DTrace Programming Workshop

DTrace on Solaris 10,

OpenSolaris,

and other Operating Systems

Context-Switch
Achieve Performance

About this document

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The Workshop Agenda

- DAY 1
  - General Solaris Performance Monitoring
  - Introducing DTrace
- DAY 2
  - Programming in D
  - The DTrace Mentality
- DAY 3
  - Applying DTrace (*A day of workshop*)

WorkshopModules

- Module 1 – *Solaris 8, 9 & 10 Performance Tools*
- Module 2 – Introducing DTrace
- Module 3 – Command Line DTrace
- Module 4 – DTrace one-liners
- Module 5 – DTrace Mentality 1
- Module 6 – Providers
- Module 7 – The D Language
- Module 8 – Advanced Scripting
- Module 9 – The DTraceToolkit
- Module 10 – DTrace Mentality 2
- References

  Some topics presented are based on the book: "*Solaris Performance and Tools: `DTrace` and `mdb` Techniques for Solaris 10 and OpenSolaris*" written by Richard McDougall, Jim Mauro & Brendan Gregg

About the slides and presentation

- These slides cover key topics
- We will cover many side topics, elaborate further, answer questions, run demos, and discuss many performance-related topics
- As such, if we deviate from the slides – **don't panic!**
  It's all part of the workshop delivery.

MODULE 1:

General Solaris Performance Monitoring

- *What can be observed? And, how quickly can it be observed?*
- *What can't be observed? And, why?*
- *What is the impact of observation?*

- DTrace wins thanks to its ability to observe at such a fine level of detail with minimal system overhead - (*but, may not always be the required utility! - This is why we need to understand general utilities*)

An example fault…

- "Where has my CPU gone?" using standard Solaris tools

  … *An interactive demo using sar and vmstat* …

The Solaris Toolkit

- Consists of many, many tools

  `sar, ps, prstat, ptree, pstack, pmap, vmstat, mpstat, iostat, netstat, kstat, ndd, mdb, truss, sotruss, apptrace, prex, cpustat, trapstat, lockstat ...`

- These is no single tool to rule them all (*not even DTrace!*)

Brendan Gregg tried…

```
$ sysperfstat 1
        ------Utilisation ------              ------Saturation -----
Time          %CPU  %Mem  %Disk  %Net    CPU  Mem  Disk  Net
23:27:41     0.85  44.11   2.40  0.19   0.01   0.00  0.00  0.00
23:27:42     3.00  80.98   0.00  0.00   0.00   0.00  0.00  0.00
23:27:43     2.00  80.98   0.00  0.00   0.00   0.00  0.00  0.00
23:27:44    17.00  80.98   0.00  0.00   0.00   0.00  0.00  0.00
23:27:45    46.00  80.49  22.05 54.20   1.00   0.00  0.00  0.00
23:27:46    50.00  79.83  14.19 78.18   0.00   0.00  0.00  0.00
23:27:47    48.00  79.39   8.04 80.94   0.00   0.00  0.00  0.00
23:27:48    54.00  79.62   3.06 70.89   4.00   0.00  0.00  0.00
23:27:49    39.00  79.43   6.78 74.52   0.00   0.00  0.00  0.00
```

- Such a tool serves one role but not all.
- In this case, it provides the "view from 20,000 feet"

Coping with many tools:

We will…

- Categorise by Approach
- Categorise by Resource Type
- Create at a checklist of tools (*including the detail in these slides*)
- Study some, be aware what else exists (*just remembering that something is doable is valuable!*)

Categorize by Approach:

- 1. Monitoring
  - *Monitoring multiple hosts*
  - *Gathering long term data*
- 2. Identification
  - *Examining system-wide health*
- 3. Analysis
  - *Focusing on details*

Examples:

- 1. Monitoring
  - SNMP, `sar`, SunMC, centralised `syslog`, ...
- 2. Identification
  - kstat (`vmstat, mpstat, iostat,` ...)
  - procfs (`ps, prstat,` ...)
  - mnttab (`df`)
- 3. Analysis
  - `truss, apptrace, prex, lockstat,` ...

Hints:

- Be careful when using **`sar`**:
  - `sar` *has sampling issues*
  - *the default configuration needs tuning*

- Try **`truss -ft ioctl sar -u 1 5`**
  (*Yes*, `sar` *always reads every statistic it can report on!*
  Now, compare this to how `mpstat` *works*)

Solaris 10 now uses SNMP:

- User-based Security Model (USM)
  – usernames, passwords, encryption
- View-based Access Control MIB (VACM)
  – restricting views
- These provide greatly improved security - *a trait of the Solaris 10 OS*

Categorize Tools by Resource Type:

- CPU - `vmstat, mpstat, sar, prstat, ps`
- Memory - `vmstat, swap, prstat, ::memstat (`*`mdb`*`), ps, pmap`
- Disk - `iostat, taztool, iosnoop, iotop`
- Network - `netstat, kstat, ndd, nicstat`

Tools Checklist:

- The following list of tools serves to:
  - *provide a checklist*
  - *show what is doable – you'll remember later*
  - *show what can be done – the right tool for the job*
  - *show what can't be done – where DTrace can help*
  - *provide starting points for using DTrace*

Monitoring Tools and Utilities

- uptime
- /usr/bin/ps
- /usr/ucb/ps
- prstat
- prstat -m
- vmstat
- mpstat
- iostat
- prex/tnf
- psio *
- netstat -i
- nicstat *
- netstat -rn
- sar
- sar -u
- sar -q
- kstat
- K9Toolkit *
- ndd
- checkcable *
- cpustat
- CacheKit *
- busstat
- trapstat
- lockstat
- truss
- sotruss
- apptrace
- truss -ua.out
- adb
- mdb -k
- mdb -p
- lastcomm
- BSM auditing
- snmpwalk

**Those listed in blue are written by Brendan Gregg*

uptime

```
$ uptime
9:37am up 371 day(s), 16:07, 6 users, load average: 0.02, 0.02, 0.02
```

- load average: 1, 5 and 15 minute averages.
  - *These were once the average length of the combined dispatcher queues + currently running threads, sampled during clock().*
  - *It is now microstate accounting based, and is all the thread's usr + sys + CPU latency times.*
  - *load averages tend to over-simplify CPU issues!*
- Can't customise the interval
- DTrace can trace scheduler activity

BTW – 371 days is nothing; Brendan maintains the "Sun Book of Records" (google it), where the current record is more than 2001 days!

/usr/bin/ps

```
$ ps -ef
UID   PID  PPID  C    STIME TTY TIME CMD
root    0     0  0   May 28 ? 0:08 sched
root    1     0  0   May 28 ? 0:48 /etc/init
root    2     0  0   May 28 ? 0:02 pageout
root    3     0  0   May 28 ? 89:39 fsflush
root 2316     1  0   May 28 ? 0:00 /usr/lib/saf/sac -t 300
nobody 22112 22111 0 Feb 15 ? 231:44 (squid)
root 2061     1  0   May 28 ? 0:12 /usr/sbin/rpcbind
root   73     1  0   May 28 ? 0:00 /usr/lib/sysevent/syseventd
root   78     1  0   May 28 ? 0:01 /usr/lib/picl/picld
...
```

- Useful to check long-term processes
- Default fields are not hugely useful, use **`-o`**
- DTrace can access similar *procfs* statistics, and gather many additional statistics

/usr/ucb/ps

```
$ /usr/ucb/ps auxww
USER       PID %CPU  %MEM     SZ  RSS  TT    S    START   TIME COMMAND
root      3768  3.0   0.8   3216 2856 pts/2  O  16:24:40  0:00 /usr/ucb/ps -
   auxww
root      3453  0.2   0.8   4544 2904   ?    S  15:59:10  0:01
   /usr/lib/ssh/sshd
root       498  0.1   0.8   4680 2944   ?    S    May 03  0:29
   /usr/lib/ssh/sshd
brendan 17545  0.1   0.6   2648 2080 pts/2  S    May 08  0:04 /bin/bash
brendan  3769  0.1   0.3    984  808 pts/2  S  16:24:40  0:00 head
brendan  2408  0.1   1.4   6800 5112   ?    S    May 28  92:28 SCREEN
root      2037  0.1   0.3    2024 800   ?    S    May 28 168:21
   /usr/sbin/in.routed
root      3765  0.1   0.3    1016 816   ?    S  16:24:28  0:00 sleep 15

nobody 22112   0.1  22.7   91504 84352 ?    S    Feb 15 231:44 (squid)
```

- Sorting by %CPU is nice
- Fields colliding is not nice
- `pargs` is better at viewing full *arg* listings

prstat

```
$ prstat
PID  USERNAME  SIZE  RSS   STATE  PRI NICE  TIME CPU PROCESS/NLWP
3453 root     4544K 2904K sleep   59   0 0:00:01 0.7% sshd/1
5558 irc      8152K 3832K sleep   59   0 0:15:41 0.4% irssi/1
3944 brendan  4584K 4224K  cpu0   39   0 0:00:00 0.4% prstat/1
25442brendan  2312K  296K sleep   59   0 0:05:05 0.1% telnet/1
3939 root     1016K  816K sleep   59   0 0:00:00 0.0% sleep/1
17545brendan  2648K 2080K sleep   49   0 0:00:04 0.0% bash/1
2037 root     2024K  800K sleep   59   0 2:48:21 0.0% in.routed/1
Total: 114 processes, 197 lwps, load averages: 0.04, 0.02, 0.03
```

- Great summary view
- Doesn't wallop the CPU
- DTrace can also provide updating summaries, of a simple nature

prstat -m

```
$ prstat -m
PID USERNAME  USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/NLWP
3999 brendan  0.4 1.3 0.0 0.0 0.0 0.0  98 0.0  9   0  259  0 prstat/1
2408 brendan  0.7 0.1 0.0 0.0 0.0 0.0  99 0.0  6   0   30  0 screen-3.9.8/1
19763 brendan 0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  5   0   13  0 sdtperfmeter/1
2150 root     0.0 0.0  -   -   -   -  100  -   8   0   26  0 nscd/2
578  root     0.0 0.0  -   -   -   -  100  -   0   0    0  0 picld/4
73   root     0.0 0.0  -   -   -   -  100  -   0   0    0  0 syseventd/14
2061 root     0.0 0.0  -   -   -   -  100  -   0   0    0  0 rpcbind/1
22112 root    0.0 0.0  -   -   -   -  100  -   2   0    2  0 squid/1
Total: 114 processes, 197 lwps, load averages: 0.00, 0.02, 0.02
```

- Microstate accounting – *great breakdown of process time (very useful!)*
- Restricted to pre-determined accounting states
- DTrace can measure custom states – of your own choice!

vmstat

```
$ vmstat 1 3
 kthr      memory            page            disk          faults      cpu
 r b w   swap  free  re  mf pi po fr de sr dd s1 -- --   in   sy   cs us sy id
 0 0 0 1610024 679984 39 173 652 1 1  0 47 111 0  0  0  517 3930  822 13  5 83
 1 0 0 1537160 580800 25 445 3099 0 0 0  0 424 0  0  0 1097 10161 1023 73 11 16
 1 0 0 1536736 580352 24 348 2931 0 0 0  0 383 0  0  0 1042 10531 982 17 11 72

$ vmstat -p 1 3
     memory           page          executable      anonymous      filesystem
   swap  free  re  mf  fr  de  sr  epi  epo  epf  api  apo  apf  fpi  fpo  fpf
 1614624 686176 40 180  1   0  49   44    0    0    0    0    0  354    1    1
 1525904 564008 16 72   0   0   0  103    0    0    0    0    0 11374   0    0
 1523736 561936 35 412  0   0   0   78    0    0    0    0    0 10649   0    0
```

- Best system-wide view
- Can't view statistics by-process, by-zone, ...
- DTrace can take these stats and drill further – *answering who causes them and why*

mpstat

```
$ mpstat 5
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0  149  65    0   491  389  713  153    0    1    1  3262   11   4   0  85
  0  363 161    0   685  583  733  285    0    1    0 21210   85  15   0   0
  0  284 263    0  1198 1097 1177  507    0    1    0 21892   78  22   0   0
  0  334 1198    0  2781 2679 2836 1342    0    0    0 15970   78  22   0   0
  0  323 1072    0  2495 2393 2570 1207    0    0    0 15327   79  21   0   0
  0  296 1087    0  2509 2407 2616 1228    0    1    0 14000   79  20   0   0
  0  261 897    0  2146 2044 2240 1047    0    0    0 10994   83  17   0   0
```

- Good by-CPU summary
- DTrace can also measure by-CPU
- DTrace finally explains where those *xcals* come from

iostat

```
$ iostat -xnmPz 1
                extended device statistics
r/s   w/s   kr/s    kw/s   wait   actv   wsvc_t asvc_t   %w %b device
0.0   0.0    0.1    0.1    0.0    0.0   19.4     11.6    0  0 c0t0d0s0
0.0   0.0    0.0    0.0    0.0    0.0   56.4     11.4    0  0 c0t0d0s1
0.0   0.0    0.0    0.0    0.0    0.0   94.9     15.6    0  0 c0t0d0s3
0.0   0.0    0.0    0.0    0.0    0.0   92.4     14.6    0  0 c0t0d0s4
0.0   0.0    0.0    0.0    0.0    0.0   37.7     10.0    0  0 c0t0d0s5
0.0   0.0    0.0    0.0    0.0    0.0   15.8     12.1    0  0 c0t0d0s7 (/data)
0.0   0.1    0.4    0.4    0.0    0.0    1.8      4.3    0  0 c0t2d0s0 (/)
0.1   0.2    4.1    3.1    0.0    0.0   37.4      6.7    0  0 c0t2d0s1 (/export/home)
0.1   0.0    0.2    0.5    0.0    0.0    3.3     12.7    0  0 c0t2d0s3 (/squidcache)
0.0   0.0    0.0    0.0    0.0    0.0    0.0      4.4    0  0 mars:vold(pid2295)
...
```

- Excellent per-disk/partition/controller summary
- No by-process summary, or event details
- DTrace solves both

prex/tnfxtract/tnfdump

- `prex`: *enables static probes to record event details to a (kernel-based) buffer*
- `tnfxtract`: *extracts buffer contents* to a file
- `tnfdump`: *converts buffer contents (in file) to text output (stdout)*
- DTrace has this exact functionality, and more (*dynamic!*)

prex/tnfxtract/tnfdump

```
# tnfdump tnffile.tnf
probe    tnf_name: "syscall_end" tnf_string: "keys syscall thread;file
    ../../sparc/os/syscall.c;line 797;"
probe    tnf_name: "syscall_start" tnf_string: "keys syscall thread;file
    ../../sparc/os/syscall.c;line 494;"
probe    tnf_name: "thread_block" tnf_string: "keys synch;file
    ../../common/tnf/tnf_res.c;line 287;"
...
--------------- --------------- ----- ----- ---------- --- -------------------------
    ------------------------
    Elapsed (ms)       Delta (ms)   PID LWPID    TID     CPU Probe Name
    Data / Description . . .
--------------- --------------- ----- ----- ---------- --- -------------------------
    ------------------------
        0.000000         0.000000  1028     1 0x30002532020   0 syscall_end
    rval1: 0 rval2: 3298578425768 errno: 0
        0.077490         0.077490  1028     1 0x30002532020   0 syscall_start
    sysnum: 4
        0.152817         0.075327  1028     1 0x30002532020   0 syscall_end
    rval1: 6 rval2: 8195 errno: 0
        0.166153         0.013336  1028     1 0x30002532020   0 syscall_start
    sysnum: 3
        0.218053         0.051900  1028     1 0x30002532020   0 thread_block
    reason: 0x300046ee362 stack: <tnf_symbols>
        0.232830         0.014777  1028     1 0x30002532020   0 thread_state
    state: 7
        0.240759         0.007929  1028     1 0x30002532020   0 thread_state
    tid: 0x2a10001fcc0 state: 1
```

psio

```
# ./psio 1
    UID    PID   PPID   %I/O      STIME    TTY    TIME    CMD
brendan  13271  10093   65.4   23:20:16  pts/20   0:01    grep brendan contents
   root      0      0    0.0     Mar 16      ?    0:16    sched
   root      1      0    0.0     Mar 16      ?    0:10    /etc/init
   root      2      0    0.0     Mar 16      ?    0:00    pageout
```

- http://www.brendangregg.com/psio.html
- Solved %Disk I/O by-process
- Could only run for short intervals
- DTrace takes this much further – tracing events, by-process info, ...

netstat -i

```
$ netstat -i 1 5
    input   bge0      output     input  (Total)    output
packets errs  packets errs  colls  packets errs  packets errs  colls
42158   0     44249   0     0      84626   0     88808   0     0
21      0     18      0     0      42      0     36      0     0
5       0     4       0     0      10      0     8       0     0
4       0     4       0     0      8       0     8       0     0
4       0     3       0     0      8       0     6       0     0
```

- An approximation of activity
- No further details for analysis
- Packets are not bytes!
- Both `kstat` and DTrace provide more info

nicstat

```
$ nicstat 1
Time        Int   rKb/s   wKb/s   rPk/s   wPk/s    rAvs    wAvs  %Util   Sat
18:23:49   hme0    4.12    4.69    6.88    7.43  613.61  645.92   0.07  0.00
18:23:50   hme0    0.19    0.23    2.01    2.01   98.00  116.00   0.00  0.00
18:23:51   hme0    1.41    4.45   13.00   17.00  111.38  267.88   0.05  0.00
18:23:52   hme0    0.99    3.64    9.00   11.00  112.89  339.09   0.04  0.00
18:23:53   hme0    0.10    0.23    1.00    2.00   98.00  116.00   0.00  0.00
```

- *http://www.brendangregg.com/k9toolkit.html*
- Uses `kstat`, written in both C and Perl
- Provides bytes, %Utilisation

netstat -rn

```
$ netstat -rn
Routing Table: IPv4
Destination          Gateway           Flags    Ref      Use    Interface
--------------     --------------    ------- -----  -------  -------------
220.244.170.56     220.244.170.58    U          1    18146    hme0:1
192.168.0.0        192.168.0.2       U          1    12537    hme0:2
192.168.1.0        192.168.1.1       U          1    32151    hme0
224.0.0.0          192.168.1.1       U          1        0    hme0
default            220.244.170.57    UG         1        3
127.0.0.1          127.0.0.1         UH         4       81    lo0
```

- Check for unexpected routes
- You discover problems after the fact
- DTrace can snoop changes live (*OK, so can `route monitor`. Who has used* `route monitor`*?*)

sar

```
$ sar 1 5
SunOS mars 5.9 Generic_118558-05 sun4u  05/11/2006

18:33:46     %usr    %sys    %wio   %idle
18:33:47        2       2       0      96
18:33:48        4       1       0      95
18:33:49        3       4       5      88
18:33:50        0       2       0      98
18:33:51        4       3       3       9
```

- System Activity Reporter
- Prints a variety of *kstats*
- Can collect historic data, to identify long term patterns
- Has several issues

sar -u

```
$ sar -u
SunOS mars 5.9 Generic_118558-05 sun4u  05/11/2006
00:00:01      %usr     %sys     %wio    %idle
01:00:01         1        1        0       98
02:00:01         2        1        0       98
03:00:01         1        1        0       98
04:00:00         1        1        0       98
05:00:01         0        0        0       99
...
```

- This shows historic data from `sar -u`
- `%wio` is always zero in Solaris 10
  (*it was never properly understood anyway*)
- Note that the system is idle

sar -c

```
$ sar -c
SunOS mars 5.9 Generic_118558-05 sun4u  05/11/2006
17:39:05 scall/s sread/s swrit/s  fork/s  exec/s rchar/s wchar/s
17:39:10    3805    1262      43   12.57    6.39  359217   22116
17:39:15    2882     937      31    6.40    3.20  286867   19712
17:39:20    1550     579      68    3.40    2.40  545063  493898
17:39:25    3039    1580      41    2.60    1.60 1312734  162488
...
```

- This shows that processes are being created (*forks & execs*)
- *Does not help identify which processes are being started!*
  - Is this where DTrace can be used?

sar -q

```
$ sar -q
SunOS mars 5.9 Generic_118558-05 sun4u 05/11/2006
00:00:01 runq-sz %runocc swpq-sz %swpocc
01:00:01   1.4      0 5    1.0    100
02:00:01   1.0      1 5    1.0    100
03:00:01   1.2      0 5    1.0    100
04:00:00   1.4      0 5    1.0    100
```

- `sar -q` shows run queue sizes
- This is the same period as before, and shows a > 1.0 run queue size. Huh?

kstat

```
# kstat -pm cpu_info
cpu_info:0:cpu_info0:brand          UltraSPARC-IIIi
cpu_info:0:cpu_info0:chip_id        0
cpu_info:0:cpu_info0:class          misc
cpu_info:0:cpu_info0:clock_MHz      1062
cpu_info:0:cpu_info0:core_id        0
cpu_info:0:cpu_info0:cpu_fru        hc:///component=MB
cpu_info:0:cpu_info0:cpu_type       sparcv9
cpu_info:0:cpu_info0:crtime         40.28150371
cpu_info:0:cpu_info0:device_ID      208525810884
cpu_info:0:cpu_info0:fpu_type       sparcv9
…
```

- Great resource
- `libkstat`, `Sun::Solaris::Kstat`, or `/usr/bin/kstat`
- `netstat -k` is deprecated from Solaris 10 onwards
- Many kstats are not documented
- `kstat` finds problems, DTrace analyses them

K9Toolkit

http://www.brendangregg.com/k9toolkit.html

- A Perl `kstat` collection

- Contains:
  - `sysperfstat`
  - `checkcable`
  - `nicstat`
  - `prtdevs`
  - *and more...*

ndd

```
# ndd /dev/hme link_speed
1
# ndd /dev/rtls link_speed
operation failed: Invalid argument
```

- Accesses read/write settings for network related drivers
- There are consistency issues between interface types

checkcable

```
# checkcable
Interface   Link    Duplex    Speed    AutoNEG
hme0          UP      FULL      100         ON
hme1          UP      HALF       10         ON
```

http://www.brendangregg.com

- Translates both ndd and *kstats*

- May not be needed in the long term (*interface kstats are getting better*)

cpustat

```
# cpustat -c pic0=EC_ref,pic1=EC_hit 1 5
time     cpu    event     pic0      pic1
1.008      0    tick     77992     63504
2.008      0    tick     81972     65364
3.008      0    tick     76869     62250
4.008      0    tick     77347     62518
5.008      0    tick     76023     62405
5.008      1   total    390203    316041
```

- Examine CPU PICs
- Observe I$, D$, E$ performance
- Use `cputrack` for per-process info
- Info available is CPU-type dependant

CacheKit

```
# ccachestat 5 5
    ---I-Cache ---          ---D-Cache ---          ---E-Cache --
  total  miss    %hit    total   miss   %hit    total   miss   %hit
  7424k  107k   98.55    2476k    39k  98.39     879k   200k  77.20
  7941k  107k   98.65    3502k    53k  98.46     860k   211k  75.43
 39082k  504k   98.71   15243k   293k  98.08    3420k   487k  85.75
 19926k  248k   98.75    4985k   103k  97.92    1531k   277k  81.89
 11028k  146k   98.67    5340k    95k  98.21    1856k   326k  82.42
```

http://www.brendangregg.com/cachekit.html

- Digs out useful info, calculates hit ratios
- Needs updates to measure newer CPUs

busstat

```
# busstat -w ac,pic0=clock_cycles,pic1=mem_bank0_rds 2 100
time    dev    event0             pic0    event1            pic1
2       ac0    clock_cycles  167242902    mem_bank0_rds     3144
2       ac1    clock_cycles  167254476    mem_bank0_rds     1392
4       ac0    clock_cycles  168025190    mem_bank0_rds    40302
...
```

- Measures bus PICs
- No public PIC documentation (*yet*)
  - *Has anyone actually used this other than Sun-trained engineers?*

trapstat

```
# trapstat -t 10
cpu m| itlb-miss %tim itsb-miss %tim | dtlb-miss %tim dtsb-miss %tim |%tim
-----+-------------------------------+-------------------------------+----
  0 u|       669  0.0         2  0.0 |       158  0.0         2  0.0 | 0.0
  0 k|        46  0.0         0  0.0 |     24594  1.2        13  0.0 | 1.2
=====+===============================+===============================+====
 ttl |       715  0.0         2  0.0 |     24752  1.2        15  0.0 | 1.3

# trapstat
trapstat: not implemented on i86pc
```

- MMU statistics
- Check this to see if MPSS needs tuning

lockstat

```
# lockstat -k sleep 5
Adaptive mutex block: 6 events in 5.638 seconds (1 events/sec)
Count   indv   cuml   rcnt    nsec   Lock            Caller
  2      33%    33%   0.00   71995   0x30000e723c0   clock
  1      17%    50%   0.00   85133   0x300055ffcb0   rctl_test_entity
  1      17%    67%   0.00   77176   0x300040b2888   rctl_test_entity
  1      17%    83%   0.00   70159   0x30000e72280   clock
  1      17%   100%   0.00   73192   0x30000e722c0   clock
```

- Kernel lock statistics – quite useful
- What entirely different mode of operation does `lockstat` provide?

lockstat -I

```
# lockstat -kIi 997 sleep 5

Profiling interrupt: 5066 events in 5.062 seconds (1001 events/sec)

Count indv cuml rcnt     nsec CPU+PIL                Caller
-------------------------------------------------------------------------
 4699  93%  93% 0.00      401 cpu[0]                 idle
  189   4%  96% 0.00      394 cpu[0]                 generic_idle_cpu
   38   1%  97% 0.00     1708 cpu[0]                 ufs_scan_inodes
   38   1%  98% 0.00     1938 cpu[0]                 mutex_enter
   20   0%  98% 0.00     2014 cpu[0]                 caslong
   10   0%  99% 0.00     1339 cpu[0]                 (usermode)
    5   0%  99% 0.00     3219 cpu[0]+10              set_anoninfo
...
    1   0% 100% 0.00     1246 cpu[0]                 trap
    1   0% 100% 0.00     1005 cpu[0]                 pagefault
-------------------------------------------------------------------------
```

- `-I` samples the kernel
- DTrace can both sample *and* trace

truss

- Trace *syscalls* and *signals*. Uses the `procfs` *ctl* files.
- `truss` is "violent"... *can slow target by 70%*
- Can't trace all processes at the same time

- `truss` behaves synchronously to *syscalls*
- DTrace buffers system-wide *syscall* details and reads the buffer asynchronously - so slows the target < 1%

sotruss

- Shared library tracing
- Was added in Solaris 2.6

- It uses the dynamic linker to trace details
- Not so clever with function arguments

apptrace

- Shared library tracing
- Was added in Solaris 8

- Evaluates arguments
- DTrace has this functionality

truss -ua.out

```
# truss -ua.out banner hello
execve("/usr/bin/banner", 0xFFBFFCCC, 0xFFBFFCD8)  argc = 2
resolvepath("/usr/lib/ld.so.1", "/lib/ld.so.1", 1023) = 12
...
/1: getpid()                                                = 2202 [2201]
/1: setustack(0xFF3A2088)
/1@1:     -> _init(0x22088, 0xff36cbc0, 0xa7a48, 0xff2c08d0)
/1@1:     <- _init() = 0x22088
/1@1:     -> main(0x2, 0xffbffccc, 0xffbffcd8, 0x22000)
...
/1: memcntl(0xFF260000, 6576, MC_ADVISE, MADV_WILLNEED, 0, 0) = 0
/1: close(3)                                                = 0
/1: munmap(0xFF380000, 8192)                          = 0
/1@1:       -> banner(0xffbffda7, 0x2251c, 0x5c810, 0x0)
/1@1:         -> banset(0x20, 0x2251c, 0x0, 0x0)
/1@1:         <- banset() = 0
/1@1:         -> convert(0x68, 0x2276f, 0x2276e, 0x20)
/1@1:         <- convert() = 104
/1@1:         -> banfil(0x2245c, 0x2251c, 0xffffff76, 0xffffff6f)
...
```

- Traces user functions
- -u can also trace library calls

adb/mdb

- Perform core dump analysis – *processes*
- Perform crash dump analysis – *kernel*

- `mdb` was added in Solaris 8 and enhanced in Solaris 9

mdb -k

```
# mdb -k
Loading modules: [ unix krtld genunix specfs dtrace ufs pcisch
ip sctp usba s1394 fcp fctl nca lofs zfs random crypto nfs
audiosup logindmux sd ptm md cpc sppp wrsmd fcip ]
> ::mappings
            BASE             LIMIT              SIZE        NAME
         1000000          18fa000            8fa000        ktextseg
         18fa000          1e00000            506000        valloc
        70000000         80000000          10000000        vseg32
        edd00000         f0000000           2300000        debugseg
     2a100000000      2a17e258000           7e258000        pseg
     2a750000000      2a757680000           7680000         mapseg
     30000000000      70000000000       40000000000         vseg
     70000000000      70001246000           1246000         mem64
800000000000000 800010000000000     100000000000         pmseg
> ::quit
```

- Visit kernel-land

mdb -k

```
> ::pgrep syslog | ::print proc_t
{
    p_exec = 0x300059d7e40
    p_as = 0x30003c05a38
    p_lockp = 0x30001178c40
    p_crlock = {
    _opaque         = [ 0 ]
    }
    p_cred = 0x3000037c168
    p_swapcnt =     0
    p_stat = '\002'
    p_wcode = '\0'
    p_pidflag =     0
    p_wdata = 0
    p_ppid = 0x1
    p_link = 0
    p_parent = 0x30000343360
    p_child = 0
    p_sibling =     0x300053bec18
    p_psibling = 0x300053c6fc8
...
```

- Walk kernel structures
- DTrace does this too

mdb -p

```
# mdb -p `pgrep -o syslogd`
Loading    modules: [ ld.so.1 libc.so.1 libuutil.so.1 ]
> ::mappings
    BASE    LIMIT    SIZE  NAME
   10000    22000    12000 /usr/sbin/syslogd
   32000    34000     2000 /usr/sbin/syslogd
   34000    82000    4e000 /usr/sbin/syslogd
fe77a000 fe77c000     2000 [ anon ]
fe87a000 fe87c000     2000 [ anon ]
...
ff370000 ff388000    18000 /lib/libscf.so.1
ff398000 ff39a000     2000 /lib/libscf.so.1
ff3a4000 ff3a6000     2000 [ anon ]
ff3b0000 ff3de000    2e000 /lib/ld.so.1
ff3ee000 ff3f0000     2000 /lib/ld.so.1
ff3f0000 ff3f2000     2000 /lib/ld.so.1
…
```

- Visit *userland*
- DTrace does this too (*copyin/copyout*)

Process Accounting

```
# lastcomm
man      root    term/a          0.02 secs Fri May 12 18:25
sh       root    term/a          0.00 secs Fri May 12 18:25
more     root    term/a          0.01 secs Fri May 12 18:25
sh       root    term/a          0.00 secs Fri May 12 18:25
mv       root    term/a          0.01 secs Fri May 12 18:25
sh       root    term/a          0.00 secs Fri May 12 18:25
...
```

- Log process creation
- Extended accounting adds task and flow
- Limited details, no process *args*
- DTrace does this much better for short intervals

BSM Auditing

- Logs plenty of details
- Should be customised
- Not really an *as-needed* troubleshooting tool
  - DTrace serves this role

Net-SNMP

```
$ snmpwalk -v1 -c public localhost| more
SNMPv2-MIB::sysDescr.0 = STRING: SunOS jupiter 5.10 Generic i86pc
SNMPv2-MIB::sysObjectID.0 = OID: NET-SNMP-MIB::netSnmpAgentOIDs.3
DISMAN-EVENT-MIB::sysUpTimeInstance = Timeticks: (774102766) 89 days,
14:17:07.66
SNMPv2-MIB::sysContact.0 = STRING: "System administrator"
SNMPv2-MIB::sysName.0 = STRING: jupiter
SNMPv2-MIB::sysLocation.0 = STRING: "System administrators office"
SNMPv2-MIB::sysServices.0 = INTEGER: 72
SNMPv2-MIB::sysORLastChange.0 = Timeticks: (90) 0:00:00.90
SNMPv2-MIB::sysORID.1 = OID: IF-MIB::ifMIB
SNMPv2-MIB::sysORID.2 = OID: SNMPv2-MIB::snmpMIB
SNMPv2-MIB::sysORID.3 = OID: TCP-MIB::tcpMIB
SNMPv2-MIB::sysORID.4 = OID: IP-MIB::ip
SNMPv2-MIB::sysORID.5 = OID: UDP-MIB::udpMIB
...
```

- Added to Solaris 10

Unanswered Questions

- disk I/O by process (*easily!*)
- network I/O by process
- short-lived process analysis (*easily!*)
- interrupt driver on-CPU time

- *What else couldn't you answer on older versions of Solaris?*

The source of your data is…

procfs (/proc)	kstat	TNF	*various*
/usr/bin/ps	iostat	prex	BSM audit
/usr/ucb/ps	kstat	tnfxtract	trapstat
prstat	mpstat	tnfdump	lockstat
ptree	sar	tnfmerge	mdb
pmap	vmstat	tnfview	truss
pstack		taztool	apptrace
pldd		SWAT	pacct
…<pfiles>…			lastcomm

END OF MODULE 1

- Module 1 – Solaris 8 & 9 Performance Tools
- Module 2 – *Introducing DTrace*
- Module 3 – Command Line DTrace
- Module 4 – DTrace one-liners
- Module 5 – DTrace Mentality 1
- Module 6 – Providers
- Module 7 – The D Language
- Module 8 – Advanced Scripting
- Module 9 – The DTraceToolkit
- Module 10 – DTrace Mentality 2
- References

Module 2

Introducing DTrace

- What DTrace is
- What role DTrace plays
- A one-liner Demonstration
- DTrace Scripting
- DTrace resources

What is Dtrace?

- Exists in Solaris 10 (*and later releases*)
- Also available with OpenSolaris (*and more…*)

  Check out Mac OS X Leopard!

- To run the `dtrace` utility, you must be the **`root`** user or have access to a role with the appropriate privileges (*set using RBAC*)

- Requires access to the Solaris **`global`**

Dtrace

- DTrace can be difficult to fully explain!
  The more you use it, the more potential you should see for its application.

  In the workshop, we will describe and make use of the following…:

  a) DTrace features and options

  b) The detail that it allows you to view

  c) What is "DTrace"

  d) When to use it

  e) Demonstrations

DTrace Features

- A framework for performance observability and debugging in real-time
- Examines from user space to the kernel,
  - *user-land functions and instructions*
  - *library calls and instructions*
  - *system calls*
  - *kernel functions*
  - *device driver functions*

  ... all from the same tool
- Is safe to use in production (*if applied correctly!*)

DTrace Features

- Can examine applications without restarting them (*but can also stop a running process!*)
- Dynamically inserts trace points into the kernel and running applications, called ***probes***
- Has low impact when running (*if applied to a relatively small number of probes that are firing*), and zero impact when no probes are firing
- Can trace any number of over 40,000

DTrace Features

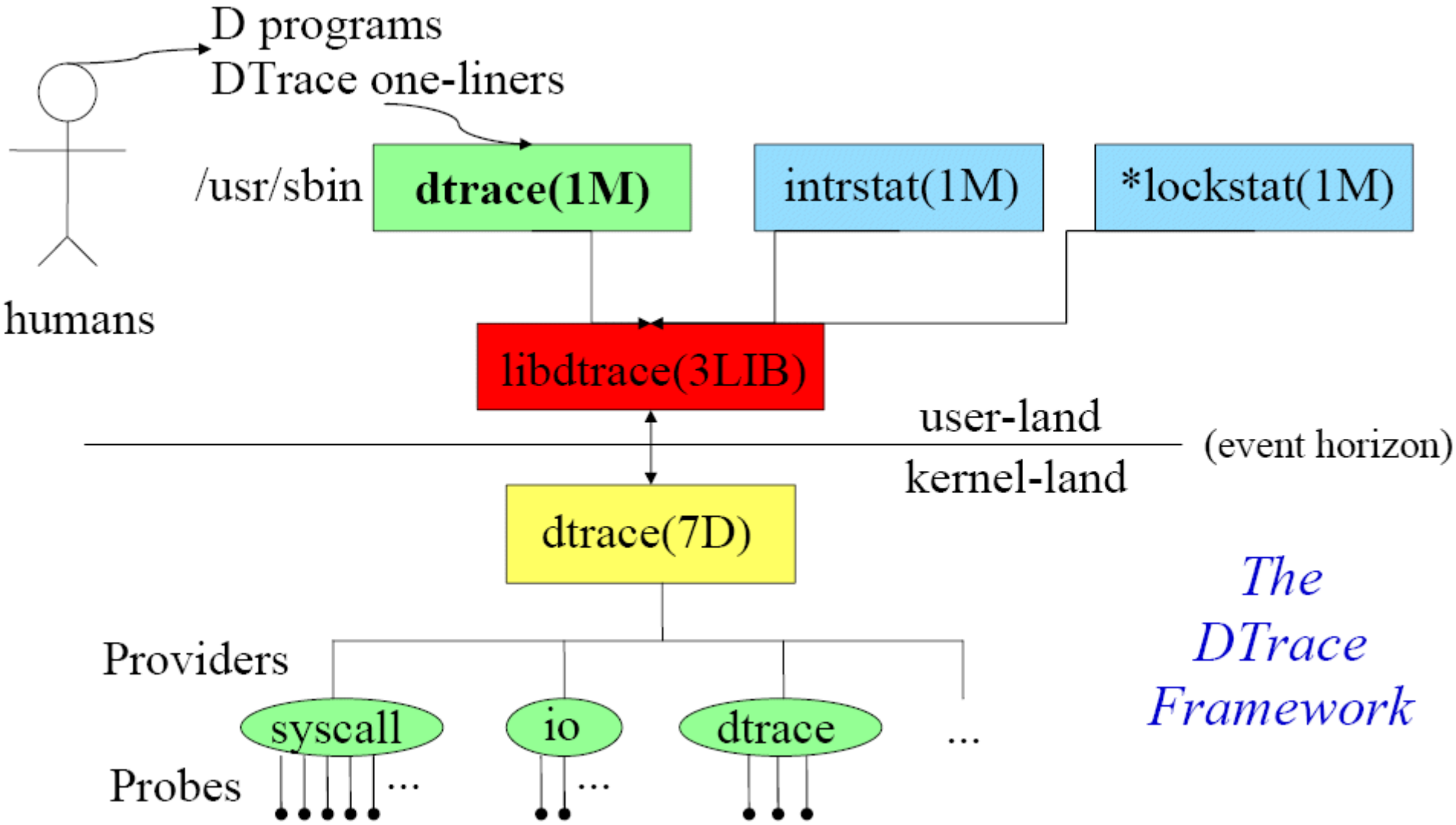
- Can trace as many application probes as it finds functions and instructions (*possibly millions*)
- Can trace system boot activity – *before init!*
- Provides a C-like language for writing custom scripts
- Has solved countless long-term performance issue mysteries – *often easily*
- One of the most significant additions to the field of Operating Systems

What DTrace is like

- DTrace has similar features to the following,
  - *truss* *tracing system calls*
  - *apptrace* *tracing library calls*
  - *truss -ua.out* *tracing user functions*
  - *prex/tnf** *tracing kernel functions*
  - *lockstat* *profiling the kernel*
  - *mdb -k* *access to kernel VM*
  - *mdb -p* *access to user VM*
  - *C, awk* *programming languages*

  ... and there is more

What is "DTrace"



The DTrace Framework

When to use DTrace

- System Administrators can use DTrace for performance analysis and troubleshooting …

1. Monitoring
   - *SNMP, sar, SunMC, SWAT ...*
2. Identification
   - kstat (*vmstat, mpstat, iostat, ...*)
   - procfs (*ps, prstat*), ...
3. Analysis

   → DTrace ←

When to use DTrace

- Application developers can use DTrace for code profiling and fault finding …

1. *Development*
   - IDEs, vim/emacs
2. *Testing*
   - Compiler profiling, coded statistics
     - → DTrace ←
3. *Production*
   - coded statistics
     - → DTrace ←

Demonstration

- This demonstration will introduce key DTrace elements and terminology
- The aim is to explain the following:

```
# dtrace -n 'syscall::exec*:return { trace(execname); }'
dtrace: description 'syscall::exec*:return ' matched 2 probes
CPU   ID                                    FUNCTION:NAME
0   5992                                     exece:return   staroffice
0   5992                                     exece:return   grep
0   5992                                     exece:return   grep
0   5992                                     exece:return   soffice
0   5992                                     exece:return   dirname
0   5992                                     exece:return   expr
0   5992                                     exece:return   basename
0   5992                                     exece:return   expr
0   5992                                     exece:return   sopatchlevel.sh
0   5992                                     exece:return   dirname
0   5992                                     exece:return   expr
...
```

Listing Probes #1

```
# dtrace -l
ID    PROVIDER      MODULE                          FUNCTION   NAME
1     dtrace                                                   BEGIN
2     dtrace                                                   END
3     dtrace                                                   ERROR
4        fbt           pool                          pool_info  entry
5        fbt           pool                          pool_info  return
6       fbt            pool                        pool_detach  entry
...
# dtrace -l | wc -l
44797
```

- `dtrace -l` lists the current probes
- For this demonstration, there were 44797 probes. The number varies depending on the OS build and which providers have been recently used.

Listing Probes #2

```
# dtrace -lv
    ID    PROVIDER            MODULE                          FUNCTION NAME
…
    8        fbt              pool                          pool_open entry

        Probe Description Attributes
                Identifier Names: Private
                Data Semantics:   Private
                Dependency Class: Unknown

        Argument Attributes
                Identifier Names: Private
                Data Semantics:   Private
                Dependency Class: ISA

        Argument Types
                args[0]: dev_t *
                args[1]: int
                args[2]: int
                args[3]: cred_t *
...
```

- `dtrace -lv` lists the probes with attribute and argument details - *Solaris 10 Update 3 & later*

Listing Probes #3

- `-P` *`provider`*
  lists the current probes for the named provider

```
# dtrace -lP sched
   ID   PROVIDER            MODULE                          FUNCTION NAME
 1426      sched              unix                 resume_from_zombie off-cpu
 1427      sched              unix                            resume off-cpu
 1433      sched              unix                           preempt preempt
 1437      sched              unix                            resume on-cpu
 1442      sched              unix                           setkpdq enqueue
 1443      sched              unix                        setfrontdq enqueue
 1444      sched              unix                         setbackdq enqueue
 1445      sched              unix                           dispdeq dequeue
 1446      sched              unix                              disp dequeue
 1451      sched              unix                             swtch remain-cpu
 1454      sched              unix                       cpu_surrender surrender
 1455      sched           genunix                     turnstile_block sleep
...
```

Finding Probes

- Since there are so many probes, being able to find useful probes is a crucial task
- `grep` can be used to filter the `dtrace -l` output, since `grep` is well known and RE's are powerful

```
# dtrace -l | grep 'syscall.*exec'
1089   syscall                                exec entry
1090   syscall                                exec return
5991   syscall                               exece entry
5992   syscall                               exece return
```

- Here we matched two forms of exec()

Specifying probes #1

```
# dtrace -ln 'syscall::exec:entry'
ID    PROVIDER      MODULE                          FUNCTION  NAME
1089   syscall                                          exec  entry
# dtrace -ln 'syscall::exec*:'
ID    PROVIDER      MODULE                          FUNCTION  NAME
1089   syscall                                          exec entry
1090   syscall                                          exec  return
5991   syscall                                         exece  entry
5992   syscall                                         exece  return
```

- First, a single probe was matched by specifying its fully qualified probe name
- Second, multiple probes were matched. `'*'` is a wildcard, as are blank fields `':::'`

  [Remember to protect meta-characters with the ' quote]

Specifying Probes #2

- Short cuts exist – dropping left-hand fields is the same as using wildcards.
- For example, the following are the same

```
dtrace:::BEGIN
:::BEGIN
BEGIN
```

- `dtrace:::BEGIN` fires when DTrace begins tracing, much the same as awk's BEGIN (*and used for the same reasons too – setting variables and printing headers*).

Specifying Probes #3

- The following are not the same:

  `syscall::read:entry`

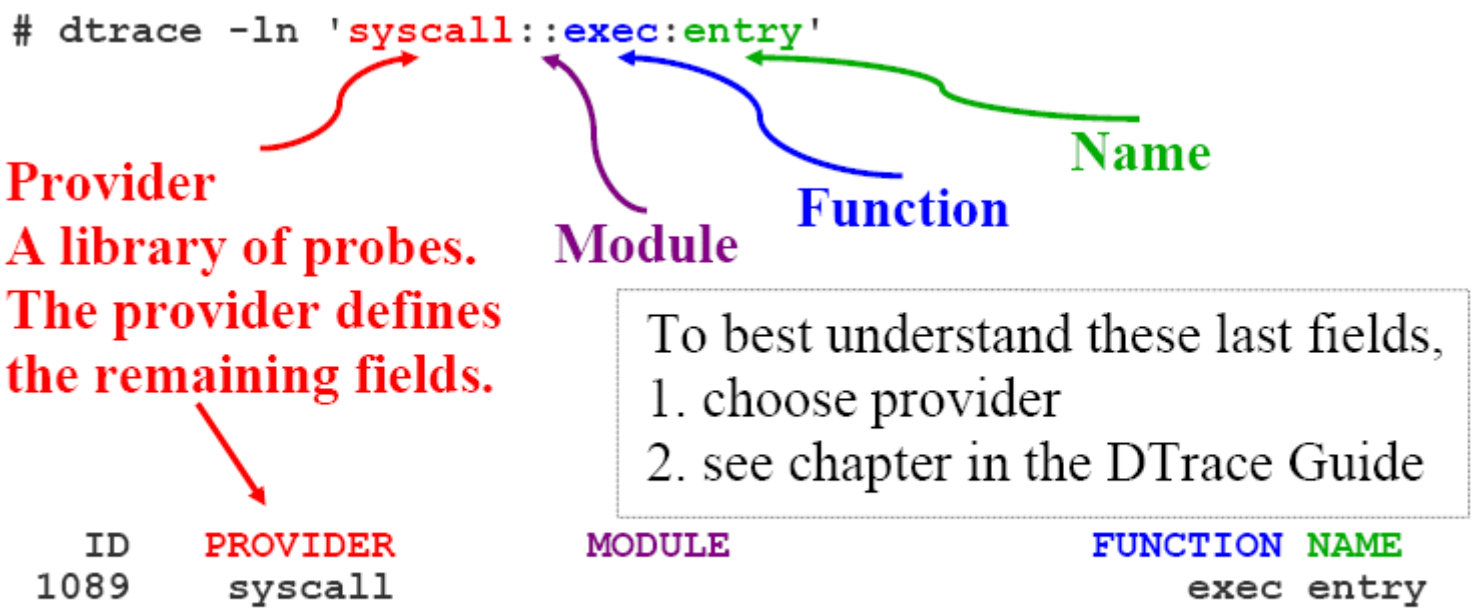
  `read:entry`

```
# dtrace -ln 'read:entry'
ID    PROVIDER   MODULE                    FUNCTION  NAME
1073   syscall                                 read  entry
12978      fbt   genunix                        read  entry
49474   pid581   libc.so.1                      read  entry
```

- If we only intended to match the syscall `read()`, this shortcut matches others by mistake.

Brendan's Programming Style Hint:
Use fully-qualified Probe names - They are safest!

Probe Names



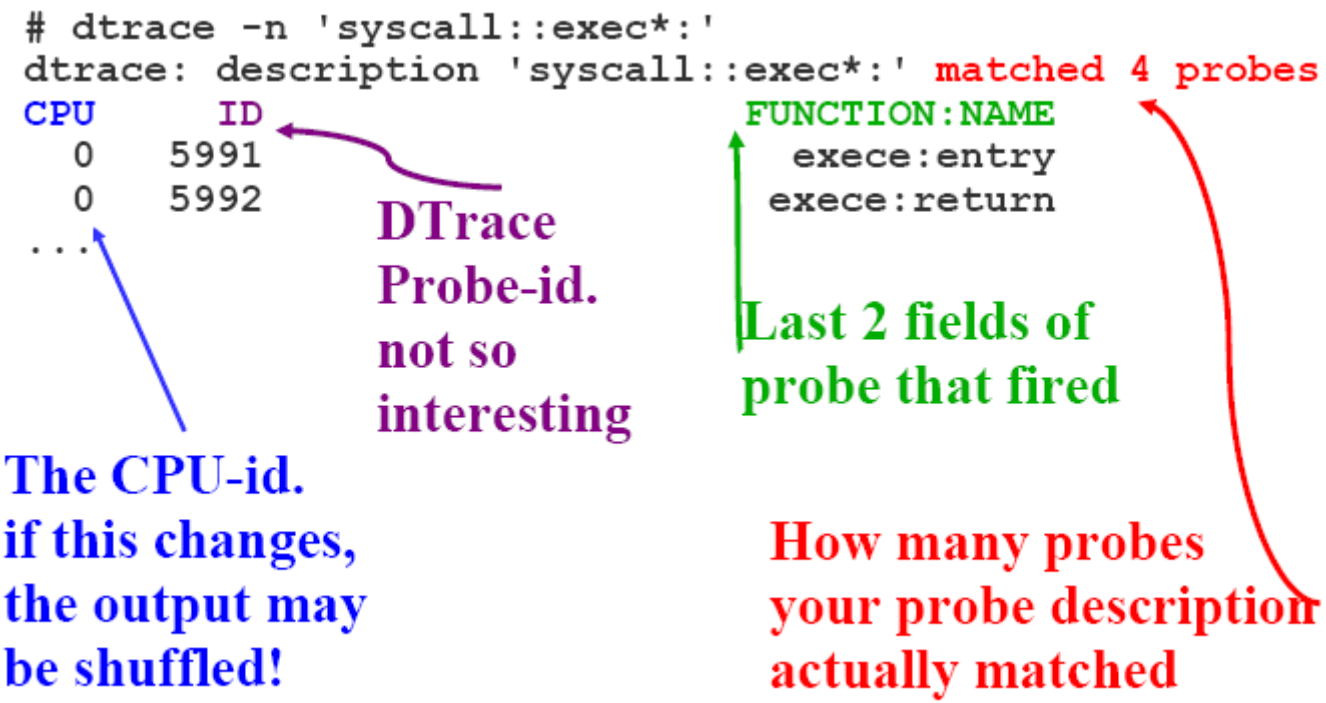
Tracing

- After finding the desired probes (`-l`), you are ready to trace activity:

```
# dtrace -n 'syscall::exec*:'
dtrace: description 'syscall::exec*:' matched 4 probes
CPU     ID                    FUNCTION:NAME
0    5991                      exece:entry
0    5992                     exece:return
0    5991                      exece:entry
0    5992                     exece:return
0    5991                      exece:entry
...
```

- This is the default output
- Each output line represents a probe firing

Default Output



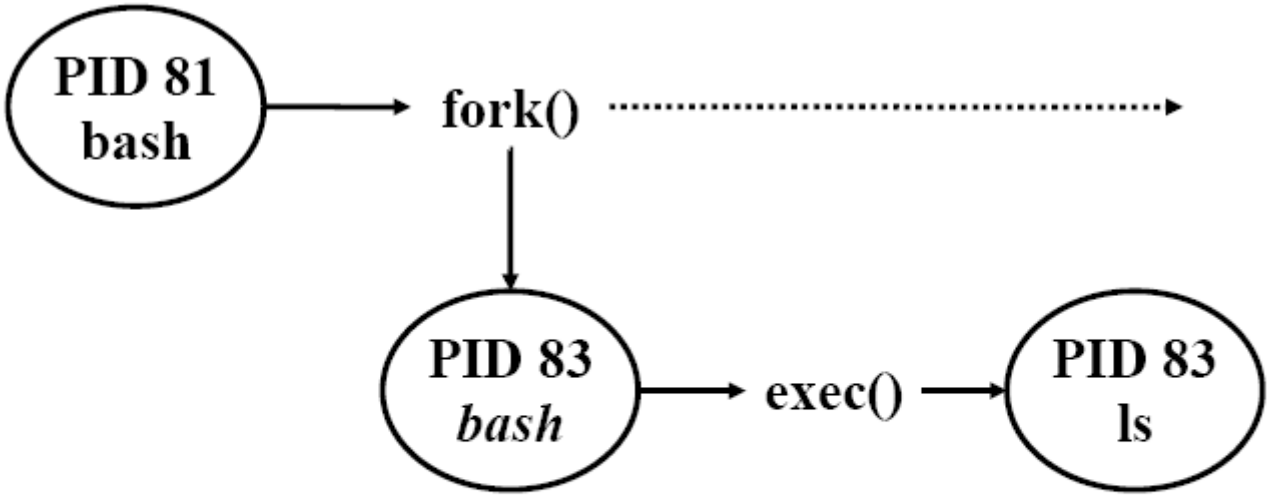
Actions

- A custom action can be performed when a probe fires:

```
# dtrace -n 'syscall::exec*: { trace(execname); }'
dtrace: description 'syscall::exec*: ' matched 4 probes
CPU     ID                                    FUNCTION:NAME
  0   5991                                      exece:entry  bash
  0   5992                                     exece:return  date
  0   5991                                      exece:entry  bash
  0   5992                                     exece:return  ls
...
```

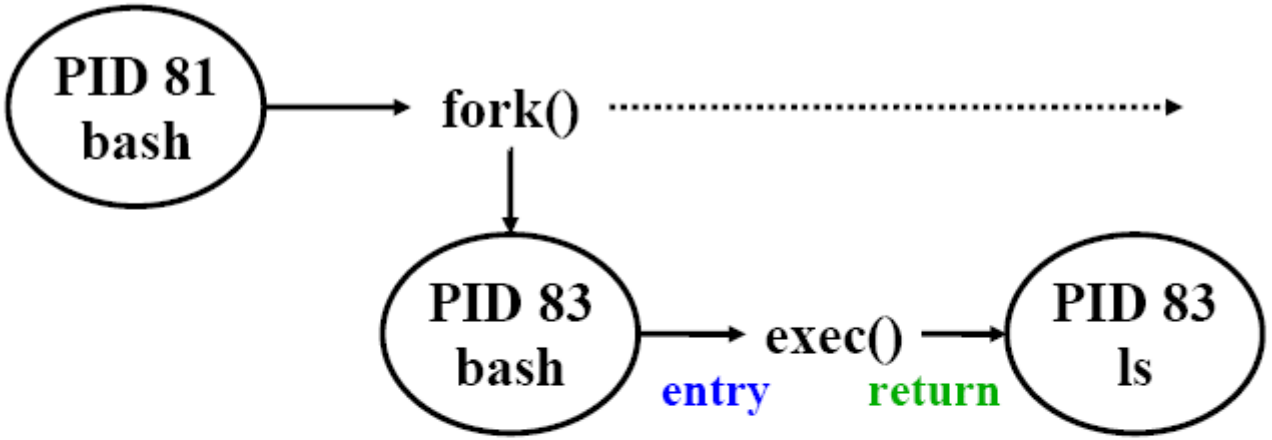
- `trace()` prints one argument
- `execname` is the in-built 'D' variable relating to the process name

Process Creation



- *fork variants: fork1(2), forkall(2), vfork(2)*
- *exec variants: exec(2), execve(2)*

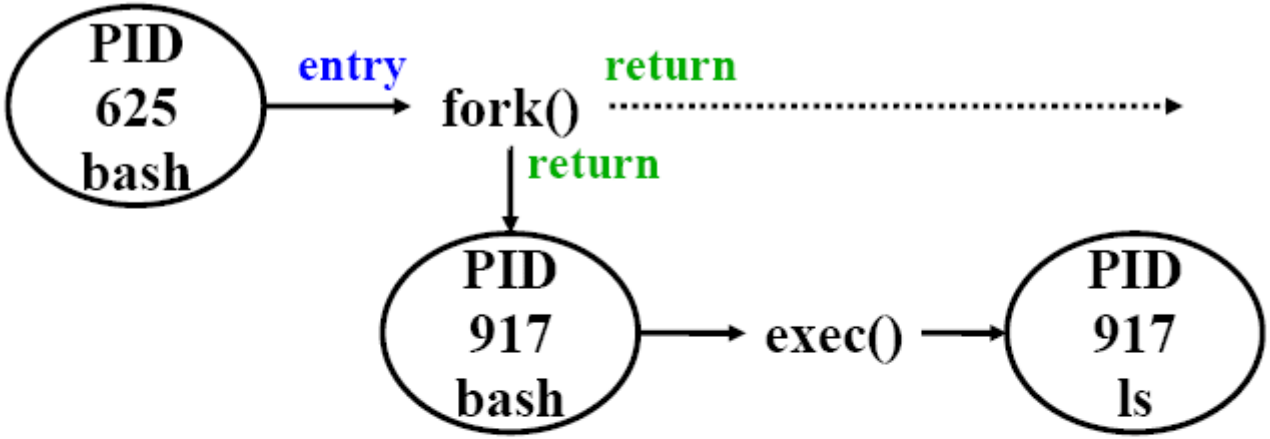
Syscall Entry and return: exec()




```
# dtrace -n 'syscall::exec*: { trace(execname); }'
dtrace: description 'syscall::exec*: ' matched 4 probes
CPU     ID                    FUNCTION:NAME
  0   5991                      exece:entry   bash
  0   5992                     exece:return   ls
...
```

- Both syscall entry and return can be traced

Syscall Entry and return: fork()




```
# dtrace -n 'syscall::fork*: { trace(pid); }'
dtrace: description 'syscall::fork*: ' matched 4 probes
CPU     ID                    FUNCTION:NAME
  0   6127                      fork1:entry       625
  0   6128                     fork1:return       917
  0   6128                     fork1:return       625
```

- Two returns! And the child returned first.

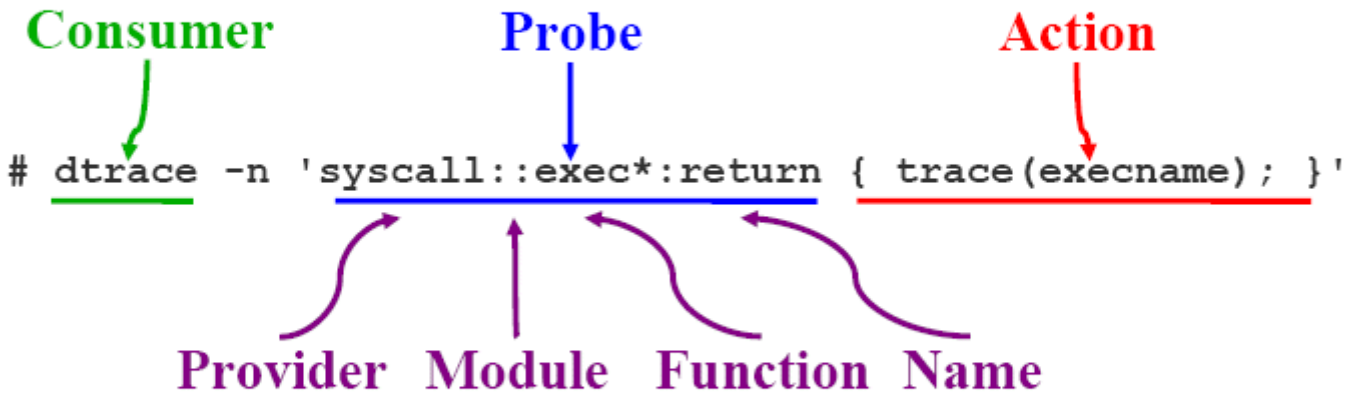
Tracing Process Creation

```
# dtrace -n 'syscall::exec*:return { trace(execname); }'
dtrace: description 'syscall::exec*:return ' matched 2 probes
CPU     ID                                    FUNCTION:NAME
  0   5992                                     exece:return  staroffice
  0   5992                                     exece:return  grep
  0   5992                                     exece:return  grep
  0   5992                                     exece:return  soffice
  0   5992                                     exece:return  dirname
  0   5992                                     exece:return  expr
  0   5992                                     exece:return  basename
  0   5992                                     exece:return  expr
...
```

- For `exec()` the return probe is traced, as this is when the destination `execname` is available on-CPU
- This shows new processes from running "`soffice`"

Terminology

- A summary of DTrace terminology,



It's important to be able to talk-the-talk...

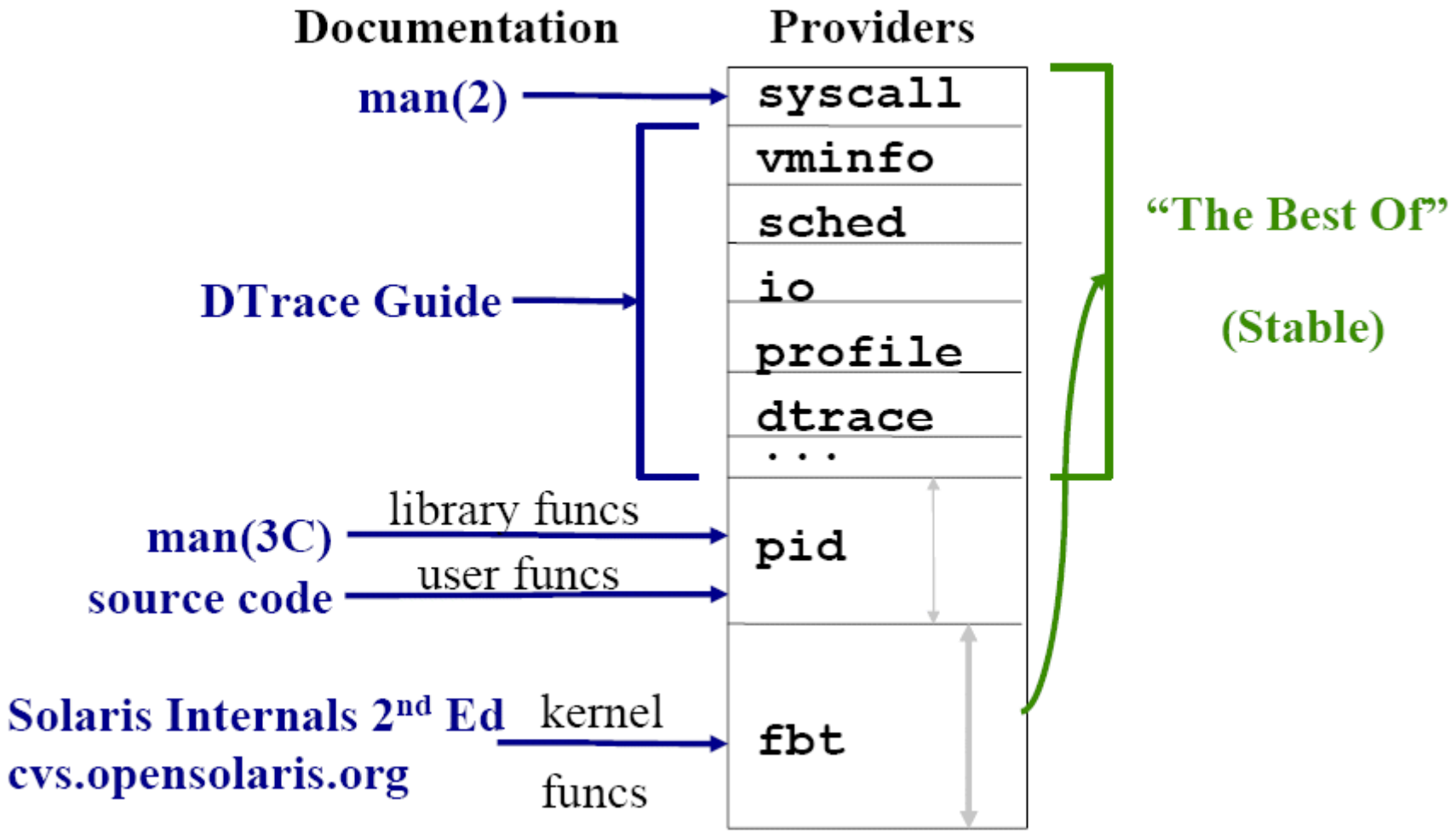
Provider Info

- There are many providers,
  - `syscall` System call entry/return probes
  - `vminfo` Virtual Memory statistic probes
  - `sysinfo` Classic sysinfo statistic probes
  - `io` Disk and NFS events
  - `sched` system scheduling events
  - `profile` fixed sampling
  - `dtrace` program BEGIN/END probes
  - `pid` user-level tracing
  - `fbt` raw kernel tracing
  - ...

Provider Questions

- *Where are syscalls documented?*
- The pid provider traces user-level activity:
  Where are library functions documented?
  Where are user functions documented?
- The fbt provider traces kernel-level activity:
  Where are kernel functions documented?
- DTrace provides its own custom providers:
  Where would they be documented?

Documentation



Action Intro

- `trace()` prints 1 argument
- `printf()` may also be used
- DTrace built-in variables include:
  - `execname` process name
  - `pid` process ID
  - `timestamp` time since boot, nanoseconds
  - `probefunc` probe function component
  - `probename` probe name component
  - `curthread` pointer to current thread
  - `curpsinfo` pointer to `psinfo` like structure

`printf()` Example

- Enhancing our previous one-liner,

```
# dtrace -n 'syscall::exec*:return { printf("%6d %s", pid, execname); }'
dtrace: description 'syscall::exec*:return ' matched 2 probesCPU ID FUNCTION:NAME
0    5992    exece:return                        28751  staroffice
0    5992    exece:return                        28752  grep
0    5992    exece:return                        28755  grep
0    5992    exece:return                        28753  soffice
...
```

- format characters include:
  - %d integers
  - %f floats
  - %s strings
  - %S safe strings – *escaped binary characters*
  - %Y text formatted time (*use with* `walltimestamp`)

Style Hint:
Use spaces after commas

walltimestamp

```
# dtrace -n 'syscall::exec*:return { printf("%-20Y %6d %s", walltimestamp, pid,
execname); }'
dtrace: description 'syscall::exec*:return ' matched 2 probesCPU ID FUNCTION:NAME
0 5992      execve:return    2006 May 22 02:12:36  28762 staroffice
0 5992      execve:return    2006 May 22 02:12:36  28763 grep
0 5992      execve:return    2006 May 22 02:12:36  28765 grep
0 5992      execve:return    2006 May 22 02:12:36  28766 soffice
0 5992      execve:return    2006 May 22 02:12:36  28767 dirname
0 5992      execve:return    2006 May 22 02:12:36  28764 expr
0 5992   execve:return       2006 May 22 02:12:36  28768 basename
 ...
```

- Our output still contains the DTrace defaults. This can be eliminated using `-q`.
- Our command is > 80 characters. This can be better managed using a script file.

quiet mode

```
# dtrace -qn 'syscall::exec*:return { printf("%-20Y %6d
   %s\n",walltimestamp, pid, execname); }'
2006 May 22 02:14:36 28773 staroffice
2006 May 22 02:14:36 28774 grep
2006 May 22 02:14:36 28776 grep
2006 May 22 02:14:36 28777 soffice
2006 May 22 02:14:36 28778 dirname
2006 May 22 02:14:36 28775 expr
2006 May 22 02:14:36  28779 basename
2006 May 22 02:14:36 28780 expr
2006 May 22 02:14:36 28781 sopatchlevel.sh
2006 May 22 02:14:36 28782 dirname
^C
```

- `dtrace -q` suppresses the default output
- A \n is now needed to terminate each line

DTrace Script File

```
# cat -n exec.d
1 #!/usr/sbin/dtrace -qs
2
3 syscall::exec*:return
4 {
5         printf("%-20Y %6d %s\n", walltimestamp, pid, execname);
6 }
#
# chmod u+x exec.d
#
# ./exec.d
2006 May 22 02:20:59  28788  staroffice
2006 May 22 02:20:59  28789  grep
2006 May 22 02:20:59  28791  grep
2006 May 22 02:20:59  28792  soffice
2006 May 22 02:20:59  28793  dirname
...
```

Style Hint:
Indent actions

- So far, so good. The script file is easier to edit.
- Some improvements can be made...

DTrace Scripting

```
# cat -n exec.d
1 #!/usr/sbin/dtrace -s
2
3 #pragma D option quiet
4
5 dtrace:::BEGIN
6 {
7         printf("%-20s %6s %s\n", "TIME", "PID", "CMD");
8 }
9
10 syscall::exec*:return
11 {
12         printf("%-20Y %6d %s\n", walltimestamp, pid, execname);
13 }
#
# ./exec.d
TIME                  PID   CMD
2006 May 22 02:24:17 28801 staroffice
2006 May 22 02:24:17 28802 grep
2006 May 22 02:24:17 28804 grep
2006 May 22 02:24:17 28805 soffice
...
```

DTrace Scripting

- Seems like awk!
- `#pragma D option quiet` is the same as `-q`, however is more obvious (*especially when more options are being used in the script*).
- Printing a heading serves to both label the output and to indicate when DTrace has began tracing

  `dtrace:::BEGIN` probe fires at start (*heading*)

  `dtrace:::END` probe fires at end (*reports*)

curpsinfo->pr_psargs

- To print more than just the execname, try:

```
# dtrace -qn 'syscall::exec*:return { printf("%6d %s\n", pid, curpsinfo->pr_psargs); }'
29396 /bin/sh /usr/bin/soffice
29397 grep StarOffice 7 /export/home/brendan/.sversionrc
29398 grep StarOffice 7 /export/home/brendan/.sversionrc
29396 /bin/sh /usr/staroffice7/program/soffice
29400 /usr/bin/sh /usr/bin/dirname /usr/staroffice7/program/soffice
29400 /usr/bin/expr /usr/staroffice7/program/soffice/ : \(/\)/*[^/]*//*$ |
/usr/staro
29402 /usr/bin/sh /usr/bin/basename /usr/staroffice7/program/soffice
29402 /usr/bin/expr //usr/staroffice7/program/soffice : \(.*[^/]\)/*$ :
.*/\(..*\) :
29404 /bin/sh /usr/staroffice7/program/sopatchlevel.sh
29405 /usr/bin/sh /usr/bin/dirname /usr/staroffice7/program/sopatchlevel.sh
29405 /usr/bin/expr /usr/staroffice7/program/sopatchlevel.sh/ :\(/\)/*[^/]*//*$ | /u
29406 uname -s
^C
```

DTrace Resources

- OpenSolaris DTrace Community
  http://www.opensolaris.org/os/community/dtrace
- DTrace Guide
  http://docs.sun.com/app/docs/doc/817-6223
- DTrace Tools
  http://www.brendangregg.com/dtrace.html
- *Solaris Performance and Tools: DTrace and MDB Techniques for Solaris 10 and OpenSolaris*.
  McDougall/Gregg/Mauro ISBN: 0-13-156819-1

End of Module 2

- Module 1 – Solaris 8 & 9 Performance Tools
- Module 2 – Introducing DTrace
- Module 3 – *Command Line DTrace*
- Module 4 – DTrace one-liners
- Module 5 – DTrace Mentality 1
- Module 6 – Providers
- Module 7 – The D Language
- Module 8 – Advanced Scripting
- Module 9 – The DTraceToolkit
- Module 10 – DTrace Mentality 2
- References

Module 3

Command Line DTrace

- The *syscall* Provider
- *entry/return* Arguments
- Predicates
- Aggregations
- Stack tracing
- Intro to *sysinfo* Provider
- Intro to *profile* Provider

syscall Provider

- This provider traces system call entry and returns
- *syscalls* are the interface between user-land and the kernel, and reflect much of an application's behaviour
- *syscalls* are well documented – man(2)
- This provider is a great place to start learning DTrace

entry Arguments

- The *syscall* entry arguments are available as unsigned 64-bit ints, with the names: *`arg0, arg1,arg2, ...`*
- These arguments can be casted if need be to the appropriate types. eg, *`(int)arg0`*
- Typed versions may be provided as *`args[0],args[1], args[2], ...`*
- Arguments are listed in the *syscall*'s `man` page

entry Argument Examples

- syscall::read:entry,
  - *arg0* (int) file descriptor
  - *arg1* (void *) buffer
  - *arg2* (size_t) requested read size
- syscall::mkdir:entry,
  - *arg0* (char *) path
  - *arg1* (mode_t) mode
- String pointers can't be read unless you dereference them. Use `copyinstr()`.
- Entry Arguments: Integers

entry Arguments: Integers

```
# dtrace -n 'syscall::read:entry { trace(arg2); }'
dtrace: description 'syscall::read:entry ' matched 1 probe
CPU  ID                    FUNCTION:NAME
0  1073                       read:entry 8192
0  1073                       read:entry 8192
0  1073                       read:entry 8192
0  1073                       read:entry 1495
0  1073                       read:entry 1329
0  1073                       read:entry 785
0  1073                       read:entry 4096
0  1073                       read:entry 4096
...
```

- Integer arguments are easy to use.
- Here `read()`'s `arg2` is printed – the requested read size. Most are over 1 Kbyte.

entry Arguments: Strings

```
# dtrace -n 'syscall::open:entry { trace(copyinstr(arg0)); }'
dtrace: description 'syscall::open:entry ' matched 1 probe
CPU  ID                                    FUNCTION:NAME
0  1077                                      open:entry  /var/ld/ld.config
0  1077                                      open:entry  /usr/lib/libc.so.1
0  1077                                      open:entry  /var/ld/ld.config
0  1077                                      open:entry  /usr/lib/libgen.so.1
0  1077                                      open:entry  /usr/lib/libc.so.1
0  1077                                      open:entry  /var/ld/ld.config
0  1077                                      open:entry  /usr/lib/libgen.so.1
0  1077                                      open:entry  /usr/lib/libc.so.1
0  1077                                      open:entry  /var/ld/ld.config
0  1077                                      open:entry  /usr/lib/libc.so.1
...
```

- `copyinstr()` is a convienent function to fetch strings from user-land to the kernel.
- `copyin()` also exists, for fetching any data.

return Code

- The syscall return code is available from the `return` probe as *`arg0`*.
- The man page for the *syscall* should explain what the return code is.
- In general, the return code is,

  `-1` failure

  `>= 0` success
- If a *syscall* fails, the error code is available as the DTrace built-in *errno*.
  See `/usr/include/sys/errno.h` for a description.

return Code Example

- For example, `syscall::read:return` has,
  `arg0` number of successful bytes read,
  or
  `-1` for failure

```
# dtrace -n 'syscall::read:return { trace(arg0); }'
dtrace: description 'syscall::read:return ' matched 1 probe
CPU  ID                                    FUNCTION:NAME
0  1074                                      read:return   80
0  1074                                      read:return   45
0  1074                                      read:return   63
0  1074                                      read:return   63
0  1074                                      read:return   80
0  1074                                      read:return  315
0  1074                                      read:return   80
...
```

- Most actual bytes read are < 1 Kbyte.

return Code Hints

- The `return` code is often typed as an *int*, but sometimes (x86) isn't:

```
# dtrace -n 'syscall::open:return { trace(arg0); }'
dtrace: description 'syscall::open:return ' matched 1 probe
CPU   ID                                    FUNCTION:NAME
0   1078                                      open:return   4294967295
0   1078                                      open:return            3
0   6280                                    open64:return   4294967295
^C
# dtrace -n 'syscall::open:return { trace((int)arg0); }'
dtrace: description 'syscall::open:return ' matched 1 probe
CPU  ID                                    FUNCTION:NAME
0  1078                                      open:return  -1
0  1078                                      open:return   3
0  6280                                    open64:return  -1
```

- Here a `cat /etc/shadow` was run as non-root on x86, with *arg0* uncasted and casted.

Questions

- Would it be useful to only trace syscalls that failed? (ie, `return arg0 == -1`)
- Would it be useful to trace *syscalls* with unusual entry arguments: eg, `read()`s of a size less than 8 bytes?
- Would it be useful to match on `execname` and `pid`?
- You could just dump everything and `grep` later.
  But there is a better way...

Predicates

- Allow filtering of trace data
- Are a boolean expression used to determine if an action is performed
- *For example:*

```
# dtrace -n 'syscall::read:entry /arg2 < 8/ { printf("%-16s %d", execname, arg2); }'
dtrace: description 'syscall::read:entry ' matched 1 probe
CPU  ID                                    FUNCTION:NAME
0  1073                                       read:entry  bash 1
0  1073                                       read:entry  bash 1
0  1073                                       read:entry  bash 1

...
```

- This matches < 8 byte requested `read()`s.

Predicates

- General Syntax:

```
probe-description
/predicate/
{
    action;action; ...
}
```

Style Hint:
Place the probe, predicate and actions on separate lines

- This is the most common way DTrace does `if-then-else` statements (*which DTrace does not have directly*).

Predicate Examples

- `/execname == "ls"/`
  process is `ls` - will match multiple processes, all called `ls`
- `/(int)arg0 < 0/`
  arg0 as int is less than `0`
- `/pid != 0/`
  not the kernel
- `/pid/`
  same as above
- `/execname != "dtrace" && pid != 0/`
  neither the dtrace command nor the kernel

truss-like DTrace

```
# dtrace -n 'syscall:::entry /execname == "ls"/ { printf("%x %x %x",
arg0, arg1, arg2); }'
dtrace: description 'syscall:::entry ' matched 231 probes
CPU  ID                                    FUNCTION:NAME
0  6247                                 resolvepath:entry 8047fed 804738c 3ff
0  6119                                   sysconfig:entry 6 468d fec1d444
0  6247                                 resolvepath:entry d27fd9dc 804738c 3ff
0  6093                                       xstat:entry 2 8047fed 80477b8
0  1077                                        open:entry d27f7a24 0 0
0  6093                                       xstat:entry 2 d27fbf38 8047070
0  6247                                 resolvepath:entry d27fbf38 80470f8 3ff
0  1077                                        open:entry d27fbf38 0 0
...
```

- This snoops syscalls from all processes called `ls`
- It prints three arguments in hex (*or tries to*)
- The output is verbose. Much more so for bigger apps. Remember `truss -c`?

Aggregations

- A DTrace variable type.
- In rough order of complexity,

» char
» int
» long
» double
» float
» pointer Variable
» array
» associative array
» aggregation
» struct
» object

Common Programming Language Types

Why Aggregations First?

- Aggregations are introduced early because we want you to use them as much as possible!
- Their advantages are:
  - They summarise the data in often the most appropriate way – providing the final report
  - Aggregations are fast – they do not lock between CPUs in the same way as other data types

Aggregation: count()

```
# dtrace -n 'syscall:::entry { @fred = count(); }'
dtrace: description 'syscall:::entry ' matched 231 probes
^C
          11783
```

- The Aggregation name is `@fred`
- The Aggregation function is `count()` -which counts occurrences
- When *Ctrl-C* is typed, DTrace prints `@fred`. This is for convenience. Manually printing aggregations is possible, if desired.
- Here, DTrace observed 11783 system calls.

Aggregation by execname

```
# dtrace -n 'syscall:::entry { @fred[execname] = count(); }'
dtrace: description 'syscall:::entry ' matched 231 probes
^C
svc.configd                                                       1
svc.startd                                                        3
nautilus                                                          3
httpd                                                             6
nscd                                                             38
java                                                             73
bash                                                             95
dtrace                                                          119
sshd                                                            128
acroread                                                        321
find                                                          15068
```

- The key is now `execname`, using `@fred[execname]`
- This is producing a frequency count by `execname` report
- Here, `find` processes caused 15,068 *syscalls*

Aggregation by syscall

```
# dtrace -n 'syscall:::entry /execname == "find"/ { @fred[probefunc] = count(); }'
dtrace: description 'syscall:::entry ' matched 231 probes
^C

    write                                                    47
    fcntl                                                   127
    fsat                                                    127
    close                                                   129
    fstat64                                                 254
    fchdir                                                  256
    getdents64                                              261
    acl                                                    3131
    gtime                                                  3131
    lstat64                                                3132
```

- `probefunc` is the 3rd probe field, which for the *syscall* provider is the *syscall* name
- Here, we can see which *syscalls* `find` is calling

Aggregation Syntax

- The general syntax is:
  `@name[key] = function(args)`
- The name and the key are optional
- Examples,
  - `@num[execname] = count();`
  - `@[execname] = count();`
  - `@total = count();`
- Multiple keys can be used. Eg,
  `@num[pid, execname] = count();`

Brendan's Style Hint:
I like to name my aggregates

Multiple Keys

```
# dtrace -n 'syscall:::entry { @num[pid, execname] = count(); }'
dtrace: description 'syscall:::entry ' matched 231 probes
^C
      3104 gnome-terminal                                               2
      3153 gnome-terminal                                               2
      3098 nautilus                                                     3
      4804 java                                                        10
       599 sshd                                                        24
      8117 acroread                                                    45
     28921 dtrace                                                      71
       113 nscd                                                       270
     28920 find                                                      3418
```

- The key is now *[pid, execname]*
- DTrace has printed them in neat columns Any fancier key combinations, and DTrace may not be so neat – we'll need to tweak the output.

Aggregating Functions

- So far we have only seen `count()`.
  Which is certainly fairly useful.
- Aggregating functions:
  - `count()` count occurrences
  - `sum(value)` sum value
  - `avg(value)` average value
  - `min(value)` find value minimum
  - `max(value)` find value maximum
  - `quantize(value)` power-of-2 distribution plot
  - `lquantize(value, min, max, step)` linear distribution plot

Aggregation Demos

- The Aggregating functions will be used to analyse the behaviour of the following wc command:

```
# wc /usr/share/man/windex
```

- This file is 1064644 bytes (1040 Kbytes)
- The wc command will read through the input file – so there should be many *syscalls* to trace.

Aggregation sum()

```
# dtrace -n 'syscall::read:entry { @bytes[execname] = sum(arg2); }'
dtrace: description 'syscall::read:entry ' matched 1 probe
^C
bash                                                              4
sshd                                                          98304
wc                                                           942080
```

- This sums the requested `read()` bytes by `execname`
- `wc` requested 942080 bytes. This almost matches the file:

```
# ls -l /usr/share/man/windex
-rw-r--r--1 root root 931886 Dec 22 14:23 /usr/share/man/windex
```

  - *Why would there be a difference?*

sum() on return

- Summing the return is now attempted,

```
# dtrace -n 'syscall::read:return { @bytes[execname] = sum(arg0); }'
dtrace: description 'syscall::read:return ' matched 1 probe
^C
sshd                                                              188
wc                                                             931886
```

- Perfect match!

```
# ls -l /usr/share/man/windex
-rw-r--r--1 root root 931886 Dec 22 14:23 /usr/share/man/windex
```

  - *BE CAREFUL: syscalls can return -1 for failure – which would wreck our sum( ) value. A predicate could be used to avoid this.*

Questions

- What would be the size of each read?
- How many reads would occur?

Aggregation avg()

- The average read size can be aggregated:

```
# dtrace -n 'syscall::read:return { @bytes[execname] = avg(arg0); }'
dtrace: description 'syscall::read:return ' matched 1 probe
^C
bash                                                              1
sshd                                                             37
wc                                                             8103
```

- The average read size is 8103 bytes.
- Since 8 Kbytes == 8192 bytes, it sounds like there is an 8 Kbyte ceiling. Could we check this?

Aggregation min(), max()

- The following fetches the *min* then *max*:

```
# dtrace -n 'syscall::read:return { @bytes[execname] = min(arg0); }'
dtrace: description 'syscall::read:return ' matched 1 probe
^C
wc                                                              0
bash                                                            1
sshd                                                            2

# dtrace -n 'syscall::read:return { @bytes[execname] = max(arg0); }'
dtrace: description 'syscall::read:return ' matched 1 probe
^C
bash                                                            1
sshd                                                           52
wc                                                           8192
```


- 8.00 Kbytes is indeed the maximum.

Aggregation count()

- Counting syscalls is always useful:

```
# dtrace -n 'syscall::read:entry { @num[execname] = count(); }'
dtrace: description 'syscall::read:entry ' matched 1 probe^C
bash                                                              4
sshd                                                              8
wc                                                              115
```

- 115 `reads()`s occurred.
- This makes sense,
  - *average read size = 8103 bytes*
  - *file size = 931886 bytes*
  - *931886 / 8103 = 115.005*

Aggregations so far

- By running,
  - `count()`
  - `sum()`
  - `min(), max()`
  - `avg()`

  we have learnt much about the behaviour of the `wc` command.

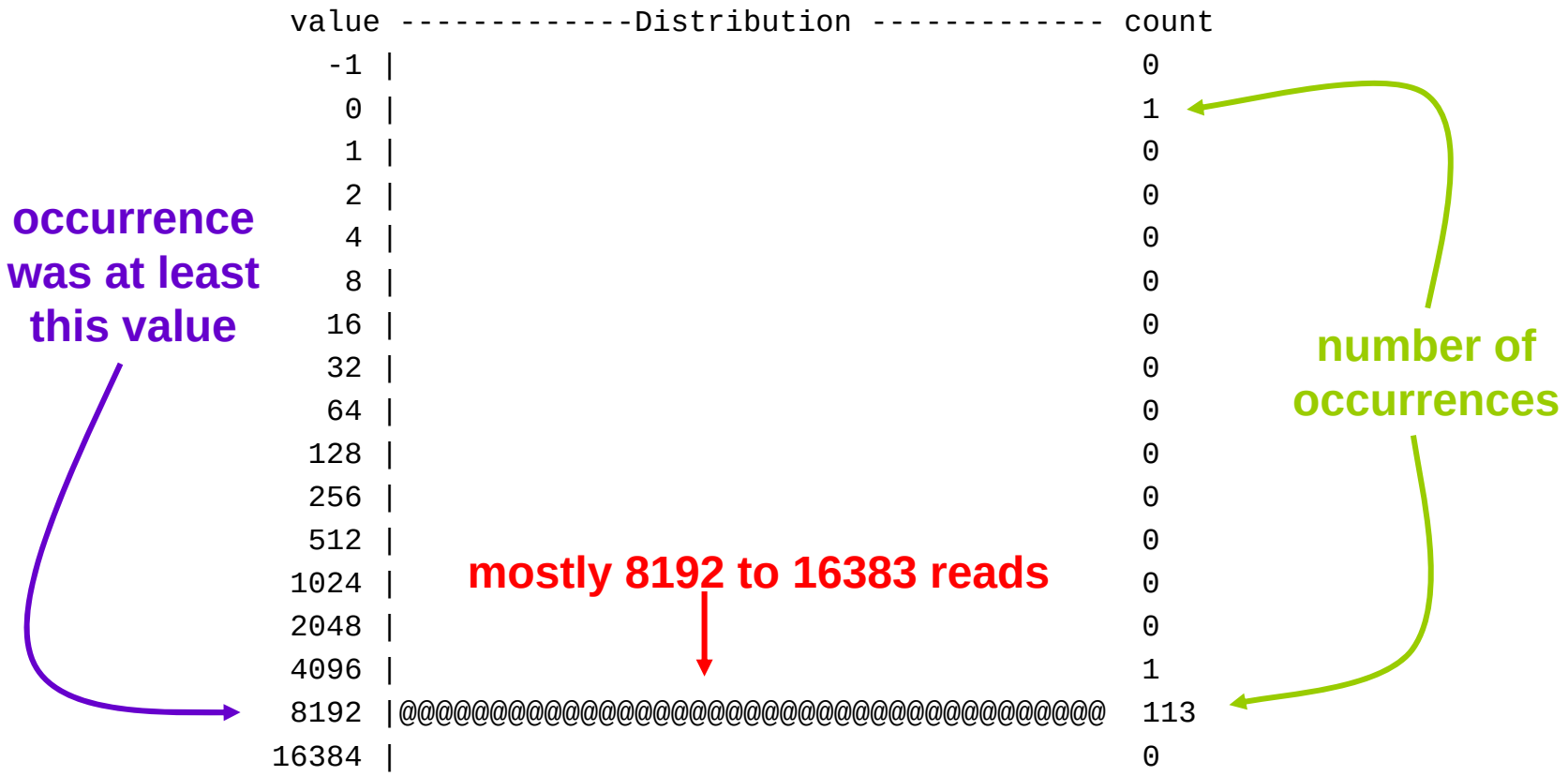
- Similar knowledge can be gained much more quickly using `quantize()`.

Aggregation quantize()

```
# dtrace -n 'syscall::read:return { @dist[execname] = quantize(arg0); }'
dtrace: description 'syscall::read:return ' matched 1 probe
^C
...
wc

           value ------------Distribution ------------ count
              -1 |                                         0
               0 |                                         1
               1 |                                         0
               2 |                                         0
               4 |                                         0
               8 |                                         0
              16 |                                         0
              32 |                                         0
              64 |                                         0
             128 |                                         0
             256 |                                         0
             512 |                                         0
            1024 |                                         0
            2048 |                                         0
            4096 |                                         1
            8192 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  113
           16384 |                                         0
```

Distribution plots



- Conveys a *count*, *min*, *max*, *avg*, (*and with some mental calculations*) a *sum*; all at once!

Aggregation lquantize()

- When power-of-2 distributions are not suitable, `lquantize` provides linear customisable distributions

- The arguments are:
  `lquantize(value, min, max, step)`

Aggregation lquantize()

```
# dtrace -n 'syscall::read:entry { @dist[execname] = lquantize(arg0, 0, 128, 1); }'
dtrace: description 'syscall::read:entry ' matched 1 probe
^C
bash

           value ------------Distribution ------------ count
            < 0 |                                       0
              0 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 4
              1 |                                       0

...
wc

           value ------------Distribution ------------ count
              2 |                                       0
              3 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 115
              4 |                                       0
```

- This shows that wc used File Descriptor 3 for `read()`s, while `bash` used File Descriptor 0 (*stdin*).

Raw Data

- Remember that raw data can always be dumped, for other post processing:

```
# dtrace -n 'syscall::read:return /execname == "wc"/ { trace(arg0); }'
dtrace: description 'syscall::read:return ' matched 1 probe
CPU  ID                                                    FUNCTION:NAME
0  1074                                                      read:return  8192
0  1074                                                      read:return  8192
0  1074                                                      read:return  8192
...
0  1074                                                      read:return  8192
0  1074                                                      read:return  6190
0  1074                                                      read:return     0
^C
```

- Aggregations are great summaries, but sometimes you just want the raw data.

Stack Traces

- DTrace provides 3 stack trace functions:
  - `stack()` kernel stack trace
  - `ustack()` user stack trace
  - `jstack()` java stack trace

- These explain why your event is occurring – the ancestry

- `dtrace`(1M) needs the process to still exist to evaluate symbols for `ustack()` and `jstack()`.

ustack()

```
# dtrace -n 'syscall::read:return /execname == "bash"/ { ustack(); }'
dtrace: description 'syscall::read:return ' matched 1 probe
CPU     ID                                    FUNCTION:NAME
0     1074                                      read:return
                          libc.so.1`_read+0x15
                          bash`rl_getc+0x1f
                          bash`rl_read_key+0xad
                          bash`readline_internal_char+0x5c
                          bash`0x80abf72
                          bash`0x80abf8c
                          bash`readline+0x37
                          bash`0x80675ad
                          bash`0x8067525
                          bash`0x8067d2b
                          bash`0x80686b4
                          bash`0x8068275
                          bash`yyparse+0x12f
                          bash`parse_command+0x56
                          bash`read_command+0x8c
                          bash`reader_loop+0xdd
                          bash`main+0x638
                          bash`0x806395a
^C
```

ustack() Short Lived Processes

- Now we will run `ustack()` on the `read()` from the short-lived `wc` command:

```
# dtrace -n 'syscall::read:return /execname == "wc"/ { ustack(); }'
dtrace: description 'syscall::read:return ' matched 1 probe
CPU     ID                                    FUNCTION:NAME
0     1074                                      read:return
                          0xd279e465
                          0xd27856de
                          0x8050c70
                          0x8050a56
```

- `wc` completes and disappears before the `dtrace`(1M) command can read its symbol table.

ustack() and mdb

- One technique is to use mdb to set a breakpoint on exit (*another uses DTrace*):

```
$ mdb /usr/bin/wc
> exit:b
> :r /usr/share/man/windex
>  11821   113846    931886  /usr/share/man/windex
mdb: stop at 0x805090c
mdb: target stopped at:
PLT:exit: jmp *0x8062014
>
# dtrace -n 'syscall::read:return /execname == "wc"/ { ustack(); }'
dtrace: description 'syscall::read:return ' matched 1 probe
CPU   ID                                    FUNCTION:NAME
0    1074                                     read:return
              libc.so.1`_read+0x15
              libc.so.1`fread+0xb6
              wc`main+0x184
              wc`0x8050a56
              …
```

ustack() Aggregations

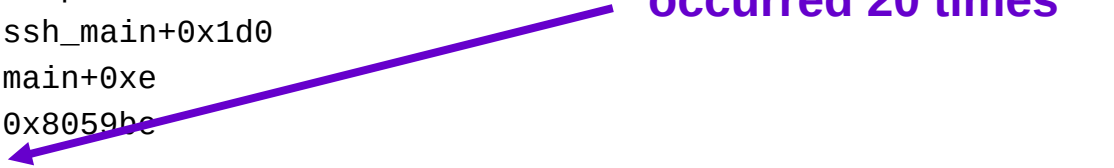
- The entire stack trace can be used as a key.
- This measures the most frequent stack trace that caused the probe.
- The stack can be truncated using an integer argument: eg, `ustack(5)` for 5 lines only.

```
# dtrace -n 'syscall::read:return /execname == "zsh"/ { @num[ustack()] = count(); }'
dtrace: description 'syscall::read:return ' matched 1 probe
^C

              libc.so.1`_read+0x15
              libc.so.1`getlogin+0x2a
              zsh`createparamtable+0x1e2
              zsh`setupvals+0x5bd
              zsh`zsh_main+0xlae
              zsh`zsh_main+0xe
              zsh`zsh_0x8059b9e
                  1
```

…continued

```
libc.so.1`_read+0x15
zle.so`0xd251fd22
zle.so`getkey+0x130
zle.so`0xd251f520
zle.so`getkeymapcmd+0x48
zle.so`getkeycmd+0x2c
zle.so`zlecore+0x6b
zle.so`zleread+0x403
zsh`autoload_zleread+0x3e
zsh`0x8079c59
zsh`ingetc+0x6d
zsh`0x80734fa
zsh`gettok+0x18
zsh`yylex+0x17
zsh`parse_event+0x23
zsh`loop+0x91
zsh`ssh_main+0x1d0
zsh`main+0xe
zsh`0x8059be
 20
```



Back to the syscall provider

- So far we have just used the *syscall* provider
- There are some difficulties to be aware of: when tracing writes – be aware that there are:
  - `write(), writev(), pwrite(), pwrite64()`
- when tracing reads – be aware that there are:
  - `read(), readv(), pread(), pread64()`
  - There is also `readlink()` -for symlinks
- Other variants exist: `open(), open64()...`
- `readv()` and `writev()` cause problems – fetching the size from an *iovec* isn't easy

sysinfo Provider Intro

- *sysinfo* provides probes that trace regular system activity
- `sysinfo:::readch` traces all the read variants and provides the successful bytes read as `arg0`
- `sysinfo:::writech` traces all the write variants,and provides the successful bytes written as `arg0`
- Don't need to worry about *syscall* return of -1

Bytes Read by Process Name

- sysinfo does this easily,

```
# dtrace -n 'sysinfo:::readch { @bytes[execname] = sum(arg0); }'
dtrace: description 'sysinfo:::readch ' matched 4 probes
^C
    bash                                                          14
    sshd                                                         591
```

- Handles *read* variants
- This could use `quantize()`, or trace `writech`
- We should now be able to construct many useful one-liners using *syscall*, *sysinfo* and *aggregations*

Profile Provider Intro

- profile samples activity at a custom rate
- The maximum sample rate is 5000 Hertz

```
# dtrace -n 'profile:::profile-100hz { @num[execname] = count(); }'
dtrace: description 'profile:::profile-100hz ' matched 1 probe
^C
  dirname                                                   1
  bash                                                      2
  sopatchlevel.sh                                           2
  uname                                                     2
  expr                                                      3
  soffice                                                   3
  staroffice                                                3
  javaldx                                                   4
  soffice.bin                                               8
  pagein                                                   84
  sched                                                   389
```

- This is sampling `execname` at 100 Hertz

profile and ustack()

```
# dtrace -n 'profile:::profile-100hz /execname == "prstat"/ { @num[ustack(5)] =
    count(); }'
dtrace: description 'profile:::profile-100hz ' matched 1 probe
^C
                libc.so.1`memcpy+0x41
                prstat`0x8053a54
                prstat`main+0x791
                prstat`0x8051dc2
                    1
...
                libc.so.1`_pread+0x15
                prstat`0x8053606
                prstat`0x80537d3
                prstat`main+0x791
                prstat`0x8051dc2
                   39
```

Style Hint:
The hz isn't necessary but it helps readability

- This can help identify where a process is spending its time (*extremely useful!*)

Using profile

- The *profile* provider allows simple and useful one-liners and scripts to be written
- The overheads of using profile are fixed to the sampling rate; unlike other providers, where a high frequency of traced events can slow the target
- Be aware of sampling issues. *If accurate measurements are desired, use other providers to trace on an event-by-event basis*.

End of Module 3

- Module 1 – Solaris 8 & 9 Performance Tools
- Module 2 – Introducing DTrace
- Module 3 – Command Line DTrace
- Module 4 – *DTrace one-liners*
- Module 5 – DTrace Mentality 1
- Module 6 – Providers
- Module 7 – The D Language
- Module 8 – Advanced Scripting
- Module 9 – The DTraceToolkit
- Module 10 – DTrace Mentality 2
- References

Module 4

DTrace one-liners

- List useful one-liners
- Discuss when to use them

One-Liners

- One-Liners Are Great
- Remember "*handy one-liners for sed*"?
- One-liners can provide simple solutions to common problems
- One-liners may not need the same arduous approval procedures that scripts may require
- Someone once emailed Brendan Gregg to say:

  "…thanks for the DTraceToolkit. I got as far as the one-liners, and found I could do everything I needed to."

  (so much for Brendan writing >100 scripts!)

Useful One-Liners

- The DTrace one-liners list is kept in the DTraceToolkit under `Docs/oneliners.txt`

`http://www.opensolaris.org/os/community/dtrace/dtracetoolkit`

or

`http://www.brendangregg.com/dtrace.html#DTraceToolkit`

- So far we have covered enough DTrace syntax to understand most of them.
- Many probes these one-liners use will be new, but readily understandable in such a practical context.
- *We will demonstrate many of these now ...*

One-Liners #1

New processes with arguments,
```
dtrace -n 'proc:::exec-success { trace(curpsinfo->pr_psargs); }'
```
Files opened by process name,
```
dtrace -n 'syscall::open*:entry { printf("%s %s",execname,copyinstr(arg0)); }'
```
Files created using `creat()` by process name,
```
dtrace -n 'syscall::creat*:entry { printf("%s %s",execname,copyinstr(arg0)); }'
```
Syscall count by process name,
```
dtrace -n 'syscall:::entry { @num[execname] = count(); }'
```
Syscall count by syscall,
```
dtrace -n 'syscall:::entry { @num[probefunc] = count(); }'
```
Syscall count by process ID,
```
dtrace -n 'syscall:::entry { @num[pid,execname] = count(); }'
```
Read bytes by process name,
```
dtrace -n 'sysinfo:::readch { @bytes[execname] = sum(arg0); }'
```
Write bytes by process name,
```
dtrace -n 'sysinfo:::writech { @bytes[execname] = sum(arg0); }'
```

One-Liners #2

Read size distribution by process name,

```
dtrace -n 'sysinfo:::readch { @dist[execname] = quantize(arg0); }'
```

Write size distribution by process name,

```
dtrace -n 'sysinfo:::writech { @dist[execname] = quantize(arg0); }'
```

Disk size by process ID,

```
dtrace -n 'io:::start { printf("%d %s %d",pid,execname,args[0]->b_bcount); }'
```

Disk size aggregation

```
dtrace -n 'io:::start { @size[execname] = quantize(args[0]->b_bcount); }'
```

Pages paged in by process name,

```
dtrace -n 'vminfo:::pgpgin { @pg[execname] = sum(arg0); }'
```

Minor faults by process name,

```
dtrace -n 'vminfo:::as_fault { @mem[execname] = sum(arg0); }'
```

Interrupts by CPU,

```
dtrace -n 'sdt:::interrupt-start { @num[cpu] = count(); }'
```

CPU cross calls by process name,

```
dtrace -n 'sysinfo:::xcalls { @num[execname] = count(); }'
```

One-Liners #3

Lock time by process name,

```
dtrace -n 'lockstat:::adaptive-block { @time[execname] = sum(arg1); }'
```

Lock distribution by process name,

```
dtrace -n 'lockstat:::adaptive-block { @time[execname] = quantize(arg1); }'
```

Kernel funtion calls by module

```
dtrace -n 'fbt:::entry { @calls[probemod] = count(); }'
```

Stack size for processes

```
dtrace -n 'sched:::on-cpu { @[execname] = max(curthread->t_procp->p_stksize);}'
```

Kill all top processes when they are invoked,

```
dtrace -wn 'syscall::exece:return /execname == "top"/ { raise(9); }'
```

New processes with arguments and time,

```
dtrace -qn 'syscall::exec*:return { printf("%Y %s\n",walltimestamp,
    curpsinfo->pr_psargs); }'
```

Successful signal details,

```
dtrace -n 'proc:::signal-send /pid/ { printf("%s -%d %d",execname,args[2],
    args[1]->pr_pid); }'
```

End of Module 4

- Module 1 – Solaris 8 & 9 Performance Tools
- Module 2 – Introducing DTrace
- Module 3 – Command Line DTrace
- Module 4 – DTrace one-liners
- Module 5 – *DTrace Mentality 1*
- Module 6 – Providers
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- Module 10 – DTrace Mentality 2
- References

Module 5

DTrace Mentality 1

- Approach Strategies
- Thinking in DTrace

Strategy #1: snoop or summary

- snoop
  - \+ *watch events as they occur*
  - \+ *raw data shows all details*
  - \- *may be too verbose*
    achieved using trace() or printf()
- summary
  - \+ *produce a summary report of data*
  - \+ *often the fastest way to process data*
  - \- *may lose information due to summarising*
    achieved using aggregates @

Snoop

```
# dtrace -n 'syscall::exece:return { trace(execname); }'
dtrace: description 'syscall::exece:return ' matched 1 probe
CPU  ID                                    FUNCTION:NAME
0   5992                                        exece:return  staroffice
0   5992                                   exece:return  grep
0   5992                                   exece:return  grep
0   5992                                   exece:return  soffice
0   5992                                   exece:return  dirname
0   5992                                     exece:return  expr
...
```

- Output “chugs” along at 1 Hertz. To improve:

  `dtrace -x switchrate=10hz` <command line

  `#pragma D option switchrate=10hz` <script

- Output can be shuffled slightly – check the CPU column, or print timestamp and post-process.

Summary

```
# dtrace -n 'syscall::exece:return { @num[execname] = count(); }'
dtrace: description 'syscall::exece:return ' matched 1 probe
^C
  soffice.bin                                                       1
  pagein                                                            1
  javaldx                                                           1
  basename                                                          1
  sopatchlevel.sh                                                   1
  soffice                                                           1
  staroffice                                                        1
  dirname                                                           2
  grep                                                              2
  expr                                                              3
  uname                                                             4
```

- The most frequent occurring item is often an issue, but not always.

Strategy #: Drill down analysis

- Start broad, then focus on potential issues
- For example:

```
# vmstat 1
kthr      memory             page            disk          faults         cpu
r b w   swap  free     re   mf pi po fr de sr cd s0 -- --   in   sy      cs us sy id
0 0 41 857772 109964   20   86 24  1  1  0  4  2  0  0  0  277  416      216 1  1 98
0 0 51 707120  75408    0   36  0  0  0  0  0  0  0  0  0  290 1218      268 1  3 96
0 0 51 707120  75408    0    0  0  0  0  0  0  0  0  0  0  279 1285      269 1  4 95
0 0 51 707120  75408    0    0  0  0  0  0  0  0  0  0  0  285 1188      263 0  3 97
0 0 51 707120  75408    0    0  0  0  0  0  0  0  0  0  0  276 1154      234 1  3 96
^C
```

- `vmstat` provides a general system-wide view - a good starting point. Module 1 lists others.
- *What may be interesting from this output?*

Drill down analysis

- `vmstat` showed many syscalls
- DTrace can identify if a single process (name) is responsible:

```
# dtrace -n 'syscall:::entry { @num[execname] = count(); }'
dtrace: description 'syscall:::entry ' matched 231 probes
^C
    svc.configd                                                   1
    inetd                                                         1
    nscd                                                         13
    httpd                                                        15
    svc.startd                                                   46
    sshd                                                         56
    java                                                        155
    dtrace                                                      167
    acroread                                                    659
    top                                                        4615
```

Drill down analysis

- `top` is calling most of the system calls
- Now the syscall type is identified:

```
# dtrace -n 'syscall:::entry /execname == "top"/ { @num[probefunc] = count(); }'
dtrace: description 'syscall:::entry ' matched 231 probes
^C
    pollsys                                                           7
    write                                                             7
    gtime                                                             7
    sysconfig                                                         7
    getuid                                                            7
    uadmin                                                            7
    llseek                                                           14
    getdents64                                                       14
    ioctl                                                            28
    open                                                           2121
    read                                                           2121
    close                                                          2121
```

Drill down analysis

- `open(), read(), close()` were all called 2121 times – perhaps by the same function.
- DTrace can now aggregate the user stack for these functions:

```
# dtrace -n 'syscall::open:entry /execname == "top"/ {@num[ustack()] = count(); }'
dtrace: description 'syscall::open:entry ' matched 1 probe
^C
                libc.so.1`__open+0x15
                libc.so.1`open+0x77
                top`getptable+0xe5
                top`get_process_info+0x14
                top`main+0x695
                top`_start+0x80
               2424
```

Drill down analysis

```
  libc.so.1`__open+0x15
  libc.so.1`open+0x77
  top`getptable+0xe5
  top`get_process_info+0x14
  top`main+0x695top`_start+0x80
2424
```

the culprit

- The same stack trace is seen for all *syscalls*
- Great – we have identified the function responsible for calling so many *syscalls*

What can be done next?

Further drill down analysis

- Other analysis that can then be performed:
  - examine arguments to *syscalls* to understand the nature of the activity
  - measure elapsed and on-cpu timestamps to prove that this large number of *syscalls* really is an issue *(it may not be!)*
  - read the source code to the application *(if available)* to fully understand the issue and suggest a fix.
  - examine activity from other providers other than the *syscall* layer
- A lot more can be done. *We have only just begun!*

Strategy #3: Frequency count

- When in doubt, frequency count.

```
# dtrace -n 'sysinfo::: /execname == "top"/ { @num[probename] = count(); }'
dtrace: description 'sysinfo::: ' matched 59 probes
^C
  trap                                                              2
  writech                                                           9
  syswrite                                                          9
  outch                                                             9
  inv_swtch                                                        48
  pswitch                                                          68
  readch                                                         2727
  sysread                                                        2727
  namei                                                          2727
```

- Be aware that this is counting the occurrences thata probe was fired - ie, the `readch` statistic probe was called 2727 times.

  Don't infer too much...

Frequency Count

```
# dtrace -n 'sysinfo::: /execname == "top"/ { @num[probename] = sum(arg0); }'
dtrace: description 'sysinfo::: ' matched 59 probes
^C
  syswrite                                                        8
  inv_swtch                                                      38
  pswitch                                                        56
  sysread                                                      2424
  namei                                                        2424
  writech                                                      3135
  outch                                                        3158
  readch                                                     814464
```

- Now we can see the value of the statistic: `readch` is at 814464 bytes.

Frequency Count

```
# dtrace  -ln  mib:::  |  wc
486 2430 41475
```

- Why study 485 probes if most are never called?

If it's never called, it's never called!

```
# dtrace -n 'mib::: { @num[probename] = count(); }'
dtrace: description 'mib::: ' matched 485 probes
^C
  udpInDatagrams                                                1
  ipInDelivers                                                  1
  tcpInAckBytes                                                74
  tcpRttUpdate                                                 74
  tcpInDataInorderSegs                                         74
  tcpInAckSegs                                                 74
  tcpInDataInorderBytes                                        74
  ipOutRequests                                                81
  tcpOutDataBytes                                              81
  tcpOutDataSegs                                               81
  ipInReceives                                                142
```

Strategy #4: Known Count

- Cause a fault or workload a known number of times. Probes of interest will occur that known number of times (or a multiple).
- Here a non-root user modifies `/etc/motd` and tries to save 17 times:

```
# dtrace -n 'syscall::entry /execname == "vi"/ { @num[probefunc] = count(); }'
dtrace: description 'syscall::entry ' matched 231 probes
^C
  getpid                                                        17
  stat64                                                        17
  ioctl                                                         34
  read                                                          51
  write                                                        102
```

All multiples of 17!

Yellow Pig

- Brendan likes to create 17 events, as 17 is not a commonly occurring number, and is more likely to be related to your test. A similar moderately sized prime would be 23.
- The number of eyelashes on a yellow pig is supposedly 17
- Hence, the "***Yellow Pig*** *number*" is 17
- "***Yellow Pig Day***" is July 17th, celebrated by mathematicians (*who else would?*)

  (*This isn't made up - try Google, Yahoo, Ask!*)

Strategy #5: Aggregate Stacks

- Stack Traces can be aggregated in at least two ways:
- A) Event probes
  - when an event of interest occurs, the stack is aggregated
  - this can explain why the event is taking place – the functions that lead up to the event
- B) Profile sampling
  - the stack trace is aggregated at 100hz (*at least*)
  - this is a crude but often effective way to show where the application is spending most of its time

Event Probes with Stacks

- Lets see why Xvnc calls so many `read()`s:

```
# dtrace -n 'syscall::read:entry /execname == "Xvnc"/ { @num[ustack()] = count(); }'
dtrace: description 'syscall::read:entry ' matched 1 probe
^C
...
                libc.so.1`_read+0x15
                Xvnc`0x8094a5b
                Xvnc`_XSERVTransRead+0x15
                Xvnc`ReadRequestFromClient+0x11e
                Xvnc`Dispatch+0xdb
                Xvnc`main+0x479
                Xvnc`_start+0x5d
                309

                libc.so.1`_read+0x15
                Xvnc`ReadExact+0x4b
                Xvnc`rfbProcessClientMessage+0x73
                Xvnc`rfbCheckFds+0x109
                Xvnc`ProcessInputEvents+0xb
                Xvnc`Dispatch+0x65
                Xvnc`main+0x479
                Xvnc`_start+0x5d
                618
```

Profile Sampling with Stack

- Lets sample to estimate why Xvnc is on-CPU:

```
# dtrace -n 'profile:::profile-1000hz /execname == "Xvnc"/ {
@num[ustack()] = count(); }'
dtrace: description 'profile:::profile-1000hz ' matched 1 probe
^C
...
              Xvnc`cfb32FillRectSolidCopy+0x9c
              200

              libc.so.1`_writev+0x15
              Xvnc`0x8094aaf
              Xvnc`_XSERVTransWritev+0x15
              Xvnc`FlushClient+0x72
              Xvnc`FlushAllOutput+0xeb
              Xvnc`Dispatch+0x11d
              Xvnc`main+0x479
              Xvnc`_start+0x5d
              370
```

That looks interesting

Thinking in DTrace

- DTrace itself is an easy language, with the syntax well defined in the DTrace Guide
- Being successful with DTrace is about the application – being able to think in DTrace
- Tips for thinking in DTrace
  - *practise, practise, practise*
  - *know the existing tools inside out (Module 1)*
  - *know the OS well (Solaris Internals 2nd edition)*
  - *study source code, and how applications are constructed and operate*
  - *be willing to think outside the box!*

End of Module 5

- Module 1 – Solaris 8 & 9 Performance Tools
- Module 2 – Introducing DTrace
- Module 3 – Command Line DTrace
- Module 4 – DTrace one-liners
- Module 5 – DTrace Mentality 1
- Module 6 – *Providers*
- Module 7 – The D Language
- Module 8 – Advanced Scripting
- Module 9 – The DTraceToolkit
- Module 10 – DTrace Mentality 2
- References

Module 6

Providers

- Provider Guide
- Using *fbt*
- Using *pid*

Providers

- *syscall* System call entry and return probes
- *sysinfo* Classic sysinfo statistic probes
- *vminfo* Virtual Memory statistic probes
- *io* Disk and NFS events
- *proc* Process events such as creation
- *sched* System scheduling events
- *lockstat* Kernel synchronisation lock events
- *plockstat* User synchronisation lock events
- *mib* MIB statistic updates
- *fasttrap* User location tracing
- *fpuinfo* SPARC FPU simulation events

Providers

- *sdt* Statically defined tracing
- *profile* Fixed sampling
- *dtrace* Program BEGIN/END probes
- *fbt* Raw kernel tracing
- *pid* User-level tracing

- Check the DTrace Guide for additional providers

syscall

- Example one-liner:

```
# Syscall count by syscall,
dtrace -n 'syscall:::entry { @num[probefunc] = count(); }'
```

- Probes the interface between user-land and the kernel
- Provides many insights into an application's behaviour
- *syscalls* are documented in section 2 of the man pages: `man -s 2 intro`

sysinfo

- Example one-liner:

```
# Read bytes by process name,
dtrace -n 'sysinfo:::readch { @bytes[execname] = sum(arg0); }'
```

- Probes the *sysinfo* statistics, which are provided by *kstat* to tools such as `mpstat`
- Provides many insights into application and system behaviour
- Documented in the DTrace Guide (*chap 23*)
- Also see: `/usr/include/sys/sysinfo.h,cpu_sysinfo.h`

vminfo

- Example one-liner:

```
# Pages paged in by process name,
dtrace -n 'vminfo:::pgpgin { @pg[execname] = sum(arg0); }'
```

- Probes the *vminfo* statistics, which are provided by *kstat* to tools such as `vmstat`
- Provides many insights into virtual memory behaviour
- Documented in the DTrace Guide (*chap 24*)
- Also see: `/usr/include/sys/sysinfo.h,cpu_vminfo.h`

io

- Example one-liner:

```
# Disk size aggregation
dtrace -n 'io:::start { @sz[execname] = quantize(args[0]->b_bcount); }'
```

- Probes I/O events, for both disk and NFS
- Provides a probe for the start and finish of each I/O transaction
- Provides crucial data for understanding how applications are driving the disks
- Documented in the DTrace Guide (*chap 27*)
- *Note - There is also a provider specific to ZFS!*

proc

- Example one-liner:

```
# New processes with arguments,
dtrace -n 'proc:::exec-success { trace(curpsinfo->pr_psargs); }'
```

- Probes process events such as *exec*, *exit*, thread creation and signals
- Provides high level probes so that process analysis can be performed easily
- Documented in the DTrace Guide (*chap 25*)

sched

- Example one-liner:

```
# Times the scheduler begins to run a thread,
dtrace -n 'sched:::on-cpu { @on[execname] = count(); }'
```

- Probes thread scheduling events
- Provides high level probes so that scheduler analysis can be performed easily
- Documented in the DTrace Guide (*chap 26*)
- Also see Solaris Internals 2nd edition

fbt

- Example one-liner:

```
# Kernel funtion calls by module
dtrace -n 'fbt:::entry { @calls[probemod] = count(); }'
```

- Function Boundary Tracing – traces raw kernel function events
- These probes are regarded as ***unstable*** - their names and arguments can and do change between minor releases of Solaris (*which is why we have the higher level providers*)
- *fbt* makes up the bulk of the probes: 30,000+

fbt

- Since *fbt* can trace the entire kernel, observing just about any kernel behaviour is possible
- Enabling all *fbt* probes (30,000+) will slow the kernel noticeably. ***Be selective!***
- Documentation for the *fbt* probes (*which is really documentation for the kernel*) is in:
  - The DTrace Guide (chap 20)
  - Solaris Internals 2nd edition
  - cvs.opensolaris.org

pid

- Example one-liner,

```
# Trace user-level function entries,
dtrace -n 'pid$target:a.out::entry' -c 'some_command'
```

- The pid provider runs a command (-c *cmd*), or traces a particular process (-p *PID*).
- The pid provider can:
  - trace user functions
  - trace user instructions
  - trace library functions
  - trace library instructions
- The pid provider can create millions of probes

pid:::

- The provider name is,

  `pid`*`PID`* Where *PID* is the target to trace

  `pid`*`81`* Trace PID *81*

  `pid`*`$target`* Trace the target of -c or -p

- The full syntax is:
  `pid`*`PID`*`:``segment``:``function``:``name`

  `segment` is the name of the mapping. eg,

  - `libc.so.1` (or "libc") a library
  - `a.out` the binary

  `function` is the function name. eg, "main"

  `name` is *entry*, *return*, or instruction *address*

pid demonstrations

- user functions,

```
# dtrace -n 'pid$target:a.out::entry'  -c 'ping mars'
dtrace: description 'pid$target:a.out::entry' matched 16 probes
mars is alive
dtrace: pid 29890 has exited
CPU   ID                                    FUNCTION:NAME
0   39187                                      __fsr:entry
0   39188                                     main:entry
0   39191                       send_scheduled_probe:entry
0   39198                           set_IPv4_options:entry
0   39190                           schedule_sigalrm:entry
0   39199                                check_reply:entry
0   39195                                  seq_match:entry
0   39191                       send_scheduled_probe:entry
```

pid demonstrations

- user instructions,

```
# dtrace -n 'pid$target:a.out:set_IPv4_options:'  -c 'ping mars'
dtrace: description 'pid$target:a.out:set_IPv4_options:' matched 169 probes
mars is alive
dtrace: pid 29900 has exited
CPU   ID                                    FUNCTION:NAME
0   39188                          set_IPv4_options:entry
0   39189                              set_IPv4_options:0
0   39190                              set_IPv4_options:1
0   39191                              set_IPv4_options:3
0   39192                              set_IPv4_options:6
0   39193                              set_IPv4_options:7
0   39194                              set_IPv4_options:8
0   39195                              set_IPv4_options:9
0   39196                             set_IPv4_options:10
0   39197                             set_IPv4_options:12
0   39198                             set_IPv4_options:19
…
0   39187                         set_IPv4_options:return
```

pid demonstrations

- library functions,

```
# dtrace -n 'pid$target:::entry' -c 'ping mars'
dtrace: description 'pid$target:::entry' matched 5318 probes
mars is alive
dtrace: pid 29905 has exited
CPU   ID                                    FUNCTION:NAME
0   39320                              call_array:entry
0   39321                               call_init:entry
0   39352                                   leave:entry
0   39351                              fmap_setup:entry
0   39596                                  munmap:entry
0   39296                            rt_bind_clear:entry
0   39287                           _rt_bind_clear:entry
0   39294                          rt_mutex_unlock:entry
0   39289                                 _rt_null:entry
0   39296                            rt_bind_clear:entry
0   39287                           _rt_bind_clear:entry
0   65195                               libc_init:entry
0   63314                                  atexit:entry
0   64852                                 lmalloc:entry
...
```

pid demonstrations

- library instructions,

```
# dtrace -n 'pid$target:libc:getpid:' -c 'ping mars'
dtrace: description 'pid$target:libc:getpid:' matched 9 probes
mars is alive
dtrace: pid 29914 has exited
CPU  ID                                    FUNCTION:NAME
0   39188                                   getpid:entry
0   39189                                       getpid:0
0   39190                                       getpid:5
0   39191                                       getpid:6
0   39192                                       getpid:b
0   39193                                       getpid:d
0   39194                                      getpid:13
0   39195                                      getpid:15
0   39187                                  getpid:return
0   39188                                   getpid:entry
0   39189                                       getpid:0
0   39190                                       getpid:5
0   39191                                       getpid:6
...
```

End of Module 6

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Module 7

The D Language

- Comments
- Variable Types
- Macros
- Script Options
- Pragmas

Comments

- The D language is related to the C programming language. This includes comment syntax:

```
/* this is a one line comment */

/*
 * This is a
 * block comment.
 */
```

Variable Types

- DTrace tries to figure out the variable type on its first declaration
- Variable types can be pre-declared
- Types include:
  - integer
  - string
  - pointer
  - associative array
  - aggregate
  - thread-local *(linked specifically to an event thread!)*
  - clause-local *(local to a DTrace program clause)*

Integer Variables

- Using integers:

`int mycount;`	declaration
`mycount = 1;`	declaration / setting
`mycount++;`	increment by 1
`/mycount >= 10/`	testing in a predicate

- A declaration of the form `int mycount;` ***must*** be placed outside of any action block. *Such declarations are usually placed at the top of the program.*

String Variables

- Using strings:

`string name;`	declaration
`name = “Fred Nurke”;`	declaration / setting
`/name == “Fred”/`	predicate testing
`name = 0;`	memory cleanup

- Strings are null terminated
- `printf()` supports,
  - `%s` string format
  - `%S` safe string format (*escapes odd chars*)

Pointers

- Used in the same way as C programming
- DTrace can walk most structures without casting (eg, *`vnode_t, proc_t, ...`*)
- Special builtins,

  `curthread` pointer to the *on-cpu thread*

  `curpsinfo` pointer to a *psinfo* like structure

- Eg,

  `curpsinfo->pr_psargs` 80 char arg list

  `curthread->t_procp->p_lwpcnt` # of LWPs

Associative Arrays

- Also known as "*hashed arrays*", or "*key/value arrays*"
- Using associative arrays:

`string name[int];`	declaration
`name[3] = "Fred";`	declaration / setting
`/name[3] == "Fred"/`	predicate testing
`name[3] = 0;`	memory cleanup
`name["sd0", 1] = 4;`	two key array

- Try to use aggregates instead

Aggregates

- Discussed in Module 3
- Using Aggregates:

`@name[keys] = func();`	setting
`printa("%s... %@d", @name);`	printing
`trunc(@name);`	clearing
`trunc(@name, size);`	truncating to size
`clear(@name);`	clearing values
`normalize(@name, n);`	dividing by n

- Aggregates perform well, and produce great reports

Thread-Local

- A variable that is stored private to each thread *(linked to a probe firing on an event)*
- Using thread-local:

`self->start = timestamp;`	setting
`self int start;`	declaration
`/self->start > 0/`	predicates
`self->start = 0;`	memory cleanup

- Thread-local variables are crucial, and are used heavily when scripting in DTrace.

Clause-Local

- A temporary variable for calculations within an action clause *(and available only in that clause!)*
- Using clause-local:

```
this->delta = 5;          setting
this int delta;           declaration
```

- These are used to improve performance, rather than using global integers or strings that require lock overheads between CPUs
- Only use these within one action

Kernel Variables

- Any symbol from the kernel can be read, along with its *struct* members
- Example kernel variables:

`` `freemem ``	free mem in pages
`` `utsname.nodename ``	hostname

- Often only the source code can explain what these really are
- Module variables can also be read (*prefix with the module name*)

Macro Variables

- DTrace provides some useful macro variables for scripting:

`$1, $2, ...`	arguments to script as *ints*
`$$1, $$2, ...`	arguments to script as *strings*
`$pid`	*PID* of dtrace(1M)
`$uid`	real *UID* of dtrace(1M)
`$target`	*PID target* of dtrace (-c or -p)

- For the argument variables to assume default values (0 or “”), use:

```
#pragma D option defaultargs
```

Script Options

- When writing complex scripts, it can be useful for them to process options. Eg:

```
# opt/DTT/dvmstat -h
USAGE: dvmstat [-h] { -p PID | -n name | command }
          -p PID               # examine this PID
          -n name              # examine this process name
eg,
    dvmstat -p 1871            # examine PID 1871
    dvmstat -n tar             # examine processes called "tar"
    dvmstat df -h              # run and examine "df -h"
```

- Currently this is best achieved by embedding the DTrace script inside a shell script, and using the shell's *getopts* function. Be careful to write neatly and follow programming best practices – *such scripts can get messy very quickly*.

Pragmas

- These change the behaviour of DTrace, and often an alternative to command line options
- Useful pragmas include:

```
#pragma D option quiet
#pragma D option switchrate=10hz
#pragma D option bufsize=16m
#pragma D option flowindent
#pragma D option destructive
```

- Others are listed in the DTrace Guide (*chapter 16*)

Destructive Actions

- These do more than just read data:

`stop();`	freeze the current process
`raise(sig#);`	send this *sig* to the current PID
`chill(#ns);`	pause for # nanoseconds
`system(cmd);`	run this shell command
`copyout(buf, addr, bytes);`	copy this data to user-land

- *Use extreme caution when using destructive actions!*
- *Restart a stopped process:*
  `system("/usr/bin/prun %d", pid);`

Destructive Actions: An example

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

#pragma D option quiet
#pragma D option destructive


syscall::chmod:entry
{
    stop() ;
    self->start = pid ;
    system("/usr/bin/ptree %d", self->start) ;
    printf("The chmod command was: %d %s\n", self->start, curpsinfo-
    >pr_psargs) ;
    printf("Executed by the userID: %d \n", uid) ;
    system("/usr/bin/prun %d", self->start) ;
}

syscall::chmod:return
/self->start/
{
    self->start = 0
}
```

Destructive action is applied

The process is stopped.

The process is re-started.
In the interim, we can trace process details.

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Module 8

Advanced Scripting

- Step through an example script
- Discuss script internals

Example: shortlived.d

- The following is from the DTraceToolkit:

```
# ./shortlived.d
Tracing... Hit Ctrl-C to stop.
^C
short lived processes: 0.924 secs
total sample duration: 4.308 secs

Total time by process name,
               soffice       3 ms
      sopatchlevel.sh      10 ms
                 grep      14 ms
                uname      24 ms
              javaldx      33 ms
                 expr      36 ms
           soffice.bin      93 ms
                pagein     696 ms

Total time by PPID,
             29854         30 ms
               625         93 ms
             29846        786 ms
```

Style Hint:
Say `Sampling`, if sampling and `Tracing`, if tracing

Style Hint:
Show units on output, if possible (such as secs, ms, ns)

shortlived.d

- `shortlived.d` calculates CPU time consumed by short-lived processes (*processes that began and ended while DTrace was tracing*).
- A common performance issue is short-lived processes hogging the CPU, which can be difficult to identify using traditional tools such as `prstat`
- It is useful to discuss the entire internals of this script, from comments to code.

shortlived.d

```
#!/usr/sbin/dtrace -qs
/*
* shortlived.d -determine time spent by short lived processes.
* Written in DTrace (Solaris 10 3/05).
*
* 27-May-2006, ver 0.94
*
* USAGE: shortlived.d         # wait, then hit Ctrl-C
*
* Applications that run many short lived processes can cause load
* on the system that is difficult to identify -the processes
* aren't sampled in time by programs such as prstat. This program
* illustrates how much time was spent processing those extra
* processes, and a table of process name by total times for each.
*
* SEE ALSO: execsnoop
*
* Notes:
* -The measurements are minimum values, not all of the overheads
* caused by process generation and destruction are measured (DTrace
* can do so, but the script would become seriously complex).
* -The summary values are accurate, the by program and by PPID values
* are usually slightly smaller due to rounding errors.
```

Style Hint:
Comment & Document

shortlived.d

```
* COPYRIGHT: Copyright (c) 2005, 2006 Brendan Gregg.
*
* CDDL HEADER START *
* The contents of this file are subject to the terms of the
* Common Development and Distribution License, Version 1.0 only
* (the "License"). You may not use this file except in compliance
* with the License. *
* You can obtain a copy of the license at Docs/cddl1.txt
* or http://www.opensolaris.org/os/licensing.
* See the License for the specific language governing permissions
* and limitations under the License.
*
* CDDL HEADER END *
* 22-Apr-2005 Brendan Gregg  Created this.
*/
```

Style Hint:
Histories are crucial

shortlived.d

```
/*
 * Start
 */

dtrace:::BEGIN
{
          /* save start time */
          start = timestamp;

          /* this is time spent on short lived processes */
          procs = 0;

          /* print header */
          printf("Tracing... Hit Ctrl-C to stop.\n");
}
```

Style Hint:
Comment often. You'll forget why you did something when you come back to the script later!

shortlived.d

```
/*
 * Measure parent fork time
 */

syscall::*fork*:entry
{
          /* save start of fork */
          self->fork = vtimestamp;
}

syscall::*fork*:return
/arg0 != 0 && self->fork/
{

          /* record on-CPU time for the fork syscall */
          procs += vtimestamp -self->fork;
          self->fork = 0;
}

/*
 * Measure child processes time
 */
```

Style Hint:
arg0 != 0 is verbose to aid readability

shortlived.d

```
syscall::*fork*:return
/arg0 == 0/
{
        /* save start of child process */
        self->start = vtimestamp;

        /* memory cleanup */
        self->fork = 0;
}

proc:::exit/self->start/
{
        /* record on-CPU time for process execution */
        this->oncpu = vtimestamp -self->start;procs += this->oncpu;

        /* sum on-CPU by process name and ppid */
        @Times_exec[execname] = sum(this->oncpu/1000000);
        @Times_ppid[ppid] = sum(this->oncpu/1000000);

        /* memory cleanup */
        self->start = 0;
}
```

shortlived.d

```
/*
 * Print report
 */

dtrace:::END
{
    this->total = timestamp -start;
    printf("short lived processes: %6d.%03d secs\n",
          procs/1000000000, (procs%1000000000)/1000000);
    printf("total sample duration: %6d.%03d secs\n",
          this->total/1000000000, (this->total%1000000000)/1000000);
    printf("\nTotal time by process name,\n");
    printa("%18s %@12d ms\n", @Times_exec);
    printf("\nTotal time by PPID,\n");
    printa("%18d %@12d ms\n", @Times_ppid);
}
```

Style Hint:
80 char width,
4 char continuation

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Module 9

The DTrace Toolkit

- Introduce the DTrace Toolkit
- Explain the layout
- A recipe for getting started

DTrace Toolkit

`http://www.opensolaris.org/os/community/dtrace/dtracetoolkit`

`http://www.brendangregg.com/dtrace.html`

- Version 0.99 contains 230 scripts
- Freeware (CDDL)
- Serves to:
  - Provide tools to analyse common problems
  - Provide numerous demonstrations of programming in D
  - Help promote the use of DTrace
- Originally written for Solaris 10 3/05
- Newer tools written for Solaris 10 8/07

Main Parts

- The DTraceToolkit is currently 3 main parts:
  - The Scripts *
  - Man Pages Man
  - Examples (found in the `Docs/Examples` directory)
- There is a man page for every script, and an example file for every script.
- It took considerable time to write 200+ man pages – *so please read them!*
- The *Example* files are often more useful than the man pages

Installation

- Isn't actually required – the scripts can be run immediately after extraction into a directory
- If desired, an install script has been provided. It prompts for install options, and defaults to installing under `/opt/DTT`

```
# ./install
DTraceToolkit Installation
--------------------------
DTraceToolkit version 0.99, 30-Sep-2007

hit Ctrl-C any time you wish to quit.

Enter target directory for installation [/opt/DTT]:
```

Script Layout

- The scripts are positioned in a hierarchy - the most useful are in the top-level directory; the others are in meaningful sub-directories
- The `Bin` directory contains *symlinks* to all the scripts (*in their respective sub-class directories*):

```
# ls -F /opt/DTT
Apps/         Examples/     Java/          opensnoop*    Shell/
Bin/          execsnoop*    JavaScript/    Perl/         Snippits/
Code/         FS/           Kernel/        Php/          statsnoop*
Cpu/          Guide         License@       Proc/         System/
dexplorer*    hotkernel*    Locks/         procsystime*  Tcl/
Disk/         hotuser*      Man/           Python/       User/
Docs/         Include/      Mem/           README@       Version
dtruss*       iopattern*    Misc/          Ruby/         Zones/
dvmstat*      iosnoop*      Net/           rwsnoop*
errinfo*      iotop*        Notes /        rwtop*
```

The Scripts

- If they end in .d, they are pure DTrace. See the man page or try reading their header.
- If they don't end in .d, they are wrapped in shell or Perl. See their man page or try running them with the -h option.
- If they begin with:
  - *Tracing... Hit Ctrl-C to end*
    they are tracing events
  - *Sampling... Hit Ctrl-C to end*
    they are sampling events using the profile provider

Man Pages

- Man Pages can be read using,

MANPATH=$MANPATH:/opt/DTT/Man # or wherever

man iosnoop

Reformatting page. Please Wait... done

USER COMMANDS iosnoop(1m)

NAME

iosnoop - snoop I/O events as they occur. Uses DTrace.

SYNOPSIS

iosnoop [-a|-A|-Deghinostv] [-d device] [-f filename] [-mmount_point] [-n name] [-p PID]

DESCRIPTION

iosnoop prints I/O events as they happen, with useful details such as UID, PID, block number, size, filename, etc.

This is useful to determine the process responsible for using the disks, as well as details on what activity the process is requesting. Behaviour such as random or sequential I/O can be observed by reading the block numbers.

The Example Files

- Read using:

```
# more Docs/Examples/bitesize_example.txt
In this example, bitesize.d was run for several seconds then Ctrl-C was hit. As
bitesize.d runs it records how processes on the system are accessing the disks -
in particular the size of the I/O operation. It is usually desirable for processes
to be requesting large I/O operations rather than taking many small "bites".

The final report highlights how processes performed. The find command mostly read
1K blocks while the tar command was reading large blocks -
both as expected.

# bitesize.d
Tracing... Hit Ctrl-C to end.
^C
    PID    CMD
   7110    -bash\0
             value -------------Distribution ------------- count
               512 |                                         0
              1024 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 2
```

The Toolkit Script Directories

- There are, amongst the directories:

`Bin/`	Symlinks to the scripts
`Apps/`	Application specific scripts
`Cpu/`	Scripts for CPU analysis
`Disk/`	Scripts for disk I/O analysis
`Extra/`	Misc scripts
`Kernel/`	Scripts for kernel analysis
`Locks/`	Scripts for lock analysis
`Mem/`	Scripts for memory analysis
`Net/`	Scripts for network analysis
`Proc/`	Scripts for process analysis
`System/`	Scripts for system analysis
`User/`	Scripts for user based activity analysis
`Zones/`	Scripts for analysis by zone

- Remember to check the top-level scripts first

DTrace Toolkit Recipe

- Running the following scripts in this order has proved a useful recipe:
  1) execsnoop
  2) iosnoop
  3) opensnoop
  4) errinfo
  5) procsystime
  6) rwtop
  7) iotop
  8) dvmstat
  9) Disk/bitesize.d

dexplorer

- This exists to capture DTrace data in the most broad possible way
- It creates a tar file containing the output from numerous DTrace commands
- If you only had 5 minutes to *DTrace* a server, `dexplorer` may be the best tool to run – it creates many files for later offline analysis
- An HTML-iser for `dexplorer` has yet to be written (*this is a work-in-progress*)

Behind the DTrace Toolkit

- The DTraceToolkit is a product of much testing – far more time has gone into testing the scripts than actually writing them
- The scripts need to be tested on:
  - SPARC and x86
  - Solaris 10 3/05, Solaris 10 1/06, ...
  - Different builds of OpenSolaris (*makes a huge difference for any fbt based scripts*)
  - All possible workloads
- If a script's output is 99% correct, *is that correct?*

Testing

- *A script's output that is incorrect 1% of the time is incorrect!*
- Imagine a `ps -ef` that has 1 bad line out of every 100.
- Only in some cases is this acceptable – where the data is clearly marked as an estimation.
- For example, `prstat`'s "SIZE" and "RSS" are not 100% accurate, but they are still useful estimates so long as we are aware that they are estimates.

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Module 10

DTrace Mentality 2

- More DTrace Strategies

Strategy #6: Elapsed Time

- Elapsed time is the calculated using,

```
start = timestamp;
...
elapsed = timestamp - start;
```

- Elapsed time explains why an application is experiencing slow response times
- Elapsed time includes disk I/O times, network I/O times, scheduling latency, ...
- Elapsed times can be measured at the application, treating the OS as a black box

Measuring Times

- Some difficulties when measuring these:
  - *Knowing what is the start probe and what is the end probe.*
    - If you are lucky, the provider will already have it as :entry and :return, or :start and :done.
    - If you are unlucky, you will need to find the probes from which it is available. Try a previous strategy – “known count”.
  - *Associating the start probe to the end probe*
    - If you are lucky, they will be in the same thread and you can use a thread-local variable. Eg, self->start
    - If you are unlucky, you'll need associative arrays and some other ID as the key.

Strategy #7: On-CPU Time

- On-CPU time is the calculated using:

```
start = vtimestamp;
...
oncpu = vtimestamp -start;
```

- On-CPU time explains why the CPUs are busy
- On-CPU time excludes disk I/O times, network I/O times, scheduling latency, ...

Elapsed vs On-CPU

```
# more Docs/Examples/dtruss_example.txt
...
In the following example, syscall elapsed and overhead times are measured.
Elapsed times represent the time from syscall start to finish; overhead
times measure the time spent on the CPU,

# dtruss -eon bash
PID/LWP    ELAPSD    CPU SYSCALL(args)                    = return
3911/1:        41     26 write(0x2, "l\0", 0x1)           = 1 0
3911/1:   1001579     43 read(0x0, "s\0", 0x1)            = 1 0
3911/1:        38     26 write(0x2, "s\0", 0x1)           = 1 0
3911/1:   1019129     43 read(0x0, " \001\0", 0x1)        = 1 0
3911/1:        38     26 write(0x2, " \0", 0x1)          = 1 0
3911/1:    998533     43 read(0x0, "-\0", 0x1)            = 1 0
3911/1:        38     26 write(0x2, "-\001\0", 0x1)       = 1 0
3911/1:   1094323     42 read(0x0, "l\0", 0x1)            = 1 0
3911/1:        39     27 write(0x2, "l\001\0", 0x1)       = 1 0
3911/1:   1210496     44 read(0x0, "\r\0", 0x1)           = 1 0
3911/1:        40     28 write(0x2, "\n\001\0", 0x1)      = 1 0
3911/1:         9      1 lwp_sigmask(0x3, 0x2, 0x0)       = 0xFFBFFEFF 0
3911/1:        70     63 ioctl(0x0, 0x540F, 0x80F6D00)    = 0 0
```

Strategy #8: Milestones

- Try to understand the behaviour of the target by identifying application-level activity milestones. *For example:*
  - establishing a connection
  - beginning a transaction
  - completing a transaction
  - writing to a log
- These may be identified using:
  - the probe name – ie, the function name
  - ustack() when solaris statistics are triggered
  - engaging in “known count” strategy
  - dereferencing random strings

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DTrace Workshop Exercises

- Now it's time for you to get your hands dirty solving a variety of problems (*guidance will be available*)
- If relevant, problems can be created on your systems at random
- When you solve them, don't shout out the answer!
- Many people find this is the best way to learn – *you need to think on your own and practice with DTrace coding*
- Good Luck! Enjoy ☺

DTrace Workshop Exercises

- A range of exercises will be provided by the instructor running the workshop

- The exercises will include accessing the documentation and examples in the DTrace Toolkit - You will, therefore, be expected to install the most recent DTrace Toolkit onto your systems.