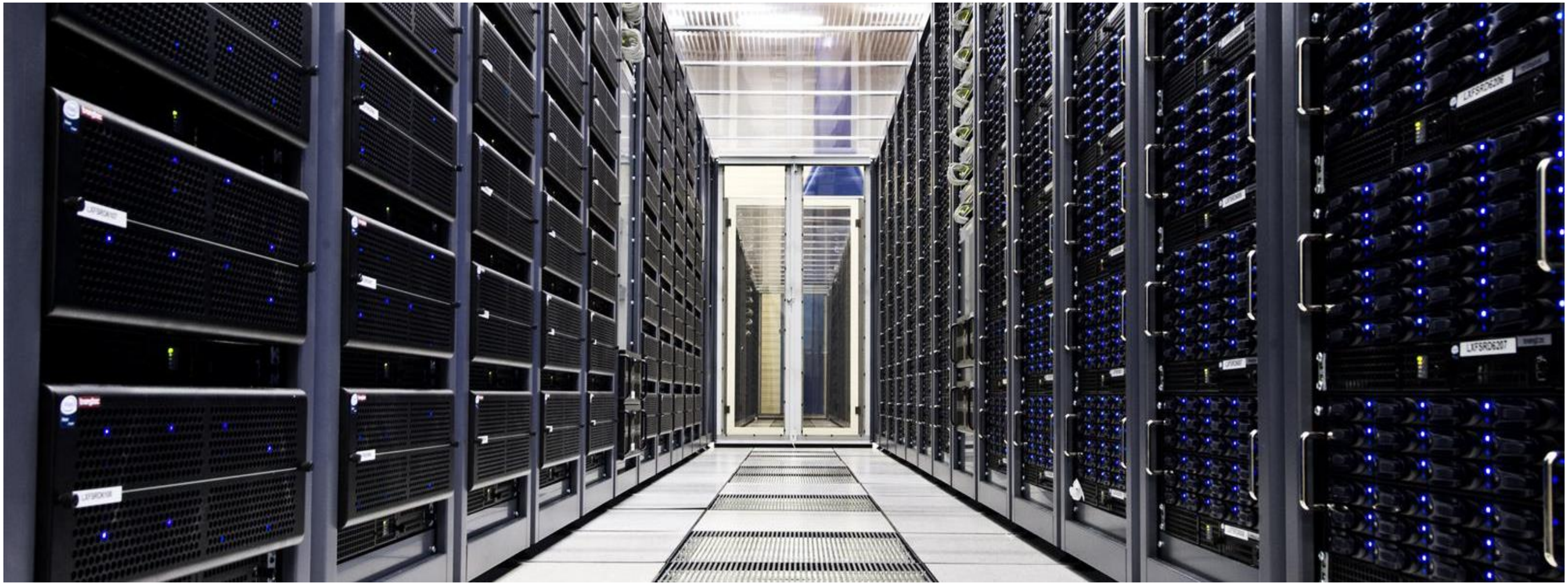
CERN

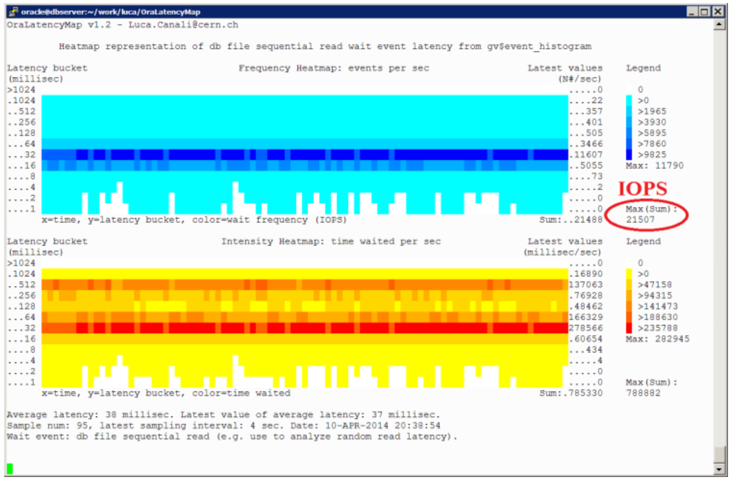
Modern Linux Tools for Oracle Troubleshooting

Luca Canali, CERN
Zbigniew Baranowski, CERN
UKOUG TECH14, Liverpool, December 2014



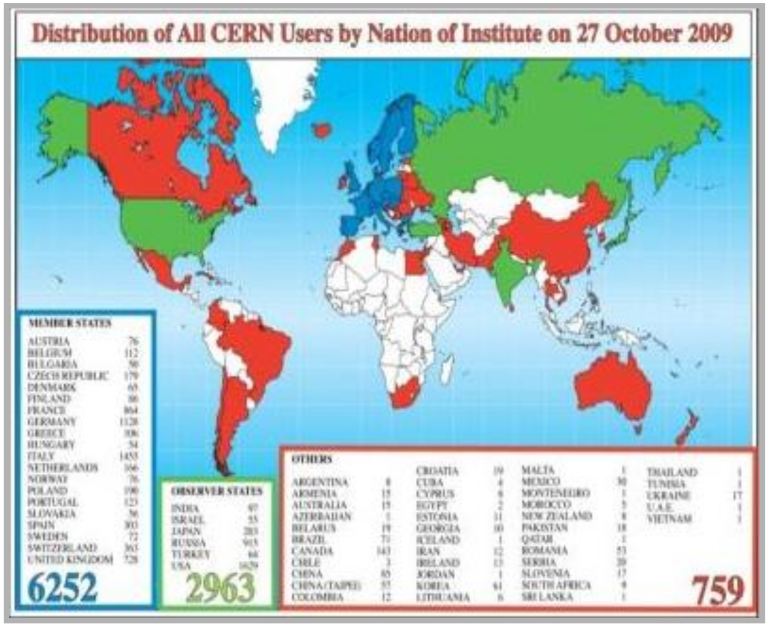
About Luca

- Senior DBA and team lead at CERN IT
  - Joined CERN in 2005
  - Working with Oracle RDBMS since 2000
- Passionate to learn and share knowledge, how to get most value from database technology
- @LucaCanaliDB and http://cern.ch/canali



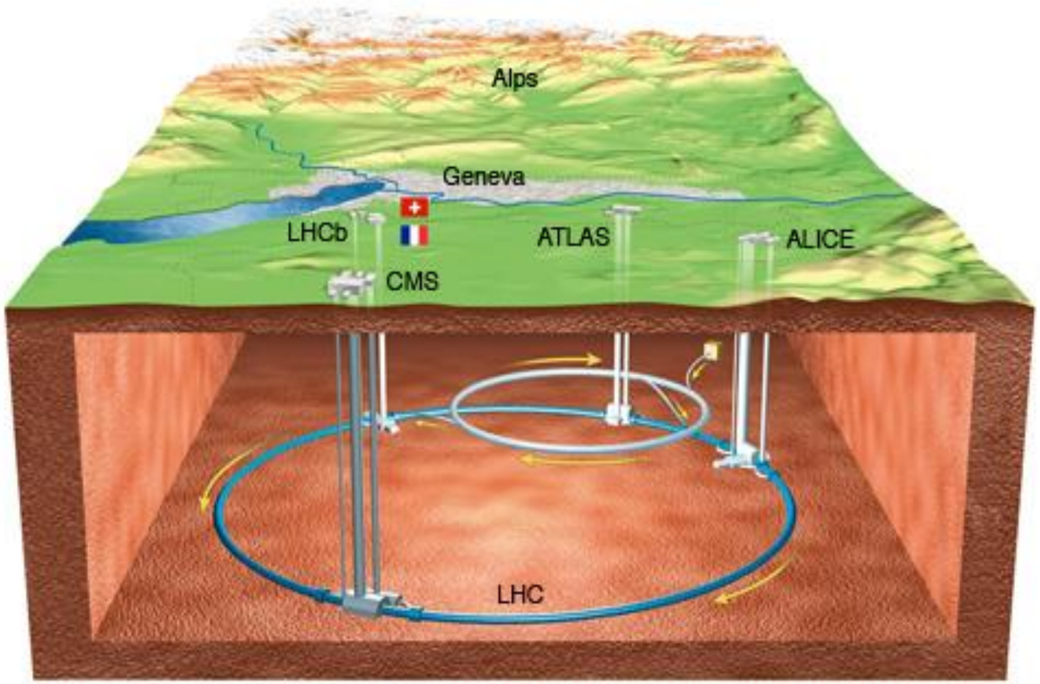
About CERN

- CERN - European Laboratory for Particle Physics
- Founded in 1954 by 12 countries for fundamental physics research in a post-war Europe
- Today 21 member states + world-wide collaborations
  - About ~1000 MCHF yearly budget
  - 2’300 CERN personnel + 10’000 users from 110 countries



LHC is the world's largest particle accelerator

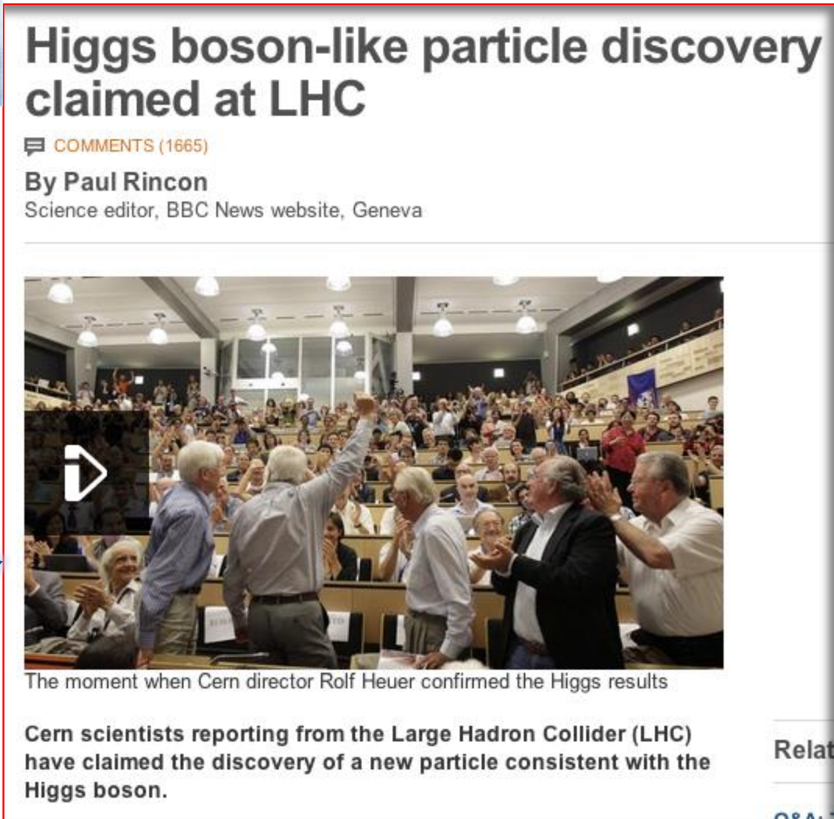
- LHC = Large Hadron Collider
  - 27km ring of superconducting magnets
  - Currently undergoing upgrades, restart in 2015



From particle to article..

How do you get from this

to this



Higgs boson-like particle discovery claimed at LHC

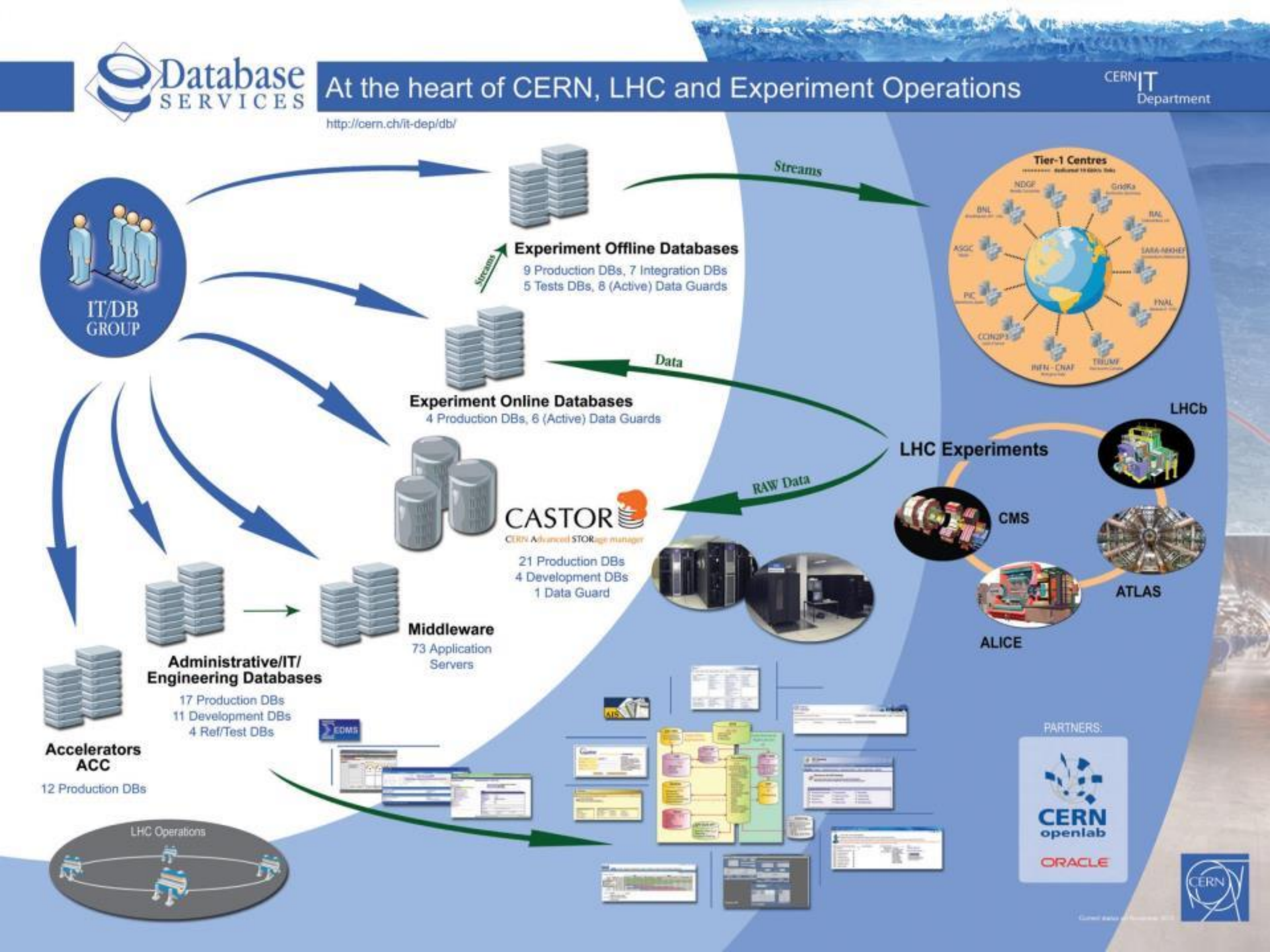
COMMENTS (1665)

By Paul Rincon
Science editor, BBC News website, Geneva

The moment when Cern director Rolf Heuer confirmed the Higgs results

Cern scientists reporting from the Large Hadron Collider (LHC) have claimed the discovery of a new particle consistent with the Higgs boson.

Relat



Database SERVICES
At the heart of CERN, LHC and Experiment Operations
CERN IT Department
http://cern.ch/it-dep/db/
IT/DB GROUP
Streams
Experiment Offline Databases
9 Production DBs, 7 Integration DBs
5 Tests DBs, 8 (Active) Data Guards
Streams
Tier-1 Centres
NDGF
GridKa
BNL
RAL
ASGC
SARA-NIKHEF
PIC
FNAL
CCIN2P3
INFN - CNAF
TRIUMF
Data
Experiment Online Databases
4 Production DBs, 6 (Active) Data Guards
LHC Experiments
LHCb
CMS
ATLAS
ALICE
RAW Data
CASTOR
CERN Advanced STORage manager
21 Production DBs
4 Development DBs
1 Data Guard
Middleware
73 Application Servers
Administrative/IT/ Engineering Databases
17 Production DBs
11 Development DBs
4 Ref/Test DBs
Accelerators ACC
12 Production DBs
LHC Operations
EDMS
AIS
PARTNERS:
CERN openlab
ORACLE
CERN

This talk covers Linux tools for advanced tracing and Oracle investigations

- Modern tools opening new roads: Perf, DTrace, Systemtap, …
  - Probes on the OS to understand system calls
  - Probes for the userspace to understand Oracle internals
- This is a short exploration rather than a lesson
- Focus on techniques that you can use today

Prerequisites

- Not covered here are many of the common and most used tools and utilities
  - top
  - strace
  - vmstat
  - iostat, sar, collectl, dstat
  - use of the /proc filesystem (ex cat /proc/meminfo)
  - ...

You can probably run userspace and dynamic tracing tools in Linux already

- Available with RHEL/OEL 6 or higher
- You gain:
  - Tools for advanced troubleshooting
  - Insights in the working of Oracle and OS

Do I need dynamic tracing when I have Oracle wait events?

- Data beyond wait events
  - Instrument the latency details of ‘on CPU’ time
  - Many Oracle wait events don’t provide good measurements of I/O latency

- Wait event data + user space tracing + OS tracing = new insights

About Zbigniew

- since 2009 at CERN
  - Developer
  - Researcher
  - DBA
- DBA with > 5 years of experience
- Already presented twice at UKOUG
  - about Streams and GoldenGate

Long Running Query -> on CPU?

- Enterprise Manager

Statistics | Activity | Plan | Plan Control | Tuning History | **SQL Monitoring**

Status	Duration	SQL Plan Hash	User	Parallel	Database Time	IO Requests	Start	Ended
	3.0m	4175421420	SYS		3.0m		10:29:29 PM	
	1.5m	4175421420	SYS		1.5m		10:14:55 PM	10:16:26 PM
	9.9m	4175421420	SYS		9.9m		9:24:43 PM	9:34:35 PM

- OS

```
  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
92971 oracle    20   0  100g  66m  37m R 100.0  0.1  83:37.95 oracle
 4598 oracle    20   0  619m  38m  14m S  1.3  0.0 403:50.17 gipcd.bin
 4109 root      20   0 1837m  63m  29m S  1.0  0.0 215:24.56 ohasd.bin
```

- Execution plan

```
-------------------------------------------------------------------------------------------------
| Id  | Operation                       | Name                   | Rows  | Bytes | Cost (%CPU)| Time     |
-------------------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT                |                        |       |       | 42899 (100)|          |
|   1 |  SORT ORDER BY                  |                        |  296M|   10G| 42899   (61)| 00:08:35 |
|   2 |   HASH GROUP BY                 |                        |  296M|   10G| 42899   (61)| 00:08:35 |
|*  3 |    HASH JOIN                    |                        |  296M|   10G| 18028    (6)| 00:03:37 |
|   4 |     TABLE ACCESS BY INDEX ROWID| EVENTHISTORY_TEST      |  2500 | 65000 |   337    (0)| 00:00:05 |
|*  5 |      INDEX RANGE SCAN           | EVENTHISTORY_TEST_TS   |  2500 |       |     9    (0)| 00:00:01 |
|   6 |     TABLE ACCESS FULL           | EVENTHISTORY_TEST      |   11M|  146M| 16710    (1)| 00:03:21 |
-------------------------------------------------------------------------------------------------
```

Snapper Can Help

```
-- Session Snapper v3.10 by Tanel Poder @ E2SN ( http://tech.e2sn.com )

-----------------------------------------------------------------------------------------------------------------
    SID, USERNAME  , TYPE, STATISTIC                                  ,         DELTA, HDELTA/SEC,    %TIME, GRAPH
-----------------------------------------------------------------------------------------------------------------
   2416, SYS       , STAT, session logical reads                      ,          1130,        113,
   2416, SYS       , STAT, consistent gets                            ,          1130,        113,
   2416, SYS       , STAT, consistent gets from cache                 ,          1130,        113,
   2416, SYS       , STAT, consistent gets from cache (fastpath)      ,          1130,        113,
   2416, SYS       , STAT, logical read bytes from cache              ,       9256960,     925.7k,
   2416, SYS       , STAT, no work - consistent read gets             ,          1130,        113,
   2416, SYS       , STAT, table scan rows gotten                     ,        172892,     17.29k,
   2416, SYS       , STAT, table scan blocks gotten                   ,          1130,        113,
   2416, SYS       , TIME, PL/SQL execution elapsed time              ,       9422513,   942.25ms,    94.2%, |@@@@@@@@@@|
   2416, SYS       , TIME, DB CPU                                     ,       9991481,   999.15ms,    99.9%, |@@@@@@@@@@|
   2416, SYS       , TIME, sql execute elapsed time                   ,       9999279,   999.93ms,   100.0%, |@@@@@@@@@@|
   2416, SYS       , TIME, DB time                                    ,       9999279,   999.93ms,   100.0%, |@@@@@@@@@@|
--  End of Stats snap 1, end=2014-12-03 22:37:29, seconds=10


-----------------------------------------------------------------------
Active% | SQL_ID          | EVENT                               | WAIT_CLASS
-----------------------------------------------------------------------
   100% | 8dhtawwt478tg   | ON CPU                              | ON CPU
```

Reading from db cache

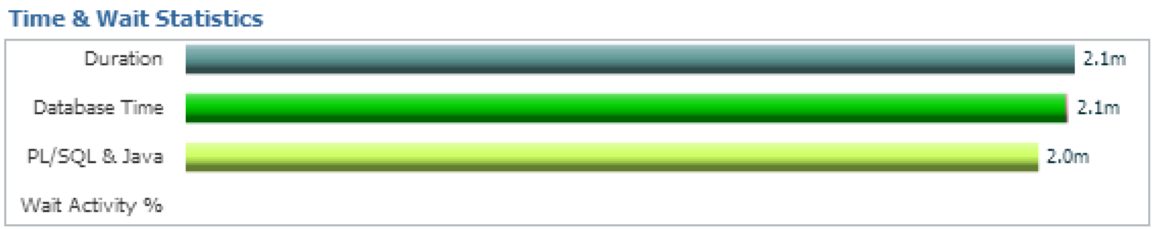
PL/SQL?

Wait event interface not much useful in this case

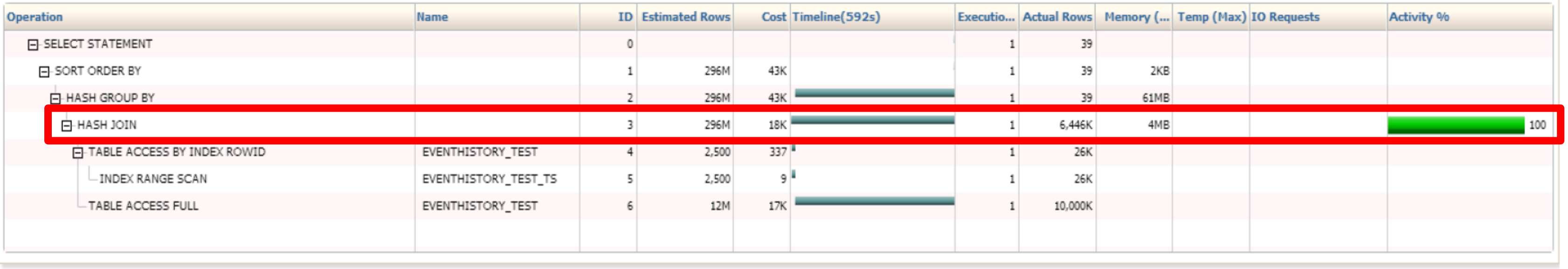
SQL Monitor

- Buffer gets

- PL/SQL almost all the time



- 100% activity on the hash join



Operation	Name	ID	Estimated Rows	Cost	Timeline(592s)	Executio...	Actual Rows	Memory (...	Temp (Max)	IO Requests	Activity %
SELECT STATEMENT		0				1	39				
SORT ORDER BY		1	296M	43K		1	39	2KB			
HASH GROUP BY		2	296M	43K		1	39	61MB			
HASH JOIN		3	296M	18K		1	6,446K	4MB			100
TABLE ACCESS BY INDEX ROWID	EVENTHISTORY_TEST	4	2,500	337		1	26K				
INDEX RANGE SCAN	EVENTHISTORY_TEST_TS	5	2,500	9		1	26K				
TABLE ACCESS FULL	EVENTHISTORY_TEST	6	12M	17K		1	10,000K				

- Can we get more? Lets try with perf

Perf

- Linux profiler tool for
  - performance counters (PCL)
  - events observer (LPE)

- Integrated into the kernel
  - Available for kernel versions >= 2.6.31 (RHEL6)

- Safe to use on production systems

Live view of top active functions

```
perf top [-p <pid of process> ]
```

```
Samples: 169K of event 'cycles', Event count (approx.): 36226334492
  38.56%  oracle                  [.] lnxdiv
  12.06%  oracle                  [.] lnxadd
   9.25%  oracle                  [.] lnxmul
   7.07%  oracle                  [.] lnxsub
   3.70%  oracle                  [.] lnxmin
   3.51%  oracle                  [.] pevm_icd_call_common
   2.29%  libc-2.12.so            [.] memmove
   2.24%  oracle                  [.] pfrinstr_BCTR
   1.65%  oracle                  [.] pfrinstr_ADDN
   1.64%  oracle                  [.] pfrinstr_CVTIN
   1.54%  oracle                  [.] pfrrun_no_tool
   1.53%  oracle                  [.] pfrinstr_MULN
   1.48%  oracle                  [.] pfrinstr_DIVN
   1.21%  oracle                  [.] pesmod
   1.03%  oracle                  [.] lnxtru
   1.01%  oracle                  [.] pisonu
   0.97%  oracle                  [.] lnxmod
   0.72%  libc-2.12.so            [.] __sigsetjmp
   0.71%  oracle                  [.] pfrinstr_MOVAN
   0.69%  oracle                  [.] peginu
   0.67%  oracle                  [.] pfrinstr_BCAL
   0.65%  oracle                  [.] __intel_new_memcpy
   0.56%  oracle                  [.] lnxcopy
   0.56%  oracle                  [.] _intel_fast_memcpy
```

What are those Oracle functions?

- Complete description of the functions called by Oracle with is not officially published, but…
- Google it or just guess ;)
- Backups of some MOS notes can be handy
  - "ORA-600 Lookup Error Categories” (formerly 175982.1)
- For actions which are part of query execution
  - http://blog.tanelpoder.com/files/scripts/tools/unix/os_explain by Tanel Poder

What have we learned so far?

- Our sql is running some arithmetic operations:
  - function lnxdiv (38%) => division
  - function lnxadd (10%) => addition
  - function lnxmul (9%) => multiplication

- Is it all the time like that?
- Why (by whom) they are called?

Recording Samples with Perf

- Function currently being executed sampling

```
perf record [-p <pid of process>] [-F <frequency> ]
```

- Full stack sampling

```
perf record -g -p <pid of process> [-F <frequency> ]
```

- Be careful with the sampling frequency
  - 99Hz is reasonable
- Samples are recorded to a binary file ‘perf.data’

Displaying Recoded Data

- In human readable format (same as top)

```
perf report
```

```
Samples: 58K of event 'cycles', Event count (approx.): 1607803529979
+  40.92%  oracle  oracle          [.] lnxdiv
+  10.77%  oracle  oracle          [.] lnxadd
+   9.67%  oracle  oracle          [.] lnxmul
+   5.45%  oracle  oracle          [.] lnxsub
+   3.82%  oracle  oracle          [.] lnxmin
+   3.25%  oracle  oracle          [.] pevm_icd_call_common
+   2.45%  oracle  libc-2.12.so    [.] memmove
+   2.14%  oracle  oracle          [.] pfrinstr_BCTR
+   1.59%  oracle  oracle          [.] pfrrun_no_tool
+   1.58%  oracle  oracle          [.] pfrinstr_MULN
+   1.52%  oracle  oracle          [.] pfrinstr_CVTIN
+   1.42%  oracle  oracle          [.] pfrinstr_DIVN
+   1.42%  oracle  oracle          [.] pfrinstr_ADDN
+   1.23%  oracle  oracle          [.] pesmod
+   1.21%  oracle  oracle          [.] pisonu
+   1.14%  oracle  oracle          [.] lnxmod
+   1.06%  oracle  oracle          [.] lnxtru
+   0.76%  oracle  oracle          [.] pfrinstr_MOVAN
+   0.71%  oracle  oracle          [.] __intel_new_memcpy
+   0.66%  oracle  oracle          [.] peginu
+   0.63%  oracle  oracle          [.] pfrinstr_BCAL
+   0.63%  oracle  libc-2.12.so    [.] __sigsetjmp
+   0.56%  oracle  oracle          [.] _intel_fast_memcpy
+   0.52%  oracle  oracle          [.] lnxcopy
```

Displaying Recorded Stacks

perf report --stdio

- Tree format

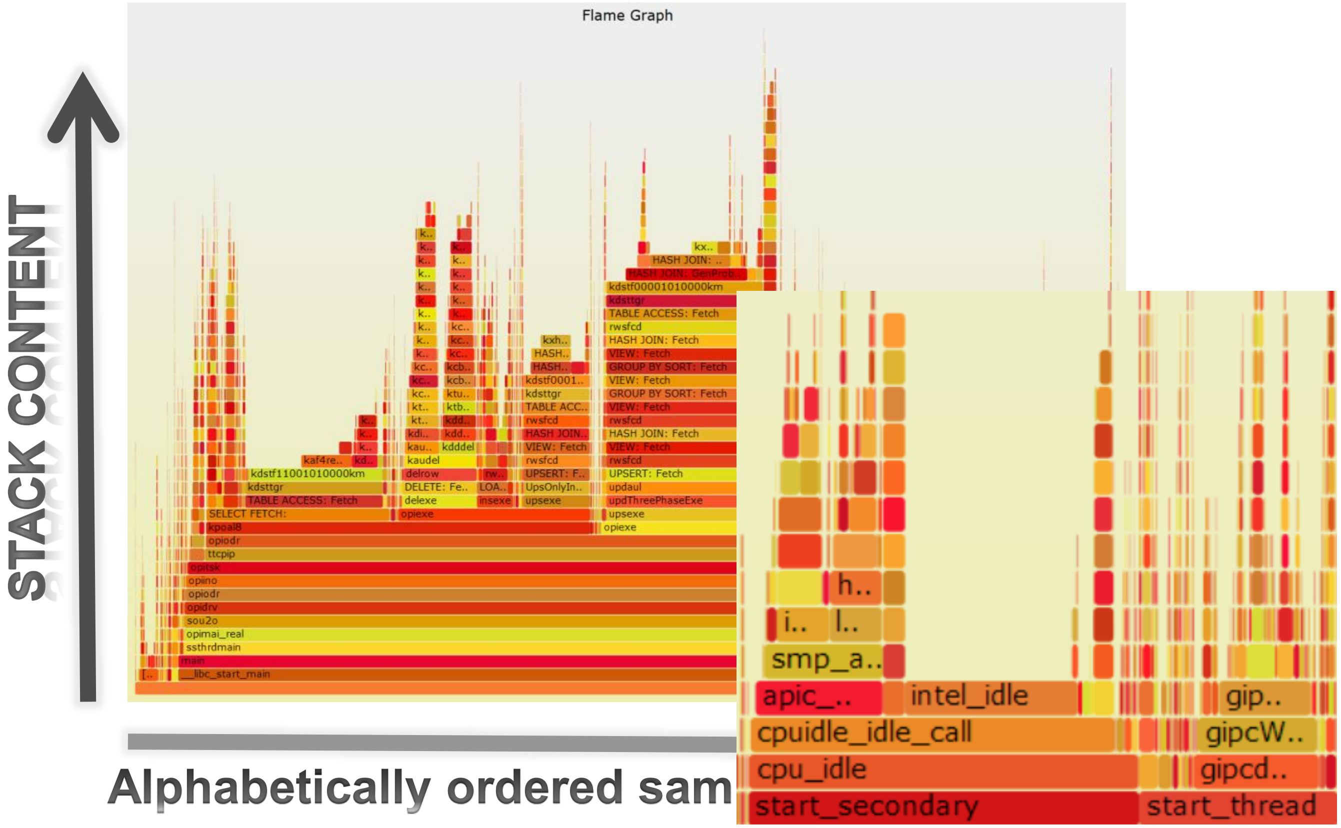
```
# Event count (approx.): 1607803529979
#
# Overhead  Command       Shared Object                                 Symbol
# ........  .......  .................  ....................................
#
    40.92%   oracle   oracle              [.] lnxdiv
             |
             --- lnxdiv
                |
                |--62.43%-- pfrinstr_DIVN
                |          pfrrun_no_tool
                |          pfrrun
                |          plsql_run
                |          peidxr_run
                |          peidxexe
                |          kkxdexe
                |          kkxmpexe
                |          kgmexec
                |          evapls
                |          evaopn2
                |          |
                |          |--96.92%-- qerhjSplitProbe
                |          |          qerhjInnerProbeHashTable
                |          |          kdstf00001010000km
                |          |          kdsttgr
                |          |          qertbFetch
                |          |          rwsfcd
                |          |          qerhjFetch
                |          |          qerghFetch
                |          |          qersoProcessULS
                |          |          qersoFetch
                |          |          opifch2
                |          |          kpoal8
                |          |          opiodr
                |          |          ttcpip
                |          |          opitsk
:
```

Not easy to read!

There is a way of making stack samples easier to read…

Flame Graphs

- Visualization of stack samples



- Author: http://www.brendangregg.com/

How to create a flame graph

1. Collect stack samples of our process under investigation

```
perf record -a -g -F99 -p <pid of process>
```

2. Dumpstack traces in a text file

```
perf script > myperf_script.txt
```

3. Get scripts: https://github.com/brendangregg/FlameGraph

4. Create a flame graph

```
grep -v 'cycles:' myperf_script.txt|
../FlameGraph-master/stackcollapse-perf.pl |
../FlameGraph-master/flamegraph.pl --title "My graph"
```

Flame Graph for our SQL

- Is called lnxdiv in at least 2 different places

FG for Oracle Operations

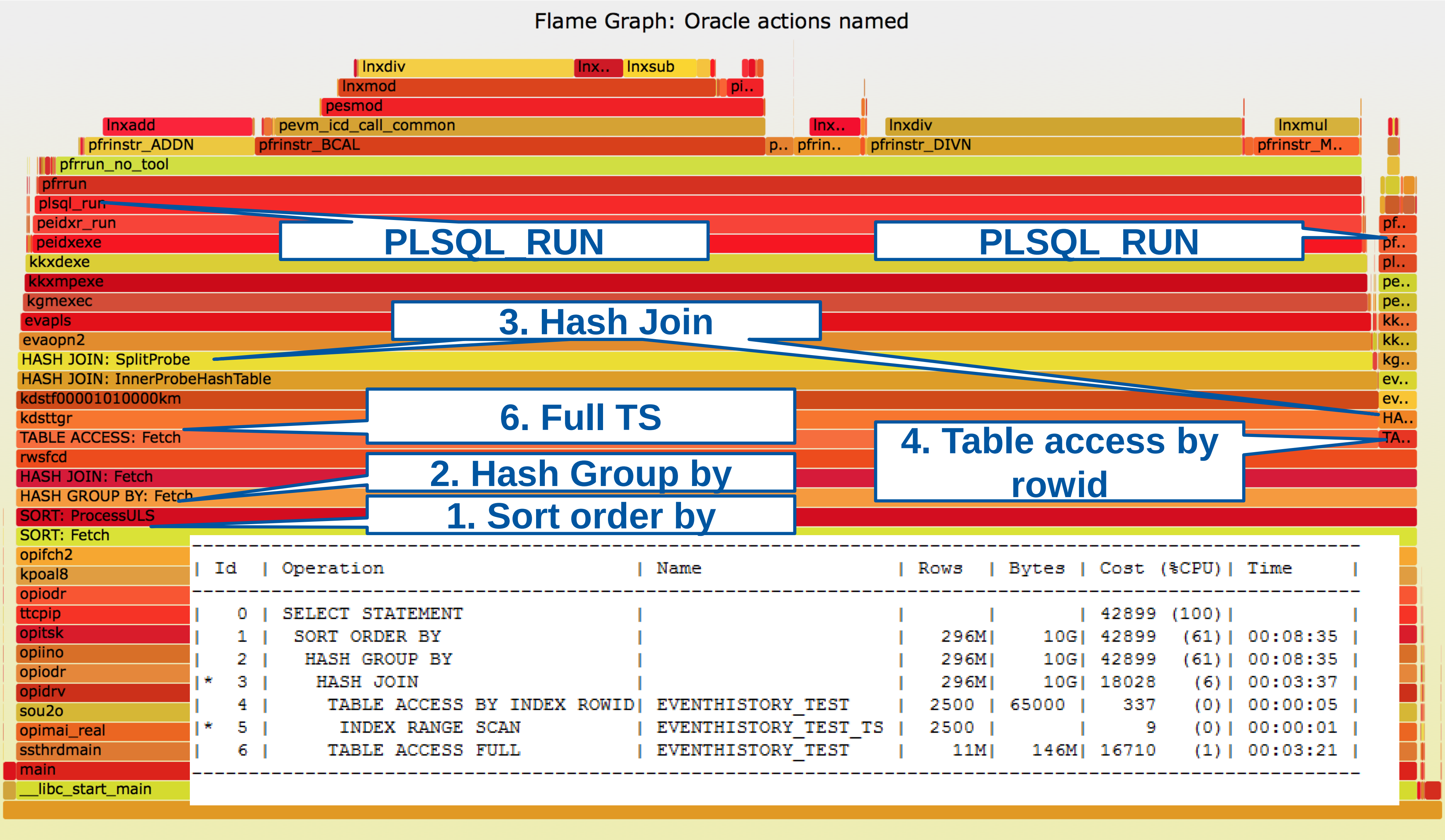
4a) Extract sed commands from os_explain script (by Tanel Poder)

```
wget http://blog.tanelpoder.com/files/scripts/tools/unix/os_explain
grep  "s\/q" os_explain > os_explain.sed
```

4b) Create the flame graph using os_explain mapping

```
grep -v 'cycles:' myperf_script.txt|
sed -f os_explain.sed|
../FlameGraph-master/stackcollapse-perf.pl |
../FlameGraph-master/flamegraph.pl --title ”My FG" >Figure1.svg
```

Flame Graph for our SQL

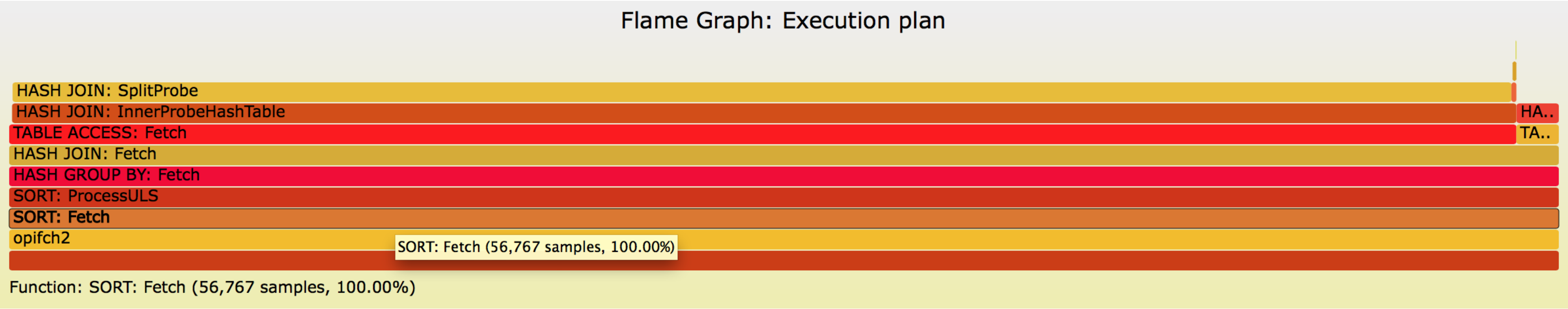


Id	Operation	Name	Rows	Bytes	Cost (%CPU)	Time
0	SELECT STATEMENT				42899 (100)	
1	SORT ORDER BY		296M	10G	42899 (61)	00:08:35
2	HASH GROUP BY		296M	10G	42899 (61)	00:08:35
* 3	HASH JOIN		296M	10G	18028 (6)	00:03:37
4	TABLE ACCESS BY INDEX ROWID	EVENTHISTORY_TEST	2500	65000	337 (0)	00:00:05
* 5	INDEX RANGE SCAN	EVENTHISTORY_TEST_TS	2500		9 (0)	00:00:01
6	TABLE ACCESS FULL	EVENTHISTORY_TEST	11M	146M	16710 (1)	00:03:21

FG for an Execution Plan

- Create flame graph for query execution operations only:

```
grep -i -e qer -e opifch -e ^$ myperf_script.txt|
sed -f os_explain.sed|
../FlameGraph-master/stackcollapse-perf.pl|
../FlameGraph-master/flamegraph.pl --title "Flame Graph Rowsource:
my select" >Figure2.svg
```



What was the join condition of the query?

- **compute**(range_scan.VALUE_NUMBER,1000) = **compute**(full_table.VALUE_NUMBER,100)

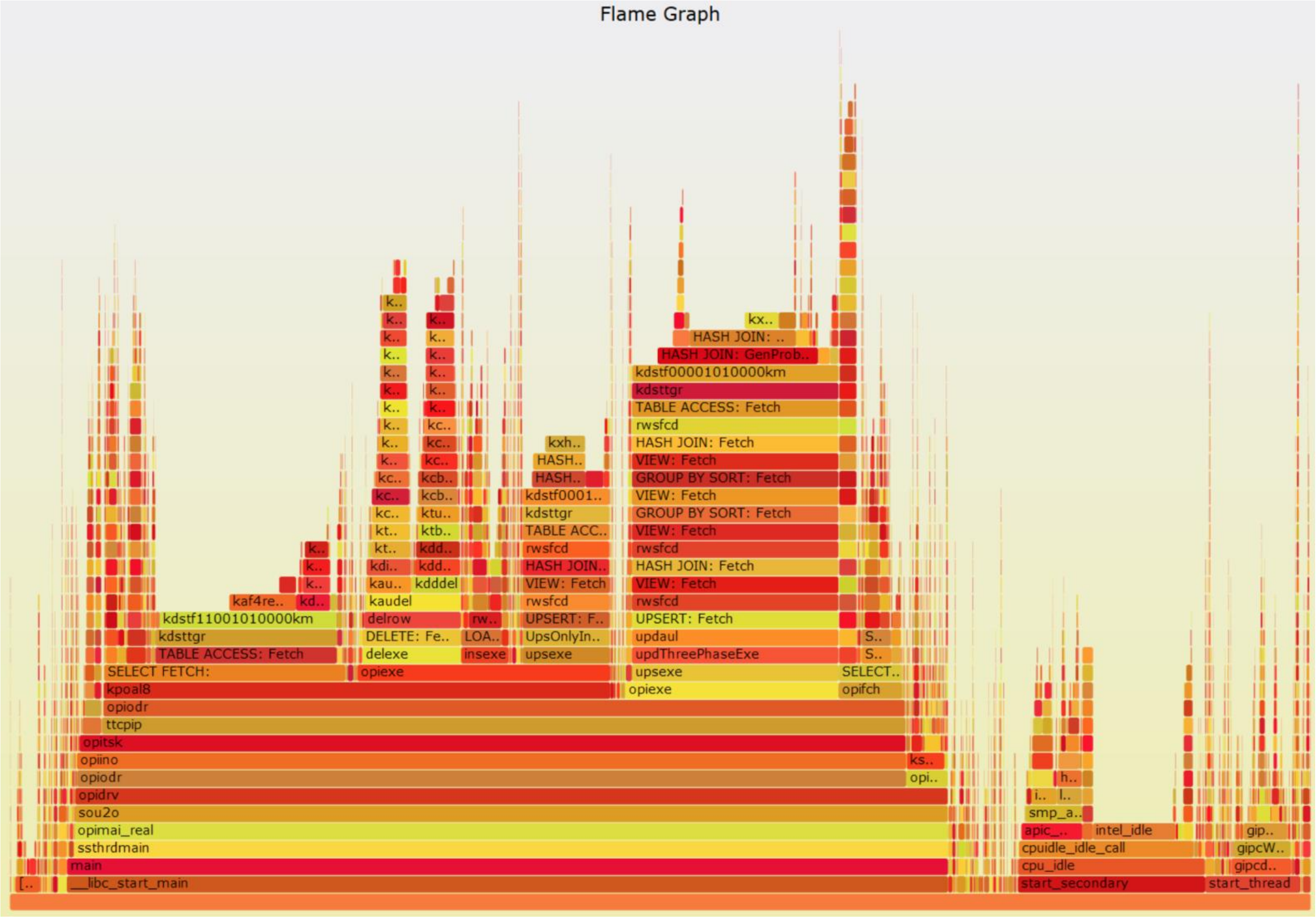
```
Predicate Information (identified by operation id):
---------------------------------------------------

   3 - access("COMPUTE"("T1"."VALUE_NUMBER",1000)="COMPUTE"("T2"."VALUE_NUMBER",100))
   5 - access("T1"."TS">=TO_TIMESTAMP('01-NOV-09 04.06.44.759000000 PM') AND
              "T1"."TS"<=TO_TIMESTAMP('20-NOV-09 10.06.44.759000000 PM'))
```

```
create function compute(val in number,j number) return varchar2
as
    ret number:=0;
begin
   FOR i IN 1..j loop
       ret:=ret + mod(val * i,100) / i;
   end loop;
  return ret;
end;
```

FG for Server Profiling

- Entire server workload captured from 20 sec



Perf & Flame Graphs: Summary

- Perf
  - user space exploration
  - available >RHEL 6
  - there other useful features (events tracing and probes)
- Flame graph
  - call stack visualization
- Perf + flame graph
  - Performance investigation
    - When wait-event interface does not deliver relevant information – CPU intensive processing

Advanced Tracing for Linux

- Solaris has DTrace since 2005, Linux is catching up
- Currently many tools available
  - Oracle Linux DTrace, Dtrace4linux, SystemTap, perf_events, ftrace, ktap, LTTng, eBPF, sysdig
  - Most of them still in development

DTrace and Linux

- DTrace license is CDDL, incompatible with GPL
- There are 2 ports of DTrace for Linux
    - Both still in active development
    - Oracle’s port for OEL (for ULN subscribers)
        - Notably it does not yet have userspace tracing with the ‘pid provider’
    - ‘dtrace4linux’: a one-person effort
        - unstable but with more functionality

How to Measure Latency with Dynamic Tracing

The main ingredients:

- Trigger execution probe at the start of a system call (or a users function)
- Run a probe at the return from the call
- Measure the elapsed time
- Aggregate data in a latency histogram

An Example with DTrace

- Measure latency histogram of pread64 calls
  - Note: IOPS and latency of random reads very important for troubleshooting OLTP performance

```
# dtrace -n '

syscall::pread64:entry { self->s = timestamp; }

syscall::pread64:return /self->s/ {
@pread["ns"] = quantize(timestamp -self->s);
self->s = 0;
}

tick-10s {
printa(@pread);
trunc(@pread);
}'
```

SystemTap

- Backed by Red Hat, started in 2005
  - Version 1.0 in 2009
- Works by compiling and loading kernel modules
- Scripting language similar to C, allows adding C extensions
- Easy to start working with it:
  - Look at example probes and build from there
  - Many similarities between DTrace and SystemTap probes

SystemTap Userspace Probes

- Probes into executable processes (userspace)
  - Read function arguments
  - Read from process memory (ex: SGA and PGA)
- Linux support
  - UTRACE -> available with SystemTap also in RHEL6
  - UPROBES -> replace UTRACE for kernel version from 3.5, available with SystemTap and more tools
  - Dtrace4linux can also do userspace tracing

How to check if userspace tracing is available/active on your system

- This is how to check if UTRACE extensions are configured:

```
# grep CONFIG_UTRACE /boot/config-`uname -r`
CONFIG_UTRACE=y
```

- This is how to check if UPROBES are available:

```
# grep CONFIG_UPROB /boot/config-`uname -r`
CONFIG_UPROBES=y
CONFIG_UPROBE_EVENT=y
```

Key functions to probe the Oracle wait event interface

Function name	Purpose	Selected parameters
KSKTHBWT	Kernel Service Kompile Thread Begin Wait. This function is called at the start of an Oracle wait event. The suffix “bwt" most likely stands for “begin wait". kslwtbctx is its parent function call and marks the start of a wait event.	register r13 -> points into X$KSUSE (V$SESSION) SGA segmented array register rsi -> timestamp of the beginning of the wait (in microseconds) register rdx -> wait event number
KSKTHEWT	Kernel Service Kompile Thread End Wait. This function is called at the end of an Oracle wait event. The suffix "ewt" most likely stands for "end wait". kslwtectx is its parent function call marking the end of a wait event.	register r13 -> points into X$KSUSE (V$SESSION) SGA segmented array register rdi -> timestamp of the beginning of the wait (in microseconds) register rsi -> wait event number

Systemtap can read from the Oracle wait event interface

Example: how to write a probe tracing the beginning of each wait event:

```
probe process("oracle").function("kskthbwt") {

   xksuse = register("r13")-3928 # offset for 12.1.0.2
   ksusenum = user_uint16(xksuse + 1704)

   printf("DB WAIT EVENT BEGIN: timestamp_ora=%ld, 
pid=%d, sid=%d, event#=%u\n", register("rsi"), pid(), 
ksusenum, register("rdx"))

}
```

How to read X$KSUSE from SGA

- X$KSUSE -> underlying table of V$SESSION
  - It's a segmented array
  - Base of the array record: from CPU register R13
    - With offset that is version-dependent
    - The column offsets (record values) are available by querying X$KQFCO and X$KQFTA
    - Records contain info on: userid, sql_hash, wait elapsed time, …

Example: How to collect wait event histograms with microsec resolution

- V$EVENT_HISTOGRAM useful to study latency
  - However only milisec precision, a problem when studying SSD latency
  - Note 12.1.0.2 has V$EVENT_HISTOGRAM_MICRO
- Solution: userspace tracing of Oracle processes
  - Provides way to collect and display microsec-precision histograms for all Oracle versions
  - Capture event# and wait time in microseconds
  - Collect data in a SystemTap aggregate
  - Print output as a histogram

Example of wait event histograms collected with SystemTap

```
# stap -v histograms_oracle_events_11204.stp -x <pid>
# Note: omit -x to trace all oracle processes

Histogram of db file sequential read waits in microseconds (us):

  value |-------------------------------------------------- count
    128 |@                                                   33
    256 |@@@                                                 60
    512 |@@@                                                 61
   1024 |@@@@                                                93
   2048 |@@@@@@@@@@@@@                                      260
   4096 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@    951
   8192 |@@@@@@@@@@@@@@@@@@@@@@@@@@                         538
  16384 |@@                                                  47
  32768 |@@@                                                 71
  65536 |@                                                   34
 131072 |@@@@@@@                                            153
 262144 |@@@                                                 62
 524288 |                                                    16
```

SystemTap Probes for Oracle Logical and Physical I/O

Identify the Oracle internal functions of interest:

Function	Description
kcbgtcr	Kernel Cache Buffers Get Consistent Read Used for consistent reads
kcbgcur	Kernel Cache Buffers Current Read Used for current reads
kcbzib	kcbZIB should stand for: Z (kcbz.o is a module for physical IO helper functions), IB: Input Buffer Oracle will perform physical read(s) into the buffer cache
kcbzgb	The suffix GB in kcbZGB should stand for: Get (space for) Buffer. Oracle allocates space in the buffer cache for a given block (typically before I/O operations).
kcbzvb	Invoked after Oracle has performed I/O to read a given block Note: this function is used both for reads in the buffer cache and for direct reads

Find the key function call parameters and their meaning

- Identify the function parameters of interest (block number, file number, etc)
- Example for kcbgtcr and kcbgcur

```
tbs#              = user_int32(%rdi)
rel file n#       = user_int32(%rdi+4) >> 22 & 0x003FFFFF
block#            = user_int32(%rdi+4) & 0x003FFFFF
data_object_id# = user_int32(%rdi+8)
object_id#        = user_int32(%rdi+12)

Note: for bigfile tablespaces: block# = user_int32(%rdi+4)
```

Putting it all together: Trace wait events + logical and physical I/O

- Provide insights on how Oracle does the I/O
  - What are the I/O-related wait events really measuring?
  - Can we rely on the measurements of wait elapsed time to understand I/O latency?
- Trace:

```
# stap -v
trace_oracle_logicalio_wait_events_physicalio_12102.stp
-x <pid> | sed -f eventsname.sed
```

Example of tracing 'db file sequential read' wait event

```
==========
DB LOGICAL IO Consistent Read (kcbgtcr) for block: tbs#=7, rfile#=0, block#=2505675,
obj#=32174
  ->kcbzib, Oracle logical read operations require physical reads into the buffer
cache
     -> kcbzgb, Oracle has allocated buffer cache space for block: tbs#=7, rfile#=0,
block#=2505675, obj#=32174
==========
DB WAIT EVENT BEGIN: timestamp_ora=498893930487, pid=15559, sid=21, event=db file
sequential read

OS: ->pread: timestamp=498893930555, program=oracle_15559_or, pid=15559, fd=264,
offset=83048882176, count(bytes)=8192
OS:    ->ioblock.request, timestamp=498893930588, pid=15559, devname=sdl,
sector=162204848, size=8192, rw=0, address_bio=18446612144946364800
OS:    <-ioblock.end, timestamp=498893934550, pid=0, devname=sdl, sector=162204864,
rw=0, address_bio=18446612144946364800
OS: <-pread: timestamp=498893934592, program=oracle_15559_or, local_clock_us(),
pid=15559, return(bytes)=8192

DB WAIT EVENT END: timestamp_ora=498893934633, pid=15559, sid=21, name=SYSTEM,
event=db file sequential read, p1=7, p2=2505675, p3=1, wait_time=4146, obj=32172,
sql_hash=964615745
==========
  ->kcbzvb, Oracle has performed I/O on: file#=7, block#=2505675, rfile#=0
==========
```

What the trace shows about ‘db file sequential read’

- Oracle starts with a logical I/O
- If the block is not in the buffer cache a physical read is initiated
  - A block in the buffer cache is allocated
  - The wait event db file sequential read is started
- Oracle calls pread to read 8KB
  - This passed on to the block I/O interface
- After the read is done, the wait event ends
- Comment on the wait time: db file sequential read is dominated by synchronous I/O wait time

The Case of Direct Reads and Tracing Oracle Asynchronous I/O

- Asynchronous I/O is used by Oracle to optimize I/O throughput
  - OS calls used: IO_SUBMIT and IO_GETEVENTS
  - We consider the case of ASM on block devices
- Findings:
  - Oracle can perform reads that are not instrumented by the wait event interface
  - The wait event 'direct path read', does not instrument all the reads
  - The wait event elapsed time is not the I/O latency

```
==========
OS: ->io_submit: timestamp=769804010693, program=oracle_18346_or, pid=18346, nr(num I/O)=1
              1: file descriptor=258, offset=93460627456, bytes=1048576, opcode=0
OS: <-io_submit: timestamp=769804010897, program=oracle_18346_or, pid=18346, return(num I/O)=1
….many more io_submit and also io_getevents..
==========
DB WAIT EVENT BEGIN: timestamp_ora=769804024008, pid=18346, sid=250, event#=direct path read
LIBAIO:->io_getevents_0_4: timestamp=769804024035, program=oracle_18346_or, pid=18346, min_nr=1,
timeout.tv_sec=600
OS: ->io_getevents: timestamp=769804024060, program=oracle_18346_or, pid=18346, min_nr=1,
timeout={.tv_sec=600, .tv_nsec=0}
OS: <-io_getevents: timestamp=769804028511, program=oracle_18346_or, pid=18346, return(num I/O)=4
              0:, fildes=260, offset=79065776128, bytes=1048576
              1:, fildes=261, offset=89295683584, bytes=1048576
              2:, fildes=263, offset=84572897280, bytes=1048576
              3:, fildes=262, offset=94479843328, bytes=1048576
LIBAIO:->io_getevents_0_4: timestamp=769804028567, program=oracle_18346_or, pid=18346, min_nr=1,
timeout.tv_sec=600
OS: ->io_getevents: timestamp=769804028567, program=oracle_18346_or, pid=18346, min_nr=1,
timeout={.tv_sec=600, .tv_nsec=0}
OS: <-io_getevents: timestamp=769804034142, program=oracle_18346_or, pid=18346, return(num I/O)=1
              0:, fildes=264, offset=83009470464, bytes=1048576
LIBAIO:->io_getevents_0_4: timestamp=769804034797, program=oracle_18346_or, pid=18346, min_nr=1,
timeout.tv_sec=600
OS: ->io_getevents: timestamp=769804034834, program=oracle_18346_or, pid=18346, min_nr=1,
timeout={.tv_sec=600, .tv_nsec=0}
OS: <-io_getevents: timestamp=769804037359, program=oracle_18346_or, pid=18346, return(num I/O)=4
              0:, fildes=265, offset=93436510208, bytes=1048576
              1:, fildes=267, offset=89061851136, bytes=1048576
              2:, fildes=269, offset=78286684160, bytes=1048576
              3:, fildes=268, offset=83802259456, bytes=983040
DB WAIT EVENT END: timestamp_ora=769804037433, pid=18346, sid=250, name=SYSTEM, event#=direct
path read, p1=7, p2=4324864, p3=128, wait_time
=13425, obj=32176, sql_hash=1782650121
==========
```

Oracle wait events for asynchronous I/O cannot be used to study latency

Example of how to measure I/O latency from the block I/O interface using SystemTap:

```
global latencyTimes, requestTime[10000]

probe ioblock_trace.request {
   requestTime[$bio] = gettimeofday_us()
}

probe ioblock.end {
   t = gettimeofday_us()
   s = requestTime[$bio]
   if (s > 0) {
       latencyTimes <<< (t-s)
       delete requestTime[$bio]
   }
}
```

Another way to measure I/O from the OS: using Ftrace

- https://github.com/brendangregg/perf-tools

```
# ./iolatency 10
Tracing block I/O. Output every 10 seconds. Ctrl-C to to end.

  >=(ms) .. <(ms)   : I/O      |Distribution                          |
       0 -> 1       : 95       |##                                    |
       1 -> 2       : 74       |##                                    |
       2 -> 4       : 475      |#########                             |
       4 -> 8       : 2035     |######################################|
       8 -> 16      : 1245     |########################              |
      16 -> 32      : 37       |#                                     |
      32 -> 64      : 11       |#                                     |
      64 -> 128     : 7        |#                                     |
     128 -> 256     : 23       |#                                     |
     256 -> 512     : 10       |#                                     |
     512 -> 1024    : 4        |#                                     |
```

Example: Probe all blocks subject to physical I/O for performance investigations

- Goal: analyse physical reads: how many are ‘new’ and how many are repeated reads
  - Aid for sizing DB cache and SSD storage cache
  - SystemTap probe on kcbzvb (block read)
  - Can drill down per file/object number/process
- Example:

```
# stap -g -v oracle_read_profile.stp

number of distinct blocks read: 24513631
total number of blocks read:    86711189
```

Build Your Own Lab and Experiment

- Install a test environment (under VirtualBox)
  - RHEL/OEL 6.5 or higher
  - RHEL/OEL 7.0 with 3.10 kernel as preference
- Install additional packages
  - kernel-devel
  - debuginfo and debuginfo-common packages (available from https://oss.oracle.com)
- Install the advanced tracing tools
  - SystemTap version 2.5 or higher

Additional Tips for Userspace Investigations of Oracle

- Information on Oracle internal functions from MOS
  - Get a copy of "Note 175982.1"
- gdb (GNU debugger)
  - Read memory, stack backtraces and registers with gdb
  - Know the Linux call convention: args are in %rdi, %rsi,…
- Stack profile visualisations with flamegraphs
  - Help understand which functions are called more often
- DTrace-based tracing:
  - 'Digger' by Alexander Anokhin (best on Solaris DTrace)

Wish List: Statically Defined Probes in Oracle Code

- Statically defined probes
  - Make userspace tracing more clean and stable across versions
  - An elegant and direct way of collecting and aggregating info from the Oracle engine and correlate with OS data
- Examples of database engines that have static probes:
  - MySQL and PosgreSQL

Wish List: More Info on Oracle Functions, Variables, SGA Structures

- Oracle provides symbols in the executable
  - However no info on the kernel functions
  - Ideally we would like to have Oracle debuginfo
  - Documentation on what the functions do, which parameters they have, etc
- We can profit from knowledge sharing in the community
  - There is much more to investigate!

Acknowledgements and Contacts

- CERN Colleagues and in particular the Database Services Group
  - Our shared blog: http://db-blog.web.cern.ch/

- Additional credits
  - Frits Hoogland for original work and collaboration on the research
  - Many thanks to for sharing their work and original ideas: Tanel Poder, Brendan Gregg, Alexander Anokhin, Kevin Closson

Example SystemTap Scripts for Oracle Userspace Investigations

- Download from: http://cern.ch/canali/resources.htm

```
histograms_oracle_events_11204.stp
histograms_oracle_events_12102.stp
histograms_oracle_events_version_independent.stp
trace_oracle_events_11204.stp
trace_oracle_events_12102.stp
trace_oracle_logicalio_wait_events_physicalio_11204.stp
trace_oracle_logicalio_wait_events_physicalio_12102.stp
trace_oracle_logical_io_basic.stp
trace_oracle_logical_io_count.stp
trace_oracle_wait_events_asyncio_libaio_11204.stp
trace_oracle_wait_events_asyncio_libaio_12102.stp
measure_io_patterns
  blockio_latency.stp
  Oracle_read_profile.stp
  Oracle_read_profile_drilldown_file.stp
  Oracle_read_profile_drilldown_objectnum.stp
experimental
   logical_io_latency.stp
   ..
```

Conclusions

- Linux tools for advanced troubleshooting
  - OS dynamic tracing, userspace tracing, ..
  - Extend and complement Oracle wait interface data
  - Collect data not available with other methods
- Perf and Systemtap
  - Already available on RHEL6 or higher
  - Powerful and fun to work with
  - Easy to start: build on example scripts
- Happy testing!

www.cern.ch