DTracing the Cloud

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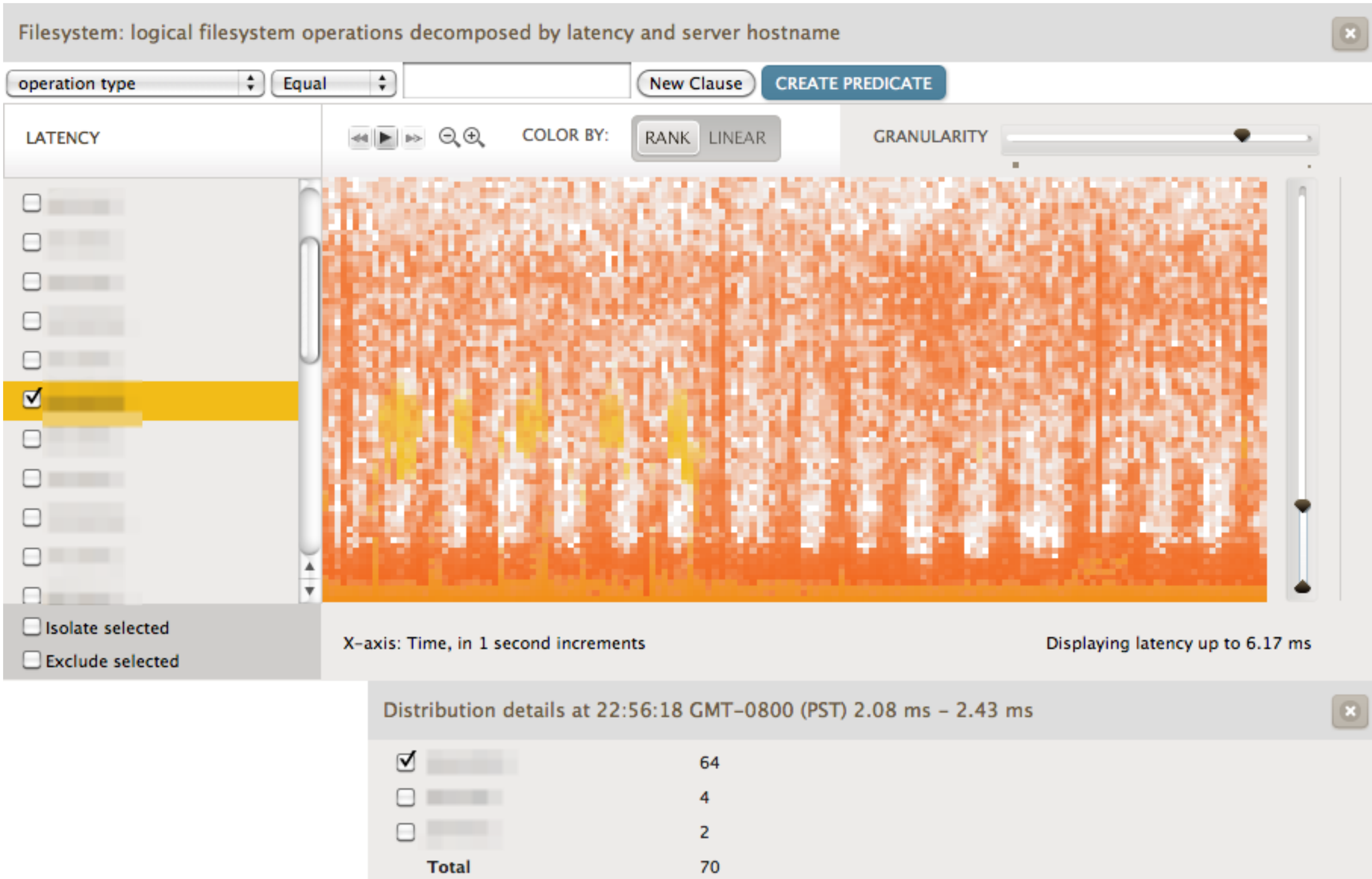
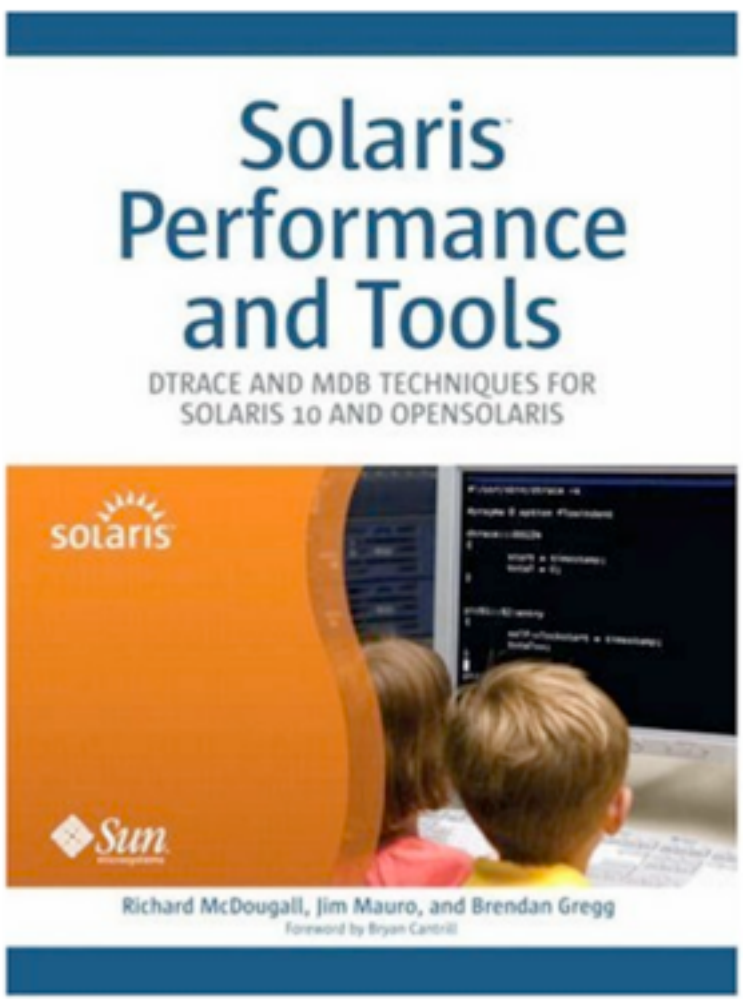
DTracing the Cloud



whoami

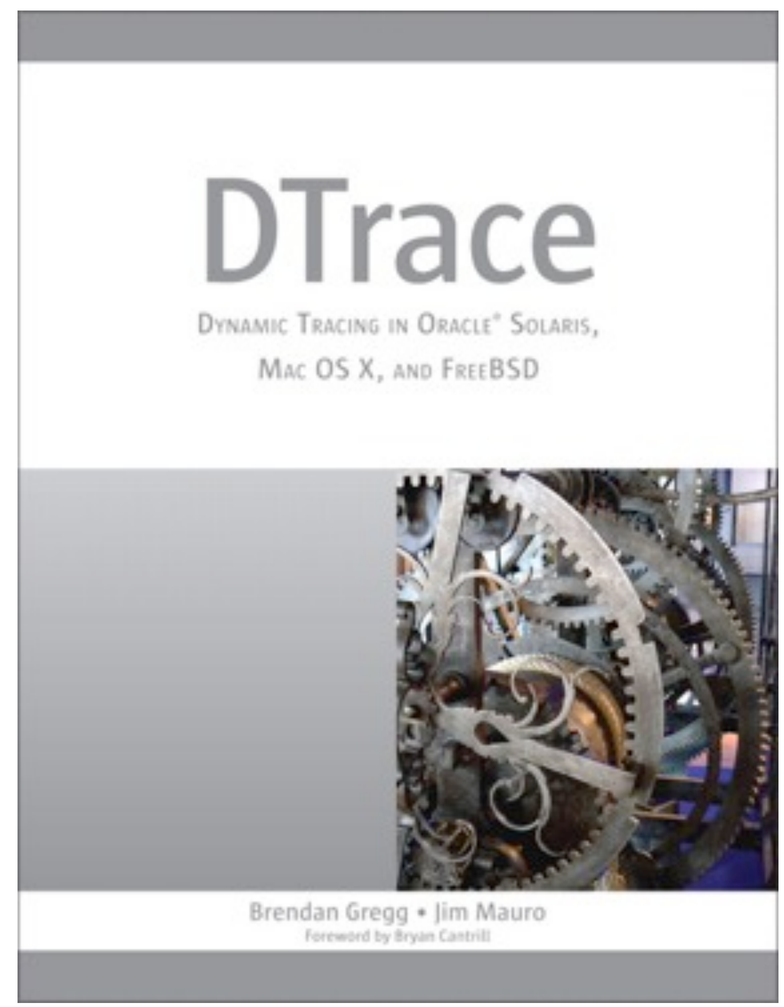
Joyent

- G'Day, I'm Brendan
- These days I do performance analysis of the cloud
- I use the right tool for the job; sometimes traditional, often DTrace.



Traditional + some DTrace ←

All DTrace →



DTrace

- DTrace is a magician that conjures up rainbows, ponies and unicorns — and does it all entirely safely and in production!

DTrace

- Or, the version with fewer ponies:
- DTrace is a **performance analysis and troubleshooting tool**
  - Instruments all software, kernel and user-land.
  - Production safe. Designed for minimum overhead.
  - Default in SmartOS, Oracle Solaris, Mac OS X and FreeBSD. Two Linux ports are in development.
- There's a couple of awesome books about it.

illumos

- Joyent's SmartOS uses (and contributes to) the illumos kernel.
  - illumos is the most DTrace-featured kernel
- illumos community includes Bryan Cantrill & Adam Leventhal, DTrace co-inventors (pictured on right).

Agenda

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- Theory
  - Cloud types and DTrace visibility
- Reality
  - DTrace and Zones
  - DTrace Wins
- Tools
  - DTrace Cloud Tools
  - Cloud Analytics
- Case Studies

Theory

Monday, October 1, 12

Cloud Types

- We deploy two types of virtualization on SmartOS/illumos:
  - Hardware Virtualization: KVM
  - OS-Virtualization: Zones

Cloud Types, cont.

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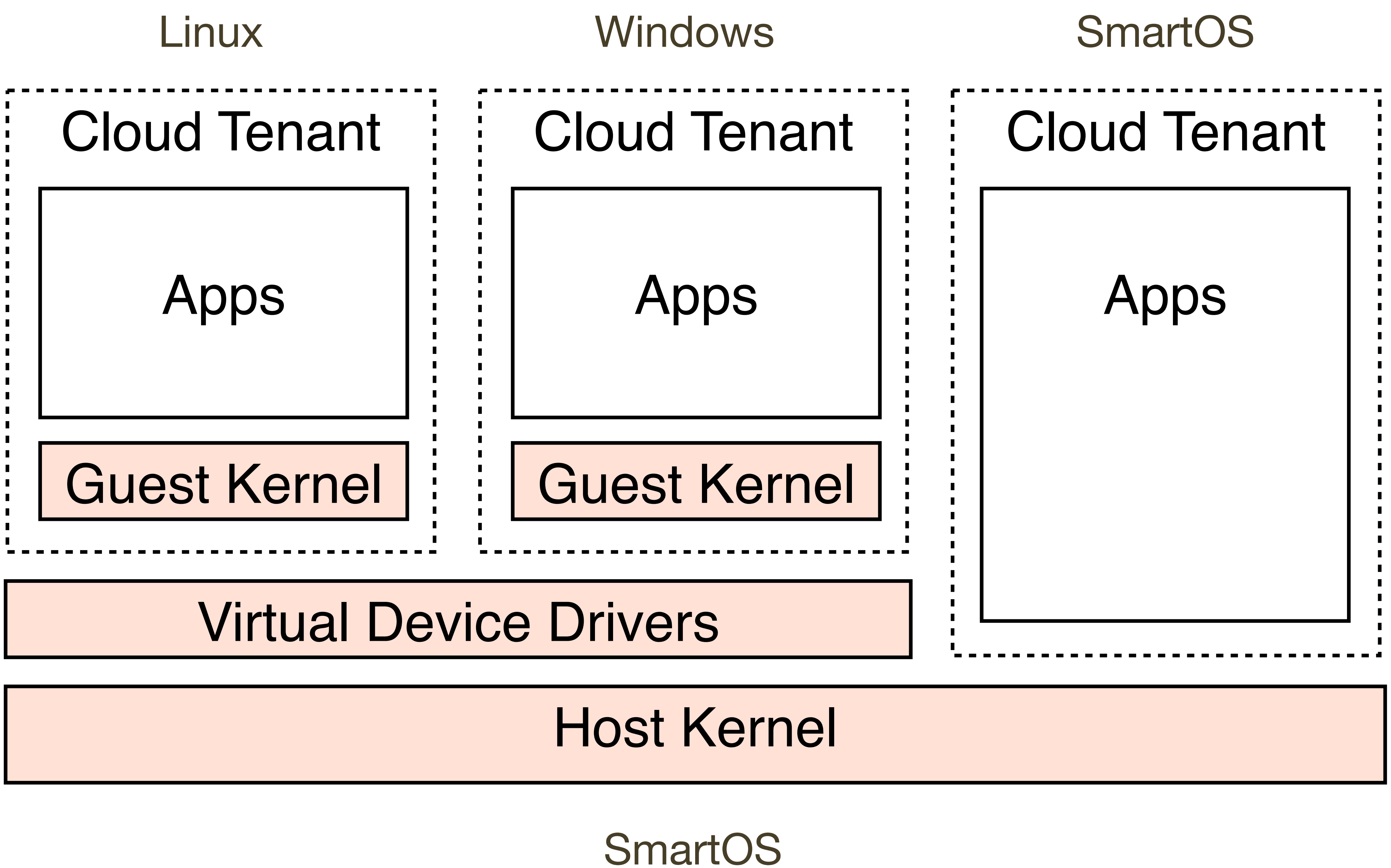
- Both virtualization types can co-exist:



Cloud Types, cont.

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- KVM
  - Used for Linux and Windows guests
  - Legacy apps
- Zones
  - Used for SmartOS guests (zones) called SmartMachines
  - Preferred over Linux:
    - Bare-metal performance
    - Less memory overheads
    - Better visibility (debugging)
  - Global Zone == host, Non-Global Zone == guest
  - Also used to encapsulate KVM guests (double-hull security)

Cloud Types, cont.

- DTrace can be used for:
  - Performance analysis: user- and kernel-level
  - Troubleshooting
- Specifically, for the cloud:
  - Performance effects of multi-tenancy
  - Effectiveness and troubleshooting of performance isolation
- Four contexts:
  - KVM host, KVM guest, Zones host, Zones guest
  - FAQ: What can DTrace see in each context?

Hardware Virtualization: DTrace Visibility

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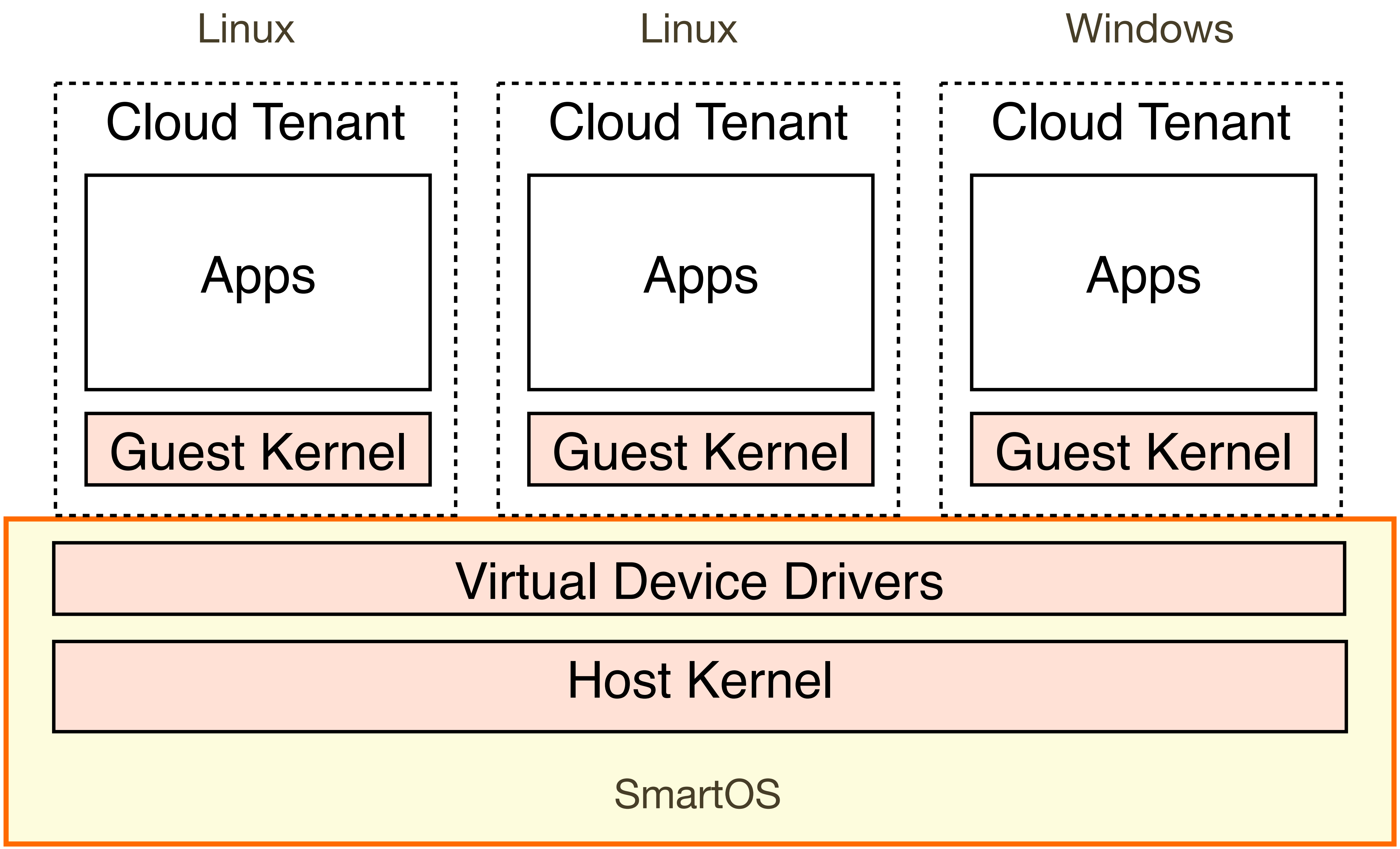
- As the cloud operator (host):



Hardware Virtualization: DTrace Visibility

- Host can see:
  - Entire host: kernel, apps
  - Guest disk I/O (block-interface-level)
  - Guest network I/O (packets)
  - Guest CPU MMU context register
- Host can't see:
  - Guest kernel
  - Guest apps
  - Guest disk/network context (kernel stack)
  - ... unless the guest has DTrace, and access (SSH) is allowed

Hardware Virtualization: DTrace Visibility

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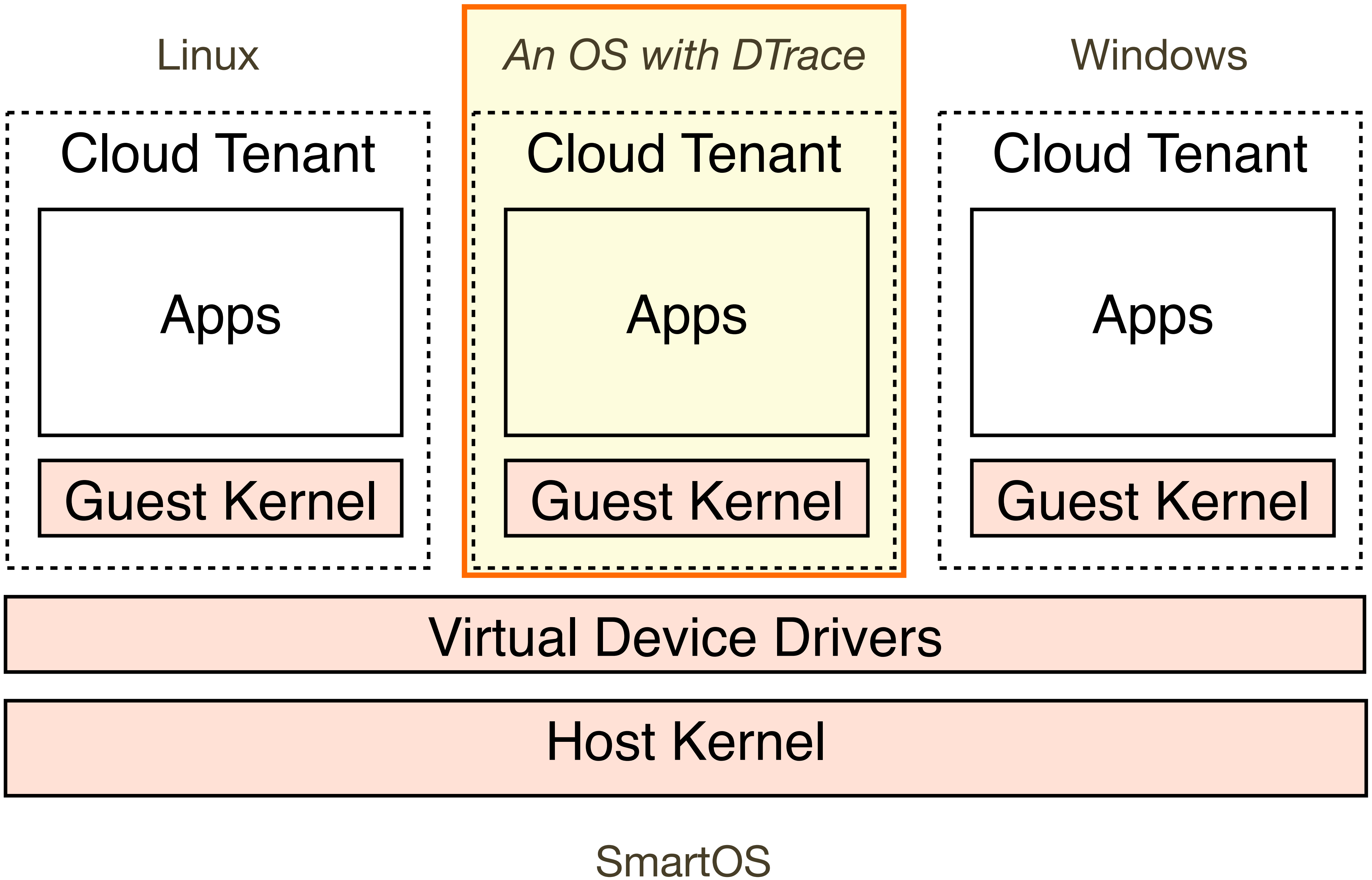
- As a tenant (guest):

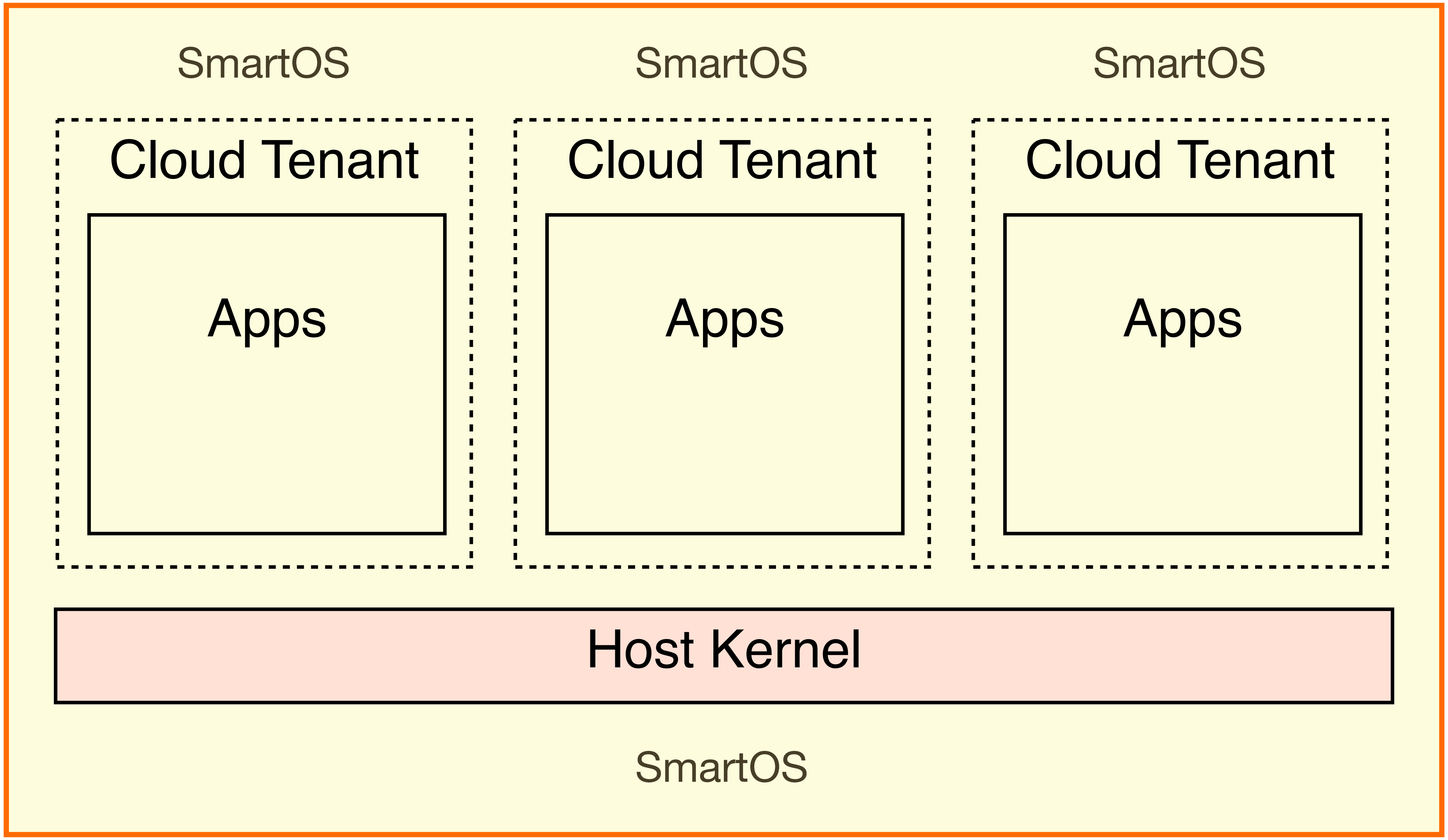


Hardware Virtualization: DTrace Visibility

- Guest can see:
  - Guest kernel, apps, provided DTrace is available
- Guest can't see:
  - Other guests
  - Host kernel, apps

OS Virtualization: DTrace Visibility

- As the cloud operator (host):

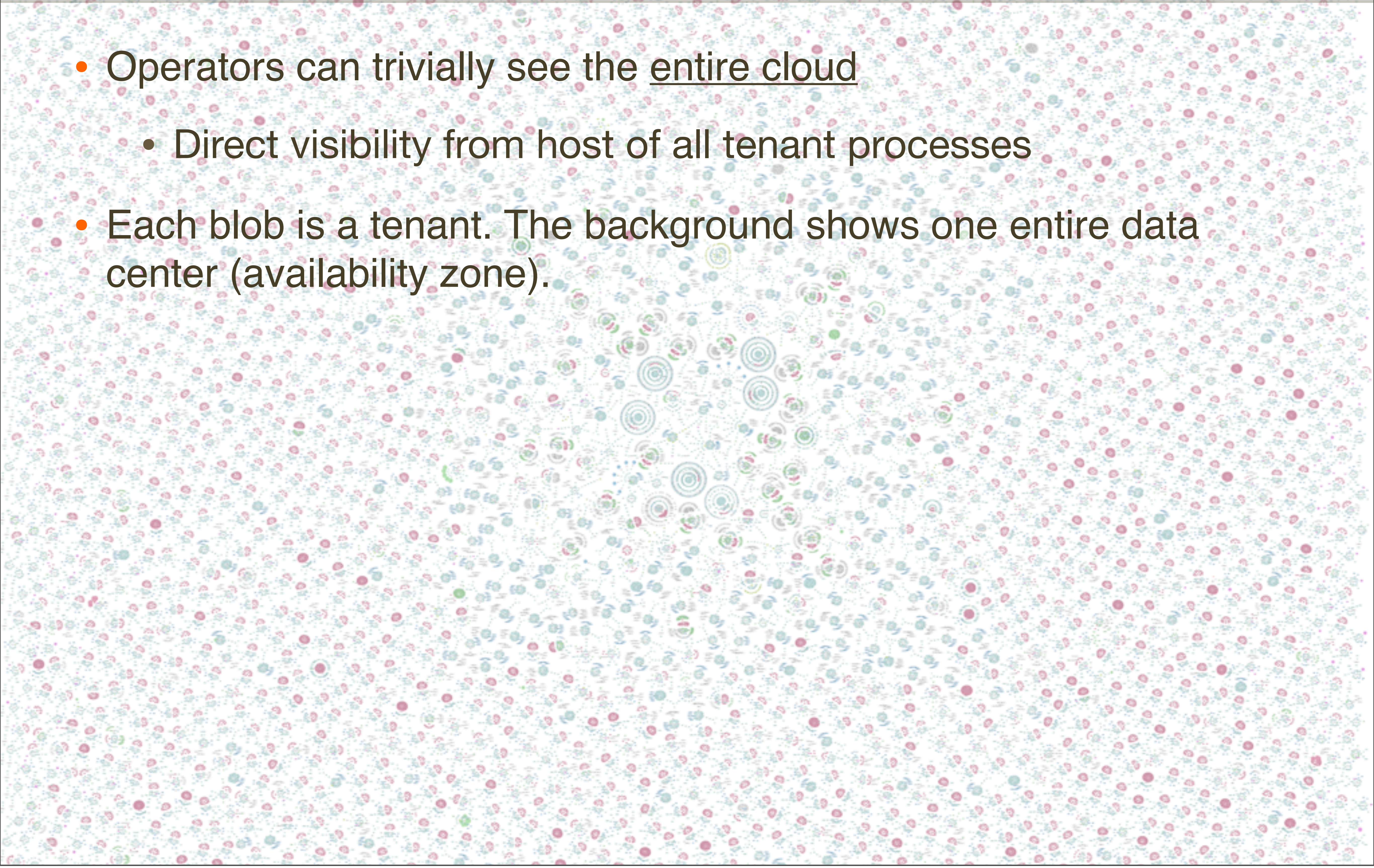


OS Virtualization: DTrace Visibility

- Host can see:
  - Entire host: kernel, apps
  - Entire guests: apps

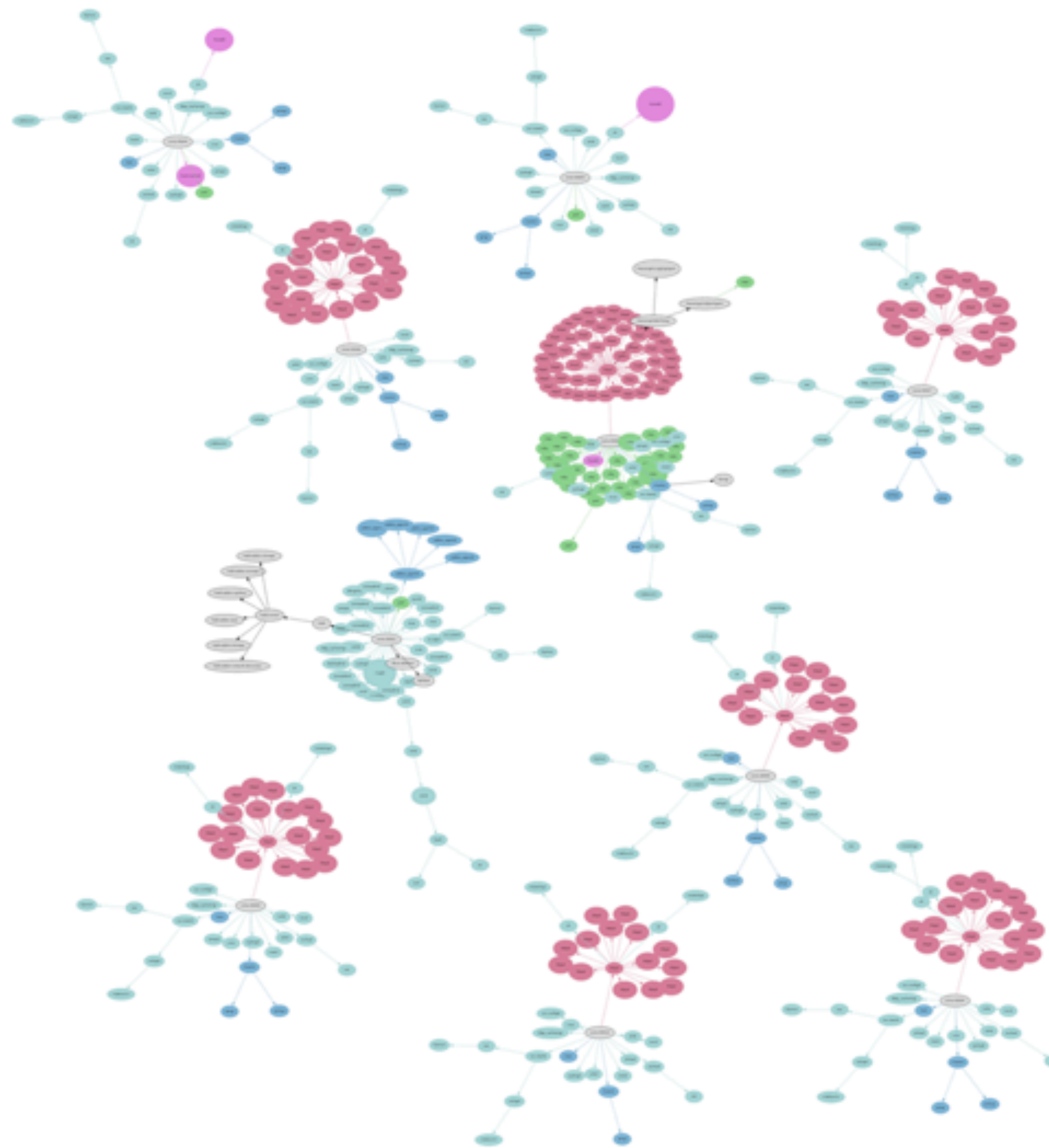
OS Virtualization: DTrace Visibility

- Operators can trivially see the entire cloud
  - Direct visibility from host of all tenant processes
- Each blob is a tenant. The background shows one entire data center (availability zone).



OS Virtualization: DTrace Visibility

- Zooming in, 1 host, 10 guests:
- All can be examined with 1 DTrace invocation; don't need multiple SSH or API logins per-guest. Reduces observability framework overhead by a factor of 10 (guests/host)



- This pic was just created from a process snapshot (ps)
http://dtrace.org/blogs/brendan/2011/10/04/visualizing-the-cloud/

OS Virtualization: DTrace Visibility

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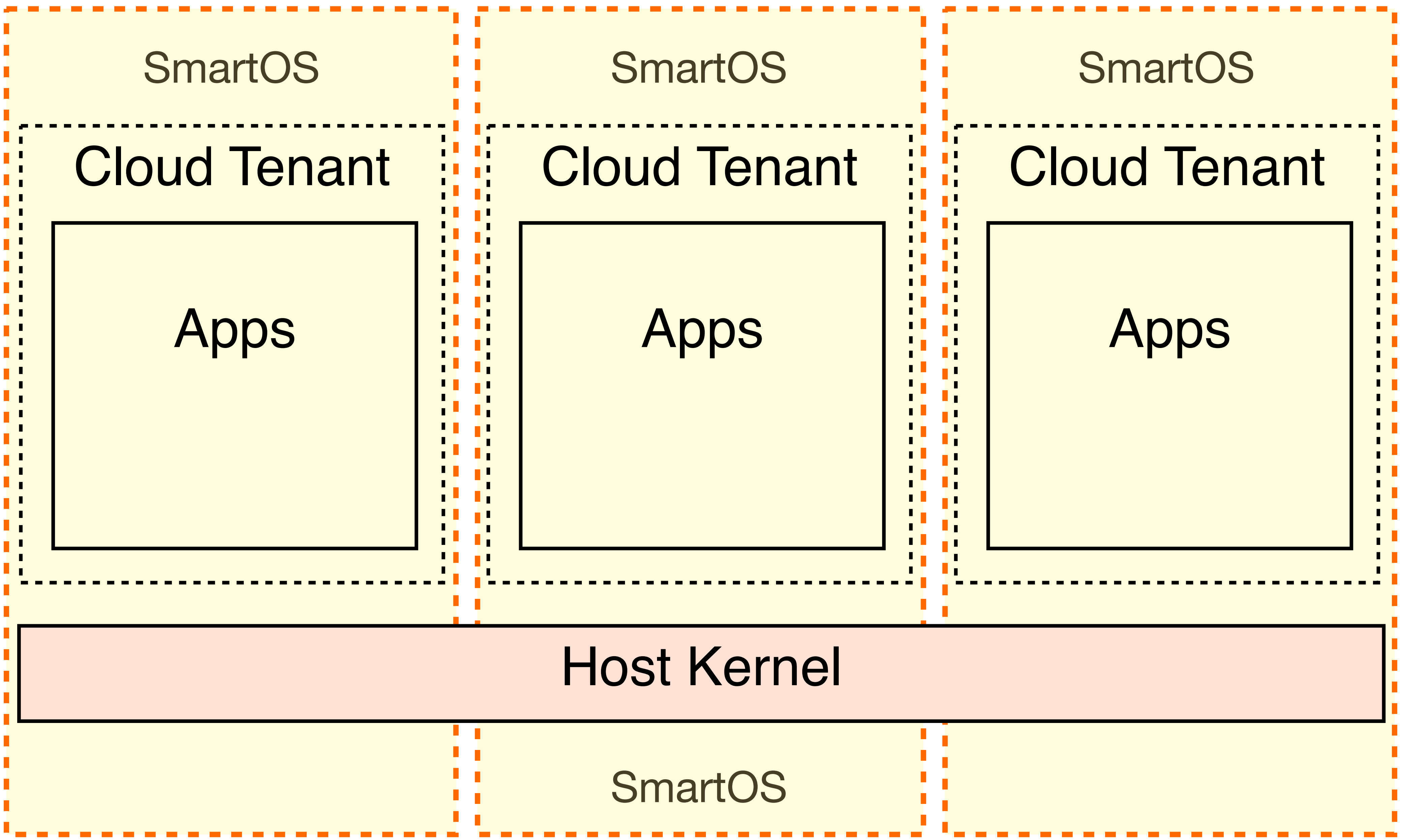
- As a tenant (guest):



OS Virtualization: DTrace Visibility

- Guest can see:
  - Guest apps
  - Some host kernel (in guest context), as configured by DTrace zone privileges
- Guest can't see:
  - Other guests
  - Host kernel (in non-guest context), apps

OS Stack DTrace Visibility

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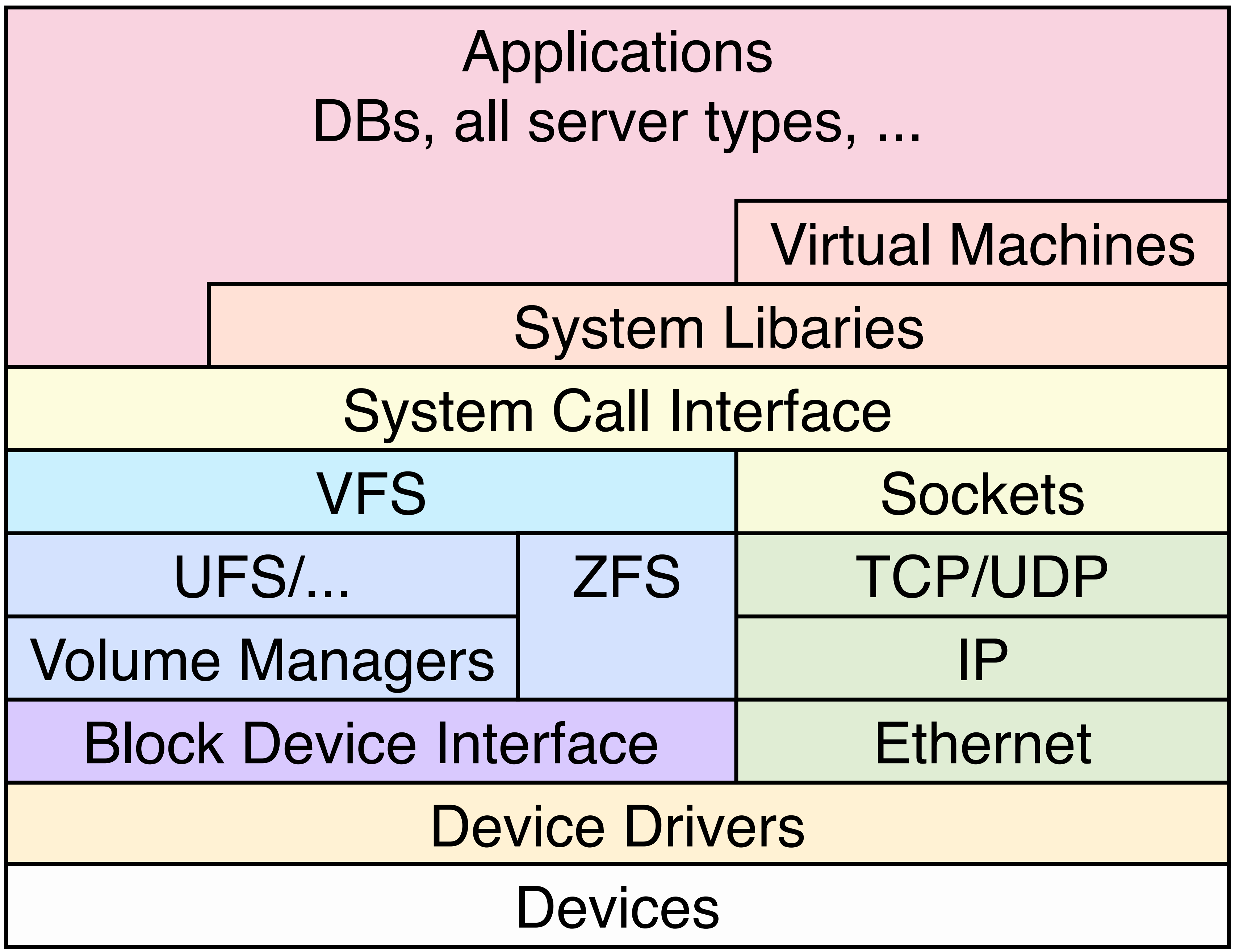
- Entire operating system stack (example):



OS Stack DTrace Visibility

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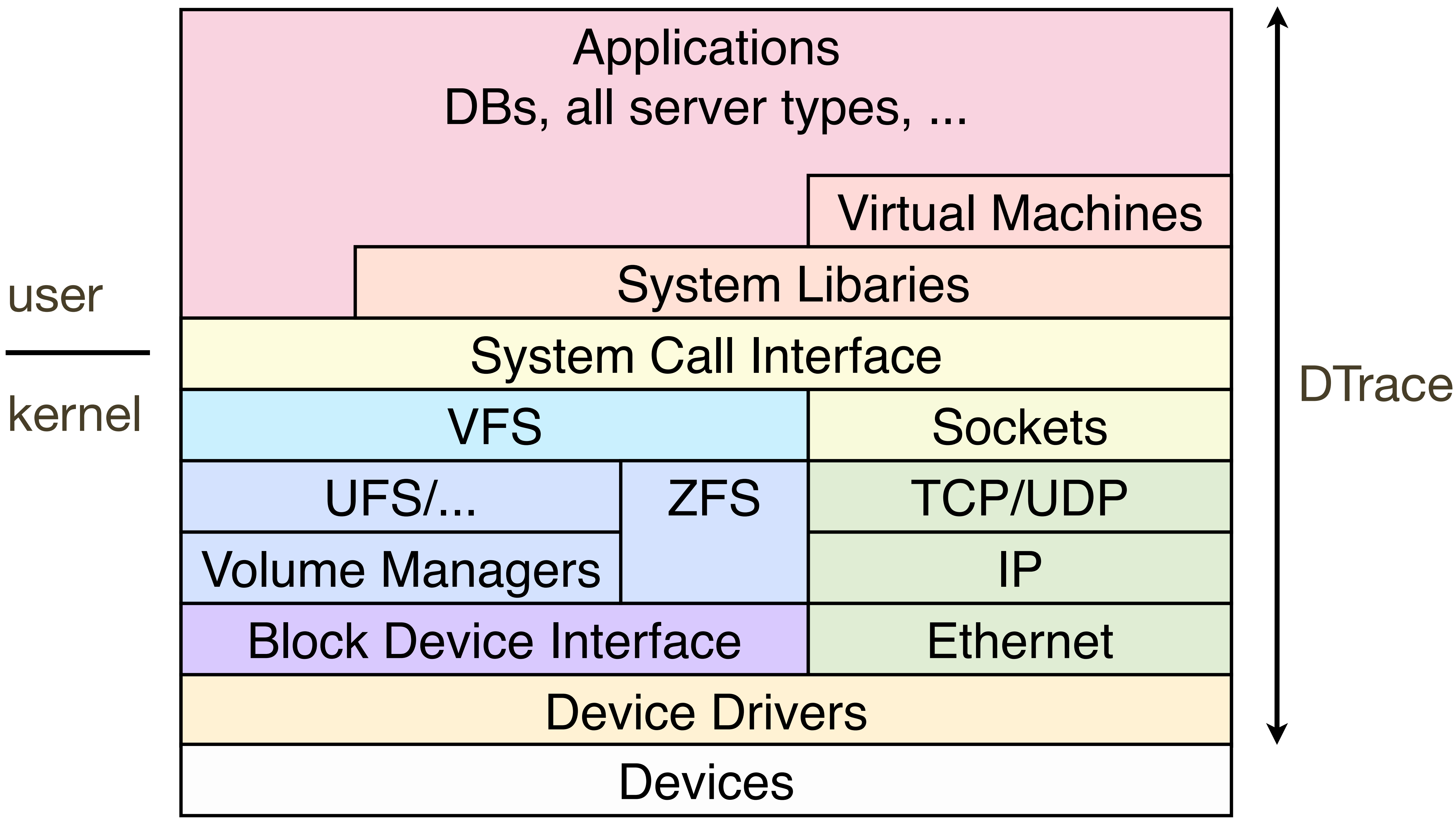
- Entire operating system stack (example):



Reality

DTrace and Zones

- DTrace and Zones were developed in parallel for Solaris 10, and then integrated.
- DTrace functionality for the Global Zone (GZ) was added first.
  - This is the host context, and allows operators to use DTrace to inspect all tenants.
- DTrace functionality for the Non-Global Zone (NGZ) was harder, and some capabilities added later (2006):
  - Providers: syscall, pid, profile
  - This is the guest context, and allows customers to use DTrace to inspect themselves only (can't see neighbors).

DTrace and Zones, cont.

DTrace and Zones, cont.

- GZ DTrace works well.
- We found many issues in practice with NGZ DTrace:
  - Can't read fds[] to translate file descriptors. Makes using the syscall provider more difficult.

```
# dtrace -n 'syscall::read:entry /fds[arg0].fi_fs == "zfs"/ { @ =
quantize(arg2); }'
dtrace: description 'syscall::read:entry ' matched 1 probe
dtrace: error on enabled probe ID 1 (ID 4: syscall::read:entry): invalid
kernel access in predicate at DIF offset 64
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kernel access in predicate at DIF offset 64
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kernel access in predicate at DIF offset 64
dtrace: error on enabled probe ID 1 (ID 4: syscall::read:entry): invalid
kernel access in predicate at DIF offset 64
[...]
```

DTrace and Zones, cont.

- Can’t read curpsinfo, curlwpsinfo, which breaks many scripts (eg, curpsinfo->pr_psargs, or curpsinfo->pr_dmodel)

```
# dtrace -n 'syscall::exec*:return { trace(curpsinfo->pr_psargs); }'
dtrace: description 'syscall::exec*:return ' matched 1 probe
dtrace: error on enabled probe ID 1 (ID 103: syscall::exece:return): invalid
kernel access in action #1 at DIF offset 0
dtrace: error on enabled probe ID 1 (ID 103: syscall::exece:return): invalid
kernel access in action #1 at DIF offset 0
dtrace: error on enabled probe ID 1 (ID 103: syscall::exece:return): invalid
kernel access in action #1 at DIF offset 0
dtrace: error on enabled probe ID 1 (ID 103: syscall::exece:return): invalid
kernel access in action #1 at DIF offset 0
[...]
```

- Missing proc provider. Breaks this common one-liner:

```
# dtrace -n 'proc:::exec-success { trace(execname); }'
dtrace: invalid probe specifier proc:::exec-success { trace(execname); }:
probe description proc:::exec-success does not match any probes
[...]
```

DTrace and Zones, cont.

- Missing vminfo, sysinfo, and sched providers.
- Can’t read cpu built-in.
- profile probes behave oddly. Eg, profile:::tick-1s only fires if tenant is on-CPU at the same time as the probe would fire. Makes any script that produces interval-output unreliable.

DTrace and Zones, cont.

- These and other bugs have since been fixed for SmartOS/illumos (thanks Bryan Cantrill!)
- Now, from a SmartOS Zone:

```
# dtrace -n 'proc:::exec-success { @[curpsinfo->pr_psargs] = count(); }
profile:::tick-5s { exit(0); }'
dtrace: description 'proc:::exec-success ' matched 2 probes
CPU     ID                    FUNCTION:NAME
 13  71762                         :tick-5s

  -bash                                                             1
  /bin/cat -s /etc/motd                                             1
  /bin/mail -E                                                      1
  /usr/bin/hostname                                                 1
  /usr/sbin/quota                                                   1
  /usr/bin/locale -a                                                2
  ls -l                                                             3
  sh -c /usr/bin/locale -a                                          4
```

- Trivial DTrace one-liner, but represents much needed functionality.

DTrace Wins

- Aside from the NGZ issues, DTrace has worked well in the cloud and solved numerous issues. For example (these are mostly from operator context):

#	Target	Analyzed	Key Tool	Fixed	Specific	Improvement
1	Redis	System	DTrace	Application	app config	up to 1000x
2	Riak	System	mpstat	Application	app config	2x
3	MySQL	System	DTrace	System	device tuning	up to 380x
4	Various	System	DTrace	System	kernel tuning	up to 2800x
5	Network Stack	System	DTrace	System	kernel code	up to 4.5x
6	Database	System	DTrace	Application	app config	~20%
7	Database	System	DTrace	System	library code	~10%
8	Riak	System	DTrace	System	library code	up to 100x
9	Various	System	DTrace	System	kernel code	up to 2x
10	KVM	System	DTrace	System	kvm config	8x

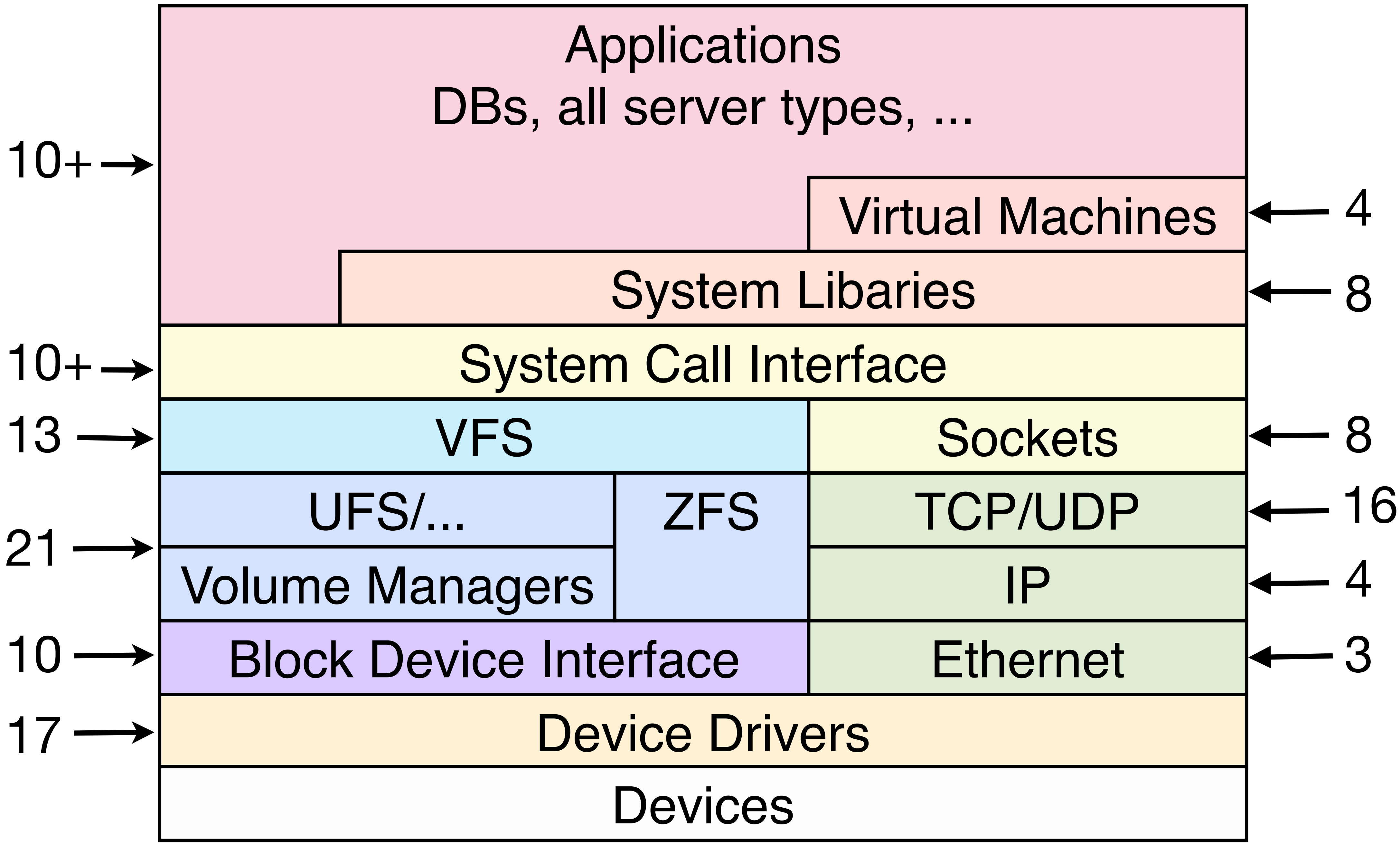
- http://dtrace.org/blogs/brendan/2012/08/09/10-performance-wins/

DTrace Wins, cont.

- Not surprising given DTrace's visibility...

DTrace Wins, cont.

- For example, DTrace script counts from the DTrace book:



Tools

Ad-hoc

- Write DTrace scripts as needed
- Execute individually on hosts, or,
- With ah-hoc scripting, execute across all hosts (cloud)
- My ad-hoc tools include:
  - DTrace Cloud Tools
  - Flame Graphs

Ad-hoc: DTrace Cloud Tools

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- Contains around 70 ad-hoc DTrace tools written by myself for operators and cloud customers.

```
./fs/metaslab_free.d
./fs/spasync.d
./fs/zfsdist.d
./fs/zfsslower.d
./fs/zfsslowzone.d
./fs/zfswhozone.d
./fs/ziowait.d
./mysql/innodb_pid_iolatency.d
./mysql/innodb_pid_ioslow.d
./mysql/innodb_thread_concurrency.d
./mysql/libmysql_pid_connect.d
./mysql/libmysql_pid_qtime.d
./mysql/libmysql_pid_snoop.d
./mysql/mysqld_latency.d
./mysql/mysqld_pid_avg.d
./mysql/mysqld_pid_filesort.d
./mysql/mysqld_pid_fslatency.d
[...]
```

```
./net/dnsconnect.d
./net/tcp-fbt-accept_sdc5.d
./net/tcp-fbt-accept_sdc6.d
./net/tcpconnreqmaxq-pid_sdc5.d
./net/tcpconnreqmaxq-pid_sdc6.d
./net/tcpconnreqmaxq_sdc5.d
./net/tcpconnreqmaxq_sdc6.d
./net/tcplistendrop_sdc5.d
./net/tcplistendrop_sdc6.d
./net/tcpretranshosts.d
./net/tcpretransport.d
./net/tcpretranssnoop_sdc5.d
./net/tcpretranssnoop_sdc6.d
./net/tcpretransstate.d
./net/tcptimewait.d
./net/tcptimewaited.d
./net/tcptimretransdropsnoop_sdc6.d
[...]
```

- Customer scripts are linked from the “smartmachine” directory
- https://github.com/brendangregg/dtrace-cloud-tools

Ad-hoc: DTrace Cloud Tools, cont.

- For example, tcplistendrop.d traces each kernel-dropped SYN due to TCP backlog overflow (saturation):

```
# ./tcplistendrop.d
TIME                     SRC-IP           PORT     DST-IP           PORT
2012 Jan 19 01:22:49  10.17.210.103    25691 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.17.210.108    18423 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.17.210.116    38883 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.17.210.117    10739 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.17.210.112    27988 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.17.210.106    28824 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.12.143.16     65070 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.17.210.100    56392 -> 192.192.240.212    80
2012 Jan 19 01:22:49  10.17.210.99     24628 -> 192.192.240.212    80
[...]
```

- Can explain multi-second client connect latency.

Ad-hoc: DTrace Cloud Tools, cont.

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- tcplistendrop.d processes IP and TCP headers from the in-kernel packet buffer:

```
fbt::tcp_input_listener:entry  { self->mp = args[1]; }
fbt::tcp_input_listener:return { self->mp = 0; }

mib:::tcpListenDrop
/self->mp/
{
        this->iph = (ipha_t *)self->mp->b_rptr;
        this->tcph = (tcph_t *)(self->mp->b_rptr + 20);
        printf("%-20Y  %-18s %-5d -> %-18s %-5d\n", walltimestamp,
            inet_ntoa(&this->iph->ipha_src),
            ntohs(*(uint16_t *)this->tcph->th_lport),
            inet_ntoa(&this->iph->ipha_dst),
            ntohs(*(uint16_t *)this->tcph->th_fport));
}
```

- Since this traces the fbt provider (kernel), it is operator only.

Ad-hoc: DTrace Cloud Tools, cont.

- A related example: tcpconnreqmaxq-pid*.d prints a summary, showing backlog lengths (on SYN arrival), the current max, and drops:

```
tcp_conn_req_cnt_q distributions:

  cpid:3063                                         max_q:8
           value  ------------- Distribution ------------- count
              -1 |                                         0
               0 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 1
               1 |                                         0

  cpid:11504                                        max_q:128
           value  ------------- Distribution ------------- count
              -1 |                                         0
               0 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@      7279
               1 |@@                                       405
               2 |@                                        255
               4 |@                                        138
               8 |                                         81
              16 |                                         83
              32 |                                         62
              64 |                                         67
             128 |                                         34
             256 |                                         0

tcpListenDrops:
   cpid:11504                    max_q:128                    34
```

Text

Ad-hoc: Flame Graphs

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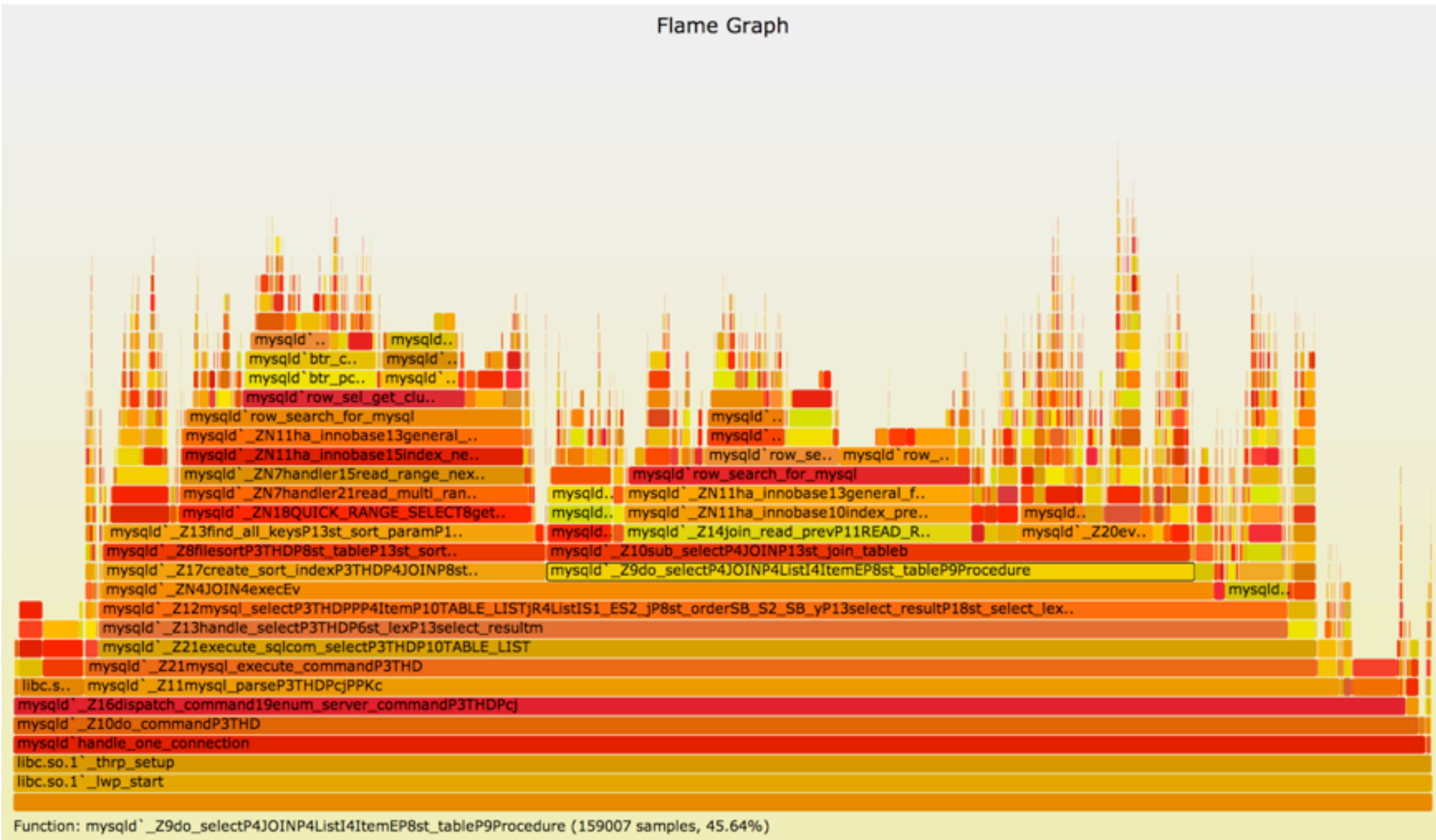
- Visualizing CPU time using DTrace profiling and SVG

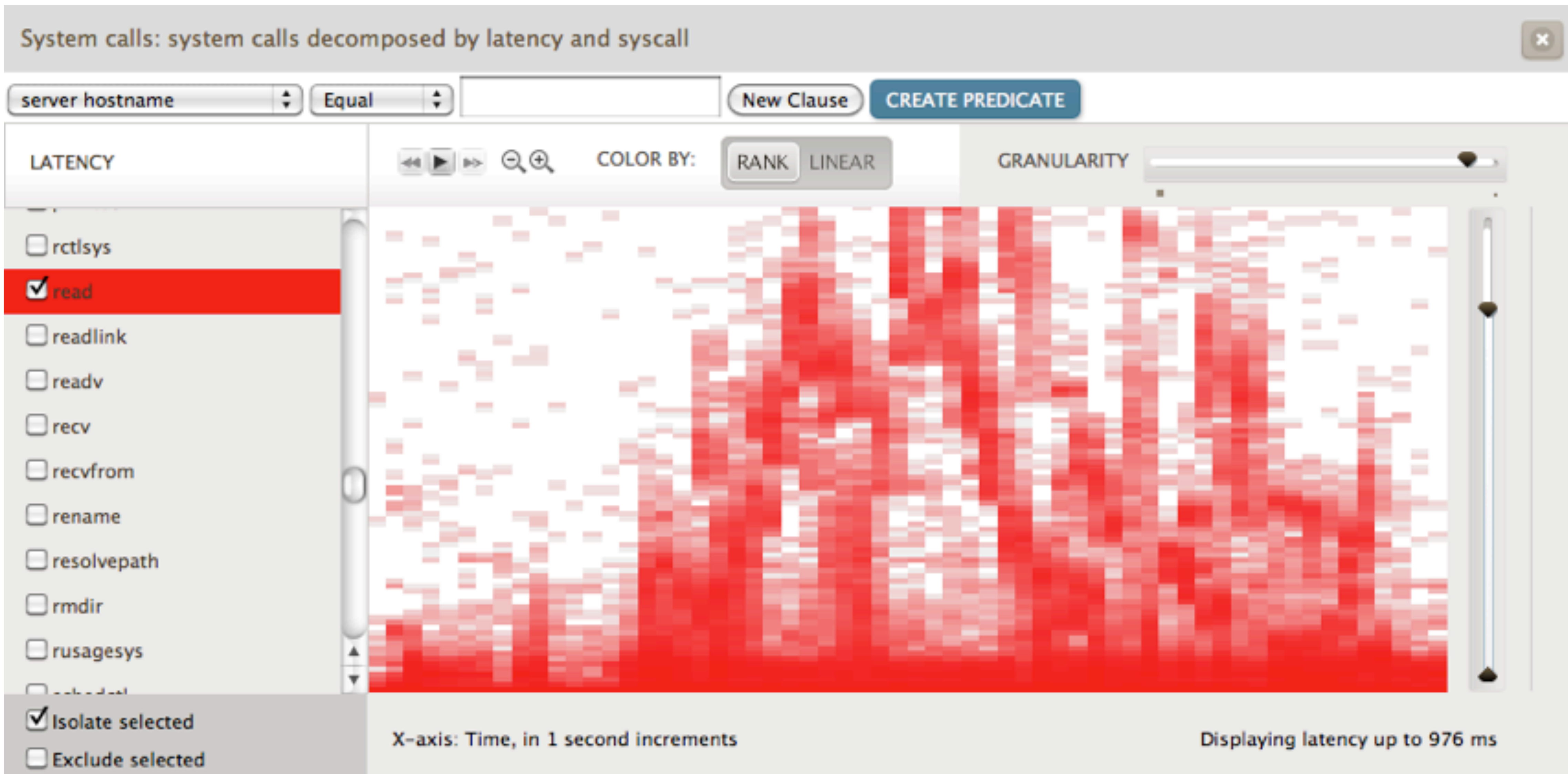


Product

- Cloud observability products including DTrace:
  - Joyent's Cloud Analytics

Product: Cloud Analytics

- Syscall latency across the entire cloud, as a heat map!

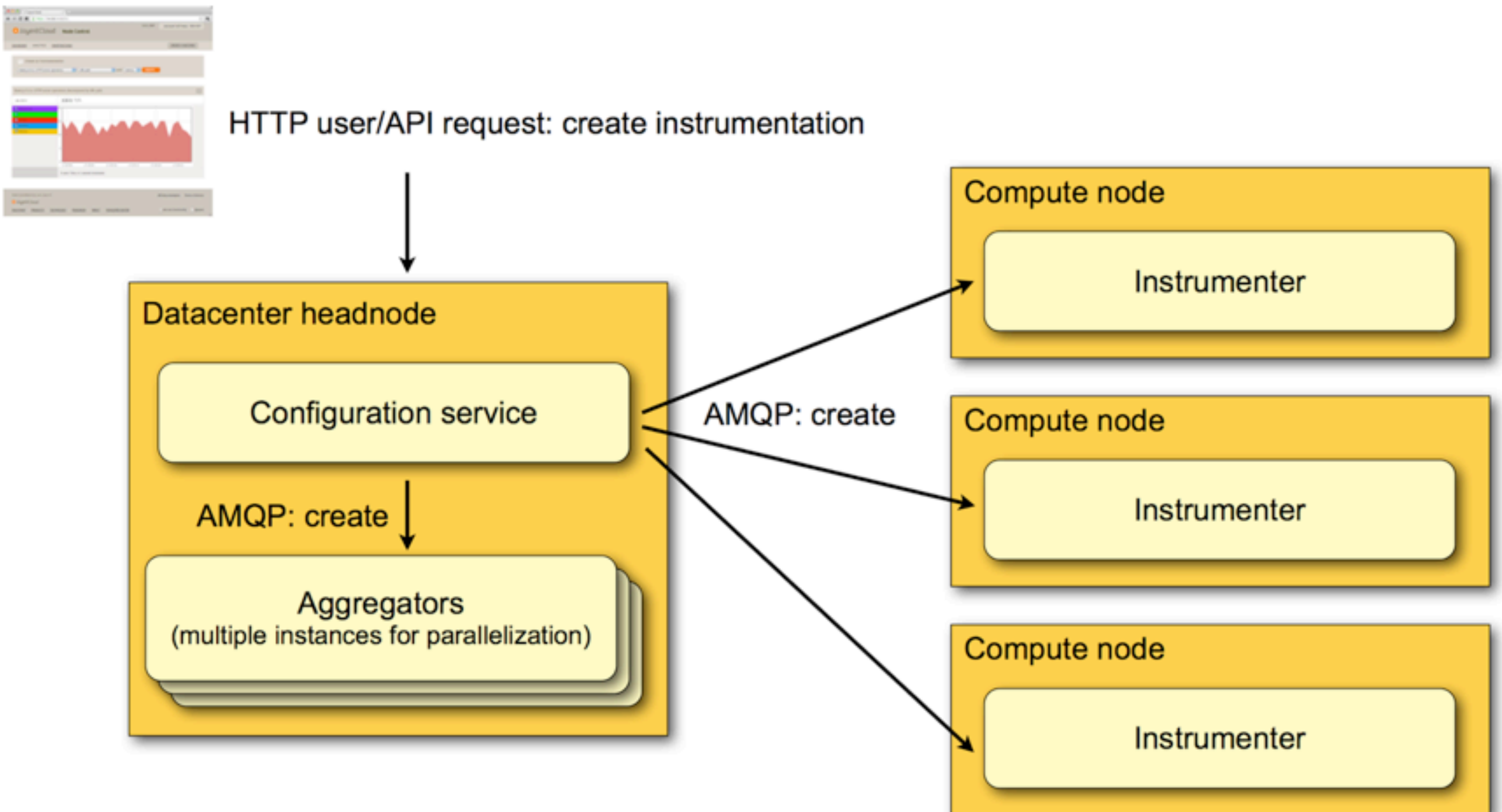


Product: Cloud Analytics, cont.

- For operators and cloud customers
- Observes entire cloud, in real-time
- Latency focus, including heat maps
- Instrumentation: DTrace and kstats
- Front-end: Browser JavaScript
- Back-end: node.js and C

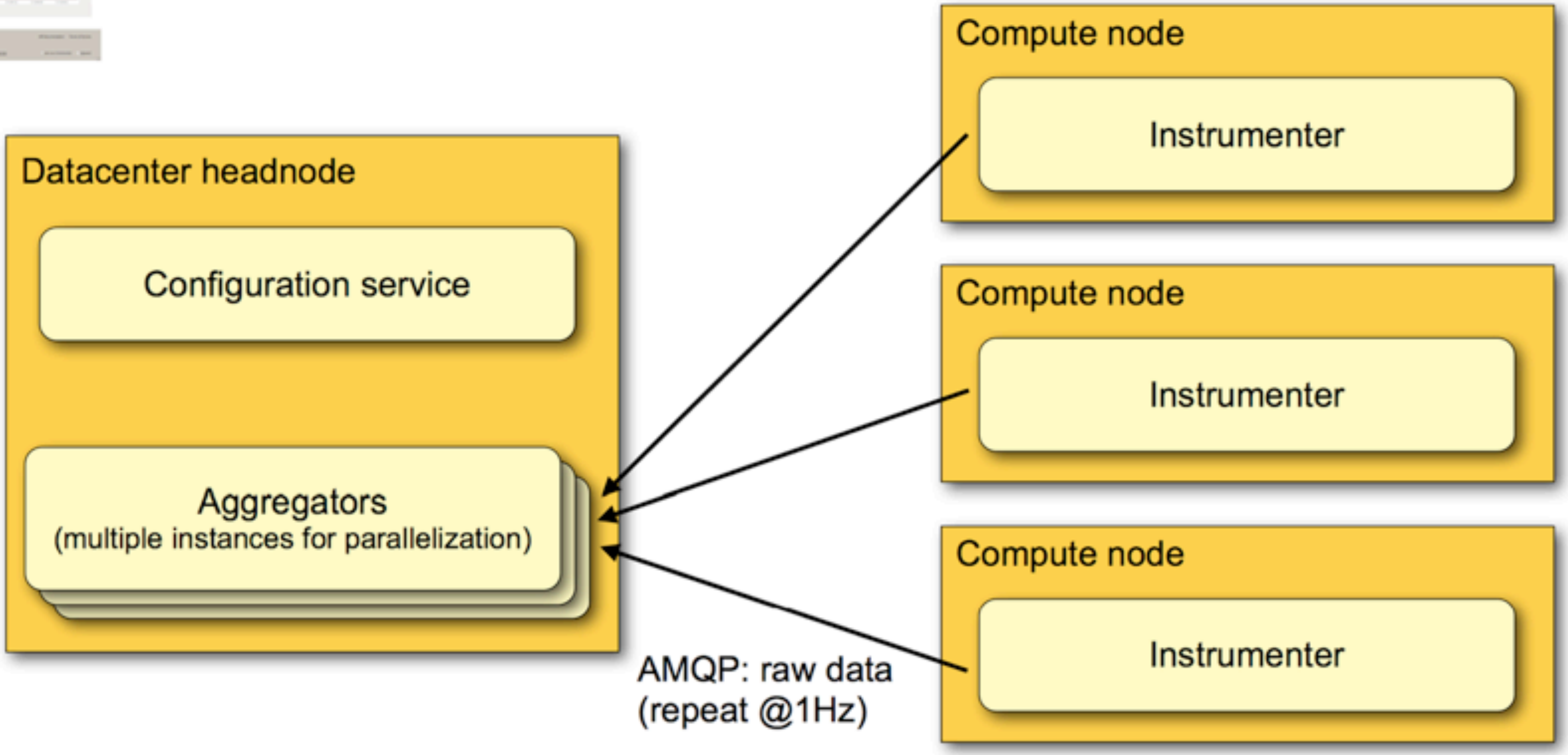
Product: Cloud Analytics, cont.

- Creating an instrumentation:



Product: Cloud Analytics, cont.

- Aggregating data across cloud:



Product: Cloud Analytics, cont.

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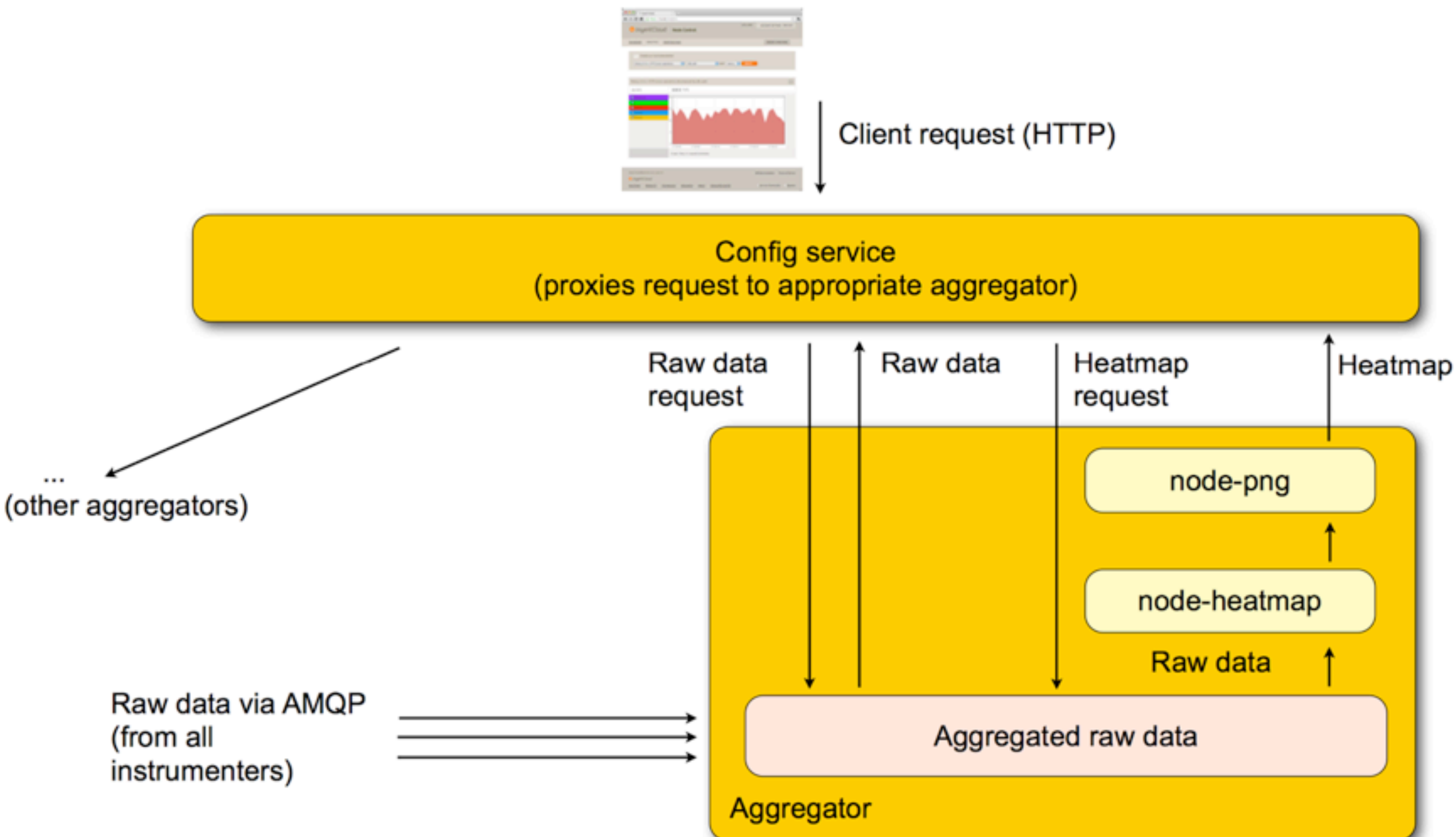
- Visualizing data:



Product: Cloud Analytics, cont.

- By-host breakdowns are essential:

Switch from cloud to host in one click

Case Studies

Case Studies

- Slow disks
- Scheduler

Slow disks

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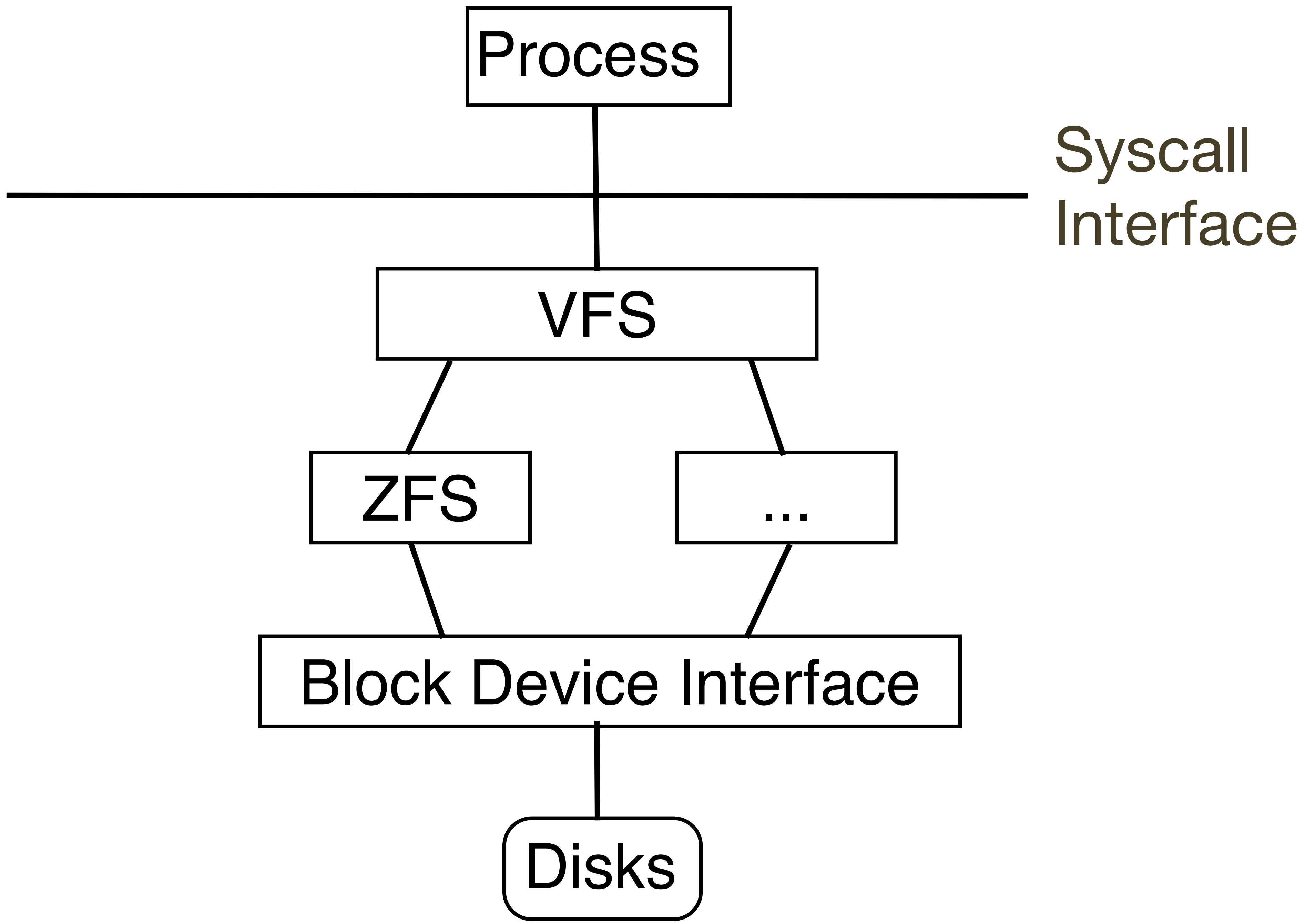
- Customer complains of poor MySQL performance.
  - Noticed disks are busy via iostat-based monitoring software, and have blamed noisy neighbors causing disk I/O contention.
- Multi-tenancy and performance isolation are common cloud issues

Slow disks, cont.

- Unix 101



Slow disks, cont.

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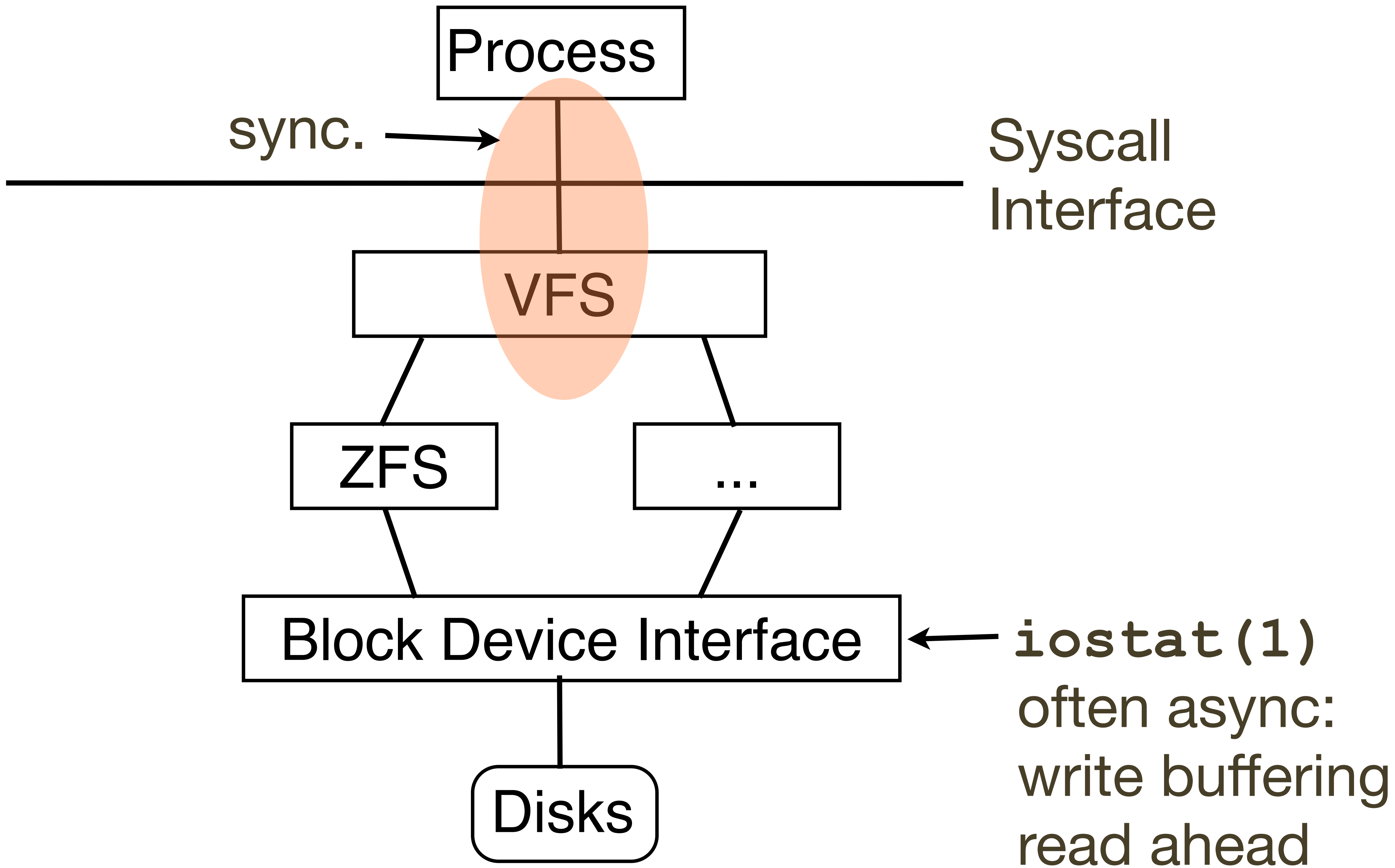
- Unix 101



Slow disks, cont.

- By measuring FS latency in application-synchronous context we can either confirm or rule-out FS/disk origin latency.
  - Including expressing FS latency during MySQL query, so that the issue can be quantified, and speedup calculated.
- Ideally, this would be possible from within the SmartMachine, so both customer and operator can run the DTrace script. This is possible using:
  - pid provider: trace and time MySQL FS functions
  - syscall provider: trace and time read/write syscalls for FS file descriptors (hence needing fds[].fi_fs; otherwise cache open())

Slow disks, cont.

- mysql_pid_fslatency.d from dtrace-cloud-tools:

```
# ./mysqld_pid_fslatency.d -n 'tick-10s { exit(0); }' -p 7357
Tracing PID 7357... Hit Ctrl-C to end.
MySQL filesystem I/O: 55824; latency (ns):

  read
           value  ------------- Distribution ------------- count
            1024 |                                         0
            2048 |@@@@@@@@@@                               9053
            4096 |@@@@@@@@@@@@@@@@@                        15490
            8192 |@@@@@@@@@@@                              9525
           16384 |@@                                       1982
           32768 |                                         121
           65536 |                                         28
          131072 |                                         6
          262144 |                                         0

  write
           value  ------------- Distribution ------------- count
            2048 |                                         0
            4096 |                                         1
            8192 |@@@@@@                                   3003
           16384 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@             13532
           32768 |@@@@@                                    2590
           65536 |@                                        370
          131072 |                                         58
          262144 |                                         27
          524288 |                                         12
         1048576 |                                         1
         2097152 |                                         0
         4194304 |                                         10
         8388608 |                                         14
        16777216 |                                         1
        33554432 |                                         0
```

Slow disks, cont.

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            8192 |@@@@@@@@@@@                              9525
           16384 |@@                                       1982
           32768 |                                         121
           65536 |                                         28
          131072 |                                         6
          262144 |                                         0

  write
           value  ------------- Distribution ------------- count
            2048 |                                         0
            4096 |                                         1
            8192 |@@@@@@                                   3003
           16384 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@             13532
           32768 |@@@@@                                    2590
           65536 |@                                        370
          131072 |                                         58
          262144 |                                         27
          524288 |                                         12
         1048576 |                                         1
         2097152 |                                         0
         4194304 |                                         10
         8388608 |                                         14
        16777216 |                                         1
        33554432 |                                         0
```

DRAM cache hits (→ 16384)

Disk I/O (→ 4194304–8388608)

Slow disks, cont.

- mysql_pid_fslatency.d is about 30 lines of DTrace:

```
pid$target::os_file_read:entry,
pid$target::os_file_write:entry,
pid$target::my_read:entry,
pid$target::my_write:entry
{
	self->start = timestamp;
}

pid$target::os_file_read:return  { this->dir = "read"; }
pid$target::os_file_write:return { this->dir = "write"; }
pid$target::my_read:return       { this->dir = "read"; }
pid$target::my_write:return      { this->dir = "write"; }

pid$target::os_file_read:return,
pid$target::os_file_write:return,
pid$target::my_read:return,
pid$target::my_write:return
/self->start/
{
	@time[this->dir] = quantize(timestamp - self->start);
	@num = count();
	self->start = 0;
}

dtrace:::END
{
	printa("MySQL filesystem I/O: %@d; latency (ns):\n", @num);
	printa(@time);
	clear(@time); clear(@num);
}
```

Slow disks, cont.

- mysql_pid_fslatency.d is about 30 lines of DTrace:

```
pid$target::os_file_read:entry,
pid$target::os_file_write:entry,
pid$target::my_read:entry,
pid$target::my_write:entry
{
	self->start = timestamp;
}

pid$target::os_file_read:return  { this->dir = "read"; }
pid$target::os_file_write:return { this->dir = "write"; }
pid$target::my_read:return       { this->dir = "read"; }
pid$target::my_write:return      { this->dir = "write"; }

pid$target::os_file_read:return,
pid$target::os_file_write:return,
pid$target::my_read:return,
pid$target::my_write:return
/self->start/
{
	@time[this->dir] = quantize(timestamp - self->start);
	@num = count();
	self->start = 0;
}

dtrace:::END
{
	printa("MySQL filesystem I/O: %@d; latency (ns):\n", @num);
	printa(@time);
	clear(@time); clear(@num);
}
```

Thank you MySQL!
If not that easy,
try syscall with fds[]

Slow disks, cont.

- Going for the slam dunk:

```
# ./mysqld_pid_fslatency_slowlog.d 29952
2011 May 16 23:34:00 filesystem I/O during query > 100 ms: query 538 ms,
fs 509 ms, 83 I/O
2011 May 16 23:34:11 filesystem I/O during query > 100 ms: query 342 ms,
fs 303 ms, 75 I/O
2011 May 16 23:34:38 filesystem I/O during query > 100 ms: query 479 ms,
fs 471 ms, 44 I/O
2011 May 16 23:34:58 filesystem I/O during query > 100 ms: query 153 ms,
fs 152 ms, 1 I/O
2011 May 16 23:35:09 filesystem I/O during query > 100 ms: query 383 ms,
fs 372 ms, 72 I/O
2011 May 16 23:36:09 filesystem I/O during query > 100 ms: query 406 ms,
fs 344 ms, 109 I/O
2011 May 16 23:36:44 filesystem I/O during query > 100 ms: query 343 ms,
fs 319 ms, 75 I/O
2011 May 16 23:36:54 filesystem I/O during query > 100 ms: query 196 ms,
fs 185 ms, 59 I/O
2011 May 16 23:37:10 filesystem I/O during query > 100 ms: query 254 ms,
fs 209 ms, 83 I/O
```

- Shows FS latency as a proportion of Query latency
- mysld_pid_fslatency_slowlog*.d in dtrace-cloud-tools

Slow disks, cont.

- The cloud operator can trace kernel internals. Eg, the VFS->ZFS interface using zfsslower.d:

```
# ./zfsslower.d 10
TIME                     PROCESS   D     KB    ms  FILE
2012 Sep 27 13:45:33 zlogin    W       0    11 /zones/b8b2464c/var/adm/wtmpx
2012 Sep 27 13:45:36 bash      R       0    14 /zones/b8b2464c/opt/local/bin/zsh
2012 Sep 27 13:45:58 mysqld    R    1024    19 /zones/b8b2464c/var/mysql/ibdata1
2012 Sep 27 13:45:58 mysqld    R    1024    22 /zones/b8b2464c/var/mysql/ibdata1
2012 Sep 27 13:46:14 master    R       1    6  /zones/b8b2464c/root/opt/local/
libexec/postfix/qmgr
2012 Sep 27 13:46:14 master    R       4    5  /zones/b8b2464c/root/opt/local/etc/
postfix/master.cf
[...]
```

- My go-to tool (does all apps). This example showed if there were VFS-level I/O > 10ms? (arg == 10)
- Stupidly easy to do

Slow disks, cont.

- zfs_read() entry -> return; same for zfs_write().

```
[...]
fbt::zfs_read:entry,
fbt::zfs_write:entry
{
    self->path = args[0]->v_path;
    self->kb = args[1]->uio_resid / 1024;
    self->start = timestamp;
}

fbt::zfs_read:return,
fbt::zfs_write:return
/self->start && (timestamp - self->start) >= min_ns/
{
    this->iotime = (timestamp - self->start) / 1000000;
    this->dir = probefunc == "zfs_read" ? "R" : "W";
    printf("%-20Y %-16s %1s %4d %6d %s\n", walltimestamp,
        execname, this->dir, self->kb, this->iotime,
        self->path != NULL ? stringof(self->path) : "<null>");
}
[...]
```

- zfsslower.d originated from the DTrace book

Slow disks, cont.

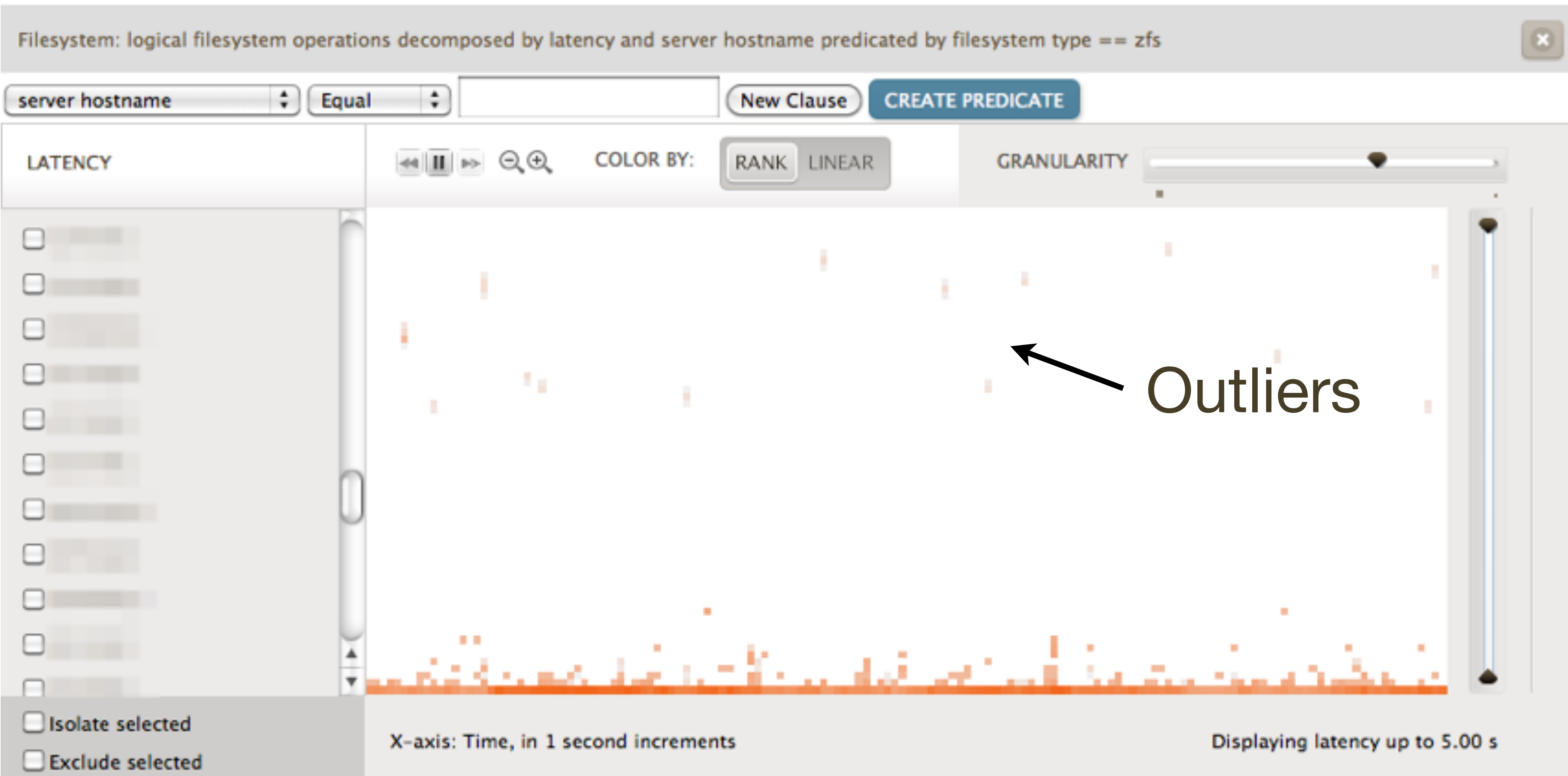
- The operator can use deeper tools as needed. Anywhere in ZFS.

```
# dtrace -n 'io:::start { @[stack()] = count(); }'
dtrace: description 'io:::start ' matched 6 probes
^C
              genunix`ldi_strategy+0x53
              zfs`vdev_disk_io_start+0xcc
              zfs`zio_vdev_io_start+0xab
              zfs`zio_execute+0x88
              zfs`zio_nowait+0x21
              zfs`vdev_mirror_io_start+0xcd
              zfs`zio_vdev_io_start+0x250
              zfs`zio_execute+0x88
              zfs`zio_nowait+0x21
              zfs`arc_read_nolock+0x4f9
              zfs`arc_read+0x96
              zfs`dsl_read+0x44
              zfs`dbuf_read_impl+0x166
              zfs`dbuf_read+0xab
              zfs`dmu_buf_hold_array_by_dnode+0x189
              zfs`dmu_buf_hold_array+0x78
              zfs`dmu_read_uio+0x5c
              zfs`zfs_read+0x1a3
              genunix`fop_read+0x8b
              genunix`read+0x2a7
              143
```

Slow disks, cont.

Joyent

- Cloud Analytics, for either operator or customer, can be used to examine the full latency distribution, including outliers:



This heat map shows FS latency for an entire cloud data center

Slow disks, cont.

- Found that the customer problem was not disks or FS (99% of the time), but was CPU usage during table joins.
- On Joyent's IaaS architecture, it's usually not the disks or filesystem; useful to rule that out quickly.
- Some of the time it is, due to:
  - Bad disks (1000+ms I/O)
  - Controller issues (PERC)
  - Big I/O (how quick is a 40 Mbyte read from cache?)
  - Other tenants (benchmarking!). Much less for us now with ZFS I/O throttling (thanks Bill Pijewski), used for disk performance isolation in the SmartOS cloud.

Slow disks, cont.

- Customer resolved real issue
- Prior to DTrace analysis, had spent months of poor performance believing disks were to blame

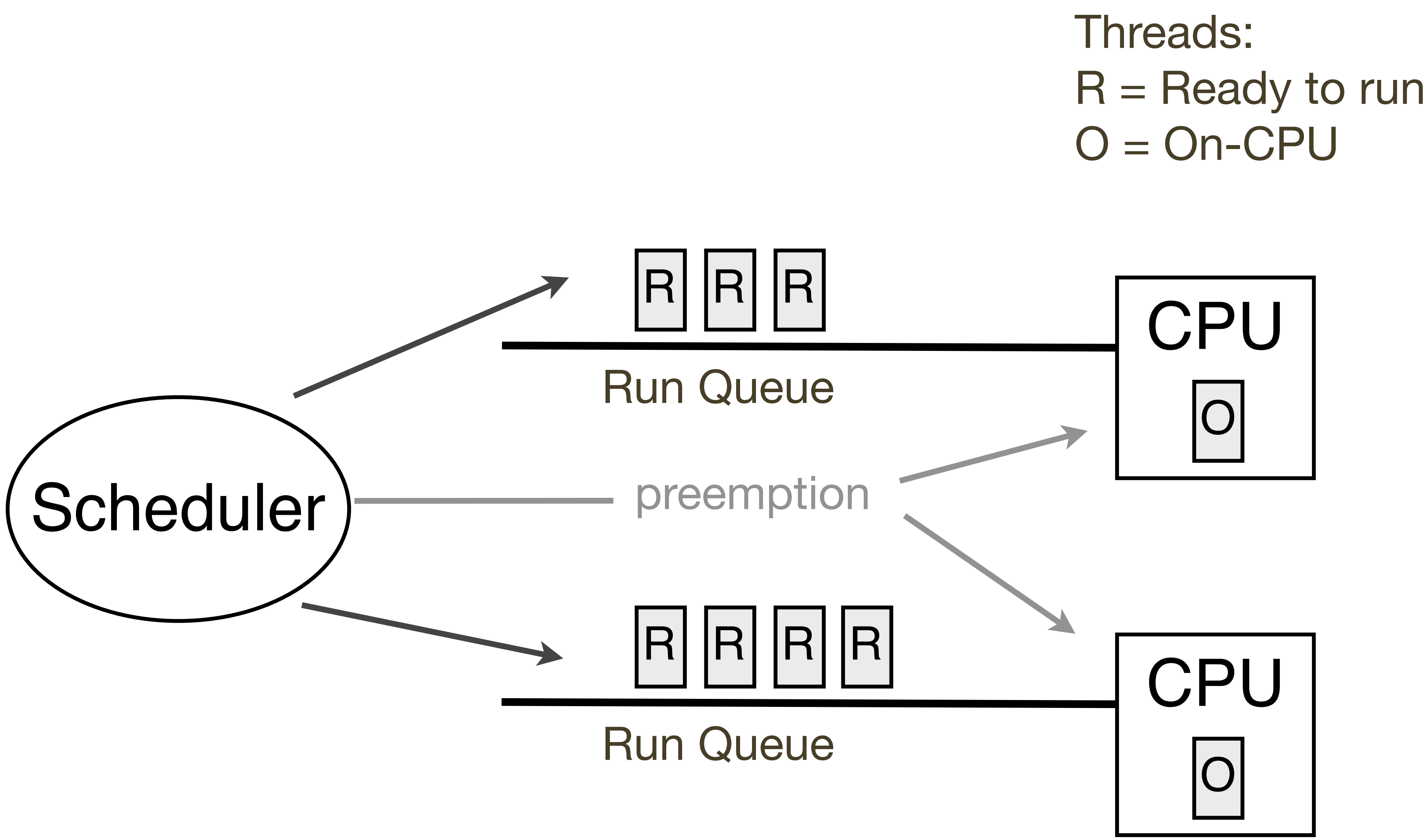
Kernel scheduler

- Customer problem: occasional latency outliers
- Analysis: no smoking gun. No slow I/O or locks, etc. Some random dispatcher queue latency, but with CPU headroom.

```
$ prstat -mLc 1
   PID USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/LWPID
 17930 103       21 7.6 0.0 0.0 0.0  53  16 9.1 57K   1 73K   0 beam.smp/265
 17930 103       20 7.0 0.0 0.0 0.0  57  16 0.4 57K   2 70K   0 beam.smp/264
 17930 103       20 7.4 0.0 0.0 0.0  53  18 1.7 63K   0 78K   0 beam.smp/263
 17930 103       19 6.7 0.0 0.0 0.0  60  14 0.4 52K   0 65K   0 beam.smp/266
 17930 103      2.0 0.7 0.0 0.0 0.0  96 1.6 0.0  6K   0  8K   0 beam.smp/267
 17930 103      1.0 0.9 0.0 0.0 0.0  97 0.9 0.0   4   0  47   0 beam.smp/280
[...]
```

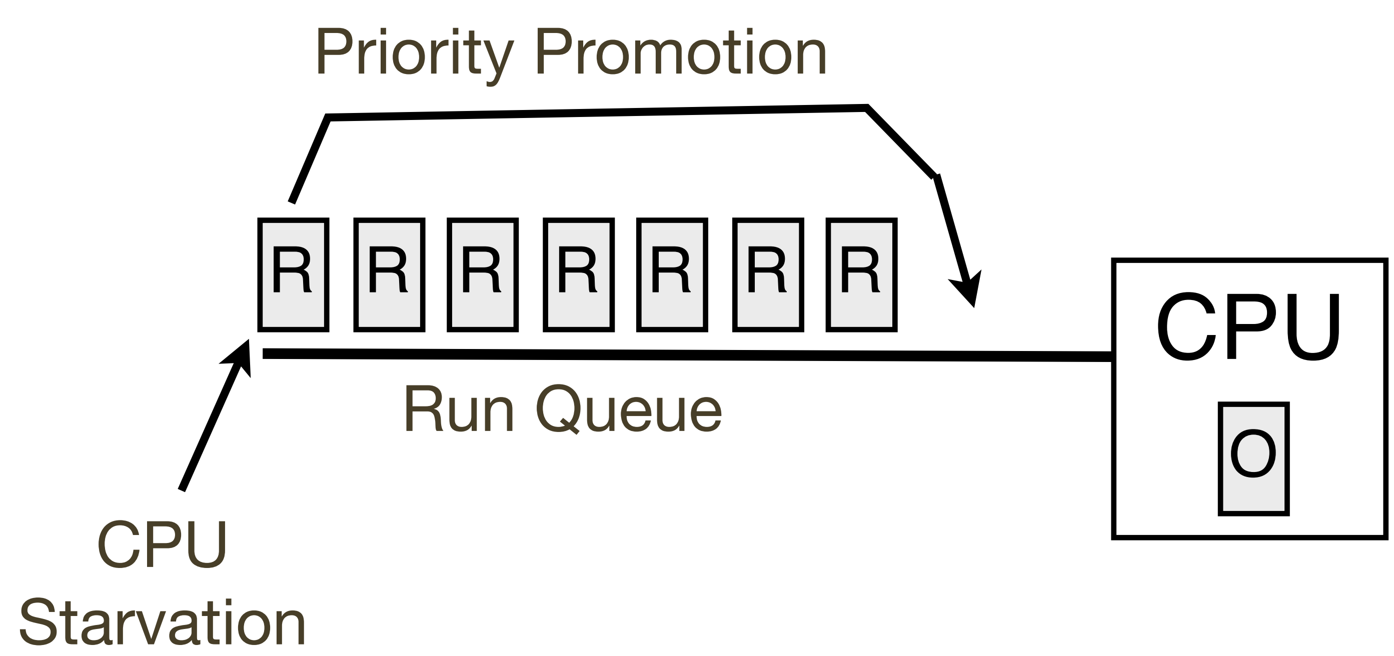
Kernel scheduler, cont.

- Unix 101



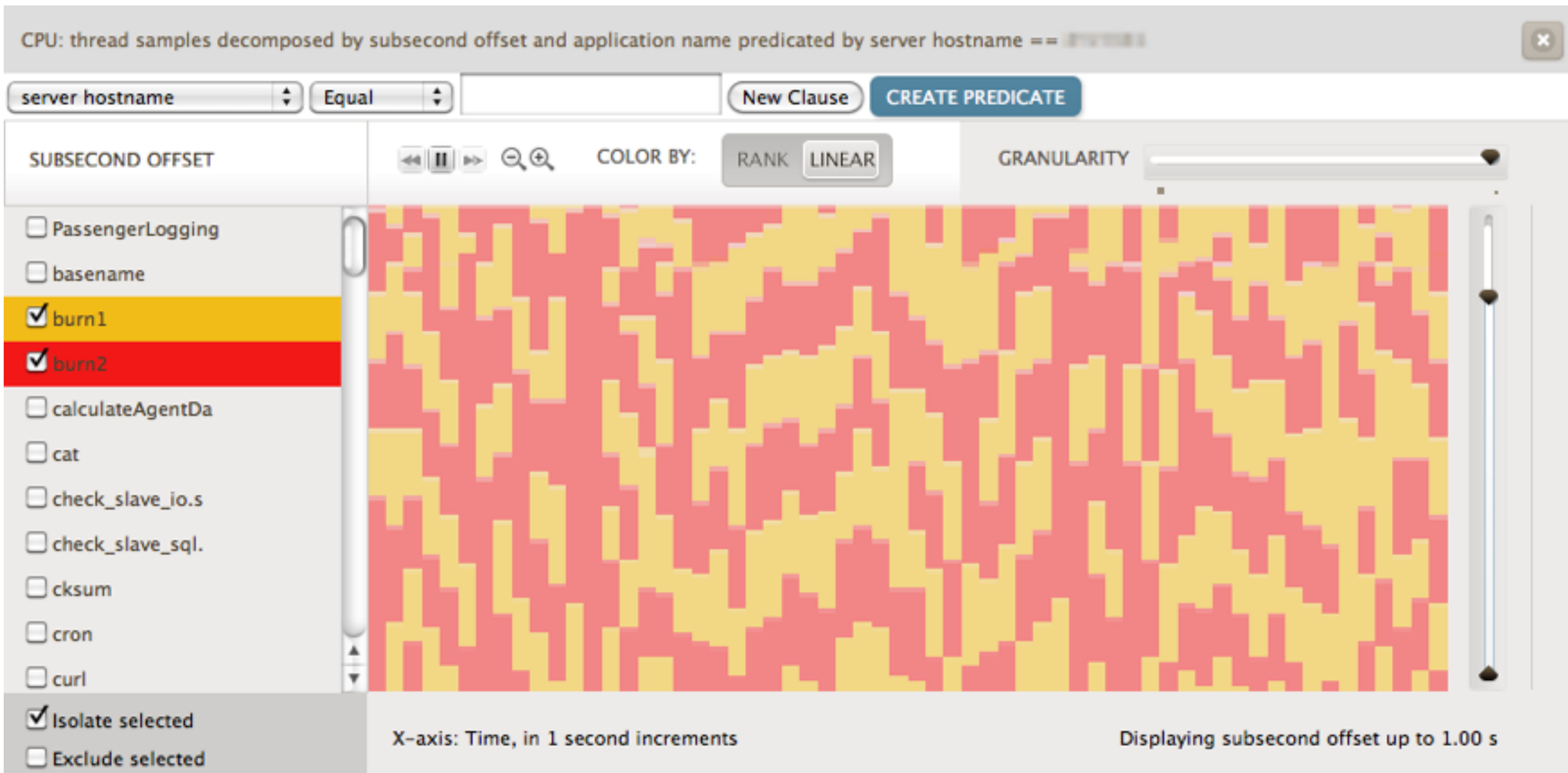
Kernel scheduler, cont.

- Unix 102
- TS (and FSS) check for CPU starvation



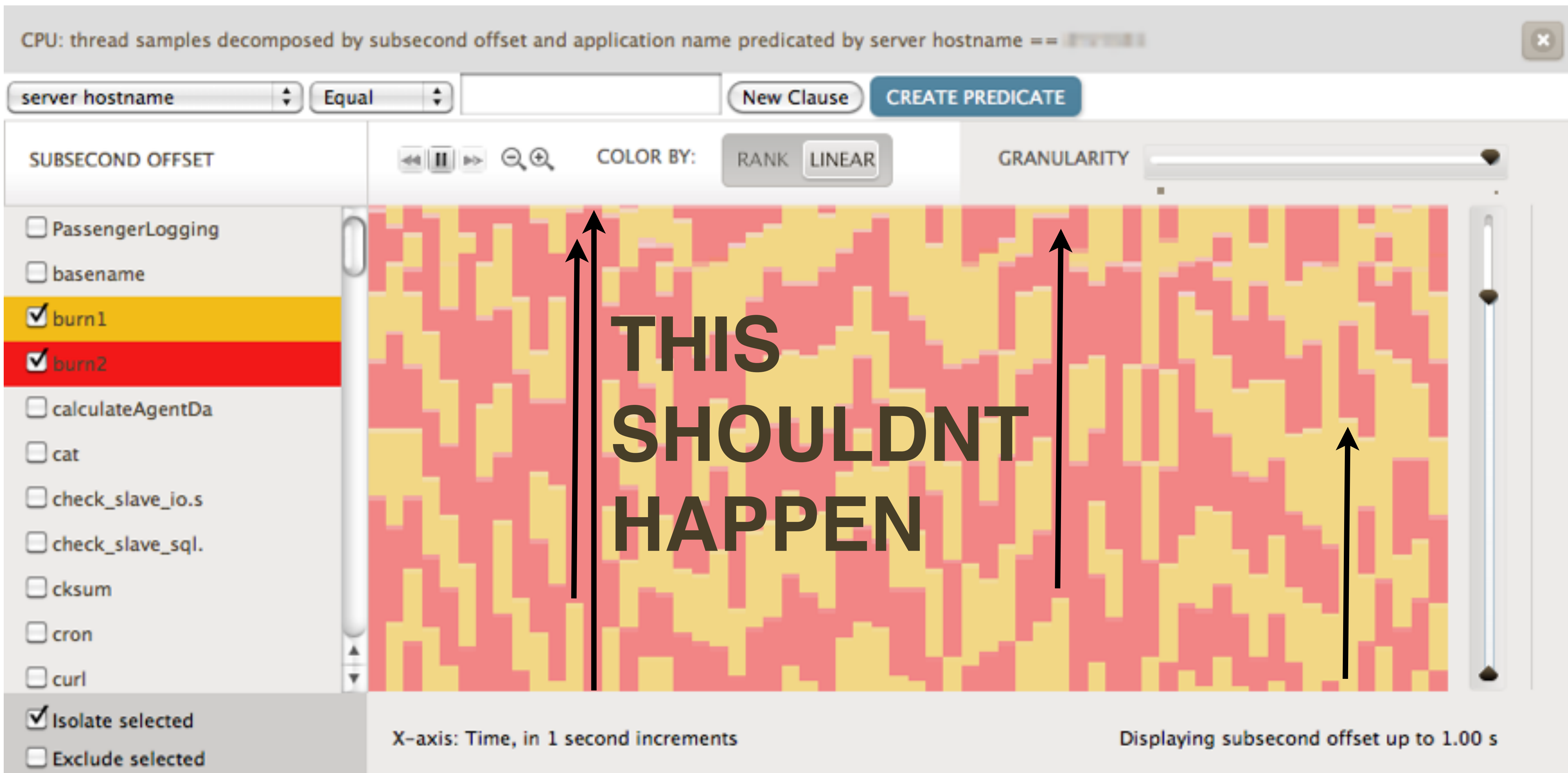
Kernel scheduler, cont.

- Experimentation: run 2 CPU-bound threads, 1 CPU
- Subsecond offset heat maps:



Kernel scheduler, cont.

- Experimentation: run 2 CPU-bound threads, 1 CPU
- Subsecond offset heat maps:



Kernel scheduler, cont.

- Worst case (4 threads 1 CPU), 44 sec dispq latency

```
# dtrace -n 'sched:::off-cpu /execname == "burn1"/ { self->s = timestamp; }
 sched:::on-cpu /self->s/ { @["off-cpu (ms)"] =
 lquantize((timestamp - self->s) / 1000000, 0, 100000, 1000); self->s = 0; }'

  off-cpu (ms)
           value  ------------- Distribution ------------- count
             < 0 |                                         0
               0 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  387184
            1000 |                                         2256
            2000 |                                         1078
            3000 |                                         862
            4000 |                                         1070
            5000 |                                         637
            6000 |                                         535
[...]
           41000 |                                         3
           42000 |                                         2
           43000 |                                         2
           44000 |                                         1
           45000 |                                         0
```

Expected
Bad
Inconceivable

ts_maxwait @pri 59 = 32s, FSS uses ?

Kernel scheduler, cont.

- FSS scheduler class bug:
  - FSS uses a more complex technique to avoid CPU starvation. A thread priority could stay high and on-CPU for many seconds before the priority is decayed to allow another thread to run.
  - Analyzed (more DTrace) and fixed (thanks Jerry Jelinek)
- Under (too) high CPU load, your runtime can be bound by how well you schedule, not do work
  - Cloud workloads scale fast, hit (new) scheduler issues

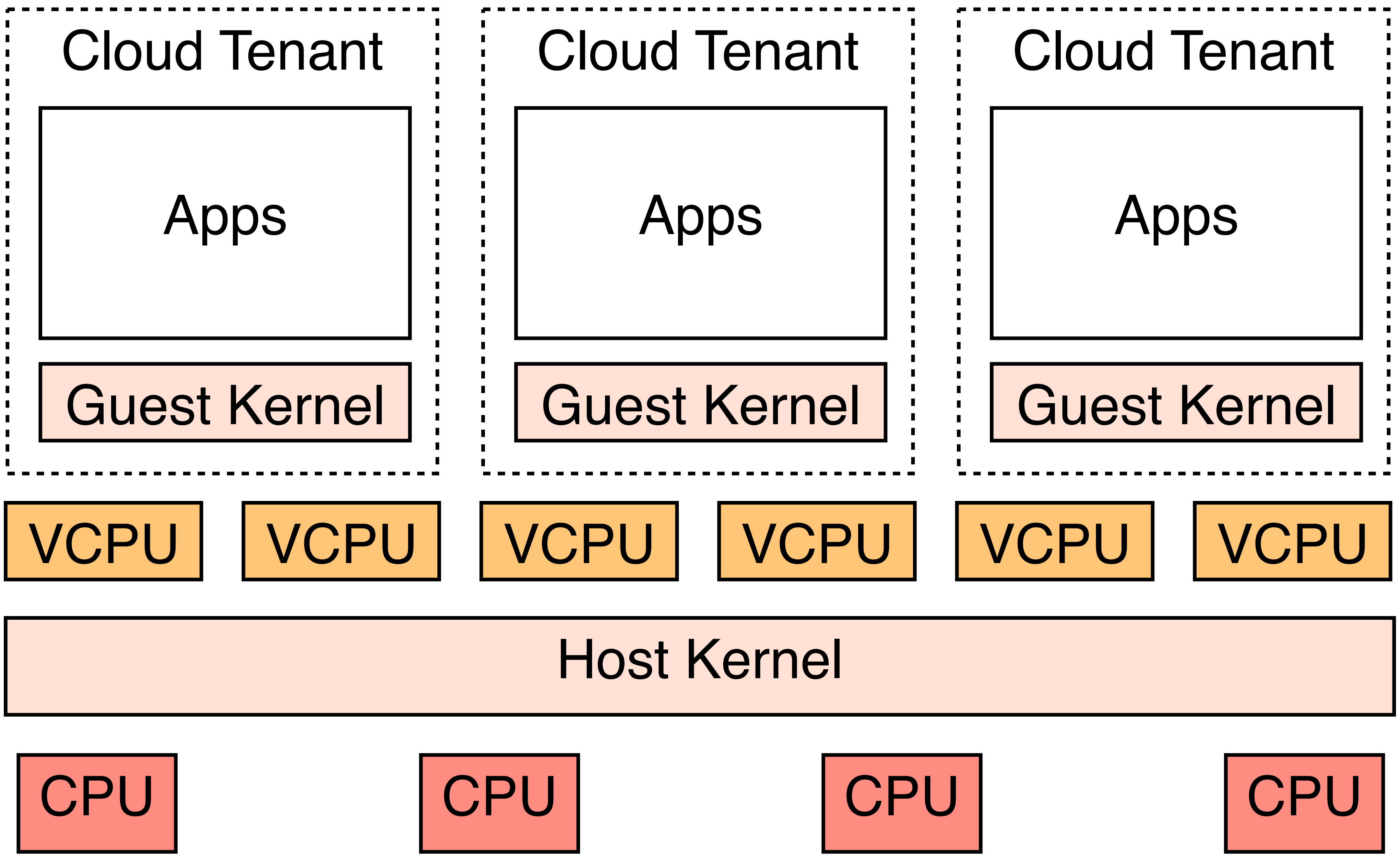
Kernel scheduler, cont.

- Required the operator of the cloud to debug
  - Even if the customer doesn't have kernel-DTrace access in the zone, they still benefit from the cloud provider having access
  - Ask your cloud provider to trace scheduler internals, in case you have something similar
- On Hardware Virtualization, scheduler issues can be terrifying

Kernel scheduler, cont.

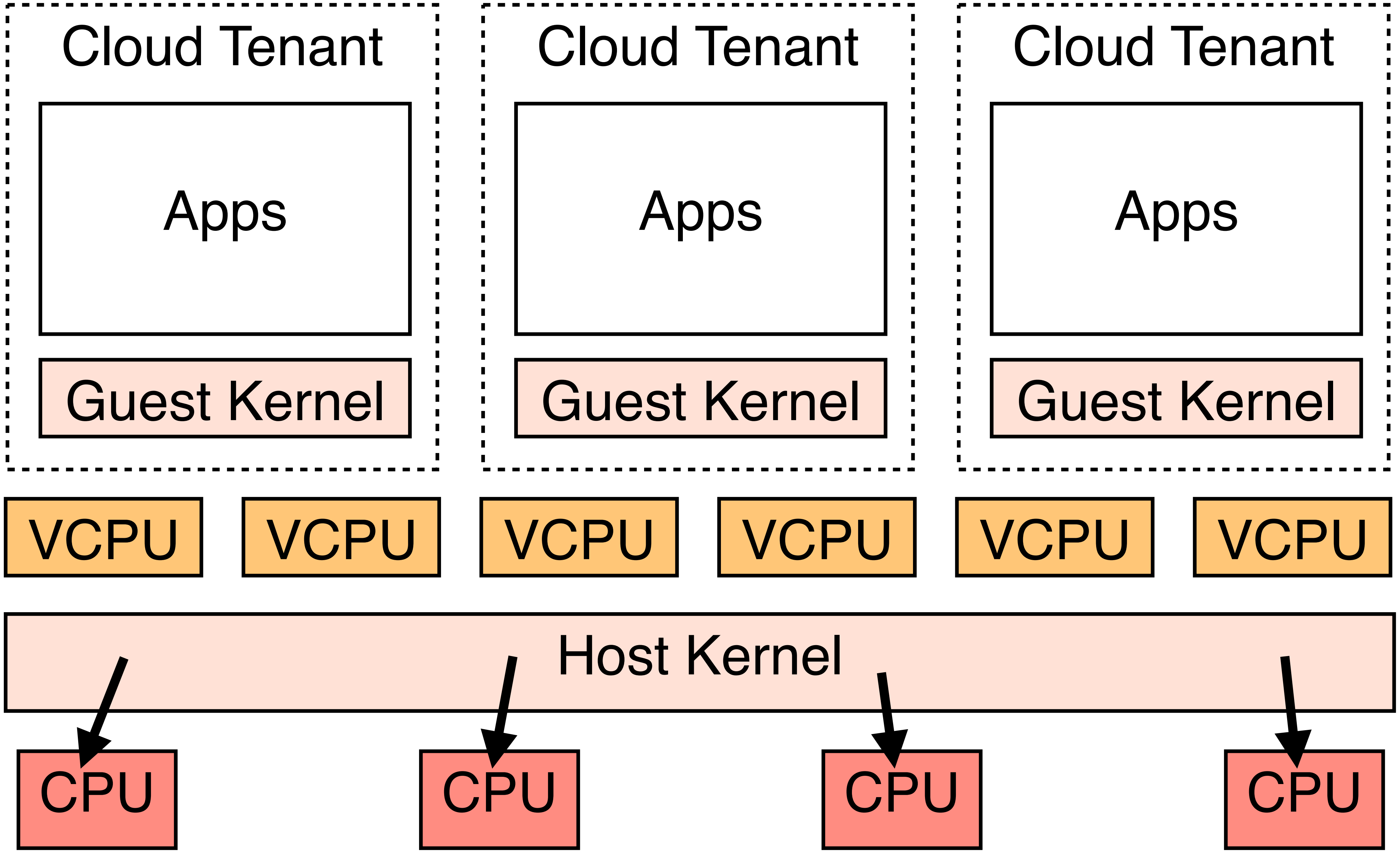
Joyent

- Each kernel believes they own the hardware.



Kernel scheduler, cont.

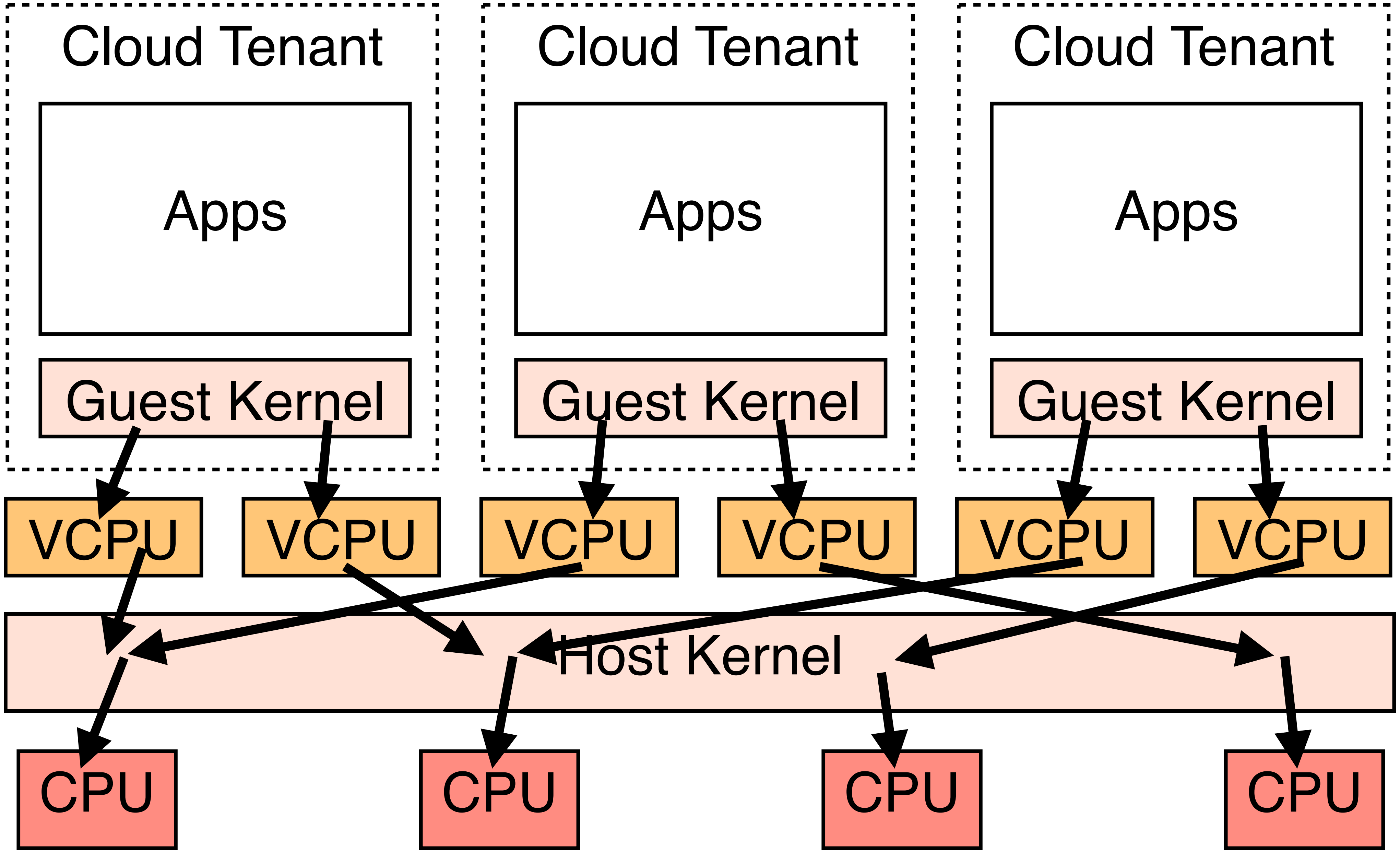
- One scheduler:



Kernel scheduler, cont.

Joyent

- Many schedulers. Kernel fight!



Kernel scheduler, cont.

- Had a networking performance issue on KVM; debugged using:
  - Host: DTrace
  - Guests: Prototype DTrace for Linux, SystemTap
- Took weeks to debug the kernel scheduler interactions and determine the fix for an 8x win.
- Office wall (output from many perf tools, including Flame Graphs):

Thank you!

- http://dtrace.org/blogs/brendan
- email brendan@joyent.com
- twitter @brendangregg
- Resources:
  - http://www.slideshare.net/bcantrill/dtrace-in-the-nonglobal-zone
  - http://dtrace.org/blogs/dap/2011/07/27/oscon-slides/
  - https://github.com/brendangregg/dtrace-cloud-tools
  - http://dtrace.org/blogs/brendan/2011/12/16/flame-graphs/
  - http://dtrace.org/blogs/brendan/2012/08/09/10-performance-wins/
  - http://dtrace.org/blogs/brendan/2011/10/04/visualizing-the-cloud/
- Thanks @dapsays and team for Cloud Analytics, Bryan Cantrill for DTrace fixes, @rmustacc for KVM perf war, and @DeirdreS for another great event.