Oracle and storage IOs, explanations and experience at CERN
CHEP 2009 [paper 28]

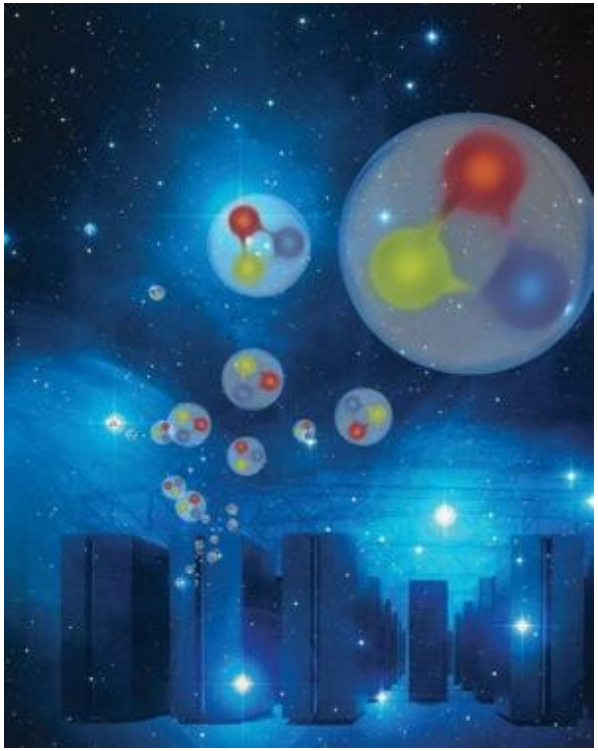

Image courtesy of Forschungszentrum Jülich / Seitenplan, with material from NASA, ESA and AURA/Caltech

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Outline

- Logical and Physical IO
- Measuring IO
- Exadata
- SSD
- Conclusions
- References

PIO versus LIO

- Even so memory access is fast compared to disk access, LIO are actually expensive
- LIO cost latching and CPU
- Tuning using LIO reduction as a reference is advised

- See “Why You Should Focus on LIOs Instead of PIOs” Carry Millsap

How to measure IO (1/4)

- One has to measure “where the PIO are performed” and “how long they take / how many per second are performed”
- Oracle instrumentation and counters provide us the necessary information, raw and aggregated
- Counters:
  - Aggr file: V$FILESTAT / DBA_HIST_FILESTATXS (*), V$FILE_HISTOGRAM
  - Aggr session: V$SESS_IO
  - Aggr system-wide: V$SYSSTAT

How to measure IO (2/4)

- Individual wait events:
  - 10046 event or EXECUTE DBMS_MONITOR.SESSION_TRACE_ENABLE(83,5, TRUE, FALSE); then EXECUTE DBMS_MONITOR.SESSION_TRACE_DISABLE(83,5);
  - Trace file contains lines like:

```
WAIT #5: nam='db file sequential read'
  ela=6784 file#=6 block#=467667 blocks=1
  obj#=73442 tim=1490530491532
```

- Session wait: V$SESSION_WAIT (V$SESSION 10.1+)
- Aggregated wait events:
  - Aggr session: V$SESSION_EVENT
  - Aggr system-wide: V$SYSTEM_EVENT

How to measure IO (3/4)

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- Statspack/AWR(*) reports

```
SQL> execute dbms_workload_repository.create_snapshot;
...
SQL> @?/rdbms/admin/awrrpt

Top 5 Timed Foreground Events
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
                                                           Avg
                                                          wait   % D
Event                                 Waits     Time(s)    (ms)   time Wait Class
------------------------------ ------------ ----------- ------ ------ ----------
db file sequential read              17,049         122      7   94.2 User I/O
DB CPU                                               7           5.3
log file sync                            4           2    570    1.8 Commit
db file scattered read                  21           0      1     .0 User I/O
control file sequential read           694           0      0     .0 System I/O

^LWait Event Histogram                        DB/Inst: ORCL/orcl  Snaps: 367-368
-> Units for Total Waits column: K is 1000, M is 1000000, G is 1000000000
-> % of Waits: value of .0 indicates value was <.05%. Value of null is truly 0
-> % of Waits: column heading of <=1s is truly <1024ms, >1s is truly >=1024ms
-> Ordered by Event (idle events last)

                                                % of Waits
                                -----------------------------------------------
                         Total
Event                    Waits  <1ms  <2ms  <4ms  <8ms <16ms <32ms  <=1s   >1s
-------------------------- ----- ----- ----- ----- ----- ----- ----- ----- -----
SQL*Net message to client     1  100.0
control file parallel writ   40                                55.0  45.0
control file sequential re  758  100.0
db file parallel write      111                1.8   3.6  27.9  31.5  35.1
db file scattered read       22   95.5                            4.5
db file sequential read      16K   3.5    .0   4.5  58.1  32.9    .9    .1
```

How to measure IO (4/4)

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```
^LTablespace IO Stats                          DB/Inst: ORCL/orcl  Snaps: 367-368
-> ordered by IOs (Reads + Writes) desc

Tablespace
------------------------------
                 Av      Av     Av                       Av     Buffer Av Buf
         Reads Reads/s Rd(ms) Blks/Rd       Writes Writes/s      Waits Wt(ms)
-------------- ------- ------ ------- ------------ -------- ---------- ------
TESTTBS
        16,323     131    7.5     1.0            0        0          0    0.0
SYSAUX
           614       5    0.0     1.0          121        1          0    0.0
SYSTEM
           221       2    0.0     1.6            7        0          0    0.0
UNDOTBS1
             1       0    0.0     1.0           17        0          0    0.0
          -------------------------------------------------------------

^LFile IO Stats                                DB/Inst: ORCL/orcl  Snaps: 367-368
-> ordered by Tablespace, File

Tablespace               Filename
------------------------ ----------------------------------------------------
                 Av      Av     Av                       Av     Buffer Av Buf
         Reads Reads/s Rd(ms) Blks/Rd       Writes Writes/s      Waits Wt(ms)
-------------- ------- ------ ------- ------------ -------- ---------- ------
SYSAUX                   /export/home/oracle/app/oracle/oradata/orcl/sysaux01
           614       5    0.0     1.0          121        1          0    0.0
SYSTEM                   /export/home/oracle/app/oracle/oradata/orcl/system01
           221       2    0.0     1.6            7        0          0    0.0
TESTTBS                  /ORA/orcl_testtbs.dbf
         8,001      64    7.5     1.0            0        0          0    0.0
TESTTBS                  /ORA2/orcl_testtbs2.dbf
         8,322      67    7.5     1.0            0        0          0    0.0
UNDOTBS1                 /export/home/oracle/app/oracle/oradata/orcl/undotbs0
             1       0    0.0     1.0           17        0          0    0.0
          -------------------------------------------------------------
```

ASH and IO (1/2)

- Using ASH(*)
  - Sampling of session information every 1s
  - Not biased (just time sampling), so reliable source of information
  - Obviously not all information is recorded so some might be missed
- Can be accessed via
  - @ashrpt / @ashrpti
  - v$active_session_history / DBA_HIST_ACTIVE_SESS_HISTORY(*)

ASH and IO (2/2)

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```
SQL> EXECUTE DBMS_MONITOR.SESSION_TRACE_ENABLE(69,17062, TRUE, FALSE);

PL/SQL procedure successfully completed.

SQL> select to_char(sample_time,'HH24MISS') ts,seq#,p1,p2,time_waited from v$active_session_history where SESSION_ID=
69 and session_serial#=17062
  2  and SESSION_STATE = 'WAITING' and event='db file sequential read' and sample_time>sysdate -5/24/3600
  3  order by sample_time;

TS           SEQ#         P1         P2 TIME_WAITED
------ ---------- ---------- ---------- -----------
001557      45565          6     449426        5355
001558      45716          6     179376       10118
001559      45862          6     702316        7886
001600      46014          7      91988        5286
001601      46167          7     424665        7594
001602      46288          6     124184           0

SQL> EXECUTE DBMS_MONITOR.SESSION_TRACE_DISABLE(69,17062);

PL/SQL procedure successfully completed.

-bash-3.00$ grep -n 124184 orcl_ora_15854.trc
676:WAIT #2: nam='db file sequential read' ela= 5355 file#=6 block#=449426 blocks=1 obj#=73442 tim=2707602560910
[...]
829:WAIT #2: nam='db file sequential read' ela= 10118 file#=6 block#=179376 blocks=1 obj#=73442 tim=2707603572300
[...]
977:WAIT #2: nam='db file sequential read' ela= 7886 file#=6 block#=702316 blocks=1 obj#=73442 tim=2707604583489
[...]
1131:WAIT #2: nam='db file sequential read' ela= 5286 file#=7 block#=91988 blocks=1 obj#=73442 tim=2707605593626
[...]
1286:WAIT #2: nam='db file sequential read' ela= 7594 file#=7 block#=424665 blocks=1 obj#=73442 tim=2707606607137
[...]
1409:WAIT #2: nam='db file sequential read' ela= 8861 file#=6 block#=124184 blocks=1 obj#=73442 tim=2707607617211
```

Cross verification, ASH and 10046 trace (1/2)

- How to identify which segments are accessed most often from a given session? (ashrpti can do it as well)

- Ultimate information is in a 10046 trace
- Extract necessary information, load into t(p1,p2)

```
> grep "db file sequential read" accmeas2_j004_32116.trc  | head -2
WAIT #12: nam='db file sequential read' ela= 11175 file#=13 block#=200041
blocks=1 obj#=67575 tim=1193690114589134
WAIT #12: nam='db file sequential read' ela= 9454 file#=6 block#=587915
blocks=1 obj#=67577 tim=1193690114672648

accmeas_2 bdump > grep "db file sequential read" accmeas2_j004_32116.trc
| head -2 | awk  '{print $9"="$10}' | awk -F= '{print $2","$4}'
13,200041
6,587915

SQL> select distinct
e.owner,e.segment_name,e.PARTITION_NAME,(e.bytes/1024/1024) size_MB from
t, dba_extents e where e.file_id=t.p1 and t.p2 between e.block_id and
e.block_id+e.blocks order by e.owner,e.segment_name,e.PARTITION_NAME;
```

Cross verification, ASH and 10046 trace (2/2)

- Take information from v$active_session_history

```
create table t as select p1,p2 from v$active_session_history h where
h.module like 'DATA_LOAD%' and h.action like 'COLLECT_DN%' and
h.event ='db file sequential read' and h.sample_time>sysdate-4/24;

SQL> select distinct
e.owner,e.segment_name,e.PARTITION_NAME,(e.bytes/1024/1024) size_MB from
t, dba_extents e where e.file_id=t.p1 and t.p2 between e.block_id and
e.block_id+e.blocks order by e.owner,e.segment_name,e.PARTITION_NAME;
```

ashrpti and DB objects

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```
CSR:SQL> select user_id from dba_users where username='CINBAD';
   USER_ID
----------
        55
CSR:SQL> select event,user_id,session_id,session_serial#,to_char(SAMPLE_TIME,'YYYYMMDD-
HH24MISS') from v$active_session_history where SAMPLE_TIME>sysdate-2/24 and user_id=55 and
event is not null order by sample_time;

EVENT                          USER_ID SESSION_ID SESSION_SERIAL# TO_CHAR(SAMPLE_
------------------------- ---------- ---------- --------------- ---------------
[...]
db file sequential read            55        530           28609 20081130-225208
db file sequential read            55        530           28609 20081130-230708

CSR:SQL> @ashrpti
[...]
Specify SESSION_ID (eg: from V$SESSION.SID) report target:
Defaults to NULL:
Enter value for target_session_id: 530
[...]
```

Top DB Objects

- With respect to Application, Cluster, User I/O and buffer busy waits only.

Object ID	% Activity	Event	% Event	Object Name (Type)	Tablespace
101841	2.38	db file sequential read	2.38	CINBAD.SFL_IP_PK (INDEX)	INDX01
101847	2.38	db file sequential read	2.38	CINBAD.SFL_IP_UDP_PK (INDEX)	INDX01

OS level

- First identify how the IO is performed:
  - DstackProf (Tanel Poder)
  - strace (Linux) / truss (Solaris)
  - Dtruss
  - DTrace (example later)

DStackProf example

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```
-bash-3.00$ ./dstackprof.sh 11073

DStackProf v1.02 by Tanel Poder ( http://www.tanelpoder.com )
Sampling pid 11073 for 5 seconds with stack depth of 100 frames...
[...]
780 samples with stack below

__________________
libc.so.1`_pread
skgfqio
ksfd_skgfqio
ksfd_io
ksfdread1                       ksfd: support for various kernel associated capabilities
kcfrbd                          manages and coordinates operations on the control file(s)
kcbzib
kcbgtcr                         kcb: manages Oracle's buffer cache operation as well as
operations used by capabilities such as direct load, has clusters , etc.
ktrget2                         ktr - kernel transaction read consistency
kdsgrp                          kds: operations on data such as retrieving a row and updating
existing row data
qetlbr
qertbFetchByRowID   qertb - table row source
qerjotRowProc                   qerjo - row source: join
kdstf0000001000kmP
kdsttgr                         kds: operations on data such as retrieving a row and updating
existing row data
qertbFetch                      qertb - table row source
qerjotFetch                     qerjo - row source: join
qergsFetch                      qergs - group by sort row source
opifch2
Kpoal8 / opiodr / ttcpip/ opitsk / opiino / opiodr / opidrv / sou2o / a.out`main / a.out`_start
```

note 175982.1

OS level (btw exec plan)

- BTW you can get the status of execution this way, instead of looking at note 175982.1, you can use Tanel Poder's os_explain.sh

```
-bash-3.00$  pstack 11073| ./os_explain.sh
   kpoal8
    SELECT FETCH:
     GROUP BY SORT: Fetch
      NESTED LOOP JOIN: Fetch
       TABLE ACCESS: Fetch
        kdsttgr
         kdstf0000001000kmP
          NESTED LOOP JOIN: RowProc
           TABLE ACCESS: FetchByRowID
            qetlbr
             kdsgrp
              ktrget2
               kcbgtcr
                kcbzib
                 kcfrbd
                  ksfdread1
                   ksfd_io
                    ksfd_skgfqio
                     skgfqio
                      _pread
```

```
SQL> select * from table(dbms_xplan.display_cursor
('8st7asbzt4jz7',null,'BASIC'));
[...]

PLAN_TABLE_OUTPUT
-----------------------------------------------------
|   1 |  SORT AGGREGATE               |             |
|   2 |   NESTED LOOPS                |             |
|   3 |    TABLE ACCESS FULL          | PROBETEST1  |
|   4 |    TABLE ACCESS BY USER ROWID| TESTTABLE1  |
-----------------------------------------------------
```

OS level

- You can measure (with the least overhead), selecting only the syscalls that you need
- For example, pread

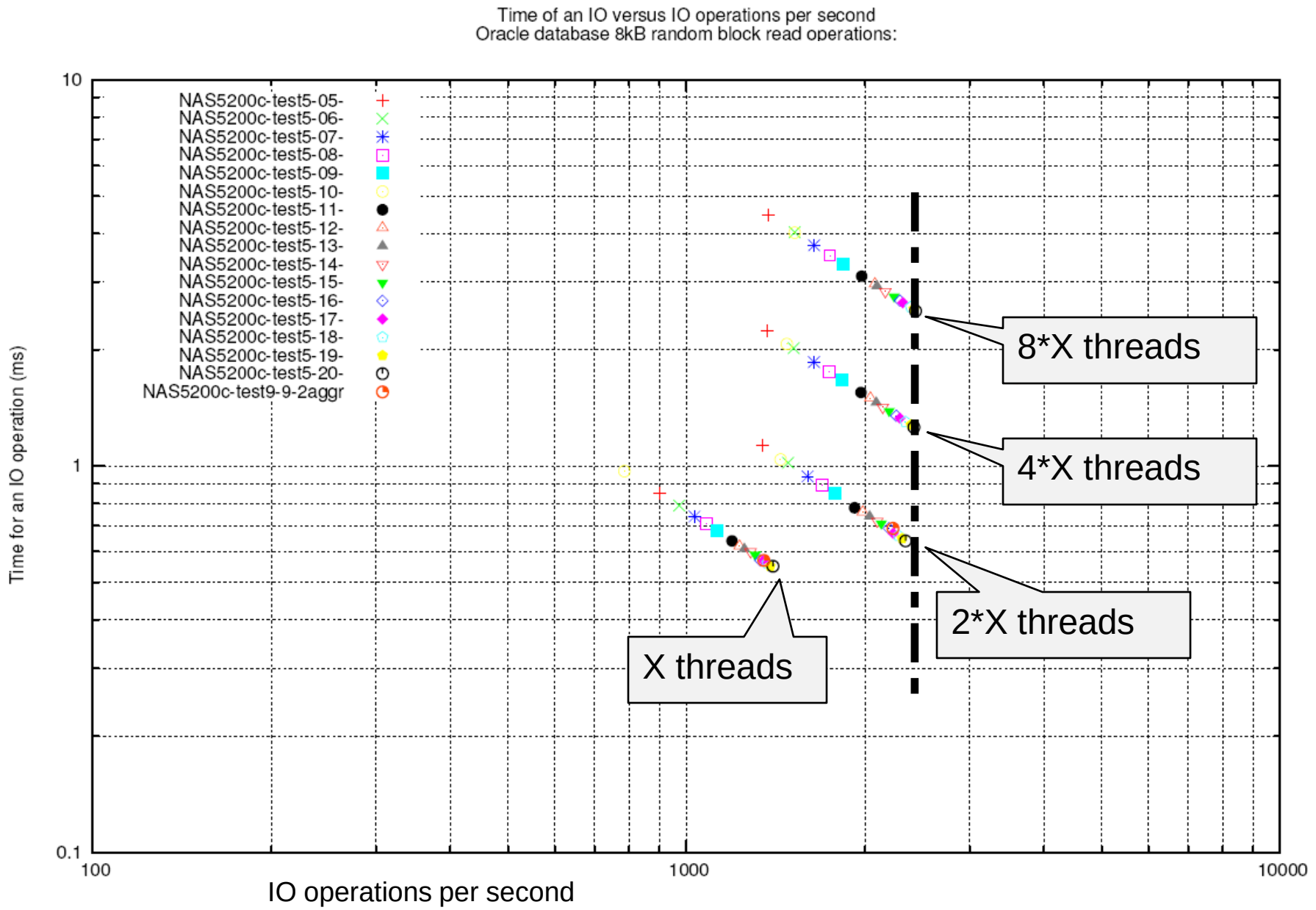
```
-bash-3.00$ truss -t pread -Dp 17924
/1:      0.0065 pread(258, "06A2\0\001CA9EE1\0 !B886".., 8192, 0x153DC2000) = 8192
/1:      0.0075 pread(257, "06A2\0\0018CFEE4\0 !C004".., 8192, 0x19FDC8000) = 8192
/1:      0.0078 pread(258, "06A2\0\001C4CEE9\0 !92AA".., 8192, 0x99DD2000) = 8192
/1:      0.0103 pread(257, "06A2\0\00188 S F\0 !A6C9".., 8192, 0x10A68C000) = 8192
/1:      0.0072 pread(257, "06A2\0\0018E kD7\0 !CFC2".., 8192, 0x1CD7AE000) = 8192

-bash-3.00$ truss -t pread -Dp 15854 2>&1 | awk '{s+=$2; if (NR%1000==0) {print NR " " s " "
s/NR}}'
1000 7.6375  0.0076375
2000 15.1071 0.00755355
3000 22.4648 0.00748827
```

Overload at disk driver / system level (1/2)

- Each (spinning) disk is capable of ~ 100 to 300 IO operations per second depending on the speed and controller capabilities
- Putting many requests at the same time from the Oracle layer, makes as if IO takes longer to be serviced

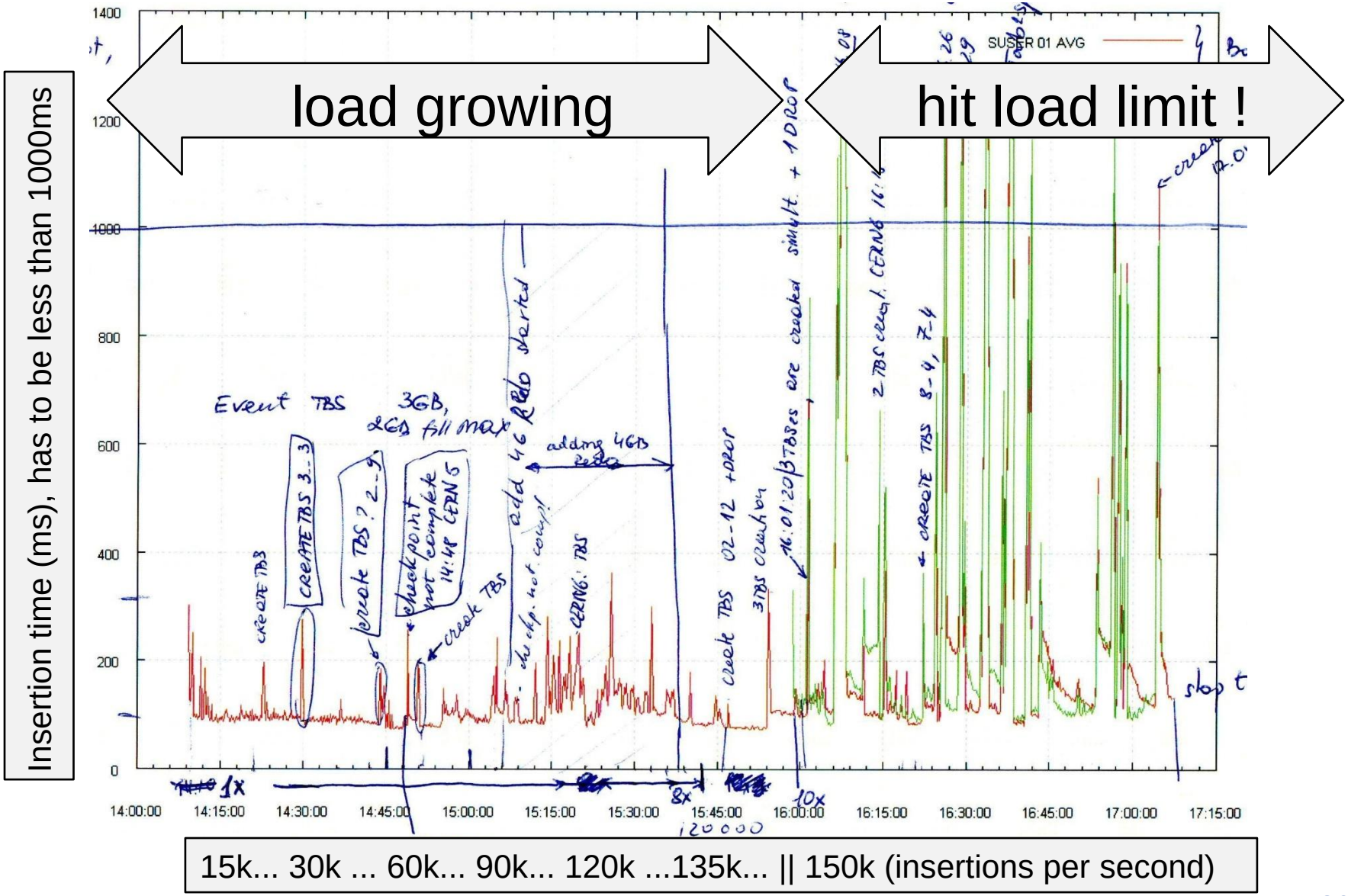
Overload at disk driver level / system level (2/2)



Overload at CPU level (1/)

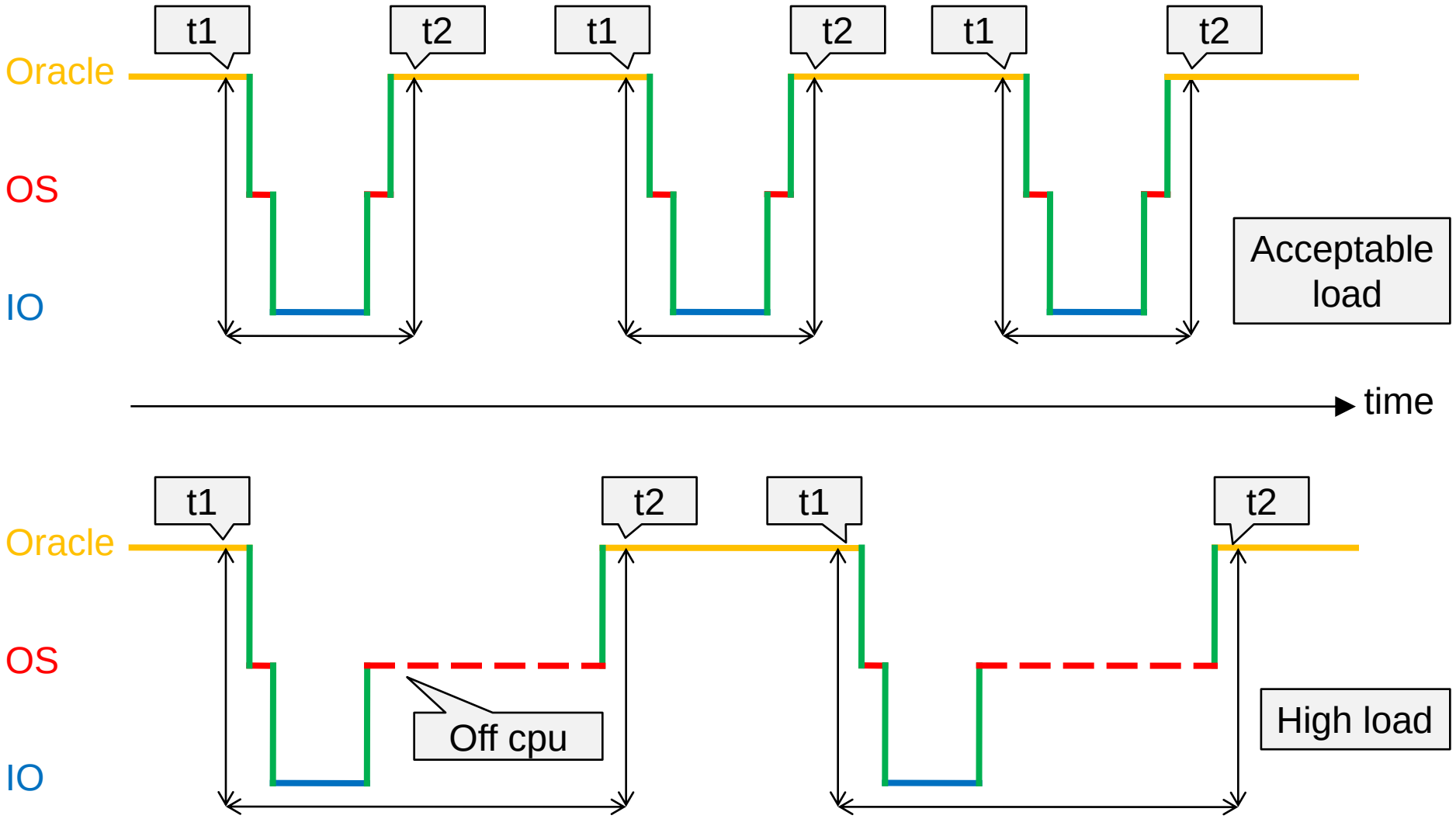
- Observed many times: “the storage is slow” (and storage administrators/specialists say “storage is fine / not loaded”)
- Typically happens that observed (from Oracle rdbms point of view) IO wait times are long if CPU load is high
- Instrumentation / on-off cpu

Overload at CPU level (2/) example



15k... 30k ... 60k... 90k... 120k ...135k... || 150k (insertions per second)

OS level / high-load



Overload at CPU level (3/), Dtrace

- Dtrace (Solaris) can be used at OS level to get (detailed) information at OS level

```
syscall::pread:entry
/pid == $target && self->traceme == 0 /
{
  self->traceme = 1;
  self->on = timestamp;
  self->off= timestamp;
  self->io_start=timestamp;
}

syscall::pread:entry
/self->traceme == 1 /
{
  self->io_start=timestamp;
}

syscall::pread:return
/self->traceme == 1 /
{
  @avgs["avg_io"] = avg(timestamp-self->io_start);
  @[tid,"time_io"] = quantize(timestamp-self->io_start);
  @counts["count_io"] = count();
}
```

Dtrace

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```
sched:::on-cpu
/pid == $target && self->traceme == 1 /
{
  self->on = timestamp;
  @[tid,"off-cpu"] = quantize(self->on - self->off);
  @totals["total_cpu_off"] = sum(self->on - self->off);
  @avgs["avg_cpu_off"] = avg (self->on - self->off);
  @counts["count_cpu_on"] = count();
}
sched:::off-cpu
/self->traceme == 1/
{
  self->off= timestamp;
  @totals["total_cpu_on"] = sum(self->off - self->on);
  @avgs["avg_cpu_on"] = avg(self->off - self->on);
  @[tid,"on-cpu"] = quantize(self->off - self->on);
  @counts["count_cpu_off"] = count();
}

tick-1sec
/i++ >= 5/
{
  exit(0);
}
```

Dtrace, “normal load”

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```
-bash-3.00$ sudo ./cpu.d4 -p 15854
dtrace: script './cpu.d4' matched 7 probes
CPU     ID                    FUNCTION:NAME
  3  52078                       :tick-1sec

  avg_cpu_on                                                169114
  avg_cpu_off                                              6768876
  avg_io                                                   6850397

[...]

        1  off-cpu
           value  ------------- Distribution ------------- count
          524288 |                                         0
         1048576 |                                         2
         2097152 |@@@@                                     86
         4194304 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ 577
         8388608 |@@@@@@@@@@                               189
        16777216 |                                         2
        33554432 |                                         0

[...]

  count_cpu_on                                                 856
  count_io                                                     856
  count_cpu_off                                                857
  total_cpu_on                                           144931300
  total_cpu_off                                         5794158700
```

Dtrace, “high load”

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```
-bash-3.00$ sudo ./cpu.d4 -p 15854
dtrace: script './cpu.d4' matched 7 probes
CPU     ID                    FUNCTION:NAME
  2  52078                       :tick-1sec

  avg_cpu_on                                                  210391
  avg_cpu_off                                               10409057
  avg_io                                                     10889597
[...]
        1  off-cpu
           value  ------------- Distribution ------------- count
            8192 |                                         0
           16384 |                                         4
           32768 |@                                        11
           65536 |                                         2
          131072 |                                         0
          262144 |                                         0
          524288 |                                         0
         1048576 |                                         0
         2097152 |@                                        15
         4194304 |@@@@@@@@@@@@@@@                          177
         8388608 |@@@@@@@@@@@@@@@@@@@@@@@@                 249
        16777216 |@@@                                      41
        33554432 |                                         4
        67108864 |                                         0
[...]
  count_io                                                       486
  count_cpu_on                                                   503
  count_cpu_off                                                  504
  total_cpu_on                                             106037500
  total_cpu_off                                           5235756100
```

Exadata (1/2)

- Exadata has a number of offload features, most published about are row selection and column selection
- Some of our workloads are data insertion intensive, for these the tablespace creation is/can be a problem
- Additional load, additional IO head moves, additional bandwidth usage on the connection server→storage
- Exadata has file creation offloading
- Tested recently with 4 Exadata cells storage. Tests done with Anton Topurov / Ela Gajewska-Dendek

Swingbench in action

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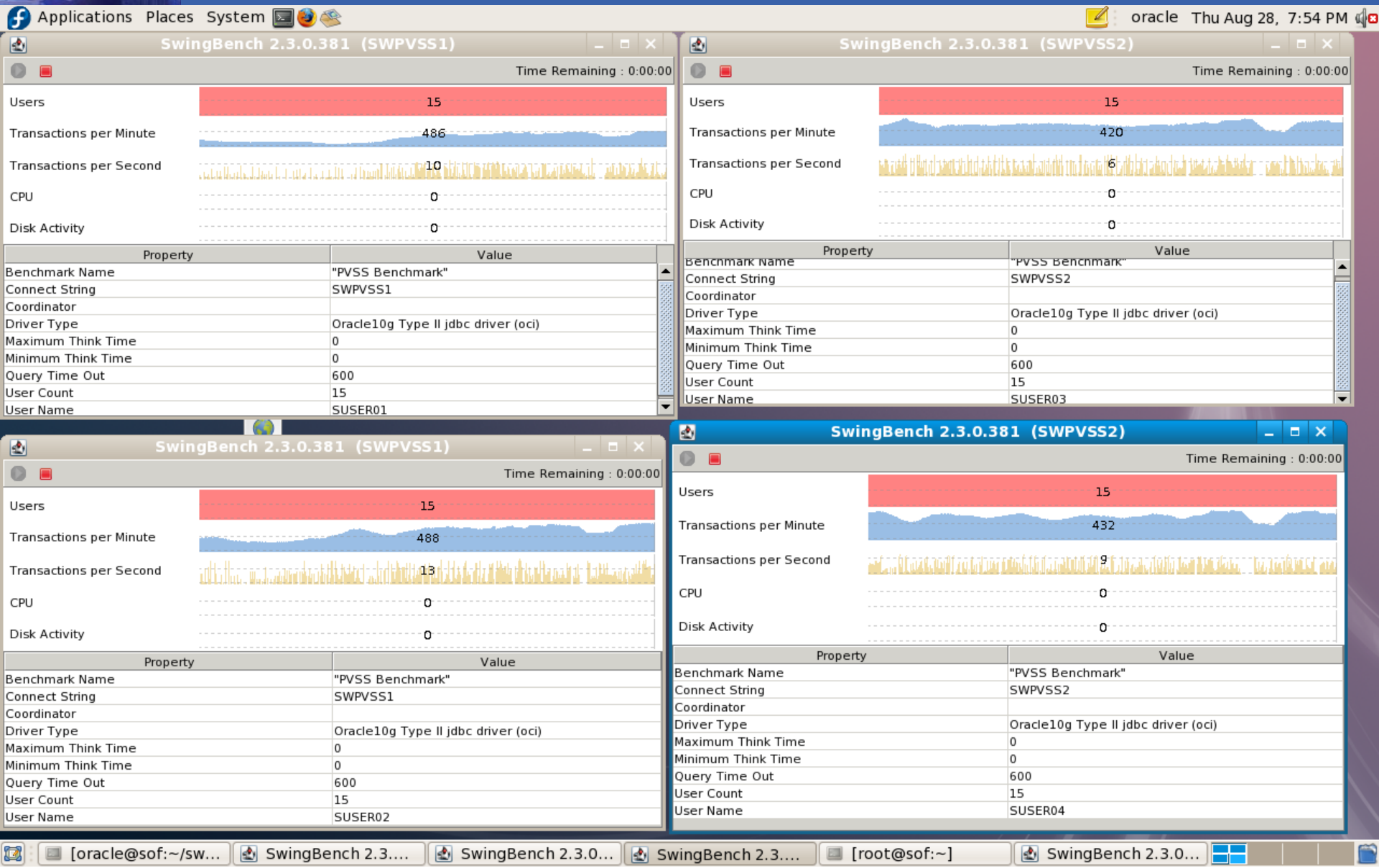
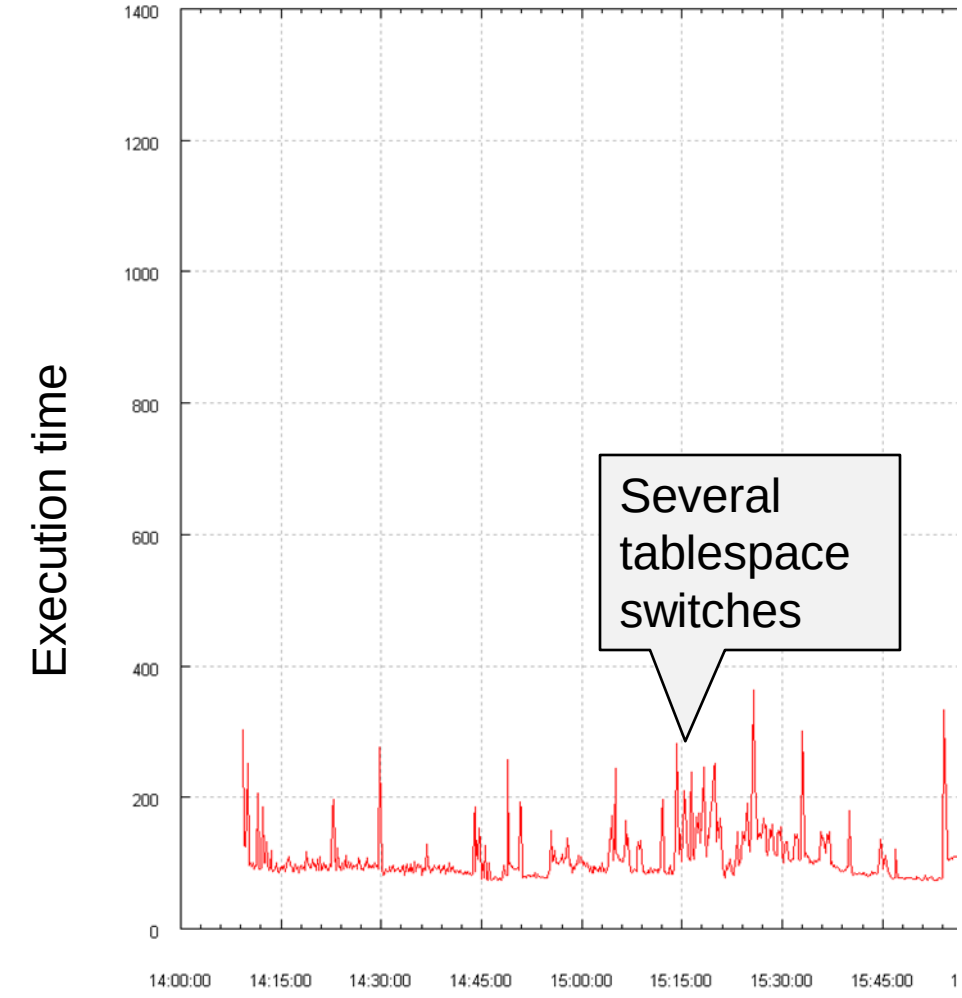
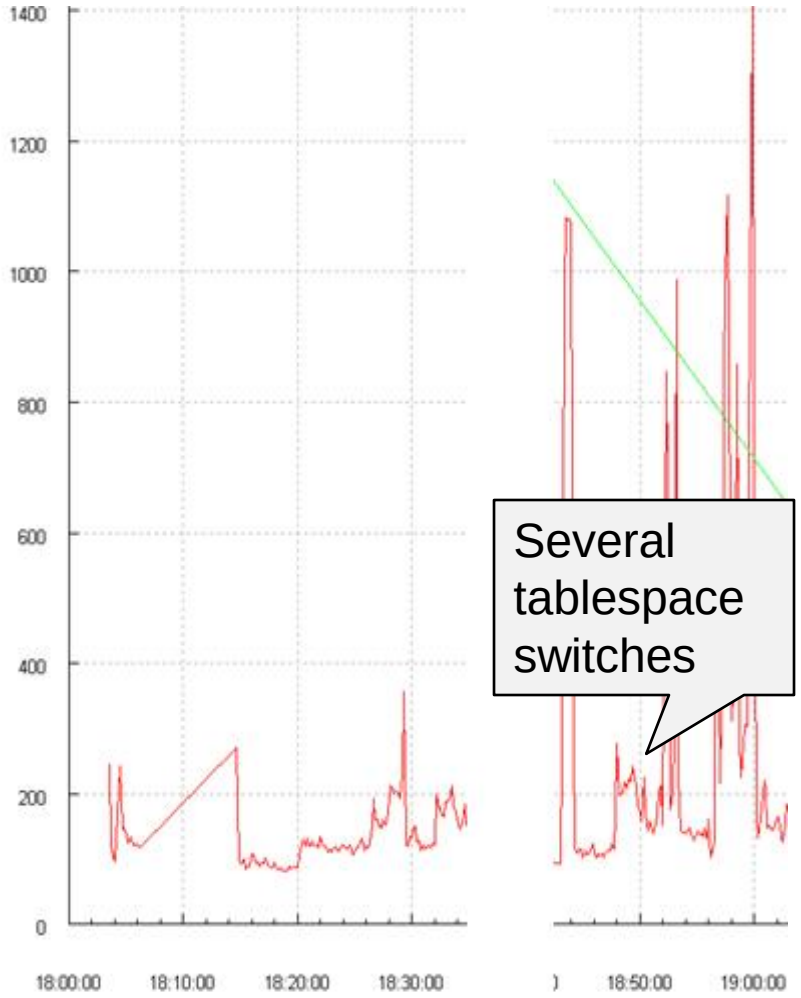


Exadata (2/2)



_cell_fcre=true



_cell_fcre=false

SSD (1/6)

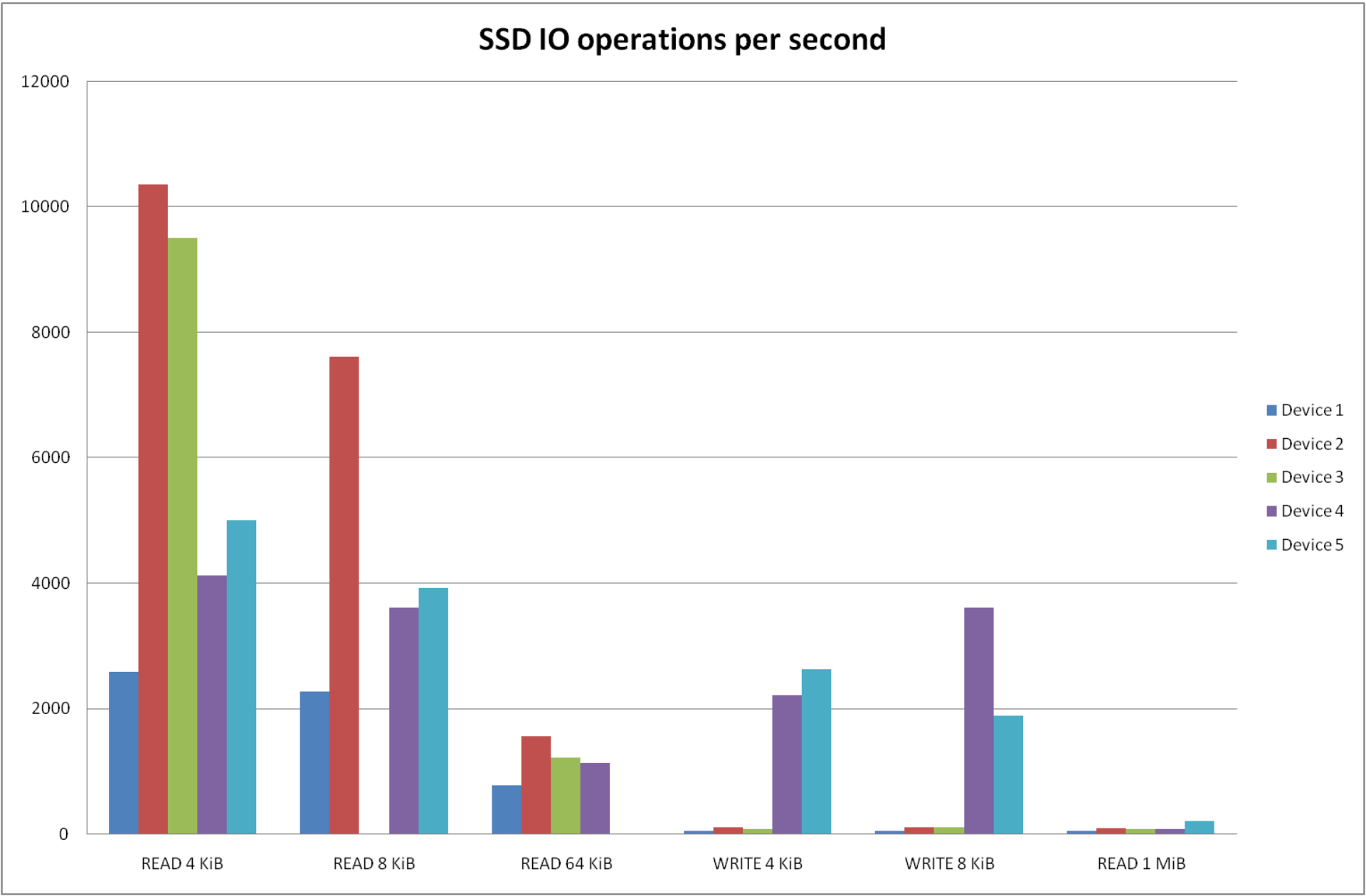
- Solid-State Drive, based on flash, means many different things
- **Single Level Cell (more expensive, said to be more reliable / faster)** / Multiple Level Cell
- Competition in the consumer market is shown on the bandwidth...

- Tests done thanks to Peter Kelemen / CERN – Linux (some done only by him)

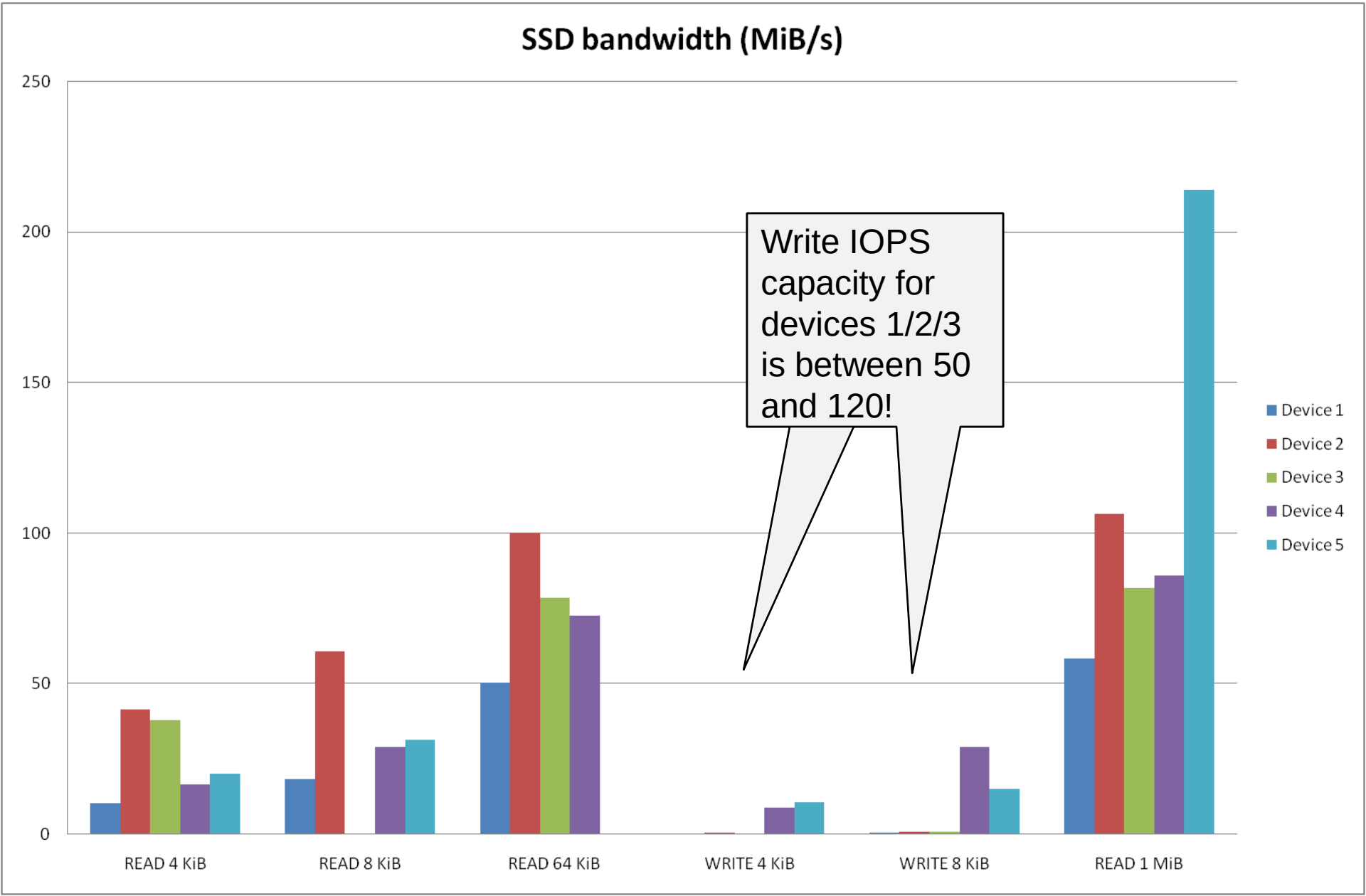
SSD (2/6)

- Here are results for 5 different types / models
- Large variety, even the “single cell” SSDs
- (as expected) The biggest difference is with the writing IO operations per second

SSD (4/6)


SSD IO operations per second
12000
10000
8000
6000
4000
2000
0
READ 4 KiB
READ 8 KiB
READ 64 KiB
WRITE 4 KiB
WRITE 8 KiB
READ 1 MiB
Device 1
Device 2
Device 3
Device 4
Device 5

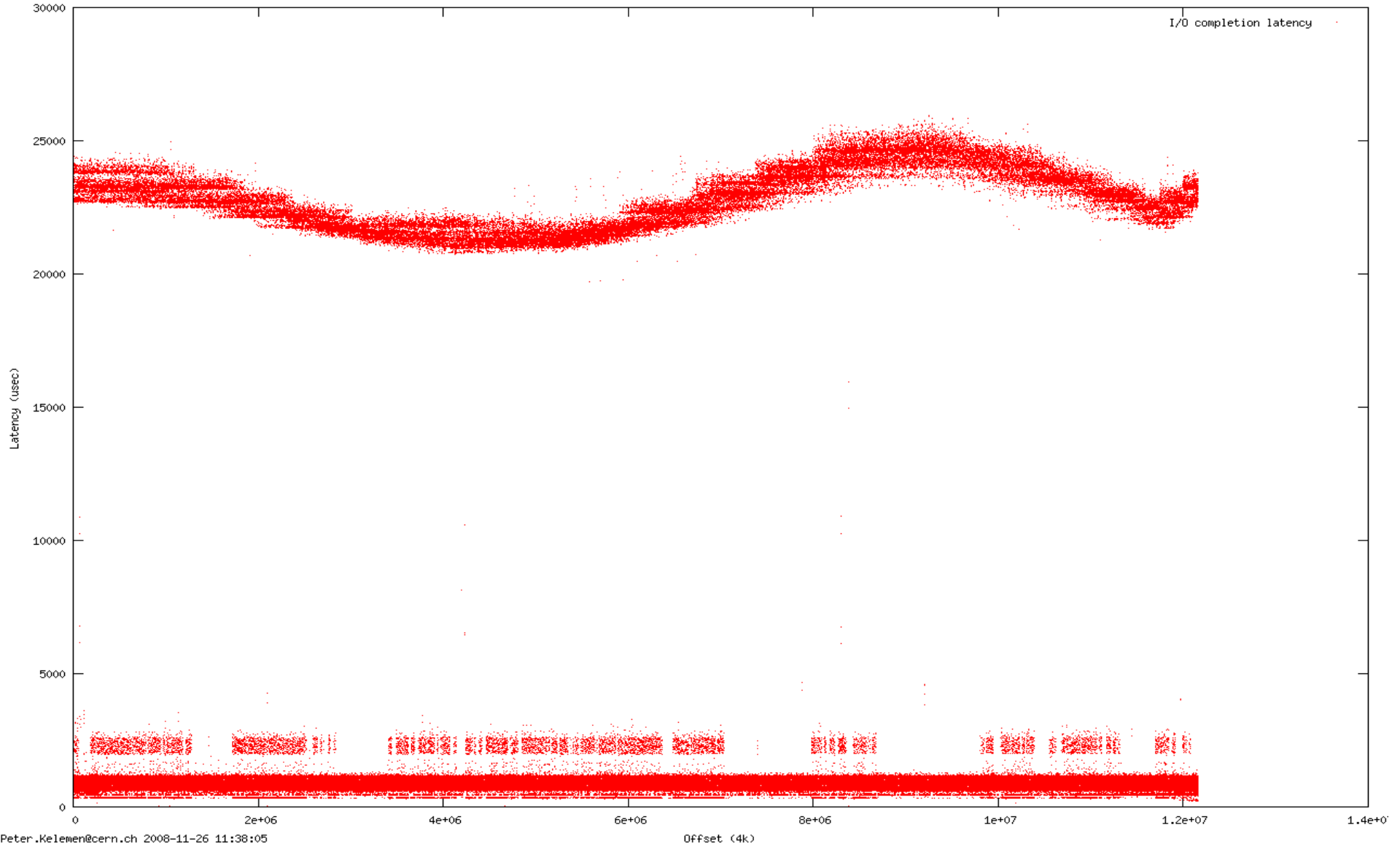
SSD (3/6)


SSD bandwidth (MiB/s)
250
200
150
100
50
0
READ 4 KiB
READ 8 KiB
READ 64 KiB
WRITE 4 KiB
WRITE 8 KiB
READ 1 MiB
Write IOPS capacity for devices 1/2/3 is between 50 and 120!
Device 1
Device 2
Device 3
Device 4
Device 5

SSD (5/6) “devices 4 and 5”

- “expensive” and “small” (50GB), complex, very promising
- For random read small IO operations (4kiB or 8kiB), we measure ~4000 to 5000 IOPS (compare to 26 disks)
- For random write operations (4kiB or 8kiB), we measure 2000 to 3000+ write IOPS (compare to 13 disks)
- But for some of the 8K offsets the I/O completion latency is 10× the more common 0.2 ms
- “Wear-levelling/erasure block artefact”? Reported to the vendor

SSD (6/6)


I/O completion latency
Latency (usec)
30000
25000
20000
15000
10000
5000
0
0
2e+06
4e+06
6e+06
8e+06
1e+07
1.2e+07
1.4e+07
Offset (4k)
Peter.Kelemen@cern.ch 2008-11-26 11:38:05

Conclusions

- New tools like Dtrace change the way we can track IO operations
- Overload in IO and CPU can not be seen from Oracle IO views
- Exadata offloading operations can be interesting (and promising)
- Flash SSD are coming, a lot of differences between them. Writing is the issue (and is a driving price factor). Not applicable for everything. Not to be used for everything for now (as write cache? Oracle redo logs)They change the way IO are perceived. Test/test/test!

References

- Why You Should Focus on LIOs Instead of PIOs Author, Cary Millsap http://www.hotsos.com/e-library/abstract.php?id=7
- Tanel Poder DStackProf http://tanelpoder.otepad.com/script:dstackprof.sh
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Q&A