DTrace Topics: Introduction

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```
dtrace -n 'syscall:::entry { @[exe
dtrace: description 'syscall:::entry
^C

  iscsitgtd                        1
  nscd                             1
  operapluginclean                 3
  screen-4.0.2                     3
  devfsadm                         4
  httpd                           10
  sendmail                        10
  xload                           10
  evince                          12
  operapluginwrapp                20
    lock                          20
    pd                            25
    mIconMan                      32
                                  81
    Pager                        170
    ce                           432
    e-terminal                   581
    2                           1045
                                1833
                                2574
    a                           2923
    g                           4723
    ffice.bin                   5037
```

DTrace Topics: Introduction

- This presentation is an introduction to DTrace, and is part of the “DTrace Topics” collection.
  - Difficulty: 
  - Audience: Everyone
- These slides cover:
  - What is DTrace
  - What is DTrace for
  - Who uses DTrace
  - DTrace Essentials
  - Usage Features

What is DTrace

- DTrace is a dynamic troubleshooting and analysis tool first introduced in the Solaris 10 and OpenSolaris operating systems.
- DTrace is many things, in particular:
  - A tool
  - A programming language interpreter
  - An instrumentation framework
- DTrace provides observability across the entire software stack from one tool. This allows you to examine software execution like never before.

DTrace example #1

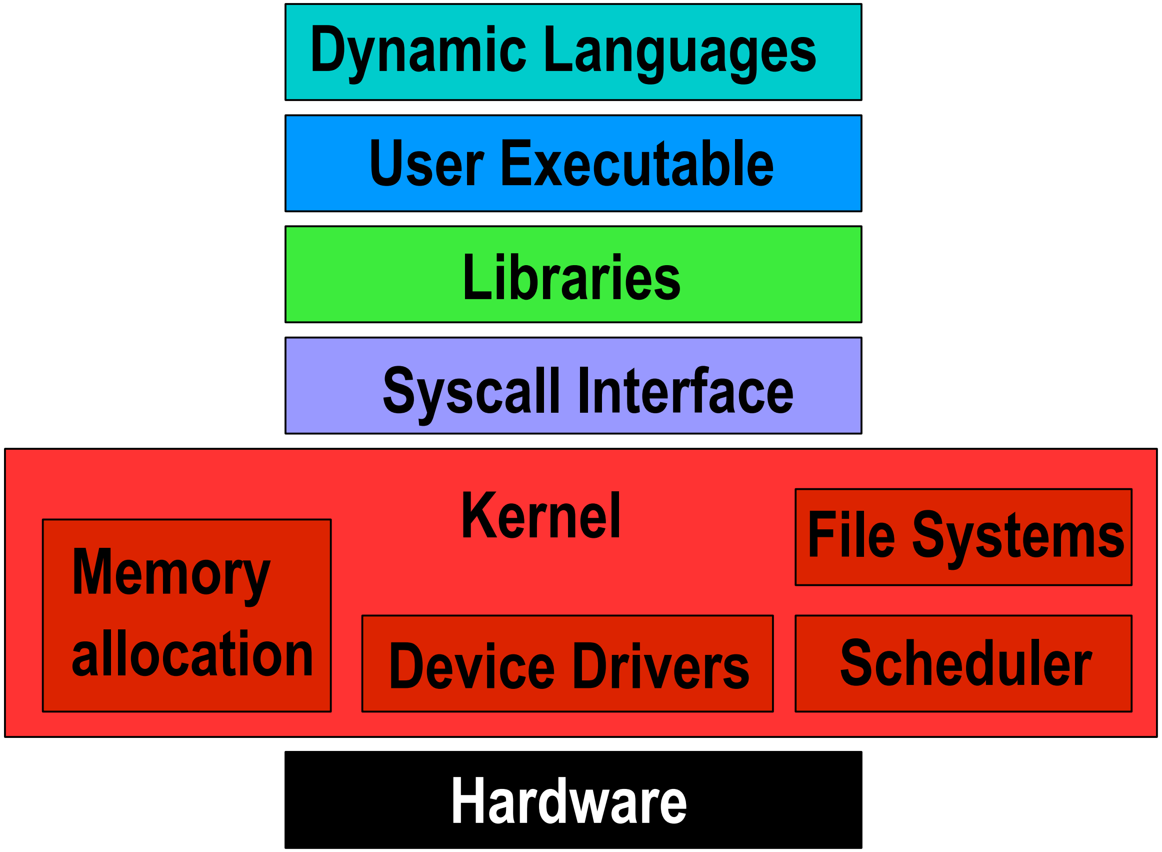
- Tracing new processes system-wide,

```
# dtrace -n 'syscall::exece:return { trace(execname); }'
dtrace: description 'syscall::exece:return ' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0  76044                     exece:return   man
  0  76044                     exece:return   sh
  0  76044                     exece:return   neqn
  0  76044                     exece:return   tbl
  0  76044                     exece:return   nroff
  0  76044                     exece:return   col
  0  76044                     exece:return   sh
  0  76044                     exece:return   mv
  0  76044                     exece:return   sh
  0  76044                     exece:return   more
```

System calls are only one layer of the software stack.

The Entire Software Stack

- How did you analyze these?



Examples:

Java, JavaScript, ...

/usr/bin/*

/usr/lib/*

man -s2

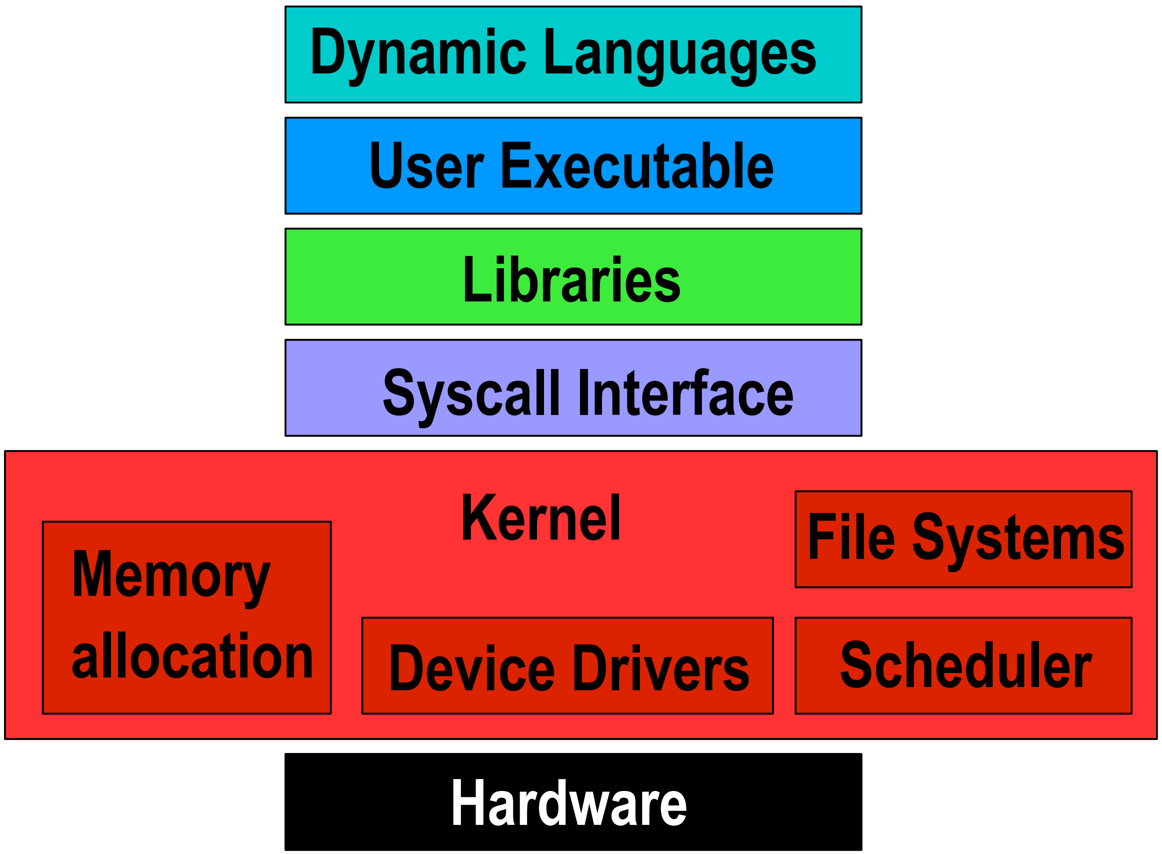
VFS, DNLC, UFS, ZFS, TCP, IP, ...

sd, st, hme, eri, ...

disk data controller

The Entire Software Stack

- It was possible, but difficult:



Previously:

debuggers

truss -ua.out

apptrace, sotruss

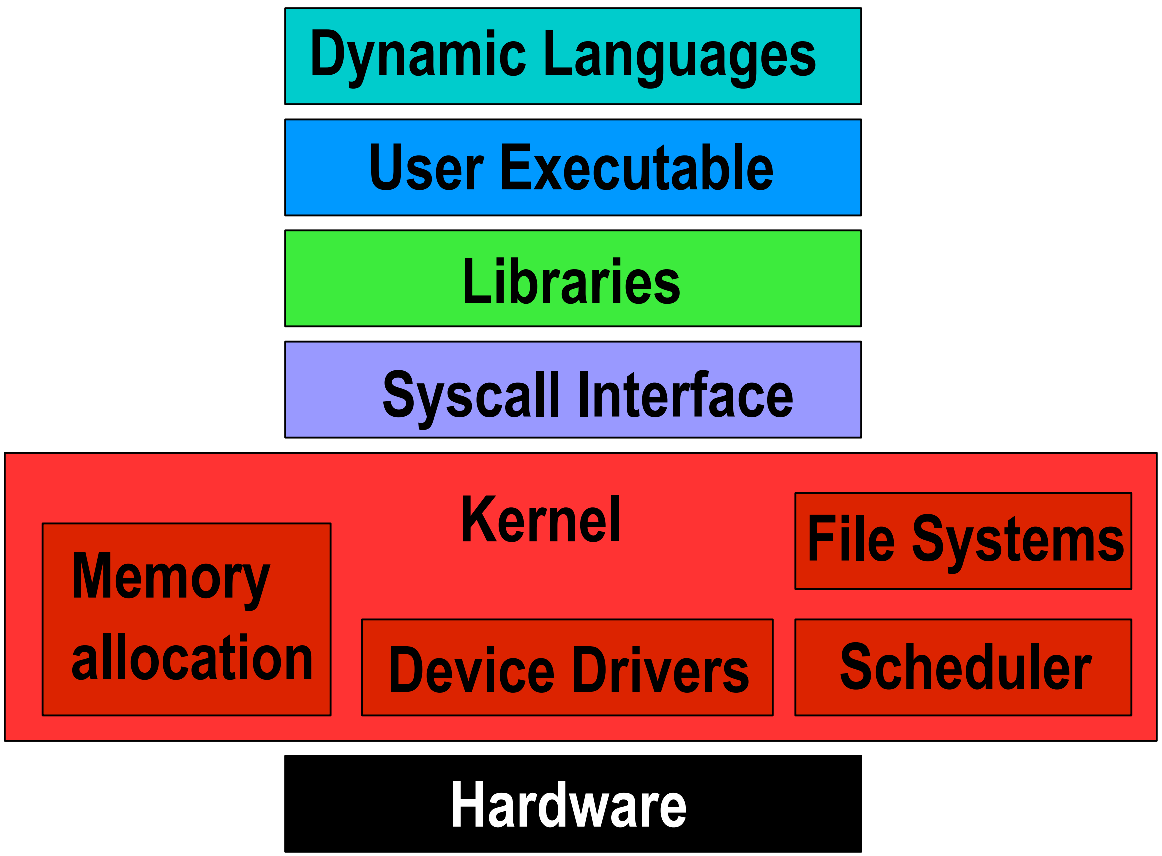
truss

prex; tnf*
lockstat
mdb

kstat, PICs, guesswork

The Entire Software Stack

- DTrace is all seeing:



DTrace visibility:

Yes, with providers

Yes

Yes

Yes

Yes

No. Indirectly, yes

What DTrace is like

- DTrace has the combined capabilities of numerous previous tools and more:

Tool	Capability
truss -ua.out	tracing user functions
apptrace	tracing library calls
truss	tracing system calls
prex; tnf*	tracing some kernel functions
lockstat	profiling the kernel
mdb -k	accessing kernel VM
mdb -p	accessing process VM

Plus a programming language similar to C and awk.

Syscall Example

- Using truss:

Only examine 1 process

```
$ truss date
execve("/usr/bin/date", 0x08047C9C, 0x08047CA4)  argc = 1
resolvepath("/usr/lib/ld.so.1", "/lib/ld.so.1", 1023) = 12
resolvepath("/usr/bin/date", "/usr/bin/date", 1023) = 13
xstat(2, "/usr/bin/date", 0x08047A58)              = 0
open("/var/ld/ld.config", O_RDONLY)                = 3
fxstat(2, 3, 0x08047988)                           = 0
mmap(0x00000000, 152, PROT_READ, MAP_SHARED, 3, 0) = 0xFEFB0000
close(3)                                           = 0
mmap(0x00000000, 4096, PROT_READ|PROT_WRITE|PROT_EXEC, MAP_PRIVATE|MAP_ANON, -1
sysconfig(_CONFIG_PAGESIZE)                        = 4096
[...]
```

Output is limited to provided options

truss *slows down* the target

Syscall Example

- Using DTrace:

You choose the output

```
# dtrace -n 'syscall:::entry { printf("%16s %x %x", execname, arg0, arg1); }'
dtrace: description 'syscall:::entry ' matched 233 probes
CPU     ID                    FUNCTION:NAME
  1  75943                       read:entry             Xorg f 8047130
  1  76211                  setitimer:entry             Xorg 0 8047610
  1  76143                     writev:entry             Xorg 22 80477f8
  1  76255                    pollsys:entry             Xorg 8046da0 1a
  1  75943                       read:entry             Xorg 22 85121b0
  1  76035                      ioctl:entry      soffice.bin 6 5301
  1  76035                      ioctl:entry      soffice.bin 6 5301
  1  76255                    pollsys:entry      soffice.bin 8047530 2
[...]
```

Minimum performance cost

Watch every process

What is DTrace for

- Troubleshooting software bugs
  - Proving what the problem is, and isn't.
  - Measuring the magnitude of the problem.
- Detailed observability
  - Observing devices, such as disk or network activity.
  - Observing applications, whether they are from Solaris, 3rd party, or in-house.
- Capturing profiling data for performance analysis
  - If there is latency somewhere, DTrace can find it

What isn't DTrace

- DTrace isn't a replacement for kstat or SMNP
  - > kstat already provides inexpensive long term monitoring.
- DTrace isn't sentient, it needs to borrow *your* brain to do the thinking
- DTrace isn't “dTrace”

Who is DTrace for

- Application Developers
  - > Fetch in-flight profiling data without restarting the apps, even on customer production servers.
  - > Detailed visibility of all the functions that they wrote, and the rest of the software stack.
  - > Add static probes as a stable debug interface.
- Application Support
  - > Provides a comprehensive insight into application behavior.
  - > Analyze faults and root-cause performance issues.
  - > Prove where issues are, and measure their magnitude.

Who is DTrace for

- System Administrators
  - Troubleshoot, analyze, investigate where never before.
  - See more of your system - fills in many observability gaps.
- Database Administrators
  - Analyze throughput performance issues across all system components.
- Security Administrators
  - Customized short-term auditing
  - Malware deciphering

Who is DTrace for

- Kernel Engineers
  - Fetch kernel trace data from almost every function.
  - Function arguments are auto-casted providing access to all struct members.
  - Fetch nanosecond timestamps for function execution.
  - Troubleshoot device drivers, including during boot.
  - Add statically defined trace points for debugging.

How to use DTrace

- DTrace can be used by either:
  - > Running prewritten one-liners and scripts
    - – DTrace one-liners are easy to use and ofter useful, http://www.solarisinternals.com/dtrace
    - – The DtraceToolkit contains over 100 scripts ready to run, http://www.opensolaris.org/os/community/dtrace/dtracetoolkit
  - > Writing your own one-liners and scripts
    - – Encouraged – the possibilities are endless
    - – It helps to know C
    - – It can help to know operating system fundamentals

DTrace wins

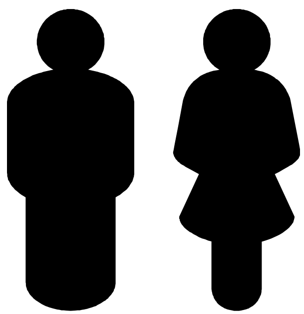
- Finding unnecessary work
  - > Having deep visibility often finds work being performed that isn't needed. Eliminating these can produce the biggest DTrace wins – 2x, 20x, etc.
- Solving performance issues
  - > Being able to measure where the latencies are, and show what their costs are. These can produce typical performance wins – 5%, 10%, etc.

DTrace wins

- Finding bugs
  > Many bugs are found though static debug frameworks; DTrace is a dynamic framework that allows custom and comprehensive debug info to be fetched when needed.
- Proving performance issues
  > Many valuable DTrace wins have no immediate percent improvement, they are about gathering evidence to prove the existence and magnitude of issues.

Example scenario: The past

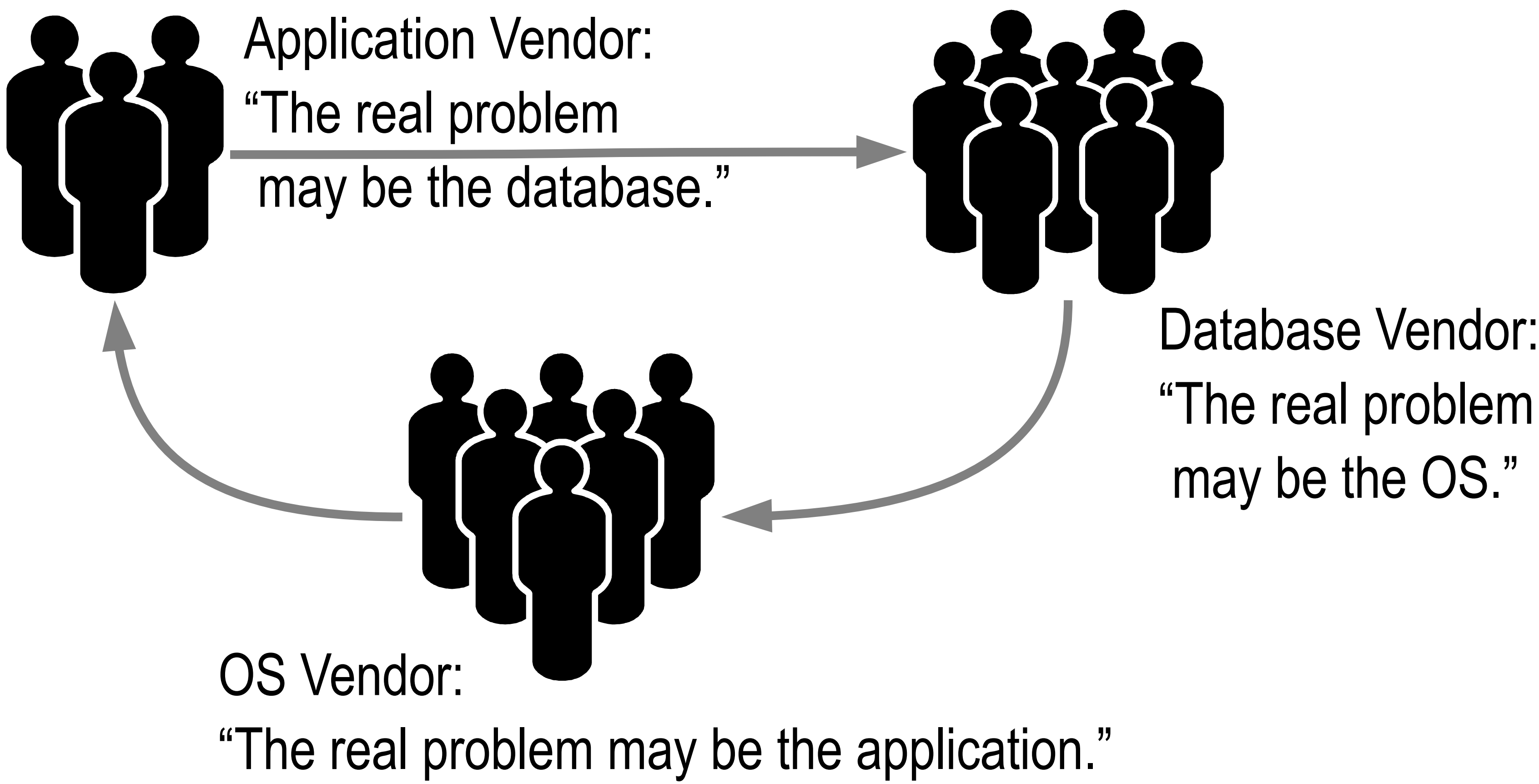
- Take a performance issue on a complex customer system,



Customer:
"Why is our system slow?"

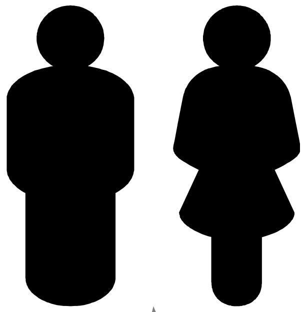
- With previous observability tools, customers could often find problems but not take the measurements needed to prove that they found **the** problem.
  - > What is the latency cost for this issue? As a percent?

Example scenario: The past

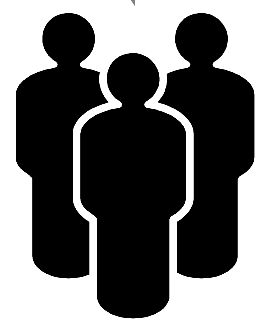


- The “blame wheel”

Example scenario: The past



Customer:
“I think I've found the issue in the application code.”



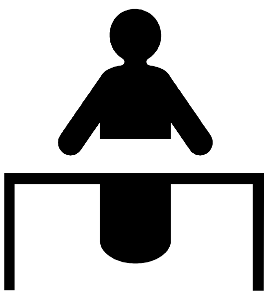
Application Vendor:
“That issue is costly to fix. We are happy to fix it, so long as you can prove that this is **the** issue.”

- The lack of proof can mean stalemate.

Example scenario: The future

A happy ending

- With DTrace, all players can examine all of the software themselves.



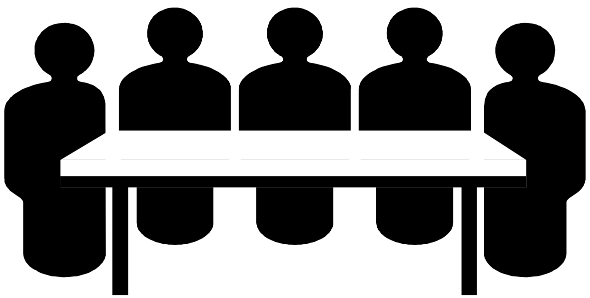
Customer:
"I *measured* the problem,
it is in the application."

Application Vendor:
"I'd better fix that right away."

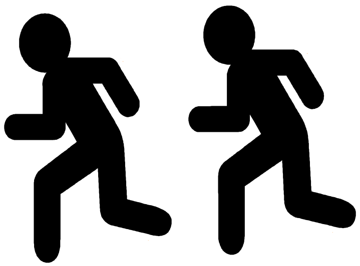
  - Example: "80% of the average transaction time is spent in the application waiting for user-level locks."

Example scenario: The future

An alternate happy ending for application vendors



Application Vendor:
"We measured the problem
and found it was in the OS."



OS Vendor:
"We'd better fix that right away."

- Example: "80% of our average transaction time is consumed by a bug in libc."

Answers to initial questions

- DTrace is not available for Solaris 9.
- You need to be root, or have the correct privileges, to run /usr/sbin/dtrace.
- There is a GUI called chime.
- DTrace is safe for production use, provided you don't deliberately try to cause harm.
- DTrace has low impact when in use, and zero impact when not.

What's next:

- We just covered:
  - > *What is DTrace*
  - > *What is DTrace for*
  - > *Who uses DTrace*
- Next up is:
  - > DTrace Essentials
  - > Usage Features

Terminology

- Example #1

consumer — probe — action

```
# dtrace -n 'syscall::exece:return { trace(execname); }'
dtrace: description 'syscall::exece:return ' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0  76044                     exece:return   man
  0  76044                     exece:return   sh
  0  76044                     exece:return   neqn
  0  76044                     exece:return   tbl
  0  76044                     exece:return   nroff
[...]
```

Consumer

- Consumers of libdtrace(3LIB),

`dtrace`	command line and scripting interface
`lockstat`	kernel lock statistics
`plockstat`	user-level lock statistics
`intrstat`	run-time interrupt statistics

- libdtrace is currently a private interface and not to be used directly (nor is there any great reason to); the supported interface is dtrace(1M).
  - NOTE: You are still encouraged to use libkstat(3LIB) and proc(4) directly, rather than wrapping /usr/bin consumers.

Privileges

```
$ id
uid=1001(user1) gid=1(other)
$ /usr/sbin/dtrace -n 'syscall::exece:return'
dtrace: failed to initialize dtrace: DTrace requires additional privileges
```

- Non-root users need certain DTrace privileges to be able to use DTrace.
- These privileges are from the Solaris 10 “Least Privilege” feature.

Probes

- Data is generated from instrumentation points called "probes".
- DTrace provides thousands of probes.
- Probe examples:

Probe Name	**Description**
`syscall::read:entry`	A read() syscall began
`proc:::exec-success`	A process created successfully
`io:::start`	An I/O was issued (disk/vol/NFS)
`io:::done`	An I/O completed

Probe Names

- Probe names are a four-tuple:

Provider Module Function Name

```
syscall::exece:return
```

> - Provider — A library of related probes.
> - Module — The module the function belongs to, either a kernel module or user segment.
> - Function — The function name that contains the probe.
> - Name — The name of the probe.

Listing Probes

- `dtrace -l` lists all currently available probes that you have privilege to see, with one probe per line:

```
# dtrace -l
   ID   PROVIDER            MODULE                          FUNCTION NAME
    1     dtrace                                                     BEGIN
    2     dtrace                                                     END
    3     dtrace                                                     ERROR
    4      sched                FX                          fx_yield schedctl-yi
[...]
# dtrace -l | wc -l
   69880
```

- Here the root user sees 69,879 available probes.
- The probe count changes – it is dynamic (DTrace).

Tracing Probes

- `dtrace -n` takes a probe name and enables tracing:

```
# dtrace -n syscall::exece:return
dtrace: description 'syscall::exece:return' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0  76044                     exece:return
  0  76044                     exece:return
^C
```

- The default output contains:
  - `CPU` CPU id that event occured on (if this changes, the output may be shuffled)
  - `ID` DTrace probe id
  - `FUNCTION:NAME` Part of the probe name

Providers

- Examples of providers:

Provider	Description
`syscall`	system call entries and returns
`proc`	process and thread events
`sched`	kernel scheduling events
`sysinfo`	system statistic events
`vminfo`	virtual memory events
`io`	system I/O events
`profile`	fixed rate sampling
`pid`	user-level tracing
`fbt`	raw kernel tracing

Providers

- Example of probes:

Provider	Example probe
`syscall`	`syscall::read:entry`
`proc`	`proc:::exec-success`
`sched`	`sched:::on-cpu`
`sysinfo`	`sysinfo:::readch`
`vminfo`	`vminfo:::maj_fault`
`io`	`io:::start`
`profile`	`profile:::profile-1000hz`
`pid`	`pid172:libc:fopen:entry`
	`pid172:a.out:main:entry`
`fbt`	`fbt::bdev_strategy:entry`

Providers

- Providers are documented in the DTrace Guide, as separate chapters.
- Providers are dynamic, the number of available probes can vary.
- Some providers are "unstable interface", such as `fbt` and `sdt`.
  - This means that their probes, while useful, may vary in name and arguments between Solaris versions.
  - Try to use stable providers instead (if possible).

Provider Documentation

- Some providers assume a little background knowledge, other providers assume a lot. Knowing where to find supporting documentation is important.
- Where do you find documentation on:
  - > Syscalls?
  - > User Libraries?
  - > Application Code?
  - > Kernel functions?

Provider Documentation

- Additional documentation may be found here:

Target	Provider	Additional Docs
syscalls	`syscall`	man(2)
libraries	`pid:lib*`	man(3C)
app code	`pid:a.out`	source code?
raw kernel	`fbt`	Solaris Internals 2nd Ed, http://cvs.opensolaris.org

Actions

- When a probe fires, an action executes.
- Actions are written in the D programming language.
- Actions can:
  - print output
  - save data to variables, and perform calculations
  - walk kernel or process memory
- With destruction actions allowed, actions can:
  - raise signals on processes
  - execute shell commands
  - write to some areas of memory

trace() Example

```
# dtrace -n 'syscall::exece:return { trace(execname); }'
dtrace: description 'syscall::exece:return ' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0  76044                     exece:return   man
  0  76044                     exece:return   sh
  0  76044                     exece:return   neqn
  0  76044                     exece:return   tbl
  0  76044                     exece:return   nroff
  0  76044                     exece:return   col
[...]
```

- The trace() action accepts one argument and prints it when the probe fired.

printf() Example

```
# dtrace -n 'syscall::exece:return { printf("%6d %s\n", pid, execname); }'
dtrace: description 'syscall::exece:return ' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0  74415                 exece:return   4301 sh
  0  74415                 exece:return   4304 neqn
  0  74415                 exece:return   4305 nroff
  0  74415                 exece:return   4306 sh
  0  74415                 exece:return   4308 sh
[...]
```

- DTrace ships with a powerful printf(), to print formatted output.

Default Variables

- Numerous predefined variables can be used, eg:
  - `pid`, `tid` Process ID, Thread ID
  - `timestamp` Nanosecond timestamp since boot
  - `probefunc` Probe function name (3rd field)
  - `execname` Process name
  - `arg0`, ... Function arguments and return value
  - `errno` Last syscall failure error code
  - `curpsinfo` Struct contating current process info, eg, `curpsinfo->pr_psargs` – process + args
- Pointers and structs! DTrace can walk memory using C syntax, and has kernel types predefined.

curthread

- `curthread` is a pointer to current kthread_t

  From here you can walk kernel memory and answer endless questions about OS internals.
- Eg, the current process user_t is,

  ```
  curthread->t_procp->p_user
  ```
- You might not ever use curthread, but it is good to know that you can. (And there are other ways to get inside the kernel).

Opinion:
curthread is like the down staircase in nethack, angband, moria, ...

Variable Types

- DTrace supports the following variable types:
  - Integers
  - Structs
  - Pointers
  - Strings
  - Associative arrays
  - Aggregates
- Including types from /usr/include/sys, eg uint32_t.

Aggregations

- A great feature of DTrace is to process data as it is captured, such as using aggregations.
- Eg, frequency counting syscalls:

```
# dtrace -n 'syscall:::entry { @num[probefunc] = count(); }'
dtrace: description 'syscall:::entry ' matched 233 probes
^C
[...]
  writev                                                         170
  write                                                          257
  read                                                           896
  pollsys                                                        959
  ioctl                                                         1253
```

`@num` is the aggregation variable, `probefunc` is the key, and `count()` is the aggregating function.

Aggregating Functions

- These include:
  - `count()` count events, useful for frequency counts
  - `sum(value)` sum the value
  - `avg(value)` average the value
  - `min(value)` find the value minimum
  - `max(value)` find the value maximum
  - `quantize(value)` print power-2 distribution plots

Quantize

- Very cool function, here we quantize write sizes:

```
# dtrace -n 'sysinfo:::writech { @dist[execname] = quantize(arg0); }'
dtrace: description 'sysinfo:::writech ' matched 4 probes
^C
[...]
  ls
           value  ------------- Distribution ------------- count
               4 |                                         0
               8 |                                         2
              16 |                                         0
              32 |@@@@@@@@@@@@@@@@@@@                      118
              64 |@@@@@@@@@@@@@@@@@@@@@                    127
             128 |                                         0
[...]
```

- Here we see that `ls` processes usually write between 32 and 127 bytes. Makes sense?

ls -l

```
# ls -l /etc
dttotal 793
lrwxrwxrwx   1 root     root            12 Mar 21 03:28 TIMEZONE -> default/init
drwxr-xr-x   4 root     sys              6 Apr 16 06:59 X11
drwxr-xr-x   2 adm      adm              3 Mar 20 09:25 acct
drwxr-xr-x   3 root     root             3 Apr 16 23:11 ak
lrwxrwxrwx   1 root     root            12 Mar 21 03:28 aliases -> mail/aliases
drwxr-xr-x   5 root     sys              5 Feb 20 23:29 amd64
drwxr-xr-x   7 root     bin             18 Mar 20 09:20 apache
drwxr-xr-x   4 root     bin              7 Feb 20 23:12 apache2
drwxr-xr-x   2 root     sys              5 Feb 20 23:27 apoc
-rw-r--r--   1 root     bin           1012 Mar 20 09:33 auto_home
-rw-r--r--   1 root     bin           1066 Mar 20 09:33 auto_master
lrwxrwxrwx   1 root     root            16 Mar 21 03:28 autopush -> ../sbin/autopu
[...]
```

`ls` writes one line at a time, each around 80 chars long.

Predicates

- DTrace predicates are used to filter probes, so that the action fires when a conditional is true.

```
probename /predicate/ { action }
```

- Eg, syscalls for processes called “bash”:

```
# dtrace -n 'syscall:::entry /execname == "bash"/ { @num[probefunc] =
count(); }'
dtrace: description 'syscall:::entry ' matched 233 probes
^C

  exece                                                            2
[...]
  read                                                            29
  write                                                           31
  lwp_sigmask                                                     42
  sigaction                                                       62
```

Scripting

- If your one-liners get too long, write scripts. Eg, bash-syscalls.d:

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

syscall:::entry
/execname == "bash"/
{
        @num[probefunc] = count();
}
```

- Getting it running:

```
# chmod 755 bash-syscalls.d
# ./bash-syscalls.d
dtrace: script './bash-syscalls.d' matched 233 probes
[...]
```

What's next:

- We just covered:
  > *What is DTrace*
  > *What is DTrace for*
  > *Who uses DTrace*
  > *DTrace Essentials*
- Next up is:
  > Usage Features

Measuring Time

- Access to high resolution timestamps is of particular use for performance analysis.
  - `timestamp` time since boot in nanoseconds
  - `vtimestamp` thread on-CPU timestamp
- Measuring these for application and operating system function calls will answer:
  - `timestamp` where is the latency?
  - `vtimestamp` why are the CPUs busy?

Printing Stacks

- Printing user and kernel stack traces explains both *why* and the *how* something happened.
- Why is bash calling read()? Using `ustack()`:

```
# dtrace -n 'syscall::read:entry /execname == "bash"/ { ustack(); }'
dtrace: description 'syscall::read:entry ' matched 1 probe
CPU     ID                    FUNCTION:NAME
  0  74314                       read:entry
              libc.so.1`_read+0x7
              bash`rl_getc+0x22
              bash`rl_read_key+0xad
              bash`readline_internal_char+0x5f
              bash`0x80b1171
              bash`0x80b118c
              bash`readline+0x3a
[...]
```

Ahh, readline()

End of Intro

- DTrace is a big topic, but you don't need to know it all to get value from DTrace.
- To learn more, browse "DTrace Topics", http://www.solarisinternals.com/dtrace.

  Here you will find:
  > A wiki version of this presentation
  > The PDF for this presentation
  > dozens of other DTrace Topics (eg, one-liners!)
- Also see the "Solaris Performance and Tools" book,
  http://www.sun.com/books/catalog/solaris_perf_tools.xml

Sampling

- DTrace isn't just about tracing events, DTrace can also sample at customized rates.
- Eg, sampling 5-level user stack traces from Xorg:

```
# dtrace -n 'profile-1001 /execname == "Xorg"/ { @[ustack(5)] = count(); }'
dtrace: description 'profile-1001 ' matched 1 probe
^C
              libfb.so`fbSolid+0x2c6
              libfb.so`fbFill+0xb8
              libfb.so`fbPolyFillRect+0x1d5
              nvidia_drv.so`0xfe09e87b
              Xorg`miColorRects+0x124
               41

              nvidia_drv.so`_nv000592X+0x3d
              0x1016c00
               87
```

nvidia was on-CPU 87 times

See Also

- DTrace home: http://www.opensolaris.org/os/community/dtrace
  - Main site of links
  - DTrace-discuss mailing list
- Team DTrace blogs:
  - http://blogs.sun.com/bmc
  - http://blogs.sun.com/mws
  - http://blogs.sun.com/ahl
- DTraceToolkit:
  - http://www.opensolaris.org/os/community/dtrace/dtracetoolkit

dtrace:::END

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