the DTrace discussion mailing list or go to the illumos-docbooks repository and click "Issues".

Typographic Conventions

The following table describes the typographic conventions that are used in this book.

<table>
<thead>
<tr>
<th>Typeface</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>AaBbCc123</td>
<td>The names of commands, files, and directories, and onscreen computer output</td>
<td>Edit your .login file. Use <code>ls -a</code> to list all files. <code>machine_name%</code> you have mail.</td>
</tr>
</tbody>
</table>
Table 1: (continued)

<table>
<thead>
<tr>
<th>Typeface</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>AaBbCc123</td>
<td>What you type, contrasted with onscreen computer output</td>
<td>machine_name% su</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Password: su</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aabbcc123</td>
<td>Placeholder: replace with a real name or value</td>
<td>The command to remove a file is rm filename.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AaBbCc123</td>
<td>Book titles, new terms, and terms to be emphasized</td>
<td>Read Chapter 6 in the User’s Guide.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A cache is a copy that is stored locally.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do not save the file.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Note: Some emphasized items appear bold online.</td>
</tr>
</tbody>
</table>

Shell Prompts in Command Examples

The following table shows the default UNIX® system prompt and superuser prompt for the C shell, Bourne shell, and Korn shell.

Table 2: Shell Prompts

<table>
<thead>
<tr>
<th>Shell</th>
<th>Prompt</th>
</tr>
</thead>
<tbody>
<tr>
<td>C shell</td>
<td>machine_name%</td>
</tr>
<tr>
<td>C shell for superuser</td>
<td>machine_name#</td>
</tr>
<tr>
<td>Bourne shell and Korn shell</td>
<td>$</td>
</tr>
<tr>
<td>Bourne shell and Korn shell for superuser</td>
<td>#</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

WELCOME to Dynamic Tracing in the illumos Operating System! If you have ever wanted to understand the behavior of your system, DTrace is the tool for you. DTrace is a comprehensive dynamic tracing facility that is built into illumos that can be used by administrators and developers on live production systems to examine the behavior of both user programs and of the operating system itself. DTrace enables you to explore your system to understand how it works, track down performance problems across many layers of software, or locate the cause of aberrant behavior. As you’ll see, DTrace lets you create your own custom programs to dynamically instrument the system and provide immediate, concise answers to arbitrary questions you can formulate using the DTrace D programming language. The first section of this chapter provides a quick introduction to DTrace and shows you how to write your very first D program. The rest of the chapter introduces the complete set of rules for programming in D as well as tips and techniques for performing in-depth analysis of your system. You can share your DTrace experiences and scripts with the rest of the DTrace community on the DTrace discussion mailing list. All of the example scripts presented in this guide can be found on your illumos system in the directory /usr/demo/dtrace.

1.1 DTrace on other Operating Systems

Since the source to DTrace was made available in 2005, it has been ported to several other operating systems including:

- Mac OS X
- FreeBSD
- Two different ports to Linux
- Sony Playstation Vita
- QNX

This guide has a focus on the illumos Operating System, but much of the content is applicable to all Operating Systems with DTrace.
1.2 Getting Started

DTrace helps you understand a software system by enabling you to dynamically modify the operating system kernel and user processes to record additional data that you specify at locations of interest, called probes. A probe is a location or activity to which DTrace can bind a request to perform a set of actions, like recording a stack trace, a timestamp, or the argument to a function. Probes are like programmable sensors scattered all over your illumos system in interesting places. If you want to figure out what’s going on, you use DTrace to program the appropriate sensors to record the information that is of interest to you. Then, as each probe fires, DTrace gathers the data from your probes and reports it back to you. If you don’t specify any actions for a probe, DTrace will just take note of each time the probe fires.

Every probe in DTrace has two names: a unique integer ID and a human-readable string name. We’re going to start learning DTrace by building some very simple requests using the probe named BEGIN, which fires once each time you start a new tracing request. You can use the dtrace(1M) utility’s -n option to enable a probe using its string name. Type the following command:

```bash
# dtrace -n BEGIN
```

After a brief pause, you will see DTrace tell you that one probe was enabled and you will see a line of output indicating that the BEGIN probe fired. Once you see this output, dtrace remains paused waiting for other probes to fire. Since you haven’t enabled any other probes and BEGIN only fires once, press Control-C in your shell to exit dtrace and return to your shell prompt:

```bash
# dtrace -n BEGIN
```

The output tells you that the probe named BEGIN fired once and both its name and integer ID, 1, are printed. Notice that by default, the integer name of the CPU on which this probe fired is displayed. In this example, the CPU column indicates that the dtrace command was executing on CPU 0 when the probe fired.

You can construct DTrace requests using arbitrary numbers of probes and actions. Let’s create a simple request using two probes by adding the END probe to the previous example command. The END probe fires once when tracing is completed. Type the following command, and then again press Control-C in your shell after you see the line of output for the BEGIN probe:

```bash
# dtrace -n BEGIN -n END
```

As you can see, pressing Control-C to exit dtrace triggers the END probe. dtrace reports this probe firing before exiting.

Now that you understand a little bit about naming and enabling probes, you’re ready to write the DTrace version of everyone’s first program, “Hello, World.” In addition to constructing DTrace experiments on the
command line, you can also write them in text files using the D programming language. In a text editor, create a new file called hello.d and type in your first D program:

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

After you have saved your program, you can run it using the `dtrace -s` option. Type the following command:

```
# dtrace -s hello.d
```

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

As you can see, `dtrace` printed the same output as before followed by the text “hello, world”. Unlike the previous example, you did not have to wait and press Control-C, either. These changes were the result of the actions you specified for your `BEGIN` probe in `hello.d`. Let’s explore the structure of your D program in more detail in order to understand what happened.

Each D program consists of a series of clauses, each clause describing one or more probes to enable, and an optional set of actions to perform when the probe fires. The actions are listed as a series of statements enclosed in braces `{ }` following the probe name. Each statement ends with a semicolon (`;`). Your first statement uses the function `trace` 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 function `exit` to indicate that DTrace should cease tracing and exit the `dtrace` command. DTrace provides a set of useful functions like `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. The complete set of D functions is described in Chapter 10.

By now, if you’re familiar with the C programming language, you’ve probably realized from the name and our examples 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. You’ll learn more about these features in subsequent chapters. If you’ve written a C program before, you will be able to immediately transfer most of your knowledge to building tracing programs in D. If you’ve never written a C program before, learning D is still very easy. You will understand all of the syntax by the end of this chapter. But first, let’s take a step back from language rules and learn more about how DTrace works, and then we’ll return to learning how to build more interesting D programs.

### 1.3 Providers and Probes

In the preceding examples, you learned to use two simple probes named `BEGIN` and `END`. But where did these probes come from? DTrace probes come from a set of kernel modules 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 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. To list all of the available probes on your system, type the command:

```
# dtrace -l
```

<table>
<thead>
<tr>
<th>ID</th>
<th>PROVIDER</th>
<th>MODULE</th>
<th>FUNCTION</th>
<th>NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dtrace</td>
<td></td>
<td>BEGIN</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>dtrace</td>
<td></td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>dtrace</td>
<td></td>
<td>ERROR</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>lockstat</td>
<td>genunix</td>
<td>mutex_enter</td>
<td>adaptive-acquire</td>
</tr>
<tr>
<td>5</td>
<td>lockstat</td>
<td>genunix</td>
<td>mutex_enter</td>
<td>adaptive-block</td>
</tr>
<tr>
<td>6</td>
<td>lockstat</td>
<td>genunix</td>
<td>mutex_enter</td>
<td>adaptive-spin</td>
</tr>
<tr>
<td>7</td>
<td>lockstat</td>
<td>genunix</td>
<td>mutex_exit</td>
<td>adaptive-release</td>
</tr>
</tbody>
</table>

... many lines of output omitted ...

```
```

It might take some time to display all of the output. To count up all your probes, you can type the command:

```
# dtrace -l | wc -l
30122
```

You might observe a different total on your machine, as the number of probes varies depending on your operating platform and the software you have installed. As you can see, there are a very large number of probes available to you so you can peer into every previously dark corner of the system. In fact, even this output isn’t the complete list because, as you’ll see later, some providers offer the ability to create new probes on-the-fly based on your tracing requests, making the actual number of DTrace probes virtually unlimited.

Now look back at the output from `dtrace -l` in your terminal window. Notice that each probe has the two names we mentioned earlier, an integer ID and a human-readable name. The human-readable name is composed of four parts, shown as separate columns in the `dtrace` output. The four parts of a probe name are:

- **Provider**: The name of the DTrace provider that is publishing this probe. The provider name typically corresponds to the name of the DTrace kernel module that performs the instrumentation to enable the probe.
- **Module**: If this probe corresponds to a specific program location, the name of the module in which the probe is located. This name is either the name of a kernel module or the name of a user library.
- **Function**: If this probe corresponds to a specific program location, the name of the program function in which the probe is located.
- **Name**: The final component of the probe name is a name that gives you some idea of the probe’s semantic meaning, such as `BEGIN` or `END`.

When writing out 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 used earlier. 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...
1.4 Compilation and Instrumentation

concept like the idea of the end of your tracing request. A probe that has a module and function as part of its name is known as an anchored probe, and one that does not is known as unanchored.

By convention, if you do not specify all of the fields of a probe name, then DTrace matches your request to all of the probes that have matching values in the parts of the name that you do specify. In other words, when you used the probe name BEGIN earlier, you were actually telling DTrace to match any probe whose name field is BEGIN, regardless of the value of the provider, module, and function fields. As it happens, there is only one probe matching that description, so the result is the same. But 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 anchored to any function. Therefore, the hello.d program could have been written as follows and would produce the same result:

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

Now that you understand where probes originate from and how they are named, we’re going to learn a little more about what happens when you enable probes and ask DTrace to do something, and then we’ll return to our whirlwind tour of D.

1.4 Compilation and Instrumentation

When you write traditional programs in illumos, you 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 used earlier to write the hello.d program. Once your program is compiled, it is sent into the operating system kernel for execution by DTrace. There the probes that are named in your program are enabled and the corresponding provider performs whatever instrumentation is needed 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. Once your experiment is complete and the dtrace command exits, all of the probes 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 one where the DTrace software is not installed.

The instrumentation for each probe is performed dynamically on the live running operating system or on user processes 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 ask DTrace to do: no extraneous data is traced, no one big “tracing switch” is turned on in the system, and 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, and 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 on the same system using DTrace without interfering with one another.
Unlike programs written in C and C++ and similar to programs 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 run-time 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 illumos kernel or one of the processes running on your system. These safety features allow you to use DTrace in a production environment without worrying about crashing or corrupting your system. If you make a programming mistake, DTrace will report your error to you, disable your instrumentation, and you can correct your mistake and try again. The DTrace error reporting and debugging features are described later in this book.

The following diagram shows the different components of the DTrace architecture, including providers, probes, the DTrace kernel software, and the dtrace command.

![Figure 1.1: Overview of the DTrace Architecture and Components](image)

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

### 1.5 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-nsec for some integer n, the profile provider will create a probe that fires every n seconds. Type the following source code and save it in a file named counter.d:

```d
/*
 * Count off and report the number of seconds elapsed
 */
```
1.5. Variables and Arithmetic Expressions

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 Control-C, and then prints the total at the end:

# dtrace -s counter.d

dtrace: script 'counter.d' matched 3 probes
CPU ID  FUNCTION:NAME
0  25499 :tick-1sec  1
0  25499 :tick-1sec  2
0  25499 :tick-1sec  3
0  25499 :tick-1sec  4
0  25499 :tick-1sec  5
0  25499 :tick-1sec  6
^C
0  2  :END  6
#

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:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>char</td>
<td>Character or single byte integer</td>
</tr>
<tr>
<td>int</td>
<td>Default integer</td>
</tr>
<tr>
<td>short</td>
<td>Short integer</td>
</tr>
<tr>
<td>long</td>
<td>Long integer</td>
</tr>
<tr>
<td>long long</td>
<td>Extended long integer</td>
</tr>
</tbody>
</table>
1. Introduction

The sizes of these types are dependent on the operating system kernel’s data model, described in Chapter 2. 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 which fires once per second on an available processor. The clause contains two statements, the first assigning `i` to the previous value plus one, and the second tracing the new value of `i`. All the usual C arithmetic operators are available in D; the complete list is found in Chapter 2. Also as in C, the `++` operator can be used as shorthand for incrementing the corresponding variable by one. 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.

1.6 Predicates

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 that can be used to prefix program clauses. 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`:

```d
8
```
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:

```
# d trace -s countdown.d
d trace: script 'countdown.d' matched 3 probes
CPU ID FUNCTION:NAME
  0 25499 :tick-1sec 10
  0 25499 :tick-1sec 9
  0 25499 :tick-1sec 8
  0 25499 :tick-1sec 7
  0 25499 :tick-1sec 6
  0 25499 :tick-1sec 5
  0 25499 :tick-1sec 4
  0 25499 :tick-1sec 3
  0 25499 :tick-1sec 2
  0 25499 :tick-1sec 1
  0 25499 :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; the complete list is found in Chapter 2. 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:

```d
i = 10
once per second,
    if i is greater than zero
        trace(i--);
    otherwise 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’s 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 illumos system call. The next example uses DTrace to observe every time your shell performs a read(2) or write(2) system call. First, open two terminal windows, one to use for DTrace and the other containing the shell process you’re going to watch. In the second window, type the following command to obtain the process ID of this shell:

```
# echo $$
12345
```

Now go back to your first terminal window and type the following D program and save it in a file named rw.d. As you type in the program, replace 12345 with the process ID of the shell that was printed in response to your echo command.

```d
syscall::read:entry,
syscall::write:entry
/pid == 12345/
{
}
```

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’re done typing 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
```
You are now watching your shell perform read(2) and write(2) 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(2) and write(2) in the same manner, the script uses a single probe clause with multiple probe descriptions by separating the descriptions with commas like this:

```plaintext
syscall::read:entry,
system::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 == 12345/
```

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. Here is a list of a few DTrace variables you can use to write your first D programs:

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Data Type</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>errno</td>
<td>int</td>
<td>Current <code>errno</code> value for system calls</td>
</tr>
<tr>
<td>execname</td>
<td>string</td>
<td>Name of the current process’s executable file</td>
</tr>
<tr>
<td>pid</td>
<td>pid_t</td>
<td>Process ID of the current process</td>
</tr>
<tr>
<td>tid</td>
<td>id_t</td>
<td>Thread ID of the current thread</td>
</tr>
<tr>
<td>probeprov</td>
<td>string</td>
<td>Current probe description’s provider field</td>
</tr>
<tr>
<td>probemod</td>
<td>string</td>
<td>Current probe description’s module field</td>
</tr>
<tr>
<td>probefunc</td>
<td>string</td>
<td>Current probe description’s function field</td>
</tr>
<tr>
<td>probename</td>
<td>string</td>
<td>Current probe description’s name field</td>
</tr>
</tbody>
</table>

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 `truss(1)`. 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:

```plaintext
syscall:::entry
/pid == 12345/
{
}
```
Try typing a few commands in the shell such as `cd`, `ls`, and `date` and see what your DTrace program reports.

### 1.7 Output Formatting

System call tracing is a powerful way to observe the behavior of most user processes. If you’ve used the illumos truss(1) utility before as an administrator or developer, you’ve probably learned that it’s a useful tool to keep around for whenever there is a problem. If you’ve never used `truss` before, give it a try right now by typing this command into one of your shells:

```
$ truss date
```

You will see a formatted trace of all the system calls executed by `date(1)` followed by its one line of output at the end. The following example improves upon the earlier `rw.d` program by formatting its output to look more like `truss(1)` so you can more easily understand the output. Type the following program and save it in a file called `trussrw.d`:

#### Example 1.2: trussrw.d: Trace System Calls with truss(1) Output Format

```c
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("\t\t = %d\n", arg1);
}
```

In this example, the constant `12345` is replaced with the label `$1` in each predicate. This label allows 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 `trussrw.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 will only see the output for the data that you explicitly traced. Type the following command (replacing `12345` with the process ID of a shell process) and then press return a few times in the specified shell:

```
# dtrace -q -s trussrw.d 12345
```

```
write(2, 0x8089e48, 1) = 1
read(63, 0x8090a38, 1024) = 0
read(63, 0x8090a38, 1024) = 0
write(2, 0x8089e48, 52) = 52
read(0, 0x8089878, 1) = 1
write(2, 0x8089e48, 1) = 1
read(63, 0x8090a38, 1024) = 0
read(63, 0x8090a38, 1024) = 0
write(2, 0x8089e48, 52) = 52
```
Now let's 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(2) and write(2). But for this example, a new function, printf, is used to trace data and print it out in a specific format:

```c
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 `trussrw.d`:

- `%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(3C)` library routine or the shell `printf(1)` utility. If you've never seen `printf` before, the formats and options are explained in detail in Chapter 12. You should read this chapter carefully even if you're 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 trussrw.d
```

To print the name of the read or write system call and its arguments, use the `printf` statement:
printf("%s(%d, 0x%lx, %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 Chapter 3. The first argument to read(2) and write(2) 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 will insert extra blanks to align the output.

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

```d
syscall::read:return,
syscall::write:return
/pid == $1/
{
    printf("\t\t = %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. The complete list of escape sequences is found in Chapter 2.

1.8 Arrays

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’ll be happy to know you can use any type in D that you can in C. If you’re not a C expert, don’t worry: the different kinds of data types are all described in Chapter 2. D also supports a special kind of variable called an associative array. An associative array is similar to a normal array in that it associates a set of keys with a set of values, but in an associative array the keys are not limited to integers of a fixed range.

D associative arrays can be indexed by a list of one or more values of any type. Together the individual key values form a tuple that is used to index into the array and access or modify the value corresponding to that key. Every tuple used with a given associative array must conform to the same type signature; that is, each tuple key must be of the same length and have the same key types in the same order. The value associated with each element of a given associative array is also of a single fixed type for the entire array. For example, the following D statement defines a new associative array a of value type int with the tuple signature [ string, int ] and stores the integer value 456 in the array:

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

Once an array is defined, its elements can be accessed like any other D variable. For example, the following D statement modifies the array element previously stored in a by incrementing the value from 456 to 457:

```d
a["hello", 123]++;
```
The values of any array elements you have not yet assigned are set to zero. Now let’s use an associative array in a D program. Type the following program and save it in a file named `rwtime.d`:

```d
Example 1.3: rwtime.d: Time read(2) and write(2) Calls

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 `trussrw.d`, specify the ID of shell process when you execute `rwtime.d`. If you type a few shell commands, you’ll see the amount 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 'pgrep -n ksh'
dtrace: script 'rwtime.d' matched 4 probes
CPU ID FUNCTION:NAME
0 33 read:return 22644 nsecs
0 33 read:return 3382 nsecs
0 35 write:return 25952 nsecs
0 33 read:return 916875239 nsecs
0 35 write:return 27320 nsecs
0 33 read:return 9022 nsecs
0 33 read:return 3776 nsecs
0 35 write:return 17164 nsecs
...
^C
```

To trace the elapsed time for each system call, you must instrument both the entry to and return from `read(2)` and `write(2)` and sample 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’s easier to use an associative array indexed by the probe function name. Here is the first probe clause:

```d
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, similar to the illumos library routine `gethrtime(3C)`. Once the entry timestamp is saved, the corresponding return probe samples `timestamp` again and reports the difference between the current time and the saved value:
1. INTRODUCTION

```d
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(2) system call for input when you execute `dtrace`, the `read:return` probe will fire without a preceding `read:entry` for this first read(2) and `ts[probefunc]` will evaluate to zero because it has not yet been assigned.

1.9 External Symbols and Types

DTrace instrumentation executes inside the illumos 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 book includes books that can help you learn more about illumos operating system internals.

D uses the backquote 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 illumos kernel contains a C declaration of a system tunable named `kmem_flags` for enabling memory allocator debugging features. See the [illumos Tunable Parameters Reference Manual](#) for more information about `kmem_flags`. This tunable is declared in C in the kernel source code as follows:

```c
int kmem_flags;
```

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

```d
trace(`kmem_flags);
```

DTrace associates each kernel symbol with the type used for it in the corresponding operating system C code, providing easy source-based access to the native operating system data structures. Kernel symbol names are kept in a separate namespace from D variable and function identifiers, so you never need to worry about these names conflicting with your D variables.

You have now completed a whirlwind tour of DTrace and you’ve learned many of the basic DTrace building blocks necessary to build larger and more complex D programs. The following chapters 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’ll see how to use DTrace to connect user application behavior to system behavior, giving you the capability to analyze your entire software stack.

You’ve only just begun!
Chapter 2

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 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 chapter describes the detailed set of rules for types, operators, and expressions.

2.1 Identifier Names and Keywords

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

D language keywords are special identifiers reserved for use in the programming language syntax itself. These names are always specified in lower case and may not be used for the names of D variables.

Table 2.1: D Keywords

<table>
<thead>
<tr>
<th>auto</th>
<th>goto</th>
<th>sizeof</th>
</tr>
</thead>
<tbody>
<tr>
<td>break</td>
<td>if</td>
<td>static</td>
</tr>
<tr>
<td>case</td>
<td>import</td>
<td>string</td>
</tr>
<tr>
<td>char</td>
<td>inline</td>
<td>string</td>
</tr>
<tr>
<td>const</td>
<td>int</td>
<td>struct</td>
</tr>
<tr>
<td>continue</td>
<td>long</td>
<td>switch</td>
</tr>
<tr>
<td>counter</td>
<td>offsetof</td>
<td>this</td>
</tr>
<tr>
<td>default</td>
<td>probe</td>
<td>translator</td>
</tr>
<tr>
<td>do</td>
<td>provider</td>
<td>typedef</td>
</tr>
<tr>
<td>double</td>
<td>register</td>
<td>union</td>
</tr>
<tr>
<td>else</td>
<td>restrict</td>
<td>unsigned</td>
</tr>
<tr>
<td>enum</td>
<td>return</td>
<td>void</td>
</tr>
<tr>
<td>extern</td>
<td>self</td>
<td>volatile</td>
</tr>
<tr>
<td>float</td>
<td>short</td>
<td>while</td>
</tr>
<tr>
<td>for</td>
<td>signed</td>
<td>xlate</td>
</tr>
</tbody>
</table>
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 

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. Keywords associated with control-flow in ANSI-C are reserved for future use in D.

### 2.2 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. D provides a 32-bit and 64-bit data model for use in writing programs. The data model used when executing your program is the native data model associated with the active operating system kernel. You can determine the native data model for your system using `isainfo -b`.

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

<table>
<thead>
<tr>
<th>Type Name</th>
<th>32-bit Size</th>
<th>64-bit Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>char</td>
<td>1 byte</td>
<td>1 byte</td>
</tr>
<tr>
<td>short</td>
<td>2 bytes</td>
<td>2 bytes</td>
</tr>
<tr>
<td>int</td>
<td>4 bytes</td>
<td>4 bytes</td>
</tr>
<tr>
<td>long</td>
<td>4 bytes</td>
<td>8 bytes</td>
</tr>
<tr>
<td>long long</td>
<td>8 bytes</td>
<td>8 bytes</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int8_t</td>
<td>1 byte signed integer</td>
</tr>
<tr>
<td>int16_t</td>
<td>2 byte signed integer</td>
</tr>
<tr>
<td>int32_t</td>
<td>4 byte signed integer</td>
</tr>
<tr>
<td>int64_t</td>
<td>8 byte signed integer</td>
</tr>
<tr>
<td>intptr_t</td>
<td>Signed integer of size equal to a pointer</td>
</tr>
<tr>
<td>uint8_t</td>
<td>1 byte unsigned integer</td>
</tr>
<tr>
<td>uint16_t</td>
<td>2 byte unsigned integer</td>
</tr>
<tr>
<td>uint32_t</td>
<td>4 byte unsigned integer</td>
</tr>
</tbody>
</table>
2.3. Constants

Table 2.3: (continued)

<table>
<thead>
<tr>
<th>Type Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>uint64_t</td>
<td>8 byte unsigned integer</td>
</tr>
<tr>
<td>uintptr_t</td>
<td>Unsigned integer of size equal to a pointer</td>
</tr>
</tbody>
</table>

These type aliases are equivalent to using the name of the corresponding base type in the previous table and are appropriately defined for each data model. For example, the type name uint8_t is an alias for the type unsigned char. See Chapter 8 for information on how to define your own type aliases for use in your D programs.

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 using the printf function. The floating-point types listed in the following table may be used:

Table 2.4: D Floating-Point Data Types

<table>
<thead>
<tr>
<th>Type Name</th>
<th>32–bit Size</th>
<th>64–bit Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>float</td>
<td>4 bytes</td>
<td>4 bytes</td>
</tr>
<tr>
<td>double</td>
<td>8 bytes</td>
<td>8 bytes</td>
</tr>
<tr>
<td>long double</td>
<td>16 bytes</td>
<td>16 bytes</td>
</tr>
</tbody>
</table>

D also provides the special type string to represent ASCII strings. Strings are discussed in more detail in Chapter 6.

2.3 Constants

Integer constants can be written in decimal (12345), octal (012345), or hexadecimal (0x12345). 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 following suffixes to any integer constant to explicitly specify its 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 and must contain either a decimal point (12.345) or an exponent (123e45) or both (123.34e-5). Floating-point constants are assigned the type double.
by default. You can apply one of the following suffixes to any floating-point constant to explicitly specify its D type:

```
f or F         float
l or L         long double
```

Character constants are written as a single character or escape sequence enclosed in a pair of single quotes ('a'). Character constants are assigned the type `int` and are equivalent to an integer constant whose value is determined by that character’s value in the ASCII character set. You can refer to `ascii(5)` for a list of characters and their values. You can also use any of the special escape sequences shown in the following table in your character constants. D supports the same escape sequences found in ANSI-C.

You can include more than one character specifier inside single quotes to create integers whose individual bytes 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 may contain any of the special character escape sequences shown for character constants above. 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 that 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, as described in Chapter 6.

### 2.4 Arithmetic Operators

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

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Addition</td>
</tr>
<tr>
<td>-</td>
<td>Subtraction</td>
</tr>
<tr>
<td>*</td>
<td>Multiplication</td>
</tr>
<tr>
<td>/</td>
<td>Division</td>
</tr>
<tr>
<td>%</td>
<td>Modulus</td>
</tr>
</tbody>
</table>

---
20
2.5. Relational Operators

Arithmetic in D may only be performed on integer operands, or on pointers, as discussed in Chapter 5. 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 check for these conditions yourself in situations where overflow and underflow can occur.

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 will automatically disable the affected instrumentation and report the error. Errors detected by DTrace have no effect on other DTrace users or on the operating system kernel, so you don’t need to worry about causing any damage if your D program inadvertently contains one of these errors.

In addition to these binary operators, the + and – operators may also be used as unary operators as well; these operators have higher precedence than any of the binary arithmetic operators. The order of precedence and associativity properties for all the D operators is presented in Table 2.11. You can control precedence by grouping expressions in parentheses ( ).

### 2.5 Relational Operators

D provides the binary relational operators shown in the following table for use in your programs. These operators all have the same meaning as they do in ANSI-C.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
<td>left-hand operand is less than right-operand</td>
</tr>
<tr>
<td>&lt;=</td>
<td>left-hand operand is less than or equal to right-hand operand</td>
</tr>
<tr>
<td>&gt;</td>
<td>left-hand operand is greater than right-hand operand</td>
</tr>
<tr>
<td>&gt;=</td>
<td>left-hand operand is greater than or equal to right-hand operand</td>
</tr>
<tr>
<td>==</td>
<td>left-hand operand is equal to right-hand operand</td>
</tr>
<tr>
<td>!=</td>
<td>left-hand operand is not equal to right-hand operand</td>
</tr>
</tbody>
</table>

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 may 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(3C) on the two operands. Here are some example D string comparisons and their results:
Relational operators may 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 Chapter 8.

### 2.6 Logical Operators

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;&amp;</td>
<td>logical AND: true if both operands are true</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>logical XOR: true if exactly one operand is true</td>
<td></td>
</tr>
</tbody>
</table>

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

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.

### 2.7 Bitwise Operators

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>bitwise AND</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>bitwise OR</td>
</tr>
<tr>
<td>^</td>
<td>bitwise XOR</td>
<td></td>
</tr>
<tr>
<td>&lt;&lt;</td>
<td>shift the left-hand operand left by the number of bits specified by the right-hand operand</td>
<td></td>
</tr>
</tbody>
</table>
2.8 Assignment Operators

Table 2.9: (continued)

| >> | 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 where exactly 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 will produce 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.

2.8 Assignment Operators

D provides the following binary assignment operators 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 2.10: D Assignment Operators

| = | 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 described earlier. For example, the expression \( x = x + 1 \)
is equivalent to the expression \( x += 1 \), except that the expression \( x \) is evaluated once. These assignment
operators obey 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 so far in combination to form
expressions of arbitrary complexity. You can use parentheses ( ) to group terms in complex expressions.

### 2.9 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 in ANSI-C. These operators can only be applied to variables,
and 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 expressions produce identical results:

\[
\begin{align*}
  x &= x + 1; \\
  y &= ++x;
\end{align*}
\]

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 expressions produce identical results:

\[
\begin{align*}
  y &= x; \\
  y &= x--; \quad x -= 1;
\end{align*}
\]

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 \text{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
referenced by the pointer. Pointers and pointer arithmetic in D are discussed in Chapter 5.

### 2.10 Conditional Expressions

Although D does not provide support for if-then-else constructs, it does provide support for simple
conditional expressions 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 this example, the expression \( i == 0 \) is first evaluated to determine whether it is true or false. If the first
expression is true, the second expression is evaluated and the \? : expression returns its value. If the first
expression is false, the third expression is evaluated and the \? : expression return its value.
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-z, or A-Z and return the value of this character when interpreted as a digit in a hexadecimal (base 16) integer:

```d
textval = (c >= '0' && c <= '9') ? c - '0' :
            (c >= 'a' && c <= 'z') ? c + 10 - 'a' : c + 10 - 'A';
```

The first expression used with `?:` must be a pointer or integer in order to be evaluated for its truth value. The second and third expressions may 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, as discussed in Chapter 1.

### 2.11 Type Conversions

When expressions are constructed using operands of different but compatible types, type conversions are performed in order 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 above 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 of lower rank is first *promoted* to the type of 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 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 Chapter 6. An integer or pointer cast is formed using an expression such as:

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

where 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.
2.12 Precedence

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

Table 2.11: D Operator Precedence and Associativity

<table>
<thead>
<tr>
<th>Operators</th>
<th>Associativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>() [] -&gt; .</td>
<td>left to right</td>
</tr>
<tr>
<td>! ~ ++ --* &amp; (type) sizeof stringof offsetof xlate</td>
<td>right to left</td>
</tr>
<tr>
<td>* /% + - &lt;&lt; &gt;&gt; &lt; &lt;= &gt; = == != &amp; ^</td>
<td>left to right</td>
</tr>
<tr>
<td></td>
<td>left to right</td>
</tr>
<tr>
<td></td>
<td>left to right</td>
</tr>
<tr>
<td></td>
<td>left to right</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>+= -= *= /= %= &amp;= ^=</td>
<td>= &lt;&lt;= &gt;&gt;=</td>
</tr>
<tr>
<td>,</td>
<td>left to right</td>
</tr>
</tbody>
</table>

There are several operators in the table that we have not yet discussed; these will be covered in subsequent chapters:

- **sizeof**: Computes the size of an object (Chapter 7)
- **offsetof**: Computes the offset of a type member (Chapter 7)
- **stringof**: Converts the operand to a string (Chapter 6)
- **xlate**: Translates a data type (Chapter 40)
- **unary &**: Computes the address of an object (Chapter 5)
- **unary ***: Dereferences a pointer to an object (Chapter 5)
- **-> and .**: Accesses a member of a structure or union type (Chapter 7)

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

The () entry in the table of operator precedence represents a function call; examples of calls to functions such as `printf` and `trace` are presented in Chapter 1. A comma is also used in D to list arguments to functions and to form lists of associative array keys. This comma is not the same as the comma operator and does not guarantee left-to-right evaluation. The D compiler provides no guarantee as to the order...
of evaluation of arguments to a function or keys to an associative array. You should be careful of using expressions with interacting side-effects, such as the pair of expressions \( i \) and \( i++ \), in these contexts.

The \([\text{ ]}\) entry in the table of operator precedence represents an array or associative array reference. Examples of associative arrays are presented in Chapter 1. A special kind of associative array called an *aggregation* is described in Chapter 9. The \([\text{ ]}\) operator can also be used to index into fixed-size C arrays as well, as described in Chapter 5.
Chapter 3

Variables

D provides two basic types of variables for use in your tracing programs: scalar variables and associative arrays. We briefly illustrated the use of these variables in our examples in Chapter 1. This chapter explores the rules for D variables in more detail and how variables can be associated with different scopes. A special kind of array variable, called an aggregation, is discussed in Chapter 9.

3.1 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 both arrays of objects as well as composite structures. DTrace also represents strings as fixed-size scalars by permitting them to grow up to a predefined maximum length. Control over string length in your D program is discussed further in Chapter 6.

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 \( \text{int} \), you can simply assign it a value of type \( \text{int} \) in any probe clause:

```d
BEGIN
{  
  \( x = 123; \)
}
```

Scalar variables created in this manner are global variables: their name and data storage location is defined once and is visible in every clause of your D program. Any time you reference the identifier \( x \), 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 to 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. Explicit variable declarations are not necessary in most D programs, but are sometimes 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.

```d
int \( x; \) /* declare an integer \( x \) for later use */
```

BEGIN
{
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, but limits are defined by the DTrace implementation and by the memory available on your system. The D compiler will enforce any of the limitations that can be applied at the time you compile your program. You can learn more about how to tune options related to program limits in Chapter 16.

### 3.2 Associative Arrays

Associative arrays are used to represent collections of data elements that can be retrieved by specifying a name 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 itself 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 give you the ability to create a dynamic history of events and state captured in your D program that you can use to create more complex control flows.

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

```d
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" ]`:

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

The type of each object contained in the array is also fixed for all elements in a given array. Because `a` was first assigned using the integer 456, every subsequent value stored in the array will also be of type `int`. You can use any of the assignment operators defined in Chapter 2 to modify associative array elements, subject to the operand rules defined for each operator. The D compiler will produce an appropriate error message if you attempt an incompatible assignment. You can use any type with an associative array key or value that you can use with a scalar variable. You cannot nest an associative array within another associative array as a key or value.

You can reference an associative array 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: the tuple must be of the same length and each type in the list of actual parameters must be compatible with the corresponding type in the formal key signature. For example, if an associative array `x` is defined as follows:

```d
x = 123;
...
)
```
3.3. 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 associated with each thread. Thread-local variables are referenced by applying the `->` operator to the special identifier `self`:

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

This D fragment example enables the probe on the read(2) 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 used on the right-hand side of the first assignment statement (in this example, `int`).

Each time the variable `self->read` is referenced in your D program, the data object 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...
3. Variables

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.

Once 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. See Chapter 16 for other techniques to fine-tune the dynamic variable space from which thread-local variables are allocated.

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

```d
self->x = 123; /* integer value */
self->s = "hello"; /* string value */
self->a[123, 'a'] = 456; /* associative array */
```

Like any D variable, you don’t need to explicitly declare thread-local variables before using them. If you want to create a declaration anyway, you can place one outside of your program clauses by prepending the keyword `self`:

```d
self int x; /* declare int x as a thread-local variable */
```

```d
syscall::read:entry
{
    self->x = 123;
}
```

Thread-local variables are kept in a separate namespace from global variables so 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 a text editor, type in the following program and save it in a file named `rtime.d`:

---

**Example 3.1: rtime.d: Compute Time Spent in read(2)**

```d
syscall::read:entry
{
    self->t = timestamp;
}
syscall::read:return
/self->t != 0/
{
    printf("%d/%d spent %d nsecs in read(2)\n", pid, tid, timestamp - self->t);
    /*
    * We’re done with this thread-local variable; assign zero to it
    * to allow the DTrace runtime to reclaim the underlying storage.
    */
    self->t = 0;
}
```
Now go to your shell and start the program running. Wait a few seconds and you should start to see some output. If no output appears, try running a few commands.

```
# dtrace -q -s rtime.d
100480/1 spent 11898 nsecs in read(2)
100441/1 spent 6742 nsecs in read(2)
100480/1 spent 4619 nsecs in read(2)
100452/1 spent 19560 nsecs in read(2)
100452/1 spent 3648 nsecs in read(2)
100441/1 spent 6645 nsecs in read(2)
100452/1 spent 5168 nsecs in read(2)
100452/1 spent 20329 nsecs in read(2)
100452/1 spent 3596 nsecs in read(2)
...
^C
#
```

`rtime.d` uses a thread-local variable named `t` to capture a timestamp on entry to `read(2)` by any thread. Then, in the return clause, the program prints out the amount of time spent in `read(2)` 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 performing the `read(2)`. Because `self->t` is no longer needed once this information is reported, it is then assigned 0 to allow DTrace to reuse the underlying storage associated with `t` for the current thread.

Typically you will see many lines of output without even doing anything because, behind the scenes, server processes and daemons are executing `read(2)` all the time even when you aren’t doing anything. Try changing the second clause of `rtime.d` to use the `execname` variable to print out the name of the process performing a `read(2)` to learn more:

```
printf("%s/%d spent %d nsecs in read(2)\n",
  execname, tid, timestamp - self->t);
```

If you find a process that’s of particular interest, add a predicate to learn more about its `read(2)` behavior:

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

### 3.4 Clause-Local Variables

You can also define D variables whose storage is reused for each D program clause. Clause-local variables are similar to automatic variables in a C, C++, or Java language program that are active during each invocation of a function. Like all D program variables, clause-local variables are created on their first assignment. These variables can be referenced and assigned by applying the `->` operator to the special identifier `this`:

```
BEGIN
{
  this->secs = timestamp / 1000000000;
  ...
}
```
If you want to explicitly declare a clause-local variable before using it, you can do so using the `this` keyword:

```c
this int x; /* an integer clause-local variable */
this char c; /* a character clause-local variable */
BEGIN
{
    this->x = 123;
    this->c = 'D';
}
```

Clause-local variables are only active for the lifetime of a given probe clause. After DTrace performs the actions associated with your clauses for a given probe, the storage for all clause-local variables is reclaimed and reused for the next clause. For this reason, clause-local variables are the only D variables that are not initially filled with zeroes. Note that if your program contains multiple clauses for a single probe, any clause-local variables will remain intact as the clauses are executed, as shown in the following example:

```
Example 3.2: clause.d: Clause-local Variables
```

```c
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 enabling the same probe, running the above program will always produce the same output:

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

3. VARIABLES
While clause-local variables are persistent across clauses 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 may 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. Once a clause-local variable is defined, this name and type signature may be used in any subsequent D program clause. You cannot rely on the storage location to be the same across different clauses.

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.

### 3.5 Built-in Variables

The following table provides a complete list of D built-in variables. All of these variables are scalar global variables; no thread-local or clause-local variables or built-in associative arrays are currently defined by D.

<table>
<thead>
<tr>
<th>Type and Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>int64_t arg0, ..., arg9</code></td>
<td>The first ten input arguments to a probe represented as raw 64-bit integers. If fewer than ten arguments are passed to the current probe, the remaining variables return zero.</td>
</tr>
<tr>
<td><code>args[]</code></td>
<td>The typed arguments to the current probe, if any. The <code>args[]</code> array is accessed using an integer index, but each element is defined to be the type corresponding to the given probe argument. For example, if <code>args[]</code> is referenced by a <code>read(2)</code> system call probe, <code>args[0]</code> is of type <code>int</code>, <code>args[1]</code> is of type <code>void *</code>, and <code>args[2]</code> is of type <code>size_t</code>.</td>
</tr>
<tr>
<td><code>uintptr_t caller</code></td>
<td>The program counter location of the current thread just before entering the current probe.</td>
</tr>
<tr>
<td><code>chipid_t chip</code></td>
<td>The CPU chip identifier for the current physical chip. See Chapter 26 for more information.</td>
</tr>
<tr>
<td>Type and Name</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>processorid_t cpu</td>
<td>The CPU identifier for the current CPU. See Chapter 26 for more information.</td>
</tr>
<tr>
<td>cpuinfo_t *curcpu</td>
<td>The CPU information for the current CPU. See Chapter 26 for more information.</td>
</tr>
<tr>
<td>lwpsinfo_t *curlwpsinfo</td>
<td>The lightweight process (LWP) state of the LWP associated with the current thread. This structure is described in further detail in the proc(4) manual page.</td>
</tr>
<tr>
<td>psinfo_t *curpsinfo</td>
<td>The process state of the process associated with the current thread. This structure is described in further detail in the proc(4) manual page.</td>
</tr>
<tr>
<td>kthread_t *curthread</td>
<td>The address of the operating system kernel’s internal data structure for the current thread, the kthread_t. The kthread_t is defined in &lt;sys/thread.h&gt;. Refer to Solaris Internals for more information on this variable and other operating system data structures.</td>
</tr>
<tr>
<td>string cwd</td>
<td>The name of the current working directory of the process associated with the current thread.</td>
</tr>
<tr>
<td>uint_t epid</td>
<td>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.</td>
</tr>
<tr>
<td>int errno</td>
<td>The error value returned by the last system call executed by this thread.</td>
</tr>
<tr>
<td>string execname</td>
<td>The name that was passed to exec(2) to execute the current process.</td>
</tr>
<tr>
<td>gid_t gid</td>
<td>The real group ID of the current process.</td>
</tr>
<tr>
<td>uint_t id</td>
<td>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.</td>
</tr>
<tr>
<td>uint_t ipl</td>
<td>The interrupt priority level (IPL) on the current CPU at probe firing time. Refer to Solaris Internals for more information on interrupt levels and interrupt handling in the illumos operating system kernel.</td>
</tr>
<tr>
<td>lgrp_id_t lgrp</td>
<td>The latency group ID for the latency group of which the current CPU is a member. See Chapter 26 for more information.</td>
</tr>
<tr>
<td>pid_t pid</td>
<td>The process ID of the current process.</td>
</tr>
<tr>
<td>pid_t ppid</td>
<td>The parent process ID of the current process.</td>
</tr>
<tr>
<td>string probefunc</td>
<td>The function name portion of the current probe’s description.</td>
</tr>
<tr>
<td>string probemod</td>
<td>The module name portion of the current probe’s description.</td>
</tr>
<tr>
<td>string probename</td>
<td>The name portion of the current probe’s description.</td>
</tr>
<tr>
<td>string probeprov</td>
<td>The provider name portion of the current probe’s description.</td>
</tr>
<tr>
<td>psetid_t pset</td>
<td>The processor set ID for the processor set containing the current CPU. See Chapter 26 for more information.</td>
</tr>
<tr>
<td>string root</td>
<td>The name of the root directory of the process associated with the current thread.</td>
</tr>
<tr>
<td>uint_t stackdepth</td>
<td>The current thread’s stack frame depth at probe firing time.</td>
</tr>
</tbody>
</table>
### 3.6. External Variables

D uses the backquote character (`) as a special scoping operator for accessing variables that are defined in the operating system and not in your D program. For example, the illumos kernel contains a C declaration of a system tunable named `kmem_flags` for enabling memory allocator debugging features. See the *illumos Tunable Parameters Reference Manual* for more information about `kmem_flags`. This tunable is declared as a C variable in the kernel source code as follows:

```c
int kmem_flags;
```

To access the value of this variable in a D program, use the D notation:

```
kmem_flags
```

DTrace associates each kernel symbol with the type used for the symbol in the corresponding operating system C code, providing easy source-based access to the native operating system data structures. In order to use external operating system variables, you will need access to the corresponding operating system source code.

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

---

### Table 3.1: (continued)

<table>
<thead>
<tr>
<th>Type and Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>id_t tid</td>
<td>The thread ID of the current thread. For threads associated with user processes, this value is equal to the result of a call to pthread_self(3C).</td>
</tr>
<tr>
<td>uint64_t timestamp</td>
<td>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.</td>
</tr>
<tr>
<td>uid_t uid</td>
<td>The real user ID of the current process.</td>
</tr>
<tr>
<td>uint64_t uregs[]</td>
<td>The current thread’s saved user-mode register values at probe firing time. Use of the <code>uregs[]</code> array is discussed in Chapter 33.</td>
</tr>
<tr>
<td>uint64_t vmregs[]</td>
<td>The current thread’s active virtual machine register values at probe firing time. Use of the <code>vmregs[]</code> array is discussed in Chapter 42.</td>
</tr>
<tr>
<td>uint64_t vtimestamp</td>
<td>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.</td>
</tr>
<tr>
<td>uint64_t walltimestamp</td>
<td>The current number of nanoseconds since 00:00 Universal Coordinated Time, January 1, 1970.</td>
</tr>
</tbody>
</table>

Functions built into the D language such as `trace` are discussed in Chapter 10.
these details might cease to work when you next upgrade the corresponding piece of software. For this reason, external variables are typically used by kernel and device driver developers and service personnel in order to debug performance or functionality problems using DTrace. To learn more about the stability of your D programs, refer to Chapter 39.

Kernel symbol names are kept in a separate namespace from D variable and function identifiers, so you never need to worry about these names conflicting with your D variables. When you prefix a variable with a backquote, the D compiler searches the known kernel symbols in order using the list of loaded modules in order to find a matching variable definition. Because the illumos 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 whose variable should be accessed prior to the backquote in the symbol name. For example, each loadable kernel module typically provides a _fini(9E) function, so to refer to the address of the _fini function provided by a kernel module named foo, you would write:

```d
foo'_fini
```

You can apply any of the D operators to external variables, except those that modify values, subject to the usual rules for operand types. When you launch DTrace, the D compiler loads the set of variable names corresponding to the active kernel modules, so declarations of these variables are not required. 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 you are observing.
Chapter 4

D Program Structure

D programs consist of a set of clauses that describe probes to enable and predicates and actions to bind to these probes. D programs can also contain declarations of variables, as described in Chapter 3, and definitions of new types, described in Chapter 8. This chapter formally describes the overall structure of a D program and features for constructing probe descriptions that match more than one probe. We’ll also discuss the use of the C preprocessor, cpp, with D programs.

4.1 Probe Clauses and Declarations

As shown in our examples so 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 has the general form:

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

The predicate and list of action statements may be omitted. Any directives found outside probe clauses are referred to as declarations. Declarations may only be used outside of probe clauses. No declarations inside of the enclosing { } are permitted and declarations may not be interspersed between the elements of the probe clause shown above. Whitespace can be used to separate any D program elements and to indent action statements.

Declarations can be used to declare D variables and external C symbols as discussed in Chapter 3, or to define new types for use in D, as described in Chapter 8. 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. D pragmas are used, for example, to set run-time DTrace options; see Chapter 16 for details.

4.2 Probe Descriptions

Every D program clause begins with a list of one or more probe descriptions, each taking the usual form:
**4. D Program Structure**

_provided: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 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, future versions of DTrace might include new providers whose probes 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 published by the DTrace `syscall` provider.

Probe descriptions also support a pattern matching syntax similar to the shell _globbing_ pattern matching syntax described in sh(1). 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. The complete probe description must match on every field in order to successfully match and enable a probe. A probe description field that is not a pattern must exactly match the corresponding field of the probe. A description field that is empty matches any probe.

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>_*</code></td>
<td>Matches any string, including the null string.</td>
</tr>
<tr>
<td><code>_?</code></td>
<td>Matches any single character.</td>
</tr>
<tr>
<td><code>_[]</code></td>
<td>Matches any one of the enclosed characters. A pair of characters separated by <code>_–</code> matches any character between the pair, inclusive. If the first character after the <code>_[</code> is <code>_!</code>, any character not enclosed in the set is matched.</td>
</tr>
<tr>
<td><code>_\</code></td>
<td>Interpret the next character as itself, without any special meaning.</td>
</tr>
</tbody>
</table>

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 using the patterns on the command line with `dtrace -l`. For example, the command `dtrace -l -f kmem_*` lists all DTrace probes in functions whose names 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 words “lwp” or “sock” fire:

```
syscall::*lwp::*entry, syscall::*sock::*entry
|
    trace(timestamp);
```


A probe description may also specify a probe using its integer probe ID. For example, the clause:

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

could be used to enable probe ID 12345, as reported by `dtrace -l -i 12345`. 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.

### 4.3 Predicates

Predicates are expressions enclosed in slashes // that are evaluated at probe firing time to determine whether the associated actions should be executed. Predicates are the primary conditional construct 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 previously described D operators and may 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.

### 4.4 Actions

Probe actions are described by a list of statements separated by semicolons (;) and enclosed in braces { }. If you only want to note that a particular probe fired on a particular CPU without tracing any data or performing any additional actions, you can specify an empty set of braces with no statements inside.

### 4.5 Use of the C Preprocessor

The C programming language used for defining illumos 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 -C` option. This option causes `dtrace` to first execute the `cpp(1)` 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*.

The D compiler automatically loads the set of C type descriptions associated with the operating system implementation, but you can use the preprocessor to include other type definitions such as types 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. Typical C header files include only external declarations of types and symbols, which will be correctly interpreted by the D compiler. The D compiler cannot parse C header files that include additional program elements like C function source code and will produce an appropriate error message.
Chapter 5

Pointers and 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 chapter 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 chapter as the D pointer syntax is the same as the corresponding ANSI-C syntax. You should read Section 5.8 and Section 5.9 as they describe features and issues specific to DTrace.

5.1 Pointers and Addresses

The illumos 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 on memory resources is referred to as an address space, which associates a range of address values (either \[0 \ldots 0xffffffff\] for a 32-bit address space or \[0 \ldots 0xffffffffffffffff\] 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 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 to indicate you want to declare a pointer type. For example, the declaration:

```d
int *p;
```

declares a D global variable named `p` that is a pointer to an integer. This declaration means that `p` itself is an integer of size 32 or 64-bits whose value 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 `isainfo(1) -b` command to determine the number of bits 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 using the & operator. For example, the operating system kernel source code declares an int kmem_flags tunable. You could trace the address of this int by tracing the result of applying the & operator to the name of that object in D:

```d
trace(&'kmem_flags);
```

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:

```d
p = &'kmem_flags;
trace(*p);
trace('kmem_flags);
```

The left-hand fragment creates a D global variable pointer p. Because the kmem_flags object is of type int, the type of the result of &'kmem_flags is int *(that is, pointer to int). The left-hand fragment traces the value of *p, which follows the pointer back to the data object kmem_flags. This fragment is therefore the same as the right-hand fragment, which simply traces the value of the data object directly using its name.

### 5.2 Pointer Safety

If you are a C or C++ programmer, you may be a bit frightened after reading the previous section because you know that misuse of pointers in your programs can cause your programs to crash. DTrace is a robust, safe environment for executing your D programs where these mistakes cannot cause program crashes. You may indeed write a buggy D program, but invalid D pointer accesses will not cause DTrace or the operating system kernel to fail or crash in any way. Instead, the DTrace software will detect any invalid pointer accesses, disable your instrumentation, and report the problem back to you for debugging.

If you have programmed in the Java programming language, you probably know 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 found in the Java programming language that prevent buggy programs from damaging themselves or each other. DTrace’s error reporting is similar to the run-time environment for the Java programming language that detects a programming error and reports an exception back to you.

To see DTrace’s error handling and reporting, write a deliberately bad D program using pointers. In an editor, type the following D program and save it in a file named badptr.d:

```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 to be 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 using the expression \*x, and 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 error:

```d
# dtrace -s badptr.d
dtrace: script '/dev/stdin' matched 1 probe
CPU ID FUNCTION:NAME
dtrace: error on enabled probe ID 1 (ID 1: dtrace::BEGIN): invalid address
(Dx0) in action #2 at DIF offset 4
dtrace: 1 error on CPU 0
^C
```

The other problem that can arise from programs that use invalid pointers is an alignment error. By architectural convention, fundamental data objects such as integers are aligned in memory according to their size. For example, 2-byte integers are aligned on addresses that are multiples of 2, 4-byte integers on multiples of 4, and so on. If you dereference a pointer to a 4-byte integer and your pointer address is an invalid value that is not a multiple of 4, your access will fail with an alignment error. Alignment errors in D almost always indicate that your pointer has an invalid or corrupt value due to a bug in your D program. You can create an example alignment error by changing the source code of badptr.d to use the address `(int *)2` instead of NULL. Because `int` is 4 bytes and 2 is not a multiple of 4, the expression `\*x` results in a DTrace alignment error.

For details about the DTrace error mechanism, see Section 17.3.

5.3 Array Declarations and Storage

D provides support for scalar arrays in addition to the dynamic associative arrays described in Chapter 3. 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, but these are sometimes needed when accessing existing operating system array data structures declared in C. Aggregations are described in Chapter 9.

A D scalar array of 5 integers would be declared by using the type int and suffixing the declaration with the number of elements in square brackets as follows:

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

The following diagram shows a visual representation of the array storage:

```
```

Figure 5.1: Scalar Array Representation

The D expression `a[0]` is used to refer 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 five integers referenced by an integer key as follows:
Pointers and Arrays

5. Pointers and Arrays

int a[int];

and 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 allocated for the array. An associative array, on the other hand, 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 will be allocated by DTrace which may or may not be consecutive. Associative array keys are abstract names for the corresponding value that 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 will always create 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 see the definition of the array size and infer that the array is a scalar array.

5.4 Pointer and Array Relationship

Pointers and arrays have a special relationship in D, just as they do in ANSI-C. An 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, so 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 left-hand fragment, the pointer p is assigned to the address of the first array element in 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 right-hand 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 DTrace runtime environment. If you access memory beyond the end of an array’s predefined value, you will either get an unexpected result or DTrace will report an invalid address error, as shown in the previous example. As always, you can’t damage DTrace itself or your operating system, but you will 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. An array variable names the array storage itself, not the location of an integer that in turn contains the location of the array. This difference is illustrated in the following diagram:
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 simply copies the pointer address in \( y \) to the storage location 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 an array, the statement \( p = a \) is permitted; this statement is equivalent to the statement \( p = &a[0] \).

5.5 Pointer Arithmetic

Since pointers are just integers 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:

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

This fragment creates an integer pointer \( x \) and then trace 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 \( x \) were assigned to the address of an array \( a \) like the one shown in Figure 5.2, 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 using the \( += \), \( + \), or \( ++ \) operators.

Pointer arithmetic is also applied 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:

```d
int *x, *y;
int a[5];
BEGIN {
    x = &a[0];
```
5.6 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 using the type `void *`, where the keyword `void` represents the absence of specific type information, or using the built-in type alias `uintptr_t` which is aliased to an unsigned integer type of size 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` may 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 may 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.

5.7 Multi-Dimensional Arrays

Multi-dimensional scalar arrays are used infrequently in D, but are provided for compatibility with ANSI-C and for observing and accessing operating system data structures created 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 12 rows by 34 columns, you would write the declaration:

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

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

```d
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.

You should 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 will report an appropriate error message and refuse to compile your program.

5.8 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 order to 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, be sure not to cache the address 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 using their name or by applying the array index operator [ ] to a D scalar or associative array. You may only call functions defined by the DTrace environment by name as specified in Chapter 10. Indirect function calls using pointers are not permitted in D.

5.9 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. Your entire illumos system manages many address spaces: one for the operating system kernel, and one for each user process. Since 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(2)), 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 a kernel address space access, which would result in an invalid address error or in returning unexpected data to your D program depending upon 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 described in Chapter 10 to the user address space pointer. Take care when writing your D programs to name and comment variables storing user addresses appropriately to avoid confusion. You can also store user addresses as uintptr_t so you don’t accidentally compile D code that dereferences them. Techniques for using DTrace on user processes are described in Chapter 33.
Chapter 6

Strings

DTrace provides support for tracing and manipulating strings. This chapter 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 so you can easily and unambiguously use them in your tracing programs.

6.1 String Representation

Strings are represented in DTrace 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 may not exceed the length of this predefined string limit, but the limit can be modified in your D program or on the dtrace command line by tuning the strsize option. Refer to Chapter 16 for more information on 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 a char * in that it is the address of a sequence of characters, but the D compiler and D functions like trace provide enhanced capabilities when applied to expressions of type string. For example, the string type removes the ambiguity of the type char * when you need to trace the actual bytes of a string. In the D statement:

trace(s);

if s is of type char *, DTrace will trace the value of the pointer s (that is, it will trace an integer address value). In the D statement:

trace(*s);

by definition of the * operator, the D compiler will dereference the pointer s and trace the single character at that location. These behaviors are essential to permitting you to manipulate character pointers that by design 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 D statement:

trace(s);

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. You can also perform lexical comparison of expressions of type string, as described in Section 6.5.
6.2 String Constants

String constants are enclosed in 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 may also contain any of the special character escape sequences defined for character constants in Table 2.5.

6.3 String Assignment

Unlike assignment of char * variables, strings are copied by value, not by reference. String assignment is performed using the = operator and 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 variable of type string 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 6 bytes of the string "hello" into it (5 printable characters plus the null byte). String assignment is analogous to the C library function strcpy(3C), except that if the source string exceeds the limit of the storage of the destination string, the resulting string is automatically truncated 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.

6.4 String Conversion

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

s = (string) expression s = stringof ( expression )

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 will prevent you from damaging the system or DTrace, but you might end up tracing a sequence of undecipherable characters.
6.5 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`, as described in Section 6.3. All of the relational operators can be used to compare strings:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;</code></td>
<td>left-hand operand is less than right-operand</td>
</tr>
<tr>
<td><code>&lt;=</code></td>
<td>left-hand operand is less than or equal to right-hand operand</td>
</tr>
<tr>
<td><code>&gt;</code></td>
<td>left-hand operand is greater than right-hand operand</td>
</tr>
<tr>
<td><code>&gt;=</code></td>
<td>left-hand operand is greater than or equal to right-hand operand</td>
</tr>
<tr>
<td><code>==</code></td>
<td>left-hand operand is equal to right-hand operand</td>
</tr>
<tr>
<td><code>!=</code></td>
<td>left-hand operand is not equal to right-hand operand</td>
</tr>
</tbody>
</table>

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, similar to the C library routine `strcmp(3C)`. Each byte is compared using its corresponding integer value in the ASCII character set, as shown in `ascii(5)`, until a null byte is read or the maximum string length is reached. Some example D string comparisons and their results are:

```
"coffee" < "espresso"          ... returns 1 (true)
"coffee" == "coffee"           ... returns 1 (true)
"coffee" >= "mocha"            ... returns 0 (false)
```
Chapter 7

Structs and Unions

Collections of related variables can be grouped together into composite data objects called structs and unions. You can 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 chapter explores the syntax and semantics for creating and manipulating these composite types and the D operators that interact with them. The syntax for structs and unions is illustrated using several example programs that demonstrate the use of the DTrace fbt and pid providers.

7.1 Structs

The D keyword struct, short for structure, is used to introduce a new type 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, think of a D struct as a class, but one with data members only and no methods.

Let’s suppose you want to create a more sophisticated system call tracing program in D that records a number of things about each read(2) and write(2) system call executed by your shell, such as 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:

```d
syscall::read:entry, syscall::write:entry
/pid == 12345/
{
    ts[probefunc] = timestamp;
    calls[probefunc]++;
}
```

However, this clause 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 program source file:

```d
struct callinfo {
    uint64_t ts; /* timestamp of last syscall entry */
```
7. STRUCTS AND UNIONS

```c
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 used to refer back to our 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 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 itself simply defines the new type; it does not create any variables or allocate any storage in DTrace. Once declared, you can use `struct callinfo` as a type throughout the remainder of your D program, and each variable of type `struct callinfo` will store a copy of the four variables described by our structure template. The members will be 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 form:

`variable-name.member-name`

The following example is an improved program using the new structure type. Go to your editor and type in the following D program and save it in a file named `rwinfo.d`:

```d
Example 7.1: rwinfo.d: Gather read(2) and write(2) Statistics
```

```c
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 %d\n",
```
After you type in the program, run `dtrace -q -s rwinfo.d`, specifying one of your shell processes. Then go type in a few commands in your shell and, when you’re done entering your shell commands, type Control-C in the `dtrace` terminal to fire the END probe and print the results:

```
# dtrace -q -s rwinfo.d 'pgrep -n ksh'
^C
```

<table>
<thead>
<tr>
<th>calls</th>
<th>max bytes</th>
<th>elapsed nsecs</th>
</tr>
</thead>
<tbody>
<tr>
<td>read</td>
<td>36</td>
<td>1024</td>
</tr>
<tr>
<td>write</td>
<td>35</td>
<td>59</td>
</tr>
</tbody>
</table>

7.2 Pointers to Structs

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

```
struct s *sp;

(*sp).m
```

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

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

DTrace provides several built-in variables which are pointers to structs, including `curpsinfo` and `curlwpsinfo`. These pointers refer to the structs `psinfo` and `lwpsinfo` respectively, and their content provides a snapshot of information about the state of the current process and lightweight process (LWP) associated with the thread that has fired the current probe. An illumos LWP is the kernel’s representation of a user thread, upon which the illumos threads and POSIX threads interfaces are built. DTrace exports this information in the same form as the `/proc` filesystem files `/proc/pid/psinfo` and `/proc/pid/lwps/lwpid/lwpsinfo` for convenience. The `/proc` structures are used by observability and debugging tools such as `ps(1)`, `pgrep(1)`, and `truss(1)`, and are defined in the system header file `<sys/procfs.h>` and are described in the proc(4) man page. Here are few example expressions using `curpsinfo`, their types, and their meanings:

```
curpsinfo->pr_pid pid_t current process ID
curpsinfo->pr_fname char [] executable file name
curpsinfo->pr_psargs char [] initial command line arguments
```

You should review the complete structure definition later by examining the `<sys/procfs.h>` header file and the corresponding descriptions in proc(4). The next example uses the `pr_psargs` member to
identify a process of interest by matching command-line arguments.

Structs are used frequently to create complex data structures 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 illumos operating system kernel and its system interfaces. In addition to using the aforementioned `curpsinfo` struct, the next example examines some kernel structs as well by observing the relationship between the `ksyms(7D)` driver and `read(2)` requests. The driver makes use of two common structs, known as `uio(9S)` and `iovec(9S)`, to respond to requests to read from the character device file `/dev/ksyms`.

The `uio` struct, accessed using the name `struct uio` or type alias `uio_t`, is described in the `uio(9S)` manual page and is used to describe an I/O request that involves copying data between the kernel and a user process. The `uio` in turn contains an array of one or more `iovec(9S)` structures which each describe a piece of the requested I/O, in the event that multiple chunks are requested using the `readv(2)` or `writev(2)` system calls. One of the kernel device driver interface (DDI) routines that operates on `struct uio` is the function `uiomove(9F)`, which is one of a family of functions kernel drivers use to respond to user process read(2) requests and copy data back to user processes.

The `ksyms` driver manages a character device file named `/dev/ksyms`, which appears to be an ELF file containing information about the kernel’s symbol table, but is in fact an illusion created by the driver using the set of modules that are currently loaded into the kernel. The driver uses the `uiomove(9F)` routine to respond to read(2) requests. The next example illustrates that the arguments and calls to read(2) from `/dev/ksyms` match the calls by the driver to `uiomove(9F)` to copy the results back into the user address space at the location specified to read(2).

We can use the `strings(1)` utility with the `-a` option to force a bunch of reads from `/dev/ksyms`. Try running `strings -a /dev/ksyms` in your shell and see what output it produces. In an editor, type in the first clause of the example script and save it in a file named `ksyms.d`:

```d
syscall::read:entry
/curpsinfo->pr_psargs == "strings -a /dev/ksyms"/
{
    printf("read %u bytes to user address %x\n", arg2, arg1);
}
```

This first clause uses the expression `curpsinfo->pr_psargs` to access and match the command-line arguments of our `strings(1)` command so that the script selects the correct read(2) 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 in and execute the command `dtrace -q -s ksym.s d` in one shell, and then type in the command `strings -a /dev/ksyms` in another shell. As `strings(1)` executes, you will see output from DTrace similar to the following example:

```d
# dtrace -q -s ksym.s
read 8192 bytes to user address 80639fc
read 8192 bytes to user address 80639fc
read 8192 bytes to user address 80639fc
read 8192 bytes to user address 80639fc
...
^C
#
```

This example can be extended using a common D programming technique to follow a thread from this initial read(2) request deeper into the kernel. Upon entry to the kernel in `syscall::read:entry`, the next script sets a thread-local flag variable indicating this thread is of interest, and clears this flag on `syscall::read:return`. Once the flag is set, it can be used as a predicate on other probes to
instrument kernel functions such as uio(9F). The DTrace function boundary tracing (fbt) provider publishes probes for entry and return to functions defined within the kernel, including those in the DDI. Type in the following source code which uses the fbt provider to instrument uio(9F) and again save it in the file ksyms.d:

```
Example 7.2: ksyms.d: Trace read(2) and uio(9F) Relationship

/*@ *
 * When our strings(1) invocation starts a read(2), set a watched
 * flag on the current thread. When the read(2) finishes, clear the
 * watched flag.
 */
syscall::read:entry
    /curpsinfo->pr_psargs == "strings -a /dev/ksyms"/
    {
        printf("read %u bytes to user address %x\n", arg2, arg1);
        self->watched = 1;
    }
syscall::read:return
    /self->watched/
    {
        self->watched = 0;
    }

/*@ *
 * Instrument uio(9F). The prototype for this function is as follows:
 * int uio(9F)(caddr_t addr, size_t nbytes, enum uio_rw rwflag, uio_t *uio);
 */
fbt::uio:entry
    /self->watched/
    {
        this->iov = args[3]->uio_iov;
        printf("uio(9F) %u bytes to %p in pid %d\n",
            this->iov->iov_len, this->iov->iov_base, pid);
    }
```

The final clause of the example uses the thread-local variable `self->watched` to identify when a kernel thread of interest enters the DDI routine uio(9F). Once there, the script uses the built-in `args` array to access the fourth argument (`args[3]`) to uio(9F), which is a pointer to the struct `uio` representing the request. The D compiler automatically associates each member of the `args` array with the type corresponding to the C function prototype for the instrumented kernel routine. The `uio` member contains a pointer to the struct `iovec` for the request. A copy of this pointer is saved for use in our clause in the clause-local variable `this->iov`. In the final statement, the script dereferences `this->iov` to access the `iovec` members `iov_len` and `iov_base`, which represent the length in bytes and destination base address for uio(9F), respectively. These values should match the input parameters to the read(2) system call issued on the driver. Go to your shell and run `dtrace -q -s ksyms.d` and then again enter the command `strings -a /dev/ksyms` in another shell. You should see output similar to the following example:

```
# dtrace -q -s ksyms.d
read 8192 bytes at user address 80639fc
uio(9F) 8192 bytes to 80639fc in pid 101038
read 8192 bytes at user address 80639fc
```
The addresses and process IDs will be different in your output, but you should observe that the input arguments to read(2) match the parameters passed to uio-move(9F) by the ksym driver.

### 7.3 Unions

Unions are another kind of composite type 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, and the memory alignment used for the union is the maximum alignment required by the union members.

The illumos kstat framework defines a struct containing a union that is used in the following example to illustrate and observe C and D unions. The kstat framework is used to export a set of named counters representing kernel statistics such as memory usage and I/O throughput. The framework is used to implement utilities such as mpstat(1M) and iostat(1M). This framework uses struct kstat_named to represent a named counter and its value and is defined as follows:

```c
struct kstat_named {
    char name[KSTAT_STRLEN]; /* name of counter */
    uchar_t data_type;       /* data type */
    union {
        char c[16];    /* data type */
        int32_t i32;
        uint32_t ui32;
        long l;
        ulong_t ul;
        ...
    } value; /* value of counter */
};
```

The examined declaration is shortened for illustrative purposes. The complete structure definition can be found in the <sys/kstat.h> header file and is described in kstat_named(9S). The declaration above is valid in both ANSI-C and D, and defines a struct containing as one of its members a union value with members of various types, depending on the type of the counter. Notice that since the union itself is declared inside of another type, struct kstat_named, a formal name for the union type is omitted. This declaration style is known as an *anonymous union*. The member named value is of a union type described by the preceding declaration, but this union type itself has no name because it does not need to be used anywhere else. The struct member data_type is assigned a value that indicates which union member is valid for each object of type struct kstat_named. A set of C preprocessor tokens are defined for the values of data_type. For example, the token KSTAT_DATA_CHAR is equal to zero and indicates that the member value.c is where the value is currently stored.
Example 7.3 demonstrates accessing the \texttt{kstat\_named.value} union by tracing a user process. The \texttt{kstat} counters can be sampled from a user process using the \texttt{kstat\_data\_lookup(3KSTAT)} function, which returns a pointer to a \texttt{struct kstat\_named}. The \texttt{mpstat(1M)} utility calls this function repeatedly as it executes in order to sample the latest counter values. Go to your shell and try running \texttt{mpstat 1} and observe the output. Press Control-C in your shell to abort \texttt{mpstat} after a few seconds. To observe counter sampling, we would like to enable a probe that fires each time the \texttt{mpstat} command calls the \texttt{kstat\_data\_lookup(3KSTAT)} function in \texttt{libkstat}. To do so, we’re going to make use of a new DTrace provider: \texttt{pid}. The \texttt{pid} provider permits you to dynamically create probes in user processes at C symbol locations such as function entry points. You can ask the \texttt{pid} provider to create a probe at a user function entry and return sites by writing probe descriptions of the form:

\begin{verbatim}
pid\_process-ID:object-name:function-name:entry
pid\_process-ID:object-name:function-name:return
\end{verbatim}

For example, if you wanted to create a probe that fires on entry to \texttt{kstat\_data\_lookup(3KSTAT)} in process ID 12345, you would write the following probe description:

\begin{verbatim}
pid\_12345:libkstat:kstat\_data\_lookup:entry
\end{verbatim}

The \texttt{pid} provider inserts dynamic instrumentation into the specified user process at the program location corresponding to the probe description. The probe implementation forces each user thread that reaches the instrumented program location to trap into the operating system kernel and enter DTrace, firing the corresponding probe. So although the instrumentation location is associated with a user process, the DTrace predicates and actions you specify still execute in the context of the operating system kernel. The \texttt{pid} provider is described in further detail in Chapter 30.

Instead of having to edit your D program source each time you wish to apply your program to a different process, you can insert identifiers called \textit{macro variables} into your program that are evaluated at the time your program is compiled and replaced with the additional \texttt{dtrace} command-line arguments. Macro variables are specified using a dollar sign \$ followed by an identifier or digit. If you execute the command \texttt{dtrace -s script foo bar baz}, the D compiler will automatically define the macro variables \$1, \$2, and \$3 to be the tokens \texttt{foo, bar,} and \texttt{baz} respectively. You can use macro variables in D program expressions or in probe descriptions. For example, the following probe descriptions instrument whatever process ID is specified as an additional argument to \texttt{dtrace}:

\begin{verbatim}
pid\$1:libkstat:kstat\_data\_lookup:entry
\{
  self->ksname = arg1;
\}
pid\$1:libkstat:kstat\_data\_lookup:return
/self->ksname != NULL && arg1 != NULL/
\{
  this->ksp = (kstat\_named\_t *)copyin(arg1, sizeof (kstat\_named\_t));
  printf("%s has ui64 value %u\n", copyinstr(self->ksname),
          this->ksp->value.ui64);
}\n\end{verbatim}

\begin{verbatim}
pid\$1:libkstat:kstat\_data\_lookup:return
/self->ksname != NULL && arg1 == NULL/
\{
  self->ksname = NULL;
\}
\end{verbatim}
Macro variables and reusable scripts are described in further detail in Chapter 15. Now that we know how to instrument user processes using their process ID, let’s return to sampling unions. Go to your editor and type in the source code for our complete example and save it in a file named `kstat.d`:

---

**Example 7.3: kstat.d: Trace Calls to kstat_data_lookup(3KSTAT)**

```d
pid$1:libkstat:kstat_data_lookup:entry
{
    self->ksname = arg1;
}

pid$1:libkstat:kstat_data_lookup:return
/self->ksname != NULL && arg1 != NULL/
{
    this->ksp = (kstat_named_t *) copyin(arg1, sizeof (kstat_named_t));
    printf("%s has ui64 value %u
",
           copyinstr(self->ksname), this->ksp->value.ui64);
}

pid$1:libkstat:kstat_data_lookup:return
/self->ksname != NULL && arg1 == NULL/
{
    self->ksname = NULL;
}
```

Now go to one of your shells and execute the command `mpstat 1` to start mpstat(1M) running in a mode where it samples statistics and reports them once per second. Once `mpstat` is running, execute the command `dtrace -q -s kstat.d `pgrep mpstat` in your other shell. You will see output corresponding to the statistics that are being accessed. Press Control-C to abort `dtrace` and return to the shell prompt.

```
# dtrace -q -s kstat.d 'pgrep mpstat'
cpu_ticks_idle has ui64 value 41154176
cpu_ticks_user has ui64 value 1137
cpu_ticks_kernel has ui64 value 12310
cpu_ticks_wait has ui64 value 903
hat_fault has ui64 value 0
as_fault has ui64 value 48053
maj_fault has ui64 value 1144
xcalls has ui64 value 123832170
intr has ui64 value 165264090
intrthread has ui64 value 124094974
pswitch has ui64 value 840625
inv_swtch has ui64 value 1484
cpumigrate has ui64 value 36284
mutex_adenters has ui64 value 35574
rw_rdfails has ui64 value 2
rw_wrfails has ui64 value 2
...
^C
```

If you capture the output in each terminal window and subtract each value from the value reported by the previous iteration through the statistics, you should be able to correlate the `dtrace` output with the `mpstat` output. The example program records the counter name pointer on entry to the lookup function, and then performs most of the tracing work on return from `kstat_data_lookup(3KSTAT)`. The D built-in functions `copyinstr` and `copyin` copy the function results from the user process back into DTrace.
when \texttt{arg1} (the return value) is not NULL. Once the \texttt{kstat} data has been copied, the example reports the \texttt{ui64} counter value from the union. This simplified example assumes that \texttt{mpstat} samples counters that use the \texttt{value.ui64} member. As an exercise, try recoding \texttt{kstat.d} to use multiple predicates and print out the union member corresponding to the \texttt{data_type} member. You can also try to create a version of \texttt{kstat.d} that computes the difference between successive data values and actually produces output similar to \texttt{mpstat}.

\section*{7.4 Member Sizes and Offsets}

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

\texttt{sizeof expression} \hspace{1cm} \texttt{sizeof (type-name)}

For example, the expression \texttt{sizeof (uint64_t)} would return the value 8, and the expression \texttt{sizeof (callinfo.ts)} would also return 8 if inserted into the source code of our example program above. The formal return type of the \texttt{sizeof} operator is the type alias \texttt{size_t}, which is defined to be an unsigned integer of the same size as a pointer in the current data model, and is used to represent byte counts. When the \texttt{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 \texttt{sizeof} anywhere an integer constant is required.

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

\texttt{offsetof (type-name, member-name)}

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

\section*{7.5 Bit-Fields}

D also permits the definition of integer struct and union members of arbitrary numbers of bits, known as \textit{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:

\begin{verbatim}
struct s {
    int a : 1;
    int b : 3;
    int c : 12;
};
\end{verbatim}

The bit-field width is an integer constant 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 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. C and D compilers try to pack bits as efficiently as possible, but they are free to do so in any order or fashion they desire, so 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 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 may not 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 using the & operator.
Chapter 8

Type and Constant Definitions

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

8.1 Typedef

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

```
typedef unsigned char uint8_t;
```

is used internally by the D compiler to create the `uint8_t` type alias. Type aliases can be used 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:

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

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

8.2 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 using a declaration such as:
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 in the following example:

```dlang
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. Once an enumeration is defined, the enumerators can be used anywhere in a D program that an integer constant can be used. In addition, the enumeration `enum colors` is also defined as a type that is equivalent to an `int`. The D compiler will allow 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, so you cannot define the same enumerator identifier in more than one enumeration. However, you may define more than one enumerator that has 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 defined in the operating system kernel and its loadable modules, but these enumerators are not globally visible in your D program. Kernel enumerators are only visible when used as an argument to one of the binary comparison operators when compared to an object of the corresponding enumeration type. For example, the function `uiomove(9F)` has a parameter of type `enum uio_rw` defined as follows:

```dlang
enum uio_rw { UIO_READ, UIO_WRITE };
```

The enumerators UIO_READ and UIO_WRITE are not normally visible in your D program, but you can promote them to global visibility by comparing a value of type `enum uio_rw`, as shown in the following example clause:

```dlang
fbt::uiomove:entry
/args[2] == UIO_WRITE/
{
    ...
}
```

This example traces calls to the `uiomove(9F)` function for write requests by comparing `args[2]`, a variable of type `enum uio_rw`, to the enumerator UIO_WRITE. Because the left-hand argument is an enumeration type, the D compiler searches the enumeration when attempting to resolve the right-hand identifier. This feature protects your D programs against inadvertent identifier name conflicts with the large collection of enumerations defined in the operating system kernel.
8.3 Inlines

D named constants can also be defined 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 using the compiled syntax tree and not simply a set of lexical tokens. An inline directive is specified using a declaration of the form:

```plaintext
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. Once 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:

```plaintext
inline string hello = "hello";
inline int number = 100 + 23;
BEGIN
{
    trace(hello);
    trace(number);
}
```

An inline name may be used anywhere a global variable of the corresponding type can be 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 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/lib/dtrace` that contain inline directives you can use in your D programs. For example, the `signal.d` library includes directives of the form:

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

These inline definitions provide you access to the current set of illumos signal names described in signal(3HEAD). Similarly, the `errno.d` library contains inline directives for the C `errno` constants described in Intro(2).

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

8.4 Type Namespaces

This section discusses D namespaces and namespace issues related to types. 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 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 running on the system. A single D program may 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 available to DTrace and the D compiler. To manage this situation, the D compiler associates each type with a namespace identified by the containing program object. Types from a particular program object can be accessed by specifying the object name and backquote (`) scoping operator in any type name.

For example, if a kernel module named foo contains the following C type declaration:

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

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

```c
struct foo'bar foo'bar_t
```

The backquote 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 for C and D 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 acquired using the C preprocessor `cpp(1)` using the `dtrace -C` option will be processed by and added to the C scope. As a result, you can include C header files containing type declarations which 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 `uint32_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 your D program consisting of member types from other namespaces, the member types will be 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 backquote operator, the compiler searches the set of active type namespaces to find a match 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 ascending order by kernel module ID. This ordering guarantees that the binary objects that form the core kernel are searched before any loadable kernel modules, but does not guarantee any ordering properties among the loadable modules. You should use the scoping operator when accessing types defined in loadable kernel modules to avoid type name conflicts with other kernel modules.

The D compiler uses compressed ANSI-C debugging information provided with the core illumos kernel modules in order to automatically access the types associated with the operating system source code without the need for accessing the corresponding C include files. This symbolic debugging information might not be available for all kernel modules on your system. The D compiler will report an error if you attempt to access a type within the namespace of a module that lacks compressed C debugging information intended for use with DTrace.
Chapter 9

Aggregations

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 wanted to know the number of system calls by user ID, you would not necessarily care about the datum collected at each system call. 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(1) or perl(1). However, in DTrace the aggregating of data is a first-class operation. This chapter describes the DTrace facilities for manipulating aggregations.

9.1 Aggregating Functions

An aggregating function is one that has the following property:

\[ f(f(x_0) \cup f(x_1) \cup \ldots \cup f(x_n)) = f(x_0 \cup x_1 \cup \ldots \cup x_n) \]

where \( x_n \) is a set of arbitrary data. That is, applying an aggregating function to subsets of the whole and then applying it again to the results gives the same result as applying it to the whole itself. For example, consider a function \( \text{SUM} \) that 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 \( \text{SUM} \) to the entire set is \{29\}. Similarly, the result of applying \( \text{SUM} \) to the subset consisting of the first three elements is \{5\}, the result of applying \( \text{SUM} \) to the set consisting of the subsequent three elements is \{12\}, and the result of applying \( \text{SUM} \) to the remaining three elements is also \{12\}. \( \text{SUM} \) is an aggregating function because applying it to the set of these results, \{5, 12, 12\}, yields the same result, \{29\}, as applying \( \text{SUM} \) to the original data.

Not all functions are aggregating functions. An example of a non-aggregating function is the function \( \text{MEDIAN} \) that 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 it as are less than it.) The \( \text{MEDIAN} \) is derived by sorting the set and selecting the middle element. Returning to the original raw data, if \( \text{MEDIAN} \) 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 \( \text{MEDIAN} \) to the next three elements yields \{4\} and applying \( \text{MEDIAN} \) to the final three elements yields \{4\}. Applying \( \text{MEDIAN} \) to each of the subsets thus yields the set \{2, 4, 4\}. Applying \( \text{MEDIAN} \) to this set yields the result \{4\}. However, sorting the original set yields \{1, 2, 2, 2, 3, 4, 4, 5, 6\}. Applying \( \text{MEDIAN} \) to this set thus yields \{3\}. Because these results do not match, \( \text{MEDIAN} \) is not an aggregating function.
Many common functions for understanding a set of data are aggregating functions. These functions include counting the number of elements in the set, computing the minimum value of the set, computing the maximum value of the set, and summing all elements in the set. Determining the arithmetic mean of the set can be constructed from the function to count the number of elements in the set and the function to sum the number the elements in the set.

However, several useful functions are not aggregating functions. These functions include computing the mode (the most common element) of a set, the median value of the set, or the standard deviation of the set.

Applying aggregating functions to data as it is traced has a number of advantages:

- 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. After the new result is calculated, the new element may be discarded. This process reduces the amount of storage 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.

### 9.2 Aggregations

DTrace stores the results of aggregating functions in objects called *aggregations*. The aggregation results are indexed using a tuple of expressions similar to those used for associative arrays. In D, the syntax for an aggregation is:

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

where `name` is the name of the aggregation, `keys` is a comma-separated list of D expressions, `aggfunc` is one of the DTrace aggregating functions, and `args` is a comma-separated list of arguments appropriate for the aggregating function. The aggregation `name` is a D identifier that is prefixed with the special character `@`. All aggregations named in your D programs are global variables; there are no thread- or clause-local aggregations. The aggregation names are kept in a separate identifier namespace from other D global variables. Remember that `a` and `@a` are not the same variable if you reuse names. 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 `@_`.

The DTrace aggregating functions are shown in the following table. Most aggregating functions take just a single argument that represents the new datum.

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Arguments</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>count</td>
<td>none</td>
<td>The number of times called.</td>
</tr>
<tr>
<td>sum</td>
<td>scalar expr</td>
<td>The total value of the specified expressions.</td>
</tr>
<tr>
<td>avg</td>
<td>scalar expr</td>
<td>The arithmetic average of the specified expressions.</td>
</tr>
<tr>
<td>min</td>
<td>scalar expr</td>
<td>The smallest value among the specified expressions.</td>
</tr>
<tr>
<td>max</td>
<td>scalar expr</td>
<td>The largest value among the specified expressions.</td>
</tr>
</tbody>
</table>
9.2. Aggregations

Table 9.1: (continued)

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Arguments</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>lquantize</td>
<td>scalar expression, lower bound, upper</td>
<td>A linear frequency distribution, sized by the specified range, of the values of the specified expressions. Increments the value in the highest bucket that is less than the specified expression.</td>
</tr>
<tr>
<td></td>
<td>bound, step value</td>
<td></td>
</tr>
<tr>
<td>quantize</td>
<td>scalar expression</td>
<td>A power-of-two frequency distribution of the values of the specified expressions. Increments the value in the highest power-of-two bucket that is less than the specified expression.</td>
</tr>
</tbody>
</table>

For example, to count the number of write(2) system calls in the system, you could use an informative string as a key and the count aggregating function:

```c
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 the user presses Control-C. The following example output shows the result of running this command, waiting for a few seconds, and pressing Control-C:

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

write system calls 179
```

You can count system calls per process name using the execname variable as the key to an aggregation:

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

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

```
# dtrace -s writesbycmd.d
dtrace: script './writesbycmd.d' matched 1 probe
^C
dtrace 1
cat 4
sed 9
head 9
grep 14
find 15
tail 25
mountd 28
```

71
Alternatively, you might want to further examine writes organized by both executable name and file descriptor. The file descriptor is the first argument to write(2), so the following example uses a key consisting 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
```

```
^C
```

```
cat  1  58
sed  1  60
grep 1  89
tee  1  156
tee  3  156
make.bin  5  164
acomp 1  263
macrogen 4  286
cg  1  397
acomp 3  736
make.bin 1  880
iropt 4  1731
```

```
```

The following example displays the average time spent in the write system call, organized by process name. This example uses the \texttt{avg} aggregating function, specifying the expression to average as the argument. The example averages the wall clock time spent in the system call:

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

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

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

```
# dtrace -s writetime.d
```

```
dtrace: script './writetime.d' matched 2 probes
```
The average can be useful, but often does 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:

```c
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 ones. The following example shows a selection of sample output:

```plaintext
lint
value ------------- Distribution ------------- count
8192 | 0
16384 | 2
32768 | 0
65536 |@@@@@@@@@@@@@@@@@@@@@@@ 74
131072 |@@@@@@@@@@@@@@@@@@@@@@@@ 59
262144 |@@@ 14
524288 | 0

acomp
value ------------- Distribution ------------- count
4096 | 0
8192 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 840
16384 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 750
32768 |@@@ 165
65536 |@@@@@@@@@@@ 460
131072 |@@@@@@@@@@@@@@@@@@@@@@@ 446
262144 |@@@ 16
524288 | 0
1048576 | 1
2097152 | 0
```
Notice that the rows for the frequency distribution are always power-of-two values. Each rows indicates the count of the number of elements greater than or equal to the corresponding value, but less than the next larger row value. For example, the above output shows that iropt had 4,149 writes taking between 8,192 nanoseconds and 16,383 nanoseconds, inclusive.

While quantize is useful for getting quick insight into the 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 a step. 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, use a linear quantization with a small range, as shown in the following example:

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

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

```d
mountd
```

Notice that the rows for the frequency distribution are always power-of-two values. Each rows indicates the count of the number of elements greater than or equal to the corresponding value, but less than the next larger row value. For example, the above output shows that iropt had 4,149 writes taking between 8,192 nanoseconds and 16,383 nanoseconds, inclusive.

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

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

```d
mountd
```

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

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

```d
mountd
```

Notice that the rows for the frequency distribution are always power-of-two values. Each rows indicates the count of the number of elements greater than or equal to the corresponding value, but less than the next larger row value. For example, the above output shows that iropt had 4,149 writes taking between 8,192 nanoseconds and 16,383 nanoseconds, inclusive.

While quantize is useful for getting quick insight into the 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 a step. 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, use a linear quantization with a small range, as shown in the following example:

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

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

```d
mountd
```
You can also use the \texttt{lquantize} aggregating function to aggregate on time since some point in the past. This technique allows 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 executing the \texttt{date(1)} command:

```plaintext
syscall::exec:return,
systemcall::exece:return
/execname == "date"/
{
    self->start = vtimestamp;
}
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((vtimestamp - self->start) / 1000, 0, 10000, 100);
}
syscall::rexit:entry
/self->start/
{
    self->start = 0;
}
```

The preceding script provides greater insight into system call behavior when many \texttt{date(1)} processes are executed. To see this result, run \texttt{sh -c ‘while true; do date >/dev/null; done’} in one window, while executing the D script in another. The script produces a profile of the system call behavior of the \texttt{date(1)} command:

```plaintext
# dtrace -s dateprof.d
dtrace: script './dateprof.d' matched 218 probes
```
This output provides a rough idea of the different phases of the date(1) command with respect to the services required of the kernel. To better understand these phases, you might want to understand which system calls are being called when. If so, you could change the D script to aggregate on the variable `probefunc` instead of a constant string.

For some operations, visibility into microsecond resolution is critical, while for other (longer) operations, millisecond resolution is sufficient — and some classes of operations may take hundreds or thousands of milliseconds to complete. If one makes the wrong choice as the resolution of aggregation, one either ends up clogging the system with unnecessarily fine-grained data, or discarding valuable information in overly coarse-grained data. One might think that one could infer the interesting latency range from the nature of the operation, but this is unfortunately not the case: I/O operations (a typically-millisecond resolution operation) can take but microseconds, and CPU scheduling operations (a typically-microsecond resolution operation) can take hundreds of milliseconds. Indeed, the problem is that one often does not know what order of magnitude of resolution is interesting for a particular operation until one has a feel for the data for the specific operation — one needs to instrument the system to best know how to instrument the system!

To understand this case use the `llquantize` aggregating function.

Here is a simple example of how the aggregation is both logarithmic and linear:

```c
system calls over time

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>@@</td>
<td>20530</td>
</tr>
<tr>
<td>100</td>
<td>@@@@@</td>
<td>48814</td>
</tr>
<tr>
<td>200</td>
<td>@@@</td>
<td>28119</td>
</tr>
<tr>
<td>300</td>
<td>@</td>
<td>14646</td>
</tr>
<tr>
<td>400</td>
<td>@@@@@</td>
<td>41237</td>
</tr>
<tr>
<td>500</td>
<td>@@@</td>
<td>1259</td>
</tr>
<tr>
<td>600</td>
<td>@@@</td>
<td>218</td>
</tr>
<tr>
<td>700</td>
<td>@@@</td>
<td>116</td>
</tr>
<tr>
<td>800</td>
<td>@@@</td>
<td>12783</td>
</tr>
<tr>
<td>900</td>
<td>@@@@@</td>
<td>28133</td>
</tr>
<tr>
<td>1000</td>
<td>@@@@@</td>
<td>7897</td>
</tr>
<tr>
<td>1100</td>
<td>@@@@@</td>
<td>14065</td>
</tr>
<tr>
<td>1200</td>
<td>@@@@@</td>
<td>27549</td>
</tr>
<tr>
<td>1300</td>
<td>@@@@@</td>
<td>25715</td>
</tr>
<tr>
<td>1400</td>
<td>@@@@@</td>
<td>35011</td>
</tr>
<tr>
<td>1500</td>
<td>@@@@@</td>
<td>16734</td>
</tr>
<tr>
<td>1600</td>
<td>@@@</td>
<td>498</td>
</tr>
<tr>
<td>1700</td>
<td>@@@</td>
<td>256</td>
</tr>
<tr>
<td>1800</td>
<td>@@@</td>
<td>369</td>
</tr>
<tr>
<td>1900</td>
<td>@@@</td>
<td>404</td>
</tr>
<tr>
<td>2000</td>
<td>@@@</td>
<td>320</td>
</tr>
<tr>
<td>2100</td>
<td>@@@</td>
<td>555</td>
</tr>
<tr>
<td>2200</td>
<td>@@@</td>
<td>54</td>
</tr>
<tr>
<td>2300</td>
<td>@@@</td>
<td>17</td>
</tr>
<tr>
<td>2400</td>
<td>@@@</td>
<td>5</td>
</tr>
<tr>
<td>2500</td>
<td>@@@</td>
<td>1</td>
</tr>
<tr>
<td>2600</td>
<td>@@@</td>
<td>7</td>
</tr>
<tr>
<td>2700</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
```

For some operations, visibility into microsecond resolution is critical, while for other (longer) operations, millisecond resolution is sufficient — and some classes of operations may take hundreds or thousands of milliseconds to complete. If one makes the wrong choice as the resolution of aggregation, one either ends up clogging the system with unnecessarily fine-grained data, or discarding valuable information in overly coarse-grained data. One might think that one could infer the interesting latency range from the nature of the operation, but this is unfortunately not the case: I/O operations (a typically-millisecond resolution operation) can take but microseconds, and CPU scheduling operations (a typically-microsecond resolution operation) can take hundreds of milliseconds. Indeed, the problem is that one often does not know what order of magnitude of resolution is interesting for a particular operation until one has a feel for the data for the specific operation — one needs to instrument the system to best know how to instrument the system!

To understand this case use the `llquantize` aggregating function.
* magnitude 0 to magnitude 6 (inclusive) with twenty steps per
* magnitude.

```c
@ = llquantize(i++, 10, 0, 6, 20);
```

```
tick-1ms
/i == 1500/
{
    exit(0);
}
```

This example outputs:

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>45</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>65</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>85</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>90</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>95</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>150</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>200</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>250</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>300</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>350</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>400</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>450</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>500</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>550</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>600</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>650</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>700</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>750</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>800</td>
<td>@</td>
<td>50</td>
</tr>
<tr>
<td>850</td>
<td>@</td>
<td>50</td>
</tr>
</tbody>
</table>
9. Aggregations

9.3 Printing Aggregations

By default, multiple aggregations are displayed in the order they are introduced in the D program. You can override this behavior using the `println` function to print the aggregations. The `println` function also enables you to precisely format the aggregation data using a format string, as described in Chapter 12.

If an aggregation is not formatted with a `println` statement in your D program, the `dtrace` command will snapshot the aggregation data and print the results once after tracing has completed using the default aggregation format. If a given aggregation is formatted using a `println` statement, the default behavior is disabled. You can achieve equivalent results by adding the statement `println(@aggregation-name)` to a `dtrace:::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 `lquantize` and `quantize` aggregating functions displays an ASCII table of the results. Aggregation tuples are printed as if `trace` had been applied to each tuple element.

9.4 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 disjoint 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:

```d
#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
```
9.4. Data Normalization

```c
* one second.)
* /
normalize(@func, (timestamp - start) / 1000000000);
}
```

Running the above script for a brief period of time results in the following output on a desktop machine:

```bash
# dtrace -s ./normalize.d
^C
syslogd 0
rpc.rusersd 0
utmpd 0
xbiff 0
in.routed 1
sendmail 2
echo 2
FvwmAuto 2
stty 2
cut 2
init 2
pt_chmod 3
pic1d 3
utmp_update 3
httpd 4
xclock 5
basename 6
tput 6
sh 7
tr 7
arch 9
expr 10
uname 11
mibiisa 15
dirname 18
dtrace 40
ksh 48
java 58
xterm 100
nscd 120
fvwm2 154
prstat 180
perfbar 188
Xsun 1309
.netscape.bin 3005
```

normalize sets the normalization factor for the specified aggregation, but this action does not modify the underlying data. denormalize takes only an aggregation. Adding the denormalize action to the preceding example returns both raw system call counts and per-second rates:

```bash
# pragma D option quiet
BEGIN
{
    start = timestamp;
}
syscall:::entry
{
    @func[execname] = count();
}
```
9. Aggregations

}

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("Raw counts:\n");
    denormalize(@func);
    printa(@func);
}

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

```bash
# dtrace -s ./denorm.d
^C
Ran for 14 seconds.
Per-second rate:

    syslogd    0
    in.routed  0
    xbiff      1
    sendmail   2
    elm        2
    pic1d      3
    httpd      4
    xclock     6
    FvwmAuto   7
    mibiisa    22
    dtrace     42
    java       55
    xterm      75
    adeptedit  118
    nsctd      127
    prstat     179
    perfbar    184
    fvwm2      296
    Xsun       829

Raw counts:

    syslogd    1
    in.routed  4
    xbiff      21
    sendmail   30
    elm        36
    pic1d      43
    httpd      56
    xclock     91
    FvwmAuto   104
    mibiisa    314
    dtrace     592
    java       774
    xterm      1062
    adeptedit  1665
    nsctd      1781
```
Aggregations can also be renormalized. If `normalize` is called more than once for the same aggregation, the normalization factor will be the factor specified in the most recent call. The following example prints per-second rates over time:

```
Example 9.1: renormalize.d: Renormalizing an Aggregation

#pragma D option quiet
BEGIN
{
    start = timestamp;
}
syscall:::entry
{
    @func[execname] = count();
}
tick-10sec
{
    normalize(@func, (timestamp - start) / 1000000000);
    printa(@func);
}
```

### 9.5 Clearing Aggregations

When using DTrace to build simple monitoring scripts, you can periodically clear the values in an aggregation using the `clear` function. This function takes an aggregation as its only parameter. The `clear` function clears only the aggregation’s values; 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`. See Section 9.6 for details.

The following example adds `clear` to Example 9.1:

```
#pragma D option quiet
BEGIN
{
    last = timestamp;
}
syscall:::entry
{
    @func[execname] = count();
}
tick-10sec
{
    clear(@func);
    ...
}
```
9. Aggregations

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

While Example 9.1 shows the system call rate over the lifetime of the dtrace invocation, the preceding example shows the system call rate only for the most recent ten-second period.

### 9.6 Truncating aggregations

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

The parameters to `trunc` are an aggregation and an optional truncation value. Without the truncation value, `trunc` discards both aggregation values and aggregation keys for the entire aggregation. When a truncation value \( n \) is present, `trunc` discards aggregation values and keys except for those values and keys associated with the highest \( n \) values. That is, `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 \( n \), 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 augments the system call example to only display 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 output from running the above script on a lightly loaded laptop:

```
FvwmAuto 7
telnet 13
ing 14
```
9.7 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 will be dropped, a counter will be incremented, and dtrace will generate a message indicating an aggregation drop. This situation rarely occurs because DTrace keeps long-running state (consisting of the aggregation’s key and intermediate result) at user-level where space may grow dynamically. In the unlikely event that aggregation drops occur, you can increase the aggregation buffer size with the aggsize option to reduce the likelihood of drops. You can also use this option to minimize the memory footprint of DTrace. As with any size option, aggsize may be specified with any size suffix. The resizing policy of this buffer is dictated by the bufresize option. For more details on buffering, see Chapter 11. For more details on options, see Chapter 16.

An alternative method to eliminate aggregation drops is to increase the rate at which aggregation data is consumed at user-level. This rate defaults to once per second, and may be explicitly tuned with the aggrate option. As with any rate option, aggrate may be specified with any time suffix, but defaults to rate-per-second. For more details on the aggsize option, see Chapter 16.
Chapter 10

Actions and Subroutines

You can use D function calls such as trace and printf to invoke two different kinds of services provided by DTrace: actions that trace data or modify state external to DTrace, and subroutines that affect only internal DTrace state. This chapter defines the actions and subroutines and describes their syntax and semantics.

10.1 Actions

Actions 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, or 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 details on the principal buffer and buffer policies, see Chapter 11.

10.2 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. The EPID identifies a particular enabling of a particular probe with a particular predicate and actions. From the EPID, DTrace consumers can determine the probe that induced the action. Indeed, whenever any data is traced, it must be accompanied by the EPID to enable the consumer to make sense of the data. Therefore, the default action is to trace the EPID and nothing else.

Using the default action allows for simple use of dtrace(1M). For example, the following example command enables all probes in the TS timeshare scheduling module with the default action:

```
# dtrace -m TS
```

The preceding command might produce output similar to the following example:

```
# dtrace -m TS
dtrace: description 'TS' matched 80 probes
CPU ID FUNCTION:NAME
  0 12077 ts_trapret:entry
```
10.3 Data Recording Actions

The data recording actions comprise the core DTrace actions. Each of these actions records data to the principal buffer by default, but each action may also be used to record data to speculative buffers. See Chapter 11 for more details on the principal buffer. See Chapter 13 for more details on speculative buffers. The descriptions in this section 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.

trace

void trace(expression)

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

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

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. tracemem copies the memory from the address specified by addr into the directed buffer for the length specified by nbytes.
If the third argument, \texttt{dbytes} is supplied, only up to \texttt{dbytes} will be copied. \texttt{dbytes} is allowed to be a variable amount, but it must be less than or equal to \texttt{nbytes}. This is useful when you are looking at something that has a known upper bound, but the actual number of bytes may vary. For example, consider the case where you are dumping an Ethernet packet. The maximum size is based on the MTU, but the amount of data in the given packet is variable.

\texttt{print}

\begin{verbatim}
void print(address)
\end{verbatim}

The \texttt{print} action takes a D expression as its first argument and formats the output based on the type information of the expression. The type information is gathered by using built-in type information, types declared inside D scripts, and CTF (Compact C Type Format) data embedded inside of binaries. See Section 12.4 contains more information on using the \texttt{print} action.

\texttt{printf}

\begin{verbatim}
void printf(string format, ...)
\end{verbatim}

Like \texttt{trace}, the \texttt{printf} action traces D expressions. However, \texttt{printf} allows for elaborate printf(3C)-style formatting. Like printf(3C), the parameters consists of a \texttt{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 dtrace(1M) according to the specified format string. For example, the first two examples of \texttt{trace} from Section 10.3 could be combined in a single \texttt{printf}:

\begin{verbatim}
printf("execname is \$s; priority is \$d", execname, curlwpsinfo->pr_pri);
\end{verbatim}

For more information on \texttt{printf}, see Chapter 12.

\texttt{printa}

\begin{verbatim}
void printa(aggregation)
void printa(string format, aggregation)
\end{verbatim}

The \texttt{printa} action enables you to display and format aggregations. See Chapter 9 for more detail on aggregations. If a \texttt{format} is not provided, \texttt{printa} only traces a directive to the DTrace consumer that the specified aggregation should be processed and displayed using the default format. If a \texttt{format} is provided, the aggregation will be formatted as specified. See Chapter 12 for a more detailed description of the \texttt{printa} format string.

\texttt{printa} only traces a \textit{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 \texttt{printa} directive and the actual processing of the directive depends on the factors that affect buffer processing. These factors include the aggregation rate, the buffering policy and, if the buffering policy is \texttt{switching}, the rate at which buffers are switched. See Chapter 9 and Chapter 11 for detailed descriptions of these factors.
10. **Actions and Subroutines**

**stack**

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

The `stack` action records a kernel stack trace to the directed buffer. The kernel stack will be `nframes` in depth. If `nframes` is not provided, the number of stack frames recorded is the number specified by the `stackframes` option. For example:

```bash
# dtrace -n uiomove:entry'{stack()}'
```

```
CPU ID FUNCTION:NAME
0 9153 uiomove:entry
genunix'fop_write+0x1b
namefs'nm_write+0x1d
genunix'fop_write+0x1b
genunix'write+0x1f7

0 9153 uiomove:entry
genunix'fop_read+0x1b
genunix'read+0x1d4

0 9153 uiomove:entry
genunix'strread+0x394
specfs'spec_read+0x65
genunix'fop_read+0x1b
genunix'read+0x1d4

...
```

The `stack` action is a little different from other actions in that it may also be used as the key to an aggregation:

```bash
# dtrace -n kmem_alloc:entry'{@[stack()] = count()}'
```

```bash
^C
```

```
  rpcmod'endpnt_get+0x47c
  rpcmod'clnt_clts_kcallit_addr+0x26f
  rpcmod'clnt_clts_kcallit+0x22
  nfs'rfscall+0x350
  nfs'fscall+0x60
  nfs'nfs_getattr_ow+0x9e
  nfs'nfsgetattr+0x26
  nfs'nfs_getattr+0xb8
  genunix'fop_getattr+0x18
  genunix'cstat64+0x30
  genunix'cstatat64+0x4a
  genunix'1stat64+0x4c
  1
  genunix'vfs_rlock_wait+0xc
  genunix'lookupnpv+0x19d
  genunix'lookuppnat+0xe7
  genunix'lookupname+0x87
  genunix'lookupnameat+0x19
  genunix'chdir+0x18
  1
  rpcmod'endpnt_get+0x6b1
  rpcmod'clnt_clts_kcallit_addr+0x26f
```

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The `ustack` action records a user stack trace to the directed buffer. The user stack will be `nframes` in depth. If `nframes` is not provided, the number of stack frames 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 will not be translated into symbols until the `ustack` action is processed at user-level by the DTrace consumer. If `strsize` is specified and non-zero, `ustack` will allocate the specified amount of string space, and use it to perform address-to-symbol translation directly from the kernel. This direct user symbol translation is currently available only for Java virtual machines, version 1.5 and higher. Java address-to-symbol translation annotates user stacks that contain Java frames with the Java class and method name. If such frames cannot be translated, the frames will appear only as hexadecimal addresses.

The following example traces a stack with no string space, and therefore no Java address-to-symbol translation:

```
# dtrace -n syscall::write:entry'/pid == $target/{ustack(50, 0);
     exit(0)}' -c "java -version"
```
Notice that the C and C++ stack frames from the Java virtual machine are presented symbolically using C++ “mangled” symbol names, and the Java stack frames are presented only as hexadecimal addresses.

The following example shows a call to `ustack` with a non-zero string space:

```bash
# dtrace -n syscall::write:entry'/pid == $target/{ustack(50, 500); exit(0)}' -c "java -version"
```

```
dtrace: description 'syscall::write:entry' matched 1 probe
java version "1.5.0-beta3"
Java(TM) 2 Runtime Environment, Standard Edition (build 1.5.0-beta3-b58)
Java HotSpot(TM) Client VM (build 1.5.0-beta3-b58, mixed mode)
dtrace: pid 5308 has exited

CPU ID FUNCTION:NAME
0 35 write:entry
   libc.so.1'\_write+0x15
   libjvm.so'\_1cDhpiFwrite6FipkvI_I_+0xa8
   libjvm.so'JVM_Write+0x2f
d0c5c946
   libjava.so'Java_java_io_FileOutputStream\_writeBytes+0x2c
   java/io/FileOutputStream\_writeBytes
   java/io/FileOutputStream\_write
   java/io/BufferedOutputStream\_flushBuffer
   java/io/BufferedOutputStream\_flush
   java/io/PrintStream\_write
   sun/nio/cs/StreamEncoder$CharsetSE\_writeBytes
   sun/nio/cs/StreamEncoder$CharsetSE\_implFlushBuffer
   sun/nio/cs/StreamEncoder\_flushBuffer
   java/io/OutputStreamWriter\_flushBuffer
   java/io/PrintStream\_write
   java/io/PrintStream\_println
   sun/misc/Version\_print
   sun/misc/Version\_print
StubRoutines (1)
   libjvm.so'\_lcJJavaCallsLcall_helper6FpnJJavaValue_ pnMmethodHandle_pnRJavaCallArguments_pnGThread_\_v_+0x187
   libjvm.so'\_lcCosUs_exception_wrapper6FpnJJavaValue_ pnMmethodHandle_pnRJavaCallArguments_pnGThread_\_v2468_\_v_+0x14
   libjvm.so'\_lcJJavaCallsEcall6FpnJJavaValue_nMmethodHandle
```
10.3. Data Recording Actions

The above example output demonstrates symbolic stack frame information for Java stack frames. There are still some hexadecimal frames in this output because some functions are static and do not have entries in the application symbol table. Translation is not possible for these frames.

The `ustack` symbol translation for non-Java frames 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` will emit a warning message, followed by the hexadecimal stack frames, as shown in the following example:

```
dtrace: failed to grab process 100941: no such process
c7b834d4
c7bca85d
c7bc1a4c7bd4374
c7bc2628
8047efc
```

Techniques for mitigating this problem are described in Chapter 33.

Finally, because the postmortem DTrace debugger commands cannot perform the frame translation, using `ustack` with a ring buffer policy always results in raw `ustack` data.

The following D program shows an example of `ustack` that leaves `strsize` unspecified:

```
syscall::brk:entry
/execname == $$1/
{
    @[ustack(40)] = count();
}
```

To run this example for the Netscape web browser, `.netscape.bin` in default Solaris installations, use the following command:

```
# dtrace -s brk.d .netscape.bin
dtrace: description 'syscall::brk:entry' matched 1 probe
```

```
libc.so.1'__brk_unlocked+0xc
88143f688146cd
.netscape.bin' unlocked_malloc+0x3e
.netscape.bin' unlocked_calloc+0x22
.netscape.bin' calloc+0x26
.netscape.bin' IMGCB_NewPixmap+0x149
.netscape.bin' il_size+0x2f7
.netscape.bin' il_jpeg_write+0xde
8440c19
.netscape.bin' il_first_write+0x16b
839467083928e5
.netscape.bin' NET_ProcessHTTP+0xa6
.netscape.bin' NET_ProcessNet+0x49a
```
10. ACTIONS AND SUBROUTINES

jstack

void jstack(int nframes, int strsize)
void jstack(int nframes)
void jstack(void)

jstack is an alias for ustack that uses the jstackframes option for the number of stack frames the value specified by , and for the string space size the value specified by the jstackstrsize option. By default, jstacksize defaults to a non-zero value. This means that use of jstack results in a stack with Java frame translation in place.

10.4 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(1M), you can enable destructive actions using the −w option. If an attempt is made to enable destructive actions in dtrace(1M) without explicitly enabling them, dtrace will fail with a message similar to the following example:

dtrace: failed to enable 'syscall': destructive actions not allowed
Process Destructive Actions

Some destructive actions are destructive only to a particular process. These actions are available to users with the dtrace_proc or dtrace_user privileges. See Chapter 35 for details on DTrace security privileges.

**stop**

```c
void stop(void)
```

The `stop` action forces the process that fires the enabled probe to stop when it next leaves the kernel, as if stopped by a proc(4) action. The prun(1) utility may be used to resume a process that has been stopped by the `stop` 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 like mdb(1) to the process. You can also use the gcore(1) utility to save the state of a stopped process in a core file for later analysis.

**raise**

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

The `raise` action sends the specified signal to the currently running process. This action is similar to using the kill(1) command to send a process a signal. The `raise` action can be used to send a signal at a precise point in a process’s execution.

**copyout**

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

The `copyout` action copies `nbytes` from the buffer specified by `buf` to the address 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 will be generated.

**copyoutstr**

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

The `copyoutstr` action copies the string specified by `str` to the address 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 will be generated. The string length is limited to the value set by the `strsize` option. See Chapter 16 for details.

**system**

```c
void system(string program, ...)
```
The system action causes the program specified by program to be executed as if it were given to the shell as input. The program string may contain any of the printf/printa format conversions. Arguments must be specified that match the format conversions. Refer to Chapter 12 for details on valid format conversions.

The following example runs the date(1) command once per second:

```
# dtrace -wqn tick-1sec'{system("date")}'
Tue Jul 20 11:56:26 CDT 2004
Tue Jul 20 11:56:27 CDT 2004
Tue Jul 20 11:56:28 CDT 2004
Tue Jul 20 11:56:29 CDT 2004
Tue Jul 20 11:56:30 CDT 2004
```

The following example shows a more elaborate use of the action, using printf conversions in the program string along with traditional filtering tools like pipes:

```
#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 above script results in output similar to the following example:

```
# ./whosend.d
SIGINT sent to MozillaFirebird- by Bryan Cantrill
SIGINT sent to run-mozilla.sh by Bryan Cantrill
^C
SIGINT sent to dtrace by Bryan Cantrill
```

The execution of the specified command does not occur in the context of the firing probe – 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, described in Chapter 11. With the default buffering policy, the buffer processing rate is specified by the switchrate option. You can see the delay inherent in system if you explicitly tune the switchrate higher than its one-second default, as shown in the following example:

```
#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/
```

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Running the above script results in output similar to the following example:

```bash
# dtrace -s ./time.d
walltime : 2004 Jul 20 13:26:30
date : Tue Jul 20 13:26:35 CDT 2004

walltime : 2004 Jul 20 13:26:31
date : Tue Jul 20 13:26:35 CDT 2004

walltime : 2004 Jul 20 13:26:32
date : Tue Jul 20 13:26:35 CDT 2004

walltime : 2004 Jul 20 13:26:33
date : Tue Jul 20 13:26:35 CDT 2004

walltime : 2004 Jul 20 13:26:34
date : Tue Jul 20 13:26:35 CDT 2004
```

Notice that the `walltime` values differ, but the `date` values are identical. This result reflects the fact that the execution of the `date(1)` command occurred only when the buffer was processed, not when the system action was recorded.

### Kernel Destructive Actions

Some destructive actions are destructive to the entire system. These actions must obviously be used extremely carefully, as they will affect every process on the system and any other system implicitly or explicitly depending upon the affected system’s network services.

**breakpoint**

```c
void breakpoint(void)
```

The `breakpoint` action induces a kernel breakpoint, causing the system to stop and transfer control to the kernel debugger. The kernel debugger will emit a string denoting the DTrace probe that triggered the action. For example, if one were to do the following:

```bash
# dtrace -w -n clock:entry'{breakpoint()}'
dtrace: allowing destructive actions
dtrace: description 'clock:entry' matched 1 probe
```

On illumos running on SPARC, the following message might appear on the console:

```
dtrace: breakpoint action at probe fbt:genunix:clock:entry (ecb 30002765700)
Type 'go' to resume
ok
```

On illumos running on x86, the following message might appear on the console:

```
dtrace: breakpoint action at probe fbt:genunix:clock:entry (ecb d2b97060)
stopped at int20+0xb: ret
kmd[0]:
```

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The address following the probe description is the address of the enabling control block (ECB) within DTrace. You can use this address to determine more details about the probe enabling that induced the breakpoint action.

A mistake with the breakpoint action may cause it to be called far more often than intended. This behavior might in turn prevent you from even terminating the DTrace consumer that is triggering the breakpoint actions. In this situation, set the kernel integer variable dtrace_destructive_disallow to 1. This setting will disallow all destructive actions on the machine. Apply this setting only in this particular situation.

The exact method for setting dtrace_destructive_disallow will depend on the kernel debugger that you are using. If using the OpenBoot PROM on a SPARC system, use w!:

```
ok 1 dtrace_destructive_disallow w!
ok
```

Confirm that the variable has been set using w?:

```
ok dtrace_destructive_disallow w?
1
ok
```

Continue by typing go:

```
ok go
```

If using kmdb(1) on x86 or SPARC systems, use the 4-byte write modifier (W) with the / formatting dcmd:

```
kmdb[0]: dtrace_destructive_disallow/W 1
```

```
dtrace_destructive_disallow: 0x0 = 0x1
```

```
kmdb[0]:
```

Continue using :c:

```
kadb[0]: :c
```

After continuing, you will need to explicitly reset dtrace_destructive_disallow back to 0 to re-enable destructive actions, using mdb(1):

```
# echo "dtrace_destructive_disallow/W 0" | mdb -kw
dtrace_destructive_disallow: 0x1 = 0x0
```

```
#
```

The panic action causes a kernel panic when triggered. This action should be used to force a system crash dump at a time of interest. You can use this action together with ring buffering and postmortem analysis to understand a problem. For more information, see Chapter 11 and Chapter 37 respectively. When the panic action is used, a panic message appears that denotes the probe causing the panic. For example:
10.4. Destructive Actions

panic[cpu0]/thread=30001830b80: dtrace: panic action at probe 
syscall::mmap:entry (ecb 300000acfc8)

000002a10050b840 dtrace:dtrace Probe+518 (fffe, 0, 1830f88, 1830f88, 
30002fb8040, 300000acfc8)
%1-3: 0000000000000000 0000300030e4d80 000030003418000 0000300018c0800
%1-7: 000002a10050b980 0000000000000050 0000000000000000 0000000000000002
000002a10050ba30 genunix:dtrace_syscall32+44 (0, 2000, 5, 
80000002, 3, 1898400)
%1-3: 00000300030de730 00000002200008 0000000000e0 00000000184d928
%1-7: 00000300030de000 000000000000730 000000000000010

syncing file systems... 2 done 
dumping to /dev/dsk/c0t0d0s1, offset 214827008, content: kernel
100% done: 11837 pages dumped, compression ratio 4.66, dump 
succeeded
rebooting...

syslogd(1M) will also emit a message upon reboot:

Jun 10 16:56:31 machine1 savecore: [ID 570001 auth.error] reboot after panic:
dtrace: panic action at probe syscall::mmap:entry (ecb 300000acfc8)

The message buffer of the crash dump also contains the probe and ECB responsible for the panic action.

chill

void chill(int nanoseconds)

The chill action causes DTrace to spin for the specified number of nanoseconds. chill is primarily useful for exploring problems that might be timing related. For example, you can use this action to open race condition windows, or to bring periodic events into or out of phase with one another. Because interrupts are disabled while in DTrace probe context, any use of chill will induce interrupt latency, scheduling latency, and dispatch latency. Therefore, chill can cause unexpected systemic effects and it should not used indiscriminately. Because system activity relies on periodic interrupt handling, DTrace will refuse 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 will report an illegal operation error, as shown in the following example:

```
# dtrace -w -n syscall::open:entry'{chill(500000001)}'
dtrace: allowing destructive actions
dtrace: description 'syscall::open:entry' matched 1 probe
dtrace: 57 errors
CPU ID FUNCTION:NAME
dtrace: error on enabled probe ID 1 (ID 14: syscall::open: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 the following command:

```
# dtrace -w -n syscall::open:entry'(chill(500000000); chill(250000001);)'
```
10.5 Special Actions

This section describes actions that are neither data recording actions nor destructive actions.

Speculative Actions

The actions associated with speculative tracing are `speculate`, `commit`, and `discard`. These actions are discussed in Chapter 13.

\textbf{exit}

\begin{verbatim}
void exit(int status)
\end{verbatim}

The \texttt{exit} action is used to immediately stop tracing, and to inform the DTrace consumer that it should cease tracing, perform any final processing, and call exit(3C) with the status specified. Because \texttt{exit} returns a status to user-level, it is a data recording action. However, unlike other data storing actions, \texttt{exit} cannot be speculatively traced. \texttt{exit} will cause the DTrace consumer to exit regardless of buffer policy. Because \texttt{exit} is a data recording action, it \textit{can} be dropped.

When \texttt{exit} is called, only DTrace actions already in progress on other CPUs will be completed. No new actions will occur on any CPU. The only exception to this rule is the processing of the \texttt{END} probe, which will be called after the DTrace consumer has processed the \texttt{exit} action and indicated that tracing should stop.

10.6 Subroutines

Subroutines differ from actions because they generally only affect internal DTrace state. Therefore, there are no destructive subroutines, and subroutines never trace data into buffers. Many subroutines have analogs in the Section 9F or Section 3C interfaces. See Intro(9F) and Intro(3) for more information on the corresponding subroutines.

\textbf{alloca}

\begin{verbatim}
void *alloca(size_t size)
\end{verbatim}

\texttt{alloca} allocates \texttt{size} bytes out of scratch space, and returns a pointer to the allocated memory. The returned pointer is guaranteed to have 8-byte alignment. Scratch space is only valid for the duration of a clause. Memory allocated with \texttt{alloca} will be deallocated when the clause completes. If insufficient scratch space is available, no memory is allocated and an error is generated.

\textbf{basename}

\begin{verbatim}
string basename(char *str)
\end{verbatim}

\texttt{basename} is a D analogue for basename(1). This subroutine creates a string that consists of a copy of the specified string, but without any prefix that ends in `/`. The returned string is allocated out of scratch memory, and is therefore valid only for the duration of the clause. If insufficient scratch space is available, \texttt{basename} does not execute and an error is generated.
**bcopy**

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

*bcopy* copies *size* bytes from the memory pointed to by *src* to the memory 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**

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

*cleanpath* creates a string that consists 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 one.

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 be in /net/foo not /.

This limitation is due to the fact that *cleanpath* is called in the context of a firing probe, where full symbolic link resolution or 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 space is available, *cleanpath* does not execute and an error is generated.

**copyin**

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

*copyin* copies the specified size in bytes from the specified user address 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 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 space is available, *NULL* is returned, and an error is generated. See Chapter 33 for techniques to reduce the likelihood of *copyin* errors.

**copyinstr**

```c
string copyinstr(uintptr_t addr)
```

*copyinstr* copies a null-terminated C string from the specified user address 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 associated with the current thread. The string length is limited to the value set by the *strsize* option; see Chapter 16 for details. As with *copyin*, 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 space is available, *NULL* is returned, and an error is generated. See Chapter 33 for techniques to reduce the likelihood of *copyinstr* errors.
**copyinto**

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

copyinto copies the specified size in bytes from the specified user address into the DTrace scratch buffer specified by dest. The user address is interpreted as an address in the space of the process 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 scratch space, no copying takes place, and an error is generated. See Chapter 33 for techniques to reduce the likelihood of copyinto errors.

**ddi_pathname**

```c
string ddi_pathname(struct dev_info *dip, minor_t minor)
```

ddi_pathname returns the path of the device represented by dip and minor inside the /devices tree.

**dirname**

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

dirname is a D analogue for dirname(1). This subroutine creates a string that consists of all but the last level of the pathname 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 space is available, dirname does not execute and an error is generated.

**htons**

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

htons is a D analogue for htons(3XNET). The subroutine converts a uint16_t from the host’s byte order to network byte order (big endian).

**htonl**

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

htonl is a D analogue for htonl(3XNET). The subroutine converts a uint32_t from the host’s byte order to network byte order (big endian).

**htonll**

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

htonll is a D analogue for htonll(3XNET). The subroutine converts a uint64_t from the host’s byte order to network byte order (big endian).
index

int index(char *str, char *ptrn)

index returns the index in the string that ptrn first occurs. If it never occurs, then -1 is returned.

inet_ntoa

string inet_ntoa(ipaddr_t in)

inet_ntoa is a D analogue for inet_ntoa(3SOCKET). This subroutine takes the 32-bit integer in and prints it in dotted decimal form, eg. a.b.c.d.

inet_ntoa6

string inet_ntoa6(struct in6_addr in)

inet_ntoa6 is a D analogue for inet_ntoa6(3SOCKET). This subroutine converts an IPv6 address into a human readable colon delineated form using zero-run compression.

inet_ntop

string inet_ntop(int af, struct in6_addr in)
string inet_ntop(int af, ipaddr_t in)

inet_ntop can handle converting from multiple address families into a human readable form. Currently the supported address families are AF_INET and AF_INET6. The output is equivalent to inet_ntoa and inet_ntoa6 respectively.

lltostr

string lltostr(long long num)
string lltostr(long long num, int base)

lltostr is a D analogue for strtoll(). This subroutine creates a string that represents the value of num. If base is specified, then num is interpreted in that base.

getmajor

int getmajor(dev_t dev)

getmajor is a D analogue for the DDI getmajor(9F). This subroutine returns the major number from the device number.
**getminor**

```c
int getminor(dev_t dev)
```

getminor is a D analogue for the DDI getminor(9F). This subroutine returns the minor number from the device number.

**msgdsize**

```c
size_t msgdsize(mblk_t *mp)
```

msgdsize returns the number of bytes in the data message pointed to by mp. See msgdsize(9F) for details. msgdsize only includes data blocks of type M_DATA in the count.

**msgsize**

```c
size_t msgsize(mblk_t *mp)
```

msgsize returns the number of bytes in the message pointed to by mp. Unlike msgdsize, which returns only the number of data bytes, msgsize returns the total number of bytes in the message.

**mutex_owned**

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

mutex_owned is an implementation of mutex_owned(9F). mutex_owned returns non-zero if the calling thread currently holds the specified kernel mutex, or zero if the specified adaptive mutex is currently unowned.

**mutex_owner**

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

mutex_owner 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. See mutex_owned(9F).

**mutex_type_adaptive**

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

mutex_type_adaptive returns non-zero if the specified kernel mutex is of type MUTEX_ADAPTIVE, or zero if it is not. Mutexes are adaptive if they meet one or more of the following conditions:

- The mutex is declared statically
- The mutex is created with an interrupt block cookie of NULL
• The mutex is created with an interrupt block cookie that does not correspond to a high-level interrupt

See mutex_init(9F) for more details on mutexes. The majority of mutexes in the illumos kernel are adaptive.

### mutex_type_spin

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

mutex_type_spin returns non-zero if the specified kernel mutex is of type MUTEX_SPIN, or zero if it is not. Mutexes are spin mutexes if the mutex is created with an interrupt block cookie that corresponds to a high-level interrupt.

See mutex_init(9F) for more details on mutexes.

### ntohs

```c
uint16_t ntohs(uint16_t netshort)
```

ntohs is a D analogue for ntohs(3XNET). The subroutine converts a uint16_t from the network’s byte order to the host’s native byte order.

### ntohl

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

ntohl is a D analogue for ntohl(3XNET). The subroutine converts a uint32_t from the network’s byte order to the host’s native byte order.

### ntohll

```c
uint64_t ntohll(uint64_t netlong)
```

ntohll is a D analogue for ntohll(3XNET). The subroutine converts a uint64_t from the network’s byte order to the host’s native byte order.

### progenyof

```c
int progenyof(pid_t pid)
```

progenyof 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.

### rand

```c
int rand(void)
```

rand returns a pseudo-random integer. The number returned is a weak pseudo-random number, and should not be used for any cryptographic application.
10. Actions and Subroutines

**rindex**

```c
int rindex(char *str, char *ptrn)
```

rindex returns the index in the string that `ptrn` last occurs. If it never occurs, then -1 is returned.

**rw_iswriter**

```c
int rw_iswriter(krwlock_t *rwlock)
```

rw_iswriter returns non-zero if the specified reader-writer lock 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. See rw_init(9F).

**rw_read_held**

```c
int rw_read_held(krwlock_t *rwlock)
```

rw_read_held returns non-zero if the specified reader-writer lock is currently held by a reader. If the lock is held by a writer or not held at all, rw_read_held returns zero. See rw_init(9F).

**rw_write_held**

```c
int rw_write_held(krwlock_t *rwlock)
```

rw_write_held returns non-zero if the specified reader-writer lock is currently held by a writer. If the lock is held only by readers or not held at all, rw_write_held returns zero. See rw_init(9F).

**speculation**

```c
int speculation(void)
```

speculation reserves a speculative trace buffer for use with speculate and returns an identifier for this buffer. See Chapter 13 for details.

**strchr**

```c
string strchr(char *str, int c)
```

strchr is a D analogue for strchr(3C). This subroutine returns a string that starts at the first occurrence of the character `c`.

**strjoin**

```c
string strjoin(char *str1, char *str2)
```

strjoin 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 space is available, strjoin does not execute and an error is generated.
10.6. Subroutines

**strlen**

```c
size_t strlen(string str)
```

`strlen` returns the length of the specified string in bytes, excluding the terminating null byte.

**strrchr**

```c
string strrchr(char *str, int c)
```

`strrchr` is a D analogue for `strrchr(3C)`. This subroutine returns a string that starts at the last occurrence of the character `c`.

**strstr**

```c
string strstr(char *str, char *str2)
```

`strstr` is a D analogue for `strstr(3C)`. This subroutine returns the string based on the first occurrence of the string `str2` inside `str`.

**strtok**

```c
string strtok(char *str, char *sep)
```

`strtok` is a D analogue for `strtok(3C)`. This subroutine tokenizes `str` using the separator `sep`. On subsequent calls to `strtok`, `str` should be NULL to progress to the next token. Note that a given tokenization is only valid within multiple enablings of the same clause. You cannot continue the same tokenization across different clauses.

**substr**

```c
string substr(char *str, int start)
string substr(char *str, int start, int length)
```

`substr` returns a new string which is a portion of `str`. In the first form of `substr`, a new string is returned starting at offset `start` into the string and ends at the current end of the string. If `start` would go past the end of `str`, then the empty string is returned. In the second form, the string that is returned will be at most `length` characters long. If `length` characters from `start` would go beyond the end of `str`, then `substr` behaves as though the first form was used.

**tolower**

```c
string (char *str)
```

`tolower` returns a new string which is the lower case version of `str`. 
**toupper**

string (char *str)

toupper returns a new string which is the upper case version of str.
Chapter 11

Buffers and Buffering

DATA BUFFERING AND MANAGEMENT is an essential service provided by the DTrace framework for its clients, such as dtrace(1M). This chapter explores data buffering in detail and describes options you can use to change DTrace’s buffer management policies.

11.1 Principal Buffers

The principal buffer is present in every DTrace invocation and is the buffer to which tracing actions record their data by default. These actions include:

- `exit`
- `printf`
- `trace`
- `ustack`
- `printa`
- `stack`
- `tracemem`

The principal buffers are always allocated on a per-CPU basis. This policy is not tunable, but tracing and buffer allocation can be restricted to a single CPU by using the `cpu` option.

11.2 Principal Buffer Policies

DTrace permits tracing in highly constrained contexts in the kernel. In particular, DTrace permits tracing in contexts in which kernel software may not reliably allocate memory. The consequence of this flexibility of context is that there always exists a possibility that DTrace will attempt to trace data when there isn’t space available. DTrace must have a policy to deal with such situations when they arise, but you might wish 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 trace 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 Chapter 16 for more details on setting options.

**switch Policy**

By default, the principal buffer has a switch buffer policy. Under this policy, per-CPU buffers are allocated in pairs: 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 may be lost. Once 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: a buffer is never simultaneously traced to and copied out. This technique also avoids introducing a window 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 may be specified with any time suffix, but defaults to rate-per-second. For more details on switchrate and other options, see Chapter 16.

**Note**

To process the principal buffer at user-level at a rate faster than the default of once per second, tune the value of switchrate. The system processes actions that induce user-level activity (such as printa and system) when the corresponding record in the principal buffer is processed. The value of switchrate dictates the rate at which the system processes such actions.

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(1M) displays a message similar to the following example:

\[\text{dtrace: 11 drops on CPU 0}\]

If a given record is larger than the total buffer size, the record will be dropped regardless of buffer policy. You can reduce or eliminate drops by either 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 space for copyin, copyinstr, and alloca is allocated out of the active buffer.

**fill Policy**

For some problems, you might wish 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 has filled. Once dtrace(1M) detects a single filled buffer, tracing is stopped, all buffers are processed and dtrace exits. No further data will be 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 2K buffer with the buffer policy set to fill:

\[\# \text{dtrace -n syscall:::entry -b 2k -x bufpolicy=fill}\]

**fill Policy and END Probes**

END probes normally do not fire until tracing has been explicitly stopped by the DTrace consumer. END probes are guaranteed to only fire 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 may fire on a CPU that has a filled buffer. To accommodate END tracing in fill buffers, DTrace calculates the amount of space potentially consumed by END probes and subtracts this space from the size of the principal buffer. If the net size is negative, DTrace will refuse to start, and dtrace(1M) will output a corresponding error message:

dtrace: END enablements 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 helps you trace the events leading up to a failure. If reproducing the failure takes hours or days, you might wish to keep only the most recent data. Once a principal buffer has filled, tracing wraps around to the first entry, thereby overwriting older tracing data. You establish the ring buffer by setting the bufpolicy option to the string ring:

```bash
# dtrace -s foo.d -x bufpolicy=ring
```

When used to create a ring buffer, dtrace(1M) will not display any output until the process is terminated. At that time, the ring buffer is consumed and processed. dtrace processes each ring buffer in CPU order. Within a CPU’s buffer, trace records will be displayed in order from oldest to youngest. Just as with the switch buffering policy, no ordering exists between records from different CPUs are made. 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:

```bash
#pragma D option bufpolicy=ring
#pragma D option bufsize=16k
syscall:::entry
/execname == $1/
{
  trace(timestamp);
}
syscall::rexit:entry
{
  exit(0);
}
```

11.3 Other Buffers

Principal buffers exist in every DTrace enabling. Beyond principal buffers, some DTrace consumers may have additional in-kernel data buffers: an aggregation buffer, discussed in Chapter 9, and one or more speculative buffers, discussed in Chapter 13.

11.4 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:
11. Buffers and Buffering

Each of these options is set with a value that denotes the size. As with any size option, the value may have an optional size suffix. See Chapter 16 for more details. For example, to set the buffer size to one megabyte on the command line to `dtrace`, you can use `-x` to set the option:

```shell
# dtrace -P syscall -x bufsize=1m
```

Alternatively, you can use the `-b` option to `dtrace`:

```shell
# dtrace -P syscall -b 1m
```

Finally, you could set `bufsize` using `#pragma D` option:

```shell
#pragma D option bufsize=1m
```

The buffer size 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 buffer size defaults to four megabytes.

### 11.5 Buffer Resizing Policy

Occasionally, the system might not have adequate free kernel memory to allocate a buffer of desired size either because not enough memory is available or because the DTrace consumer has exceeded one of the tunable limits described in Chapter 16. You can configure the policy for buffer allocation failure using `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(1M)` generates a message if a buffer as allocated is smaller than the requested size:

```shell
# dtrace -P syscall -b 4g
dtrace: description 'syscall' matched 430 probes
dtrace: buffer size lowered to 128m
... 
```

or:

```shell
# 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, a failure to allocate will cause DTrace to fail to start:

```shell
# 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 of all buffers, principal, speculative and aggregation, is dictated by the `bufre size` option.
11.6 Buffer Ordering Policy

DTrace consumes its principal buffers on a per-CPU basis. This causes output to be ordered first by the order that it retrieved buffers from the CPUs and secondly by the ordering within each principal buffer. Look at the output of the following script:

```plaintext
syscall:::entry
{
    trace(timestamp);
}
```

<table>
<thead>
<tr>
<th>CPU ID</th>
<th>FUNCTION:NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 24</td>
<td>close:entry 3302220933052713</td>
</tr>
<tr>
<td>23 24</td>
<td>close:entry 3302220933064286</td>
</tr>
<tr>
<td>23 24</td>
<td>close:entry 3302220933066326</td>
</tr>
<tr>
<td>23 16</td>
<td>rexit:entry 3302220933111500</td>
</tr>
<tr>
<td>1 20</td>
<td>write:entry 3302220705802875</td>
</tr>
<tr>
<td>1 20</td>
<td>write:entry 3302220705807694</td>
</tr>
<tr>
<td>1 106</td>
<td>ioctl:entry 3302220705812112</td>
</tr>
</tbody>
</table>

Notice how the timestamps are not in the order that you might expect. All of the events on CPU23 are ordered and all the events on CPU 1 are ordered, however there is no total ordering based on time.

To instead order this based on time, one would use the `temporal` option. This can be controlled on a per-consumer basis.
Chapter 12

Output Formatting

Two built-in formatting functions are provided for use in your D programs, printf and printa. The D compiler provides features not found in the printf(3C) library routine, so you should read this chapter even if you are already familiar with printf. This chapter also discusses the formatting behavior of the trace and print functions and the default output format used by dtrace(1M) to display aggregations.

12.1 printf

The printf function combines the ability to trace data, as if by the trace function, 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.

Unlike printf(3C), DTrace printf is a built-in function that is recognized by the D compiler. The D compiler provides several useful services for DTrace printf that are not found in the C library printf:

• 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 knows 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.

In order to implement these features, the format string in the DTrace printf function must be specified as a string constant in your D program. Format strings may not 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 the next section.

- An optional minimum **field width**. If the converted value has fewer bytes than the field width, the value will be 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** that indicates 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 takes the form of a period (.) followed by either an asterisk (*), described below, or a decimal digit string.

- An optional sequence of **size prefixes** that indicate the size of the corresponding argument, described in Section 12.1. The size prefixes are not necessary in D and 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 printf(3C) function also supports conversion specifications of the form %n$ where $n$ is a decimal integer; DTrace printf 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 may appear in any order:

- The integer portion of the result of a decimal conversion (%i, %d, %u, %f, %g, or %G) is formatted with thousands grouping characters 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 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, i, o, u, x, X, e, E, f, g, and G conversions, leading zeroes (following any indication of sign or base) are used to pad to the field width. 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 D statement:

```
printf("%*d", w, x);
```

The field width can also be specified using 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 prior to the conversion argument is accessed to determine 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(3C) in order 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 allowing you to omit size prefixes and automatically determining the argument size.

The size prefixes can be placed just prior to the format conversion name and after any flags, widths, and precision specifiers. The size prefixes 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 \texttt{ll} specifies that a following \texttt{d}, \texttt{i}, \texttt{o}, \texttt{u}, \texttt{x}, or \texttt{X} conversion applies to a \texttt{long long} or unsigned \texttt{long long}.

• An optional \texttt{L} specifies that a following \texttt{e}, \texttt{E}, \texttt{f}, \texttt{g}, or \texttt{G} conversion applies to a \texttt{long double}.

• An optional \texttt{l} specifies that a following \texttt{c} conversion applies to a \texttt{wint_t} argument, and that a following \texttt{s} conversion character applies to a pointer to a \texttt{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, or if the format string is exhausted and arguments remain, the D compiler issues an appropriate error message. If an undefined conversion format is specified, the D compiler issues an appropriate error message. The conversion character sequences are:

\begin{itemize}
  \item \texttt{a} The pointer or \texttt{uintptr_t} argument is printed as a kernel symbol name in the form \texttt{module\textasciitilde symbol-name} plus an optional hexadecimal byte offset. If the value does not fall within the range defined by a known kernel symbol, the value is printed as a hexadecimal integer.
  \item \texttt{c} The \texttt{char}, \texttt{short}, or \texttt{int} argument is printed as an ASCII character.
  \item \texttt{C} The \texttt{char}, \texttt{short}, or \texttt{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 using the corresponding escape sequence as shown in Table 2.5.
  \item \texttt{d} The \texttt{char}, \texttt{short}, \texttt{int}, \texttt{long}, or \texttt{long long} argument is printed as a decimal (base 10) integer. If the argument is signed, it will be printed as a signed value. If the argument is unsigned, it will be printed as an unsigned value. This conversion has the same meaning as \texttt{i}.
  \item \texttt{e}, \texttt{E} The float, double, or long double argument is converted to the style \texttt{[-]d.ddde\pm dd}, where there is one digit before the radix character and the number of digits after it 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 \texttt{E} conversion format produces a number with \texttt{E} instead of \texttt{e} introducing the exponent. The exponent always contains at least two digits. The value is rounded up to the appropriate number of digits.
  \item \texttt{f} The float, double, or long double argument is converted to the style \texttt{[-]d.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.
  \item \texttt{g}, \texttt{G} The float, double, or long double argument is printed in the style \texttt{f} or \texttt{e} (or in style \texttt{E} in the case of a \texttt{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 used depends on the value converted: style \texttt{e} (or \texttt{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.
\end{itemize}
The char, short, int, long, or long long argument is printed as a decimal (base 10) integer. If the argument is signed, it will be printed as a signed value. If the argument is unsigned, it will be printed as an unsigned value. This conversion has the same meaning as d.

The char, short, int, long, or long long 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 will be increased if necessary to force the first digit of the result to be a zero.

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 will have 0x prepended to it.

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 all characters up to the first null character are printed. If the precision is specified, only that portion of the character array that will display 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.

The argument must be an array of char or a 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 described in Table 2.5.

The char, short, int, long, or long long argument is printed as an unsigned decimal (base 10) integer. Arguments that are signed or unsigned may be used with this conversion, and the result is always formatted as unsigned.

The int argument is converted to a wide character (wchar_t) and the resulting wide character is printed.

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 will display in the corresponding number of screen columns is printed.

The char, short, int, long, or long long 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 will have 0x (for %x) or 0X (for %X) prepended to it.

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 cftime(3C) form: “%Y %a %b %e %T %Z.” The current number of nanoseconds since 00:00 UTC, January 1, 1970 is available in the walltimestamp variable.

Print a literal % character. No argument is converted. The entire conversion specification must be %

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12.2 printa

The `printa` function is used to format the results of aggregations in a D program. The function is invoked using one of two forms:

```d
printa(@aggregation-name);
printa(format-string, @aggregation-name);
```

If the first form of the function is used, the `dtrace(1M)` command takes a consistent snapshot of the aggregation data and produces output equivalent to the default output format used for aggregations, described in Chapter 9.

If the second form of the function is used, the `dtrace(1M)` command takes a consistent snapshot of the aggregation data and produces output according to the conversions specified in the format string, according to the following rules:

- The format conversions must match the tuple signature used to create the aggregation. Each tuple element may only appear once. For example, if you aggregate a count using the following D statements:
  ```d
  @a["hello", 123] = count();
  @a["goodbye", 456] = count();
  ```
  and then add the D statement `printa(format-string, @a)` to a probe clause, `dtrace` will snapshot the aggregation data and produce output as if you had entered the statements:
  ```d
  printf(format-string, "hello", 123);
  printf(format-string, "goodbye", 456);
  ```
  and so on for each tuple defined in the aggregation.

- Unlike `printf`, the format string you use for `printa` need not include all elements of the tuple. That is, 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 corresponding conversion specifiers for them in the `printa` format string.

- The aggregation result can be 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, and may appear more than once in a format string so that your tuple result can appear anywhere in the output and can 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:

```
avg          uint64_t
count        uint64_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 and lquantize functions format their results as an ASCII table rather than as a single value.

The following D program shows a complete example of `printa`, using the `profile` provider to sample the value of `caller` and then formatting the results as a simple table:

```d
profile:::profile-997
{
    @a[caller] = count();
}
END
{
    printa("%@8u %a\n", @a);
}
```

If you use `dtrace` to execute this program, wait a few seconds, and press Control-C, you will see output similar to the following example:

```
# dtrace -s printa.d
^C
CPU ID FUNCTION:NAME
  1 2 :END 1 0x1
   1 ohci'ohci_handle_root_hub_status_change+0x148
   1 specfs'spec_write+0xe0
   1 0xff14f950
   1 genunix'cyclic_softint+0x588
   1 0xef2280c
   1 genunix'getf+0xdc
   1 ufs'ufs_ichk+0x50
   1 genunix'infpollinfo+0x80
   1 genunix'kmem_log_enter+0xle8
...
```

### 12.3. trace Default Format

If the `trace` function is used to capture data rather than `printf`, the `dtrace` command formats the results 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 will be printed as an ASCII string. If the data is any other size and is not a sequence of printable characters, it will be printed as a series of byte values formatted as hexadecimal integers.

### 12.4. print()

The `print` action formats output based on the type information that DTrace knows about. The output data is formatted based on the type. The following rules cover the output format:

- The type always precedes the data.
- All integers and pointers are printed in hex.
- Floats and doubles are printed as though the `printf` string "%.7e" were applied.
12. Output Formatting

- Long doubles are printed as though the `printf` string "%.16LE" were applied.
- Every entry in an array is printed.
- Every member in a structure is printed out. This is applied recursively.

The following examples demonstrate using the `print` action and some of its formatting characteristics. The first example shows the difference between using trace and print for a built-in variable.

```
# dtrace -qn 'BEGIN{ trace(timestamp); }'
1809563006895229
# dtrace -qn 'BEGIN{ print(timestamp); }'
uint64_t 0x66d997f0b030a
```

This example shows how a structure is printed with type information. `p0` is the global address of the first process in the illumos operating system.

```
# dtrace -qn 'BEGIN{ print('p0); }'
proc_t {
    struct vnode *p_exec = 0
    struct as *p_as = 0xfffffffffbc30ac0
    struct plock *p_lockp = 0xfffffffffbc6d3c8
    kmutex_t p_crlock = {
        void *[1] _opaque = [ 0 ]
    }
    struct cred *p_cred = 0xffffff0d29fd9db0
    int p_swapcnt = 0
    char p_stat = '"002'
    char p_wcode = '"0'
    ...
}
```

This final example shows how you might use this information with other providers.

```
# dtrace -n 'fbt::zio_done:entry{ print(*args[0]); }'
dtrace: description 'fbt::zio_done:entry' matched 1 probe
CPU ID FUNCTION:NAME
10 53680 zio_done:entry zio_t {
    zbookmark_t io_bookmark = {
        uint64_t zb_objset = 0
        uint64_t zb_object = 0
        int64_t zb_level = 0
        uint64_t zb_blkid = 0x14
    }
    zio_prop_t io_prop = {
        enum zio_checksum zp_checksum = ZIO_CHECKSUM_INHERIT
        enum zio_compress zp_compress = ZIO_COMPRESS_INHERIT
        dmu_object_type_t zp_type = DMU_OT_NONE
        uint8_t zp_level = 0
        uint8_t zp_copies = 0
        uint8_t zp_dedup = 0
        uint8_t zp_dedup_verify = 0
    }
    zio_type_t io_type = ZIO_TYPE_NULL
    enum zio_child io_child_type = ZIO CHILD_VDEV
    int io_cmd = 0
    uint8_t io_priority = 0x4
    uint8_t io_reexecute = 0
    uint8_t [2] io_state = [ 0x1, 0 ]
    uint64_t io_txg = 0x8dfb3a
```
print Type Information Sources

DTrace has three primary sources for type information for the type information used when formatting data for print action.

The D language defines fundamental types for integer and floating-point constants. These are enumerated in Chapter 2. Built-in actions, variables, and subroutines are defined in terms of these types. These types will match those that are being used by a user program or Operating System kernel.

Next, DTrace uses the types that are defined in a D script. These can be brought in by using the C Pre-processor or by declaring them directly. These can be used the same as any built-in type.

Finally, DTrace uses the C Compact Type Information (CTF) that is embedded in the operating system kernel and its modules. (DTrace does not currently use CTF data in user binaries or modules.) The system’s CTF data provides most of the types that DTrace uses via functionality such as print. For more on CTF, see ctf(4).
Chapter 13

Speculative Tracing

This chapter discusses the DTrace facility for speculative tracing, the ability to tentatively trace data and then later decide whether to commit the data to a tracing buffer or discard it. In DTrace, the primary mechanism for filtering out uninteresting events is the predicate mechanism, discussed in Chapter 4. Predicates are useful when you know at the time that a probe fires whether or not the probe event is of interest. For example, if you are only interested in activity 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. However, in other situations, you might not know whether a given probe event is of interest until some time after the probe fires.

For example, if a system call is occasionally failing with a common error code (for example, EIO or EINVAL), 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 nondeterministic, you would be forced to trace all events that might be interesting, and later post-process the data to filter out the ones that were not associated with the failing code path. In this case, even though the number of interesting events may be reasonably small, the number of events that must be traced is very large, making post-processing difficult.

You can use the speculative tracing facility in these situations to tentatively trace data at one or more probe locations, and then decide to commit the data to the principal buffer at another probe location. As a result, your trace data contains only the output of interest, no post-processing is required, and the DTrace overhead is minimized.

13.1 Speculation Interfaces

The following table describes the DTrace speculation functions:

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Args</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>speculation</td>
<td>None</td>
<td>Returns an identifier for a new speculative buffer</td>
</tr>
<tr>
<td>speculate</td>
<td>ID</td>
<td>Denotes that the remainder of the clause should be traced to the speculative buffer specified by ID</td>
</tr>
<tr>
<td>commit</td>
<td>ID</td>
<td>Commits the speculative buffer associated with ID</td>
</tr>
<tr>
<td>discard</td>
<td>ID</td>
<td>Discards the speculative buffer associated with ID</td>
</tr>
</tbody>
</table>
13. Speculative Tracing

13.2 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 may be passed to `speculate`, `commit` or `discard`. If a call to `speculation` fails, a `dtrace` message similar to the following example is generated:

```
dtrace: 2 failed speculations (no speculative buffer space available)
```

The number of speculative buffers defaults to one, but may be optionally tuned higher. See Section 13.7 for more information.

13.3 Using a Speculation

To use a speculation, an identifier returned from `speculation` must be passed to the `speculate` function in a clause before any data-recording actions. All subsequent data-recording actions in a clause containing a `speculate` will be speculatively traced. The D compiler will generate a compile-time error if a call to `speculate` follows data recording actions in a D probe clause. Therefore, clauses may 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. A `speculate` may not follow a `speculate`: only one speculation is permitted per clause. A clause that contains only a `speculate` will speculatively trace the default action, which is defined to trace only the enabled probe ID. See Chapter 10 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`. For example:

```d
syscall::open:entry
{  
    self->spec = speculation();
}

syscall::
/self->spec/
{  
    speculate(self->spec);
    printf("this is speculative");
}
```

13.4 Committing a Speculation

You commit speculations 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 to 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 beginning on one CPU and the data being copied from speculative buffers to principal buffers on all CPUs. This time is guaranteed to be no longer than the time dictated by the cleaning rate. See Section 13.7 for more details.

A committing speculative buffer will not be 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 will be silently discarded, and subsequent calls to commit or discard will silently fail. Finally, a clause containing a commit cannot contain a data recording action, but a clause may contain multiple commit calls to commit disjoint buffers.

13.5 Discarding a Speculation

You discard speculations using the discard function. When a speculative buffer is discarded, its contents are thrown away. 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 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 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, a dtrace message similar to the following example is generated:

dtrace: 905 failed speculations (available buffer(s) still busy)

The likelihood of all buffers being unavailable can be reduced by tuning the number of speculation buffers or the cleaning rate. See Section 13.7, for details.

13.6 Speculation Example

One potential use for speculations is to highlight a particular code path. The following example shows the entire code path under the open(2) system call only when the open fails:

```c
#!/usr/sbin/dtrace -Fs

syscall::open:entry,
syscall::open64:entry
{
  /*
   * The call to speculation() creates a new speculation. If this
   * fails, dtrace(1M) 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
```
Speculative Tracing

- speculatively traced; it will only appear in the data buffer if the speculation is subsequently committed.
  */
  printf("%s", stringof(copyinstr(arg0)));}
}

fbt:::
/self->spec/
{
  /*
   * A speculate() with no other actions speculates the default action: tracing the EPID.
   */
   speculate(self->spec);
}

syscall::open:return,
syscall::open64: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,
syscall::open64: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,
syscall::open64:return
/self->spec && errno == 0/
{
  /*
   * If errno is not set, we discard the speculation.
   */
   discard(self->spec);
   self->spec = 0;
}

Running the above script produces output similar to the following example:

```
# ./specopen.d
dtrace: script './specopen.d' matched 24282 probes
CPU FUNCTION
1  => open /var/ld/ld.config
1  => open
```
13.6. Speculation Example

- `copen`
- `falloc`
- `ufalloc`
- `fd_find`
- `mutex_owned`
- `mutex_owned`
- `fd_find`
- `fd_reserve`
- `mutex_owned`
- `mutex_owned`
- `fd_reserve`
- `mutex_owned`
- `fd_find`
- `mutex_owned`
- `mutex_owned`
- `fd_reserve`
- `ufalloc`
- `kmem_cache_alloc`
- `kmem_cache_alloc_debug`
- `verify_and_copy_pattern`
- `verify_and_copy_pattern`
- `file_cache_constructor`
- `mutex_init`
- `mutex_init`
- `file_cache_constructor`
- `tsc_gethtime`
- `tsc_gethtime`
- `getpcstack`
- `getpcstack`
- `kmem_log_enter`
- `kmem_log_enter`
- `kmem_cache_alloc_debug`
- `crhold`
- `crhold`
- `falloc`
- `vn_openat`
- `lookupnameat`
- `copyinstr`
- `copyinstr`
- `lookuppnat`
- `pn_fixslash`
- `pn_fixslash`
- `pn_getcomponent`
- `pn_getcomponent`
- `ufs_lookup`
- `dnlc_lookup`
- `bcmpl`
- `bcmpl`
- `dnlc_lookup`
- `ufs_laccess`
- `crgetuid`
- `crgetuid`
- `groupmember`
- `supgroupmember`
- `supgroupmember`
- `groupmember`
- `ufs_laccess`
- `ufs_lookup`
- `vn_rele`
- `vn_rele`
- `pn_getcomponent`
13. Speculative Tracing
13.7 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. If this situation, a dtrace message similar to the following example is generated:

dtrace: 38 speculative drops

Speculative drops will not prevent the full speculative buffer from being copied into the principal buffer when the buffer is committed. Similarly, speculative drops can occur even if drops were experienced on a speculative buffer that was ultimately discarded. Speculative drops can be reduced by increasing the speculative buffer size, which is tuned using the specsize option. The specsize option may 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 exist that have not yet been committed or discarded, a dtrace message similar to the following example is generated:

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 with the nspec option. The value of nspec defaults to one.

Alternatively, speculation may fail because all speculative buffers are busy. In this case, a dtrace message similar to the following example is generated:

dtrace: 1 failed speculation (available buffer(s) still busy)

This 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 with the cleanrate option. The value of cleanrate defaults to 101hz.

Note
You must specify values for the cleanrate option in number-per-second. Use the hz suffix.
Chapter 14

dtrace(1M) Utility

The generic front-end to the DTrace facility is the dtrace(1M) command, which implements a simple interface to invoke the D language compiler, the ability to retrieve buffered trace data from the DTrace kernel facility, and a set of basic routines to format and print traced data. This chapter provides a complete reference for the dtrace command.

14.1 Description

The dtrace command provides a generic interface to all of the essential services provided by the DTrace facility, including:

• Options to list the set of probes and providers currently published by DTrace

• Options to enable probes directly using any of the probe description specifiers (provider, module, function, name)

• Options to run the D compiler and compile one or more D program files or programs written directly on the command-line

• Options to generate anonymous tracing programs (see Chapter 36)

• Options to generate program stability reports (see Chapter 39)

• Options to modify DTrace tracing and buffering behavior and enable additional D compiler features (see Chapter 16)

dtrace can also be used to create D scripts by using it in a #! declaration to create an interpreter file (see Chapter 15). Finally, you can use dtrace to attempt to compile D programs and determine their properties without actually enabling any tracing using the -e option, described below.

14.2 Options

The dtrace command accepts the following options:
where predicate is any D predicate enclosed in slashes // and action is any D statement list enclosed in braces { } according to the previously described 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:

-32, -64
The D compiler produces programs using the native data model of the operating system kernel. You can use the isainfo(1) -b command to determine the current operating system data model. If the -32 option is specified, dtrace will force the D compiler to compile a D program using the 32-bit data model. If the -64 option is specified, dtrace will force the D compiler to compile a D program using the 64-bit data model. These options are typically not required as dtrace selects the native data model as the default. The data model affects the sizes of integer types and other language properties. D programs compiled for either data model may be executed on both 32-bit and 64-bit kernels. The -32 and -64 options also determine the ELF file format (ELF32 or ELF64) produced by the -G option.

-a Claim anonymous tracing state and display the traced data. You can combine the -a option with the -e option to force dtrace to exit immediately after consuming the anonymous tracing state rather than continuing to wait for new data. See Chapter 36 for more information about anonymous tracing.

-A Generate driver.conf(4) directives for anonymous tracing. If the -A option is specified, dtrace compiles any D programs specified using the -s option or on the command-line and constructs a set of dtrace(7D) configuration file directives to enable the specified probes for anonymous tracing (see Chapter 36) and then exits. By default, dtrace attempts to store the directives to the file /kernel/drv/dtrace.conf. This behavior can be modified using the -o option to specify an alternate output file.

-b Set principal trace buffer size. The trace buffer size can include any of the size suffixes k, m, g, or t as described in Chapter 36. If the buffer space cannot be allocated, dtrace attempts to reduce the buffer size or exit depending on the setting of the bufsize property.

-c Run the specified command cmd and exit upon its completion. If more than one -c option is present on the command line, dtrace exits when all commands have exited, reporting the exit status for each child process as it terminates. The process-ID of the first command is made available to any child process as it terminates. The process-ID of the first command is made available to any D programs specified on the command line or using the -s option through the $target macro variable. Refer to Chapter 15 for more information on macro variables.

-C Run the C preprocessor cpp(1) over D programs before compiling them. Options can be passed to the C preprocessor using the -D, -U, -I, and -H options. The degree of C standard conformance can be selected using the -X option. Refer to the description of the -X option for a description of the set of tokens defined by the D compiler when invoking the C preprocessor.

-D Define the specified name when invoking cpp(1) (enabled using the -C option). If an equals sign (=) and additional value are specified, the name is assigned the corresponding value. This option passes the -D option to each cpp invocation.
14.2. Options

-\texttt{e} Exit after compiling any requests and consuming anonymous tracing state (\texttt{-a} option) but prior to enabling any probes. This option can be combined with the \texttt{-a} option to print anonymous tracing data and exit, or it can be combined with D compiler options to verify that the programs compile without actually executing them and enabling the corresponding instrumentation.

-\texttt{f} Specify function name to trace or list (\texttt{-l} option). The corresponding argument can include any of the probe description forms \texttt{provider:module:function}, \texttt{module:function}, or \texttt{function}. Unspecified probe description fields are left blank and match any probes regardless of the values in those fields. If no qualifiers other than \texttt{function} are specified in the description, all probes with the corresponding \texttt{function} are matched. The \texttt{-f} argument can be suffixed with an optional D probe clause. More than one \texttt{-f} option may be specified on the command-line at a time.

-\texttt{F} Coalesce trace output by identifying function entry and return. Function entry probe reports are indented and their output is prefixed with \texttt{->}. Function return probe reports are unindented and their output is prefixed with \texttt{<-}.

-\texttt{G} Generate an ELF file containing an embedded DTrace program. The DTrace probes specified in the program are saved inside of a relocatable ELF object that can be linked into another program. If the \texttt{-o} option is present, the ELF file is saved using the pathname specified as the argument for this operand. If the \texttt{-o} option is not present and the DTrace program is contained in a file whose name is \texttt{filename.s}, then the ELF file is saved using the name \texttt{file.o}; otherwise the ELF file is saved using the name \texttt{d.out}.

-\texttt{H} Print the pathnames of included files when invoking \texttt{cpp(1)} (enabled using the \texttt{-C} option). This option passes the \texttt{-H} option to each \texttt{cpp} invocation, causing it to display the list of pathnames, one per line, to \texttt{stderr}.

-\texttt{i} Specify probe identifier to trace or list (\texttt{-l} option). Probe IDs are specified using decimal integers as shown by \texttt{dtrace -l}. The \texttt{-i} argument can be suffixed with an optional D probe clause. More than one \texttt{-i} option may be specified on the command-line at a time.

-\texttt{I} Add the specified directory \texttt{path} to the search path for \texttt{#include} files when invoking \texttt{cpp(1)} (enabled using the \texttt{-C} option). This option passes the \texttt{-I} option to each \texttt{cpp} invocation. The specified directory is inserted into the search path ahead of the default directory list.

-\texttt{l} List probes instead of enabling them. If the \texttt{-l} option is specified, \texttt{dtrace} produces a report of the probes matching the descriptions given using the \texttt{-P}, \texttt{-m}, \texttt{-f}, \texttt{-n}, \texttt{-i}, and \texttt{-s} options. If none of these options are specified, all probes are listed.

-\texttt{L} Add the specified directory \texttt{path} to the search path for DTrace libraries. DTrace libraries are used to contain common definitions that may be used when writing D programs. The specified \texttt{path} is added after the default library search path.

-\texttt{m} Specify module name to trace or list (\texttt{-l} option). The corresponding argument can include any of the probe description forms \texttt{provider:module} or \texttt{module}. Unspecified probe description fields are left blank and match any probes regardless of the values in those fields. If no qualifiers other than \texttt{module} are specified in the description, all probes with a corresponding \texttt{module} are matched. The \texttt{-m} argument can be suffixed with an optional D probe clause. More than one \texttt{-m} option may be specified on the command-line at a time.

-\texttt{n} Specify probe name to trace or list (\texttt{-l} option). The corresponding argument can include any of the probe description forms \texttt{provider:module:function:name}, \texttt{module:function:name},
function:name, or name. Unspecified probe description fields are left blank and match any probes regardless of the values in those fields. If no qualifiers other than name are specified in the description, all probes with a corresponding name are matched. The -n argument can be suffixed with an optional D probe clause. More than one -n option may be specified on the command-line at a time.

-o Specify the output file for the -A, -G, and -t options, or for the traced data. If the -A option is present and -o is not present, the default output file is /kernel/drv/dtrace.conf. If the -G option is present and the -s option’s argument is of the form filename.d and -o is not present, the default output file is filename.o; otherwise the default output file is d.out.

-p Grab the specified process-ID pid, cache its symbol tables, and exit upon its completion. If more than one -p option is present on the command line, dtrace exits when all commands have exited, reporting the exit status for each process as it terminates. The first process-ID is made available to any D programs specified on the command line or using the -s option through the $target macro variable. Refer to Chapter 15 for more information on macro variables.

-P Specify provider name to trace or list (-l option). The remaining probe description fields module, function, and name are left blank and match any probes regardless of the values in those fields. The -P argument can be suffixed with an optional D probe clause. More than one -P option may be specified on the command-line at a time.

-q Set quiet mode. dtrace will suppress messages such as the number of probes matched by the specified options and D programs and will not print column headers, the CPU ID, the probe ID, or insert newlines into the output. Only data traced and formatted by D program statements such as trace and printf will be displayed to stdout.

-s Compile the specified D program source file. If the -e option is present, the program is compiled but no instrumentation is enabled. If the -l option is present, the program is compiled and the set of probes matched by it is listed, but no instrumentation will be enabled. If neither -e nor -l are present, the instrumentation specified by the D program is enabled and tracing begins.

-S Show D compiler intermediate code. The D compiler will produce a report of the intermediate code generated for each D program to stderr.

-U Undefine the specified name when invoking cpp(1) (enabled using the -C option). This option passes the -U option to each cpp invocation.

-V Report the highest D programming interface version supported by dtrace. The version information is printed to stdout and the dtrace command exits. See Chapter 41 for more information about DTrace versioning features.

-w Permit destructive actions in D programs specified using the -s, -P, -m, -f, -n, or -i options. If the -w option is not specified, dtrace will not permit the compilation or enabling of a D program that contains destructive actions. Destructive actions are described in further detail in Chapter 10.

-x Enable or modify a DTrace runtime option or D compiler option. The options are listed in Chapter 16. Boolean options are enabled by specifying their name. Options with values are set by separating the option name and value with an equals sign (=).
Specify the degree of conformance to the ISO C standard that should be selected when invoking `cpp` (enabled using the `-C` option). The `-X` option argument affects the value and presence of the `__STDC__` macro depending upon the value of the argument letter:

**a** (default)
ISO C plus K&R compatibility extensions, with semantic changes required by ISO C. This mode is the default mode if `-X` is not specified. The predefined macro `__STDC__` has a value of 0 when `cpp` is invoked in conjunction with the `-Xa` option.

**c** (conformance)
Strictly conformant ISO C, without K&R C compatibility extensions. The predefined macro `__STDC__` has a value of 1 when `cpp` is invoked in conjunction with the `-Xc` option.

**s** (K&R C)
K&R C only. The macro `__STDC__` is not defined when `cpp` is invoked in conjunction with the `-Xs` option.

**t** (transition)
ISO C plus K&R C compatibility extensions, without semantic changes required by ISO C. The predefined macro `__STDC__` has a value of 0 when `cpp` is invoked in conjunction with the `- Xt` option.

Because the `-X` option affects only how the D compiler invokes the C preprocessor, the `-Xa` and `-Xt` options are equivalent from the perspective of D. Both options are provided to ease re-use of settings from a C build environment.

Regardless of the `-X` mode, the following additional C preprocessor definitions are always specified and valid in all modes:

- `__sun`
- `__unix`
- `__SVR4`
- `__sparc` (on SPARC® systems only)
- `__sparcv9` (on SPARC® systems only when 64–bit programs are compiled)
- `__i386` (on x86 systems only when 32–bit programs are compiled)
- `__amd64` (on x86 systems only when 64–bit programs are compiled)
- `__uname -s` or `__uname -r`, replacing the decimal point in the output of `uname` with an underbar (`_`), as in `__SunOS_5_10`
- `__SUNW_D=1`
- `__SUNW_D_VERSION=0xMMmmmuuu` (where `MM` is the Major release value in hexadecimal, `mmmu` is the Minor release value in hexadecimal, and `uuu` is the Micro release value in hexadecimal; see Chapter 41 for more information about DTrace versioning)

**-Z**
Permit probe descriptions that match zero probes. If the `-Z` option is not specified, `dtrace` will report an error and exit if any probe descriptions specified in D program files (`-s` option) or on the command-line (`-P`, `-m`, `-f`, `-n`, or `-i` options) contain descriptions that do not match any known probes.
14.3 Operands

Zero or more additional arguments may be specified on the dtrace command line to define a set of macro variables ($1, $2, and so on) to be used in any D programs specified using the -s option or on the command-line. The use of macro variables is described further in Chapter 15.

14.4 Exit Status

The following exit values are returned by the dtrace utility:

0  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 anonymous state was successfully retrieved. dtrace returns 0 even if the specified tracing requests encountered errors or drops.

1  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  Invalid command-line options or arguments were specified.
Chapter 15

Scripting

You can use the dtrace(1M) utility to create interpreter files out of D programs similar to shell scripts that you can install as reusable interactive DTrace tools. The D compiler and dtrace command provide a set of macro variables that are expanded by the D compiler that make it easy to create DTrace scripts. This chapter provides a reference for the macro variable facility and tips for creating persistent scripts.

15.1 Interpreter Files

Similar to your shell and utilities such as awk(1) and perl(1), dtrace(1M) can be used to create executable interpreter files. An interpreter file begins with a line of the 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 itself and any additional arguments specified when it was executed are then appended to the interpreter argument list. Therefore, you will always need to create DTrace interpreter files with at least these arguments:

```
#!/usr/sbin/dtrace -s
```

When your interpreter file is executed, the argument to the `-s` option will therefore be the pathname of the interpreter file itself. dtrace will then read, compile, and execute this file as if you had typed the following command in your shell:

```
# dtrace -s interpreter-file
```

The following example shows how to create and execute a dtrace interpreter file. Type the following D source code and save it in a file named interp.d:

```
#!/usr/sbin/dtrace -s
BEGIN
{
    trace("hello");
    exit(0);
}
```

Mark the interp.d file as executable and execute it as follows:
Remember that the `#!` directive must comprise the first two characters of your file with no intervening or preceding whitespace. The D compiler knows to automatically ignore this line when it processes the interpreter file.

`dtrace` uses `getopt(3C)` to process command-line options, so you can combine multiple options in your single interpreter argument. For example, to add the `-q` option to the preceding example you could change the interpreter directive to:

```
#!/usr/sbin/dtrace -qs
```

If you specify multiple option letters, the `-s` option must always end the list of boolean options so that the next argument (the interpreter file name) is processed as the argument corresponding to the `-s` option.

If you need to specify more than one option that requires an argument in your interpreter file, you will not be able to fit all your options and arguments into the single interpreter argument. Instead, use the `#pragma D` option directive syntax to set your options. All of the `dtrace` command-line options have `#pragma` equivalents that you can use, as shown in Chapter 16.

# 15.2 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 D compiler provides the following macro variables:

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>$[0-9]+</code></td>
<td>macro arguments</td>
<td>See Section 15.3</td>
</tr>
<tr>
<td><code>$egid</code></td>
<td>effective group-ID</td>
<td><code>getegid(2)</code></td>
</tr>
<tr>
<td><code>$euid</code></td>
<td>effective user-ID</td>
<td><code>geteuid(2)</code></td>
</tr>
<tr>
<td><code>$gid</code></td>
<td>real group-ID</td>
<td><code>getgid(2)</code></td>
</tr>
<tr>
<td><code>$pid</code></td>
<td>process ID</td>
<td><code>getpid(2)</code></td>
</tr>
<tr>
<td><code>$pgid</code></td>
<td>process group ID</td>
<td><code>getpgid(2)</code></td>
</tr>
<tr>
<td><code>$ppid</code></td>
<td>parent process ID</td>
<td><code>getppid(2)</code></td>
</tr>
<tr>
<td><code>$projid</code></td>
<td>project ID</td>
<td><code>getprojid(2)</code></td>
</tr>
<tr>
<td><code>$sid</code></td>
<td>session ID</td>
<td><code>getsid(2)</code></td>
</tr>
<tr>
<td><code>$target</code></td>
<td>target process ID</td>
<td>See Section 15.4</td>
</tr>
<tr>
<td><code>$taskid</code></td>
<td>task ID</td>
<td><code>gettaskid(2)</code></td>
</tr>
<tr>
<td><code>$uid</code></td>
<td>real user-ID</td>
<td><code>getuid(2)</code></td>
</tr>
</tbody>
</table>
Except for the $[0-9]+$ macro arguments and the $target$ macro variable, the macro variables all expand to integers corresponding to system attributes such as the process ID and user ID. The variables expand to the attribute value associated with the current dtrace process itself, or whatever process is running the D compiler.

Using macro variables in interpreter files enables you to create persistent D programs that do not need to be edited each time you want to use them. For example, to count all system calls except those executed by the dtrace command, you can use the following D program clause containing $pid$:

```d
syscall:::entry
/pid != $pid/ {
  @calls = count();
}
```

This clause always produces the desired result, even though each invocation of the dtrace command will have a different process ID.

Macro variables can be used anywhere an integer, identifier, or string can be used in a D program. Macro variables are expanded only once (that is, not recursively) when the input file is parsed. 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:

```d
123$pid
```

would expand to the two adjacent tokens 123 and 456, resulting in a syntax error, rather than the single integer token 123456.

Macro variables are expanded and concatenated with adjacent text inside of D probe descriptions at the start of your program clauses. For example, the following clause uses the DTrace pid provider to instrument the dtrace command:

```d
pid$pid:libc.so:printf:entry
{
  ...
}
```

Macro variables are only expanded once within each probe description field; they may not contain probe description delimiters (:).

### 15.3 Macro Arguments

The D compiler also provides a set of macro variables corresponding to any additional argument operands specified as part of the dtrace command invocation. These macro arguments are accessed using the built-in names $0$ for 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 dtrace -s option, $0$ expands to the value of the name of the input file used with this option. For D programs specified on the command-line, $0$ expands to the value of argv[0] used to exec dtrace 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:
Macro arguments can be used to create DTrace interpreter files that act like real illumos commands and use information specified by a user or by another tool to modify their behavior. For example, the following D interpreter file traces write(2) system calls executed by a particular process ID:

```
#!/usr/sbin/dtrace -s

syscall::write:entry
/pid == $1/
{
}
```

If you make this interpreter file executable, you can specify the value of $1 using an additional command-line argument to your interpreter file:

```
# chmod a+rx ./tracewrite
# ./tracewrite 12345
```

The resulting command invocation counts each write(2) system call executed by process ID 12345.

If your D program references a macro argument that is not provided on the command-line, an appropriate error message will be printed and your program will fail to compile:

```
# ./tracewrite
dtrace: failed to compile script ./tracewrite: line 4:
  macro argument $1 is not defined
```

D programs can reference unspecified macro arguments if the `defaultargs` option is set. If `default args` is set, unspecified arguments will have the value 0. See Chapter 16 for more information about D compiler options. The D compiler will also produce an error message if additional arguments are specified on the command line that are not referenced by your D program.

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 will report an appropriate error message. When specifying string macro arguments to a DTrace interpreter file, 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, $$1) to force the D compiler to interpret the argument value as if it were a string surrounded by double quotes. All the usual D string escape sequences (see Table 2.5) are expanded inside of any string macro arguments, regardless of whether they are referenced using the $arg or $$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 ("").

### 15.4 Target Process ID

Use the $target macro variable to create scripts that can be applied to a particular user process of interest that is selected on the Dtrace command line using the `-p` option or created using the `-c` option.
The D programs specified on the command line or using the \(-s\) option are compiled \textit{after} processes are created or grabbed and the $\text{target}$ variable expands to the integer process-ID of the first such process. For example, the following D script could be used to determine the distribution of system calls executed by a particular subject process:

```d
syscall:::entry
/pid == $target/
{
    @[probefunc] = count();
}
```

To determine the number of system calls executed by the date(1) command, save the script in the file `syscall.d` and execute the following command:

```bash
# dtrace -s syscall.d -c date
dtrace: script ‘syscall.d’ matched 227 probes
Fri Jul 30 13:46:06 PDT 2004
dtrace: pid 109058 has exited

gtime 1
getpid 1
getrlimit 1
xexit 1
ioctl 1
resolvepath 1
read 1
stat 1
write 1
munmap 1
close 2
fstat64 2
setcontext 2
mmap 2
open 2
brk 4
```
Chapter 16

Options and Tunables

To allow for customization, DTrace affords its consumers several important degrees of freedom. To minimize the likelihood of requiring specific tuning, DTrace is implemented using reasonable default values and flexible default policies. However, situations may arise that require tuning the behavior of DTrace on a consumer-by-consumer basis. This chapter describes the DTrace options and tunables and the interfaces you can use to modify them.

16.1 Consumer Options

DTrace is tuned by setting or enabling options. The available options are described in the table below. For some options, dtrace(1M) provides a corresponding command-line option.

<table>
<thead>
<tr>
<th>Option Name</th>
<th>Value</th>
<th>dtrace(1M) Alias</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>aggrate</td>
<td>time</td>
<td></td>
<td>Rate of aggregation reading. See Chapter 9.</td>
</tr>
<tr>
<td>aggsz</td>
<td>size</td>
<td></td>
<td>Aggregation buffer size. See Chapter 9.</td>
</tr>
<tr>
<td>bufresizer</td>
<td>auto or manual</td>
<td></td>
<td>Buffer resizing policy. See Chapter 11.</td>
</tr>
<tr>
<td>bufsize</td>
<td>size</td>
<td>-b</td>
<td>Principal buffer size. See Chapter 11.</td>
</tr>
<tr>
<td>cleanrate</td>
<td>time</td>
<td></td>
<td>Cleaning rate. Must be specified in number-per-second with the hz suffix. See Chapter 13.</td>
</tr>
<tr>
<td>cpu</td>
<td>scalar</td>
<td>-c</td>
<td>CPU on which to enable tracing. See Chapter 11.</td>
</tr>
<tr>
<td>defaultargs</td>
<td>—</td>
<td></td>
<td>Allow references to unspecified macro arguments. See Chapter 15.</td>
</tr>
<tr>
<td>destructive</td>
<td>—</td>
<td>-w</td>
<td>Allow destructive actions. See Chapter 10.</td>
</tr>
<tr>
<td>Option Name</td>
<td>Value</td>
<td>dtrace(1M) Alias</td>
<td>Description</td>
</tr>
<tr>
<td>----------------</td>
<td>-------</td>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>dynvarsize</td>
<td>size</td>
<td></td>
<td>Dynamic variable space size. See Chapter 3</td>
</tr>
<tr>
<td>flowindent</td>
<td>—</td>
<td>-F</td>
<td>Indent function entry and prefix with -&gt;; unindent function return with &lt;-. See Chapter 14.</td>
</tr>
<tr>
<td>grabanon</td>
<td>—</td>
<td>-a</td>
<td>Claim anonymous state. See Chapter 36.</td>
</tr>
<tr>
<td>jstackframes</td>
<td>scalar</td>
<td></td>
<td>Number of default stack frames for jstack. See Chapter 10.</td>
</tr>
<tr>
<td>jstackstrsize</td>
<td>scalar</td>
<td></td>
<td>Default string space size for jstack. See Chapter 10.</td>
</tr>
<tr>
<td>nspec</td>
<td>scalar</td>
<td></td>
<td>Number of speculations. See Chapter 13.</td>
</tr>
<tr>
<td>quiet</td>
<td>—</td>
<td>-q</td>
<td>Output only explicitly traced data. See Chapter 14.</td>
</tr>
<tr>
<td>specsize</td>
<td>size</td>
<td></td>
<td>Speculation buffer size. See Chapter 13.</td>
</tr>
<tr>
<td>strsize</td>
<td>size</td>
<td></td>
<td>String size. See Chapter 6.</td>
</tr>
<tr>
<td>stackframes</td>
<td>scalar</td>
<td></td>
<td>Number of stack frames. See Chapter 10.</td>
</tr>
<tr>
<td>stackindent</td>
<td>scalar</td>
<td></td>
<td>Number of whitespace characters to use when indenting stack and ustack output.</td>
</tr>
<tr>
<td>statusrate</td>
<td>time</td>
<td></td>
<td>Rate of status checking</td>
</tr>
<tr>
<td>switchrate</td>
<td>time</td>
<td></td>
<td>Rate of buffer switching. See Chapter 11.</td>
</tr>
<tr>
<td>temporal</td>
<td>—</td>
<td></td>
<td>Order output in temporal order. See Chapter 11.</td>
</tr>
<tr>
<td>ustackframes</td>
<td>scalar</td>
<td></td>
<td>Number of user stack frames. See Chapter 10.</td>
</tr>
<tr>
<td>zone</td>
<td>string</td>
<td></td>
<td>Limit USDT enablings to specified zone. See Chapter 34.</td>
</tr>
</tbody>
</table>

Values that denote sizes may be given an optional suffix of k, m, g, or t to denote kilobytes, megabytes, gigabytes, and terabytes respectively. Values that denote times may be given an optional suffix of ns, us, ms, s or hz to denote nanoseconds, microseconds, milliseconds, seconds, and number-per-second, respectively.
16.2 Modifying Options

Options may be set in a D script by using \texttt{#pragma D} followed by the string \texttt{option} and the option name. If the option takes a value, the option name should be followed by an equals sign (=) and the option value. The following examples are all valid option settings:

\begin{verbatim}
#pragma D option nspec=4
#pragma D option grabanon
#pragma D option bufsize=2g
#pragma D option switchrate=10hz
#pragma D option aggrate=100us
#pragma D option bufresize=manual
\end{verbatim}

The \texttt{dtrace(1M)} command also accepts option settings on the command-line as an argument to the \texttt{-x} option. For example:

\begin{verbatim}
# dtrace -x nspec=4 -x grabanon -x bufsize=2g \ 
    -x switchrate=10hz -x aggrate=100us -x bufresize=manual
\end{verbatim}

If an invalid option is specified, \texttt{dtrace} indicates that the option name is invalid and exits:

\begin{verbatim}
# dtrace -x wombats=25
dtrace: failed to set option -x wombats: Invalid option name
#
\end{verbatim}

Similarly, if an option value is not valid for the given option, \texttt{dtrace} will indicate that the value is invalid:

\begin{verbatim}
# dtrace -x bufsize=100wombats
dtrace: failed to set option -x bufsize: Invalid value for specified option
#
\end{verbatim}

If an option is set more than once, subsequent settings overwrite earlier settings. Some options, such as \texttt{grabanon}, may only be set. The presence of such an option sets it, and you cannot subsequently unset it.

Options that are set for an anonymous enabling will be honored by the DTrace consumer that claims the anonymous state. See Chapter 36 for information about enabling anonymous tracing.
Chapter 17

dtrace Provider

PROBES FOR TRACING the D program itself are available through the dtrace provider. You can use these probes to initialize state before tracing begins, process state after tracing has completed, and handle unexpected execution errors in other probes.

17.1 BEGIN Probe

The BEGIN probe fires before any other probe. No other probe will fire 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(2) 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. This means that the output of stack or usstack, and the value of context-specific variables (for example, 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.
17.2 The 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 spent tracing:

```
BEGIN
{
  start = timestamp;
}
/*
 * ... other tracing actions...
 */
END
{
  printf("total time: %d secs", (timestamp - start) / 1000000000);
}
```

See Section 9.4 and Section 12.2 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 traced in the END probe. See Section 11.2 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 the END probe firing. 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 using statusrate option. For more information, see Chapter 16.

17.3 ERROR Probe

The ERROR probe fires when a run-time error occurs in executing a clause for a DTrace probe. For example, if a clause attempts to dereference a NULL pointer, the ERROR probe will fire, as shown in the following example.

```
BEGIN
{
  *(char *)NULL;
}
ERROR
{
```

---

Example 17.1: error.d: Record Errors
When you run this program, you will see output like the following example:

```
# dtrace -s ./error.d
```

The output shows that the `ERROR` probe fired, and also illustrates `dtrace(1M)` reporting the error. `dtrace` has its own enabling of the `ERROR` probe to allow it to report errors. Using the `ERROR` probe, you can create your own custom error handling.

The arguments to the `ERROR` probe are as follows:

<table>
<thead>
<tr>
<th>arg1</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>arg2</td>
<td>The index of the action that caused the fault</td>
</tr>
<tr>
<td>arg3</td>
<td>The DIF offset into that action or –1 if not applicable</td>
</tr>
<tr>
<td>arg4</td>
<td>The fault type</td>
</tr>
<tr>
<td>arg5</td>
<td>Value particular to the fault type</td>
</tr>
</tbody>
</table>

The table below describes the various fault types and the value that `arg5` will have for each:

<table>
<thead>
<tr>
<th>arg4 Value</th>
<th>Description</th>
<th>arg5 Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>DTRACEFLT_UNKNOWN</code></td>
<td>Unknown fault type</td>
<td>None</td>
</tr>
<tr>
<td><code>DTRACEFLT_BADADDR</code></td>
<td>Access to unmapped or invalid address</td>
<td>Address accessed</td>
</tr>
<tr>
<td><code>DTRACEFLT_BADALIGN</code></td>
<td>Unaligned memory access</td>
<td>Address accessed</td>
</tr>
<tr>
<td><code>DTRACEFLT_ILLOP</code></td>
<td>Illegal or invalid operation</td>
<td>None</td>
</tr>
<tr>
<td><code>DTRACEFLT_DIVZERO</code></td>
<td>Integer divide by zero</td>
<td>None</td>
</tr>
<tr>
<td><code>DTRACEFLT_NOSCRATCH</code></td>
<td>Insufficient scratch space to satisfy scratch allocation</td>
<td>None</td>
</tr>
<tr>
<td><code>DTRACEFLT_KPRIV</code></td>
<td>Attempt to access a kernel address or property without sufficient privileges</td>
<td>Address accessed or 0 if not applicable</td>
</tr>
<tr>
<td><code>DTRACEFLT_UPRIV</code></td>
<td>Attempt to access a user address or property without sufficient privileges</td>
<td>Address accessed or 0 if not applicable</td>
</tr>
<tr>
<td><code>DTRACEFLT_TUPOFLOW</code></td>
<td>DTrace internal parameter stack overflow</td>
<td>None</td>
</tr>
</tbody>
</table>

If the actions taken in the `ERROR` probe itself cause an error, that error is silently dropped — the `ERROR` probe will not be recursively invoked.
17.4 Stability

The dtrace provider uses DTrace’s stability mechanism to describe its stabilities as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Stable</td>
<td>Stable</td>
<td>Common</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Stable</td>
<td>Stable</td>
<td>Common</td>
</tr>
<tr>
<td>Arguments</td>
<td>Stable</td>
<td>Stable</td>
<td>Common</td>
</tr>
</tbody>
</table>
Chapter 18

lockstat Provider

The lockstat provider makes available probes that can be used to discern lock contention statistics, or to understand virtually any aspect of locking behavior. The lockstat(1M) command is actually a DTrace consumer that uses the lockstat provider to gather its raw data.

18.1 Overview

The lockstat provider makes available two kinds of probes: contention-event probes and hold-event probes.

Contention-event probes correspond to contention on a synchronization primitive, and fire when a thread is forced to wait for a resource to become available. illumos is generally optimized for the non-contention case, so prolonged contention is not expected. These probes should be used to understand those cases where contention does arise. Because contention is relatively rare, enabling contention-event probes generally doesn’t substantially affect performance.

Hold-event probes correspond to acquiring, releasing, or otherwise manipulating a synchronization primitive. These probes can be used to answer arbitrary questions about the way synchronization primitives are manipulated. Because illumos acquires and releases synchronization primitives very often (on the order of millions of times per second per CPU on a busy system), enabling hold-event probes has a much higher probe effect than does enabling contention-event probes. While the probe effect induced by enabling them can be substantial, it is not pathological; they may still be enabled with confidence on production systems.

The lockstat provider makes available probes that correspond to the different synchronization primitives in illumos; these primitives and the probes that correspond to them are discussed in the remainder of this chapter.

18.2 Adaptive Lock Probes

Adaptive locks enforce mutual exclusion to a critical section, and may be acquired in most contexts in the kernel. Because adaptive locks have few context restrictions, they comprise the vast majority of synchronization primitives in the illumos kernel. These locks are adaptive in their behavior with respect to contention: when a thread attempts to acquire a held adaptive lock, it will determine if the owning thread is currently running on a CPU. If the owner is running on another CPU, the acquiring thread will spin. If the owner is not running, the acquiring thread will block.
The four lockstat probes pertaining to adaptive locks are in Table 18.1. For each probe, arg0 contains a pointer to the \texttt{kmutex_t} structure that represents the adaptive lock.

\begin{table}[h]
\centering
\begin{tabular}{|l|p{12cm}|}
\hline
adaptive-acquire & Hold-event probe that fires immediately after an adaptive lock is acquired. \\
\hline
adaptive-block & Contention-event probe that fires after a thread that has blocked on a held adaptive mutex has reawakened and has acquired the mutex. If both probes are enabled, \texttt{adaptive-block} fires before \texttt{adaptive-acquire}. A single lock acquisition can fire both the \texttt{adaptive-block} and the \texttt{adaptive-spin} probes. arg1 for \texttt{adaptive-block} contains the sleep time in nanoseconds. \\
\hline
adaptive-spin & Contention-event probe that fires after a thread that has spun on a held adaptive mutex has successfully acquired the mutex. If both are enabled, \texttt{adaptive-spin} fires before \texttt{adaptive-acquire}. A single lock acquisition can fire both the \texttt{adaptive-block} and the \texttt{adaptive-spin} probes. arg1 for \texttt{adaptive-spin} contains the \text{spin time}: the number of nanoseconds that were spent in the spin loop before the lock was acquired. \\
\hline
adaptive-release & Hold-event probe that fires immediately after an adaptive lock is released. \\
\hline
\end{tabular}
\caption{Adaptive Lock Probes}
\end{table}

\section*{18.3 Spin Lock Probes}

Threads cannot block in some contexts in the kernel, such as high-level interrupt context and any context manipulating dispatcher state. In these contexts, this restriction prevents the use of adaptive locks. Spin locks are instead used to effect mutual exclusion to critical sections in these contexts. As the name implies, the behavior of these locks in the presence of contention is to spin until the lock is released by the owning thread. The three probes pertaining to spin locks are in Table 18.2.

\begin{table}[h]
\centering
\begin{tabular}{|l|p{12cm}|}
\hline
spin-acquire & Hold-event probe that fires immediately after a spin lock is acquired. \\
spin-spin & Contention-event probe that fires after a thread that has spun on a held spin lock has successfully acquired the spin lock. If both are enabled, \texttt{spin-spin} fires before \texttt{spin-acquire}. arg1 for \texttt{spin-spin} contains the \text{spin time}: the number of nanoseconds that were spent in the spin state before the lock was acquired. The spin count has little meaning on its own, but can be used to compare spin times. \\
spin-release & Hold-event probe that fires immediately after a spin lock is released. \\
\hline
\end{tabular}
\caption{Spin Lock Probes}
\end{table}

Adaptive locks are much more common than spin locks. The following script displays totals for both lock types to provide data to support this observation.
lockstat:::adaptive-acquire
/_execname == "date"/
{
   @locks["adaptive"] = count();
}

lockstat:::spin-acquire
/Execname == "date"/
{
   @locks["spin"] = count();
}

Run this script in one window, and a date(1) command in another. When you terminate the DTrace script, you will see output similar to the following example:

```
# dtrace -s ./whatlock.d
dtrace: script './whatlock.d' matched 5 probes
^C
spin 26
adaptive 2981
```

As this output indicates, over 99 percent of the locks acquired in running the `date` command are adaptive locks. It may be surprising that so many locks are acquired in doing something as simple as a `date`. The large number of locks is a natural artifact of the fine-grained locking required of an extremely scalable system like the illumos kernel.

### 18.4 Thread Locks

Thread locks are a special kind of spin lock that are used to lock a thread for purposes of changing thread state. Thread lock hold events are available as spin lock hold-event probes (specifically, `spin-acquire` and `spin-release`), but contention events have their own probe specific to thread locks. The thread lock hold-event probe is in Table 18.3.

| thread-spin | Contention-event probe that fires after a thread has spun on a thread lock. Like other contention-event probes, if both the contention-event probe and the hold-event probe are enabled, `thread-spin` will fire before `spin-acquire`. Unlike other contention-event probes, however, `thread-spin` fires before the lock is actually acquired. As a result, multiple `thread-spin` probe firings may correspond to a single `spin-acquire` probe firing. |

### 18.5 Readers/Writer Lock Probes

Readers/writer locks enforce a policy of allowing multiple readers or a single writer — but not both — to be in a critical section. These locks are typically used for structures that are searched more frequently than they are modified and for which there is substantial time in the critical section. If critical section times are
short, readers/writer locks will implicitly serialize over the shared memory used to implement the lock, giving them no advantage over adaptive locks. See rwlock(9F) for more details on readers/writer locks.

The probes pertaining to readers/writer locks are in Table 18.4. For each probe, arg0 contains a pointer to the krwlock_t structure that represents the adaptive lock.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>rw-acquire</strong></td>
<td>Hold-event probe that fires immediately after a readers/writer lock is acquired. arg1 contains the constant RW_READER if the lock was acquired as a reader, and RW_WRITER if the lock was acquired as a writer.</td>
</tr>
<tr>
<td><strong>rw-block</strong></td>
<td>Contention-event probe that fires after a thread that has blocked on a held readers/writer lock has reawakened and has acquired the lock. arg1 contains the length of time (in nanoseconds) that the current thread had to sleep to acquire the lock. arg2 contains the constant RW_READER if the lock was acquired as a reader, and RW_WRITER if the lock was acquired as a writer. arg3 and arg4 contain more information on the reason for blocking. arg3 is non-zero if and only if the lock was held as a writer when the current thread blocked. arg4 contains the readers count when the current thread blocked. If both the rw-block and rw-acquire probes are enabled, rw-block fires before rw-acquire.</td>
</tr>
<tr>
<td><strong>rw-upgrade</strong></td>
<td>Hold-event probe that fires after a thread has successfully upgraded a readers/writer lock from a reader to a writer. Upgrades do not have an associated contention event because they are only possible through a non-blocking interface, rw_tryupgrade(9F).</td>
</tr>
<tr>
<td><strong>rw-downgrade</strong></td>
<td>Hold-event probe that fires after a thread had downgraded its ownership of a readers/writer lock from writer to reader. Downgrades do not have an associated contention event because they always succeed without contention.</td>
</tr>
<tr>
<td><strong>rw-release</strong></td>
<td>Hold-event probe that fires immediately after a readers/writer lock is released. arg1 contains the constant RW_READER if the released lock was held as a reader, and RW_WRITER if the released lock was held as a writer. Due to upgrades and downgrades, the lock may not have been released as it was acquired.</td>
</tr>
</tbody>
</table>

### 18.6 Stability

The lockstat provider uses DTrace’s stability mechanism to describe its stabilities as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Common</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Common</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Common</td>
</tr>
</tbody>
</table>
Chapter 19

profile Provider

The profile provider provides probes associated with a time-based interrupt firing every fixed, specified time interval. These unanchored probes that are not associated with any particular point of execution, but rather with the asynchronous interrupt event. These probes can be used to sample some aspect of system state every unit time and the samples can then be used to infer system behavior. If the sampling rate is high, or the sampling time is long, an accurate inference is possible. Using DTrace actions, the profile provider can be used to sample practically anything in the system. For example, you could sample the state of the current thread, the state of the CPU, or the current machine instruction.

Note
Thread-local variables are inaccessible to probes from the profile provider. Using the special identifier self to reference a thread-local variable with such a probe will produce no output.

19.1 profile–\( n \) probes

A profile–\( n \) probe fires every fixed interval on every CPU at high interrupt level. The probe’s firing interval is denoted by the value of \( n \): the interrupt source will fire \( n \) times per second. \( n \) may also have an optional time suffix, in which case \( n \) is interpreted to be in the units denoted by the suffix. Valid suffixes and the units they denote are listed in Table 19.1.

<table>
<thead>
<tr>
<th>Suffix</th>
<th>Time Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>nsec or ns</td>
<td>nanoseconds</td>
</tr>
<tr>
<td>usec or us</td>
<td>microseconds</td>
</tr>
<tr>
<td>msec or ms</td>
<td>milliseconds</td>
</tr>
<tr>
<td>sec or s</td>
<td>seconds</td>
</tr>
<tr>
<td>min or m</td>
<td>minutes</td>
</tr>
<tr>
<td>hour or h</td>
<td>hours</td>
</tr>
<tr>
<td>day or d</td>
<td>days</td>
</tr>
<tr>
<td>hz</td>
<td>hertz (frequency per second)</td>
</tr>
</tbody>
</table>
The following example creates a probe to fire at 97 hertz to sample the currently running process:

```d
#pragma D option quiet
profile-97
/pid != 0/
{
    @proc[pid, execname] = count();
}
END
{
    printf("%-8s %-40s %s\n", "PID", "CMD", "COUNT");
    printa("%-8d %-40s @%d\n", @proc);
}
```

Running the above example for a brief period of time results in output similar to the following example:

```
# dtrace -s ./prof.d
^C
PID   CMD         COUNT
223887 sh         1
100360 httpd     1
100409 mibiisa   1
223887 uname     1
218848 sh         2
218984 adeptedit  2
100224 nscl      3
3      fsflush    4
2      pageout    6
100372 java      7
115279 xterm     7
100460 Xsun       7
100475 perfbar    9
223888 prstat    15
```

You can also use the `profile-n` provider to sample information about the running process. The following example D script uses a 1,001 hertz profile probe to sample the current priority of a specified process:

```d
profile-1001
/pid == $1/
{
    @proc[execname] = lquantize(curlwpsinfo->pr_pri, 0, 100, 10);
}
```

To see this example script in action, type the following commands in one window:

```
$ echo $$
12345
$ while true ; do let i=0 ; done
```

In another window, run the D script for a brief period of time, replacing `12345` with the PID that your `echo` command returned:

```
# dtrace -s ./profpri.d 12345
```

```
dtrace: script './profpri.d' matched 1 probe
^C
```
This output shows the bias of the timesharing scheduling class. Because the shell process is spinning on the CPU, its priority is constantly being lowered by the system. If the shell process were running less frequently, its priority would be higher. To see this result, type Control-C in the spinning shell and run the script again:

```
# dtrace -s ./profpri.d 494621
```

```
dtrace: script './profpri.d' matched 1 probe
```

Now in the shell, type a few characters. When you terminate the DTrace script, output like the following example will appear:

```
ksh
```

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>7443</td>
</tr>
<tr>
<td>10</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>2235</td>
</tr>
<tr>
<td>20</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>1679</td>
</tr>
<tr>
<td>30</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>1119</td>
</tr>
<tr>
<td>40</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>560</td>
</tr>
<tr>
<td>50</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>554</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

Because the shell process was sleeping awaiting user input instead of spinning on the CPU, when it *did* run it was run at a much higher priority.

### 19.2 tick-n probes

Like profile-n probes, tick-n probes fire every fixed interval at high interrupt level. However, unlike profile-n probes, which fire on *every* CPU, tick-n probes fire on only *one* CPU per interval. The actual CPU may change over time. As with profile-n probes, `n` defaults to rate-per-second but may also have an optional time suffix. tick-n probes have several uses, such as providing some periodic output or taking a periodic action.

### 19.3 Arguments

The arguments to profile probes are as follows:

- **arg0**: The program counter (PC) in the kernel at the time that the probe fired, or 0 if the current process was not executing in the kernel at the time that the probe fired.
- **arg1**: The PC in the user-level process at the time that the probe fired, or 0 if the current process was executing at the kernel at the time that the probe fired.

As the descriptions imply, if arg0 is non-zero then arg1 is zero; if arg0 is zero then arg1 is non-zero.
Thus, you can use \texttt{arg0} and \texttt{arg1} to differentiate user-level from kernel level, as in this simple example:

\begin{verbatim}
profile-1ms
{
    @ticks[ arg0 ? "kernel" : "user" ] = count();
}
\end{verbatim}

19.4 Timer Resolution

The \texttt{profile} provider uses arbitrary resolution interval timers in the operating system. On architectures that do not support truly arbitrary resolution time-based interrupts, the frequency is limited by the system clock frequency, which is specified by the \texttt{hz} kernel variable. Probes of higher frequency than \texttt{hz} on such architectures will fire some number of times every \( 1/hz \) seconds. For example, a 1000 hertz \texttt{profile} probe on such an architecture with \texttt{hz} set to 100 will fire ten times in rapid succession every ten milliseconds. On platforms that support arbitrary resolution, a 1000 hertz \texttt{profile} probe would fire exactly every one millisecond.

The following example tests a given architecture’s resolution:

\begin{verbatim}
profile-5000
{
    /*
    * We divide by 1,000,000 to convert nanoseconds to milliseconds,
    * and then we take the value mod 10 to get the current
    * millisecond within a 10 millisecond window. On platforms that
    * do not support truly arbitrary resolution profile probes, all
    * of the profile-5000 probes will fire on roughly the same
    * millisecond. On platforms that support a truly arbitrary
    * resolution, the probe firings will be evenly distributed across
    * the milliseconds.
    */
    @ms = lquantize((timestamp / 1000000) % 10, 0, 10, 1);
}
\end{verbatim}

\begin{verbatim}
tick-1sec
/i++ >= 10/
{
    exit(0);
}
\end{verbatim}

On an architecture that supports arbitrary resolution \texttt{profile} probes, running the example script will yield an even distribution:

\begin{verbatim}
# dtrace -s ./restest.d
dtrace: script './restest.d' matched 2 probes
CPU ID FUNCTION:NAME
  0  33631 :tick-1sec

value  Distribution  count
< 0 | 0  0 10760
  0 |### 10842
  1 |### 10861
  2 |### 10820
  3 |### 10819
\end{verbatim}

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On an architecture that does not support arbitrary resolution profile probes, running the example script will yield an uneven distribution:

```
# dtrace -s ./restest.d
```

```
dtrace: script './restest.d' matched 2 probes
CPU ID FUNCTION:NAME
0 28321 :tick-1sec
```

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>107864</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>424</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>255</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>496</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

On these architectures, `hz` may be manually tuned in `/etc/system` to improve the effective profile resolution.

Currently, all variants of UltraSPARC (sun4u) support arbitrary resolution profile probes. Many variants of the x86 architecture (i86pc) also support arbitrary resolution profile probes, although some older variants do not.

### 19.5 Probe Creation

Unlike other providers, the profile provider creates probes dynamically on an as-needed basis. Thus, the desired profile probe might not appear in a listing of all probes (for example, by using `dtrace -l -P profile`) but the probe will be created when it is explicitly enabled.

On architectures that support arbitrary resolution profile probes, a time interval that is too short would cause the machine to continuously field time-based interrupts, thereby denying service on the machine. To prevent this situation, the profile provider will silently refuse to create any probe that would result in an interval of less than two hundred microseconds.

### 19.6 Stability

The profile provider uses DTrace’s stability mechanism to describe its stabilities as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Common</td>
</tr>
<tr>
<td>Module</td>
<td>Unstable</td>
<td>Unstable</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Common</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Common</td>
</tr>
</tbody>
</table>
Chapter 20

fbt Provider

The Function Boundary Tracing (FBT) provider provides probes associated with the entry to and return from most functions in the illumos kernel. The function is the fundamental unit of program text. In a well-designed system, each function performs a discrete and well-defined operation on a specified object or series of like objects. Therefore, even on the smallest illumos systems, FBT will provide on the order of 20,000 probes.

Similar to other DTrace providers, FBT has no probe effect when it is 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 SPARC and x86 platforms. For each instruction set, there are a small number of functions that do not call other functions and are highly optimized by the compiler (so-called leaf functions) that cannot be instrumented by FBT. Probes for these functions are not present in DTrace.

Effective use of FBT probes requires knowledge of the operating system implementation. Therefore, it is recommended that you use FBT only when developing kernel software or when other providers are not sufficient. Other DTrace providers, including syscall, sched, proc, and io, can be used to answer most system analysis questions without requiring operating system implementation knowledge.

20.1 Probes

FBT provides a probe at the boundary of most functions in the kernel. The boundary of a function is crossed by entering the function and by returning from the function. FBT thus provides two functions for every function in the kernel: one upon entry to the function, and one upon return from the function. These probes are named entry and return, respectively. The function name, and module name are specified as part of the probe. All FBT probes specify a function name and module name.

20.2 Probe arguments

entry probes

The arguments to entry probes are the same as the arguments to the corresponding operating system kernel function. These arguments may be accessed in a typed fashion by using the args[] array. These arguments may be accessed as int64_t’s by using the arg0 .. argn variables.
return probes

While a given function only has a single point of entry, it may have many different points where it returns to its caller. You are usually interested in either the value that a function returned or the fact that the function returned at all rather than the specific return path taken. FBT therefore collects a function’s multiple return sites into a single return probe. If the exact return path is of interest, you can examine the return probe args[0] value, which indicates the offset (in bytes) of the returning instruction in the function text.

If the function has a return value, the return value is stored in args[1]. If a function does not have a return value, args[1] is not defined.

20.3 Examples

You can use FBT to easily explore the kernel’s implementation. The following example script records the first ioctl(2) from any xclock process and then follows the subsequent code path through the kernel:

/*
 * To make the output more readable, we want to indent every function
 * entry (and unindent every function return). This is done by
 * setting the "flowindent" option.
 */
#pragma D option flowindent

syscall::ioctl:entry
/execname == "xclock" && guard++ == 0/
{
    self->traceme = 1;
    printf("fd: %d", arg0);
}

fbt:::
/self->traceme/
{}

syscall::ioctl:return
/self->traceme/
{
    self->traceme = 0;
    exit(0);
}

Running this script results in output similar to the following example:

# dtrace -s ./xioctl.d

dtrace: script './xioctl.d' matched 26254 probes
CPU FUNCTION
  0  => ioctl        fd: 3
  0  -> ioctl
  0  -> getf
  0  -> set_active_fd
  0  <- set_active_fd
  0  <- getf
  0  -> fop_ioctl
  0  -> sock_ioctl
  0  -> strioctl

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The output shows that an `xclock` process called `ioctl` on a file descriptor that appears to be associated with a socket.

You can also use FBT when trying to understand kernel drivers. For example, the ssd(7D) driver has many code paths by which `EIO` may be returned. FBT can be easily used to determine the precise code path that resulted in an error condition, as shown in the following example:

```bash
fbt:ssd::return
/arg1 == EIO/
{
    printf("%s+%x returned EIO.", probefunc, arg0);
}
```

For more information on any one return of `EIO`, one may wish to speculatively trace all `fbt` probes, and then commit (or discard) based on the return value of a specific function. See Chapter 13 for details on speculative tracing.

Alternatively, you can use FBT to understand the functions called within a specified module. The following example lists all of the functions called in UFS:

```bash
# dtrace -n fbt:ufs::entry'{@a[probefunc] = count()}'
dtrace: description 'fbt:ufs::entry' matched 353 probes
^C
  ufs_ioctl 1
  ufs_statvfs 1
  ufs_readlink 1
  ufs_trans_touch 1
  ufs_trans_syncip 1
  ufs_write 1
  ufs_putpages 1
  ufs_putpage 1
  ufs_syncip 1
  ufs_trans_write_resv 1
  ufs_log_amt 1
  ufs_getpage_miss 1
  ufs_trans_syncip 1
```

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If you know the purpose or arguments of a kernel function, you can use FBT to understand how or why the function is being called. For example, putnext(9F) takes a pointer to a queue(9S) structure as its first member. The q_qinfo member of the queue structure is a pointer to a qinit(9S) structure. The qi_minfo member of the qinit structure has a pointer to a module_info(9S) structure, which contains the module name in its mi_idname member. The following example puts this information together by using the FBT probe in putnext to track putnext(9F) calls by module name:

```plaintext
fbt::putnext:entry
{
    @calls[stringof(args[0]->q_qinfo->qi_minfo->mi_idname)] = count();
}
```

Running the above script results in output similar to the following example:

```
# dtrace -s ./putnext.d
^C
```

```
iprb         1
rpcmod        1
pfmod         1
timod         2
vpnmod        2
pts           40
```
20.3. Examples

You can also use FBT to determine the time spent in a particular function. The following example shows how to determine the callers of the DDI delaying routines `drv_usecwait(9F)` and `delay(9F).

```c
fbt::delay:entry,
fbt::drv_usecwait:entry
{
    self->in = timestamp
}

fbt::delay:return,
fbt::drv_usecwait:return
/self->in/
{
    @snoozers[stack()] = quantize(timestamp - self->in);
    self->in = 0;
}
```

This example script is particularly interesting to run during boot. Chapter 36 describes the procedure for performing anonymous tracing during system boot. Upon reboot, you might see output similar to the following example:

```
# dtrace -ae
ata'ata_wait+0x34
ata'ata_id_common+0xf5
ata'ata_disk_id+0x20
ata'ata_drive_type+0x9a
ata'ata_init_drive+0xa2
ata'ata_attach+0x50
genunix'devi_attach+0x75
genunix'attach_node+0xb2
genunix'i_ndi_config_node+0x97
genunix'i_ddi_attachchild+0x4b
genunix'devi_attach_node+0x3d
genunix'devi_config_one+0x1d0
genunix'ndi_devi_config_one+0xb0
devfs'dv_find+0x125
devfs'devfs_lookup+0x40
genunix'fop_lookup+0x21
genunix'lookuppnvp+0x236
genunix'lookupppnat+0xe7
genunix'lookupnameat+0x87
genunix'cstatat_getvp+0x134
```
20.4 Tail-call Optimization

When one function ends by calling another function, the compiler can engage in *tail-call optimization*, in which the function being called reuses the caller’s stack frame. This procedure is most commonly used
in the SPARC architecture, where the compiler reuses the caller’s register window in the function being called in order to minimize register window pressure.

The presence of this optimization causes the return probe of the calling function to fire before the entry probe of the called function. This ordering can lead to quite a bit of confusion. For example, if you wanted to record all functions called from a particular function and any functions that this function calls, you might use the following script:

```c
fbt::foo:entry
{
    self->traceme = 1;
}

fbt::entry
/self->traceme/
{
    printf("called %s", probefunc);
}

fbt::foo:return
/self->traceme/
{
    self->traceme = 0;
}
```

However, if `foo` ends in an optimized tail-call, the tail-called function, and therefore any functions that it calls, will not be captured. The kernel cannot be dynamically deoptimized on the fly, and DTrace does not wish to engage in a lie about how code is structured. Therefore, you should be aware of when tail-call optimization might be used.

Tail-call optimization is likely to be used in source code similar to the following example:

```c
return (bar());
```

Or in source code similar to the following example:

```c
(void) bar();
return;
```

Conversely, function source code that ends like the following example cannot have its call to `bar` optimized, because the call to `bar` is not a tail-call:

```c
bar();
return (rval);
```

You can determine whether a call has been tail-call optimized using the following technique:

- While running DTrace, trace `arg0` of the return probe in question. `arg0` contains the offset of the returning instruction in the function.

- After DTrace has stopped, use `mdb(1)` to look at the function. If the traced offset contains a call to another function instead of an instruction to return from the function, the call has been tail-call optimized.

Due to the instruction set architecture, tail-call optimization is far more common on SPARC systems than on x86 systems. The following example uses `mdb` to discover tail-call optimization in the kernel’s `dup` function:
While this command is running, run a program that performs a dup(2), such as a bash process. The above command should provide output similar to the following example:

dup+0x10
^C

Now examine the function with mdb:

```bash
# echo "dup::dis" | mdb -k
```

The output shows that dup+0x10 is a call to the fcntl function and not a ret instruction. Therefore, the call to fcntl is an example of tail-call optimization.

### 20.5 Assembly Functions

You might observe functions that seem to enter but never return or vice versa. Such rare functions are generally hand-coded assembly routines that branch to the middle of other hand-coded assembly functions. These functions should not impede analysis: the branched-to function must still return to the caller of the branched-from function. That is, if you enable all FBT probes, you should see the entry to one function and the return from another function at the same stack depth.

### 20.6 Instruction Set Limitations

Some functions cannot be instrumented by FBT. The exact nature of uninstrumentable functions is specific to the instruction set architecture.

#### x86 Limitations

Functions that do not create a stack frame on x86 systems cannot be instrumented by FBT. Because the register set for x86 is extraordinarily small, most functions must put data on the stack and therefore create a stack frame. However, some x86 functions do not create a stack frame and therefore cannot be instrumented. Actual numbers vary, but typically fewer than five percent of functions cannot be instrumented on the x86 platform.

#### SPARC Limitations

Leaf routines hand-coded in assembly language on SPARC systems cannot be instrumented by FBT. The majority of the kernel is written in C, and all functions written in C can be instrumented by FBT.
20.7 Breakpoint Interaction

FBT works by dynamically modifying kernel text. Because kernel breakpoints also work by modifying kernel text, if a kernel breakpoint is placed at an entry or return site before loading DTrace, FBT will refuse to provide a probe for the function, even if the kernel breakpoint is subsequently removed. If the kernel breakpoint is placed after loading DTrace, both the kernel breakpoint and the DTrace probe will correspond to the same point in text. In this situation, the breakpoint will trigger first, and then the probe will fire when the debugger resumes the kernel. It is recommended that kernel breakpoints not be used concurrently with DTrace. If breakpoints are required, use the DTrace breakpoint action instead.

20.8 Module Loading

The illumos kernel can dynamic load and unload kernel modules. When FBT is loaded and a module is dynamically loaded, FBT automatically provides new probes associated with the new module. If a loaded module has unenabled FBT probes, the module may be unloaded; the corresponding probes will be destroyed as the module is unloaded. If a loaded module has enabled FBT probes, the module is considered busy, and cannot be unloaded.

20.9 Stability

The FBT provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Private</td>
<td>Private</td>
<td>ISA</td>
</tr>
</tbody>
</table>

As FBT exposes the kernel implementation, nothing about it is Stable — and the Module and Function name and data stability are explicitly Private. The data stability for Provider and Name are Evolving, but all other data stabilities are Private: they are artifacts of the current implementation. The dependency class for FBT is ISA: while FBT is available on all current instruction set architectures, there is no guarantee that FBT will be available on arbitrary future instruction set architectures.
Chapter 21

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.

21.1 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 transferred back to user-level. For all syscall probes, the function name is set to be the name of the instrumented system call and the module name is undefined.

The names of the system calls as provided by the syscall provider may be found in the /etc/name_to_sysnum file. Often, the system call names provided by syscall correspond to names in Section 2 of the manual pages. However, some probes provided by the syscall provider do not directly correspond to any documented system call. The common reasons for this discrepancy are described in this section.

System Call Anachronisms

In some cases, the name of the system call as provided by the syscall provider is actually a reflection of an ancient implementation detail. For example, for reasons dating back to UNIX™ antiquity, the name of exit(2) in /etc/name_to_sysnum is rexit. Similarly, the name of time(2) is gtime, and the name of both execle(2) and execve(2) is exece.

Subcoded System Calls

Some system calls as presented in Section 2 are implemented as suboperations of an undocumented system call. For example, the system calls related to System V semaphores (semctl(2), semget(2), semids(2), semop(2), and semtimedop(2)) are implemented as suboperations of a single system call, semsys. The semsys system call takes as its first argument an implementation-specific subcode denoting the specific system call required: SEMCTL, SEMGET, SEMIDS, SEMOP or SEMTIMEOP, respectively. As a result of overloading a single system call to implement multiple system calls, there is only a single pair of syscall probes for System V semaphores: syscall::semsys:entry and syscall::semsys:return.
Large File System Calls

A 32-bit program that supports large files that exceed four gigabytes in size must be able to process 64–bit file offsets. Because large files require use of large offsets, large files are manipulated through a parallel set of system interfaces, as described in lf64(5). These interfaces are documented in lf64, but they do not have individual manual pages. Each of these large file system call interfaces appears as its own syscall probe as shown in Table 21.1.

<table>
<thead>
<tr>
<th>Large File syscall Probe</th>
<th>System Call</th>
</tr>
</thead>
<tbody>
<tr>
<td>creat64</td>
<td>creat(2)</td>
</tr>
<tr>
<td>fstat64</td>
<td>fstat(2)</td>
</tr>
<tr>
<td>fstatvfs64</td>
<td>fstatvfs(2)</td>
</tr>
<tr>
<td>getdents64</td>
<td>getdents(2)</td>
</tr>
<tr>
<td>getrlimit64</td>
<td>getrlimit(2)</td>
</tr>
<tr>
<td>lstat64</td>
<td>lstat(2)</td>
</tr>
<tr>
<td>mmap64</td>
<td>mmap(2)</td>
</tr>
<tr>
<td>open64</td>
<td>open(2)</td>
</tr>
<tr>
<td>pread64</td>
<td>pread(2)</td>
</tr>
<tr>
<td>pwrite64</td>
<td>pwrite(2)</td>
</tr>
<tr>
<td>setrlimit64</td>
<td>setrlimit(2)</td>
</tr>
<tr>
<td>stat64</td>
<td>stat(2)</td>
</tr>
<tr>
<td>statvfs64</td>
<td>statvfs(2)</td>
</tr>
</tbody>
</table>

Private System Calls

Some system calls are private implementation details of illumos subsystems that span the user-kernel boundary. As such, these system calls do not have manual pages in Section 2. Examples of system calls in this category include the signotify system call, which is used as part of the implementation of POSIX.4 message queues, and the utssys system call, which is used to implement fuser(1M).

21.2 Arguments

For entry probes, the arguments (arg0 .. argn) are the 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 system call failure.

21.3 Stability

The syscall provider uses DTrace’s stability mechanism to describe its stabilities as shown in the following table. For more information about the stability mechanism, refer to Chapter 39.
<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
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<td>Evolving</td>
<td>Common</td>
</tr>
<tr>
<td>Module</td>
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<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Unstable</td>
<td>Unstable</td>
<td>ISA</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Common</td>
</tr>
<tr>
<td>Arguments</td>
<td>Unstable</td>
<td>Unstable</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 22

sdT Provider

The statically Defined Tracing (SDT) provider creates probes at sites that a software programmer has formally designated. The SDT mechanism allows programmers to consciously choose locations of interest to users of DTrace and to convey some semantic knowledge about each location through the probe name. The illumos kernel has defined a handful of SDT probes, and will likely add more over time. DTrace also provides a mechanism for user application developers to define static probes, described in Chapter 34.

22.1 Probes

The SDT probes defined by the illumos kernel are listed in Table 22.1. The name stability and data stability of these probes are both Private because their description here thus reflects the kernel’s implementation and should not be inferred to be an interface commitment. For more information about the DTrace stability mechanism, see Section 22.4.

Table 22.1: SDT Probes

<table>
<thead>
<tr>
<th>Probe name</th>
<th>Description</th>
<th>arg0</th>
</tr>
</thead>
<tbody>
<tr>
<td>callout-start</td>
<td>Probe that fires immediately before executing a callout (see &lt;sys/callo.h&gt;). Callouts are executed by a periodic system clock, and represent the implementation for timeout(9F).</td>
<td>Pointer to the callout_t (see &lt;sys/callo.h&gt;) corresponding to the callout to be executed.</td>
</tr>
<tr>
<td>callout-end</td>
<td>Probe that fires immediately after executing a callout (see &lt;sys/callo.h&gt;).</td>
<td>Pointer to the callout_t (see &lt;sys/callo.h&gt;) corresponding to the callout just executed.</td>
</tr>
<tr>
<td>interrupt-start</td>
<td>Probe that fires immediately before calling into a device’s interrupt handler.</td>
<td>Pointer to the dev_info structure (see &lt;sys/ddi_impldefs.h&gt;) corres-ponding to the interrupting device.</td>
</tr>
</tbody>
</table>
Table 22.1: (continued)

<table>
<thead>
<tr>
<th>Probe name</th>
<th>Description</th>
<th>arg0</th>
</tr>
</thead>
<tbody>
<tr>
<td>interrupt-complete</td>
<td>Probe that fires immediately after returning from a device’s interrupt handler.</td>
<td>Pointer to dev_info structure (see &lt;sys/ddi_impldefs.h&gt;) corresponding to the interrupting device.</td>
</tr>
</tbody>
</table>

### 22.2 Examples

The following example is a script to observe callout behavior on a per-second basis:

```c
#pragma D option quiet

sdt:::callout-start
{
    @callouts[((callout_t *)arg0)->c_func] = count();
}

tick-1sec
{
    printa("%40a %10@d\n", @callouts);
    clear(@callouts);
}
```

Running this example reveals the frequent users of timeout(9F) in the system, as shown in the following output:

```
# dtrace -s ./callout.d

<table>
<thead>
<tr>
<th>FUNC</th>
<th>COUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS 'ts_update</td>
<td>1</td>
</tr>
<tr>
<td>uhci 'uhci_cmd_timeout_hdlr</td>
<td>3</td>
</tr>
<tr>
<td>genunix 'setrun</td>
<td>5</td>
</tr>
<tr>
<td>genunix 'schedpaging</td>
<td>5</td>
</tr>
<tr>
<td>ata 'ghd_timeout</td>
<td>10</td>
</tr>
<tr>
<td>uhci 'uhci_handle_root_hub_status_change</td>
<td>309</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>FUNC</th>
<th>COUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ip 'tcp_time_wait_collector</td>
<td>1</td>
</tr>
<tr>
<td>TS 'ts_update</td>
<td>1</td>
</tr>
<tr>
<td>uhci 'uhci_cmd_timeout_hdlr</td>
<td>3</td>
</tr>
<tr>
<td>genunix 'schedpaging</td>
<td>4</td>
</tr>
<tr>
<td>genunix 'setrun</td>
<td>8</td>
</tr>
<tr>
<td>ata 'ghd_timeout</td>
<td>10</td>
</tr>
<tr>
<td>uhci 'uhci_handle_root_hub_status_change</td>
<td>300</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>FUNC</th>
<th>COUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ip 'tcp_time_wait_collector</td>
<td>0</td>
</tr>
<tr>
<td>iprb 'mii_portmon</td>
<td>1</td>
</tr>
<tr>
<td>TS 'ts_update</td>
<td>1</td>
</tr>
<tr>
<td>uhci 'uhci_cmd_timeout_hdlr</td>
<td>3</td>
</tr>
<tr>
<td>genunix 'schedpaging</td>
<td>4</td>
</tr>
<tr>
<td>genunix 'setrun</td>
<td>7</td>
</tr>
<tr>
<td>ata 'ghd_timeout</td>
<td>10</td>
</tr>
</tbody>
</table>
```
The timeout(9F) interface only produces a single timer expiration. Consumers of timeout requiring interval timer functionality typically reinstall their timeout from their timeout handler. The following example shows this behavior:

```c
#pragma D option quiet

sdt:::callout-start
{
    self->callout = ((callout_t *)arg0)->c_func;
}

fbt::timeout:entry
/self->callout && arg2 <= 100/
{
    /*
     * In this case, we are most interested in interval timeout(9F)s
     * that are short. We therefore do a linear quantization from 0
     * ticks to 100 ticks. The system clock's frequency -- set
     * by the variable "hz" -- defaults to 100, so 100 system
     * clock ticks is one second.
     */
    @callout[self->callout] = lquantize(arg2, 0, 100);
}

sdt:::callout-end
{
    self->callout = NULL;
}

END
{
    printa("%a\n%@d\n\n", @callout);
}
```

Running this script and waiting several seconds before typing Control-C results in output similar to the following example:

```
# dtrace -s ./interval.d
^C

genuunix\'schedpaging

    value   Distribution    count
      24       |                      0
      25       |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 20
      26       |                      0

ata\'ghd_timeout

    value   Distribution    count
      9       |                      0
      10       |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 51
      11       |                      0

uhci\'uhci_handle_root_hub_status_change
```

uhci\'uhci_handle_root_hub_status_change 300
The output shows that `uhci_handle_root_hub_status_change` in the `uhci(7D)` driver represents the shortest interval timer on the system: it is called every system clock tick.

The `interrupt-start` probe can be used to understand interrupt activity. The following example shows how to quantize the time spent executing an interrupt handler by driver name:

```c
interrupt-start
{
    self->ts = vtimestamp;
}

interrupt-complete
/self->ts/
{
    this->devi = (struct dev_info *)arg0;
    @[stringof('devnamesp[this->devi->devi_major].dn_name),
        this->devi->devi_instance] = quantize(vtimestamp - self->ts);
}
```

Running this script results in output similar to the following example:

```
# dtrace -s ./intr.d
```

```
dtrace: script './intr.d' matched 2 probes
^C
isp
```

```
value -------------- Distribution -------------- count
0 | 0
1 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 1515
2 | 0
```

```
pcf8584
```

```
value -------------- Distribution -------------- count
64 | 0
128 | 2
256 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 157
512 |@@@@@@@@ 31
1024 | 3
2048 | 0
```

```
qlc
```

```
value -------------- Distribution -------------- count
16384 | 0
32768 |@@ 9
65536 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 126
131072 |@ 5
262144 | 2
524288 | 0
```
22.3 Creating SDT Probes

If you are a device driver developer, you might be interested in creating your own SDT probes in your illumos 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.

Declaring Probes

SDT probes are declared using the DTRACE_PROBE, DTRACE_PROBE1, DTRACE_PROBE2, DTRACE_PROBE3 and DTRACE_PROBE4 macros from <sys/sdt.h>. The module name and function name of an SDT-based probe corresponds to the kernel module and function of the probe. The name of the probe depends on the name given in the DTRACE_PROBEn macro. If the name contains no two consecutive underbars (_), the name of the probe is as written in the macro. If the name contains any two consecutive underbars, the probe name converts the consecutive underbars to a single dash (-). For example, if a DTRACE_PROBE macro specifies transaction__start, the SDT probe will be named transaction-start. This substitution allows C code to provide macro names that are not valid C identifiers without specifying a string.

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. You can use the command dtrace -l -P sdt -m module on your driver module to list the probes you have installed and the full names that will be seen by users of DTrace.
Probe Arguments

The arguments for each SDT probe are the arguments specified in the corresponding DTRACE_PROBEn macro reference. The number of arguments depends on which macro was used to create the probe: DTRACE_PROBE1 specifies one argument, DTRACE_PROBE2 specifies two arguments, and so on. When declaring your SDT probes, you can minimize their disabled probe effect by not dereferencing pointers and 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.

22.4 Stability

The SDT provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Private</td>
<td>Private</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Private</td>
<td>Private</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 23

sysinfo Provider

The sysinfo provider makes available probes that correspond to kernel statistics classified by the name sys. Because these statistics provide the input for system monitoring utilities like mpstat(1M), the sysinfo provider enables quick exploration of observed aberrant behavior.

23.1 Probes

The sysinfo provider makes available probes that correspond to the fields in the sys named kernel statistic: a probe provided by sysinfo fires immediately before the corresponding sys value is incremented. The following example shows how to display both the names and the current values of the sys named kernel statistic using the kstat(1M) command.

```
$ kstat -n sys
module: cpu instance: 0
name: sys class: misc
   bawrite  123
   bread     2899
   bwrite    17995
...
```

The sysinfo probes are described in Table 23.1.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bawrite</td>
<td>Probe that fires whenever a buffer is about to be asynchronously written out to a device.</td>
</tr>
<tr>
<td>bread</td>
<td>Probe that fires whenever a buffer is physically read from a device. bread fires after the buffer has been requested from the device, but before blocking pending its completion.</td>
</tr>
<tr>
<td>bwrite</td>
<td>Probe that fires whenever a buffer is about to be written out to a device, whether synchronously or asynchronously.</td>
</tr>
<tr>
<td>idlethread</td>
<td>Probe that fires whenever a CPU enters the idle loop.</td>
</tr>
<tr>
<td>intrblk</td>
<td>Probe that fires whenever an interrupt thread blocks.</td>
</tr>
<tr>
<td>inv_swtch</td>
<td>Probe that fires whenever a running thread is forced to involuntarily give up the CPU.</td>
</tr>
<tr>
<td>lread</td>
<td>Probe that fires whenever a buffer is logically read from a device.</td>
</tr>
</tbody>
</table>
Table 23.1: (continued)

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>lwrite</td>
<td>Probe that fires whenever a buffer is logically written to a device</td>
</tr>
<tr>
<td>modload</td>
<td>Probe that fires whenever a kernel module is loaded.</td>
</tr>
<tr>
<td>modunload</td>
<td>Probe that fires whenever a kernel module is unloaded.</td>
</tr>
<tr>
<td>msg</td>
<td>Probe that fires whenever a msgsnd(2) or msgrcv(2) system call is made, but</td>
</tr>
<tr>
<td></td>
<td>before the message queue operations have been performed.</td>
</tr>
<tr>
<td>mutex_adenters</td>
<td>Probe that fires whenever an attempt is made to acquire an owned adaptive</td>
</tr>
<tr>
<td></td>
<td>lock. If this probe fires, one of the lockstat provider’s adaptive-block or</td>
</tr>
<tr>
<td></td>
<td>adaptive-spin probes will also fire. See Chapter 18 for details.</td>
</tr>
<tr>
<td>namei</td>
<td>Probe that fires whenever a name lookup is attempted in the filesystem.</td>
</tr>
<tr>
<td>nthreads</td>
<td>Probe that fires whenever a thread is created.</td>
</tr>
<tr>
<td>phread</td>
<td>Probe that fires whenever a raw I/O read is about to be performed.</td>
</tr>
<tr>
<td>phwrite</td>
<td>Probe that fires whenever a raw I/O write is about to be performed.</td>
</tr>
<tr>
<td>procovf</td>
<td>Probe that fires whenever a new process cannot be created because the</td>
</tr>
<tr>
<td></td>
<td>system is out of process table entries.</td>
</tr>
<tr>
<td>pswitch</td>
<td>Probe that fires whenever a CPU switches from executing one thread to</td>
</tr>
<tr>
<td></td>
<td>executing another.</td>
</tr>
<tr>
<td>readch</td>
<td>Probe that fires after each successful read, but before control is returned</td>
</tr>
<tr>
<td></td>
<td>to the thread performing the read. A read may occur through the read(2),</td>
</tr>
<tr>
<td></td>
<td>readv(2) or pread(2) system calls. arg0 contains the number of bytes that</td>
</tr>
<tr>
<td></td>
<td>were successfully read.</td>
</tr>
<tr>
<td>rw_rdfails</td>
<td>Probe that fires whenever an attempt is made to read-lock a readers/writer</td>
</tr>
<tr>
<td></td>
<td>when the lock is either held by a writer, or desired by a writer. If this</td>
</tr>
<tr>
<td></td>
<td>probe fires, the lockstat provider’s rw-block probe will also fire. See</td>
</tr>
<tr>
<td></td>
<td>Chapter 18 for details.</td>
</tr>
<tr>
<td>rw_wrfails</td>
<td>Probe that fires whenever an attempt is made to write-lock a readers/writer</td>
</tr>
<tr>
<td></td>
<td>lock when the lock is held either by some number of readers or by another</td>
</tr>
<tr>
<td></td>
<td>writer. If this probe fires, the lockstat provider’s rw-block probe will</td>
</tr>
<tr>
<td></td>
<td>also fire. See Chapter 18 for details.</td>
</tr>
<tr>
<td>sema</td>
<td>Probe that fires whenever a semop(2) system call is made, but before any</td>
</tr>
<tr>
<td></td>
<td>semaphore operations have been performed.</td>
</tr>
<tr>
<td>sysexec</td>
<td>Probe that fires whenever an exec(2) system call is made.</td>
</tr>
<tr>
<td>sysfork</td>
<td>Probe that fires whenever a fork(2) system call is made.</td>
</tr>
<tr>
<td>sysread</td>
<td>Probe that fires whenever a read(2), readv(2), or pread(2) system call is</td>
</tr>
<tr>
<td></td>
<td>made.</td>
</tr>
<tr>
<td>sysvfork</td>
<td>Probe that fires whenever a vfork(2) system call is made.</td>
</tr>
<tr>
<td>syscall</td>
<td>Probe that fires whenever a write(2), writev(2), or pwrite(2) system call is</td>
</tr>
<tr>
<td></td>
<td>made.</td>
</tr>
<tr>
<td>trap</td>
<td>Probe that fires whenever a processor trap occurs. Note that some processors,</td>
</tr>
<tr>
<td></td>
<td>in particular UltraSPARC variants, handle some light-weight traps through</td>
</tr>
<tr>
<td></td>
<td>a mechanism that does not cause this probe to fire.</td>
</tr>
<tr>
<td>ufsdirblk</td>
<td>Probe that fires whenever a directory block is read from the UFS file system.</td>
</tr>
<tr>
<td></td>
<td>See ufs(7FS) for details on UFS.</td>
</tr>
<tr>
<td>ufsiget</td>
<td>Probe that fires whenever an inode is retrieved. See ufs(7FS) for details on</td>
</tr>
<tr>
<td>ufsinopage</td>
<td>Probe that fires after an in-core inode without any associated data pages has</td>
</tr>
<tr>
<td></td>
<td>been made available for reuse. See ufs(7FS) for details on UFS.</td>
</tr>
</tbody>
</table>
23.2 Arguments

The arguments to sysinfo probes are as follows:

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>arg0</td>
<td>The value by which the statistic is to be incremented. For most probes, this argument is always 1, but for some probes this argument may take other values.</td>
</tr>
<tr>
<td>arg1</td>
<td>A pointer to the current value of the statistic to be incremented. This value is a 64-bit quantity that will be incremented by the value in arg0. Dereferencing this pointer enables consumers to determine the current count of the statistic corresponding to the probe.</td>
</tr>
<tr>
<td>arg2</td>
<td>A pointer to the cpu_t structure that corresponds to the CPU on which the statistic is to be incremented. The structure’s definition can be found in &lt;sys/cpuvar.h&gt;, but it is part of the kernel implementation and should be considered Private.</td>
</tr>
</tbody>
</table>

The value of arg0 is 1 for most sysinfo probes. However, the readch and writech probes set arg0 to the number of bytes read or written, respectively. This features permits you to determine the size of reads by executable name, as shown in the following example:

```
# dtrace -n readch’[@[execname] = quantize(arg0)]’
dtrace: description ‘readch’ matched 4 probes
^C
```

```
xclock
value ------------- Distribution ------------- count
  16 | 0
  32 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 1
  64 | 0

acroread
value ------------- Distribution ------------- count
  16 | 0
  32 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 3
  64 | 0
```

FvwmAuto

```
value ------------- Distribution ------------- count
```
The `sysinfo` provider sets `arg2` to be a pointer to a `cpu_t`, a structure internal to the kernel implementation. The `sysinfo` probes fire on the CPU on which the statistic is being incremented. Use the `cpu_id` member of the `cpu_t` structure to determine the CPU of interest.

### 23.3 Example

Examine the following output from `mpstat(1M)`:  

```
CPU mif mjf xcal intr ithr cs wicsm migr smtx srw syscl us r sys wt idl
12  90  22  5760  422  299  435  26  71  116  11  1372  5  19  17  60
```
From the above output, you might conclude that the \texttt{xcal} field seems too high, especially given the relative idleness of the system. \texttt{mpstat} determines the value in the \texttt{xcal} field by examining the \texttt{xcalls} field of the \texttt{sys} kernel statistic. This aberration can therefore be explored easily by enabling the \texttt{xcalls} \texttt{sysinfo} probe, as shown in the following example:

```
# dtrace -n xcalls'[@execname] = count()'
```

dtrace: description 'xcalls' matched 4 probes

```
^C
dterm
nsrd
in.mpathd
top
lockd
java_vm
ksh
iCald.pl6+RPATH
nwadmin
fsflush
nsrindexd
in.rlogind
in.routed
dtrace
rpc.rstatd
imapd
sched
nfsd
find
```

The output shows where to look for the source of the cross-calls. Some number of \texttt{find(1)} processes are causing the majority of the cross-calls. The following D script can be used to understand the problem in further detail:

```d
syscall:::entry
/execname == "find"/
{
    self->syscall = probefunc;
    self->insys = 1;
}

sysinfo:::xcalls
/execname == "find"/
{
    @[self->insys ? self->syscall : "<none>"] = count();
}
```

The output shows where to look for the source of the cross-calls. Some number of \texttt{find(1)} processes are causing the majority of the cross-calls. The following D script can be used to understand the problem in further detail:

```d
syscall:::entry
/execname == "find"/
{
    self->syscall = probefunc;
    self->insys = 1;
}

sysinfo:::xcalls
/execname == "find"/
{
    @[self->insys ? self->syscall : "<none>"] = count();
}
```

```
syscall:::return
/self->insys/
```
This script uses the syscall provider to attribute cross-calls from find to a particular system call. Some cross-calls, such as those resulting from page faults, might not emanate from system calls. The script prints "<none>" in these cases. Running the script results in output similar to the following example:

```
# dtrace -s ./find.d
  dtrace: script './find.d' matched 444 probes
    ^C
    <none> 2
    lstat64 2433
    getdents64 14873
```

This output indicates that the majority of cross-calls induced by find are in turn induced by getdents(2) system calls. Further exploration would depend on the direction you want to explore. If you want to understand why find processes are making calls to getdents, you could write a D script to aggregate on usock when find induces a cross-call. If you want to understand why calls to getdents are inducing cross-calls, you could write a D script to aggregate on stack when find induces a cross-call. Whatever your next step, the presence of the xcalls probe has enabled you to quickly discover the root cause of the unusual monitoring output.

### 23.4 Stability

The sysinfo provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Private</td>
<td>Private</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 24

vminfo Provider

The vminfo provider makes available probes that correspond to the vm kernel statistics. Because these statistics provide the input for system monitoring utilities like vmstat(1M), the vminfo provider enables quick exploration of observed aberrant behavior.

24.1 Probes

The vminfo provider makes available probes that correspond to the fields in the vm named kernel statistic: a probe provided by vminfo fires immediately before the corresponding vm value is incremented. To display both the names and the current values of the vm named kernel statistic, use the kstat(1M) command, as shown in the following example:

```bash
$ kstat -n vm
module: cpu  instance: 0
name:  vm  class:  misc
  anonfree     13
  anonpgin     2620
  anonpgout    13
  as_fault    12528831
  cow_fault  2278711
  crtime     202.10625712
  dfree      1328740
  execfree   0
  execpgin   5541
  ...
```

The vminfo probes are described in Table 24.1.

<table>
<thead>
<tr>
<th>Table 24.1: vminfo Probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>anonfree</td>
</tr>
<tr>
<td>anonpgin</td>
</tr>
</tbody>
</table>
### Table 24.1: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>anonpgout</td>
<td>Probe that fires whenever a modified anonymous page is paged out to a swap device.</td>
</tr>
<tr>
<td>as_fault</td>
<td>Probe that fires whenever a fault is taken on a page and the fault is neither a protection fault nor a copy-on-write fault.</td>
</tr>
<tr>
<td>cow_fault</td>
<td>Probe that fires whenever a copy-on-write fault is taken on a page. arg0 contains the number of pages that are created as a result of the copy-on-write.</td>
</tr>
<tr>
<td>dfree</td>
<td>Probe that fires whenever a page is freed as a result of paging activity. Whenever dfree fires, exactly one of anonfree, execfree or fsfree will also subsequently fire.</td>
</tr>
<tr>
<td>execfree</td>
<td>Probe that fires whenever an unmodified executable page is freed as a result of paging activity.</td>
</tr>
<tr>
<td>execpgin</td>
<td>Probe that fires whenever an executable page is paged in from the backing store.</td>
</tr>
<tr>
<td>execpgout</td>
<td>Probe that fires whenever a modified executable page is paged out to the backing store. Most paging of executable pages occurs in terms of execfree. execpgout can only fire if an executable page is modified in memory, an uncommon occurrence in most systems.</td>
</tr>
<tr>
<td>fsfree</td>
<td>Probe that fires whenever an unmodified file system data page is freed as part of paging activity.</td>
</tr>
<tr>
<td>fspgin</td>
<td>Probe that fires whenever a file system page is paged in from the backing store.</td>
</tr>
<tr>
<td>fspgout</td>
<td>Probe that fires whenever a modified file system page is paged out to the backing store.</td>
</tr>
<tr>
<td>kernel_asflt</td>
<td>Probe that fires whenever a page fault is taken by the kernel on a page in its own address space. Whenever kernel_asflt fires, it will be immediately preceded by a firing of the as_fault probe.</td>
</tr>
<tr>
<td>maj_fault</td>
<td>Probe that fires whenever a page fault is taken that results in I/O from a backing store or swap device. Whenever maj_fault fires, it will be immediately preceded by a firing of the pgin probe.</td>
</tr>
<tr>
<td>pgfrec</td>
<td>Probe that fires whenever a page is reclaimed off of the free page list.</td>
</tr>
<tr>
<td>pgin</td>
<td>Probe that fires whenever a page is paged in from the backing store or from a swap device. This probe differs from maj_fault in that maj_fault only fires when a page is paged in as a result of a page fault. pgin fires every time a page is paged in, regardless of the reason.</td>
</tr>
<tr>
<td>pgout</td>
<td>Probe that fires whenever a page is paged out to the backing store or to a swap device.</td>
</tr>
<tr>
<td>pgpgin</td>
<td>Probe that fires whenever a page is paged in from the backing store or from a swap device. The only difference between pgpgin and pgin is that pgpgin contains the number of pages paged in as arg0. (pgin always contains 1 in arg0.)</td>
</tr>
<tr>
<td>pgpgout</td>
<td>Probe that fires whenever a page is paged out to the backing store or to a swap device. The only difference between pgpgout and pgout is that pgpgout contains the number of pages paged out as arg0. (pgout always contains 1 in arg0.)</td>
</tr>
<tr>
<td>pgrec</td>
<td>Probe that fires whenever a page is reclaimed.</td>
</tr>
<tr>
<td>pgrrun</td>
<td>Probe that fires whenever the pager is scheduled.</td>
</tr>
</tbody>
</table>
24.3. Example

Table 24.1: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pgswapin</td>
<td>Probe that fires whenever pages from a swapped-out process are swapped in.</td>
</tr>
<tr>
<td></td>
<td>The number of pages swapped in is contained in arg0.</td>
</tr>
<tr>
<td>pgswapout</td>
<td>Probe that fires whenever pages are swapped out as part of swapping out a</td>
</tr>
<tr>
<td></td>
<td>process. The number of pages swapped out is contained in arg0.</td>
</tr>
<tr>
<td>prot_fault</td>
<td>Probe that fires whenever a page fault is taken due to a protection violation.</td>
</tr>
<tr>
<td>rev</td>
<td>Probe that fires whenever the page daemon begins a new revolution through</td>
</tr>
<tr>
<td></td>
<td>all pages.</td>
</tr>
<tr>
<td>scan</td>
<td>Probe that fires whenever the page daemon examines a page.</td>
</tr>
<tr>
<td>softlock</td>
<td>Probe that fires whenever a page is faulted as a part of placing a software</td>
</tr>
<tr>
<td></td>
<td>lock on the page.</td>
</tr>
<tr>
<td>swapin</td>
<td>Probe that fires whenever a swapped-out process is swapped back in.</td>
</tr>
<tr>
<td>swapout</td>
<td>Probe that fires whenever a process is swapped out.</td>
</tr>
<tr>
<td>zfod</td>
<td>Probe that fires whenever a zero-filled page is created on demand.</td>
</tr>
</tbody>
</table>

24.2 Arguments

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>arg0</td>
<td>The value by which the statistic is to be incremented. For most probes, this</td>
</tr>
<tr>
<td></td>
<td>argument is always 1, but for some it may take other values; these probes</td>
</tr>
<tr>
<td></td>
<td>are noted in Table 24.1.</td>
</tr>
<tr>
<td>arg1</td>
<td>A pointer to the current value of the statistic to be incremented. This</td>
</tr>
<tr>
<td></td>
<td>value is a 64–bit quantity that will be incremented by the value in arg0.</td>
</tr>
<tr>
<td></td>
<td>Dereferencing this pointer allows consumers to determine the current count</td>
</tr>
<tr>
<td></td>
<td>of the statistic corresponding to the probe.</td>
</tr>
</tbody>
</table>

24.3 Example

Examine the following output from vmstat(1M):

<table>
<thead>
<tr>
<th>kthr</th>
<th>memory</th>
<th>page</th>
<th>disk</th>
<th>faults</th>
<th>cpu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>b</td>
<td>w</td>
<td>swap</td>
<td>free</td>
<td>re</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1341844</td>
<td>836720</td>
<td>26</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1341344</td>
<td>835300</td>
<td>238</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1340764</td>
<td>833668</td>
<td>24</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1340420</td>
<td>833024</td>
<td>24</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1340068</td>
<td>831520</td>
<td>14</td>
</tr>
</tbody>
</table>

The pi column in the above output denotes the number of pages paged in. The vminfo provider enables you to learn more about the source of these page-ins, as shown in the following example:

```
dtrace -n pgin'{@[execname] = count()}'
dtrace: description 'pgin' matched 1 probe
^C
```

```
xterm            1
ksh              1
ls               2
lpstat           7
sh               17
```

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The output shows that a process associated with the StarOffice™ software, soffice.bin, is responsible for most of the page-ins. To get a better picture of soffice.bin in terms of virtual memory behavior, you could enable all vminfo probes. The following example runs dtrace(1M) while launching the StarOffice software:

dtrace -P vminfo'/execname == "soffice.bin"/{@[probename] = count()}'

dtrace: description 'vminfo' matched 42 probes

The following example script provides more information about the virtual memory behavior of the StarOffice software during its startup:

```c
vminfo:::maj_fault,
vminfo:::zfod,
vminfo:::as_fault
/execname == "soffice.bin" && start == 0/
{
    /*
     * This is the first time that a vminfo probe has been hit; record
     * our initial timestamp.
     */
    start = timestamp;
}
vminfo:::maj_fault,
vminfo:::zfod,
vminfo:::as_fault
/execname == "soffice.bin"/
{
    /*
     * Aggregate on the probename, and lquantize() the number of seconds
     * since our initial timestamp. (There are 1,000,000,000 nanoseconds
     * in a second.) We assume that the script will be terminated before
```
24.3. Example

* 60 seconds elapses.
*/
 @[probename] =
    lquantize((timestamp - start) / 1000000000, 0, 60);
}

Run the script while again starting the StarOffice software. Then, create a new drawing, create a new presentation, and then close all files and quit the application. Press Control-C in the shell running the D script. The results provide a view of some virtual memory behavior over time:

```
# dtrace -s ./soffice.d

dtrace: script './soffice.d' matched 10 probes
^C

maj_fault

value --------------- Distribution --------------- count
  7 | 0
  8 |@@@@@@@@@@ 88
  9 |@@@@@@@@@@@@@@@@@@@@@@ 194
 10 |@ 18
 11 | 0
 12 | 0
 13 | 2
 14 | 0
 15 | 1
 16 |@@@@@@@@@@ 82
 17 | 0
 18 | 0
 19 | 2
 20 | 0

zfod

value --------------- Distribution --------------- count
 < 0 | 0
  0 |@@@@@@@@@@ 525
  1 |@@@@@@@@@@ 605
  2 |@@ 208
  3 |@@@@ 280
  4 | 4
  5 | 0
  6 | 0
  7 | 0
  8 | 44
  9 |@@ 161
 10 | 2
 11 | 0
 12 | 0
 13 | 4
 14 | 0
 15 | 29
 16 |@@@@@@@@@@@@@@@@ 1048
 17 | 24
 18 | 0
 19 | 0
 20 | 1
 21 | 0
 22 | 3
 23 | 0

as_fault
```
The output shows some StarOffice behavior with respect to the virtual memory system. For example, the \texttt{majFault} probe didn’t fire until a new instance of the application was started. As you would hope, a “warm start” of StarOffice did not result in new major faults. The \texttt{asFault} output shows an initial burst of activity, latency while the user located the menu to create a new drawing, another period of idleness, and a final burst of activity when the user clicked on a new presentation. The \texttt{zfod} output shows that creating the new presentation induced significant pressure for zero-filled pages, but only for a short period of time.

The next iteration of DTrace investigation in this example would depend on the direction you want to explore. If you want to understand the source of the demand for zero-filled pages, you could aggregate on \texttt{ustack} in a \texttt{zfod} enabling. You might want to establish a threshold for zero-filled pages and use the \texttt{stop} destructive action to stop the offending process when the threshold is exceeded. This approach would enable you to use more traditional debugging tools like \texttt{truss(1)} or \texttt{mdb(1)}. The \texttt{vminfo} provider enables you to associate statistics seen in the output of conventional tools like \texttt{vmstat(1M)} with the applications that are inducing the systemic behavior.

## 24.4 Stability

The \texttt{vminfo} provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
</tbody>
</table>
## 24.4. Stability

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arguments</td>
<td>Private</td>
<td>Private</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 25

**proc Provider**

The **proc** provider makes available probes pertaining to the following activities: process creation and termination, LWP creation and termination, executing new program images, and sending and handling signals.

### 25.1 Probes

The **proc** probes are described in Table 25.1.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>create</strong></td>
<td>Probe that fires when a process is created using fork(2), forkall(2), fork1(2), or vfork(2). The psinfo_t corresponding to the new child process is pointed to by args[0]. You can distinguish vfork from the other fork variants by checking for PR_VFORKP in the pr_flag member of the forking thread's lwpsinfo_t. You can distinguish fork1 from forkall by examining the pr_nlwp members of both the parent process's psinfo_t (curpsinfo) and the child process's psinfo_t (args[0]). Because the create probe only fires after the process has been successfully created, and because LWP creation is part of creating a process, lwp-create will fire for any LWPs created at process creation time before the create probe fires for the new process.</td>
</tr>
<tr>
<td><strong>exec</strong></td>
<td>Probe that fires whenever a process loads a new process image with a variant of the exec(2) system call: exec(2), execle(2), execlp(2), execv(2), execve(2), or execvp(2). 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 probe or the exec-success probe will subsequently fire in the same thread. The path of the new process image is pointed to by args[0].</td>
</tr>
<tr>
<td><strong>exec-failure</strong></td>
<td>Probe that fires when an exec(2) variant has failed. This probe fires only after the exec probe has fired in the same thread. The errno(3C) value is provided in args[0].</td>
</tr>
<tr>
<td>Probe</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>exec-success</td>
<td>Probe that fires when an exec(2) 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 the exec-success probe fires, process variables like execname and curpsinfo contain the process state after the new process image has been loaded.</td>
</tr>
<tr>
<td>exit</td>
<td>Probe that fires when the current process is exiting. The reason for exit, which is expressed as one of the SIGCHLD siginfo.h(3HEAD) codes, is contained in args[0].</td>
</tr>
<tr>
<td>fault</td>
<td>Probe that fires when a thread experiences a machine fault. The fault code (as defined in proc(4)) is in args[0]. The siginfo structure corresponding to the fault is pointed to by args[1]. Only those faults that induce a signal can trigger the fault probe.</td>
</tr>
<tr>
<td>lwp-create</td>
<td>Probe that fires when an LWP is created, typically as a result of thr_create(3C). The lwpsinfo_t corresponding to the new thread is pointed to by args[0]. The psinfo_t of the process containing the thread is pointed to by args[1].</td>
</tr>
<tr>
<td>lwp-start</td>
<td>Probe that fires within the context of a newly created LWP. The lwp-start probe will fire before any user-level instructions are executed. If the LWP is the first LWP in the process, the start probe will fire, followed by lwp-start.</td>
</tr>
<tr>
<td>lwp-exit</td>
<td>Probe that fires when an LWP is exiting, due either to a signal or to an explicit call to thr_exit(3C).</td>
</tr>
<tr>
<td>signal-discard</td>
<td>Probe that 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].</td>
</tr>
<tr>
<td>signal-send</td>
<td>Probe that fires when a signal is sent to a thread or process. The signal-send probe fires in the context of the sending process and 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.</td>
</tr>
<tr>
<td>signal-handle</td>
<td>Probe that 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 value of args[1] is NULL if there is no siginfo_t structure or if the signal handler does not have the SA_SIGINFO flag set. The address of the signal handler in the process is in args[2].</td>
</tr>
<tr>
<td>signal-clear</td>
<td>Probes that fires when a pending signal is cleared because the target thread was waiting for the signal in sigwait(2), sigwaitinfo(3RT), or sigtimedwait(3RT). 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.</td>
</tr>
</tbody>
</table>
25.2 Arguments

The argument types for the `proc` probes are listed in Table 25.2. The arguments are described in Table 25.1.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>create</td>
<td>psinfo_t *</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>exec</td>
<td>char *</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>exec-failure</td>
<td>int</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>exit</td>
<td>int</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>fault</td>
<td>int</td>
<td>siginfo_t *</td>
<td>—</td>
</tr>
<tr>
<td>lwp-create</td>
<td>lwpsinfo_t *</td>
<td>psinfo_t *</td>
<td>—</td>
</tr>
<tr>
<td>lwp-start</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>lwp-exit</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>signal-discard</td>
<td>lwpsinfo_t *</td>
<td>psinfo_t *</td>
<td>int</td>
</tr>
<tr>
<td>signal-discard</td>
<td>lwpsinfo_t *</td>
<td>psinfo_t *</td>
<td>int</td>
</tr>
<tr>
<td>signal-send</td>
<td>lwpsinfo_t *</td>
<td>psinfo_t *</td>
<td>int</td>
</tr>
<tr>
<td>signal-handle</td>
<td>int</td>
<td>siginfo_t *</td>
<td>void</td>
</tr>
<tr>
<td>signal-clear</td>
<td>int</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>start</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**lwpsinfo_t**

Several `proc` probes have arguments of type `lwpsinfo_t`, a structure that is documented in `proc(4)`. The definition of the `lwpsinfo_t` structure as available to DTrace consumers is as follows:

```c
typedef struct lwpsinfo {
    int pr_flag; /* flags; see below */
    id_t pr_lwpid; /* LWP id */
    uintptr_t pr_addr; /* internal address of thread */
    uintptr_t pr_wchan; /* wait addr for sleeping thread */
    char pr_stype; /* synchronization event type */
    char pr_state; /* numeric thread state */
    char pr_sname; /* printable character for pr_state */
    char pr_nice; /* nice for cpu usage */
} lwpsinfo_t;
```
short pr_syscall; /* system call number (if in syscall) */
int pr_pri; /* priority, high value = high priority */
char pr_clname[PRCLSZ]; /* scheduling class name */
processorid_t pr_onpro; /* processor which last ran this thread */
processorid_t pr_bindpro; /* processor to which thread is bound */
psetid_t pr_bindpset; /* processor set to which thread is bound */
}
lwpsinfo_t;

The `pr_flag` field is a bit-mask holding flags describing the process. These flags and their meanings are described in Table 25.3.

<table>
<thead>
<tr>
<th>pr_flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR_ISSYS</td>
<td>The process is a system process.</td>
</tr>
<tr>
<td>PR_VFORKP</td>
<td>The process is the parent of a vfork(2)’d child.</td>
</tr>
<tr>
<td>PR_FORK</td>
<td>The process has its inherit-on-fork mode set.</td>
</tr>
<tr>
<td>PR_RLC</td>
<td>The process has its run-on-last-close mode set.</td>
</tr>
<tr>
<td>PR_KLC</td>
<td>The process has its kill-on-last-close mode set.</td>
</tr>
<tr>
<td>PR_ASYNC</td>
<td>The process has its asynchronous-stop mode set.</td>
</tr>
<tr>
<td>PR_KLC</td>
<td>The process has its run-on-last-close mode set.</td>
</tr>
<tr>
<td>PR_MSACCT</td>
<td>The process has microstate accounting enabled.</td>
</tr>
<tr>
<td>PR_MSFORK</td>
<td>The process microstate accounting is inherited on fork.</td>
</tr>
<tr>
<td>PR_BPTADJ</td>
<td>The process has its breakpoint adjustment mode set.</td>
</tr>
<tr>
<td>PR_PTRACE</td>
<td>The process has its ptrace(3C)-compatibility mode set.</td>
</tr>
<tr>
<td>PR_STOPPED</td>
<td>The thread is an LWP that is stopped.</td>
</tr>
<tr>
<td>PR_ISTOP</td>
<td>The thread is an LWP stopped on an event of interest.</td>
</tr>
<tr>
<td>PR_DSTOP</td>
<td>The thread is an LWP that has a stop directive in effect.</td>
</tr>
<tr>
<td>PR_STEP</td>
<td>The thread is an LWP that has a single-step directive in effect.</td>
</tr>
<tr>
<td>PR_ASLEEP</td>
<td>The thread is an LWP in an interruptible sleep within a system call.</td>
</tr>
<tr>
<td>PR_DETACH</td>
<td>The thread is a detached LWP. See pthread_create(3C) and pthread_join(3C).</td>
</tr>
<tr>
<td>PR_DAEMON</td>
<td>The thread is a daemon LWP. See pthread_create(3C).</td>
</tr>
<tr>
<td>PR_AGENT</td>
<td>The thread is the agent LWP for the process.</td>
</tr>
<tr>
<td>PR_IDLE</td>
<td>The thread is the idle thread for a CPU. Idle threads only run on a CPU</td>
</tr>
<tr>
<td></td>
<td>when the run queues for the CPU are empty.</td>
</tr>
</tbody>
</table>

The `pr_addr` field is the address of a private, in-kernel data structure representing the thread. While the data structure is private, the `pr_addr` field may be used as a token unique to a thread for the thread’s lifetime.

The `pr_wchan` field is set when the thread is sleeping on a synchronization object. The meaning of the `pr_wchan` field is private to the kernel implementation, but the field may be used as a token unique to the synchronization object.

The `pr_stype` field is set when the thread is sleeping on a synchronization object. The possible values for the `pr_stype` field are in Table 25.4.
Table 25.4: pr_stype Values

<table>
<thead>
<tr>
<th>pr_stype</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOBJ_MUTEX</td>
<td>Kernel mutex synchronization object. Used to serialize access to shared data regions in the kernel. See Chapter 18 and mutex_init(9F) for details on kernel mutex synchronization objects.</td>
</tr>
<tr>
<td>SOBJ_RWLOCK</td>
<td>Kernel readers/writer synchronization object. Used to synchronize access to shared objects in the kernel that can allow multiple concurrent readers or a single writer. See Chapter 18 and rwlock(9F) for details on kernel readers/writer synchronization objects.</td>
</tr>
<tr>
<td>SOBJ_CV</td>
<td>Condition variable synchronization object. A condition variable is designed to wait indefinitely until some condition becomes true. Condition variables are typically used to synchronize for reasons other than access to a shared data region, and are the mechanism generally used when a process performs a program-directed indefinite wait. For example, blocking in poll(2), pause(2), wait(3C), and the like.</td>
</tr>
<tr>
<td>SOBJ_SEMA</td>
<td>Semaphore synchronization object. A general-purpose synchronization object that – like condition variable objects – does not track a notion of ownership. Because ownership is required to implement priority inheritance in the illumos kernel, the lack of ownership inherent in semaphore objects inhibits their widespread use. See semaphore(9F) for details.</td>
</tr>
<tr>
<td>SOBJ_USER</td>
<td>A user-level synchronization object. All blocking on user-level synchronization objects is handled with SOBJ_USER synchronization objects. User-level synchronization objects include those created with mutex_init(3C), sema_init(3C), rwlock_init(3C), cond_init(3C) and their POSIX equivalents.</td>
</tr>
<tr>
<td>SOBJ_USER_PI</td>
<td>A user-level synchronization object that implements priority inheritance. Some user-level synchronization objects that track ownership additionally allow for priority inheritance. For example, mutex objects created with pthread_mutex_init(3C) may be made to inherit priority using pthread_mutexattr_setprotocol(3C).</td>
</tr>
<tr>
<td>SOBJ_SHUTTLE</td>
<td>A shuttle synchronization object. Shuttle objects are used to implement doors. See door_create(3DOOR) for more information.</td>
</tr>
</tbody>
</table>

The pr_state field is set to one of the values in Table 25.5. The pr_sname field is set to a corresponding character shown in parentheses in the same table.

Table 25.5: pr_state Values

<table>
<thead>
<tr>
<th>pr_state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSLEEP (S)</td>
<td>The thread is sleeping. The sched:::sleep probe will fire immediately before a thread’s state is transitioned to SSLEEP.</td>
</tr>
<tr>
<td>SRUN (R)</td>
<td>The thread is runnable, but is not currently running. The sched:::enqueue probe will fire immediately before a thread’s state is transitioned to SRUN.</td>
</tr>
<tr>
<td>SZOMB (Z)</td>
<td>The thread is a zombie LWP.</td>
</tr>
<tr>
<td>SSTOP (T)</td>
<td>The thread is stopped, either due to an explicit proc(4) directive or some other stopping mechanism.</td>
</tr>
</tbody>
</table>
Table 25.5: (continued)

| SIDL (I) | The thread is an intermediate state during process creation. |
| SONDPROC (O) | The thread is running on a CPU. The sched:::on-cpu probe will fire in the context of the SONDPROC thread a short time after the thread’s state is transitioned to SONDPROC. |

**psinfo_t**

Several proc probes have an argument of type psinfo_t, a structure that is documented in proc(4). The definition of the psinfo_t structure as available to DTrace consumers is as follows:

```c
typedef struct psinfo {
    int pr_nlwp;  /* number of active lwps in the process */
    pid_t pr_pid; /* unique process id */
    pid_t pr_ppid; /* process id of parent */
    pid_t pr_ppgid; /* 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 */
    gid_t pr_gid; /* real group id */
    gid_t pr_egid; /* effective group id */
    uintptr_t pr_addr; /* address of process */
    dev_t pr_ttydev; /* controlling tty device (or PRNODEV) */
    timespec_t pr_start; /* process start time, from the epoch */
    char pr_fname[PRFNSZ]; /* name of execed file */
    char pr_psargs[PRARGSZ]; /* initial characters of arg list */
    int pr_argc; /* initial argument count */
    uintptr_t pr_argv; /* address of initial argument vector */
    uintptr_t pr_envp; /* address of initial environment vector */
    char pr_dmodel; /* data model of the process */
    taskid_t pr_taskid; /* task id */
    projid_t pr_projid; /* project id */
    poolid_t pr_poolid; /* pool id */
    zoneid_t pr_zoneid; /* zone id */
} psinfo_t;
```

The pr_dmodel field is set to either PR_MODEL_32, denoting a 32–bit process, or PR_MODEL_64, denoting a 64–bit process.

### 25.3 Examples

**exec**

You can use the exec probe to easily determine which programs are being executed, and by whom, as shown in the following example:

```bash
#pragma D option quiet

proc:::exec
{
    self->parent = execname;
}
```
Running the example script for a short period of time on a build machine results in output similar to the following example:

```
# dtrace -s ./whoexec.d
^C
WHO       WHAT       COUNT
make.bin  yacc       1
tcsh       make       1
make.bin  spec2map   1
sh         grep       1
lint       lint2      1
sh         lint       1
sh         ln         1
cc         ld         1
make.bin  cc         1
lint       lint1      1
sh         lex        1
make.bin  mv         2
sh         sh         3
sh         make       3
sh         sed        4
sh         tr         4
make       make.bin   4
sh         install.bin 5
sh         rm         6
cc         ir2hf      33
cc         ube        33
sh         date       34
sh         mcs        34
cc         acomp      34
sh         cc         34
sh         basename   34
basename  expr       34
make.bin  sh         87
```
25. **proc provider**

**start and exit**

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:

```plaintext
proc:::start
{
    self->start = timestamp;
}

proc:::exit
/self->start/
{
    @[execname] = quantize(timestamp - self->start);
    self->start = 0;
}
```

Running the example script on the build server for several seconds results in output similar to the following example:

```plaintext
# dtrace -s ./progtime.d
```

```
dtrace: script './progtime.d' matched 2 probes
```

```
^C
```

```
ir2hf  
value -------------- Distribution -------------- count
  4194304 | 0
  8388608 | 0
 16777216 |@@@@@@@@@@@@@@@@@@@@@@@ 14
 33554432 |@@@@@@@@@@@@@@@@@@@@@@@@@@ 9
 67108864 |@@@@@@@@@@@@@@@@@@ 3
134217728 |@@ 1
268435456 |@@ 2
536870912 |@@@ 3
1073741824 |@@@@@ 5
```

```
ube  
value -------------- Distribution -------------- count
 16777216 | 0
 33554432 |@@@@@@@@@@@@@@@@@@@ 6
 67108864 |@@@@@@@@@@@@@@@@@@@@@@ 3
134217728 |@@@@@@@@@@@@@@@@@@@@@@@@@@ 14
268435456 |@@@@@@@@@@@@@@@@@@@@@@@@@@ 9
536870912 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
```

```
acomp  
value -------------- Distribution -------------- count
  8388608 | 0
 16777216 |@@ 2
 33554432 |@@ 2
 67108864 |@@ 2
134217728 |@@@ 3
268435456 |@@@ 3
536870912 |@@@@@@ 5
1073741824 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
```

202
### Examples

#### cc

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#### sh

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#### make.bin

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<td>1</td>
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<td>1073741824</td>
<td>@@@@@@@@@@</td>
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<td>@@@@@@@@@@@</td>
<td>0</td>
</tr>
</tbody>
</table>

### lwp-start and lwp-exit

Instead of knowing the amount of time that a particular process takes to run, you might want to know how long individual threads take to run. The following example shows how to use the lwp-start and lwp-exit probes for this purpose:

```c
proc:::lwp-start
/tid != 1/
{
    self->start = timestamp;
}
```
25. **PROC PROVIDER**

```c
proc:::lwp-exit
/self->start/
{
    @[execname] = quantize(timestamp - self->start);
    self->start = 0;
}
```

Running the example script on an NFS and calendar server results in output similar to the following example:

```bash
# dtrace -s ./lwptime.d
```
```
dtrace: script './lwptime.d' matched 3 probes
```
```
^C
```
```
ns
```c
    value ------------- Distribution ------------- count
    131072 |        |
    262144 |@        |
    524288 |@@      |
   1048576 |@@@@@@|
   2097152 |@@@@@@@@@@|
   4194304 |@@@@@@|
   8388608 |@@@@@@|
  16777216 |@@@@@@@@|
  33554432 |@@@@@@@@|
  67108864 |@@@@@@@@|
 134217728 |@@@@@@@@|
 268435456 |

```
```
mountd
```c
    value ------------- Distribution ------------- count
     524288 |        |
   1048576 |@       |
   2097152 |@       |
   4194304 |@@@@    |
   8388608 |@       |
  16777216 |@       |
  33554432 |@@@@    |
  67108864 |@@@@    |
 134217728 |@       |
 268435456 |
 536870912 |@       |
 1073741824 |@       |
 2147483648 |@@@@    |
 4294967296 |@@@@    |
 8589934592 |@@@@    |
17179869184 |@       |
34359738368 |
68719476736 |

```
```
automountd
```c
    value ------------- Distribution ------------- count
   1048576 |        |
   2097152 |
   4194304 |@@@@    |
   8388608 |
  16777216 |
  33554432 |
  67108864 |@@@@    |
```
```
```
signal-send

You can use the signal-send probe to determine the sending and receiving process associated with any signal, as shown in the following example:

```c
#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 example:

```
# dtrace -s ./sig.d
^C
```

<table>
<thead>
<tr>
<th>SENDER</th>
<th>RECIPIENT</th>
<th>SIG</th>
<th>COUNT</th>
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<td>xterm</td>
<td>soffice.bin</td>
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<td>1</td>
</tr>
</tbody>
</table>
25.4 Stability

The `proc` provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 26

**sched Provider**

The `sched` provider makes available probes 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.

### 26.1 Probes

The `sched` probes are described in Table 26.1.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
</table>
| change-pri | Probe that 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]`. |
| dequeue | Probe that 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`. |
Table 26.1: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>enqueue</td>
<td>Probe that 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.</td>
</tr>
<tr>
<td>off-cpu</td>
<td>Probe that 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 curpsinfo variable describes the process containing the current thread. The lwpsinfo_t structure 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].</td>
</tr>
<tr>
<td>on-cpu</td>
<td>Probe that fires when a CPU has just begun execution of a thread. The curcpu variable indicates the current CPU. The curlwpinfo variable indicates the thread that is beginning execution. The curpsinfo variable describes the process containing the current thread.</td>
</tr>
<tr>
<td>preempt</td>
<td>Probe that 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.</td>
</tr>
<tr>
<td>remain-cpu</td>
<td>Probe that 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 curlwpinfo variable indicates the thread that is beginning execution. The curpsinfo variable describes the process containing the current thread.</td>
</tr>
</tbody>
</table>
Table 26.1: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>schedctl-nopreempt</td>
<td>Probe that fires when a thread is preempted and then re-enqueued at the front of the run queue due to a preemption control request. See schedctl_init(3C) for details on preemption control. As with preempt, either off-cpu or remain-cpu will fire after schedctl-nopreempt. Because schedctl-nopreempt denotes a re-enqueuing of the current thread at the front of the run queue, remain-cpu is more likely to fire after schedctl-nopreempt than off-cpu. The lwpsinfo_t of the thread being preempted is pointed to by args[0]. The psinfo_t of the process containing the thread is pointed to by args[1].</td>
</tr>
<tr>
<td>schedctl-preempt</td>
<td>Probe that fires when a thread that is using preemption control is nonetheless preempted and re-enqueued at the back of the run queue. See schedctl_init(3C) for details on preemption control. As with preempt, either off-cpu or remain-cpu will fire after schedctl-preempt. Like preempt (and unlike schedctl-nopreempt), schedctl-preempt denotes a re-enqueuing of the current thread at the back of the run queue. As a result, off-cpu is more likely to fire after schedctl-preempt than remain-cpu. The lwpsinfo_t of the thread being preempted is pointed to by args[0]. The psinfo_t of the process containing the thread is pointed to by args[1].</td>
</tr>
<tr>
<td>schedctl-yield</td>
<td>Probe that fires when a thread that had preemption control enabled and its time slice artificially extended executed code to yield the CPU to other threads.</td>
</tr>
<tr>
<td>sleep</td>
<td>Probe that 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.</td>
</tr>
<tr>
<td>surrender</td>
<td>Probe that fires when a CPU has been instructed by another CPU to make a scheduling decision – often because a higher-priority thread has become runnable.</td>
</tr>
<tr>
<td>tick</td>
<td>Probe that 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].</td>
</tr>
</tbody>
</table>
Table 26.1: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>wakeup</td>
<td>Probe that 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.</td>
</tr>
</tbody>
</table>

26.2 Arguments

The argument types for the sched probes are listed in Table 26.2; the arguments are described in Table 26.1.

Table 26.2: sched Probe Arguments

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>change-pri</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>pri_t</td>
<td>—</td>
</tr>
<tr>
<td>dequeue</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>cpuinfo_t</td>
<td>—</td>
</tr>
<tr>
<td>enqueue</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>cpuinfo_t</td>
<td>int</td>
</tr>
<tr>
<td>off-cpu</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>on-cpu</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>preempt</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>remain-cpu</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>schedctl-nopreempt</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>schedctl-preempt</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>schedctl-yield</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>sleep</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>surrender</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>tick</td>
<td>lwpsinfo_t</td>
<td>psinfo_t</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
As Table 26.2 indicates, many sched probes have arguments consisting of a pointer to an lwpsinfo_t and a pointer to a psinfo_t, indicating a thread and the process containing the thread, respectively. These structures are described in detail in Section 25.2 and Section 25.2, respectively.

**cpuinfo_t**

The cpuinfo_t structure defines a CPU. As Table 26.2 indicates, arguments to both the enqueue and dequeue probes include a pointer to a cpuinfo_t. Additionally, the cpuinfo_t corresponding to the current CPU is pointed to by the curcpu variable. The definition of the cpuinfo_t structure is as follows:

```c
typedef struct cpuinfo {
    processorid_t cpu_id;  /* CPU identifier */
    psetid_t cpu_pset;     /* processor set identifier */
    chipid_t cpu_chip;     /* chip identifier */
    lgrp_id_t cpu_lgrp;    /* locality group identifier */
    processor_info_t cpu_info;  /* CPU information */
} cpuinfo_t;
```

The cpu_id member is the processor identifier, as returned by psrinfo(1M) and p_online(2).

The cpu_pset member is the processor set that contains the CPU, if any. See psrset(1M) for more details on processor sets.

The cpu_chip member is the identifier of the physical chip. Physical chips may contain several CPUs. See psrinfo(1M) for more information.

The cpu_lgrp member is the identifier of the locality group associated with the CPU. See liblgrp(3LIB) for details on latency groups.

The cpu_info member is the processor_info_t structure associated with the CPU, as returned by processor_info(2).

### 26.3 Examples

**on-cpu and off-cpu**

One common question you might want answered is which CPUs are running threads and for how long. You can use the on-cpu and off-cpu probes to easily answer this question on a system-wide basis as shown in the following example:
sched:::on-cpu
{
    self->ts = timestamp;
}

sched:::off-cpu
/self->ts/
{
    @[cpu] = quantize(timestamp - self->ts);
    self->ts = 0;
}

Running the above script results in output similar to the following example:

```
# dtrace -s ./where.d
```
```
dtrace: script './where.d' matched 5 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 above output shows that on CPU 1 threads tend to run for less than 100 microseconds at a stretch, or for approximately 10 milliseconds. A noticeable gap between the two clusters of data shown in the histogram. You also might be interested in knowing which CPUs are running a particular process. You can use the on-cpu and off-cpu probes for answering this question as well. The following script displays which CPUs run a specified application over a period of ten seconds:

```c
#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 of imapd over %d seconds:\n\n",
           (timestamp - start) / 1000000000);
    printf("CPU microseconds\n--- ------------\n");
    normalize(@, 1000);
    printa("%3d @(\n", @);
}
```

Running the above script on a large mail server and specifying the IMAP daemon results in output similar to the following example:

```
# 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
```

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illuminos takes into account the amount of time that a thread has been sleeping when selecting a CPU on which to run the thread: a thread that has been sleeping for less time tends not to migrate. You can use the off-cpu and on-cpu probes to observe this behavior:

```c
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 above script for approximately 30 seconds results in output similar to the following example:

```
# dtrace -s ./howlong.d

dtrace: script './howlong.d' matched 5 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 |@@@ 14714
```

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The example output shows 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 once a certain threshold is exceeded.

The final example using off-cpu and on-cpu shows how to use these probes along with the pr_stype field to determine why threads sleep and for how long:

```c
sched:::off-cpu
(curlwpsinfo->pr_state == SSLEEP/ 
  { /*
      * We’re sleeping. Track our sobj type.
      */
      self->sobj = curlwpsinfo->pr_stype;
      self->bedtime = timestamp;
  })

sched:::off-cpu
(curlwpsinfo->pr_state == SRUN/ 
  { self->bedtime = timestamp;
  })

sched:::on-cpu
/self->bedtime && !self->sobj/
  { @["preempted"] = quantize(timestamp - self->bedtime);
    self->bedtime = 0;
  }

sched:::on-cpu
/self->sobj/
  { @[self->sobj == SOBJ_MUTEX ? "kernel-level lock" :
      self->sobj == SOBJ_RWLOCK ? "rwlock" :
      self->sobj == SOBJ_CV ? "condition variable" :
      self->sobj == SOBJ_SEMA ? "semaphore" :
      self->sobj == SOBJ_USER ? "user-level lock" :
```
self->sobj == SOBJ_USER_PI ? "user-level prio-inheriting lock" : 
self->sobj == SOBJ_SHUTTLE ? "shuttle" : "unknown"] = 
quantize(timestamp - self->bedtime);

self->sobj = 0;
self->bedtime = 0;
}

Running the above script for several seconds results in output similar to the following example:

```
# dtrace -s ./whatfor.d

dtrace: script './whatfor.d' matched 12 probes

^C

kernel-level lock
value -------------- Distribution ------------ count
16384 | 0
32768 | 3
65536 | 11
131072 | 1
262144 | 0

preempted
value -------------- Distribution ------------ count
16384 | 0
32768 | 4
65536 | 408
131072 | 1031
262144 | 156
524288 | 116
1048576 | 51
2097152 | 42
4194304 | 16
8388608 | 15
16777216 | 4
33554432 | 8
67108864 | 0

semaphore
value -------------- Distribution ------------ count
32768 | 0
65536 | 61
131072 | 553
262144 | 63
524288 | 36
1048576 | 7
2097152 | 22
4194304 | 44
8388608 | 84
16777216 | 36
33554432 | 3
67108864 | 6
134217728 | 0
268435456 | 0
536870912 | 0
1073741824 | 0
2147483648 | 0
4294967296 | 0
8589934592 | 0
17179869184 | 1
34359738368 | 0
```
### shuttle

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>32768</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>65536</td>
<td>@@@</td>
<td>2</td>
</tr>
<tr>
<td>131072</td>
<td>@@@@@@@@@@@@@</td>
<td>6</td>
</tr>
<tr>
<td>262144</td>
<td>@@@@@</td>
<td>2</td>
</tr>
<tr>
<td>524288</td>
<td>@@@</td>
<td>0</td>
</tr>
<tr>
<td>1048576</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2097152</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>4194304</td>
<td>@@@@@</td>
<td>2</td>
</tr>
<tr>
<td>8388608</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>16777216</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>33554432</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>67108864</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>134217728</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>268435456</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>536870912</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1073741824</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2147483648</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>4294967296</td>
<td>@@@@@@</td>
<td>2</td>
</tr>
<tr>
<td>8589934592</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>17179869184</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>34359738368</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

### condition variable

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>32768</td>
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<td>0</td>
</tr>
<tr>
<td>65536</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>131072</td>
<td>@@@@@@@@@@@@@</td>
<td>1579</td>
</tr>
<tr>
<td>262144</td>
<td>@@@</td>
<td>340</td>
</tr>
<tr>
<td>524288</td>
<td>@@@</td>
<td>268</td>
</tr>
<tr>
<td>1048576</td>
<td>@@@@</td>
<td>1028</td>
</tr>
<tr>
<td>2097152</td>
<td>@@@@</td>
<td>1007</td>
</tr>
<tr>
<td>4194304</td>
<td>@@@</td>
<td>1176</td>
</tr>
<tr>
<td>8388608</td>
<td>@@@@@</td>
<td>1257</td>
</tr>
<tr>
<td>16777216</td>
<td>@@@@@@@@@@@@@</td>
<td>4385</td>
</tr>
<tr>
<td>33554432</td>
<td></td>
<td>295</td>
</tr>
<tr>
<td>67108864</td>
<td></td>
<td>157</td>
</tr>
<tr>
<td>134217728</td>
<td></td>
<td>96</td>
</tr>
<tr>
<td>268435456</td>
<td></td>
<td>48</td>
</tr>
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<td>536870912</td>
<td></td>
<td>144</td>
</tr>
<tr>
<td>1073741824</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>2147483648</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>4294967296</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>8589934592</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>17179869184</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>34359738368</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>68719476736</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

### enqueue and dequeue

When a CPU becomes idle, the dispatcher looks for work enqueued on other (non-idle) CPUs. The following example uses the dequeue probe to understand how often applications are transferred and by which CPU:

```plaintext
#pragma D option quiet
```
sched:::dequeue
/args[2]->cpu_id != --1 && cpu != args[2]->cpu_id &&
  (curlwpsinfo->pr_flag & PR_IDLE)/
{
  @[stringof(args[1]->pr_fname), args[2]->cpu_id] =
    lquantize(cpu, 0, 100);
}
END
{
  printa("%s stolen from CPU %d by:
%@d
", @);
}

The tail of the output from running the above script on a 4 CPU system results in output similar to the
following example:

```
# dtrace -s ./whosteal.d
^C ...
nsccd stolen from CPU 1 by:

  value    Distribution    count
    1          0
    2 28
    3          0

snmpd stolen from CPU 1 by:

  value    Distribution    count
  < 0        0
    0          1
    1          0
    2 31
    3          2
    4          0

sched stolen from CPU 1 by:

  value    Distribution    count
  < 0        0
    0          3
    1          0
    2 36
    3          5
    4          0
```

Instead of knowing which CPUs took which work, you might want to know the CPUs on which processes
and threads are waiting to run. You can use the enqueue and dequeue probes together to answer this
question:

```
sched:::enqueue
{
  self->ts = timestamp;
}

sched:::dequeue
/self->ts/
{
  @[args[2]->cpu_id] = quantize(timestamp - self->ts);
```
self->ts = 0;
}

Running the above script for several seconds results in output similar to the following example:

```bash
# dtrace -s ./qtime.d
dtrace: script './qtime.d' matched 5 probes
^C
```

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>4096</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8192</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>16384</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1024</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>2048</td>
<td>262</td>
<td></td>
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<tr>
<td>4096</td>
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<tr>
<td>8192</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>16384</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>32768</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>65536</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>131072</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>262144</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>524288</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1048576</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2097152</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4194304</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8388608</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>16777216</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>33554432</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>67108864</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>134217728</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>268435456</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>536870912</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1073741824</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2147483648</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4294967296</td>
<td>76</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1024</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>2048</td>
<td>491</td>
<td></td>
</tr>
<tr>
<td>4096</td>
<td>241</td>
<td></td>
</tr>
<tr>
<td>8192</td>
<td>91</td>
<td></td>
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<tr>
<td>16384</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>32768</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>65536</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>131072</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>262144</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>524288</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1048576</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2097152</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4194304</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8388608</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>16777216</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>33554432</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>67108864</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>134217728</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

219
Notice the non-zero values at the bottom of the example output. These data points reveal several instances on both CPUs where a thread was enqueued to run for several seconds.

Instead of 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:

```
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 above script for approximately 30 seconds on a largely idle uniprocessor laptop system results in output similar to the following example:

```
# dtrace -s ./qlen.d
```

```
dtrace: script './qlen.d' matched 5 probes
```

```
^C
```

```
0 value -------------- Distribution ------------ count
< 0 | 0
0 |@@@ outrageously long
1 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2 |@@
3 |@ 12655
4 | 1722
5 | 701
6 | 302
7 | 63
8 | 23
9 | 12
10 | 24
11 | 58
12 | 14
13 | 3
14 | 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 queue was very short (three or fewer threads in length). However, given that the system was largely idle, the exceptional data points at the bottom of the table might be unexpected. For example, why was the run queue as long as 13 runnable threads? To explore this question, 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 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. If it does, 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. Once the kernel dequeues the last thread that was enqueued at the timestamp of the longest length, the script commits the speculation data. This script is shown below:

```c
#pragma D option quiet
#pragma D option nspec=4
#pragma D option specsize=100k

int maxlen;
int spec[int];

sched::enqueue
{
    this->len = ++glen[this->cpu = args[2]->cpu_id];
    in[args[0]->pr_addr] = timestamp;
}
/nsched::enqueue
  if(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
  if(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);
  }
/nsched::dequeue
  if(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
/*
 * 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 above script on the same uniprocessor laptop results in output similar to the following example:

# dtrace -s ./whoqueue.d
Run queue of length 3:
 0/0 (sched)
 0/0 (sched)
 101170/1 (dtrace)
Run queue of length 4:
 0/0 (sched)
 100356/1 (Xsun)
 100420/1 (xterm)
 101170/1 (dtrace)
Run queue of length 5:
 0/0 (sched)
 0/0 (sched)
 100356/1 (Xsun)
 100420/1 (xterm)
 101170/1 (dtrace)
Run queue of length 7:
 0/0 (sched)
 100221/18 (nscd)
 100221/17 (nscd)
 100221/16 (nscd)
 100221/13 (nscd)
 100221/14 (nscd)
 100221/15 (nscd)
Run queue of length 16:
 100821/1 (xterm)
 100768/1 (xterm)
 100365/1 (fvwm2)
 101118/1 (xterm)
 100577/1 (xterm)
 101170/1 (dtrace)
 101020/1 (xterm)

222
The output reveals that the long run queues are due to many runnable xterm processes. This experiment coincided with a change in virtual desktop, and therefore the results are probably due to some sort of X event processing.

**sleep and wakeup**

In Section 26.3, the final example demonstrated that a burst in run queue length was due to runnable xterm processes. One hypothesis is that the observations resulted from a change in virtual desktop. You can use the wakeup probe to explore this hypothesis by determining who is waking the xterm processes, and when, as shown in the following example:

```
#pragma D option quiet

dtrace:::BEGIN
{
    start = timestamp;
}

sched:::wakeup
/stringof(args[1]->pr_fname) == "xterm"/
{
    @[execname] = lquantize((timestamp - start) / 1000000000, 0, 10);
}

profile:::tick-1sec
/+x == 10/
{
    exit(0);
}
```

To investigate the hypothesis, run the above script, waiting roughly five seconds, and switch your virtual desktop exactly once. If the burst of runnable xterm processes is due to switching the virtual desktop, the output should show a burst of wakeup activity at the five second mark.

```
# dtrace -s ./xterm.d

Xsun

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>@</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>@@@@@@@@@@@@@</td>
<td>32</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
```
The output does show that the X server is waking xterm processes, clustered around the time that you
switched virtual desktops. If you wanted to understand the interaction between the X server and the
xterm processes, you could aggregate on user stack traces when the X server fires the wakeup probe.

Understanding the performance of client/server systems like the X windowing system requires understand-
ing the clients on whose behalf the server is doing work. This kind of question is difficult to answer with
conventional performance analysis tools. However, if you have a model where a client sends a message to
the server and sleeps pending the server’s processing, you can use the wakeup probe to determine the
client for whom the request is being performed, as shown in the following example:

```c
self int last;
sched:::wakeup
/self->last && args[0]->pr_stype == SOBJ_CV/
{
    @[stringof(args[1]->pr_fname)] = sum(vtimestamp - self->last);
    self->last = 0;
}
sched:::wakeup
/execname == "Xsun" && self->last == 0/
{
    self->last = vtimestamp;
}
```

Running the above script results in output similar to the following example:

```
dtrace -s ./xwork.d
```
```
dtrace: script './xwork.d' matched 14 probes
^C
```
```
xterm 9522510
soffice.bin 9912594
fvwm2 100423123
MozillaFirebird 312227077
acroread 345901577
```

This output reveals that much Xsun work is being done on behalf of the processes acroread, Mozilla
Firebird and, to a lesser degree, fvwm2. Notice that the script only examined wakeups from condition
variable synchronization objects (SOBJ_CV). As described in Table 25.4, condition variables are the type
of synchronization object typically used to synchronize for reasons other than access to a shared data
region. In the case of the X server, a client will wait for data in a pipe by sleeping on a condition variable.

You can additionally use the sleep probe along with the wakeup probe to understand which applications
are blocking on which applications, and for how long, as shown in the following example:

```c
#pragma D option quiet
sched:::sleep
/!(curlwpsinfo->pr_flag & PR_ISSYS) && curlwpsinfo->pr_stype == SOBJ_CV/
{
    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]);
}
```

224
```c
    bedtime[0]->pr_addr = 0;
}

END
{
    printa("%s sleeping on %s:\n\d\n", @);
}
```

The tail of the output from running the example script for several seconds on a desktop system resembles the following example:

```
# dtrace -s ./whofor.d
^C
...
```

- **xterm sleeping on Xsun:**

```
<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>131072</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>262144</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>524288</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1048576</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2097152</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>4194304</td>
<td>@@@@</td>
<td>45</td>
</tr>
<tr>
<td>8388608</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>16777216</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>33554432</td>
<td>@@@</td>
<td>83</td>
</tr>
<tr>
<td>67108864</td>
<td>@</td>
<td>164</td>
</tr>
<tr>
<td>134217728</td>
<td>@@@</td>
<td>147</td>
</tr>
<tr>
<td>268435456</td>
<td>@@@</td>
<td>56</td>
</tr>
<tr>
<td>536870912</td>
<td>@</td>
<td>17</td>
</tr>
<tr>
<td>1073741824</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>2147483648</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4294967296</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>8589934592</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>17179869184</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
```

- **fvwm2 sleeping on Xsun:**

```
<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>32768</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>65536</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>67</td>
</tr>
<tr>
<td>131072</td>
<td>@@@</td>
<td>16</td>
</tr>
<tr>
<td>262144</td>
<td>@@</td>
<td>6</td>
</tr>
<tr>
<td>524288</td>
<td>@</td>
<td>3</td>
</tr>
<tr>
<td>1048576</td>
<td>@@@@</td>
<td>15</td>
</tr>
<tr>
<td>2097152</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>4194304</td>
<td></td>
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<tr>
<td>8388608</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>16777216</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>33554432</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>67108864</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>134217728</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>268435456</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>536870912</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1073741824</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2147483648</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>4294967296</td>
<td></td>
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<tr>
<td>8589934592</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>17179869184</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>34359738368</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>
```
You might want to understand how and why MozillaFirebird is blocking on itself. You could modify the above script as shown in the following example to answer this question:

```c
#pragma D option quiet
sched:::sleep
  /execname == "MozillaFirebird" && curlwpsinfo->pr_stype == SOBJ_CV/
  {
    bedtime[curlwpsinfo->pr_addr] = timestamp;
  }

sched:::wakeup
  /execname == "MozillaFirebird" && bedtime[0] = pr_addr/[/
  {
    @[0]->pr_pid, args[0]->pr_lwpid, pid, curlwpsinfo->pr_lwpid] =
    quantize(timestamp - bedtime[0]-pr_addr]);
    bedtime[0] = 0;
  }

sched:::wakeup
  /bedtime[0] = pr_addr/[/
  {
    bedtime[0] = 0;
  }

END
  {
    printa("%d/%d sleeping on %d/%d\n", @);
  }
```
Running the modified script for several seconds results in output similar to the following example:

```bash
# dtrace -s ./firebird.d
^C

100459/1 sleeping on 100459/13:

```
value -------------- Distribution ------------ count
262144 |                    0
524288 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 1
1048576 | 0
```

100459/13 sleeping on 100459/1:

```
value -------------- Distribution ------------ count
16777216 | 0
33554432 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 1
67108864 | 0
```

100459/1 sleeping on 100459/2:

```
value -------------- Distribution ------------ count
16384 | 0
32768 |@@@@ 5
65536 |@ 2
131072 |@@@@@@ 15
262144 | 1
524288 | 1
1048576 | 0
2097152 |@@ 3
4194304 |@@@@@ 13
8388608 |@@@ 8
16777216 |@@@@@ 13
33554432 |@@ 6
67108864 | 0
```

100459/1 sleeping on 100459/5:

```
value -------------- Distribution ------------ count
16384 | 0
32768 |@@@@@@ 12
65536 |@@ 5
131072 |@@@@@@ 15
262144 | 1
524288 | 1
1048576 | 0
2097152 |@@@ 8
4194304 |@@@@@ 13
8388608 |@@@ 8
16777216 |@@@@@ 13
33554432 |@@ 6
67108864 | 0
```

100459/2 sleeping on 100459/1:
### SCHED PROVIDER

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>16384</td>
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<td>0</td>
</tr>
<tr>
<td>32768</td>
<td>@@@@@@@@@@@@@</td>
<td>11</td>
</tr>
<tr>
<td>65536</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>131072</td>
<td>@</td>
<td>2</td>
</tr>
<tr>
<td>262144</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>524288</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1048576</td>
<td>@@@@</td>
<td>3</td>
</tr>
<tr>
<td>2097152</td>
<td>@</td>
<td>1</td>
</tr>
<tr>
<td>4194304</td>
<td>@@</td>
<td>2</td>
</tr>
<tr>
<td>8388608</td>
<td>@@</td>
<td>2</td>
</tr>
<tr>
<td>16777216</td>
<td>@</td>
<td>1</td>
</tr>
<tr>
<td>33554432</td>
<td>@@@@@@@@@@@@@</td>
<td>5</td>
</tr>
<tr>
<td>67108864</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>134217728</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>268435456</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>536870912</td>
<td>@</td>
<td>1</td>
</tr>
<tr>
<td>1073741824</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2147483648</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4294967296</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

100459/5 sleeping on 100459/1:

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>16384</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>32768</td>
<td>@</td>
<td>1</td>
</tr>
<tr>
<td>65536</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>131072</td>
<td>@@@</td>
<td>4</td>
</tr>
<tr>
<td>262144</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>524288</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1048576</td>
<td>@@@@</td>
<td>5</td>
</tr>
<tr>
<td>2097152</td>
<td>@@@@</td>
<td>10</td>
</tr>
<tr>
<td>4194304</td>
<td>@@@@@@@@@@@</td>
<td>77</td>
</tr>
<tr>
<td>8388608</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>270</td>
</tr>
<tr>
<td>16777216</td>
<td>@@@@@@@@@@@</td>
<td>43</td>
</tr>
<tr>
<td>33554432</td>
<td>@</td>
<td>20</td>
</tr>
<tr>
<td>67108864</td>
<td>@</td>
<td>14</td>
</tr>
<tr>
<td>134217728</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>268435456</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>536870912</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1073741824</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

You can also use the sleep and wakeup probes to understand the performance of door servers such as the name service cache daemon, as shown in the following example:

```c
sched:::sleep
curlwpsinfo->pr_stype == SOBJ_SHUTTLE/
{
    bedtime[curlwpsinfo->pr_addr] = timestamp;
}

sched:::wakeup
execname == "nscd" && bedtime[args[0]->pr_addr] /
{
    @[stringof(curpsinfo->pr_fname), stringof(args[1]->pr_fname)] = quantize(timestamp - bedtime[args[0]->pr_addr]);
    bedtime[args[0]->pr_addr] = 0;
}
```
The tail of the output from running the above script on a large mail server resembles the following example:

```plaintext
imapd
value -------------- Distribution ------------ count
16384 | 0
32768 | 2
65536 | @@@@@@@@@@@@@@@@@@@@@@@@@@@@ 57
131072 | @@@@@@@@@@@@@@@@ 37
262144 | 3
524288 | @@ 11
1048576 | @@@ 10
2097152 | @@@ 9
4194304 | @@@ 1
8388608 | 0

mountd
value -------------- Distribution ------------ count
65536 | 0
131072 | @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 49
262144 | @@ 6
524288 | @@ 1
1048576 | 0
2097152 | 0
4194304 | @@@@ 7
8388608 | @ 3
16777216 | 0

sendmail
value -------------- Distribution ------------ count
16384 | 0
32768 | @@ 18
65536 | @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 205
131072 | @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 154
262144 | @@ 23
524288 | 5
1048576 | @@@@ 50
2097152 | 7
4194304 | 5
8388608 | 2
16777216 | 0

automountd
value -------------- Distribution ------------ count
32768 | 0
65536 | @@@@@@@@@@@ 22
131072 | @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 51
262144 | @@ 6
524288 | 1
1048576 | 0
2097152 | 2
4194304 | 2
8388608 | 1
16777216 | 1
33554432 | 1
```
You might be interested in the unusual data points for automountd or the persistent data point at over one millisecond for sendmail. You can add additional predicates to the above script to hone in on the causes of any exceptional or anomalous results.

**preempt, remain-cpu**

Because illumos is a preemptive system, higher priority threads preempt lower priority ones. Preemption can induce a significant latency bubble in the lower priority thread, so you might want to know which threads are being preempted by which other threads. The following example shows how to use the preempt and remain-cpu probes to display this information:

```c
#pragma D option quiet

define sched:::preempt { 
    self->preempt = 1; }
define sched:::remain-cpu /self->preempt/ { 
    self->preempt = 0; }
define 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("%25s %3s %25s %3s %5s\n", "PREEMPTOR", "PRI", 
    "PREEMPTED", "PRI", "); 
    printa("%25s %3d %25s %3d %5d\n", 0); 
}
```

Running the above script for several seconds on a desktop system results in output similar to the following example:

```
# dtrace -s ./whopreempt.d
^C

<table>
<thead>
<tr>
<th>PREEMPTOR</th>
<th>PRI</th>
<th>PREEMPTED</th>
<th>PRI</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>sched</td>
<td>60</td>
<td>Xsun</td>
<td>53</td>
<td>1</td>
</tr>
<tr>
<td>xterm</td>
<td>59</td>
<td>Xsun</td>
<td>53</td>
<td>1</td>
</tr>
<tr>
<td>MozillaFirebird</td>
<td>57</td>
<td>Xsun</td>
<td>53</td>
<td>1</td>
</tr>
</tbody>
</table>
```
change-pri

Preemption is based on priorities, so you might want to observe changes in priority over time. The following example uses the change-pri probe to display this information:

```
sched::change-pri
{
    @[stringof(args[0]->pr_clname)] =
        lquantize(args[2] - args[0]->pr_pri, -50, 50, 5);
}
```

The example script captures the degree to which priority is raised or lowered, and aggregates by scheduling class. Running the above script results in output similar to the following example:

```
# dtrace -s ./pri.d
```
```
dtrace: script './pri.d' matched 10 probes
^C
```
```
<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; -50</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>-50</td>
<td>@</td>
<td>38</td>
</tr>
<tr>
<td>-45</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>-40</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>-35</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>-30</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>-25</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>-20</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>-15</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>-10</td>
<td>@@@@@@@@@@@@</td>
<td>201</td>
</tr>
<tr>
<td>-5</td>
<td>@@@@@@@@@@@</td>
<td>160</td>
</tr>
<tr>
<td>0</td>
<td>@@@@@@@@@@</td>
<td>138</td>
</tr>
<tr>
<td>5</td>
<td>@</td>
<td>47</td>
</tr>
<tr>
<td>10</td>
<td>@</td>
<td>66</td>
</tr>
<tr>
<td>15</td>
<td>@</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>@</td>
<td>26</td>
</tr>
<tr>
<td>25</td>
<td>@</td>
<td>28</td>
</tr>
</tbody>
</table>
```
The output shows the priority manipulation of the Interactive (IA) scheduling class. Instead of seeing priority manipulation, you might want to see the priority values of a particular process and thread over time. The following script uses the change-pri probe to display this information:

```
#pragma D option quiet

BEGIN {
    start = timestamp;
}

sched:::change-pri
/args[1]->pr_pid == $1 && args[0]->pr_lwpid == $2/ {
    printf("%d %d\n", timestamp - start, args[2]);
}

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

To see the change in priorities over time, type the following command in one window:

```
$ echo $$
139208
$ while true ; do let i=0 ; done
```

In another window, run the script and redirect the output to a file:

```
# dtrace -s ./pritime.d 139208 1 > /tmp/pritime.out
```

You can use the file `/tmp/pritime.out` that is generated above as input to plotting software to graphically display priority over time. gnuplot is a freely available plotting package that is available for illumos through several distributors, including pkgsrc.

**tick**

illumos uses *tick-based CPU accounting*, in which a system clock interrupt fires at a fixed interval and attributes CPU utilization to the threads and processes running at the time of the tick. The following
example shows how to use the `tick` probe to observe this attribution:

```bash
# dtrace -n sched:::tick'{@[stringof(args[1]->pr_fname)] = count()}'

arch 1
sh 1
sed 1
echo 1
ls 1
FvwmAuto 1
pwd 1
awk 2
basename 2
expr 2
resize 2
tput 2
uname 2
fsflush 2
dirname 4
vim 9
fvwm2 10
ksh 19
xterm 21
Xsun 93
MozillaFirebird 260
```

The system clock frequency varies from operating system to operating system, but generally ranges from 25 hertz to 1024 hertz. The illumos system clock frequency is adjustable, but defaults to 100 hertz.

The `tick` probe only fires if the system clock detects a runnable thread. To use the `tick` probe to observe the system clock’s frequency, you must have a thread that is always runnable. In one window, create a looping shell as shown in the following example:

```bash
$ while true ; do let i=0 ; done
```

In another window, run the following script:

```c
uint64_t last[int];

sched:::tick
{/last[cpu]/
  @[cpu] = min(timestamp - last[cpu]);
}
sched:::tick
{    last[cpu] = timestamp;
}
```

```bash
# dtrace -s ./ticktime.d
dtrace: script './ticktime.d' matched 2 probes

0 9883789
```

The minimum interval is 9.8 millisecond, which indicates that the default clock tick frequency is 10 milliseconds (100 hertz). The observed minimum is somewhat less than 10 milliseconds due to jitter.
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 will either over-account for the thread or under-account for the thread, depending on whether the accounting is done before or after time-related dispatching scheduling activity. In illumos, accounting is performed before time-related dispatching. As a result, the system will under-account for threads running at regular interval. If such threads run for less than the clock tick interval, they can effectively “hide” behind the clock tick. The following example shows the degree to which the system has such threads:

```c
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`:

```bash
# dtrace -s ./tick.d
dtrace: script './tick.d' matched 4 probes
^C
tick
  value -------------- Distribution ------------ count
  6 | 0
  7 |@ 3
  8 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
  9 |

enqueue
  value -------------- Distribution ------------ count
  < 0 | 0
  0 |@@ 267
  1 |@@ 300
  2 |@@ 259
  3 |@@ 291
  4 |@@@ 360
  5 |@@ 305
  6 |@@ 295
  7 |@@ 522
  8 |@@@@ 1315
  9 |@@@ 337
```

The output histogram named `tick` shows that the clock tick is firing at an 8 millisecond offset. If scheduling were not at all associated with the clock tick, the output for `enqueue` would be evenly spread across the ten millisecond interval. However, the output shows a spike at the same 8 millisecond offset, indicating that at least some threads in the system are being scheduled on a time basis.

### 26.4 Stability

The `sched` provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.
<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 27

io Provider

The io provider makes available probes related to disk input and output. The io provider enables quick exploration of behavior observed through I/O monitoring tools such as iostat(1M). For example, using the io provider, you can understand I/O by device, by I/O type, by I/O size, by process, by application name, by file name, or by file offset.

27.1 Probes

The io probes are described in Table 27.1.

Table 27.1: io Probes

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>start</td>
<td>Probe that fires when an I/O request is about to be made either to a peripheral device or to an NFS server. The bufinfo_t corresponding to the I/O request is pointed to by args[0]. The devinfo_t of the device to which the I/O is being issued is pointed to by args[1]. The fileinfo_t of the file that corresponds to the I/O request is pointed to by args[2]. Note that file information availability depends on the filesystem making the I/O request. See Section 27.2 for more information.</td>
</tr>
<tr>
<td>done</td>
<td>Probe that fires after an I/O request has been fulfilled. The bufinfo_t corresponding to the I/O request is pointed to by args[0]. 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. The devinfo_t of the device to which the I/O was issued is pointed to by args[1]. The fileinfo_t of the file that corresponds to the I/O request is pointed to by args[2].</td>
</tr>
<tr>
<td>wait-start</td>
<td>Probe that fires immediately before a thread begins to wait pending completion of a given I/O request. The buf(9S) structure corresponding to the I/O request for which the thread will wait is pointed to by args[0]. The devinfo_t of the device to which the I/O was issued is pointed to by args[1]. The fileinfo_t of the file that corresponds to the I/O request is pointed to by args[2]. Some time after the wait-start probe fires, the wait-done probe will fire in the same thread.</td>
</tr>
</tbody>
</table>
Table 27.1: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>wait-done</td>
<td>Probe that fires when a thread is done waiting for the completion of a given I/O request. The bufinfo_t corresponding to the I/O request for which the thread will wait is pointed to by args[0]. The devinfo_t of the device to which the I/O was issued is pointed to by args[1]. The fileinfo_t of the file that corresponds to the I/O request is pointed to by args[2]. The wait-done probe fires only after the wait-start probe has fired in the same thread.</td>
</tr>
</tbody>
</table>

Note that 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(3C) request.

27.2 Arguments

The argument types for the io probes are listed in Table 27.2. The arguments are described in Table 27.1.

Table 27.2: io Probe Arguments

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>start</td>
<td>struct buf *</td>
<td>devinfo_t *</td>
<td>fileinfo_t *</td>
</tr>
<tr>
<td>done</td>
<td>struct buf *</td>
<td>devinfo_t *</td>
<td>fileinfo_t *</td>
</tr>
<tr>
<td>wait-start</td>
<td>struct buf *</td>
<td>devinfo_t *</td>
<td>fileinfo_t *</td>
</tr>
<tr>
<td>wait-done</td>
<td>struct buf *</td>
<td>devinfo_t *</td>
<td>fileinfo_t *</td>
</tr>
</tbody>
</table>

Each io probe has arguments consisting of a pointer to a buf(9S) structure, a pointer to a devinfo_t, and a pointer to a fileinfo_t. These structures are described in greater detail in this section.

bufinfo_t structure

The bufinfo_t structure is the abstraction that describes an I/O request. The buffer corresponding to an I/O request is pointed to by args[0] in the start, done, wait-start, and wait-done probes. The bufinfo_t structure definition is as follows:

```c
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;      /* block # on device */
    size_t b_resid;        /* # of bytes not transferred */
    size_t b_bufsize;      /* size of allocated buffer */
} bufinfo_t;
```
The **b_flags** member indicates the state of the I/O buffer, and consists of a bitwise-or of different state values. The valid state values are in Table 27.3.

### Table 27.3: b_flags Values

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_DONE</td>
<td>Indicates that the data transfer has completed.</td>
</tr>
<tr>
<td>B_ERROR</td>
<td>Indicates an I/O transfer error. It is set in conjunction with the b_error field.</td>
</tr>
<tr>
<td>B_PAGEIO</td>
<td>Indicates that the buffer is being used in a paged I/O request. See the description of the b_addr field for more information.</td>
</tr>
<tr>
<td>B_PHYS</td>
<td>Indicates that the buffer is being used for physical (direct) I/O to a user data area.</td>
</tr>
<tr>
<td>B_READ</td>
<td>Indicates that data is to be read from the peripheral device into main memory.</td>
</tr>
<tr>
<td>B_WRITE</td>
<td>Indicates that the data is to be transferred from main memory to the peripheral device.</td>
</tr>
<tr>
<td>B_ASYNC</td>
<td>The I/O request is asynchronous, and will not be waited upon. The wait-start and wait-done probes don’t fire for asynchronous I/O requests. Note that some I/Os directed to be asynchronous might not have B_ASYNC set: the asynchronous I/O subsystem might implement the asynchronous request by having a separate worker thread perform a synchronous I/O operation.</td>
</tr>
</tbody>
</table>

The **b_bcount** field is the number of bytes to be transferred as part of the I/O request.

The **b_addr** field is the virtual address of the I/O request, unless B_PAGEIO is set. The address is a kernel virtual address unless B_PHYS is set, in which case it is a user virtual address. If B_PAGEIO is set, the b_addr field contains kernel private data. Exactly one of B_PHYS and B_PAGEIO can be set, or neither flag will be set.

The **b_lblkno** field 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.

The **b_resid** field is set to the number of bytes not transferred because of an error.

The **b_bufsize** field contains the size of the allocated buffer.

The **b_iiodone** field identifies a specific routine in the kernel that is called when the I/O is complete.

The **b_error** field may hold an error code returned from the driver in the event of an I/O error. **b_error** is set in conjunction with the B_ERROR bit set in the b_flags member.

The **b_edev** field contains the major and minor device numbers of the device accessed. Consumers may 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 corresponding to the destination device of an I/O is pointed to by args[1] in the start, done, wait-start, and wait-done probes. The members of devinfo_t are as follows:

```c
typedef struct devinfo {
    int dev_major;    /* major number */
    int dev_minor;    /* minor number */
    int dev_instance; /* instance number */
    string dev_name; /* name of device */
    string dev_statname; /* name of device + instance/minor */
    string dev_pathname; /* pathname of device */
} devinfo_t;
```

The dev_major field is the major number of the device. See getmajor(9F) for more information.

The dev_minor field is the minor number of the device. See getminor(9F) for more information.

The dev_instance field is the instance number of the device. The instance of a device is different from the minor number. The minor number is an abstraction managed by the device driver. The instance number is a property of the device node. You can display device node instance numbers with prtconf(1M).

The dev_name field is the name of the device driver that manages the device. You can display device driver names with the -D option to prtconf(1M).

The dev_statname field is the name of the device as reported by iostat(1M). This name also corresponds to the name of a kernel statistic as reported by kstat(1M). This field is provided so that aberrant iostat or kstat output can be quickly correlated to actual I/O activity.

The dev_pathname field is the full path of the device. This path may be specified as an argument to prtconf(1M) to obtain detailed device information. The path specified by dev_pathname includes components expressing the device node, the instance number, and the minor node. However, all three of these elements aren’t 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 may differ in dev_pathname.

fileinfo_t

The fileinfo_t structure provides information about a file. The file to which an I/O corresponds is pointed to by args[2] in the start, done, wait-start, and wait-done probes. The presence of file information is contingent upon the filesystem providing this information when dispatching I/O requests. Some filesystems, especially third-party filesystems, might not provide this information. Also, I/O requests might emanate from a filesystem for which no file information exists. For example, any I/O to filesystem metadata will not be associated with any one file. Finally, some highly optimized filesystems might aggregate I/O from disjoint files into a single I/O request. In this case, the filesystem 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. Alternately, the filesystem might provide no file information at all in this case.

The definition of the fileinfo_t structure is as follows:

```c
typedef struct fileinfo {
    string fi_name;    /* name (basename of fi_pathname) */
    string fi_dirname; /* directory (dirname of fi_pathname) */
} 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 will be set to the string `<none>`. In some rare cases, the pathname associated with a file might be unknown. In this case, the `fi_name` field will be set to the string `<unknown>`.

The `fi_dirname` field contains *only* the directory component of the file name. As with `fi_name`, this string may be set to `<none>` if no file information is present, or `<unknown>` if the pathname associated with the file is not known.

The `fi_pathname` field contains the full pathname to the file. As with `fi_name`, this string may be set to `<none>` if no file information is present, or `<unknown>` if the pathname 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 filesystem.

### 27.3 Examples

The following example script displays pertinent information for every I/O as it’s issued:

```c
#pragma D option quiet
BEGIN
{ printf("%10s %58s %2s\n", "DEVICE", "FILE", "RW");
 }
io:::start
{ printf("%10s %58s %2s\n", args[1]->dev_statname,
    args[2]->fi_pathname, args[0]->b_flags & B_READ ? "R" : "W");
 }
```

The output of the example when cold-starting Acrobat Reader on an x86 laptop system resembles the following example:

```
$ dtrace -s ./iosnoop.d
DEVICE FILE RW
  cmdk0 /opt/Acrobat4/bin/acroread R
  cmdk0 /opt/Acrobat4/bin/acroread R
  cmdk0 <unknown> R
  cmdk0 /opt/Acrobat4/Reader/AcroVersion R
  cmdk0 <unknown> R
  cmdk0 <unknown> R
  cmdk0 <none> R
  cmdk0 <none> R
  cmdk0 /usr/lib/locale/iso_8859_1/iso_8859_1.so.3 R
  cmdk0 /usr/lib/locale/iso_8859_1/iso_8859_1.so.3 R
  cmdk0 /usr/lib/locale/iso_8859_1/iso_8859_1.so.3 R
```

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The <none> entries in the output indicate that the I/O doesn’t correspond to the data in any particular file: these I/Os are due to metadata of one form or another. The <unknown> entries in the output indicate that the pathname for the file is not known. This situation is relatively rare.

You could make the example script slightly more sophisticated by using an associative array to track the time spent on each I/O, as shown in the following example:

```c
#pragma D option quiet
BEGIN
{
    printf("%10s %58s %2s %7s\n", "DEVICE", "FILE", "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 %58s %2s %3d.%03d\n", args[1]->dev_statname,
        args[2]->fi_pathname, args[0]->b_flags & B_READ ? "R" : "W",
        ...}
```
27.3. Examples

The output of the above example while hot-plugging a USB storage device into an otherwise idle x86 laptop system is shown in the following example:

```
# dtrace -s ./iotime.d

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>FILE</th>
<th>RW</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>cmdk0</td>
<td>/kernel/drv/scsa2usb</td>
<td>R</td>
<td>24.781</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/kernel/drv/scsa2usb</td>
<td>R</td>
<td>25.208</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>25.981</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/kernel/drv/scsa2usb</td>
<td>R</td>
<td>5.448</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>4.172</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/kernel/drv/scsa2usb</td>
<td>R</td>
<td>2.620</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>0.252</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;unknown&gt;</td>
<td>R</td>
<td>3.213</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>W</td>
<td>3.011</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;unknown&gt;</td>
<td>R</td>
<td>2.197</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>2.680</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>W</td>
<td>0.436</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>0.542</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>W</td>
<td>0.339</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>0.414</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>W</td>
<td>0.344</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>0.361</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>W</td>
<td>0.315</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/var/adm/messages</td>
<td>W</td>
<td>0.421</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>W</td>
<td>0.349</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>R</td>
<td>1.524</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;unknown&gt;</td>
<td>R</td>
<td>3.648</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/librcm.so.1</td>
<td>R</td>
<td>2.553</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/librcm.so.1</td>
<td>R</td>
<td>1.332</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/librcm.so.1</td>
<td>R</td>
<td>0.222</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/librcm.so.1</td>
<td>R</td>
<td>0.228</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/librcm.so.1</td>
<td>R</td>
<td>0.927</td>
</tr>
<tr>
<td>cmdk0</td>
<td>&lt;none&gt;</td>
<td>R</td>
<td>1.189</td>
</tr>
<tr>
<td>...</td>
<td>/usr/lib/devfsadm/linkmod</td>
<td>R</td>
<td>1.110</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_audio_link.so</td>
<td>R</td>
<td>1.763</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_audio_link.so</td>
<td>R</td>
<td>0.161</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_cfg_link.so</td>
<td>R</td>
<td>0.819</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_cfg_link.so</td>
<td>R</td>
<td>0.168</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_disk_link.so</td>
<td>R</td>
<td>0.886</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_disk_link.so</td>
<td>R</td>
<td>0.185</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_fssnap_link.so</td>
<td>R</td>
<td>0.778</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_fssnap_link.so</td>
<td>R</td>
<td>0.166</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_lofi_link.so</td>
<td>R</td>
<td>1.634</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_lofi_link.so</td>
<td>R</td>
<td>0.163</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_md_link.so</td>
<td>R</td>
<td>0.477</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_md_link.so</td>
<td>R</td>
<td>0.161</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_misc_link.so</td>
<td>R</td>
<td>0.198</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_misc_link.so</td>
<td>R</td>
<td>0.168</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_misc_link.so</td>
<td>R</td>
<td>0.247</td>
</tr>
<tr>
<td>cmdk0</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_misc_link_i386.so</td>
<td>R</td>
<td>1.735</td>
</tr>
<tr>
<td>...</td>
<td>/usr/lib/devfsadm/linkmod/SUNW_misc_link_i386.so</td>
<td>R</td>
<td>1.735</td>
</tr>
</tbody>
</table>
```

You can make several observations about the mechanics of the system based on this output. First, note the long time to perform the first several I/Os, which took about 25 milliseconds each. This time might have
been due to the cmdk0 device having been power managed on the laptop. Second, observe the I/O due to the scsa2usb(7D) driver loading to deal with USB Mass Storage device. Third, note the writes to /var/adm/messages as the device is reported. Finally, observe the reading of the device link generators (the files ending in link.so), which presumably deal with the new device.

The io provider enables in-depth understanding of iostat(1M) output. Assume you observe iostat output similar to the following example:

<table>
<thead>
<tr>
<th>device</th>
<th>r/s</th>
<th>w/s</th>
<th>kr/s</th>
<th>kw/s</th>
<th>wait</th>
<th>actv</th>
<th>svc_t</th>
<th>%w</th>
<th>%b</th>
</tr>
</thead>
<tbody>
<tr>
<td>cmdk0</td>
<td>8.0</td>
<td>0.0</td>
<td>399.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>sd0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>sd2</td>
<td>0.0</td>
<td>109.0</td>
<td>0.0</td>
<td>435.9</td>
<td>0.0</td>
<td>1.0</td>
<td>8.9</td>
<td>0</td>
<td>97</td>
</tr>
<tr>
<td>nfs1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>nfs2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

You can use the iotime.d script to see these I/Os as they happen, as shown in the following example:

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>FILE</th>
<th>RW</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.856</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.729</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.890</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.759</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.884</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.746</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.891</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.760</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.889</td>
<td></td>
</tr>
<tr>
<td>cmdk0</td>
<td>/export/archives/archives.tar R</td>
<td>0.827</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.537</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.887</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.763</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.878</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.751</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.884</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.760</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>3.994</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.653</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.896</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.975</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>1.405</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.724</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>1.841</td>
<td></td>
</tr>
<tr>
<td>cmdk0</td>
<td>/export/archives/archives.tar R</td>
<td>0.549</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.543</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.863</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.734</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.859</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.754</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.914</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.751</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.902</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.735</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.908</td>
<td></td>
</tr>
<tr>
<td>sd2</td>
<td>/mnt/archives.tar W</td>
<td>0.753</td>
<td></td>
</tr>
</tbody>
</table>

This output appears to show that the file archives.tar is being read from cmdk0 (in /export/archives), and being written to device sd2 (in /mnt). This existence of two files named archives.
tar that are being operated on separately in parallel seems unlikely. To investigate further, you can aggregate on device, application, process ID and bytes transferred, as shown in the following example:

```c
#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 %15d\n", @);
}
```

Running this script for a few seconds results in output similar to the following example:

```bash
# dtrace -s ./whoio.d
^C
DEVICE APP PID BYTES
  cmdk0 cp 790 1515520
  sd2 cp 790 1527808
```

This output shows that this activity is a copy of the file archives.tar from one device to another. This conclusion leads to another natural question: is one of these devices faster than the other? Which device acts as the limiter on the copy? To answer these questions, you need to know the effective throughput of each device rather than the number of bytes per second each device is transferring. You can determine the throughput with the following example script:

```c
#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 can’t 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 is
   * what we do below.
   */
```
Running the example script for several seconds yields the following output:

```
<table>
<thead>
<tr>
<th>value</th>
<th>---------------</th>
<th>Distribution</th>
<th>---------------</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>64</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>128</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>256</td>
<td>@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@</td>
<td>2257</td>
<td></td>
<td></td>
</tr>
<tr>
<td>512</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1024</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

cmdk0 (/devices/pci@0,0/pci-ide@1f,1/ide@0/cmdk@0,0:a)

```
<table>
<thead>
<tr>
<th>value</th>
<th>---------------</th>
<th>Distribution</th>
<th>---------------</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>256</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>512</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1024</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2048</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4096</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 8192 | @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
value='STORAGE DEVICE'
name='inquiry-vendor-id' type=string items=1
value='Generic'
name='inquiry-device-type’ type=int items=1
value=00000000
name='usb' type=boolean
name='compatible’ type=string items=1
value='sd'
name='lun’ type=int items=1
value=00000000
name='target’ type=int items=1
value=00000000

As the emphasized terms indicate, this device is a removable USB storage device.

The examples in this section have explored all I/O requests. However, you might only be interested in one type of request. The following example tracks the directories in which writes are occurring, along with the applications performing the writes:

```bash
#pragma D option quiet
io:::start
/args[0]->b_flags & B_WRITE/
{
    @[execname, args[2]->fi_dirname] = count();
}
END
{
    printf("%20s %51s %5s\n", "WHO", "WHERE", "COUNT");
    printa("%20s %51s %5@d\n", @);
}
```

Running this example script on a desktop workload for a period of time yields some interesting results, as shown in the following example output:

```bash
# dtrace -s ./whowrite.d
^C
WHO WHERE COUNT
su /var/adm 1
fsflush /etc 1
fsflush / 1
fsflush /var/log 1
fsflush /export/bmc/lisa 1
esd /export/bmc/.phoenix/default/78cxczuy.slt/Cache 1
fsflush /export/bmc/.phoenix 1
esd /export/bmc/.phoenix/default/78cxczuy.slt 1
vi /var/tmp 2
vi /etc 2
cat <none> 2
bash / 2
vi <none> 3
xterm /var/adm 3
fsflush /export/bmc 7
MozillaFirebird <none> 8
vim /export/bmc 9
MozillaFirebird /export/bmc 10
fsflush /var/adm 11
devfsadm /dev 14
```
As the output indicates, virtually all writes are associated with the Mozilla Firebird cache. The writes labeled <none> are likely due to writes associated with the UFS log, writes that are themselves induced by other writes in the filesystem. See ufs(7FS) for details on logging. This example shows how to use the io provider to discover a problem at a much higher layer of software. In this case, the script has revealed a configuration problem: the web browser would induce much less I/O (and quite likely none at all) if its cache were in a directory in a tmpfs(7FS) filesystem.

The previous examples have used only the start and done probes. You can use the wait-start and wait-done probes to understand why applications block for I/O – and for how long. The following example script uses both io probes and sched probes (see Chapter 26) to derive CPU time compared to I/O wait time for the StarOffice software:

```c
#pragma D option quiet

sched:::on-cpu
/execname == "soffice.bin"/
{
  self->on = vtimestamp;
}

sched:::off-cpu
/self->on/
{
  @time["<on cpu>"] = sum(vtimestamp - self->on);
  self->on = 0;
}

io:::wait-start
/execname == "soffice.bin"/
{
  self->wait = timestamp;
}

io:::wait-done
/self->wait/
{
  @io[args[2]->fi_name] = sum(timestamp - self->wait);
  @time["<I/O wait>"] = sum(timestamp - self->wait);
  self->wait = 0;
}

END
{
  printf("Time breakdown (milliseconds):
");
  normalize(@time, 1000000);
  printa(" %5s %15d\n", "", @time);
  printf("\nI/O wait breakdown (milliseconds):
");
  normalize(@io, 1000000);
```
printa(" %-50s %15@d\n", @io);
)

Running the example script during a cold start of the StarOffice software yields the following output:

Time breakdown (milliseconds):
  <on cpu> 3634
  <I/O wait> 13114

I/O wait breakdown (milliseconds):
    soffice.tmp 0
    Office 0
    unorc 0
    sbasic.cfg 0
    en 0
    smath.cfg 0
    toolboxlayout.xml 0
    sdraw.cfg 0
    swriter.cfg 0
    Linguistic.dat 0
    scalc.cfg 0
    Views.dat 0
    Store.dat 0
    META-INF 0
    Common.xml.tmp 0
    afm 0
    libsimreg.so 1
    xiiimp.so.2 3
    outline 4
    Inet.dat 6
    fontmetric 6
    ...
    libcbl.so 44
    libj641si_g.so 46
    libX11.so.4 46
    liblng641si.so 48
    swriter.db 53
    libwpr641si.so 53
    liblocaledata_ascii.so 56
    libi18npool641si.so 65
    libdbtools2.so 69
    ofa64101.res 74
    libxcr641si.so 82
    libucpche1pl.so 83
    libso641si.so 86
    libccppuhelper3C52.so 98
    libfw1641si.so 100
    libsb641si.so 104
    libcopphtelp2.so 105
    libxo641si.so 106
    libucpfile1.so 110
    libccpu.so.3 111
    sw64101.res 114
    libdb-3.2.so 119
    libtk641si.so 126
    libdtransX11641si.so 127
    libgo641si.so 132
    libfwe641si.so 150
    libi18n641si.so 152
    libfwi641si.so 154
As this output shows, much of the cold StarOffice start time is due to waiting for I/O. (13.1 seconds waiting for I/O as opposed to 3.6 seconds on CPU.) Running the script on a warm start of the StarOffice software reveals that page caching has eliminated the I/O time, as shown in the following example output:

<table>
<thead>
<tr>
<th>Time breakdown (milliseconds):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;I/O wait&gt;</td>
<td>0</td>
</tr>
<tr>
<td>&lt;on cpu&gt;</td>
<td>2860</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I/O wait breakdown (milliseconds):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>temp</td>
<td>0</td>
</tr>
<tr>
<td>soffice.tmp</td>
<td>0</td>
</tr>
<tr>
<td>&lt;unknown&gt;</td>
<td>0</td>
</tr>
<tr>
<td>Office</td>
<td>0</td>
</tr>
</tbody>
</table>

The cold start output shows that the file applicat.rdb accounts for more I/O wait time than any other file. This result is presumably due to many I/Os to the file. To explore the I/Os performed to this file, you can use the following D script:

```d
io:::start
/execname == "soffice.bin" && args[2]->fi_name == "applicat.rdb"/ { 
  @ = lquantize(args[2]->fi_offset != -1 ? 
       args[2]->fi_offset / (1000 * 1024) : -1, 0, 1000);
}
```

This script uses the `fi_offset` field of the `fileinfo_t` structure to understand which parts of the file are being accessed, at the granularity of a megabyte. Running this script during a cold start of the StarOffice software results in output similar to the following example:

```
# dtrace -s ./applicat.d
dtrace: script './applicat.d' matched 4 probes
^C

<table>
<thead>
<tr>
<th>value</th>
<th>Distribution</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>28</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>72</td>
</tr>
</tbody>
</table>
```

27. I/O Provider
This output indicates that only the first six megabytes of the file are accessed, perhaps because the file is six megabytes in size. The output also indicates that the entire file is not accessed. If you wanted to improve the cold start time of StarOffice, you might want to understand the access pattern of the file. If the needed sections of the file could be largely contiguous, one way to improve StarOffice cold start time might be to have a scout thread run ahead of the application, inducing the I/O to the file before it’s needed. (This approach is particularly straightforward if the file is accessed using mmap(2).) However, the approximately 1.6 seconds that this strategy would gain in cold start time does not merit the additional complexity and maintenance burden in the application. Either way, the data gathered with the io provider allows a precise understanding of the benefit that such work could ultimately deliver.

27.4 Stability

The io provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 28

mib Provider

The mib provider makes available probes that correspond to counters in the illumos management information bases (MIBs). MIB counters are used by the simple network management protocol (SNMP) that allow remote monitoring of heterogeneous networking entities. You can also view the counters with the kstat(1M) and netstat(1M) commands. The mib provider facilitates quick exploration of aberrant networking behavior that is observed using either remote or local networking monitors.

28.1 Probes

The mib provider makes available probes for counters from several MIBs. The protocols that export MIBs instrumented by the mib provider are listed in Table 28.1. The table includes a reference to documentation that specifies some or all of the MIB, the name of the kernel statistic that may be used to access the running counts (using the kstat(1M) -n statistic option), and a reference to the table that has a complete definition of the probes. All MIB counters are also available through the -s option to netstat(1M).

<table>
<thead>
<tr>
<th>Protocol</th>
<th>MIB Description</th>
<th>Kernel Statistic</th>
<th>mib Probes Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICMP</td>
<td>RFC 1213</td>
<td>icmp</td>
<td>Table 28.2</td>
</tr>
<tr>
<td>IP</td>
<td>RFC 1213</td>
<td>ip</td>
<td>Table 28.3</td>
</tr>
<tr>
<td>IPsec</td>
<td>—</td>
<td>ip</td>
<td>Table 28.4</td>
</tr>
<tr>
<td>IPv6</td>
<td>RFC 2465</td>
<td>—</td>
<td>Table 28.5</td>
</tr>
<tr>
<td>SCTP</td>
<td>“SCTP MIB” (Internet draft)</td>
<td>sctp</td>
<td>Table 28.7</td>
</tr>
<tr>
<td>TCP</td>
<td>RFC 1213</td>
<td>tcp</td>
<td>Table 28.8</td>
</tr>
<tr>
<td>UDP</td>
<td>RFC 1213</td>
<td>udp</td>
<td>Table 28.9</td>
</tr>
</tbody>
</table>

Table 28.2: ICMP mib Probes

**icmpInAddrMaskReps**
Probe that fires whenever an ICMP Address Mask Reply message is received.

253
<table>
<thead>
<tr>
<th>MIB PROVIDER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 28.2</strong>: (continued)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MIB PROVIDER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>icmpInAddrMasks</strong></td>
</tr>
<tr>
<td><strong>icmpInBadRedirects</strong></td>
</tr>
<tr>
<td><strong>icmpInCksumErrs</strong></td>
</tr>
<tr>
<td><strong>icmpInDestUnreachs</strong></td>
</tr>
<tr>
<td><strong>icmpInEchoReps</strong></td>
</tr>
<tr>
<td><strong>icmpInEchos</strong></td>
</tr>
<tr>
<td><strong>icmpInErrors</strong></td>
</tr>
<tr>
<td><strong>icmpInFragNeeded</strong></td>
</tr>
<tr>
<td><strong>icmpInMsgs</strong></td>
</tr>
<tr>
<td><strong>icmpInOverflows</strong></td>
</tr>
<tr>
<td><strong>icmpInParmProbs</strong></td>
</tr>
<tr>
<td><strong>icmpInRedirects</strong></td>
</tr>
<tr>
<td><strong>icmpInSrcQuenchs</strong></td>
</tr>
<tr>
<td><strong>icmpInTimeExcds</strong></td>
</tr>
<tr>
<td><strong>icmpInTimestampReps</strong></td>
</tr>
<tr>
<td><strong>icmpInTimestamps</strong></td>
</tr>
<tr>
<td><strong>icmpInUnknowns</strong></td>
</tr>
<tr>
<td><strong>icmpOutAddrMaskReps</strong></td>
</tr>
<tr>
<td><strong>icmpOutDestUnreachs</strong></td>
</tr>
<tr>
<td><strong>icmpOutDrops</strong></td>
</tr>
<tr>
<td><strong>icmpOutEchoReps</strong></td>
</tr>
</tbody>
</table>
### Table 28.2: (continued)

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>icmpOutErrors</td>
<td>Probe that fires whenever an ICMP message is not sent due to problems discovered within ICMP, such as a lack of buffers. This probe will not fire if errors are discovered outside the ICMP layer, such as the inability of IP to route the resulting datagram.</td>
</tr>
<tr>
<td>icmpOutFragNeeded</td>
<td>Probe that fires whenever an ICMP Destination Unreachable (Fragmentation Needed) message is sent.</td>
</tr>
<tr>
<td>icmpOutMsgs</td>
<td>Probe that fires whenever an ICMP message is sent. Whenever this probe fires, the icmpOutErrors probe might also fire if the message is determined to have ICMP-specific errors.</td>
</tr>
<tr>
<td>icmpOutParmProbs</td>
<td>Probe that fires whenever an ICMP Parameter Problem message is sent.</td>
</tr>
<tr>
<td>icmpOutRedirects</td>
<td>Probe that fires whenever an ICMP Redirect message is sent. For a host, this probe will never fire, because hosts do not send redirects.</td>
</tr>
<tr>
<td>icmpOutTimeExcds</td>
<td>Probe that fires whenever an ICMP Time Exceeded message is sent.</td>
</tr>
<tr>
<td>icmpOutTimestampReps</td>
<td>Probe that fires whenever an ICMP Timestamp Reply message is sent.</td>
</tr>
</tbody>
</table>

### Table 28.3: IP mib Probes

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipForwDatagrams</td>
<td>Probe that fires whenever a datagram is received that does not have this machine as its final IP destination, and an attempt is made to find a route to forward the datagram to that final destination. On machines that do not act as IP gateways, this probe will only fire for those packets that are source-routed through this machine, and for which the source-route option processing was successful.</td>
</tr>
<tr>
<td>ipForwProhibits</td>
<td>Probe that fires whenever a datagram is received that does not have this machine as its final IP destination, but because the machine is not permitted to act as a router, no attempt is made to find a route to forward the datagram to that final destination.</td>
</tr>
<tr>
<td>ipFragCreates</td>
<td>Probe that fires whenever an IP datagram fragment is generated as a result of fragmentation.</td>
</tr>
<tr>
<td>ipFragFails</td>
<td>Probe that fires whenever an IP datagram is discarded because it could not be fragmented, for example, because fragmentation was required and the Don’t Fragment flag was set.</td>
</tr>
<tr>
<td>ipFragOKs</td>
<td>Probe that fires whenever an IP datagram has been successfully fragmented.</td>
</tr>
<tr>
<td>ipInCksumErrs</td>
<td>Probe that fires whenever an input datagram is discarded due to a bad IP header checksum.</td>
</tr>
<tr>
<td>ipInDelivers</td>
<td>Probe that fires whenever an input datagram is successfully delivered to IP user protocols, including ICMP.</td>
</tr>
<tr>
<td>ipInDiscards</td>
<td>Probe that fires whenever an input IP datagram is discarded for reasons unrelated to the packet (for example, for lack of buffer space). This probe does not fire for any datagram discarded while awaiting reassembly.</td>
</tr>
</tbody>
</table>
Table 28.3: (continued)

<table>
<thead>
<tr>
<th>MIB Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipInHdrErrors</td>
<td>Probe that fires whenever an input datagram is discarded due to an error in its IP header, including a version number mismatch, a format error, an exceeded time-to-live, an error discovered in processing IP options, and the like.</td>
</tr>
<tr>
<td>ipInIPv6</td>
<td>Probe that fires whenever an IPv6 packet erroneously arrives on an IPv4 queue.</td>
</tr>
<tr>
<td>ipInReceives</td>
<td>Probe that fires whenever a datagram is received from an interface, even if that datagram is received in error.</td>
</tr>
<tr>
<td>ipInUnknownProtos</td>
<td>Probe that fires whenever a locally addressed datagram is received successfully but subsequently discarded because of an unknown or unsupported protocol.</td>
</tr>
<tr>
<td>ipOutDiscards</td>
<td>Probe that fires whenever an output IP datagram is discarded for reasons unrelated to the packet (for example, for lack of buffer space). This probe will fire for a packet counted in the ipForwardedDatagrams MIB counter if the packet meets such a (discretionary) discard criterion.</td>
</tr>
<tr>
<td>ipOutIPv6</td>
<td>Probe that fires whenever an IPv6 packet is sent over an IPv4 connection.</td>
</tr>
<tr>
<td>ipOutNoRoutes</td>
<td>Probe that fires whenever an IP datagram is discarded because no route could be found to transmit it to its destination. This probe will fire for a packet counted in the ipForwardedDatagrams MIB counter if the packet meets this “no-route” criterion. This probe will also fire for any datagrams which cannot be routed because all default gateways are down.</td>
</tr>
<tr>
<td>ipOutRequests</td>
<td>Probe that fires whenever an IP datagram is supplied to IP for transmission from local IP user protocols (include ICMP). Note that this probe will not fire for any packet counted in the ipForwardedDatagrams MIB counter.</td>
</tr>
<tr>
<td>ipOutSwitchIPv6</td>
<td>Probe that fires whenever a connection changes from using IPv4 to using IPv6 as its IP protocol.</td>
</tr>
<tr>
<td>ipReasmDuplicates</td>
<td>Probe that fires whenever the IP reassembly algorithm determines that an IP fragment contains only previously received data.</td>
</tr>
<tr>
<td>ipReasmFails</td>
<td>Probe that fires whenever any failure is detected by the IP reassembly algorithm. This probe does not necessarily fire for every discarded IP fragment because some algorithms, notably the algorithm in RFC 815, can lose track of fragments by combining them as they are received.</td>
</tr>
<tr>
<td>ipReasmOKs</td>
<td>Probe that fires whenever an IP datagram is successfully reassembled.</td>
</tr>
<tr>
<td>ipReasmPartDups</td>
<td>Probe that fires whenever the IP reassembly algorithm determines that an IP fragment contains both some previously received data and some new data.</td>
</tr>
<tr>
<td>ipReasmReqds</td>
<td>Probe that fires whenever an IP fragment is received that needs to be reassembled.</td>
</tr>
</tbody>
</table>
Table 28.4: IPsec mib Probes

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipsecInFailed</td>
<td>Probe that fires whenever a received packet is dropped because it fails to match the specified IPsec policy.</td>
</tr>
<tr>
<td>ipsecInSucceeded</td>
<td>Probe that fires whenever a received packet matches the specified IPsec policy and processing is allowed to continue.</td>
</tr>
</tbody>
</table>

Table 28.5: IPv6 mib Probes

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipv6IfIcmpBadHoplimit</td>
<td>Probe that fires whenever an ICMPv6 neighbor discovery protocol message is received that is found to have a Hop Limit less than the defined maximum. Such messages might not have originated from a neighbor, and are therefore discarded.</td>
</tr>
<tr>
<td>ipv6IfIcmpInAdminProhibs</td>
<td>Probe that fires whenever an ICMPv6 Destination Unreachable (Communication Administratively Prohibited) message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInBadNeighborAdvertisements</td>
<td>Probe that fires whenever an ICMPv6 Neighbor Advertisement message is received that is malformed in some way.</td>
</tr>
<tr>
<td>ipv6IfIcmpInBadNeighborSolicitations</td>
<td>Probe that fires whenever an ICMPv6 Neighbor Solicit message is received that is malformed in some way.</td>
</tr>
<tr>
<td>ipv6IfIcmpInBadRedirects</td>
<td>Probe that fires whenever an ICMPv6 Redirect message is received that is malformed in some way.</td>
</tr>
<tr>
<td>ipv6IfIcmpInDestUnreachs</td>
<td>Probe that fires whenever an ICMPv6 Destination Unreachable message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInEchoReplies</td>
<td>Probe that fires whenever an ICMPv6 Echo Reply message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInEchos</td>
<td>Probe that fires whenever an ICMPv6 Echo request message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInErrors</td>
<td>Probe that fires whenever an ICMPv6 message is received that is determined to have an ICMPv6-specific error (such as bad ICMPv6 checksum, bad length, and the like).</td>
</tr>
<tr>
<td>ipv6IfIcmpInGroupMembBadQueries</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Query message is received that is malformed in some way.</td>
</tr>
<tr>
<td>ipv6IfIcmpInGroupMembBadReports</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Report message is received that is malformed in some way.</td>
</tr>
<tr>
<td>MIB</td>
<td>Description</td>
</tr>
<tr>
<td>-----</td>
<td>-------------</td>
</tr>
<tr>
<td>ipv6IfIcmpInGroupMembOurReports</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Report message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInGroupMembQueries</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Query message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInGroupMembReductions</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Reduction message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInGroupMembResponses</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Response message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInGroupMembTotal</td>
<td>Probe that fires whenever an ICMPv6 multicast listener discovery message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInMsgs</td>
<td>Probe that fires whenever an ICMPv6 message is received. When this probe fires, the ipv6IfIcmpInErrors probe might also fire if the message has an ICMPv6-specific error.</td>
</tr>
<tr>
<td>ipv6IfIcmpInNeighborAdvertisements</td>
<td>Probe that fires whenever an ICMPv6 Neighbor Advertisement message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInNeighborSolicits</td>
<td>Probe that fires whenever an ICMPv6 Neighbor Solicit message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInOverflows</td>
<td>Probe that fires whenever an ICMPv6 message is received, but that message is subsequently dropped due to lack of buffer space.</td>
</tr>
<tr>
<td>ipv6IfIcmpInParmProblems</td>
<td>Probe that fires whenever an ICMPv6 Parameter Problem message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInRedirects</td>
<td>Probe that fires whenever an ICMPv6 Redirect message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInRouterAdvertisements</td>
<td>Probe that fires whenever an ICMPv6 Router Advertisement message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInRouterSolicits</td>
<td>Probe that fires whenever an ICMPv6 Router Solicit message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpInTimeExcds</td>
<td>Probe that fires whenever an ICMPv6 Time Exceeded message is received.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutAdminProhibs</td>
<td>Probe that fires whenever an ICMPv6 Destination Unreachable (Communication Administratively Prohibited) message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutDestUnreachs</td>
<td>Probe that fires whenever an ICMPv6 Destination Unreachable message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutEchoReplies</td>
<td>Probe that fires whenever an ICMPv6 Echo Reply message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutEchos</td>
<td>Probe that fires whenever an ICMPv6 Echo message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutErrors</td>
<td>Probe that fires whenever an ICMPv6 message is not sent due to problems discovered within ICMPv6, such as a lack of buffers. This probe will not fire if errors are discovered outside the ICMPv6 layer, such as the inability of IPv6 to route the resulting datagram.</td>
</tr>
</tbody>
</table>
### Table 28.5: (continued)

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipv6IfIcmpOutGroupMembQueries</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Query message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutGroupMembReductions</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Reduction message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutGroupMembResponses</td>
<td>Probe that fires whenever an ICMPv6 Group Membership Response message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutMsgs</td>
<td>Probe that fires whenever an ICMPv6 message is sent. When this probe fires, the ipv6IfIcmpOutErrors probe might also fire if the message has ICMPv6-specific errors.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutNeighborAdvertisements</td>
<td>Probe that fires whenever an ICMPv6 Neighbor Advertisement message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutNeighborSolicits</td>
<td>Probe that fires whenever an ICMPv6 Neighbor Solicitation message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutParmProblems</td>
<td>Probe that fires whenever an ICMPv6 Parameter Problem message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutPktTooBigs</td>
<td>Probe that fires whenever an ICMPv6 Packet Too Big message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutRedirects</td>
<td>Probe that fires whenever an ICMPv6 Redirect message is sent. For a host, this probe will never fire, because hosts do not send redirects.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutRouterAdvertisements</td>
<td>Probe that fires whenever an ICMPv6 Router Advertisement message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutRouterSolicits</td>
<td>Probe that fires whenever an ICMPv6 Router Solicit message is sent.</td>
</tr>
<tr>
<td>ipv6IfIcmpOutTimeExcds</td>
<td>Probe that fires whenever an ICMPv6 Time Exceeded message is sent.</td>
</tr>
<tr>
<td>ipv6InAddrErrors</td>
<td>Probe that fires whenever an input datagram is discarded because the IPv6 address in their IPv6 header’s destination field is not a valid address to be received by this entity. This probe will fire for invalid addresses (for example, ::0) and for unsupported addresses (for example, addresses with unallocated prefixes). For machines that are not configured to act as IPv6 routers and therefore do not forward datagrams, this probe will fire for datagrams discarded because the destination address was not a local address.</td>
</tr>
<tr>
<td>ipv6InDelivers</td>
<td>Probe that fires whenever an input datagram is successfully delivered to IPv6 user-protocols (including ICMPv6).</td>
</tr>
<tr>
<td>ipv6InDiscards</td>
<td>Probe that fires whenever an input IPv6 datagram is discarded for reasons unrelated to the packet (for example, for lack of buffer space). This probe does not fire for any datagram discarded while awaiting reassembly.</td>
</tr>
<tr>
<td>MIB Provider</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td></td>
</tr>
</tbody>
</table>

Table 28.5: (continued)

<table>
<thead>
<tr>
<th>MIB</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipv6InHdrErrors</td>
<td>Probe that fires whenever an input datagram is discarded due to an error in its IPv6 header, including a version number mismatch, a format error, an exceeded hop count, an error discovered in processing IPv6 options, and the like.</td>
</tr>
<tr>
<td>ipv6InIPv4</td>
<td>Probe that fires whenever an IPv4 packet erroneously arrives on an IPv6 queue.</td>
</tr>
<tr>
<td>ipv6InMcastPkts</td>
<td>Probe that fires whenever a multicast IPv6 packet is received.</td>
</tr>
<tr>
<td>ipv6InNoRoutes</td>
<td>Probe that fires whenever a routed IPv6 datagram is discarded because no route could be found to transmit it to its destination. This probe will only fire for packets that have originated externally.</td>
</tr>
<tr>
<td>ipv6InReceives</td>
<td>Probe that fires whenever an IPv6 datagram is received from an interface, even if that datagram is received in error.</td>
</tr>
<tr>
<td>ipv6InTooBigErrors</td>
<td>Probe that fires whenever a fragment is received that is larger than the maximum fragment size.</td>
</tr>
<tr>
<td>ipv6InTruncatedPkts</td>
<td>Probe that fires whenever an input datagram is discarded because the datagram frame didn’t carry enough data.</td>
</tr>
<tr>
<td>ipv6InUnknownProtos</td>
<td>Probe that fires whenever a locally-addressed IPv6 datagram is received successfully but subsequently discarded because of an unknown or unsupported protocol.</td>
</tr>
<tr>
<td>ipv6OutDiscards</td>
<td>Probe that fires whenever an output IPv6 datagram is discarded for reasons unrelated to the packet (for example, for lack of buffer space). This probe will fire for a packet counted in the ipv6OutForwDatagrams MIB counter if the packet meets such a (discretionary) discard criterion.</td>
</tr>
<tr>
<td>ipv6OutForwDatagrams</td>
<td>Probe that fires whenever a datagram is received that does not have this machine as its final IPv6 destination, and an attempt is made to find a route to forward the datagram to that final destination. On a machine that does not act as an IPv6 router, this probe will only fire for those packets that are source-routed through the machine, and for which the source-route option processing was successful.</td>
</tr>
<tr>
<td>ipv6OutFragCreates</td>
<td>Probe that fires whenever an IPv6 datagram fragment is generated as a result of fragmentation.</td>
</tr>
<tr>
<td>ipv6OutFragFails</td>
<td>Probe that fires whenever an IPv6 datagram is discarded because it could not be fragmented, for example, because its Don’t Fragment flag was set.</td>
</tr>
<tr>
<td>ipv6OutFragOKs</td>
<td>Probe that fires whenever an IPv6 datagrams has been successfully fragmented.</td>
</tr>
</tbody>
</table>
Table 28.5: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipv6OutIPv4</td>
<td>Probe that fires whenever an IPv6 packet is sent over an IPv4 connection.</td>
</tr>
<tr>
<td>ipv6OutMcastPkts</td>
<td>Probe that fires whenever a multicast packet is sent.ian IPv6 datagram is discarded because no route could be found to transmit it to its destination. This probe will <em>not</em> fire for packets that have originated externally.</td>
</tr>
<tr>
<td>ipv6OutNoRoutes</td>
<td>Probe that fires whenever an IPv6 datagram is supplied to IPv6 for transmission from local IPv6 user protocols (including ICMPv6). This probe will not fire for any packet counted in the ipv6ForwDatagrams MIB counter.</td>
</tr>
<tr>
<td>ipv6OutRequests</td>
<td>Probe that fires whenever an IPv6 datagram is supplied to IPv6 for transmission from local IPv6 user protocols (including ICMPv6). This probe will not fire for any packet counted in the ipv6ForwDatagrams MIB counter.</td>
</tr>
<tr>
<td>ipv6OutSwitchIPv4</td>
<td>Probe that fires whenever a connection changes from using IPv6 to using IPv4 as its IP protocol.</td>
</tr>
<tr>
<td>ipv6ReasmDuplicates</td>
<td>Probe that fires whenever the IPv6 reassembly algorithm determines that an IPv6 fragment contains only previously received data.</td>
</tr>
<tr>
<td>ipv6ReasmFails</td>
<td>Probe that fires whenever a failure is detected by the IPv6 reassembly algorithm. This probe does not necessarily fire for every discarded IPv6 fragment since some algorithms can lose track of fragments by combining them as they are received.</td>
</tr>
<tr>
<td>ipv6ReasmOKs</td>
<td>Probe that fires whenever an IPv6 datagram is successfully reassembled.</td>
</tr>
<tr>
<td>ipv6ReasmPartDups</td>
<td>Probe that fires whenever the IPv6 reassembly algorithm determines that an IPv6 fragment contains both some previously received data and some new data.</td>
</tr>
<tr>
<td>ipv6ReasmReqds</td>
<td>Probe that fires whenever an IPv6 fragment is received that needs to be reassembled.</td>
</tr>
</tbody>
</table>

Table 28.6: Raw IP mib Probes

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rawipInCksumErrs</td>
<td>Probe that fires whenever a raw IP packet is received that has a bad IP checksum.</td>
</tr>
<tr>
<td>rawipInDatagrams</td>
<td>Probe that fires whenever a raw IP packet is received.ian IPv6 datagram is discarded because no route could be found to transmit it to its destination. This probe will <em>not</em> fire for packets that have originated externally.</td>
</tr>
<tr>
<td>rawipInErrors</td>
<td>Probe that fires whenever a raw IP packet is received that is malformed in some way.</td>
</tr>
<tr>
<td>rawipInOverflows</td>
<td>Probe that fires whenever a raw IP packet is received, but that packet is subsequently dropped due to lack of buffer space.</td>
</tr>
<tr>
<td>rawipOutDatagrams</td>
<td>Probe that fires whenever a raw IP packet is sent.</td>
</tr>
<tr>
<td>rawipOutErrors</td>
<td>Probe that fires whenever a raw IP packet is not sent due to some error condition, typically because the raw IP packet was malformed in some way.</td>
</tr>
</tbody>
</table>
Table 28.7: SCTP mib Probes

<table>
<thead>
<tr>
<th>mib Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>sctpAborted</code></td>
<td>Probe that fires whenever an SCTP association has made a direct transition to the CLOSED state from any state using the ABORT primitive, denoting ungraceful termination of the association.</td>
</tr>
<tr>
<td><code>sctpActiveEstab</code></td>
<td>Probe that fires whenever an SCTP association has made a direct transition to the ESTABLISHED state from the COOKIE-ECHOED state, denoting that the upper layer has initiated the association attempt.</td>
</tr>
<tr>
<td><code>sctpChecksumError</code></td>
<td>Probe that fires whenever an SCTP packet is received from peers with an invalid checksum.</td>
</tr>
<tr>
<td><code>sctpCurrEstab</code></td>
<td>Probe that fires whenever an SCTP association is tallied as a part of reading the <code>sctpCurrEstab</code> MIB counter. An SCTP association is tallied if its current state is ESTABLISHED, SHUTDOWN-RECEIVED, or SHUTDOWN-PENDING.</td>
</tr>
<tr>
<td><code>sctpFragUsrMsgs</code></td>
<td>Probe that fires whenever a user message has to be fragmented because of the MTU.</td>
</tr>
<tr>
<td><code>sctpInClosed</code></td>
<td>Probe that fires whenever data is received on a closed SCTP association.</td>
</tr>
<tr>
<td><code>sctpInCtrlChunks</code></td>
<td>Probe that fires whenever the <code>sctpInCtrlChunks</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in args[0].</td>
</tr>
<tr>
<td><code>sctpInDupAck</code></td>
<td>Probe that fires whenever a duplicate ACK is received.</td>
</tr>
<tr>
<td><code>sctpInInvalidCookie</code></td>
<td>Probe that fires whenever an invalid cookie is received.</td>
</tr>
<tr>
<td><code>sctpInOrderChunks</code></td>
<td>Probe that fires whenever the <code>sctpInOrderChunks</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in args[0].</td>
</tr>
<tr>
<td><code>sctpInSCTPPkts</code></td>
<td>Probe that fires whenever the <code>sctpInSCTPPkts</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in args[0].</td>
</tr>
<tr>
<td><code>sctpInUnorderChunks</code></td>
<td>Probe that fires whenever the <code>sctpInUnorderChunks</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in args[0].</td>
</tr>
<tr>
<td><code>sctpListenDrop</code></td>
<td>Probe that fires whenever an incoming connection is dropped for any reason.</td>
</tr>
<tr>
<td><code>sctpOutAck</code></td>
<td>Probe that fires whenever a selective acknowledgement is sent.</td>
</tr>
<tr>
<td><code>sctpOutAckDelayed</code></td>
<td>Probe that fires whenever delayed acknowledgement processing is performed for an SCTP association. Any acknowledgements sent as a part of delayed acknowledgement processing will cause the <code>sctpOutAck</code> probe to fire.</td>
</tr>
<tr>
<td><code>sctpOutCtrlChunks</code></td>
<td>Probe that fires whenever the <code>sctpOutCtrlChunks</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in args[0].</td>
</tr>
</tbody>
</table>
Table 28.7: (continued)

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>sctpOutOfBlue</td>
<td>Probe that fires whenever an otherwise correct SCTP packet is received for which the receiver is not able to identify the association to which the packet belongs.</td>
</tr>
<tr>
<td>sctpOutOrderChunks</td>
<td>Probe that fires whenever the <code>sctpOutOrderChunks</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in <code>args[0]</code>.</td>
</tr>
<tr>
<td>sctpOutSCTPPkts</td>
<td>Probe that fires whenever the <code>sctpOutSCTPPkts</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in <code>args[0]</code>.</td>
</tr>
<tr>
<td>sctpOutUnorderChunks</td>
<td>Probe that fires whenever the <code>sctpOutUnorderChunks</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in <code>args[0]</code>.</td>
</tr>
<tr>
<td>sctpOutWinProbe</td>
<td>Probe that fires whenever a window probe is sent.</td>
</tr>
<tr>
<td>sctpOutWinUpdate</td>
<td>Probe that fires whenever a window update is sent.</td>
</tr>
<tr>
<td>sctpPassiveEstab</td>
<td>Probe that fires whenever SCTP associations have made a direct transition to the ESTABLISHED state from the CLOSED state. The remote endpoint has initiated the association attempt.</td>
</tr>
<tr>
<td>sctpReasmUsrMsgs</td>
<td>Probe that fires whenever the <code>sctpReasmUsrMsgs</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in <code>args[0]</code>.</td>
</tr>
<tr>
<td>sctpRetransChunks</td>
<td>Probe that fires whenever the <code>sctpRetransChunks</code> MIB counter is updated, either because the MIB counter is explicitly queried or because an SCTP connection is closed. The value by which the MIB counter is to be increased is in <code>args[0]</code>.</td>
</tr>
<tr>
<td>sctpShutdowns</td>
<td>Probe that fires whenever an SCTP association makes the direct transition to the CLOSED state from either the SHUTDOWN-SENT state or the SHUTDOWN-ACK-SENT state, denoting graceful termination of the association.</td>
</tr>
<tr>
<td>sctpTimHeartBeatDrop</td>
<td>Probe that fires whenever an SCTP association is aborted due to failure to receive a heartbeat acknowledgement.</td>
</tr>
<tr>
<td>sctpTimHeartBeatProbe</td>
<td>Probe that fires whenever an SCTP heartbeat is sent.</td>
</tr>
<tr>
<td>sctpTimRetrans</td>
<td>Probe that fires whenever timer-based retransmit processing is performed on an association.</td>
</tr>
<tr>
<td>sctpTimRetransDrop</td>
<td>Probe that fires whenever prolonged failure to perform timer-based retransmission results in the association being aborted.</td>
</tr>
</tbody>
</table>

Table 28.8: TCP mib Probes

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>tcpActiveOpens</td>
<td>Probe that fires whenever a TCP connection makes a direct transition from the CLOSED state to the SYN_SENT state.</td>
</tr>
</tbody>
</table>
Table 28.8: (continued)

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>tcpAttemptFails</td>
<td>Probe that fires whenever a TCP connection makes a direct transition to the CLOSED state from either the SYN_SENT state or the SYN_RCVD state and whenever a TCP connection makes a direct transition to the LISTEN state from the SYN_RCVD state.</td>
</tr>
<tr>
<td>tcpCurrEstab</td>
<td>Probe that fires whenever a TCP connection is tallied as a part of reading the tcpCurrEstab MIB counter. A TCP connection is tallied if its current state is either ESTABLISHED or CLOSE_WAIT.</td>
</tr>
<tr>
<td>tcpEstabResets</td>
<td>Probe that fires whenever a TCP connection makes the direct transition to the CLOSED state from either the ESTABLISHED state or the CLOSE_WAIT state.</td>
</tr>
<tr>
<td>tcpHalfOpenDrop</td>
<td>Probe that fires whenever a connection is dropped due to a full queue of connections in the SYN_RCVD state.</td>
</tr>
<tr>
<td>tcpInAckBytes</td>
<td>Probe that fires whenever an ACK is received for previously sent data. The number of bytes acknowledged is passed in args[0].</td>
</tr>
<tr>
<td>tcpInAckSegs</td>
<td>Probe that fires whenever an ACK is received for a previously sent segment.</td>
</tr>
<tr>
<td>tcpInAckUnsent</td>
<td>Probe that fires whenever an ACK is received for an unsent segment. Adam J.</td>
</tr>
<tr>
<td>tcpInClosed</td>
<td>Probe that fires whenever data was received for a connection in a closing state.</td>
</tr>
<tr>
<td>tcpInDataDupBytes</td>
<td>Probe that fires whenever a segment is received such that all data in the segment has been previously received. The number of bytes in the duplicated segment is passed in args[0].</td>
</tr>
<tr>
<td>tcpInDataDupSegs</td>
<td>Probe that fires whenever a segment is received such that all data in the segment has been previously received. The number of bytes in the duplicated segment is passed in args[0].</td>
</tr>
<tr>
<td>tcpInDataInorderBytes</td>
<td>Probe that fires whenever data is received such that all data prior to the new data’s sequence number has been previously received. The number of bytes received in-order is passed in args[0].</td>
</tr>
<tr>
<td>tcpInDataInorderSegs</td>
<td>Probe that fires whenever a segment is received such that all data prior to the new segment’s sequence number has been previously received.</td>
</tr>
<tr>
<td>tcpInDataPartDupBytes</td>
<td>Probe that fires whenever a segment is received such that some of the data in the segment has been previously received, but some of the data in the segment is new. The number of duplicate bytes is passed in args[0].</td>
</tr>
<tr>
<td>tcpInDataPartDupSegs</td>
<td>Probe that fires whenever a segment is received such that some of the data in the segment has been previously received, but some of the data in the segment is new. The number of duplicate bytes is passed in args[0].</td>
</tr>
<tr>
<td>tcpInDataPastWinBytes</td>
<td>Probe that fires whenever data is received that lies past the current receive window. The number of bytes is in args[0].</td>
</tr>
<tr>
<td>tcpInDataPastWinSegs</td>
<td>Probe that fires whenever a segment is received that lies past the current receive window.</td>
</tr>
<tr>
<td>Probe Name</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>tcpInDataUnorderBytes</td>
<td>Probe that fires whenever data is received such that some data prior to the new data’s sequence number is missing. The number of bytes received unordered is passed in \texttt{args[0]}.</td>
</tr>
<tr>
<td>tcpInDataUnorderSegs</td>
<td>Probe that fires whenever a segment is received such that some data prior to the new data’s sequence number is missing.</td>
</tr>
<tr>
<td>tcpInDupAck</td>
<td>Probe that fires whenever a duplicate ACK is received.</td>
</tr>
<tr>
<td>tcpInErrs</td>
<td>Probe that fires whenever a TCP error (for example, a bad TCP checksum) is found on a received segment.</td>
</tr>
<tr>
<td>tcpInSegs</td>
<td>Probe that fires whenever a segment is received, even if that segment is later found to have an error that prevents further processing.</td>
</tr>
<tr>
<td>tcpInWinProbe</td>
<td>Probe that fires whenever a window probe is received.</td>
</tr>
<tr>
<td>tcpInWinUpdate</td>
<td>Probe that fires whenever a window update is received.</td>
</tr>
<tr>
<td>tcpListenDrop</td>
<td>Probe that fires whenever an incoming connection is dropped due to a full listen queue.</td>
</tr>
<tr>
<td>tcpListenDropQ0</td>
<td>Probe that fires whenever a connection is dropped due to a full queue of connections in the SYN_RCVD state.</td>
</tr>
<tr>
<td>tcpOutAck</td>
<td>Probe that fires whenever an ACK is sent.</td>
</tr>
<tr>
<td>tcpOutAckDelayed</td>
<td>Probe that fires whenever an ACK is sent after having been initially delayed.</td>
</tr>
<tr>
<td>tcpOutControl</td>
<td>Probe that fires whenever a SYN, FIN, or RST is sent.</td>
</tr>
<tr>
<td>tcpOutDataBytes</td>
<td>Probe that fires whenever data is sent. The number of bytes sent is in \texttt{args[0]}.</td>
</tr>
<tr>
<td>tcpOutDataSegs</td>
<td>Probe that fires whenever a segment is sent.</td>
</tr>
<tr>
<td>tcpOutFastRetrans</td>
<td>Probes that fires whenever a segment is retransmitted as part of the fast retransmit algorithm.</td>
</tr>
<tr>
<td>tcpOutRsts</td>
<td>Probe that fires whenever a segment is sent with the RST flag set.</td>
</tr>
<tr>
<td>tcpOutSackRetransSegs</td>
<td>Probe that fires whenever a segment is retransmitted on a connection that has selective acknowledgement enabled.</td>
</tr>
<tr>
<td>tcpOutSegs</td>
<td>Probe that fires whenever a segment is sent that contains at least one non-retransmitted byte.</td>
</tr>
<tr>
<td>tcpOutUrg</td>
<td>Probe that fires whenever a segment is sent with the URG flag set, and with a valid urgent pointer.</td>
</tr>
<tr>
<td>tcpOutWinProbe</td>
<td>Probe that fires whenever a window probe is sent.</td>
</tr>
<tr>
<td>tcpOutWinUpdate</td>
<td>Probe that fires whenever a window update is sent.</td>
</tr>
<tr>
<td>tcpPassiveOpens</td>
<td>Probe that fires whenever a TCP connections have made a direct transition to the SYN_RCVD state from the LISTEN state.</td>
</tr>
<tr>
<td>tcpRetransBytes</td>
<td>Probe that fires whenever data is retransmitted. The number of bytes retransmitted is in \texttt{args[0]}.</td>
</tr>
<tr>
<td>tcpRetransSegs</td>
<td>Probe that fires whenever a segment is sent that contains one or more retransmitted bytes.</td>
</tr>
<tr>
<td>tcpRttNoUpdate</td>
<td>Probe that fires whenever data was received, but there was no timestamp information available with which to update the RTT.</td>
</tr>
<tr>
<td>tcpRttUpdate</td>
<td>Probe that fires whenever data was received containing the timestamp information necessary to update the RTT.</td>
</tr>
<tr>
<td>tcpTimKeepalive</td>
<td>Probe that fires whenever timer-based keep-alive processing is performed on a connection.</td>
</tr>
</tbody>
</table>
Table 28.8: (continued)

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>tcpTimKeepaliveDrop</td>
<td>Probe that fires whenever keep-alive processing results in termination of a connection.</td>
</tr>
<tr>
<td>tcpTimKeepaliveProbe</td>
<td>Probe that fires whenever a keep-alive probe is sent out as a part of keep-alive processing.</td>
</tr>
<tr>
<td>tcpTimRetrans</td>
<td>Probe that fires whenever timer-based retransmit processing is performed on a connection.</td>
</tr>
<tr>
<td>tcpTimRetransDrop</td>
<td>Probe that fires whenever prolonged failure to perform timer-based retransmission results in termination of the connection.</td>
</tr>
</tbody>
</table>

Table 28.9: UDP mib Probes

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>udpInCksumErrs</td>
<td>Probe that fires whenever a datagram is discarded due to a bad UDP checksum.</td>
</tr>
<tr>
<td>udpInDatagrams</td>
<td>Probe that fires whenever a UDP datagram is received.</td>
</tr>
<tr>
<td>udpInErrors</td>
<td>Probe that fires whenever a UDP datagram is received, but is discarded due to either a malformed packet header or the failure to allocate an internal buffer.</td>
</tr>
<tr>
<td>udpInOverflows</td>
<td>Probe that fires whenever a UDP datagram is received, but subsequently dropped due to lack of buffer space.</td>
</tr>
<tr>
<td>udpNoPorts</td>
<td>Probe that fires whenever a UDP datagram is received on a port to which no socket is bound.</td>
</tr>
<tr>
<td>udpOutDatagrams</td>
<td>Probe that fires whenever a UDP datagram is sent.</td>
</tr>
<tr>
<td>udpOutErrors</td>
<td>Probe that fires whenever a UDP datagram is not sent due to some error condition, typically because the datagram was malformed in some way.</td>
</tr>
</tbody>
</table>

28.2 Arguments

The sole argument for each mib probe has the same semantics: args[0] contains the value with which the counter is to be incremented. For most mib probes, args[0] always contains the value 1, but for some probes args[0] may take arbitrary positive values. For these probes, the meaning of args[0] is noted in the probe description.

28.3 Stability

The mib provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
### 28.3. Stability

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 29

fpuinfo Provider

The fpuinfo provider makes available probes that correspond to the simulation of floating-point instructions on SPARC microprocessors. While most floating-point instructions are executed in hardware, some floating-point operations trap into the operating system for simulation. The conditions under which floating-point operations require operating system simulation are specific to a microprocessor implementation. The operations that require simulation are rare. However, if an application uses one of these operations frequently, the effect on performance could be severe. The fpuinfo provider enables rapid investigation of floating-point simulation seen through either kstat(1M) and the fpu_info kernel statistic or trapstat(1M) and the fp-xcp-other trap.

29.1 Probes

The fpuinfo provider makes available a probe for each type of floating-point instruction that can be simulated. The fpuinfo provider has a Name Stability of CPU; the names of the probes are specific to a microprocessor implementation, and might not be available on different microprocessors within the same family. For example, some of the probes listed might only be available on UltraSPARC-III and not UltraSPARC-III+ or vice versa.

The fpuinfo probes are described in Table 29.1.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>fpu_sim_fitoq</td>
<td>Probe that fires whenever an fitoq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fitod</td>
<td>Probe that fires whenever an fitod instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fitos</td>
<td>Probe that fires whenever an fitsos instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fxtoq</td>
<td>Probe that fires whenever an fxtoq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fxtod</td>
<td>Probe that fires whenever an fxtod instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fxtos</td>
<td>Probe that fires whenever an fxtos instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fqtox</td>
<td>Probe that fires whenever an fqtox instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fdtox</td>
<td>Probe that fires whenever an fdtox instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fstoi</td>
<td>Probe that fires whenever an fstoi instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fstox</td>
<td>Probe that fires whenever an fstox instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fqtoi</td>
<td>Probe that fires whenever an fqtoi instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fdtoi</td>
<td>Probe that fires whenever an fdtoi instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fstoi</td>
<td>Probe that fires whenever an fstoi instruction is simulated by the kernel.</td>
</tr>
</tbody>
</table>
Table 29.1: (continued)

<table>
<thead>
<tr>
<th>Probe Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>fpu_sim_fsqrtrq</td>
<td>Probe that fires whenever an fsqrtrq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fsqrtd</td>
<td>Probe that fires whenever an fsqrtd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fsqrts</td>
<td>Probe that fires whenever an fsqrts instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fcmpeq</td>
<td>Probe that fires whenever an fcmpeq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fcmped</td>
<td>Probe that fires whenever an fcmped instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fcmpes</td>
<td>Probe that fires whenever an fcmpes instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fcmpq</td>
<td>Probe that fires whenever an fcmpq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fcmpd</td>
<td>Probe that fires whenever an fcmpd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fcmps</td>
<td>Probe that fires whenever an fcmps instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fdivq</td>
<td>Probe that fires whenever an fdivq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fdivd</td>
<td>Probe that fires whenever an fdivd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fdivs</td>
<td>Probe that fires whenever an fdivs instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fdmulx</td>
<td>Probe that fires whenever an fdmulx instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fmuld</td>
<td>Probe that fires whenever an fmuld instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fmulq</td>
<td>Probe that fires whenever an fmulq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fmuls</td>
<td>Probe that fires whenever an fmuls instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fsubq</td>
<td>Probe that fires whenever an fsubq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fsubd</td>
<td>Probe that fires whenever an fsubd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fsubs</td>
<td>Probe that fires whenever an fsubs instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_faddq</td>
<td>Probe that fires whenever an faddq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_faddd</td>
<td>Probe that fires whenever an faddd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fadds</td>
<td>Probe that fires whenever an fadds instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fnegd</td>
<td>Probe that fires whenever an fnegd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fnegq</td>
<td>Probe that fires whenever an fnegq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fnegs</td>
<td>Probe that fires whenever an fnegs instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fabsd</td>
<td>Probe that fires whenever an fabsd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fabsq</td>
<td>Probe that fires whenever an fabsq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fabss</td>
<td>Probe that fires whenever an fabss instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fmovd</td>
<td>Probe that fires whenever an fmovd instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_simfmovq</td>
<td>Probe that fires whenever an fmovq instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fmovs</td>
<td>Probe that fires whenever an fmovs instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fmovr</td>
<td>Probe that fires whenever an fmovr instruction is simulated by the kernel.</td>
</tr>
<tr>
<td>fpu_sim_fmovcc</td>
<td>Probe that fires whenever an fmovcc instruction is simulated by the kernel.</td>
</tr>
</tbody>
</table>
29.2 Arguments

There are no arguments to `fpuinfo` probes.

29.3 Stability

The `fpuinfo` provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>CPU</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>CPU</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>CPU</td>
</tr>
</tbody>
</table>
Chapter 30

pid Provider

The pid provider allows for tracing of the entry and return of a function in a user process as well as 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. To avoid inlining a function at compile time, consult the documentation for your compiler.

**Note**
The pid provider behaves unpredictably when it probes a function that uses function pointers to call a sub-function. You can explicitly place probes at the addresses of the function’s entry and return to analyze such functions.

30.1 Naming pid Probes

The pid provider actually defines a class of providers. Each process can potentially have its own associated pid provider. A process with ID 123, for example, would be traced by using the pid123 provider. For probes from one of these providers, the module portion of the probe description refers to an object loaded in the corresponding process’s address space. The following example uses mdb(1) to display a list of objects:

```
$ mdb -p 1234
Loading modules: [ ld.so.1 libc.so.1 ]
> ::objects
      BASE   LIMIT     SIZE  NAME
   10000 34000   24000 /usr/bin/csh
ff3c0000 ff3e8000  28000 /lib/ld.so.1
ff350000 ff37a000  2a000 /lib/libcurses.so.1
ff200000 ff2be000  2e000 /lib/libc.so.1
ff3a0000 ff3a2000  2000 /lib/libdl.so.1
ff320000 ff324000  4000 /platform/sun4u/lib/lib_csr.so.1
```
30. PID Provider

In the probe description, you name the object by the name of the file, not its full path name. You can also omit the .1 or so.1 suffix. All of the following examples name the same probe:

```
pid123:libc.so.1: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 alias a.out. The following two probe descriptions name the same probe:

```
pid123:csh:main:return
pid123:a.out:main:return
```

As with all anchored DTrace probes, the function field of the probe description names a function in the module field. A user application binary might have several names for the same function. For example, `mutex_lock` might be an alternate name for the function `pthread_mutex_lock` in `libc.so.1`. DTrace chooses one canonical name for such functions and uses that name internally. The following example shows how DTrace internally remaps module and function names to a canonical form:

```c
# dtrace -q -n pid101267:libc:mutex_lock:entry'{
    printf("%s:%s:%s:%s\n", probeprov, probemod, probefunc, probename);
}'
```

This automatic renaming means that the names of the probes you enable may be slightly different than those actually enabled. The canonical name will always be consistent between runs of DTrace on systems running the same illumos release.

See Chapter 33 for examples of how to use the pid provider effectively.

### 30.2 Function Boundary Probes

The pid provider enables you to trace function entry and return in user programs just as the FBT provider provides that capability for the kernel. Most of the examples in this manual that use the FBT provider to trace kernel function calls can be modified slightly to apply to user processes.

**entry Probes**

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.

**return Probes**

A return probes fires when the traced function returns or makes a tail call to another function. The value for `arg0` is the offset in the function of the return instruction; `arg1` holds the return value.

**Note**

Using `argN` returns the raw unfiltered values as type `int64_t`. The pid provider does not support the `args[N]` format.
30.3 Function Offset Probes

The `pid` provider lets you trace any instruction in a function. For example to trace the instruction 4 bytes into a function `main`, you could use a command similar to the following example:

```
pid123:a.out:main:4
```

Every time the program executes the instruction at address `main+4`, this probe will be activated. The arguments for offset probes are undefined. The `uregs[]` array will help you examine process state at these probe sites. See Section 33.5 for more information.

30.4 Stability

The `pid` provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
Chapter 31

plockstat Provider

The plockstat provider makes available probes that can be used to observe the behavior of user-level synchronization primitives including lock contention and hold times. The plockstat(1M) command is a DTrace consumer that uses the plockstat provider to gather data on user-level locking events.

31.1 Overview

The plockstat provider makes available probes for the following types of events:

Contention Events

These probes correspond to contention on a user-level synchronization primitive, and fire when a thread is forced to wait for a resource to become available. illumos is generally optimized for the non-contention case, so prolonged contention is not expected; these probes should be used to understand those cases where contention does arise. Because contention is designed to be (relatively) rare, enabling contention-event probes generally doesn’t have a serious probe effect; they can be enabled without concern for substantially affecting performance.

Hold Events

These probes correspond to acquiring, releasing or otherwise manipulating a user-level synchronization primitive. As such, these probes can be used to answer arbitrary questions about the way user-level synchronization primitives are manipulated. Because applications typically acquire and release synchronization primitives very often, enabling hold-event probes can have a greater probe effect than enabling contention-event probes. While the probe effect induced by enabling them can be substantial, it is not pathological; they may still be enabled with confidence on production applications.

Error Events

These probes correspond to any kind of anomalous behavior encountered when acquiring or releasing a user-level synchronization primitive. These events can be used to detect errors encountered while a thread is blocking on a user-level synchronization primitive. Error events should be extremely uncommon so enabling them shouldn’t induce a serious probe effect.
31.2 Mutex Probes

Mutexes enforce mutual exclusion to critical sections. When a thread attempts to acquire a mutex held by another thread using `mutex_lock(3C)` or `pthread_mutex_lock(3C)`, it will determine if the owning thread is running on a different CPU. If it is, the acquiring thread will *spin* for a short while waiting for the mutex to become available. If the owner is not executing on another CPU, the acquiring thread will *block*.

The four `plockstat` probes pertaining to mutexes are listed in Table 31.1. For each probe, `arg0` contains a pointer to the `mutex_t` or `pthread_mutex_t` structure (these are identical types) that represents the mutex.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>mutex-acquire</td>
<td>Hold event probe that fires immediately after a mutex is acquired. <code>arg1</code> contains a boolean value that indicates whether the acquisition was recursive on a recursive mutex. <code>arg2</code> indicates the number of iterations that the acquiring thread spent spinning on this mutex. <code>arg2</code> will be non-zero only if the <code>mutex-spin</code> probe fired on this mutex acquisition.</td>
</tr>
<tr>
<td>mutex-block</td>
<td>Contention event probe that fires before a thread blocks on a held mutex. Both <code>mutex-block</code> and <code>mutex-spin</code> might fire for a single lock acquisition.</td>
</tr>
<tr>
<td>mutex-spin</td>
<td>Contention event probe that fires before a thread begins spinning on a held mutex. Both <code>mutex-block</code> and <code>mutex-spin</code> might fire for a single lock acquisition.</td>
</tr>
<tr>
<td>mutex-release</td>
<td>Hold event probe that fires immediately after an mutex is released. <code>arg1</code> contains a boolean value that indicates whether the event corresponds to a recursive release on a recursive mutex.</td>
</tr>
<tr>
<td>mutex-error</td>
<td>Error event probe that fires when an error is encountered on a mutex operation. <code>arg1</code> is the <code>errno</code> value for the error encountered.</td>
</tr>
</tbody>
</table>

31.3 Reader/Writer Lock Probes

Reader/write locks permit multiple readers or a single writer, but not both, to be in a critical section at one time. These locks are typically used for structures that are searched more frequently than they are modified, or when threads spend substantial time in a critical section. Users interact with reader/writer locks using the illumos `rwlock(3C)` or POSIX `pthread_rwlock_init(3C)` interfaces.

The probes pertaining to readers/writer locks are in Table 31.2. For each probe, `arg0` contains a pointer to the `rwlock_t` or `pthread_rwlock_t` structure (these are identical types) that represents the adaptive lock. `arg1` contains a boolean value that indicates whether the operation was as a writer.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rw-acquire</td>
<td>Hold event probe that fires immediately after a readers/writer lock is acquired.</td>
</tr>
</tbody>
</table>
31.4 Stability

The `plockstat` provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 32

fasttrap Provider

The fasttrap provider allows for tracing at specific, preprogrammed user process locations. Unlike most other DTrace providers, the fasttrap provider is not designed for tracing system activity. Rather, this provider is meant as a way for DTrace consumers to inject information into the DTrace framework by activating the fasttrap probe.

32.1 Probes

The fasttrap provider makes available a single probe, fasttrap:::fasttrap, that fires whenever a user-level process makes a certain DTrace call into the kernel. The DTrace call to activate the probe is not publicly available at the present time.

32.2 Stability

The fasttrap provider uses DTrace’s stability mechanism to describe its stabilities, as shown in the following table. For more information about the stability mechanism, see Chapter 39.

<table>
<thead>
<tr>
<th>Element</th>
<th>Name stability</th>
<th>Data stability</th>
<th>Dependency class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provider</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Module</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Function</td>
<td>Private</td>
<td>Private</td>
<td>Unknown</td>
</tr>
<tr>
<td>Name</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
<tr>
<td>Arguments</td>
<td>Evolving</td>
<td>Evolving</td>
<td>ISA</td>
</tr>
</tbody>
</table>
Chapter 33

User Process Tracing

**DTrace** is an extremely powerful tool for understanding the behavior of user processes. DTrace can be invaluable when debugging, analyzing performance problems, or simply understanding the behavior of a complex application. This chapter focuses on the DTrace facilities relevant for tracing user process activity and provides examples to illustrate their use.

### 33.1 copyin and copyinstr Subroutines

DTrace’s interaction with processes is a little different than most traditional debuggers or observability tools. Many such tools appear to execute within the scope of the process, letting 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 illumos kernel. To access process data, a probe needs to use the `copyin` or `copyinstr` subroutines to copy user process data into the address space of the kernel.

For example, consider the following `write(2)` system call:

```d
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 passed to the `write(2)` system call:

```d
syscall::write:entry
{
    printf("%s", stringof(arg1)); /* incorrect use of arg1 */
}
```

If you try to run this script, DTrace will produce error messages similar to the following example:

```
dtrace: error on enabled probe ID 1 (ID 37: syscall::write:entry): \ninvalid address (0x10038a000) in action #1
```

The `arg1` variable, containing 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:

```d
syscall::write:entry
{
    printf("%s", copyinstr(arg1)); /* correct use of arg1 */
}
```
The output of this script shows all of the strings being passed to the write(2) system call. Occasionally, however, you might see irregular output similar to the following example:

```
0 37  write:entry madaï¿½ï¿½ï¿½ï¿½ï¿½
```

The copyinstr subroutine acts on an input argument that is the user address of a null-terminated ASCII string. However, buffers passed to the write(2) system call might refer to binary data rather than ASCII strings. To print only as much of the string as the caller intended, use the copyin subroutine, which takes a size as its second argument:

```c
syscall::write:entry
{
  printf("%s", stringof(copyin(arg1, arg2)));
}
```

Notice that the stringof operator is necessary so that DTrace properly converts the user data retrieved using copyin to a string. The use of stringof is not necessary when using copyinstr because this function always returns type string.

**Avoiding Errors**

The copyin and copyinstr subroutines cannot read from user addresses which have not yet been touched so even a valid address may cause an error if the page containing that address has not yet been faulted in by being accessed. Consider the following example:

```bash
# dtrace -n syscall::open:entry'{ trace(copyinstr(arg0)); }'
dtrace: description 'syscall::open:entry' matched 1 probe
CPU ID FUNCTION:NAME
dtrace: error on enabled probe ID 2 (ID 50: syscall::open:entry): invalid address (0x9af1b) in action #1 at DIF offset 52
```

In the above 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, wait for kernel or application to use the data before tracing it. For example, you might wait until the system call returns to apply copyinstr, as shown in the following example:

```bash
# 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
CPU ID FUNCTION:NAME
  2 51  open:return /dev/null
```

### 33.2 Eliminating dtrace(1M) Interference

If you trace every call to the write(2) system call, you will cause a cascade of output. Each call to write causes the dtrace(1M) 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. You can use a simple predicate to prevent these unwanted data from being traced:

```c
syscall::write:entry
/pid != $pid/
{
  printf("%s", stringof(copyin(arg1, arg2)));
}
```
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 the running of this script itself.

### 33.3 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 a process’s behavior, especially if the process seems to be spending a large amount of time executing or blocked in the kernel. You can use the prstat(1M) command to see where processes are spending time:

```
$ prstat -m -p 31337
  PID  USERNAME USR SYS TRP  TFL  DFL  LCK  SLP  LAT  VCX  ICX  SCL  SIG  PROCESS/NLWP
13499 user1 53 44 0.0 0.0 0.0 2.5 0.0 4K 24 9K 0 mystery/6
```

This example shows that the process 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 use a simple D program specified 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
```

```
open          1
lwp_park      2
times         4
fcntl         5
close         6
sicaction    6
read          10
ioctl         14
sigprocmask   106
write         1092
```

This report shows which system calls are being called most often, in this case, the write(2) system call. You can use the syscall provider to further examine the source of all the write system calls:

```
# dtrace -n syscall::write:entry'/pid == 31337/{ @writes[arg2] = 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
2048 |    | 0
```

285
The output shows that the process is executing many write system calls with a relatively small amount of data. This ratio could be the source of the performance problem for this particular process. This example illustrates a general methodology for investigating system call behavior.

### 33.4 ustack Action

Tracing a process thread’s stack at the time a particular probe is activated is often useful for examining a problem in more detail. The ustack action traces the user thread’s stack. If, for example, a process that opens many files occasionally fails in the open(2) system call, you can use the ustack action to discover the code path that executes the failed open:

```c
syscall::open:entry
/pid == $1/
{
    self->path = copyinstr(arg0);
}

syscall::open:return
/self->path != NULL && arg1 == -1/
{
    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 specified on the dtrace(1M) command-line:

```sh
# dtrace -s ./badopen.d 31337
dtrace: script './badopen.d' matched 2 probes
CPU ID FUNCTION:NAME
  0 40 open:return open for '/usr/lib/foo' failed
    libc.so.1__open+0x4
    libc.so.1open+0x6c
    420b0
tcsh'dosource+0xe0
tcsh'execute+0x978
tcsh'execute+0xba0
tcsh'process+0x50c
tcsh'main+0x1d54
tcsh'_start+0xdc
```

The ustack action records program counter (PC) values for the stack and dtrace(1M) resolves those PC values to symbol names by looking though the process’s symbol tables. If dtrace can’t resolve the PC value to a symbol, it will print 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 will be forced to display them as hexadecimal integers. To work around this limitation, specify a process of interest with the -c or -p option to dtrace. See Chapter 14 for details on these and other options. If the process ID or command is not known in advance, the following example D program that can be used to work around the limitation:

```c
/*
 * This example uses the open(2) system call probe, but this technique
 * is applicable to any script using the ustack() action where the stack
 * being traced is in a process that may exit soon.
*/
```
The above script stops a process just before it exits if the `ustack` action has been applied to a thread in that process. This technique ensures that the `dtrace` command will be able to resolve the PC values to symbolic names. Notice that the value of `stop_pids[pid]` is set to 0 after it has been used to clear the dynamic variable. Remember to set stopped processes running again using the `prun(1)` command or your system will accumulate many stopped processes.

### 33.5 `uregs[]` Array

The `uregs[]` array enables you to access individual user registers. The following tables list indices into the `uregs[]` array corresponding to each supported illumos system architecture.

**Table 33.1: SPARC `uregs[]` Constants**

<table>
<thead>
<tr>
<th>Constant</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_G0..R_G7</td>
<td>%g0..%g7 global registers</td>
</tr>
<tr>
<td>R_O0..R_O7</td>
<td>%o0..%o7 out registers</td>
</tr>
<tr>
<td>R_L0..R_L7</td>
<td>%l0..%l7 local registers</td>
</tr>
<tr>
<td>R_I0..R_I7</td>
<td>%i0..%i7 in registers</td>
</tr>
<tr>
<td>R_CCR</td>
<td>%ccr condition code register</td>
</tr>
<tr>
<td>R_PC</td>
<td>%pc program counter</td>
</tr>
<tr>
<td>R_NPC</td>
<td>%npc next program counter</td>
</tr>
<tr>
<td>R_Y</td>
<td>%y multiply/divide register</td>
</tr>
<tr>
<td>R_ASI</td>
<td>%asi address space identifier register</td>
</tr>
<tr>
<td>R_FPRS</td>
<td>%fprs floating-point registers state</td>
</tr>
</tbody>
</table>

**Table 33.2: x86 `uregs[]` Constants**

<table>
<thead>
<tr>
<th>Constant</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_CS</td>
<td>%cs</td>
</tr>
<tr>
<td>R_GS</td>
<td>%gs</td>
</tr>
<tr>
<td>R_ES</td>
<td>%es</td>
</tr>
<tr>
<td>R_DS</td>
<td>%ds</td>
</tr>
</tbody>
</table>
Table 33.2: (continued)

<table>
<thead>
<tr>
<th>Constant</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_EDI</td>
<td>%edi</td>
</tr>
<tr>
<td>R_ESI</td>
<td>%esi</td>
</tr>
<tr>
<td>R_EBP</td>
<td>%ebp</td>
</tr>
<tr>
<td>R_EAX</td>
<td>%eax</td>
</tr>
<tr>
<td>R_ESP</td>
<td>%esp</td>
</tr>
<tr>
<td>R_EAX</td>
<td>%eax</td>
</tr>
<tr>
<td>R_EBX</td>
<td>%ebx</td>
</tr>
<tr>
<td>R_ECX</td>
<td>%ecx</td>
</tr>
<tr>
<td>R_EDX</td>
<td>%edx</td>
</tr>
<tr>
<td>R_TRAPNO</td>
<td>%trapno</td>
</tr>
<tr>
<td>R_ERR</td>
<td>%err</td>
</tr>
<tr>
<td>R_EIP</td>
<td>%eip</td>
</tr>
<tr>
<td>R_CS</td>
<td>%cs</td>
</tr>
<tr>
<td>R_ERR</td>
<td>%err</td>
</tr>
<tr>
<td>R_EFL</td>
<td>%efl</td>
</tr>
<tr>
<td>R_UESP</td>
<td>%uesp</td>
</tr>
<tr>
<td>R_SS</td>
<td>%ss</td>
</tr>
</tbody>
</table>

On AMD64 platforms, the uregs array has the same content as it does on x86 platforms, plus the additional elements listed in the following table:

Table 33.3: AMD64 uregs[] Constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_RSP</td>
<td>%rsp</td>
</tr>
<tr>
<td>R_RFL</td>
<td>%rfl</td>
</tr>
<tr>
<td>R_RIP</td>
<td>%rip</td>
</tr>
<tr>
<td>R_RAX</td>
<td>%rax</td>
</tr>
<tr>
<td>R_RCX</td>
<td>%rcx</td>
</tr>
<tr>
<td>R_RDX</td>
<td>%rdx</td>
</tr>
<tr>
<td>R_RBX</td>
<td>%rbx</td>
</tr>
<tr>
<td>R_RBP</td>
<td>%rbp</td>
</tr>
<tr>
<td>R_RSI</td>
<td>%rsi</td>
</tr>
<tr>
<td>R_RDI</td>
<td>%rdi</td>
</tr>
<tr>
<td>R_R8</td>
<td>%r8</td>
</tr>
<tr>
<td>R_R9</td>
<td>%r9</td>
</tr>
<tr>
<td>R_R10</td>
<td>%r10</td>
</tr>
<tr>
<td>R_R11</td>
<td>%r11</td>
</tr>
<tr>
<td>R_R12</td>
<td>%r12</td>
</tr>
<tr>
<td>R_R13</td>
<td>%r13</td>
</tr>
<tr>
<td>R_R14</td>
<td>%r14</td>
</tr>
<tr>
<td>R_R15</td>
<td>%r15</td>
</tr>
</tbody>
</table>
The aliases listed in the following table can be used on all platforms:

Table 33.4: Common uregs[] Constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_PC</td>
<td>program counter register</td>
</tr>
<tr>
<td>R_SP</td>
<td>stack pointer register</td>
</tr>
<tr>
<td>R_R0</td>
<td>first return code</td>
</tr>
<tr>
<td>R_R1</td>
<td>second return code</td>
</tr>
</tbody>
</table>

### 33.6 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 found in your D programs. As a result, no pid probes are listed in the output of `dtrace -l` until you have enabled them yourself.

#### User Function Boundary Tracing

The simplest mode of operation for the pid provider is as the user space analogue to the fbt provider. The following example program traces all 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.

**Example 33.1: userfunc.d: Trace User Function Entry and Return**

```d
#pragma D option flowindent

pid$1::$2:entry
{
    self->trace = 1;
}

pid$1::$2:return
/self->trace/
{
    self->trace = 0;
}

pid$1:::entry,
pid$1:::return
/self->trace/
{
}
```
Type in the above example script and save it in a file named userfunc.d, and then chmod it to be executable. This script produces output similar to the following example:

```
# ./userfunc.d 15032 execute
```

```
dtrace: script './userfunc.d' matched 11594 probes
  0  -> execute
  0  -> execute
  0  <- Dfix
  0  -> s_strsave
  0  -> malloc
  0  <- malloc
  0  <- s_strsave
  0  -> set
  0  -> malloc
  0  <- malloc
  0  <- set
  0  -> setl
  0  -> tglob
  0  <- tglob
  0  <- setl
  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 Chapter 15) and the dtrace -c and -p options to create and grab processes of interest and instrument them using DTrace. For example, the following D script can be used to determine the distribution of function calls made to libc by a particular subject process:

```
# $target:libc.so::entry
{ }
```

To determine the distribution of such calls made by the date(1) command, save the script in a file named libc.d and execute 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

...```

---

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Tracing Arbitrary Instructions

You can use the pid provider to trace any instruction in any user function. Upon demand, the pid provider will create a probe for every instruction in a function. The name of each probe is the offset of its corresponding instruction in the function expressed as a hexadecimal integer. For example, to enable a probe associated with the instruction at offset 0x1c in function foo of module bar.so in the process with PID 123, you can 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 can use the command:

```
# dtrace -n pid123:bar.so:foo:
```

This 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, too late to reconstruct the code path. The following example demonstrates how to combine the pid provider with speculative tracing (see Chapter 13) to solve this problem by tracing every instruction in a function.

---

Example 33.2: errorpath.d: Trace User Function Call Error Path

```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 errorpath.d results in output similar to the following example:
```bash
# ./errorpath.d 100461 _chdir

```
```bash
dtrace: script './errorpath.d' matched 19 probes

<table>
<thead>
<tr>
<th>CPU ID</th>
<th>FUNCTION:NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 25253</td>
<td>_chdir:entry 81e08 6d140 ffbfc20 656c73 0</td>
</tr>
<tr>
<td>0 25253</td>
<td>_chdir:entry</td>
</tr>
<tr>
<td>0 25269</td>
<td>_chdir:0</td>
</tr>
<tr>
<td>0 25270</td>
<td>_chdir:4</td>
</tr>
<tr>
<td>0 25271</td>
<td>_chdir:8</td>
</tr>
<tr>
<td>0 25272</td>
<td>_chdir:c</td>
</tr>
<tr>
<td>0 25273</td>
<td>_chdir:10</td>
</tr>
<tr>
<td>0 25274</td>
<td>_chdir:14</td>
</tr>
<tr>
<td>0 25275</td>
<td>_chdir:18</td>
</tr>
<tr>
<td>0 25276</td>
<td>_chdir:1c</td>
</tr>
<tr>
<td>0 25277</td>
<td>_chdir:20</td>
</tr>
<tr>
<td>0 25278</td>
<td>_chdir:24</td>
</tr>
<tr>
<td>0 25279</td>
<td>_chdir:28</td>
</tr>
<tr>
<td>0 25280</td>
<td>_chdir:2c</td>
</tr>
<tr>
<td>0 25268</td>
<td>_chdir:return</td>
</tr>
</tbody>
</table>
```
Chapter 34

Statically Defined Tracing for User Applications

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.

34.1 Choosing the Probe Points

DTrace allows developers to embed static probe points in application code, including both complete applications and shared libraries. These probes can be enabled wherever the application or library is running, either in development or in 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 submitting a request and the web server responding to that 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 might 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. Will this 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 will discuss the details of how these decisions guide your static tracing definitions.

34.2 Adding Probes to an Application

DTrace probes for libraries and executables are defined in an ELF section in the corresponding application binary. This section describes how to define your probes, add them to your application source code, and augment 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 you choose will be 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 corresponding to this process would be myserv1203. In your .d source file, add a provider definition similar to the following example:

```d
provider myserv {
    ...
}
```

Next, add a definition for each probe and the corresponding arguments. The following example defines the two probes discussed in Section 34.1. The first probe has two arguments, both of type string, and the second probe has no arguments. The D compiler converts two consecutive underbars (__) in any probe name to a hyphen (-).

```d
provider myserv {
    probe query__receive(string, string);
    probe query__respond();
}
```

You should 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 Chapter 39 for more information on the DTrace stability attributes. Stability attributes are defined as shown in the following example:

```d
#pragma D attributes Evolving/Evolving/Common provider myserv
#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
```

```d
provider myserv {
    probe query__receive(string, string);
    probe query__respond();
}
```

Note
D scripts that use non-integer arguments from user added probes must use the copyin and copyin_str functions to retrieve those arguments. Please see Chapter 33 for more information.

Adding Probes to Application Code

Now that you have defined your probes in a .d file, you 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 a probe site, add a reference to the DTRACE_PROBE() macro defined in <sys/sdt.h> as shown in the following example:

```c
#include <sys/sdt.h>
...

void main_look(void)
{
    ...
    query = wait_for_new_query();
    DTRACE_PROBE2(myserv, query__receive, query->clientname, query->msg);
    process_query(query)
    ...
}
```

The suffix 2 in the macro name DTRACE_PROBE2 refers the number of arguments that are passed to the probe. The first two arguments to the probe macro are the provider name and probe name and must correspond to your D provider and probe definitions. The remaining macro arguments are the arguments assigned to the DTrace arg0..9 variables when the probes fires. Your application source code can contain multiple references to the same provider and probe name. If multiple references to the same probe are present in your source code, any of the macro references will cause the probe to fire.

### 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 together to create the finished application binary, as shown in the following example:

```
cc -c src1.c
cr -c src2.c
...
cr -o myserv src1.o src2.o ...
```

To include DTrace probe definitions in your application, add appropriate Makefile rules to your build process to execute the dtrace command as shown in the following example:

```
cr -c src1.c
cr -c src2.c
...
dtrace -G -32 -s myserv.d src1.o src2.o ...
cr -o myserv myserv.o src1.o src2.o ...
```

The dtrace command shown above post-processes the object files generated by the preceding compiler commands and generates the object file myserv.o from myserv.d and the other object files. The
dtrace –G option is used to link provider and probe definitions with a user application. The –32 option is used to build 32–bit application binaries. The –64 option is used to build 64–bit application binaries.

Enabling Applications with Probes

When an application with statically defined probes is executed it registers those probes with DTrace. Like the pid provider, a separate provider is registered for each process. If the process launched has the PID 123, then the provider would be for the previously defined myserv would be myserv123. To enable this for all current and future applications with the myserv provider you can use * as the process ID. This results in the following provider myserv*.

If you use the wildcard syntax from inside a zone, then the enabling is limited to just that particular zone. However, if the wildcard syntax is used with an enabling from the global zone, then the enabling is not restricted based on zone. If you are in the global zone and only interested in globally enabling these USDT probes for a single zone then you should use the zone option, specifying the name of the zone to be instrumented.

The following script shows how to use the zone option to only enable applications in the zone named dhcpd.

```
# pragma D option zone=dhcpd

myserv*:::
{
    @[pid] = count();
}
```
Chapter 35

Security

ILLUMOS PROVIDES PRIVILEGES that system administrators can use to grant access to DTrace to particular users or processes. DTrace enables visibility into all aspects of the system including user-level functions, system calls, kernel functions, and more. It allows for powerful actions, some of which can modify a program’s state. Just as it would be inappropriate to allow a user access to another user’s private files, a system administrator should not grant every user full access to all the facilities that DTrace offers. By default, only the super-user can use DTrace. The Least Privilege facility can be used to allow other users controlled use of DTrace.

35.1 Privileges

The illumos Least Privilege facility enables administrators to grant specific privileges to specific illumos users. To give a user a privilege on login, insert a line into the /etc/user_attr file of the form:

user-name:::defaultpriv=basic,privilege

To give a running process an additional privilege, use the ppriv(1) command:

# ppriv -s A+privilege process-ID

The three privileges that control a user’s access to DTrace features are dtrace_proc, dtrace_user, and dtrace_kernel. Each privilege permits the use of a certain set of DTrace providers, actions, and variables, and each corresponds to a particular type of use of DTrace. The privilege modes are described in detail in the following sections. System administrators should carefully weigh each user’s need against the visibility and performance impact of the different privilege modes. Users need at least one of the three DTrace privileges in order to use any of the DTrace functionality.

35.2 Privileged Use of DTrace

Users with any of the three DTrace privileges may enable probes provided by the dtrace provider (see Chapter 17), and may use the following actions and variables:
35. Security

<table>
<thead>
<tr>
<th>Providers</th>
<th>dtrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actions</td>
<td></td>
</tr>
<tr>
<td>exit</td>
<td>printf</td>
</tr>
<tr>
<td>discard</td>
<td>speculate</td>
</tr>
<tr>
<td>printa</td>
<td>trace</td>
</tr>
<tr>
<td>Variables</td>
<td></td>
</tr>
<tr>
<td>args</td>
<td>probemod</td>
</tr>
<tr>
<td>epid</td>
<td>probename</td>
</tr>
<tr>
<td>id</td>
<td>probeprov</td>
</tr>
<tr>
<td>probefunc</td>
<td>self</td>
</tr>
<tr>
<td>Address Spaces</td>
<td>None</td>
</tr>
</tbody>
</table>

35.3 dtrace_proc Privilege

The dtrace_proc privilege permits use of the fasttrap provider for process-level tracing. It also allows the use of the following actions and variables:

| Actions    |       |
| copyin     | copyout |
| copyinstr  | raise |
|           | ustack |
| Variables  |       |
| execname   | pid |
|           | uregs |
| Address Spaces | User |

This privilege does not grant any visibility to illumos kernel data structures or to processes for which the user does not have permission.

Users with this privilege may create and enable probes in processes that they own. If the user also has the proc_owner privilege, probes may be created and enabled in any process. The dtrace_proc privilege is intended for users interested in the debugging or performance analysis of user processes. This privilege is ideal for a developer working on a new application or an engineer trying to improve an application’s performance in a production environment.

Note

Users with the dtrace_proc and proc_owner privileges may enable any pid probe from any process, but can only create probes in processes whose privilege set is a subset of their own privilege set. Refer to the Least Privilege documentation for complete details.

The dtrace_proc privilege allows access to DTrace that can impose a performance penalty only on those processes to which the user has permission. The instrumented processes will impose more of a load on the system resources, and as such it may have some small impact on the overall system performance. Aside from this increase in overall load, this privilege does not allow any instrumentation that impacts performance for any processes other than those being traced. As this privilege grants users no additional visibility into other processes or the kernel itself, it is recommended that this privilege be granted to all users that may need to better understand the inner-workings of their own processes.

35.4 dtrace_user Privilege

The dtrace_user privilege permits use of the profile and syscall providers with some caveats, and the use of the following actions and variables:
### 35.6 Super User Privileges

A user with all privileges may use every provider and every action including the kernel destructive actions unavailable to every other class of user.

<table>
<thead>
<tr>
<th>Providers</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actions</td>
<td>All including destructive actions</td>
</tr>
<tr>
<td>Variables</td>
<td>All</td>
</tr>
<tr>
<td>Address Spaces</td>
<td>User</td>
</tr>
</tbody>
</table>
Chapter 36

Anonymous Tracing

This chapter describes anonymous tracing, tracing that is not associated with any DTrace consumer. Anonymous tracing is used in situations when no DTrace consumer processes can run. The most common use of anonymous tracing is to permit device driver developers to debug and trace activity that occurs during system boot. Any tracing that you can do interactively you can do anonymously. However, only the super user may create an anonymous enabling, and only one anonymous enabling can exist at any time.

36.1 Anonymous Enablings

To create an anonymous enabling, use the -A option with a dtrace(1M) invocation that specifies the desired probes, predicates, actions and options. dtrace will add a series of driver properties representing your request to the dtrace(7D) driver’s configuration file, typically /kernel/drv/dtrace.conf. These properties will be read by the dtrace(7D) driver when it is loaded. The driver will enable the specified probes with the specified actions, and create an anonymous state to associate with the new enabling. Normally, the dtrace(7D) driver is loaded on-demand, as are any drivers that act as DTrace providers. To allow tracing during boot, the dtrace(7D) driver must be loaded as early as possible. dtrace adds the necessary forceload statements to /etc/system (see system(4)) for each required DTrace provider and for dtrace(7D) itself.

Thereafter, when the system boots, a message is emitted by dtrace(7D) to indicate that the configuration file has been successfully processed.

All options may be set with an anonymous enabling, including buffer size, dynamic variable size, speculation size, number of speculations, and so on.

To remove an anonymous enabling, specify -A to dtrace without any probe descriptions.

36.2 Claiming Anonymous State

Once the machine has completely booted, any anonymous state may be claimed by specifying the -a option with dtrace. By default, -a claims the anonymous state, processes the existing data, and continues to run. To consume the anonymous state and then exit, add the -e option.

Once anonymous state has been consumed from the kernel, it cannot be replaced: the in-kernel buffers that contained it are reused. If you attempt to claim anonymous tracing state where none exists, dtrace will generate a message similar to the following example:
36. ANONYMOUS TRACING

Dtrace: could not enable tracing: No anonymous tracing state

If drops or errors have occurred, dtrace will generate the appropriate messages when the anonymous state is claimed. The messages for drops and errors are the same for both anonymous and non-anonymous state.

36.3 Anonymous Tracing Examples

The following example shows an anonymous DTrace enabling for every probe in the iprb(7D) module:

```bash
# dtrace -A -m iprb
```

Dtrace: saved anonymous enabling in /kernel/drv/dtrace.conf
Dtrace: added forceload directives to /etc/system
Dtrace: run update_drv(1M) or reboot to enable changes

# reboot

After rebooting, dtrace(7D) prints a message on the console to indicate that it is enabling the specified probes:

```
...  
Copyright 1983-2003 Sun Microsystems, Inc. All rights reserved.
Use is subject to license terms.
NOTICE: enabling probe 0 (:iprb::)
NOTICE: enabling probe 1 (dtrace:::ERROR)
configuring IPv4 interfaces: iprb0.
...
```

When the machine has rebooted, the anonymous state may be consumed by specifying the -a option with dtrace:

```bash
# dtrace -a
```

<table>
<thead>
<tr>
<th>CPU</th>
<th>ID</th>
<th>FUNCTION:NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>22954</td>
<td>_init:entry</td>
</tr>
<tr>
<td>0</td>
<td>22955</td>
<td>_init:return</td>
</tr>
<tr>
<td>0</td>
<td>22800</td>
<td>iprb_probe:entry</td>
</tr>
<tr>
<td>0</td>
<td>22934</td>
<td>iprb_get_dev_type:entry</td>
</tr>
<tr>
<td>0</td>
<td>22935</td>
<td>iprb_get_dev_type:return</td>
</tr>
<tr>
<td>0</td>
<td>22801</td>
<td>iprb_probe:return</td>
</tr>
<tr>
<td>0</td>
<td>22802</td>
<td>iprbattach:entry</td>
</tr>
<tr>
<td>0</td>
<td>22874</td>
<td>iprb_getprop:entry</td>
</tr>
<tr>
<td>0</td>
<td>22875</td>
<td>iprb_getprop:return</td>
</tr>
<tr>
<td>0</td>
<td>22934</td>
<td>iprb_get_dev_type:entry</td>
</tr>
<tr>
<td>0</td>
<td>22935</td>
<td>iprb_get_dev_type:return</td>
</tr>
<tr>
<td>0</td>
<td>22870</td>
<td>iprb_self_test:entry</td>
</tr>
<tr>
<td>0</td>
<td>22871</td>
<td>iprb_self_test:return</td>
</tr>
<tr>
<td>0</td>
<td>22958</td>
<td>iprb_hard_reset:entry</td>
</tr>
<tr>
<td>0</td>
<td>22959</td>
<td>iprb_hard_reset:return</td>
</tr>
<tr>
<td>0</td>
<td>22862</td>
<td>iprb_get_eeprom_size:entry</td>
</tr>
<tr>
<td>0</td>
<td>22826</td>
<td>iprb_shiftout:entry</td>
</tr>
<tr>
<td>0</td>
<td>22828</td>
<td>iprb_raiseclock:entry</td>
</tr>
<tr>
<td>0</td>
<td>22829</td>
<td>iprb_raiseclock:return</td>
</tr>
</tbody>
</table>

The following example focuses only on those functions called from iprbattach. In an editor, type the following script and save it in a file named iprb.d.

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fbt::iprbattach:entry
{
    self->trace = 1;
}

fbt:::
/self->trace/
()

fbt::iprbattach:return
{
    self->trace = 0;
}

Run the following commands to clear the previous settings from the driver configuration file, install the new anonymous tracing request, and reboot:

```
# dtrace -AFs iprb.d
dtrace: cleaned up old anonymous enabling in /kernel/drv/dtrace.conf
dtrace: cleaned up forceload directives in /etc/system
dtrace: saved anonymous enabling in /kernel/drv/dtrace.conf
dtrace: added forceload directives to /etc/system
dtrace: run update_drv(1M) or reboot to enable changes
# reboot
```

After rebooting, dtrace(7D) prints a different message on the console to indicate the slightly different enabling:

```
...  
Copyright 1983-2003 Sun Microsystems, Inc. All rights reserved.
Use is subject to license terms.
NOTICE: enabling probe 0 (fbt::iprbattach:entry)
NOTICE: enabling probe 1 (fbt::)
NOTICE: enabling probe 2 (fbt::iprbattach:return)
NOTICE: enabling probe 3 (dtrace::ERROR)
configuring IPv4 interfaces: iprb0.
...
```

After the machine has completely booted, run dtrace with the -a option and the -e option to consume the anonymous data and then exit.

```
# dtrace -ae
CPU FUNCTION
  0  ->  iprbattach
  0  ->  gld_mac_alloc
  0  ->  kmem_zalloc
  0  ->  kmem_cache_alloc
  0  ->  kmem_cache_alloc_debug
  0  ->  verify_and_copy_pattern
  0  <-  verify_and_copy_pattern
  0  ->  tsc_gethrtime
  0  <-  tsc_gethrtime
  0  ->  getpcstack
  0  <-  getpcstack
  0  ->  kmem_log_enter
  0  <-  kmem_log_enter
  0  <-  kmem_cache_alloc_debug
  0  <-  kmem_cache_alloc
```

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This chapter describes the DTrace facilities for postmortem extraction and processing of the in-kernel data of DTrace consumers. In the event of a system crash, the information that has been recorded with DTrace may provide the crucial clues to root-cause the system failure. DTrace data may be extracted and processed from the system crash dump to aid you in understanding fatal system failures. By coupling these postmortem capabilities of DTrace with its ring buffering buffer policy (see Chapter 11), DTrace can be used as an operating system analog to the black box flight data recorder present on commercial aircraft.

To extract DTrace data from a specific crash dump, you should begin by running the illumos Modular Debugger, mdb(1), on the crash dump of interest. The MDB module containing the DTrace functionality will be loaded automatically. To learn more about MDB, refer to the illumos Modular Debugger Guide.

37.1 Displaying DTrace Consumers

To extract DTrace data from a DTrace consumer, you must first determine the DTrace consumer of interest by running the ::dtrace_state MDB dcmd:

```
> ::dtrace_state
 ADDR MINOR PROC NAME FILE
 ccaba400  2  -  <anonymous>  -
 ccab9d80  3  d1d6d7e0  intrstat  cda37078
 cbfb56c0  4  d71377f0  dtrace  ceb51bd0
 ccabb100  5  d713b0c0  lockstat  ceb51b60
 d7ac97c0  6  d713b7e8  dtrace  ceb51ab8
```

This command displays a table of DTrace state structures. Each row of the table consists of the following information:

- The address of the state structure
- The minor number associated with the dtrace(7D) device
- The address of the process structure that corresponds to the DTrace consumer
- The name of the DTrace consumer (or <anonymous> for anonymous consumers)
- The name of the file structure that corresponds to the open dtrace(7D) device
37. Postmortem Tracing

To obtain further information about a specific DTrace consumer, specify the address of its process structure to the ::ps dcmd:

```
> d71377f0::ps
S PID PPID PGID SID UID FLAGS ADDR NAME
R 100647 100642 100647 100638 0 0x00004008 d71377f0 dtrace
```

### 37.2 Displaying Trace Data

Once you determine the consumer of interest, you can retrieve the data corresponding to any unconsumed buffers by specifying the address of the state structure to the ::dtrace dcmd. The following example shows the output of the ::dtrace dcmd on an anonymous enabling of syscall:::entry with the action trace(execname):

```
> ::dtrace_state
ADDR MINOR PROC NAME FILE
cbfb7a40 2 - <anonymous> -
```

```
> cbfb7a40::dtrace
CPU ID FUNCTION:NAME
0 344 resolvenpath:entry init
0 16 close:entry init
0 202 xstat:entry init
0 202 xstat:entry init
0 14 open:entry init
0 206 fxstat:entry init
0 186 mmap:entry init
0 186 mmap:entry init
0 186 mmap:entry init
0 190 munmap:entry init
0 344 resolvenpath:entry init
0 216 memcntl:entry init
0 16 close:entry init
0 202 xstat:entry init
0 14 open:entry init
0 206 fxstat:entry init
0 186 mmap:entry init
0 186 mmap:entry init
0 186 mmap:entry init
0 190 munmap:entry init
...```

The ::dtrace dcmd handles errors in the same way that dtrace(1M) does: if drops, errors, speculative drops, or the like were encountered while the consumer was executing, ::dtrace will emit a message corresponding to the dtrace(1M) message.

The order of events as displayed by ::dtrace is always oldest to youngest within a given CPU. The CPU buffers themselves are displayed in numerical order. If an ordering is required for events on different CPUs, trace the timestamp variable.

You can display only the data for a specific CPU by specifying the -c option to ::dtrace:

```
> cbfb7a40::dtrace -c 1
CPU ID FUNCTION:NAME
1 14 open:entry init
1 206 fxstat:entry init
```
37.2. Displaying Trace Data

Notice that `::dtrace` only processes *in-kernel* DTrace data. Data that has been consumed from the kernel and processed (through `dtrace(1M)` or other means) will not be available to be processed with `::dtrace`. To assure that the most amount of data possible is available at the time of failure, use a ring buffer buffering policy. See Chapter 11 for more information on buffer policies.

The following example creates a very small (16K) ring buffer and records all system calls and the process making them:

```
# dtrace -P syscall'{trace(curpsinfo->pr_psargs)}' -b 16k -x bufpolicy=ring
```

dtrace: description 'syscall:::entry' matched 214 probes

Looking at a crash dump taken when the above command was running results in output similar to the following example:

```
> ::dtrace_state
     ADDR  MINOR  PROC  NAME   FILE
   cdccd400      3  d15e80a0  dtrace  ced065f0

> cdccd400::dtrace

   CPU  ID    FUNCTION:NAME
     0  139  getmsg:return  mibiisa -r -p 25216
     0  138  getmsg:entry  mibiisa -r -p 25216
     0  139  getmsg:return  mibiisa -r -p 25216
     0  138  getmsg:entry  mibiisa -r -p 25216
     0  139  getmsg:return  mibiisa -r -p 25216
     0  138  getmsg:entry  mibiisa -r -p 25216
     0  139  getmsg:return  mibiisa -r -p 25216
     0  138  getmsg:entry  mibiisa -r -p 25216
     0  139  getmsg:return  mibiisa -r -p 25216
     0  138  getmsg:entry  mibiisa -r -p 25216
     0  139  ioctl:entry  mibiisa -r -p 25216
     0  137  ioctl:return  mibiisa -r -p 25216
     0  138  ioctl:entry  mibiisa -r -p 25216
     0  137  ioctl:return  mibiisa -r -p 25216
     0  138  ioctl:entry  mibiisa -r -p 25216
     0  137  ioctl:return  mibiisa -r -p 25216
     0   17  close:return  mibiisa -r -p 25216
     0  96   ioctl:entry  mibiisa -r -p 25216
     0  97   ioctl:return  mibiisa -r -p 25216
     0  96   ioctl:entry  mibiisa -r -p 25216
     0  97   ioctl:return  mibiisa -r -p 25216
     0  96   ioctl:entry  mibiisa -r -p 25216
     0  97   ioctl:return  mibiisa -r -p 25216
     0  16   close:entry  mibiisa -r -p 25216
     0  17   close:return  mibiisa -r -p 25216
     0 124  lwp_park:entry  mibiisa -r -p 25216
     1  68   access:entry  mdb -kw
     1  69   access:return  mdb -kw
     1  202  xstat:entry  mdb -kw
     1  203  xstat:return  mdb -kw
     1  14   open:entry  mdb -kw
     1  15   open:return  mdb -kw
```
Note that CPU 1’s youngest records include a series of write(2) system calls by an `mdb -kw` process. This result is likely related to the reason for the system failure because a user can modify running kernel data or text with mdb(1) when run with the `-k` and `-w` options. In this case, the DTrace data provides at least an interesting avenue of investigation, if not the root cause of the failure.
Chapter 38

Performance Considerations

Because DTrace causes additional work in the system, enabling DTrace always affects system performance in some way. Often, this effect is negligible, but it can become substantial if many probes are enabled with costly enablings. This chapter describes techniques for minimizing the performance effect of DTrace.

38.1 Limit Enabled Probes

Dynamic instrumentation techniques enable DTrace to provide unparalleled tracing coverage of the kernel and of arbitrary user processes. While this coverage allows 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. You should not, for example, enable all FBT probes if a more concise enabling will answer your question. For example, your question might allow you to concentrate on a specific module of interest or a specific function.

When using the pid provider, you should 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.

DTrace can also be used in situations where large numbers of probes must be enabled for a question to be answered. Enabling a large number of probes might slow down the system quite a bit, but it will never induce fatal failure on the machine. You should therefore not hesitate to enable many probes if required.

38.2 Use Aggregations

As discussed in Chapter 9, DTrace’s aggregations allow for a scalable way of aggregating data. Associative arrays might appear to offer similar functionality to aggregations. However, by nature of being global, general-purpose variables, they cannot offer the linear scalability of aggregations. You should therefore prefer to use aggregations over associative arrays when possible. The following example is not recommended:

```bash
syscall:::entry
{
    totals[execname]++;
```
The following example is preferable:

```c
syscall::entry
{
    @totals[execname] = count();
}
END
{
    printa("%40s @%d\n", @totals);
}
```

### 38.3 Use Cacheable Predicates

DTrace predicates are used to filter unwanted data from the experiment by tracing data is only traced 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 (for example, `/self->traceme/`) or immutable variables (for example, `/pid ==12345/`). The cost of evaluating a cached predicate is much smaller 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 imply some guidelines for constructing optimal predicates, as shown in the following table:

<table>
<thead>
<tr>
<th>Cacheable</th>
<th>Uncacheable</th>
</tr>
</thead>
<tbody>
<tr>
<td>self-&gt;mumble</td>
<td>mumble[curthread], mumble[pid, tid]</td>
</tr>
<tr>
<td>execname</td>
<td>curpsinfo-&gt;pr_fname, curthread-&gt;t_procp-&gt;p_user.u_comm</td>
</tr>
<tr>
<td>pid</td>
<td>curpsinfo-&gt;pr_pid, curthread-&gt;t_procp-&gt;p_pipd-&gt;pid_id</td>
</tr>
<tr>
<td>tid</td>
<td>curlwpsinfo-&gt;pr_lwpid, curthread-&gt;t_tid</td>
</tr>
<tr>
<td>curthread</td>
<td>curthread-&gt;any member, curlwpsinfo-&gt;any member, curpsinfo-&gt;any member</td>
</tr>
</tbody>
</table>

The following example is not recommended:

```c
syscall::read:entry
{
    follow[pid, tid] = 1;
}
```
38.3. Use Cacheable Predicates

```c
fbt::
/follow[pid, tid]/
{}

syscall::read:return
/follow[pid, tid]/
{
    follow[pid, tid] = 0;
}

The following example using thread-local variables is preferable:

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

fbt::
/self->follow/
{}

syscall::read:return
/self->follow/
{
    self->follow = 0;
}

A predicate must consist exclusively of cacheable expressions in order to be cacheable. The following predicates are 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/
```
Chapter 39

Stability

SUN OFTEN PROVIDES developers with early access to new technologies as well as observability tools that allow users to peer into the internal implementation details of user and kernel software. Unfortunately, new technologies and internal implementation details are both prone to changes as interfaces and implementations evolve and mature when software is upgraded or patched. Sun documents application and interface stability levels using a set of labels described in the attributes(5) man page to help set user expectations for what kinds of changes might occur in different kinds of future releases.

No one stability attribute appropriately describes the arbitrary set of entities and services that can be accessed from a D program. DTrace and the D compiler therefore include features to dynamically compute and describe the stability levels of D programs you create. This chapter discusses the DTrace features for determining program stability to help you design stable D programs. You can use the 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.

39.1 Stability Levels

DTrace provides two types of stability attributes for entities such as 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 based on DTrace by indicating how likely an interface or DTrace entity is to change in a future release or patch. The DTrace dependency class tells you whether an interface is common to all illumos platforms and processors, or whether the interface is associated with a particular architecture such as SPARC processors only. The two types of attributes used to describe interfaces can vary independently.

The stability values used by DTrace appear in the following list in order from lowest to highest stability. The more stable interfaces can be used by all D programs and layered applications because Sun will endeavor to ensure that these continue to work in future minor releases. Applications that depend only on Stable interfaces should reliably continue to function correctly on future minor releases and will not be broken by interim patches. The less stable interfaces allow experimentation, prototyping, tuning, and debugging on your current system, but should be used with the understanding that they might change incompatibly or even be dropped or replaced with alternatives in future minor releases.

The DTrace stability values also help you understand the stability of the software entities you are observing, in addition to the stability of the DTrace interfaces themselves. Therefore, DTrace stability values also
tell you how likely your D programs and layered tools are to require corresponding changes when you upgrade or change the software stack you are observing.

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 Sun and represents an interface developed for use by other Sun products that is not yet publicly documented for use by customers and ISVs. 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. When support of an interface is to be discontinued, Sun will attempt to provide notification before discontinuing the interface. 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 Sun. At Sun’s discretion, Sun can deliver updated and possibly incompatible versions of such interfaces as part of any release, subject to their availability from the controlling entity. Sun 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 is provided to give 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. Sun 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. Sun will make reasonable efforts to ensure compatibility with previous releases as it evolves. When non-upward compatible changes become necessary, they will 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, and when feasible, Sun will provide migration aids for binary compatibility and continued D program development.

Stable
The interface is a mature interface under Sun’s control. Sun will try to avoid non-upward-compatible changes to these interfaces, especially in minor or micro releases. If support of a Stable interface must be discontinued, Sun will attempt to provide notification and the stability level changes to Obsolete.

Standard
The interface complies with an industry standard. The corresponding documentation for the interface will describe the standard to which the interface conforms. Standards are typically controlled by a standards development organization, and 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. If the standards
development organization approves a non-upward-compatible change to a Standard interface that
Sun decides to support, Sun will announce a compatibility and migration strategy.

39.2 Dependency Classes

Since illumos and DTrace support a variety of operating platforms and processors, DTrace also labels
interfaces with a dependency class that tells you whether an interface is common to all illumos platforms
and processors, or whether the interface is associated with a particular system architecture. The dependency
class is orthogonal to the stability levels described earlier. For example, a DTrace interface can be Stable
but only supported on SPARC microprocessors, or it can be Unstable but common to all illumos systems.
The DTrace dependency classes are described in the following list in order from least common (that is,
most specific to a particular architecture) to most common (that is, common to all architectures).

Unknown
The interface has an unknown set of architectural dependencies. DTrace does not necessarily know
the architectural dependencies of all entities, such as 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 the one you are currently using.

CPU
The interface is specific to the CPU model of the current system. You can use the psrinfo(1M)
utility’s -v option to display the current CPU model and implementation names. Interfaces with
CPU model dependencies might not be available on other CPU implementations, even if those CPUs
export the same instruction set architecture (ISA). For example, a CPU-dependent interface on an
UltraSPARC-III+ microprocessor might not be available on an UltraSPARC-II microprocessor, even
though both processors support the SPARC instruction set.

Platform
The interface is specific to the hardware platform of the current system. A platform typically
associates a set of system components and architectural characteristics such as a set of supported
CPU models with a system name such as SUNW, Ultra-Enterprise-10000. You can display
the current platform name using the uname(1) -i option. The interface might not be available on
other hardware platforms.

Group
The interface is specific to the hardware platform group of the current system. A platform group
typically associates a set of platforms with related characteristics together under a single name,
such as sun4u. You can display the current platform group name using the uname(1) -m option.
The interface is available on other platforms in the platform group, but might not be available on
hardware platforms that are not members of the group.

ISA
The interface is specific to the instruction set architecture (ISA) supported by the microprocessors
on this system. The ISA describes a specification for software that can be executed on the micro-
processor, including details such as assembly language instructions and registers. You can display
the native instruction sets supported by the system using the isainfo(1) utility. The interface might
not be supported on systems that do not export any of the same instruction sets. For example, an
ISA-dependent interface on an illumos SPARC system might not be supported on an illumos x86
system.
Common

The interface is common to all illumos systems regardless of the underlying hardware. DTrace programs and layered applications that depend only on Common interfaces can be executed and deployed on other illumos systems with the same illumos and DTrace revisions. The majority of DTrace interfaces are Common, so you can use them wherever you use illumos.

39.3 Interface Attributes

DTrace describes interfaces using a triplet of attributes consisting of two stability levels and a dependency class. By convention, the interface attributes are written in the following order, separated by slashes:

\[ name-stability / data-stability / dependency-class \]

The name stability of an interface describes the stability level associated with its name as it appears in your D program or on the dtrace(1M) command-line. For example, the `execname` D variable is a Stable name: Sun guarantees that this identifier will continue to be supported in your D programs according to the rules described for Stable interfaces above.

The data stability of an interface is distinct from the stability associated with the interface name. This stability level describes Sun’s commitment to maintaining the data formats used by the interface and any associated data semantics. For example, the `pid` D variable is a Stable interface: process IDs are a Stable concept in illumos, and Sun guarantees that the `pid` variable will be of type `pid_t` with the semantic that it is set to the process ID corresponding to the thread that fired a given probe in accordance with the rules for Stable interfaces.

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 DTrace interface entities, including providers, probe descriptions, D variables, D functions, types, and program statements themselves, as we’ll see shortly. Notice 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 illumos operating platforms, but this variable provides access to a Private data format that is an artifact of the illumos kernel implementation. Most D variables are provided with Stable/Stable/Common attributes, as are the variables you define.

39.4 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 -v` option to display a report of your program’s stability. The following example uses a program written on the command line:

```bash
# dtrace -v -n dtrace:::BEGIN'{exit(0);}'
dtrace: description 'dtrace:::BEGIN' matched 1 probe
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
```
You may also wish to combine the `dtrace -v` option with the `-e` option, which tells dtrace to compile but not execute your D program, so that you can determine program stability without having to enable any probes and execute your program. Here is another example stability report:

```
# dtrace -ev -n dtrace:::BEGIN'{trace(curthread->t_procp);}'
```

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

```
# 
```

Notice that in our new program, we have referenced the D variable `curthread`, which has a Stable name, but Private data semantics (that is, if you look at it, you are accessing Private implementation details of the kernel), and 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 out of the corresponding values for each interface attributes triplet.

Stability attributes are computed for a probe description by taking the minimum stability attributes of all specified probe description fields according to the attributes published by the provider. The attributes of the available DTrace providers are shown in the chapter corresponding to each provider. DTrace providers export a stability attributes triplet for each of the four description fields for all probes published by that provider. Therefore, a provider’s name may have a greater stability than the individual probes it exports. For example, the probe description:

```
fbt:::
```

indicating that DTrace should trace entry and return from all kernel functions, has greater stability than the probe description:

```
fbt:foo:bar:entry
```

which names a specific internal function `bar` in the kernel module `foo`. For simplicity, most providers use a single set of attributes for all of the individual `module:function:name` values that they publish. Providers also specify attributes for the `args[]` array, as 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 stability attributes Unstable/Unstable/Common because the description might end up matching probes of providers that do not yet exist when used on a future version of the operating system. As such, the illumos community is not able to 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 (see Chapter 4) or macro variables such as `$1` (see Chapter 15) are treated as if they are unspecified because these description patterns might expand to match providers or probes released by Sun in future versions of DTrace and the illumos OS.
Stability attributes are computed for most D language statements by taking the minimum stability and class of the entities in the statement. For example, the following D language entities have the following attributes:

<table>
<thead>
<tr>
<th>Entity</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>D built-in variable</td>
<td>Stable/Private/Common</td>
</tr>
<tr>
<td>curthread</td>
<td></td>
</tr>
<tr>
<td>D user-defined variable</td>
<td>Stable/Stable/Common</td>
</tr>
<tr>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

If you write the following D program statement:

```d
x += curthread->t_pri;
```

then the resulting attributes of the statement are Stable/Private/Common, the minimum attributes associated with the operands `curthread` and `x`. The stability of an expression is computed by taking the minimum stability attributes of each of the operands.

Any D variables you define in your program are automatically assigned the attributes Stable/Stable/-. Common. In addition, the D language grammar and D operators are implicitly assigned the attributes Stable/Stable/Common. References to kernel symbols using the backquote (`) operator are always assigned the attributes Private/Private/Unknown 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 attributes Stable/Stable/Common. Types that are defined in the operating system implementation and provided by other type namespaces are assigned the attributes Private/Private/Unknown. The D type cast operator yields an expression whose stability attributes 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 will be associated with the C type namespace and will be assigned the attributes Stable/Stable/Common as the D compiler has no choice but to assume that you are taking responsibility for these declarations. It is therefore possible to mislead yourself 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 you are including in order to determine the correct stability levels.

### 39.5 Stability Enforcement

When developing a DTrace script or layered tool, you may wish to identify the specific source of stability issues or ensure that your program has a desired set of stability attributes. You can use the `dtrace -x amin=attributes` option to force the D compiler to produce an error when any attributes computation results in a triplet of attributes less than the minimum values you specify on the command-line. The following example demonstrates the use of `dtrace -x amin` using a snippet of D program source. Notice that attributes are specified using three labels delimited by `/` in the usual order.

```
# dtrace -x amin=Evolving/Evolving/Common
   -ev -n dtrace:::BEGIN'{trace(curthread->t_procp);}'
```

The output of the command line displays the error message indicating that the attributes for the scalar `curthread` are less than the predefined minimum.
Chapter 40

Translators

EARLIER, in Chapter 39, we learned about how DTrace computes and reports program stability attributes. Ideally, we would like to construct our DTrace programs by consuming only Stable or Evolving interfaces. Unfortunately, when debugging a low-level problem or measuring system performance, you may need to enable probes that are associated with internal operating system routines such as functions in the kernel, rather than probes associated with more stable interfaces such as system calls. The data available 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 the illumos system call interfaces. In order to aid you in writing stable D programs, DTrace provides a facility to translate implementation artifacts into stable data structures accessible from your D program statements.

40.1 Translator Declarations

A translator is a collection of D assignment statements provided by the supplier of an interface that can be used to translate an input expression into an object of struct type. To understand the need for and use of translators, we’ll consider as an example the ANSI-C standard library routines defined in stdio.h. These routines operate on a data structure named FILE whose implementation artifacts 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 private header file.

If you are writing a C program and wish to know the file descriptor corresponding to a FILE struct, you can use the fileno(3C) function to obtain the descriptor rather than dereferencing a member of the FILE struct directly. The illumos header files enforce this rule by defining FILE as an opaque forward declaration tag so it cannot be dereferenced directly by C programs that include <stdio.h>. Inside the libc.so.1 library, you can imagine that fileno is implemented in C something like this:

```c
int
fileno(FILE *fp)
{
    struct file_impl *ip = (struct file_impl *)fp;
    return (ip->fd);
}
```

Our hypothetical fileno takes a FILE pointer as an argument and casts it to a pointer to a corresponding internal libc structure, struct file_impl, and then returns the value of the fd member of the
implementation structure. Why does illumos implement interfaces like this? By abstracting the details of the current libc implementation away from client programs, Sun is able to maintain a commitment to strong binary compatibility while continuing to evolve and change the internal implementation details of libc. In our example, the fd member could change size or position within struct file_impl, even in a patch, and existing binaries calling fileno(3C) would not be affected by this change because they do not depend on these artifacts.

Unfortunately, observability software such as DTrace has the need to peer inside the implementation in order to provide useful results, and does not have the luxury of calling arbitrary C functions defined in illumos libraries or in the kernel. You could declare a copy of struct file_impl in your D program in order to instrument the routines 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, we want to provide a construct for use in D programs that is bound to the implementation of the library and is updated accordingly, but still provides an additional layer of abstraction associated with greater stability.

A new translator is created using a declaration of the 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, and 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 and identifiers corresponding translation expressions. Each member declaration must name a unique member of the output-type and must be assigned an expression of a type compatible with the member type, according to the rules for the D assignment (=) operator.

For example, we could define a struct of stable information about stdin files based on some of the available libc interfaces:

```
struct file_info {
    int file_fd; /* file descriptor from fileno(3C) */
    int file_eof; /* eof flag from feof(3C) */
};
```

A hypothetical D translator from FILE to file_info could then be declared in D as follows:

```
translator struct file_info < FILE *F > { 
    file_fd = (*((struct file_impl *)F)->fd;
    file_eof = (*((struct file_impl *)F)->eof;
};
```

In our 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(3C) shown above. A similar translation is performed to obtain the value of the EOF indicator.

Sun provides a set of translators for use with illumos interfaces that you can invoke from your D programs, and promises to maintain these translators according to the rules for interface stability defined earlier as
the implementation of the corresponding interface changes. We’ll learn about these translators later in the chapter, after we learn how to invoke translators from D. The translator facility itself is also provided for use by application and library developers who wish to offer their own translators that D programmers can use to observe the state of their software packages.

40.2 Translate Operator

The D operator `xlate` 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 form:

```d
xlate <output-type> (input-expression)
```

For example, to invoke the hypothetical translator for FILE structs defined above and access the `file_fd` member, you would write the expression:

```d
xlate <struct file_info *>(f)->file_fd;
```

where `f` is a D variable of type `FILE *`. The `xlate` expression itself is assigned the type defined by the `output-type`. Once 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 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 will only generate code corresponding 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 using the `->` operator, or you can dereference the pointer using the unary `*` operator, in which case the result behaves as if you translated the expression to a struct. If you dereference a single member, the D compiler will only generate code corresponding to the expression for that member. You may not assign a translated pointer to another D variable as the data object itself does not exist until it is copied or one of its members is referenced.

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 will produce an appropriate error message and abort 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 will be filled with zeroes.

In order to find a matching translator for an `xlate` operation, the D compiler examines the set of available translators in the following order:

• First, the compiler looks for a translation from the exact input expression type to the exact output type.

• Second, the compiler resolves the input and output types by following any typedef aliases to the underlying type names, and then looks for a translation from the resolved input type to the resolved output type.

• Third, the compiler looks for a translation from a compatible input type to the resolved output type. The compiler uses the same rules as it does 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 program compilation fails.

### 40.3 Process Model Translators

The DTrace library file `/usr/lib/dtrace/procfs.d` provides a set of translators for use in your D programs to translate from the operating system kernel implementation structures for processes and threads to the stable proc(4) structures `psinfo` and `lwpsinfo`. These structures are also used in the illumos `/proc` filesystem files `/proc/pid/psinfo` and `/proc/pid/lwps/lwpid/lwpsinfo`, and are defined in the system header file `/usr/include/sys/procfs.h`. These structures define useful Stable information about processes and threads such as the process ID, LWP ID, initial arguments, and other data displayed by the `ps(1)` command. Refer to proc(4) for a complete description of the struct members and semantics.

<table>
<thead>
<tr>
<th>Input Type</th>
<th>Input Type Attributes</th>
<th>Output Type</th>
<th>Output Type Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>proc_t *</code></td>
<td>Private/Private/Common</td>
<td><code>psinfo_t *</code></td>
<td>Stable/Stable/Common</td>
</tr>
<tr>
<td><code>kthread_t *</code></td>
<td>Private/Private/Common</td>
<td><code>lwpsinfo_t *</code></td>
<td>Stable/Stable/Common</td>
</tr>
</tbody>
</table>

### 40.4 Stable Translations

While 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 itself 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 in order to permit stable programs to be constructed. The D inline mechanism can be used to facilitate such stable translations.

The DTrace `procfs.d` library provides the `curlwpsinfo` and `curpsinfo` variables described earlier as stable translations. For example, the `curlwpsinfo` variable is actually an inline declared as follows:

```d
inline lwpsinfo_t *curlwpsinfo = xlate <lwpsinfo_t *> (curthread);
#pragma D attributes Stable/Stable/Common curlwpsinfo
```

The `curlwpsinfo` variable is defined as an inlined translation from the `curthread` variable, a pointer to the kernel’s Private data structure representing a thread, to the Stable `lwpsinfo_t` type. The D compiler processes this library file and caches the inline declaration, making `curlwpsinfo` appear as any other D variable. The `#pragma` statement following the declaration is used to explicitly reset the attributes of the `curlwpsinfo` identifier to Stable/Stable/Common, masking the reference
to `curthread` in the inlined expression. This combination of D features permits D programmers to use `curthread` as the source of a translation in a safe fashion that can be updated by Sun coincident to corresponding changes in the illumos implementation.
Chapter 41

Versioning

We learned about the DTrace features for determining the stability attributes of D programs that you create in Chapter 39. Once you have created a D program with the appropriate stability attributes, you may also wish to bind this program to a particular version of the D programming interface. The D interface version is a label applied to a particular set of types, variables, functions, constants, and translators 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 and identifiers defined in future versions of the D programming interface. You should establish version bindings for any D programs that you wish to install as persistent scripts (see Chapter 15) or use in layered tools.

41.1 Versions and Releases

The D compiler labels sets of types, variables, functions, constants, and translators corresponding to a particular software release using a version string. A version string is a period-delimited sequence of decimal integers of the form “x” (a Major release), “x.y” (a Minor release), or “x.y.z” (a Micro release). Versions are compared 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 Sun’s standard nomenclature for interface versions, as described in attributes(5). A change in the D programming interface is accompanied by a new version string. The following table summarizes the version strings used by DTrace and the likely significance of the corresponding DTrace software release.

<table>
<thead>
<tr>
<th>Release</th>
<th>Version</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>x.0</td>
<td>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 Chapter 39). The initial version of the D programming interface is labeled as version 1.0.</td>
</tr>
</tbody>
</table>
Table 41.1: (continued)

<table>
<thead>
<tr>
<th>Release</th>
<th>Version</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>x.y</td>
<td>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 Chapter 39).</td>
</tr>
<tr>
<td>Micro</td>
<td>x.y.z</td>
<td>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.</td>
</tr>
</tbody>
</table>

In general, each new version of the D programming interface will provide a superset of the capabilities offered by the previous version, with the exception of any Obsolete interfaces that have been removed.

### 41.2 Versioning Options

By default, any D programs you compile using `dtrace -s` or specify using the `dtrace -P, -m, -f, -n, or -i` command-line 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 using the `dtrace -V` option:

```bash
$ dtrace -V
dtrace: Sun D 1.0
$```

If you wish 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 (see Chapter 16), you can set the version option either on the command-line using `dtrace -x`:

```bash
# dtrace -x version=1.0 -n 'BEGIN{trace("hello");}'
```

or you can use the `#pragma D option` syntax to set the option in your D program source file:

```d
#pragma D option version=1.0
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 not offered by the D compiler, an appropriate error message will be produced and compilation will fail. You can therefore also use the version binding facility to cause execution of a D script on an older version of DTrace to fail with an obvious error message.
Prior to 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 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 may define identifiers or translators that conflict with declarations in your program source code and would therefore cause a compilation error. See Section 2.1 for tips on how to pick identifier names that are unlikely to conflict with interfaces offered by future versions of DTrace.

### 41.3 Provider Versioning

Unlike interfaces offered by the D compiler, interfaces offered by DTrace providers (that is, probes and probe arguments) are not affected by or associated with the D programming interface or the previously described version binding options. The available provider interfaces are established as part of loading your compiled instrumentation into the DTrace software in the operating system kernel and vary depending on your instruction set architecture, operating platform, processor, the software installed on your illumos system, and your current security privileges. The D compiler and DTrace runtime examine the probes described in your D program clauses and report appropriate error messages when 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; that is, you can only enable probes in D, you cannot define them, and probe names are kept in a separate namespace from other D program identifiers.

DTrace providers are delivered with a particular release of illumos and are described in the corresponding version of the illumos Dynamic Tracing Guide. The chapter of this guide corresponding to each provider will also describe any relevant changes to or new features offered by a given provider. You can use the `dtrace -l` option to explore the set of providers and probes available on your illumos system. Providers label their interfaces using the DTrace stability attributes, and you can use the DTrace stability reporting features (see Chapter 39) to determine whether the provider interfaces used by your D program are likely to change or be offered in future illumos releases.
Chapter 42

Tracing Hardware Virtual Machines

TRADITIONALLY, understanding what is going on inside of a Hardware Virtual Machine has been a black box. With DTrace you can begin to open up that black box and understand what is going on. This chapter focuses on debugging virtual machines that utilize extensions to the x86 instruction set architecture and assumes some familiarity with hardware virtual machine architecture.

42.1 Virtualization Background

In this chapter various terms have specific meanings that they don’t in other contexts. These terms are:

- host refers to the operating system that is doing the virtualization.
- guest refers to the operating system instance that is being subject to virtualization.
- Virtual Machine Monitor (VMM) refers to the piece of software that runs inside of the host operating system and provides the virtualization framework for guest operating systems. It is composed of both a kernel module and a user land process. The VMM is responsible for emulating hardware such as the i8254, i8259, PCI buses, Ethernet and disk controllers.
- Virtual CPU (vCPU) refers to a virtualized instance of a CPU that the guest operating system is exposed to and interacts with.
- Virtual Machine Control Structure (VMCS) is a structure that describes the operation of a virtual machine. There is one VMCS per logical processor per guest.

42.2 vmregs[] Array

The vmregs[] array enables you to access the registers of the currently active VMCS. These registers allow you to see the guest virtual machine state. The following tables list a subset of the indices into the vmregs[] array corresponding to each of the supported CPU architecture extensions. The full list is available in /usr/lib/dtrace/regs.d.
42. TRACING HARDWARE VIRTUAL MACHINES

Table 42.1: Intel VMX vmregs[] Constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMX_GUEST_CR0</td>
<td>%cr0</td>
</tr>
<tr>
<td>VMX_GUEST_CR3</td>
<td>%cr3</td>
</tr>
<tr>
<td>VMX_GUEST_CR4</td>
<td>%cr4</td>
</tr>
<tr>
<td>VMX_GUEST_RSP</td>
<td>%rsp</td>
</tr>
<tr>
<td>VMX_GUEST_RIP</td>
<td>%rip</td>
</tr>
<tr>
<td>VMX_GUEST_RFLAGS</td>
<td>%rflags</td>
</tr>
<tr>
<td>VMX_GUEST_CS_BASE</td>
<td>%es base</td>
</tr>
<tr>
<td>VMX_GUEST_DS_BASE</td>
<td>%es base</td>
</tr>
<tr>
<td>VMX_GUEST_ES_BASE</td>
<td>%es base</td>
</tr>
<tr>
<td>VMX_GUEST_FS_BASE</td>
<td>%es base</td>
</tr>
<tr>
<td>VMX_GUEST_GS_BASE</td>
<td>%es base</td>
</tr>
</tbody>
</table>

The vmregs[] can be combined with other providers to provide insight into what a guest virtual machine without having to access it. The following script profiles what is running on a per-guest basis using the value of %cr3. On x86 systems, that register contains the root of the page table and thus is unique on a per-process basis.

```
profile-97hz
/execename == "qemu-kvm"/
{
    @[pid, vmregs[VMX_GUEST_CR3]] = count();
}

tick-10s
{
    printf("%05d 0x%x %@d\n", @);
    exit(0);
}
```

Running this yields the following output:

```
65197 0xffffffff02d5ed3000 1
65197 0xffffffff02d5ee7000 2
65197 0x77bda000 896
```

Looking at output like this indicate to us that we primarily had one process that was accessing running on CPU inside of the guest during the ten second windows.
Chapter 43

Glossary

action

A behavior implemented by the DTrace framework that can be performed at probe firing time that either traces data or modifies system state external to DTrace. Actions include tracing data, stopping processes, and capturing stack traces, among others.

aggregation

An object that stores the result of an aggregating function as defined formally in Chapter 9, indexed by a tuple of expressions that can be used to organize the results.

clause

A D program declaration consisting of a probe specifier list, an optional predicate, and an optional list of action statements surrounded by braces { }.

consumer

A program that uses DTrace to enable instrumentation and reads out the resulting stream of trace data. The dtrace command is the canonical DTrace consumer; the lockstat(1M) utility is another specialized DTrace consumer.

DTrace

A dynamic tracing facility that provides concise answers to arbitrary questions.

enabling

A group of enabled probes and their associated predicates and actions.

predicate
A logical expression that determines whether or not a set of tracing actions should be executed when a probe fires. Each D program clause may have a predicate associated with it, surrounded by slashes `//`.

**probe**

A location or activity in the system to which DTrace can dynamically bind instrumentation including a predicate and actions. Each probe is named by a tuple indicating its provider, module, function, and semantic name. A probe may be *anchored* to a particular module and function, or it may be *unanchored* if it is not associated with a particular program location (for example, a profile timer).

**provider**

A kernel module that implements a particular type of instrumentation on behalf of the DTrace framework. The provider exports a namespace of probes and a stability matrix for its name and data semantics, as shown in the chapters of this book.

**subroutine**

A behavior implemented by the DTrace framework that can be performed at probe firing time that modifies internal DTrace state but does not trace any data. Similar to actions, subroutines are requested using the D function call syntax.

**translator**

A collection of D assignment statements that convert implementation details of a particular instrumented subsystem into a object of `struct` type that forms an interface of greater stability than the input expression.
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