Oracle Exadata and database memory

Frits Hoogland

This is the font size used for showing screen output. Be sure this is readable for you.

This is the font used to accentuate text/console output. Make sure this is readable for you too!

`whoami`

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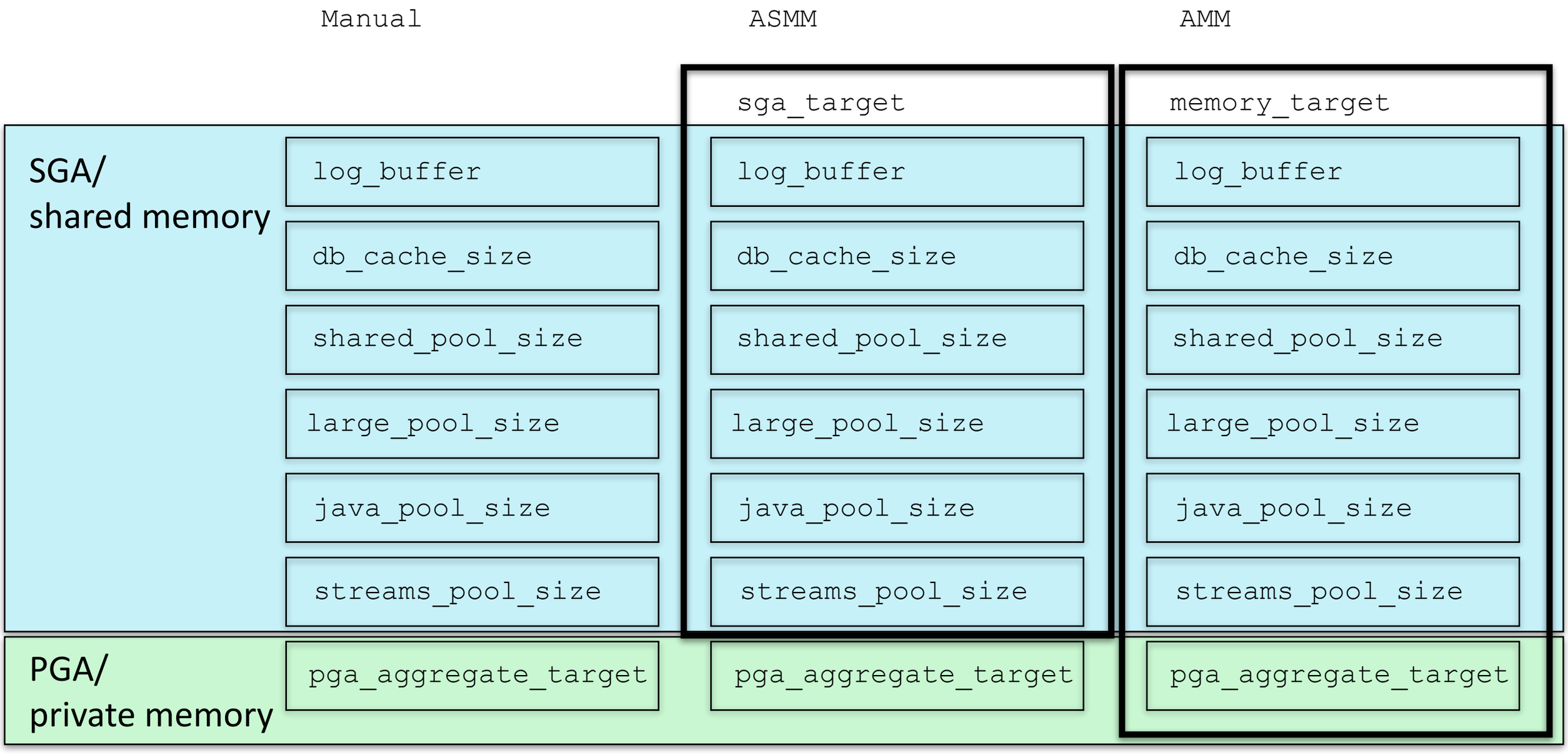
Goals & prerequisites

- Goal: Learn about Linux and Oracle database SGA&PGA memory specifics.
- Prerequisites:
  - Understanding of Linux (memory).
  - Understanding of Oracle memory.
- I talk about dedicated (non shared server) conn.

Memory models

- The Oracle database has 3 memory models:
  - Manual
  - ASMM
  - AMM

Memory models



SGA

- All memory models SGA require:
  - System V shared memory

SGA - manual & ASMM memory

```
$ sysresv -l fv12102
.. lots of other output ..
Shared Memory:
ID     KEY
117047297 0x00000000
117080066 0x00000000
117014528 0x00000000
117112835 0xd160bbe8
Semaphores:
ID     KEY
557058    0x7e75d94c
Oracle Instance alive for sid “fv12102”
```

```
$ ipcs -m

------ Shared Memory Segments --------
key        shmid      owner      perms      bytes      na
0x00000000 117014528  oracle     640        4194304    62
0x00000000 117047297  oracle     640        864026624  62
0x00000000 117080066  oracle     640        140509184  62
0xd160bbe8 117112835  oracle     640        20480      62
```

SGA - AMM memory

```
$ sysresv -l fv12102
.. lots of other output ..
Shared Memory:
ID     KEY
132448257 0x00000000
132481026 0x00000000
132415488 0x00000000
132513795 0xd160bbe8
Semaphores:
ID     KEY
557058    0x7e75d94c
Oracle Instance alive for sid “fv12102”
```

```
$ ipcs -m

------ Shared Memory Segments --------
key        shmid      owner      perms      bytes      na
0x00000000 132415488  oracle     640        4096       0
0x00000000 132448257  oracle     640        4096       0
0x00000000 132481026  oracle     640        4096       0
0xd160bbe8 132513795  oracle     640        8192       63
```

SGA - AMM memory

```
$ sysresv -l fv12102
.. lots of other output ..
Shared Memory:
ID     KEY
127598593 0x00000000
127631362 0x00000000
127565824 0x00000000
127664131 0xd160bbe8
Semaphores:
ID     KEY
557058     0x7e75d94c
Oracle Instance alive for sid “fv12102”
```

```
$ ls /dev/shm/ora_fv12102_127598593_* | wc -l
85
$ ls /dev/shm/ora_fv12102_127631362_* | wc -l
9
$ ls /dev/shm/ora_fv12102_127565824_* | wc -l
1
$ ls /dev/shm/ora_fv12102_127664131_* | wc -l
ls: cannot access /dev/shm/ora_fv12102_127664131_*: No
such file or directory
0
```

SGA - AMM memory

```
$ ls -l /dev/shm/ora_fv12102_127598593_*
-rw-r----- 1 oracle oinstall        0 Feb  9 08:39 /dev/shm/ora_fv12102_127598593_0
-rw-r----- 1 oracle oinstall        0 Feb  9 08:39 /dev/shm/ora_fv12102_127598593_1
-rw-r----- 1 oracle oinstall        0 Feb  9 08:39 /dev/shm/ora_fv12102_127598593_10
-rw-r----- 1 oracle oinstall        0 Feb  9 08:39 /dev/shm/ora_fv12102_127598593_11
..
-rw-r----- 1 oracle oinstall 16777216 Feb  9 08:39 /dev/shm/ora_fv12102_127598593_31
-rw-r----- 1 oracle oinstall 16777216 Feb  9 08:39 /dev/shm/ora_fv12102_127598593_32
-rw-r----- 1 oracle oinstall 16777216 Feb  9 08:39 /dev/shm/ora_fv12102_127598593_33
-rw-r----- 1 oracle oinstall 16777216 Feb  9 08:40 /dev/shm/ora_fv12102_127598593_34
-rw-r----- 1 oracle oinstall 16777216 Feb  9 08:50 /dev/shm/ora_fv12102_127598593_35
```

Size either 0
or granule size

Memory segments

Memory (ASMM & man)

- The SGA can be seen in /proc/PID/maps:

```
$ cat /proc/19735/maps
00400000-1093f000 r-xp 00000000 fc:02 272770084      /u01/../bin/oracle
10b3e000-10dbf000 rw-p 1053e000 fc:02 272770084      /u01/../bin/oracle
10dbf000-10df0000 rw-p 00000000 00:00 0
12266000-122a8000 rw-p 00000000 00:00 0                  [heap]
60000000-60400000 rw-s 00000000 00:0b 140083200      /SYSV00000000 (deleted)
60400000-96400000 rw-s 00000000 00:0b 140115969      /SYSV00000000 (deleted)
96400000-9ea00000 rw-s 00000000 00:0b 140148738      /SYSV00000000 (deleted)
9ec00000-9ec05000 rw-s 00000000 00:04 140181507      /SYSVd160bbe8 (deleted)
3bb3000000-3bb3020000 r-xp 00000000 fc:00 134595     /lib64/ld-2.12.so
..
```

Memory (AMM)

- Actually, the SGA files can be seen in maps too:

```
$ cat maps
..
ba000000-bb000000 rw-s 00000000 00:10 92010        /dev/shm/ora_fv12102_144474114_4
bb000000-bc000000 rw-s 00000000 00:10 92011        /dev/shm/ora_fv12102_144474114_5
bc000000-bd000000 rw-s 00000000 00:10 92012        /dev/shm/ora_fv12102_144474114_6
bd000000-be000000 rw-s 00000000 00:10 92013        /dev/shm/ora_fv12102_144474114_7
be000000-bf000000 rw-s 00000000 00:10 92014        /dev/shm/ora_fv12102_144474114_8
bf000000-bf002000 rw-s 00000000 00:04 144506883    /SYSVd160bbe8 (deleted)
3bb3000000-3bb3020000 r-xp 00000000 fc:00 134595   /lib64/ld-2.12.so
..
```

Which memory model?

- Now that we have looked at the memory models.
- The obvious question is: what to choose?
  - Manual.
  - Automatic Shared Memory Management.
  - Automatic Memory Management.

Which memory model?

- *Note the shown behaviour is limited to Linux!*
- *Investigate your own platform for options.*

- I would strongly advise to NOT use AMM.
  - /dev/shm allocations can not use huge pages.

- For serious deployments huge pages is not a choice. It is the only way to go.
- Only the SGA can be stored in huge pages!

What are huge pages

- Linux administers memory per page.
  - Normal page size 4kB.
- Every process needs maintain a table of it's virtual addresses to physical addresses.
  - Called 'pagetable'.
- The process pagetable is not pre-build.
  - Entries are added as pages are touched.
  - This includes (database) buffer cache pages.

What are huge pages

- With hugepages, a page size of 2M is used.
  - Reserved at startup (non-usable for 4kB alloc!);
    - (sysctl.conf) vm.nr_hugepages.
  - Hugepages are non-swappable.
  - Not automatic: memory allocations need to be done explicitly for huge pages.
- Huge pages results:
  - Much smaller page tables.
  - Higher TLB hit%, less CPU.

Huge pages

- Let me provide you a testcase.
  - Machine with 4G memory.
  - Database with buffer cache of ~ 1.2 G.
- Start 100 connections which do a
  - select count(*) from table;
  - Table size 960M.

Huge pages

- This is very easy to try yourself:
  - Create a table that should fit in the buffercache.
  - alter system set “_serial_direct_read”=never;
  - alter table <tablename> cache;
  - This modifies the BC LRU behaviour

```
T=0
while [ $T -lt 100 ]; do
    sqlplus ts/ts << EOF &
    select count(*) from <tablename>;
    exec dbms_lock.sleep(900);
EOF
    let T=$T+1
    sleep 0.3
done
```

Huge pages

```
$ grep -i pagetable /proc/meminfo
PageTables:        41278 kB
```

- Results:
  - After startup of database:
    - Non hugepages: 41M - 1.6%
    - Hugepages: 29M - 1.1%
  - After run with 100 sessions using the cache:
    - Non hugepages: 344M - 13.8%
    - Hugepages: 90M - 3.6%

Hugepages

- Current usage of huge pages:

```
$ grep -i hugepages /proc/meminfo
HugePages_Total:   32768
HugePages_Free:       58
HugePages_Rsvd:       58
HugePages_Surp:        0
Hugepagesize:       2048 kB
```

- Further reading:
  - http://www.kernel.org/doc/Documentation/vm/hugetlbpage.txt

Hugepages

- The database side
  - Parameter:
    - use_large_pages (>= 11.2.0.2)
      - » TRUE (default)
      - » ONLY
      - » FALSE

Hugepages

- Oracle 11.2.0.1:
  - No use_large_pages

- Oracle 11.2.0.2 and higher:
  - Set use_large_pages TRUE/ONLY

- Oracle 11.2.0.3 and higher:
  - Mixed normal/huge pages (TRUE)

SGA size

Size matters!

SGA size

BUFFER CACHE Size matters! WITH EXADATA

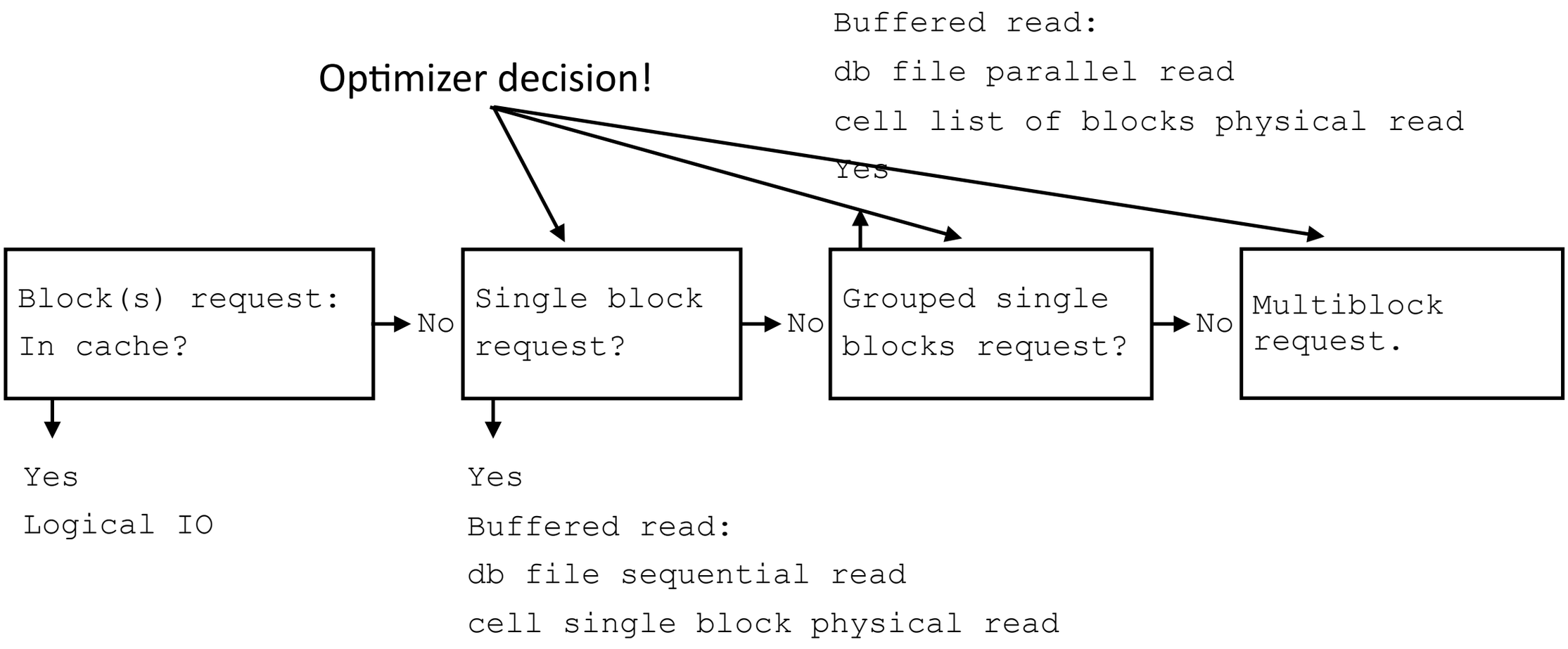
SGA size

Without exadata too!

BUFFER CACHE Size matters! WITH EXADATA

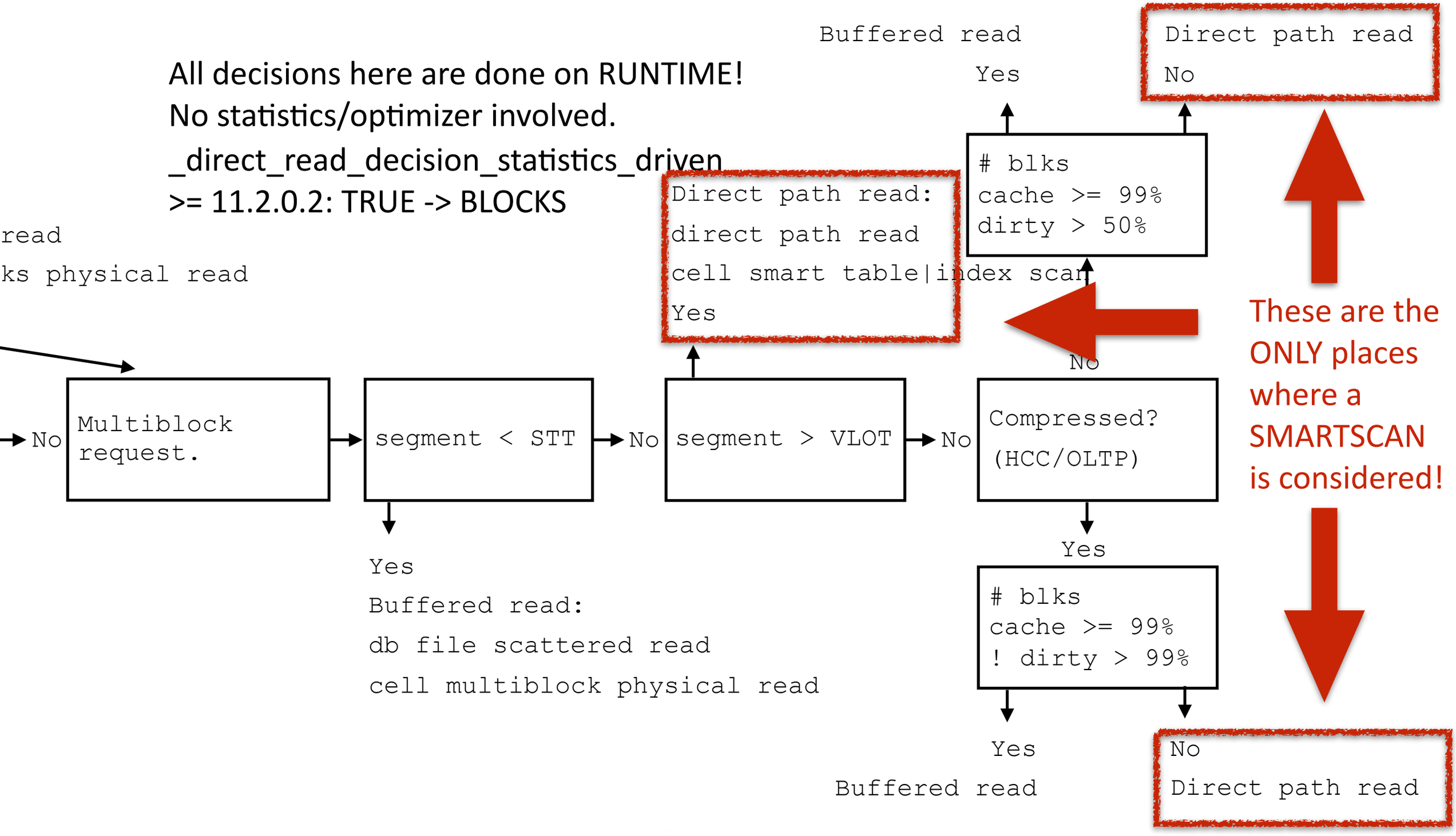
Bigger *is not always* better!

SGA size


Optimizer decision!
Buffered read:
db file parallel read
cell list of blocks physical read
Yes
Block(s) request:
In cache?
No
Single block
request?
No
Grouped single
blocks request?
No
Multiblock
request.
Yes
Logical IO
Yes
Buffered read:
db file sequential read
cell single block physical read

SGA size

All decisions here are done on RUNTIME!
No statistics/optimizer involved.
_direct_read_decision_statistics_driven
>= 11.2.0.2: TRUE -> BLOCKS



SGA size

- How did I get to these values?
  - There is a trace to see the evaluation:

```
alter session set events 'trace[nsmtio]';
```

- My setup:
- Buffercache: 4’352M
- _small_table_threshold: 106M (2%)
- _very_large_object_threshold=500 (fixed)
  - actual size= 500%*BC= 21’760M

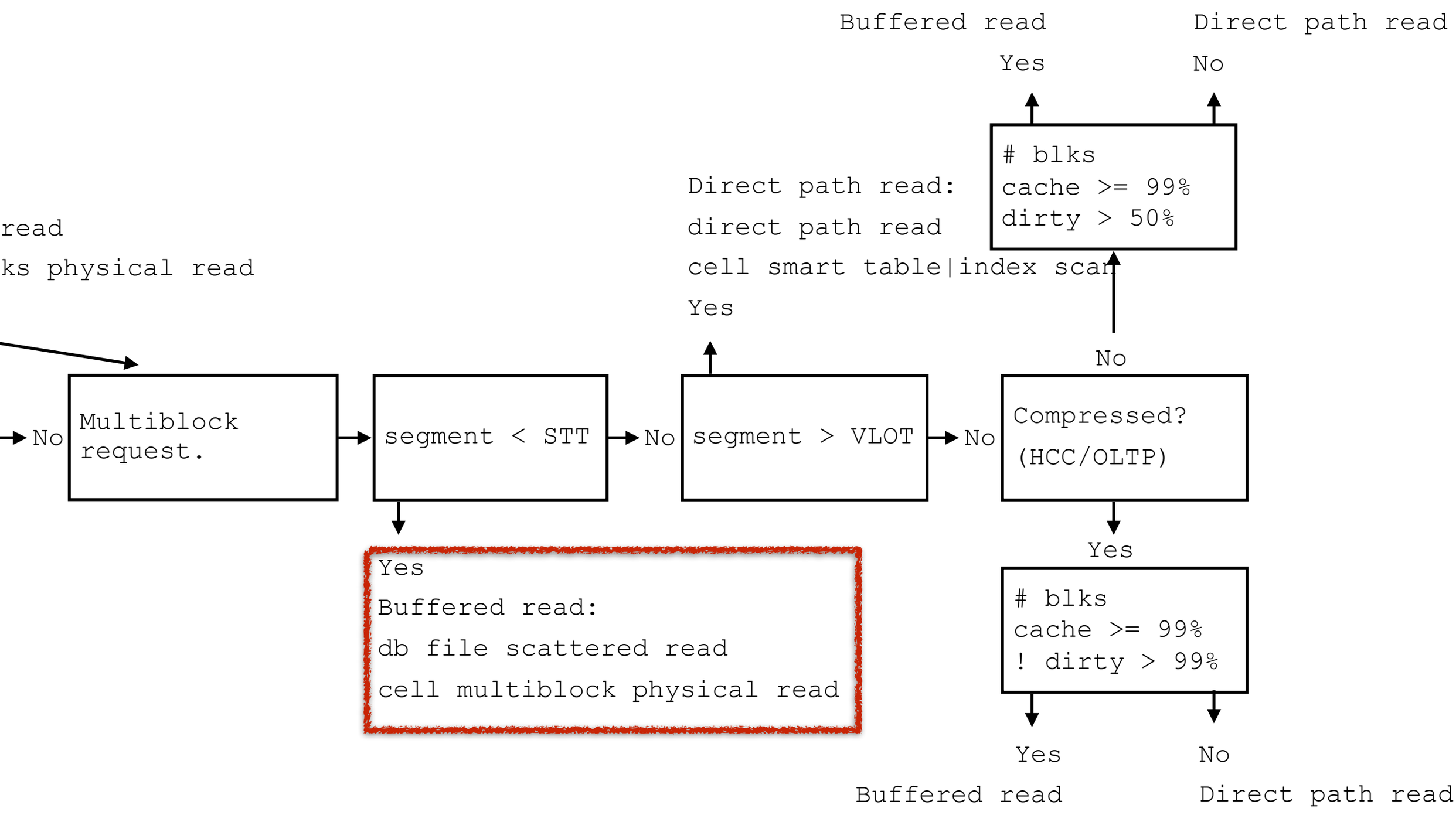
SGA size

- Small table (6 blocks), STT=13.276

```
NSMTIO: kcbism: islarge 0 next 0 nblks 6 type 3, bpid 65535, kcbisdbfc 0 kcbnhl 65536
kcbstt 13276 keep_nb 0 kcbnbh 512958 kcbnwp 4
NSMTIO: kcbism: islarge 0 next 0 nblks 6 type 2, bpid 3, kcbisdbfc 0 kcbnhl 65536 kcbstt
13276 keep_nb 0 kcbnbh 512958 kcbnwp 4
```

```
NSMTIO: qertbFetch:NoDirectRead:[- STT < OBJECT_SIZE < MTT]:Obect's size: 6 (blocks),
Threshold: MTT(66382 blocks),
_object_statistics: enabled, Sage: enabled,
Direct Read for serial qry: enabled(::::kctfsage::), Ascending SCN table scan: FALSE
flashback_table_scan: FALSE, Row Versions Query: FALSE
SqlId: fp4x7ms1295y7, plan_hash_value: 4018852438, Object#: 46418, Parition#: 0 DW_scan:
disabled
```

SGA size


Buffered read
Direct path read
Yes
No
blks
cache >= 99%
dirty > 50%
Direct path read:
direct path read
cell smart table|index scan
Yes
read
ks physical read
No
Multiblock request.
segment < STT
No
segment > VLOT
No
Compressed? (HCC/OLTP)
No
Yes
Yes
Buffered read:
db file scattered read
cell multiblock physical read
Yes
blks
cache >= 99%
! dirty > 99%
Yes
No
Buffered read
Direct path read

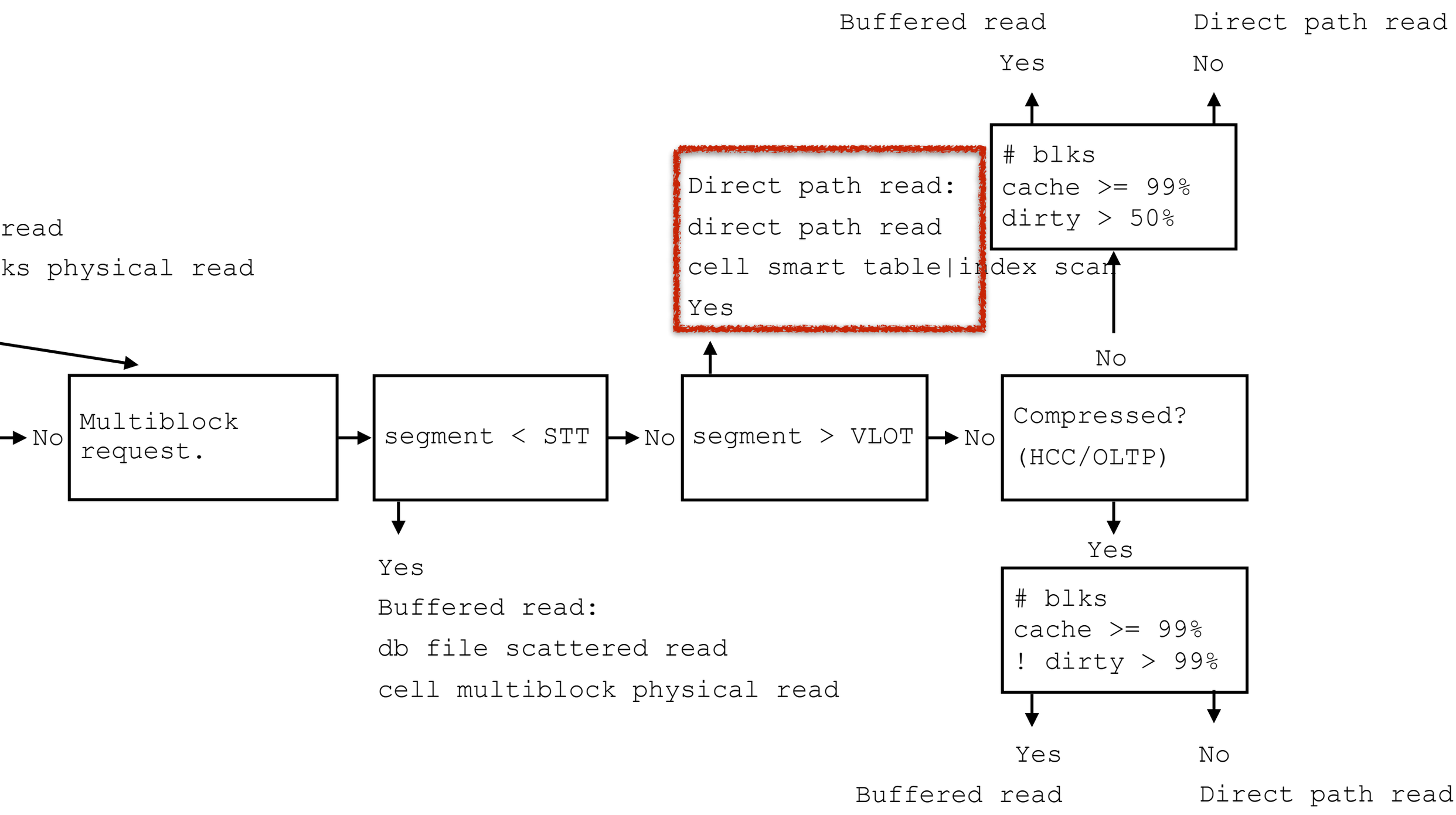
SGA size

- Very largetable(5.005.396 blocks), VLOT=3.319.140

```
NSMTIO: kcbism: islarge 1 next 0 nblks 5005396 type 3, bpid 65535, kcbisdbfc 0 kcbnhl
65536 kcbstt 13276 keep_nb 0 kcbnbh 512958 kcbnwp 4
NSMTIO: kcbism: islarge 1 next 0 nblks 5005396 type 2, bpid 3, kcbisdbfc 0 kcbnhl 65536
kcbstt 13276 keep_nb 0 kcbnbh 512958 kcbnwp 4
```

```
NSMTIO: kcbimd: nblks 5005396 kcbstt 13276 kcbpnb 66382 kcbisdbfc 3 is_medium 0
NSMTIO: kcbivlo: nblks 5005396 vlot 500 pnb 663828 kcbisdbfc 0 is_large 1
NSMTIO: qertbFetch:DirectRead:[OBJECT_SIZE>VLOT]
NSMTIO: Additional Info: VLOT=3319140
Object# = 44540, Object_Size = 5005396 blocks
SqlId = 8jbzjj236m5zd, plan_hash_value = 630573765, Partition# = 0
```

SGA size

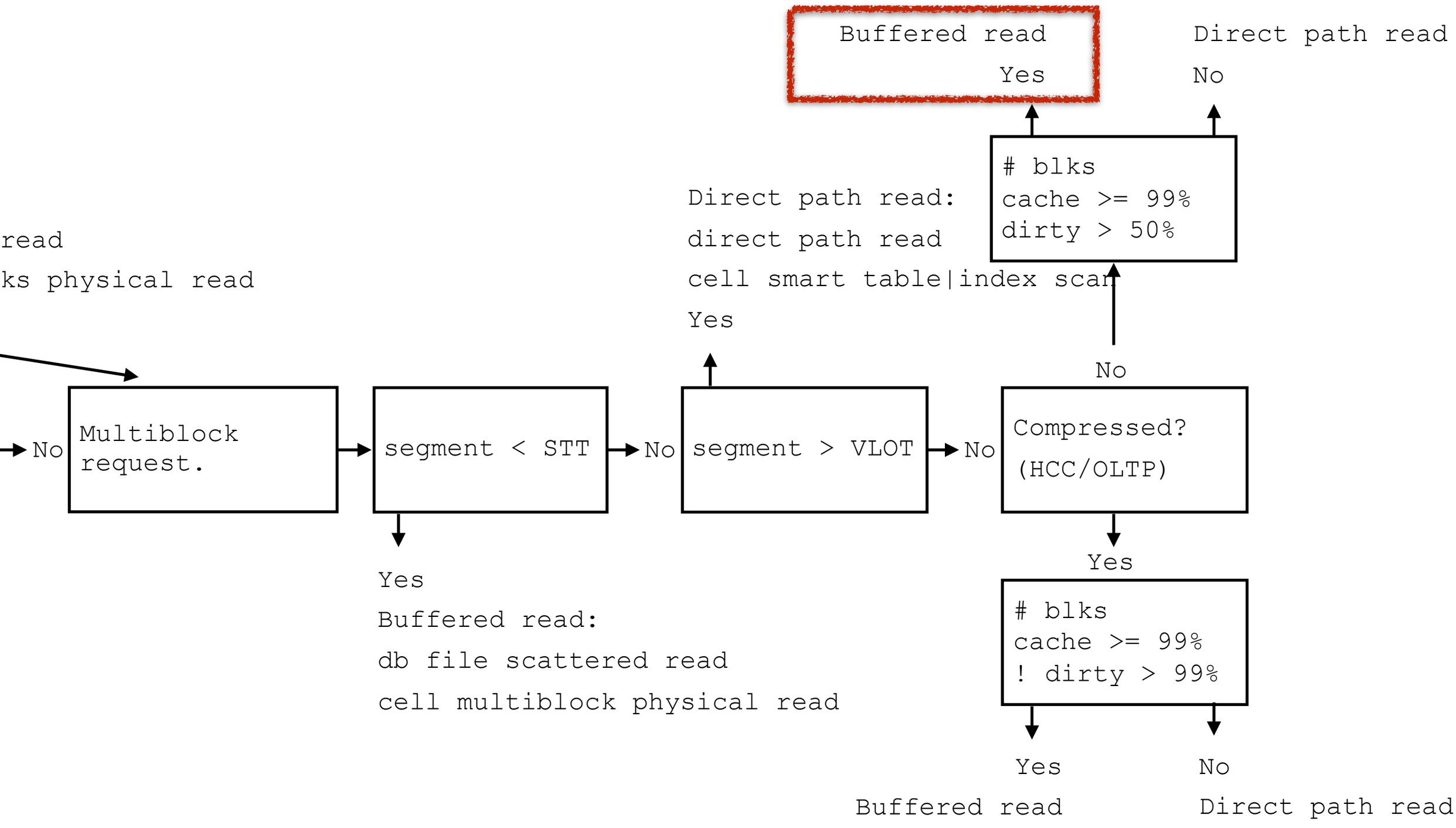

read
ks physical read
Buffered read
Direct path read
Yes
No
Direct path read:
direct path read
cell smart table|index scan
Yes
blks
cache >= 99%
dirty > 50%
No
Multiblock
request.
segment < STT
No
segment > VLOT
No
Compressed?
(HCC/OLTP)
Yes
Yes
Buffered read:
db file scattered read
cell multiblock physical read
Yes
blks
cache >= 99%
! dirty > 99%
Yes
No
Buffered read
Direct path read

SGA size

- Large table (13.328 blocks) - *just large enough*

```
NSMTIO: kcbism: islarge 1 next 0 nblks 13328 type 2, bpid 3, kcbisdbfc 0 kcbnhl 65536
kcbstt 13276 keep_nb 0 kcbnbh 512958 kcbnwp 4

NSMTIO: kcbimd: nblks 13328 kcbstt 13276 kcbpnb 66382 kcbisdbfc 3 is_medium 0

NSMTIO: kcbcmt1: hit age_diff adjts last_ts nbuf nblk has_val kcbisdbfc cache_it 0
280021454 280021454 512958 13328 1 0 1

NSMTIO: kcbivlo: nblks 13328 vlot 500 pnb 663828 kcbisdbfc 0 is_large 0

NSMTIO: qertbFetch:[MTT < OBJECT_SIZE < VLOT]: Checking cost to read from caches(local/
remote) and checking storage reduction factors (OLTP/EHCC Comp)

NSMTIO: kcbdpc:NoDirectRead:[CACHE_READ]: tsn: 7, objd: 46429, objn: 46429

ckpt: 0, nblks: 13328, ntcache: 13328, ntdist:0

Direct Path for pdb 0 tsn 7  objd 46429 objn 46429

Direct Path 0 ckpt 0, nblks 13328 ntcache 13328 ntdist 0

Direct Path mndb 0 tdiob 13 txiob 0 tciob 19

Direct path diomrc 128 dios 2 kcbisdbfc 0

NSMTIO: Additional Info: VLOT=3319140

Object# = 46429, Object_Size = 13328 blocks

SqlId = ghfymk6a2nkkm, plan_hash_value = 3246516050, Partition# = 0
```

SGA size

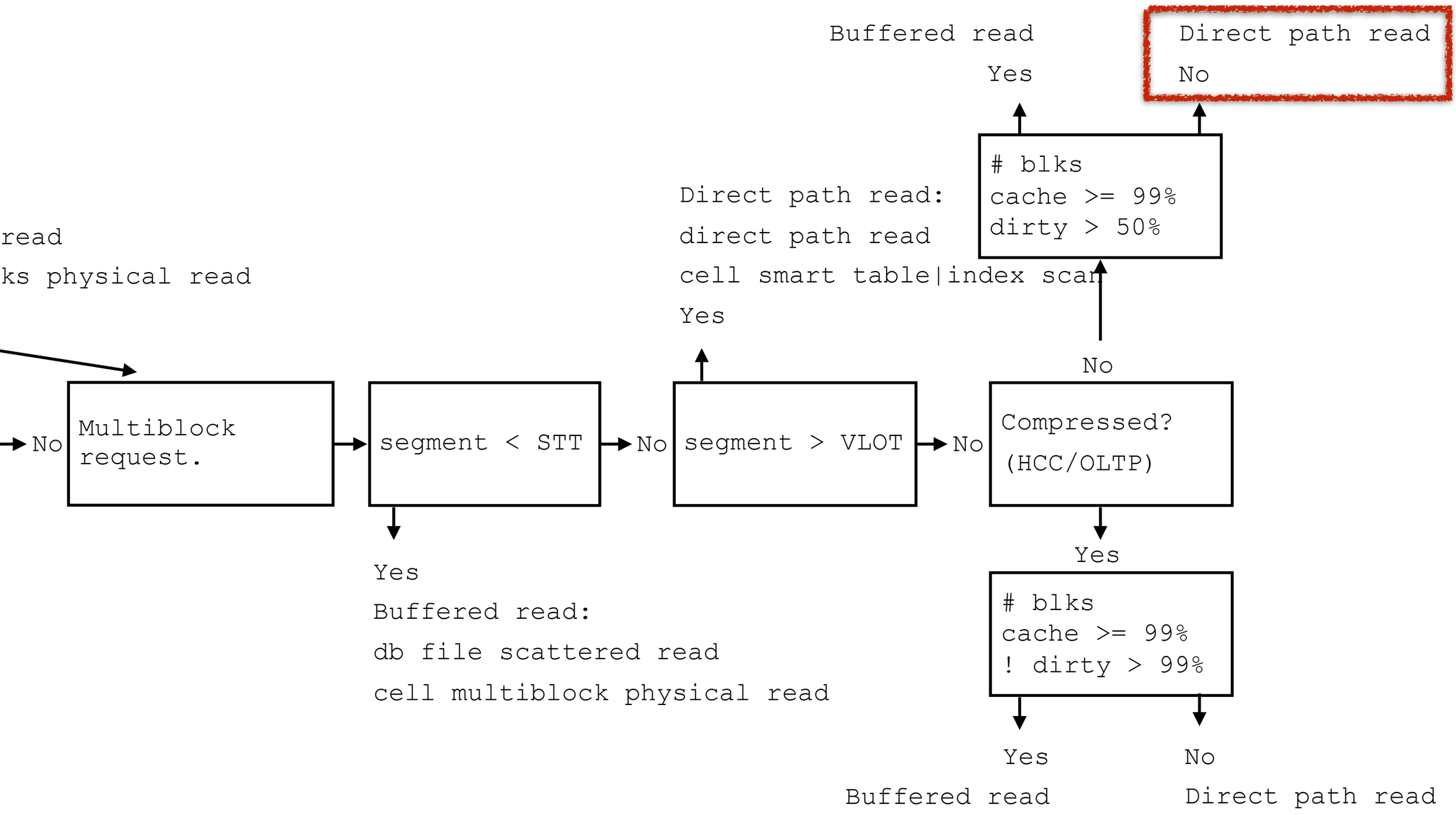

Buffered read
Yes
Direct path read
No
blks
cache >= 99%
dirty > 50%
Direct path read:
direct path read
cell smart table|index scan
Yes
read
ks physical read
No
Multiblock request.
segment < STT
No
segment > VLOT
No
Compressed? (HCC/OLTP)
No
Yes
Yes
Buffered read:
db file scattered read
cell multiblock physical read
blks
cache >= 99%
! dirty > 99%
Yes
No
Buffered read
Direct path read

SGA size

- Large table (226.384 blocks)

```
NSMTIO: kcbism: islarge 1 next 0 nblks 226384 type 2, bpid 3, kcbisdbfc 0 kcbnhl 65536
kcbstt 13276 keep_nb 0 kcbnbh 512958 kcbnwp 4
NSMTIO: kcbimd: nblks 226384 kcbstt 13276 kcbpnb 66382 kcbisdbfc 3 is_medium 0
NSMTIO: kcbivlo: nblks 226384 vlot 500 pnb 663828 kcbisdbfc 0 is_large 0
NSMTIO: qertbFetch:[MTT < OBJECT_SIZE < VLOT]: Checking cost to read from caches(local/
remote) and checking storage reduction factors (OLTP/EHCC Comp)
NSMTIO: kcbdpc:DirectRead: tsn: 7, objd: 21540, objn: 21540
ckpt: 1, nblks: 226384, ntcache: 1, ntdist:0
Direct Path for pdb 0 tsn 7  objd 21540 objn 21540
Direct Path 1 ckpt 1, nblks 226384 ntcache 1 ntdist 0
Direct Path mndb 0 tdiob 13 txiob 0 tciob 19
Direct path diomrc 128 dios 2 kcbisdbfc 0
NSMTIO: Additional Info: VLOT=3319140
Object# = 21540, Object_Size = 226384 blocks
SqlId = 71ppm0a6g1ysx, plan_hash_value = 4220890033, Partition# = 0
```

SGA size


read
ks physical read
No
Multiblock request.
segment < STT
No
segment > VLOT
No
Compressed? (HCC/OLTP)
No
Yes
blks
cache >= 99%
! dirty > 99%
Yes
No
Yes
Buffered read
No
Direct path read
Buffered read
Yes
Direct path read
No
Direct path read:
direct path read
cell smart table|index scan
Yes
blks
cache >= 99%
dirty > 50%
Yes
Buffered read:
db file scattered read
cell multiblock physical read

	Direct path threshold	Table > STT & < 5 * STT	Table > 5 * STT uncompressed buffered	Table > 5 * STT OLTP comp. buffered
11.2.0.1	5 * STT	-	> 99% or > 75% dirty	> 99% and ! 99% dirty
11.2.0.2	5 * STT	-	> 99% or > 75% dirty	> 99% or > 99% dirty
11.2.0.3	STT	Always direct path	> 99% or > 50% dirty	> 99% or > 99% dirty
11.2.0.4	STT	Always direct path	> 99% or > 50% dirty	> 99% or > 99% dirty
12.1.0.1	STT	Always direct path	> 99% or > 50% dirty	> 99% and ! 99% dirty
12.1.0.2	STT	Always direct path	> 99% or > 50% dirty	> 99% and ! 99% dirty

SGA conclusion

- You should use manual or ASMM memory.
  - Even for the ASM instance(!)
    - MOS note: 1373255.1
- SGA should use huge pages.
- Buffer cache size determines buffering decision.
  - Segment must be big enough for direct path.
    - Only direct path is considered for smartscan!
    - This means a buffercache too big can exclude segments from being smartscanned!

SGA conclusion

- With ASMM and manual memory SGA size is static.
- With AMM, shared memory granules are deflated/ inflated based on need and PGA usage.
  - On best effort (!).
  - Please don’t use AMM.

PGA

- PGA works the same way with all memory models.
  - PGA memory is **private** to the process.
- By default, PGA memory allocations are:
  - done with the mmap().
    - Anonymous memory mapping.
    - Copy on write.

- This can be seen in maps & smaps.

PGA

```
$ cat /proc/19735/maps
.. snippet ..
3bb5c00000-3bb5c16000 r-xp 00000000 fc:00 150740          /lib64/libnsl-2.12.so
3bb5c16000-3bb5e15000 ---p 00016000 fc:00 150740          /lib64/libnsl-2.12.so
3bb5e15000-3bb5e16000 r--p 00015000 fc:00 150740          /lib64/libnsl-2.12.so
3bb5e16000-3bb5e17000 rw-p 00016000 fc:00 150740          /lib64/libnsl-2.12.so
3bb5e17000-3bb5e19000 rw-p 00000000 00:00 0
7fd18198f000-7fd1819cf000 rw-p 00000000 00:00 0
7fd1819cf000-7fd181a8f000 rw-p 00000000 00:00 0
7fd181a8f000-7fd181b7f000 rw-p 00000000 00:00 0
7fd181b7f000-7fd181b8f000 rw-p 00000000 00:00 0
7fd181b8f000-7fd181c0f000 rw-p 00000000 00:00 0
7fd181c0f000-7fd181d95000 r-xp 00000000 fc:02 11036576    /u01/../lib/libshpkavx12.so
7fd181d95000-7fd181f94000 ---p 00186000 fc:02 11036576    /u01/../lib/libshpkavx12.so
7fd181f94000-7fd181fa6000 rw-p 00185000 fc:02 11036576    /u01/../lib/libshpkavx12.so
.. snippet ..
```

PGA

- Dump PGA allocations:

```
SYS@fv12102 AS SYSDBA> oradebug setospid 19735
Oracle pid: 22, Unix process pid: 19735, image: oracle@bigmachine.local (TNS V1-V3)
SYS@fv12102 AS SYSDBA> oradebug unlimit
Statement processed.
SYS@fv12102 AS SYSDBA> oradebug dump heapdump 1
Statement processed.
```

PGA

- Let’s look inside the dump:

```
$ grep -e ^HEAP -e ^Total -e ^EXTENT fv12102_ora_19735.trc
HEAP DUMP heap name="pga heap"  desc=0x7fd182686980
EXTENT 0 addr=0x7fd181aff010
..
EXTENT 35 addr=0x7fd182339b60
Total heap size    =   633576
Total free space   =    29696
HEAP DUMP heap name="top call heap"  desc=0x7fd18268cb80
EXTENT 0 addr=0x7fd181aef008
Total heap size    =   393072
Total free space   =   390248
HEAP DUMP heap name="top uga heap"  desc=0x7fd18268cda0
EXTENT 0 addr=0x7fd181b4f008
Total heap size    =   917264
Total free space   =   146944
```

PGA

- Watch what happens if you compare the heap dump with v$sesstat:

```
SYS@fv12102 AS SYSDBA> @pga 66
current pga: 979464
current uga: 413720
```

```
$ grep -e ^HEAP -e ^Total fv12102_ora_4570.trc
HEAP DUMP heap name="pga heap"  desc=0x7f8ebf3eb980
Total heap size    =   585096
Total free space   =    16392
HEAP DUMP heap name="top call heap"  desc=0x7f8ebf3f1b80
Total heap size    =    65512
Total free space   =    63000
HEAP DUMP heap name="top uga heap"  desc=0x7f8ebf3f1da0
Total heap size    =   327560
Total free space   =        0
```

PGA

- From a tuning perspective, the PGA consists of two types of memory:
  - Tunable memory.
  - Untunable memory.

PGA

- Tunable memory is:
  - Effectively the workarea's:
    - SORT, HASH JOIN, GROUP BY, BUFFER
    - BITMAP MERGE, BITMAP CONSTRUCTION

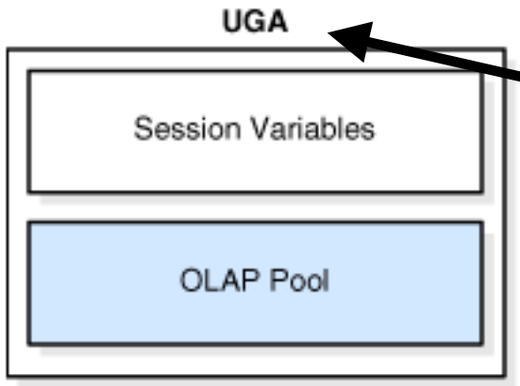
- These are tuned by PGA_AGGREGATE_TARGET
- Workarea’s are allocated in:

  UGA (session heap in the top uga heap)

PGA

- Documentation describing UGA:

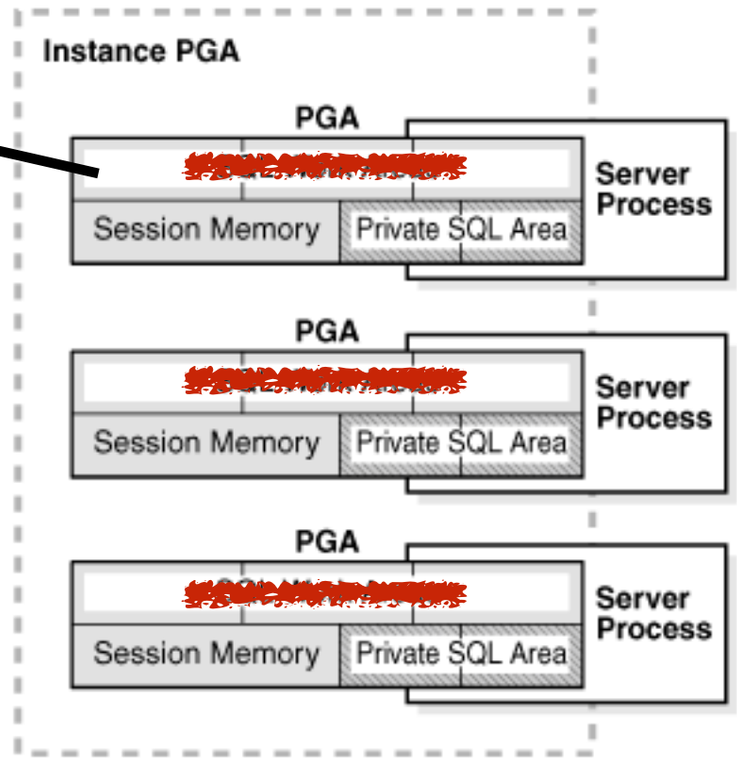
Figure 14-2 User Global Area (UGA)



Description of "Figure 14-2 User Global Area (UGA)"

- Documentation describing PGA:

Figure 14-3 Instance PGA



Description of "Figure 14-3 Instance PGA"

http://docs.oracle.com/database/121/CNCPT/memory.htm#CNCPT1238

PGA

- Untunable memory is:
  - Session information.
  - Private SQL area:
    - Cursor information, cursor state, PLSQL state, variables, PLSQL variables.

- Essentially the PGA memory allocations.

PGA

- For tunable memory area's
  - _pga_max_size: 200M > 20% P_A_T
  - _smm_(px_)max_size: 10% (50%)

- Tuning works well, buffers can be sized based on PGA memory pressure.
- Easy to flush contents to/from disk.

PGA - assoc. array

- Untunable allocations:

```
(dioncho_pga_filler.sql)

declare
 type vc2_ar is table of varchar2(32767) index by pls_integer;
 vc vc2_ar;
 v varchar2(32767);
begin
 for idx in 1 .. 30000 loop
   v := rpad('x',32767,'x');
   vc(idx) := v;
 end loop;
end;
/
```

PGA - assoc. array

- Untunable allocations:

```
SYS@fv12102 AS SYSDBA> @dioncho_pga_filler
begin pga size : 3273224
begin uga size : 1037704
end   pga size : 920252936
end   uga size : 1109312
parameter pat  : 524288000

PL/SQL procedure successfully completed.
```

PGA - open cursors

- Untunable allocations:

```
(oc_simplified.sql)

create or replace procedure recursive_open_cursor( p_number in number )
as
 l_cursor sys_refcursor;
begin
 if ( p_number = 0 ) then
  dbms_lock.sleep(120);
  return;
 end if;
 open l_cursor for select count(*) from dual;
 recursive_open_cursor(p_number-1);
 close l_cursor;
end;
/
```

PGA - open cursors

- Memory allocated after logging on:

```
SYS@fv12102 AS SYSDBA> @pga 66
current pga: 1110536
current uga: 348232
```

- Run oc_simplified.sql in session with sid 66:

```
TS@fv12102 > exec recursive_open_cursor( 900 );
.. session waiting in dbms_lock.sleep ..
```

- Memory allocated with 900 cursors:

```
SYS@fv12102 AS SYSDBA> @pga 66
current pga: 27128328
current uga: 22155736
```

PGA - open cursors

- Of course this can be tested with multiple connections:

```
T=0
while [ $T -lt 100 ]; do
    sqlplus ts/ts << EOF &
    exec recursive_open_cursor( 900 );
EOF
    let T=$T+1
    sleep 0.3
done
echo “done."
```

PGA - open cursors

- This gotten me some interesting results.
  - First of all, it lead to failure messages:

```
(screen output while running the load script)

TS@fv12102 > TS@fv12102 > TS@fv12102 > TS@fv12102 > TS@fv12102 > TS@fv12102 > BEGIN
recursive_open_cursor( 900 ); END;

*
ERROR at line 1:
ORA-03113: end-of-file on communication channel
Process ID: 16049
Session ID: 32 Serial number: 32745
```

PGA - open cursors

- The root cause is Oracle 12’s new PGA limit parm:
  - PGA_AGGREGATE_LIMIT

(alert_fv12102.log)

```
Tue Mar 03 14:39:58 2015
PGA memory used by the instance exceeds PGA_AGGREGATE_LIMIT of 2048 MB
Immediate Kill Session#: 330, Serial#: 5840
Immediate Kill Session: sess: 0x9522fac8  OS pid: 15917
Tue Mar 03 14:41:36 2015
PGA memory used by the instance exceeds PGA_AGGREGATE_LIMIT of 2048 MB
Immediate Kill Session#: 13, Serial#: 49196
Immediate Kill Session: sess: 0x95727268  OS pid: 15923
```

PGA - open cursors

- PGA_AGGREGATE_LIMIT default value:
  - The greater of:
    - 200% of PGA_AGGREGATE_TARGET.
    - 3MB * PROCESSES.
    - 2 GB.
  - Can be below 200% PAT if:
    - PAT > 90% TotMem-SGA, but minimal 100% PAT.

- In order to ignore this, I set P_A_L to 20G.

PGA - open cursors

- I ran the 100 sessions again.
  - The server started swapping.
  - Oracle will tell you if the system is swapping:

```
(alert_fv12102.log)
Tue Mar 03 14:46:49 2015
WARNING: Heavy swapping observed on system in last 5 mins.
pct of memory swapped in [38.06%] pct of memory swapped out [9.74%].
Please make sure there is no memory pressure and the SGA and PGA
are configured correctly. Look at DBRM trace file for more details.
Errors in file /u01/app/oracle/diag/rdbms/fv12102/fv12102/trace/fv12102_dbrm_14757.trc
(incident=58464):
ORA-00700: soft internal error, arguments: [kskvmstatact: excessive swapping observed],
[], [], [], [], [], [], [], [], [], []
Incident details in: /u01/app/oracle/diag/rdbms/fv12102/fv12102/incident/incdir_58464/
fv12102_dbrm_14757_i58464.trc
```

PGA - open cursors

- Once the sessions have logged on.
  - …and fetched their cursors….
- This is my PGA_AGGREGATE_TARGET:

```
SYS@fv12102 AS SYSDBA> select value/power(1024,2) from v$pgastat
where name = 'aggregate PGA target parameter';
VALUE/POWER(1024,2)
-------------------
                500
```

- This is the true allocated PGA memory:

```
SYS@fv12102 AS SYSDBA> select value/power(1024,2) from v$pgastat
where name = 'total PGA allocated';
VALUE/POWER(1024,2)
-------------------
          2208.83203
```

PGA_AGGREGATE_LIMIT

- SYS and background processes* are **not** subject to the limit.
- The limiting is not “absolute”.

- Let’s test this:
  - I set PGA_AGGREGATE_LIMIT to 600M.
  - And run dioncho_pga_filler.sql again.

PGA_AGGREGATE_LIMIT

- Result (pga_aggregate_limit set to 600m):

```
TS@fv12102 > @dioncho_pga_filler
error message  : ORA-04036: PGA memory used by the instance exceeds PGA_AGGREGATE_LIMIT
begin pga size : 2748936
begin uga size : 1298312
end   pga size : 967242248
end   uga size : 1633176
parameter pat  : 524288000

PL/SQL procedure successfully completed.
```

PGA_AGGREGATE_LIMIT

- The alert.log includes the ORA-4036:

```
Tue Mar 03 20:06:31 2015
Errors in file /u01/app/oracle/diag/rdbms/fv12102/fv12102/trace/fv12102_ora_27060.trc
(incident=63384):
ORA-04036: PGA memory used by the instance exceeds PGA_AGGREGATE_LIMIT
Incident details in: /u01/app/oracle/diag/rdbms/fv12102/fv12102/incident/incdir_63384/
fv12102_ora_27060_i63384.trc
```

- The process trace file shows a little more:

```
$ grep -e ^Process -e Just -e ^sending /u01/app/oracle/diag/rdbms/fv12102/fv12102/trace/
fv12102_ora_27060.trc
Process may have gone over pga_aggregate_limit
Just allocated 65536 bytes
Process may have gone over pga_aggregate_limit
Just allocated 65536 bytes
Process may have gone over pga_aggregate_limit
Just allocated 65536 bytes
sending 4036 interrupt
```

PGA_AGGREGATE_LIMIT

- Let’s run recursive_open_cursor(900) again.
  - Run with 33 sessions:

```
SYS@fv12102 AS SYSDBA> select name, value from v$pgastat
where name in ('aggregate PGA target parameter','total PGA allocated');

NAME                                                             VALUE
---------------------------------------------------------------- ----------
aggregate PGA target parameter                                   524288000
total PGA allocated                                              987976704
```

- PGA allocated memory grew to 987M.
  - PGA_AGGREGATE_LIMIT=600 ??

PGA_AGGREGATE_LIMIT

- There's a MOS note: 1520324.1:
  - Limiting process size with database parameter PGA_AG
  - "The PAL initialisation parameter enables you to specify a hard limit on PGA memory usage".
- The background process CKPT checks every three seconds wether the amount of memory exceeds..

hard limit…yea right

Ah…so starting sessions 3 seconds after each other should be limited correctly!

PGA_AGGREGATE_LIMIT

- Let's re-run recursive_open_cursor(900).
  - Include a sleep 3.
  - Run with 33 sessions again:

```
SYS@fv12102 AS SYSDBA> select name, value from v$pgastat
where name in ('aggregate PGA target parameter','total PGA allocated');

NAME                                                             VALUE
---------------------------------------------------------------- ----------
aggregate PGA target parameter                                   524288000
total PGA allocated                                              985552896
```

- PGA allocated memory **still** grew to 987M.
  - PGA_AGGREGATE_LIMIT=600!

PGA_AGGREGATE_LIMIT

- Further testing with recursive_open_cursor(900):
  - ORA-4036 kicked in at approx. 1010M.
  - 1010/600*100=168% !!

PGA_AGGREGATE_LIMIT

- Extra information
  - Bug 20992304 (non-public)
  - pga_aggregate_limit internally adjusted because user-specified value is below the minimum. However, show parameter does not reflect this. And no error returned to user.
- Bug 19820445 (public)
- SHOW PARAMETER PGA_AGGREGATE_LIMIT CAN NOT SHOW THE REAL VALUE

PGA limit before 12c

- Oracle introduced an event in their white paper on ‘Exadata consolidation best practices’.
  - event 10261.
  - Limit the size of the PGA heap.
  - To be able to limit PGA usage before Oracle 12c.
  - *undocumented event.*
  - Level is amount of kilobytes for the size limit.

```
SYS@fv12102 AS SYSDBA>
alter system set event = '10261 trace name context forever, level nnnn' scope=spfile;
```

PGA limit before 12c

- Testing event 10261:
  - Works on (at least) 11.2.0.4 - 11.2.0.1.
  - Is more hard limiting: Acted on PGA size 677M.
    - ALL processes subject to limit (including SYS).
    - *Is a process level limit, not an instance level limit!*
- Hitting limit:
  - version 11.2.0.4: ORA-10260 limit size n of the ..
  - < version 11.2.0.4: ORA-00600 [723], [alloc size], [top uga heap]

PGA Conclusion

- PGA memory is needed for every process.
  - A lot of the per process memory needed can **not** be tuned.
  - Actual PGA memory used is untunable memory required times number of processes.
- Untunable memory usage includes:
  - Number of open cursors, variables, arrays, collections, PL/SQL elements.

PGA Conclusion

- PGA_AGGREGATE_TARGET tunes workarea sizing.
- **Actual usage of PGA can be different from P_A_T, which means way less or way more.**

- Do not use PGA_AGGREGATE_TARGET for the intention of sizing.
  - Exception might be low connection count, high sort/hash/bitmap using connections (data warehouse).

PGA Conclusion

- With 12c, there's PGA_AGGREGATE_LIMIT.
  - Limits, but not as you would expect.
  - Kicks in rather late in my tests (168%).
  - Once limit is hit, sessions which get ORA-4036 seem quite random to me.
  - The limiting acts on PGA allocation.

PGA Conclusion

- Pre 12c, event 10261 could be used
  - This event is a limit on the *per process* PGA size.
  - All sessions are subject to this limit, incl. SYS.
  - Does not prevent excess PGA allocation due to huge number of connections.
  - If you need this, ask blessing from support.
  - Limited usability, more last resort type solution.

Q&A

Thank you for attending!

- Thanks:
  - Jason Arniel, Tanel Poder, Martin Bach, KJ Jongsma, Enkitec.

- Non-used slides after this point.

Hugepages

- 11.2.0.1
  - Set vm.nr_hugepages
  - Startup database
  - Either all is in hugepages, or not.
  - Watch /proc/meminfo

Hugepages

- 11.2.0.2
  - Set vm.nr_hugepages
  - Startup database
  - Either all is in hugepages, or not.
  - Look in alert.log:

```
Starting ORACLE instance (normal)
******************** Huge Pages Information *****************
Huge Pages memory pool detected (total: 1030 free: 1030)
Memlock limit too small: 65536 to accommodate segment size: 1050673152
Huge Pages allocation failed (free: 1030 required: 501)
Allocation will continue with default/smaller page size
*************************************************************
```

Hugepages

- 11.2.0.2
  - Set vm.nr_hugepages
  - Startup database
  - Either all is in hugepages, or not.
  - Look in alert.log:

```
Starting ORACLE instance (normal)
******************** Huge Pages Information *****************
Huge Pages memory pool detected (total: 1030 free: 1030)
DFLT Huge Pages allocation successful (allocated: 501)
************************************************************
```

Hugepages

- 11.2.0.3 / 11.2.0.4 / 12.1.0.1
  - Set vm.nr_hugepages
  - Startup database
  - Look in alert.log:

```
Starting ORACLE instance (normal)
****************** Large Pages Information *****************
Total Shared Global Region in Large Pages = 1002 MB (100%)

Large Pages used by this instance: 501 (1002 MB)
Large Pages unused system wide = 529 (1058 MB) (alloc incr 4096 KB)
Large Pages configured system wide = 1030 (2060 MB)
Large Page size = 2048 KB
************************************************************
```

Hugepages

- 11.2.0.3 / 11.2.0.4 / 12.1.0.1
  - Mixed normal and huge pages usage:

```
Starting ORACLE instance (normal)
******************** Large Pages Information *****************
Total Shared Global Region in Large Pages = 600 MB (59%)
Large Pages used by this instance: 300 (600 MB)
Large Pages unused system wide = 0 (0 KB) (alloc incr 4096 KB)
Large Pages configured system wide = 300 (600 MB)
Large Page size = 2048 KB
RECOMMENDATION:
  Total Shared Global Region size is 1002 MB. For optimal performance,
  prior to the next instance restart increase the number
  of unused Large Pages by atleast 201 2048 KB Large Pages (402 MB)
  system wide to get 100% of the Shared
  Global Region allocated with Large pages
***********************************************************
```

Hugepages

- 12.1.0.2

```
Dump of system resources acquired for SHARED GLOBAL AREA (SGA)
Mon Jan 12 01:39:17 2015
 Per process system memlock (soft) limit = 227G
Expected per process system memlock (soft) limit to lock
 SHARED GLOBAL AREA (SGA) into memory: 2050M
Available system pagesizes:
  4K, 2048K
Supported system pagesize(s):
 PAGESIZE  AVAILABLE_PAGES  EXPECTED_PAGES  ALLOCATED_PAGES  ERROR(s)
Mon Jan 12 01:39:17 2015
        4K       Configured               3                3        NONE
Mon Jan 12 01:39:17 2015
     2048K             1030            1025             1025        NONE
Mon Jan 12 01:39:17 2015
********************************************************************************
```

Hugepages

- 12.1.0.2

```
Dump of system resources acquired for SHARED GLOBAL AREA (SGA)
Per process system memlock (soft) limit = 227G
Expected per process system memlock (soft) limit to lock
 SHARED GLOBAL AREA (SGA) into memory: 2050M
Available system pagesizes:
  4K, 2048K
Supported system pagesize(s):
 PAGESIZE  AVAILABLE_PAGES  EXPECTED_PAGES  ALLOCATED_PAGES  ERROR(s)
       4K       Configured               3           220472        NONE
    2048K              600            1025              594        NONE
RECOMMENDATION:
1. For optimal performance, configure system with expected number
 of pages for every supported system pagesize prior to the next
 instance restart operation.
Mon Jan 12 02:08:54 2015
**********************************************************************
```

v$process_memory_detail

- Populate v$process_memory_detail:
- Get PID of the session to get memory details on.

```
select pid from v$process p, v$session s where s.paddr=p.addr and s.sid = nn;
```

- Issue alter session (as sys):

```
alter session set events 'immediate trace name pga_detail_get level PID';
```

- Clean up v$process_memory_detail:

```
alter session set events 'immediate trace name pga_detail_cancel level PID';
```

- Might require execution in the session to get v $process_memory_detail loaded.

Memory models

- With all 3 memory models:
  - PGA is allocated in the process' address space.
  - Private.

Virtual memory

- In order to understand memory management, a little OS theory is needed.
- Linux (and the major Unixes) use Virtual Memory.

Virtual memory

- Virtual memory means each process sees memory as a contiguous address space.
- By default, all memory is private.
- The CPU's memory management unit (MMU) translates virtual to real memory addresses.
- Virtual memory also means the storage of memory pages could be disk instead of RAM memory.

Virtual memory

- An overview of a process' address space is in:
  - /proc/<PID>/maps
- Let's look at an example: myself looking in maps with the 'cat'.

Virtual memory

```
$ cat /proc/self/maps
00400000-0040b000 r-xp 00000000 fc:00 328                /bin/cat
0060a000-0060b000 rw-p 0000a000 fc:00 328                /bin/cat
0060b000-0060c000 rw-p 00000000 00:00 0
0080a000-0080b000 rw-p 0000a000 fc:00 328                /bin/cat
01e38000-01e59000 rw-p 00000000 00:00 0                  [heap]
3bb3000000-3bb3020000 r-xp 00000000 fc:00 134595         /lib64/ld-2.12.so
3bb321f000-3bb3220000 r--p 0001f000 fc:00 134595         /lib64/ld-2.12.so
3bb3220000-3bb3221000 rw-p 00020000 fc:00 134595         /lib64/ld-2.12.so
3bb3221000-3bb3222000 rw-p 00000000 00:00 0
3bb3b8e000-3bb3b8f000 rw-p 0018e000 fc:00 134689         /lib64/libc-2.12.so
3bb398a000-3bb3b8a000 ---p 0018a000 fc:00 134689         /lib64/libc-2.12.so
3bb3b8f000-3bb3b94000 rw-p 00000000 00:00 0
7f71680d7000-7f71680da000 rw-p 00000000 00:00 0
7f71680e4000-7f71680e5000 rw-p 00000000 00:00 0
7fff43133000-7fff43154000 rw-p 00000000 00:00 0            [stack]
7fff431fb000-7fff431fd000 r-xp 00000000 00:00 0            [vdso]
ffffffffff600000-ffffffffff601000 r-xp 00000000 00:00 0    [vsyscall]
```

Virtual memory

- Modern OS’es make very smart use of executables and libraries.
  - Only one copy is used whenever possible.
  - Usage is Copy On Write (COW).

Virtual memory

- How much memory does my process use?
  - cat /proc/self/maps
- The correct answer is:

Virtual memory

Not enough information is provided at the process level to make an exact calculation.

Virtual memory

- As you might have guessed, all the smartness of sharing means true usage gets a bit unclear.
  - …And we didn't even look at Oracle yet (!!)

- To understand what I mean, look at:
  - /proc/<PID>/status

Virtual memory

```
$ cat /proc/self/status
…
VmPeak:      100988 kB
VmSize:      100988 kB
VmLck:            0 kB
VmPin:            0 kB
VmHWM:          484 kB
VmRSS:          484 kB
VmData:         184 kB
VmStk:          136 kB
VmExe:           44 kB
VmLib:         1704 kB
VmPTE:           52 kB
VmSwap:           0 kB
Threads:          1
…
```

VmSize: Total allocated and mmapped memory. “total visible in use memory”. Both shared and non-shared.

VmRSS: Resident Set Size: All memory truly used (“touched”). Both shared and non-shared.

Automatic memory management

- AMM can’t use *hugepages.*

- This disqualifies the usage of AMM for anything serious.

- Don’t use AMM.
  - Unless you got a valid reason.

Hugepages

- O/S facility
  - Memory managed per 2M instead of 4kB (page).
  - Hugepages are non-swappable.
  - Significant reduction in CPU usage.
  - Potentially severe reduction in pagetable memory allocations.
- If you are not using hugepages and are doing anything serious, you are doing it wrong!

Hugepages

- Only SGA can be stored in hugepages.
- Hugepages are reserved at startup.
  - /proc/sys/vm/nr_hugepages - vm.nr_hugepages
  - Can be modified after startup.
  - Only non-fragmented memory can be reassigned to be used as huge pages.
  - You can do severe damage by allocating too much.

Hugepages

- The database side
  - Parameter:
    - use_large_pages (>= 11.2.0.2)
      - » TRUE (default)
      - » ONLY
      - » FALSE

Hugepages

- 11.2.0.1
  - Set vm.nr_hugepages
  - Startup database
  - Either all is in hugepages, or not.
  - Watch /proc/meminfo

Hugepages

- 11.2.0.2
  - Set vm.nr_hugepages
  - Startup database
  - Either all is in hugepages, or not.
  - Look in alert.log:

```
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```

Hugepages

- 11.2.0.2
  - Set vm.nr_hugepages
  - Startup database
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************************************************************
```

Hugepages

- 11.2.0.3 / 11.2.0.4 / 12.1.0.1
  - Set vm.nr_hugepages
  - Startup database
  - Look in alert.log:

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Starting ORACLE instance (normal)
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Total Shared Global Region in Large Pages = 1002 MB (100%)

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Large Pages unused system wide = 529 (1058 MB) (alloc incr 4096 KB)
Large Pages configured system wide = 1030 (2060 MB)
Large Page size = 2048 KB
************************************************************
```

Hugepages

- 11.2.0.3 / 11.2.0.4 / 12.1.0.1
  - Mixed normal and huge pages usage:

```
Starting ORACLE instance (normal)
******************** Large Pages Information *****************
Total Shared Global Region in Large Pages = 600 MB (59%)
Large Pages used by this instance: 300 (600 MB)
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RECOMMENDATION:
  Total Shared Global Region size is 1002 MB. For optimal performance,
  prior to the next instance restart increase the number
  of unused Large Pages by atleast 201 2048 KB Large Pages (402 MB)
  system wide to get 100% of the Shared
  Global Region allocated with Large pages
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```

Hugepages

- 12.1.0.2

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Mon Jan 12 01:39:17 2015
        4K       Configured               3                3        NONE
Mon Jan 12 01:39:17 2015
     2048K             1030            1025             1025        NONE
Mon Jan 12 01:39:17 2015
**********************************************************************
```

Hugepages

- 12.1.0.2

```
Dump of system resources acquired for SHARED GLOBAL AREA (SGA)
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RECOMMENDATION:
1. For optimal performance, configure system with expected number
 of pages for every supported system pagesize prior to the next
 instance restart operation.
Mon Jan 12 02:08:54 2015
**********************************************************************
```

Memory model

- That leaves manual and ASMM as choices.
  - Some DBAs still like to set all memory areas.
  - ASMM favourited growing the shared pool.
    - Mainly seen in version 10.2.
    - Lack of bind variables.
    - Evaporating the buffer cache.
    - Recent 11.2 versions seem to be more sensible.

Memory model

- Even without ASMM Oracle can and will resize.
  - Since 11.2.0.2.
  - See bug: 13340694.
  - Expected behaviour.

- Can be disabled by an undocumented parameter.
  - _memory_imm_mode_without_autosga

About resizes.

- If you use an SPFILE
  - Oracle records the new value of a resize:
    - <instancename>.__db_cache_size=<nr>
      - Double underscore.

- So once an instance resizes, it potentially doesn't need to go through the resize to again to reach the current (assumed ideal) size.

SGA allocation

- Aside from AMM:
  - SGA memory allocation is done at startup.
  - SGA memory allocation is static.
  - *Always* allocated as System V shared memory

- With AMM:
  - A few tiny System V shared memory segments are allocated
  - Real allocations are done in granules in /dev/shm

sysresv

- Utility provided with Oracle (8.1.5+)
  - Function:
    - Show resources used.
    - Frees system V shared resources when the instance is dead.

sysresv

- shows (running sysresv without any arguments):
  - Kernel settings for shmmax,shmall,shmmni
  - Output of ‘ipcs -a’
  - Output of ‘ulimit -a’
  - /dev/shm (*tmpfs - AMM!*) usage

  - Shared memory segments of $ORACLE_SID
  - Semaphore sets of $ORACLE_SID

sysresv

```
[oracle@bigmachine [v12102] bin]$ sysresv

IPC Resources for ORACLE_SID "v12102" :
Maximum shared memory segment size (shmmax): 4398046511104 bytes
Total system shared memory (shmall): 17592186044416 bytes
Total system shared memory count (shmmni): 4096
********************** Dumping ipcs output **********************

------ Shared Memory Segments --------
key        shmid      owner      perms      bytes      nattch     status
0x00000000 104464384  oracle     640        4096       0
0x00000000 104497153  oracle     640        4096       0
0xb92c57c8 104529922  oracle     640        24576      22
0x00000000 292159491  oracle     640        4194304    69
0x00000000 292192260  oracle     640        1241513984 69
0x00000000 292225029  oracle     640        754974720  69
0x00000000 292257798  oracle     640        148066304  69
0x240b65ec 292290567  oracle     640        12288      69
```

sysresv

```
------ Semaphore Arrays --------
key        semid      owner      perms      nsems
0x77aeec14 229378     oracle     640        142
0x77aeec15 262147     oracle     640        142
0x77aeec16 294916     oracle     640        142
0x017b884c 1605637    oracle     640        104

------ Message Queues --------
key        msqid      owner      perms      used-bytes   messages

********************** End of ipcs command dump ***************
```

sysresv

```
****************** Dumping Resource Limits(s/h) ******************
core file size                          UNLIMITED/UNLIMITED
data seg size                           UNLIMITED/UNLIMITED
scheduling priority                          0 KB/0 KB
file size                               UNLIMITED/UNLIMITED
pending signals                             31 KB/31 KB
max locked memory                          227 GB/227 GB
max memory size                         UNLIMITED/UNLIMITED
open files                                  64 KB/64 KB
POSIX message queues                       800 KB/800 KB
real-time priority                           0 KB/0 KB
stack size                                  32 MB/32 MB
cpu time                                UNLIMITED/UNLIMITED
max user processes                          16 KB/16 KB
virtual memory                          UNLIMITED/UNLIMITED
file locks                              UNLIMITED/UNLIMITED
****************** End of Resource Limits Dump ******************
Total /dev/shm size: 914595840 bytes, used: 658268160 bytes
```

sysresv

```
Shared Memory:
ID     KEY
292192260 0x00000000
292225029 0x00000000
292257798 0x00000000
292159491 0x00000000
292290567 0x240b65ec
Semaphores:
ID     KEY
1605637   0x017b884c
Oracle Instance alive for sid "v12102"
```

sysresv

```
$ ipcs -a
```

```
Shared Memory:
ID     KEY
292192260 0x00000000
292225029 0x00000000
292257798 0x00000000
292159491 0x00000000
292290567 0x240b65ec
Semaphores:
ID     KEY
1605637   0x017b884c
Oracle Instance alive for sid "v12102"
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```
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0x00000000 292225029  oracle     640        754974720
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0x240b65ec 292290567  oracle     640        12288

------ Semaphore Arrays --------
key        semid      owner      perms      nsems
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0x77aeec15 262147     oracle     640        142
0x77aeec16 294916     oracle     640        142
0x017b884c 1605637    oracle     640        104
```

SGA summary

- Database SGA memory:
  - Should be configured as ASMM or manual mem.
  - Is static in allocated o/s space.
  - Should be “backed” by huge pages.

- This makes it easy for o/s memory planning.

PGA - O/S memory

- Modern platforms use virtual memory.
  - Virtual means every process has it's own *private* address space.
  - Process memory is not visible to other processes.

PGA - O/S memory

- Every process needs memory.
  - It needs to store the executable executing.
  - It needs to store/access (shared) libraries.
  - It needs a heap (allocated memory, variables).
  - It needs a stack (save c function state).

PGA - O/S memory

```
$ cat /proc/3257/maps
00400000-004d4000 r-xp 00000000 fc:00 156                                /bin/bash
006d4000-006dd000 rw-p 000d4000 fc:00 156                                /bin/bash
006dd000-006e3000 rw-p 00000000 00:00 0
008dc000-008e5000 rw-p 000dc000 fc:00 156                                /bin/bash
00bd3000-00c36000 rw-p 00000000 00:00 0                                  [heap]
3bb3020000 r-xp 00000000 fc:00 134595                                    /lib64/ld-2.12.so
3bb3220000 r--p 0001f000 fc:00 134595                                    /lib64/ld-2.12.so
3bb3221000-3bb3222000 rw-p 00000000 00:00 0
3bb3400000-3bb3402000 r-xp 00000000 fc:00 136676                         /lib64/libdl-2.12.so
3bb3402000-3bb3602000 ---p 00002000 fc:00 136676                         /lib64/libdl-2.12.so
3bb3602000-3bb3603000 r--p 00002000 fc:00 136676                         /lib64/libdl-2.12.so
3bb3603000-3bb3604000 rw-p 00003000 fc:00 136676                         /lib64/libdl-2.12.so
3bb3800000-3bb398a000 r-xp 00000000 fc:00 134689                         /lib64/libc-2.12.so
3bb398a000-3bb3b8a000 ---p 0018a000 fc:00 134689                         /lib64/libc-2.12.so
3bb3b8a000-3bb3b8e000 r--p 0018a000 fc:00 134689                         /lib64/libc-2.12.so
3bb3b8e000-3bb3b8f000 rw-p 0018e000 fc:00 134689                         /lib64/libc-2.12.so
```

Executable

Anonymous memory

Heap

Shared Library

PGA - O/S memory

```
...
3bb3b8f000-3bb3b94000 rw-p 00000000 00:00 0
7f6d19abd000-7f6d1f94e000 r--p 00000000 fc:00 131106    usr/lib/locale/locale-archive
7f6d1f94e000-7f6d1f951000 rw-p 00000000 00:00 0
7f6d1f95b000-7f6d1f95c000 rw-p 00000000 00:00 0
7fffc80ad000-7fffc80ce000 rw-p 00000000 00:00 0          [stack]
7fffc817c000-7fffc817e000 r-xp 00000000 00:00 0          [vdso]
ffffffffff600000-ffffffffff601000 r-xp 00000000 00:00 0 [vsyscall]
```

Stack

Virt Dyn Linked SO

Virt Syscall

PGA - O/S memory

- Accounting per process memory in Linux is hard.
  - A lot of memory is mapped (mmap()) in to process memory.
    - Some of it (executable/shared libraries) is COW.
      - Memory only allocated on change or first to use.

- Accounting per process memory in Linux is hard.

PGA - O/S memory

- You might ask yourself:

  – Why do I care?

PGA - Oracle foreground

```
00400000-1093f000 r-xp 00000000 fc:02 272770084      /u01/.../bin/oracle
10b3e000-10dbf000 rw-p 1053e000 fc:02 272770084      /u01/.../bin/oracle
10dbf000-10df0000 rw-p 00000000 00:00 0
117b3000-1181a000 rw-p 00000000 00:00 0              [heap]
60000000-60400000 rw-s 00000000 00:0b 111902723      /SYSV00000000 (deleted)
61000000-d8000000 rw-s 00000000 00:0b 111935492      /SYSV00000000 (deleted)
d8000000-e0e00000 rw-s 00000000 00:0b 111968261      /SYSV00000000 (deleted)
e1000000-e1003000 rw-s 00000000 00:04 112001030      /SYSV240b65ec (deleted)
3bb3b8f000-3bb3b94000 rw-p 00000000 00:00 0
3bb5800000-3bb581d000 r-xp 00000000 fc:00 136285     /lib64/libtinfo.so.5.7
3bb581d000-3bb5a1d000 ---p 0001d000 fc:00 136285     /lib64/libtinfo.so.5.7
3bb5a1d000-3bb5a21000 rw-p 0001d000 fc:00 136285     /lib64/libtinfo.so.5.7
7fefb3d76000-7fefb9c07000 r--p 00000000 fc:00 131106 /usr/lib/locale/locale-archive
7fefb9c07000-7fefb9c13000 r-xp 00000000 fc:00 131129 /lib64/libnss_files-2.12.so
7fefb9c13000-7fefb9e13000 ---p 0000c000 fc:00 131129 /lib64/libnss_files-2.12.so
7fefb9e13000-7fefb9e14000 r--p 0000c000 fc:00 131129 /lib64/libnss_files-2.12.so
7fefb9e14000-7fefb9e15000 rw-p 0000d000 fc:00 131129 /lib64/libnss_files-2.12.so
7fefb9e15000-7fefb9e18000 rw-p 00000000 00:00 0
```

Executable

SGA