Cray X1 System Performance

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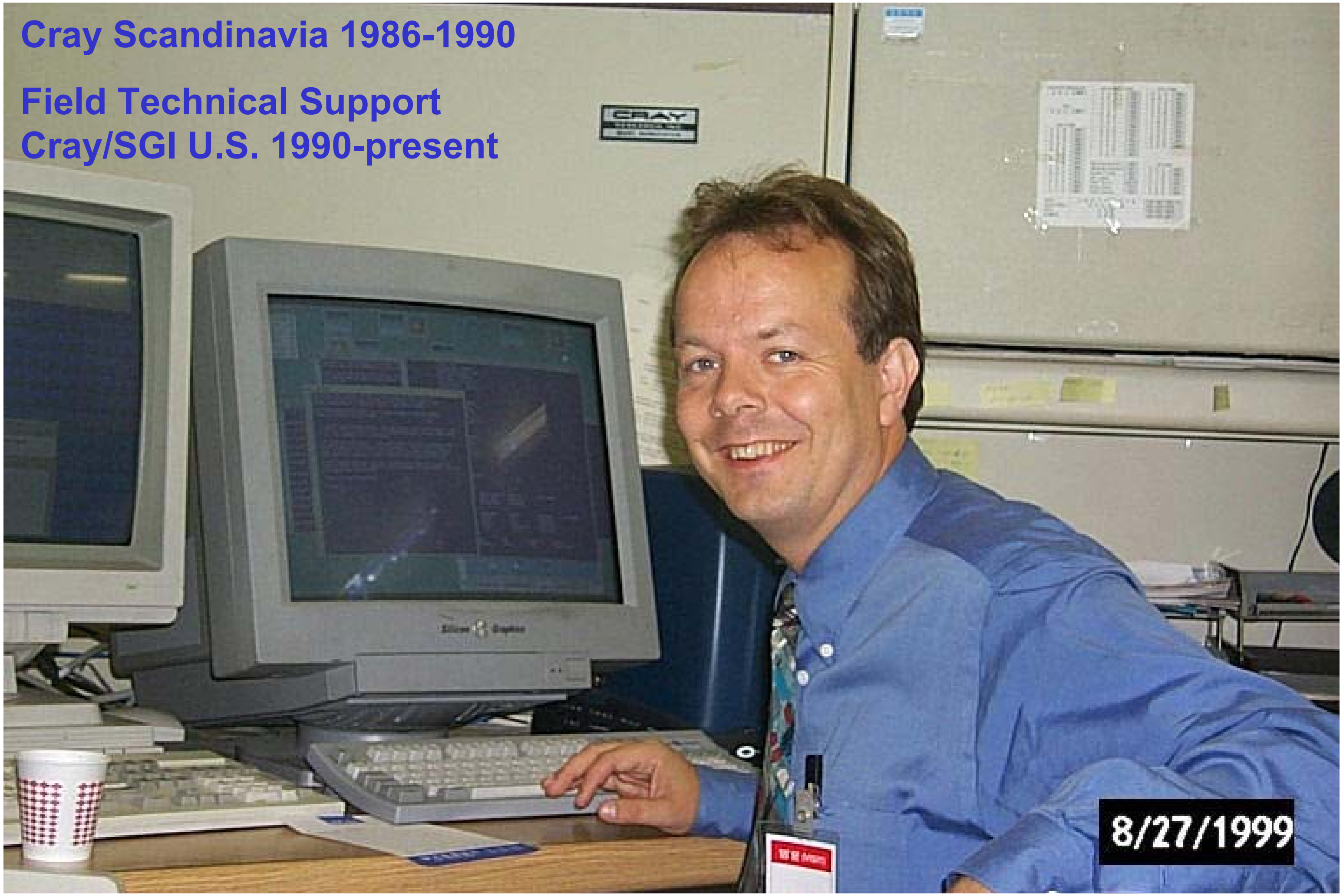
Cray X1 System Performance

About the speaker

Cray Scandinavia 1986-1990

Field Technical Support
Cray/SGI U.S. 1990-present



Cray X1 System Performance

FTS – Field Technical Support

- Software support generalists
- Preinstallation/installation support
- Travel to support Cray Field Service
- Escalations

SPS – Software Product Support

- Software support specialists
- Preinstallation/installation support
- SPR processing, SWDEV interaction
- Escalations

Part of Cray Customer Service

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Classic System Performance considerations

individual job runtime

application performance

workload throughput

user/system/idle time

transfer speeds

user code performance, optimization

scheduling configuration (psched, PBS Pro, limits)

I/O configuration and use

tunable kernel parameters

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Cray X1 I/O

Configuration

- I/O hardware configuration
- RAID configuration
- Partitioning
- XLV/XFS configuration

Usage

- User I/O
- System I/O

Monitoring

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Uncovered topics

- Monitoring details
- Swapping
  - OS node
  - APP nodes
- Oversubscription
  - CPU oversubscription
  - Memory oversubscription
- SAN configuration, performance concerns
- Networking

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Cray X1 I/O

General principles for I/O performance

- Alignment of I/O requests and file allocations
- Avoid Unix buffer cache for large files
- Large transfer sizes
  - 1Mb or more
- Utilize parallelism:
  - asynchronous I/O
  - parallel I/O streams
  - balanced distribution of I/O across available hardware

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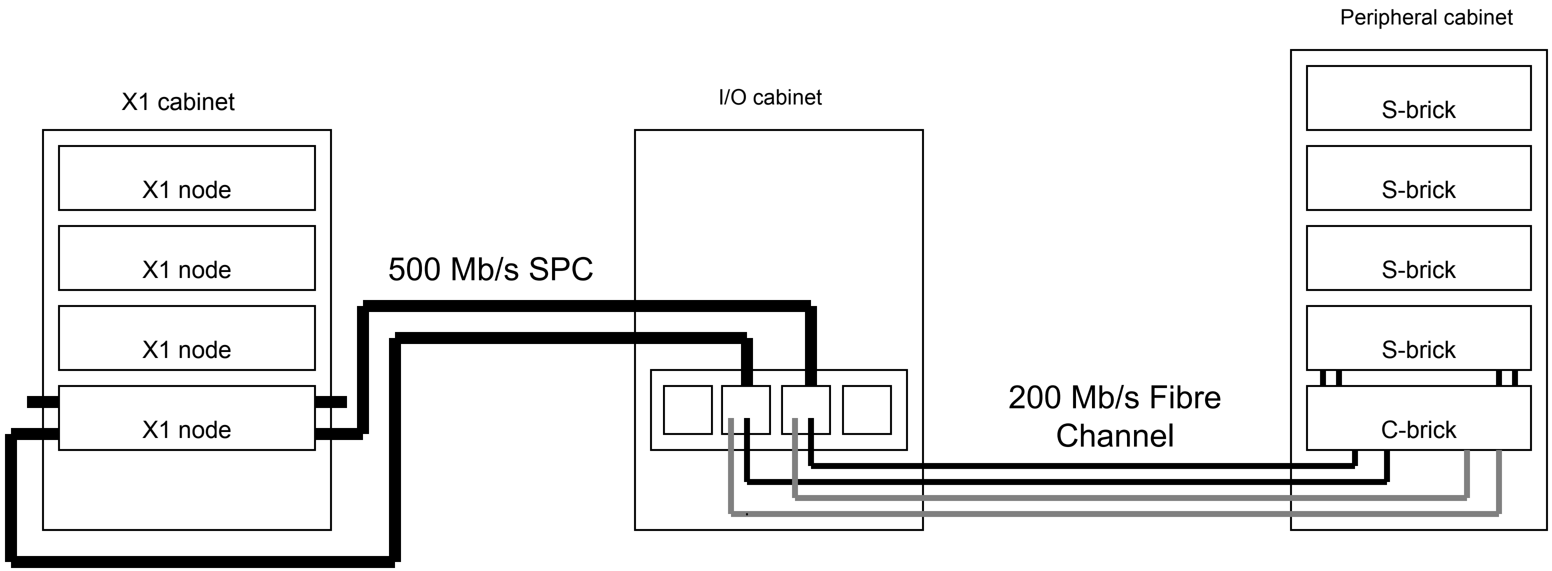
Disk cabling



Configuration determined by space, bandwidth requirements, price

Some cabling conventions and restrictions

Some bandwidth restrictions

Reflected in X1 hardware configuration file

Shipping configurations are generally balanced, symmetric

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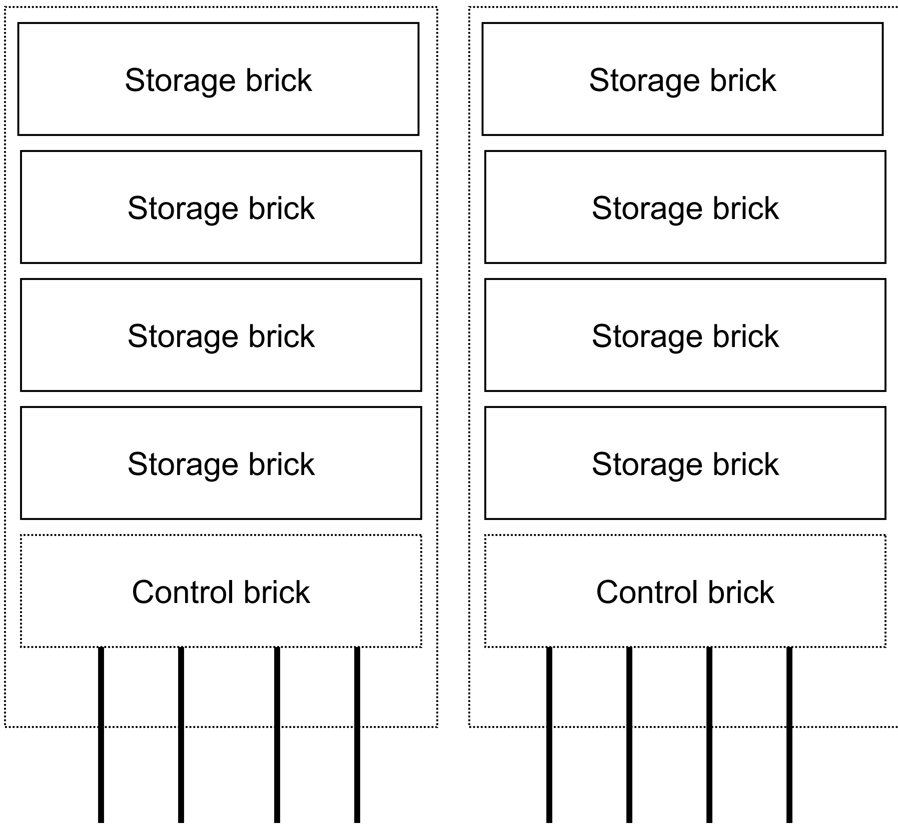
RAID configuration

Cray Storage Management (CSM)



Storage brick = 14 drives ("tray", "disk")

Each storage brick is assigned a RAID Group layout and split into LUNs

Using CSM commands for configuration rather than vendor tools

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Cray Storage Management (CSM)

Why CSM?

- **Standard interface that stays the same if the underlying RAID hardware/vendor changes**
- **Configuration control**
  - **Optimize performance for “Cray I/O”**
  - **Limited set of configurations to support/test**
  - **Control low level RAID controller parameters**
- **Maintain naming and numbering conventions**
- **Command line interface easier for remote support**
- *csmtune command initially planned for finer control*
  - *Change LUN write caching, segment sizes*

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RAID configuration

Cray Storage Management (CSM)

Prior to configuring CSM

- Collect known space requirements
- Collect known performance requirements

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RAID configuration

Cray Storage Management (CSM)

- CSM uses 'decimal' storage capacity denominations by default
  - 1 Gb = 1000 Mb
  - 1 Mb = 1000000 bytes
- Use -G option on commands to use power-of-2 values
  - 1 Gb = 1024 Mb
  - 1 Mb = 1048576 bytes

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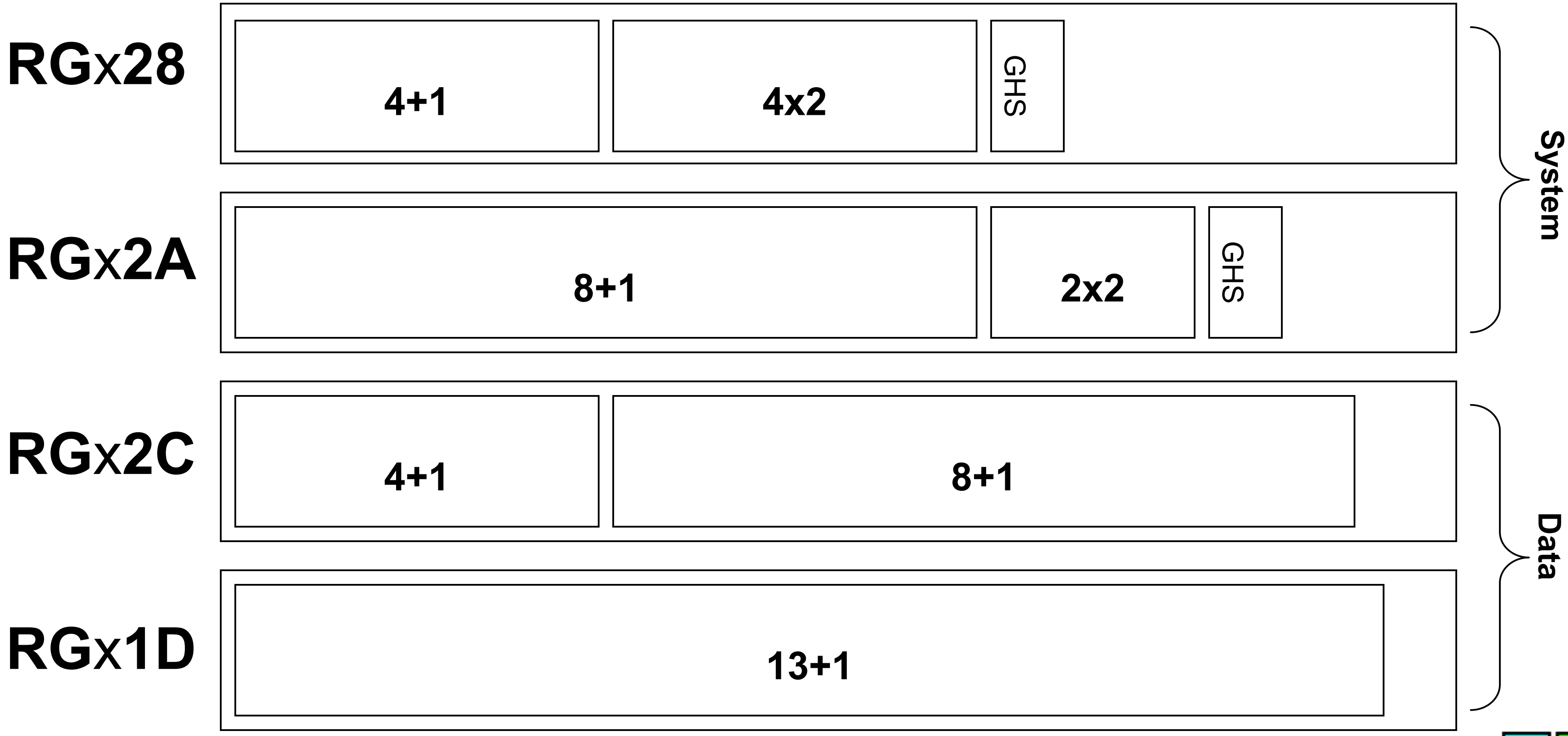
RAID configuration

Cray Storage Management (CSM)

RAID Group Layouts



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RAID configuration

Cray Storage Management (CSM)

RAID Group Layout – segment/stripe sizes

geometry	width	segment size	stripe size	512b blocks
"transaction" LUNs				
2x2	2	128Kb	256Kb	512
4x2	4	128Kb	512Kb	1024
4+1	4	128Kb	512Kb	1024
"bandwidth" LUNs				
4+1	4	256Kb	1Mb	2048
8+1	8	256Kb	2Mb	4096
"capacity" LUNs				
13+1	13	128Kb	1664Kb	3328

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RAID configuration

Cray Storage Management (CSM)

RAID Group Layout – segment/stripe sizes

```
cws% csmreport
                                 …
 01d01  - RS200 starting at Chassis:  1   Slot:  1       Profile(01d01.prf)
        1 CB200 Cbrick, with 2 RC200 RAID Controllers
        4 SB201 Sbricks ( 56  73G spindles)
                                 …
 CTLR-A (top) 10.0.117.24          Optimal    Active
   Host chn:  Tid:  0 alpa: 0xEF   Optimal    Label: CTLR-A/1
              Tid:  2 alpa: 0xE4   Optimal    Label: CTLR-A/2
   LUNs:      LUN:  0 01d02_A0_L00 Optimal    RAID-5/4+1/128KB   80GB
              LUN:  2 01d02_A0_L02 Optimal    RAID-5/4+1/128KB  211GB
              LUN:  4 01d02_A2_L04 Optimal    RAID-1/4x2/128KB   80GB
              LUN:  6 01d02_A2_L06 Optimal    RAID-1/4x2/128KB  211GB
              LUN:  8 01d04_A0_L08 Optimal    RAID-5/4+1/256KB  291GB
              LUN: 10 01d04_A2_L10 Optimal    RAID-5/8+1/256KB  583GB
              LUN: 31 UTM-A        Optimal    PseudoLUN
```

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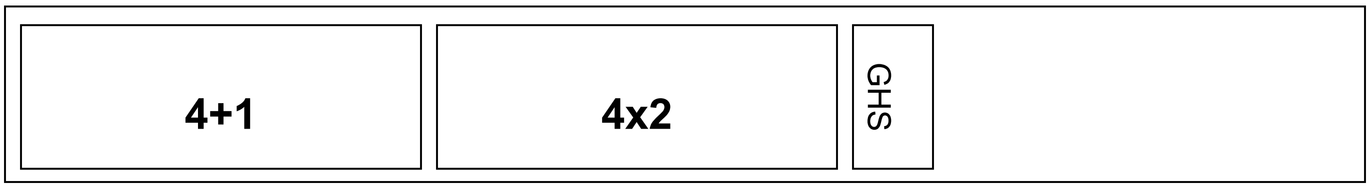
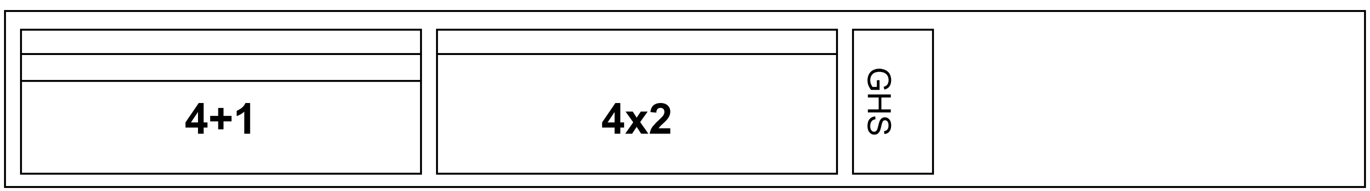
RAID configuration

Cray Storage Management (CSM)

Creating/remaking LUNs




```
cws% csmdelete 1 2 SBRICK
cws% csmadd 1 2 RG128 40:40:0 40:0
```



RAID configuration

Seeing LUNs and paths from the X1:

```
X1# /sbin/pm
pm4d7L0
        path  port    state  read blks  write blks  errs  MB/Sec
        ----  ----    -----  ---------  ----------  ----  ------
     fc2d0L0   pri   active     866071      812707     0    0.00
     fc4d2L0   pri   active     865884      817213     0    0.00
     fc1d1L0   alt  standby          0           0     0    0.00
     fc3d3L0   alt  standby          0           0     0    0.00

pm4d7L1
        path  port    state  read blks  write blks  errs  MB/Sec
        ----  ----    -----  ---------  ----------  ----  ------
     fc1d1L1   pri   active       2048           0     0    0.00
     fc3d3L1   pri   active       2048           0     0    0.00
     fc2d0L1   alt  standby          0           0     0    0.00
     fc4d2L1   alt  standby          0           0     0    0.00
```

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RAID configuration

Seeing LUNs and paths – details

```
X1# /sbin/pm -v tab
```

pm_nblks **LUN size**

pm_maxor **CTQ depth**

```
X1# /sbin/pm -v ustat
pm2d1L10           %rd  maxor  nor  wait   avg_rd  avg_wrt     sz/GBs
                  92.4      8    0     0   2991.2   3988.0      583.0

         path  port state      read blks      write blks err  MB/Sec
         ----  ---- -----      ---------      ---------- ---  ------
    fc20d0L10   pri   act      425839567        35239510   0    0.00
    fc22d2L10   pri   act      425929449        35049703   0    0.00
    fc21d1L10   alt  stby              0               0   0    0.00
    fc23d3L10   alt  stby              0               0   0    0.00
```

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RAID configuration

Partitioning LUNs with ‘parts’

Unicos/mp replacement for IRIX ‘fx’ tool

Volume header (disk label) at start of LUN

Slices aligned on 1Mb boundaries by default

```
X1# cat /etc/parts/root.cf
#
#    Partno      type       size
#
part    0                   25%
part    1        -t raw     15%
part    2                   30%
part    3                   30%
```

s0	root
s1	swap
s2	opt
s3	home

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RAID configuration

Partitioning LUNs with ‘parts’

- **Setting CTQ depth for device**
  - **CTQ default depth is 8**
- **‘modulo’ parameter for other alignments**
  - **2Mb for 8+1**
  - **13Mb for 13+1**

```
X1# cat option-RG11D.cf
#
#    Partno      type       size
#
modulo   13M
part     11                 100%
X1# /sbin/parts -w -q 8 -v \
   -c option-RG11D.cf pm0d6L4
```

Filesystem configuration

XFS filesystems

mkfs /dev/dsk/pm1d1L8s5

Creates an XFS filesystem with default parameters

Works, but does not give optimal I/O performance

Filesystem configuration

XFS filesystems

mkfs –d sunit=2048,swidth=2048 /dev/dsk/pm1d1L8s5

sunit	preferred alignment unit for allocation
swidth	preferred I/O size

Cheat sheet for sunit/swidth calculations

total stripe width	512b disk blocks	4k filesystem blocks
256K	512	64
512K	1024	128
1M	2048	256
2M	4096	512

Filesystem configuration

Creating XFS filesystems

X1# /sbin/mkfs –d sunit=2048,swidth=2048 /dev/dsk/pm1d1L8s11

```
meta-data=/dev/dsk/pm1d1L8s11    isize=256    agcount=272, agsize=261632 blks
data     =                       bsize=4096   blocks=71162368, imaxpct=25
         =                       sunit=256    swidth=256 blks, unwritten=1
naming   =version 2              bsize=4096
log      =internal log           bsize=4096   blocks=4096
realtime =none                   extsz=65536  blocks=0, rtextents=0
```

Output of XFS commands generally uses filesystem blocks (4k bytes)

This example is for a 4+1 LUN

mkfs with no options will show 0 for sunit/swidth fields

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Filesystem configuration

Inspecting mkfs parameters for XFS filesystems

X1# /sbin/mount /dev/dsk/pm1d1L8S11 /mnt

X1# /usr/sbin/xfs_growfs -n /mnt

```
meta-data=/dev/dsk/pm1d1L8s11    isize=256     agcount=272, agsize=261632 blks
data     =                       bsize=4096    blocks=71162368, imaxpct=25
         =                       sunit=256     swidth=256 blks, unwritten=1
naming   =version 2              bsize=4096
log      =internal log           bsize=4096    blocks=4096
realtime =none                   extsz=65536   blocks=0, rtextents=0
```

For filesystems mkfs'ed with no options

xfs_growfs will display 0 for sunit/swidth fields

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Filesystem configuration

Creating XLV volumes

```
X1# /usr/sbin/xlv_make
xlv_make>vol xlv0
xlv_make>log
xlv_make>plex
xlv_make>ve pm1d6L6s4
xlv_make>end
xlv_make>data
xlv_make>plex
xlv_make>ve -stripe -stripe_unit 4096
    pm1d1L1s11 pm1d6L1s11
    pm1d1L7s11 pm1d6L7s11
    pm1d1L10s11 pm1d6L10s11
xlv_make>end
```

8+1 pm1d1L10s11	**8+1** pm1d6L10s11
8+1 pm1d1L7S11	**8+1** pm1d6L7s11
8+1 pm1d1L1s11	**8+1** pm1d6L1s11

Use slices of same size, bandwidth, (RAID geometry)

Specify stripe unit in XLV configuration, using 512-byte blocks

Round-robin on controllers and IOCAs

mkfs should pick up sunit/swidth and log info from striped XLV devices

If using an external XFS log, 4x2 or 2x2 devices best for performance

Filesystem configuration

Displaying attributes of existing XLV volumes

```
X1# /usr/sbin/xlv_mgr
xlv_mgr> show -long xlv0
VOL xlv0 (complete)                (node=mfeg10)
VE xlv0.log.0.0  [active]
     start=0, end=262143, (cat)grp_size=1
     /hw/disk/pm1d6L6s4 (262144 blks)
VE xlv0.data.0.0 [active]
     start=0, end=6831611903, (stripe)grp_size=6, stripe_unit_size=4096
     /hw/disk/pm1d1L1s11 (1138601984 blks)
     /hw/disk/pm1d6L1s11 (1138601984 blks)
     /hw/disk/pm1d1L7s11 (1138601984 blks)
     /hw/disk/pm1d6L7s11 (1138601984 blks)
     /hw/disk/pm1d1L10s11 (1138601984 blks)
     /hw/disk/pm1d6L10s11 (1138601984 blks)
xlv_mgr> quit
```

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Filesystem configuration

XFS filesystem on striped XLV volume

```
X1# /usr/sbin/xfs_growfs -n /large
meta-data=/large                 isize=256    agcount=3258, agsize=262144 blks
data     =                       bsize=4096   blocks=853951488, imaxpct=25
         =                       sunit=512    swidth=3072 blks, unwritten=1
naming   =version 2              bsize=4096
log      =external               bsize=4096   blocks=32768
realtime =none                   extsz=65536  blocks=0, rtextents=0
```

Default internal log file size is 4000 filesystem blocks

Not sufficient for very fast filesystems > 300 Mbyte/s

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Filesystem configuration

XFS filesystem parameters – stripe unit, stripe width

stripe unit — alignment size for
- inode allocations
- internal log
- large files written through buffer cache

set to RAID stripe width
- RAID segment size * data width

this is *not* the "allocation unit"

stripe width — preferred I/O size
- st_blksize returned with stat(2)
- for use by libraries and commands

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Filesystem configuration

XFS filesystem parameters – log size

- internal log size defaults to 4000 filesystem blocks
- appears to limit performance to ~350 Mbytes/s
- make larger for striped XLV volumes
  - mkfs -l size=32768b internal log
  - or add external log to XLV device
- maximum usable log size is 128 Mbytes
  - or 32768 4096-byte blocks

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Filesystem configuration

XFS filesystem parameters – filesystem block size

Default is 4096 bytes

Corresponds to –P and –S for Unicos nc1fs

Change is supported but not recommended

- not proven to provide performance enhancements
- maximum of 64k bytes smaller than RAID segment size
- Increases the minimum size for all data in filesystem, including metadata, and all I/O transfers

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Filesystem configuration

XFS filesystem parameters – allocation groups

- Filesystems are divided into allocation groups
  - Default appears to be around 1 Gb per allocation group
  - Maximum allocation group size is a little less than 4 Gb
- New directories are allocated round-robin to different allocation groups
- Files stay in the allocation group of the directory
  - except when full
- Files can span multiple allocation groups
- Allocation groups allow for parallelism of f/s operations

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Filesystem configuration

XFS filesystem parameters – allocation groups

- **When fewer allocation groups might be needed**
  - Very large filesystems
  - Allocation group size limits size of extents
  - Large files get fragmented
  - System CPU time increases when filesystem gets full
- **When more allocation groups might be needed**
  - Small filesystems with many simultaneous transactions

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Filesystem configuration

XFS filesystem parameters summary

stripe unit	**-d sunit=***blocks*	
stripe width	**-d swidth=***blocks*	
internal log	**-l size=***fs_blocks***b**	**4000**
filesystem block size	**-b** *bytes*	**4096**
allocation groups	**-d agcount=***number*	

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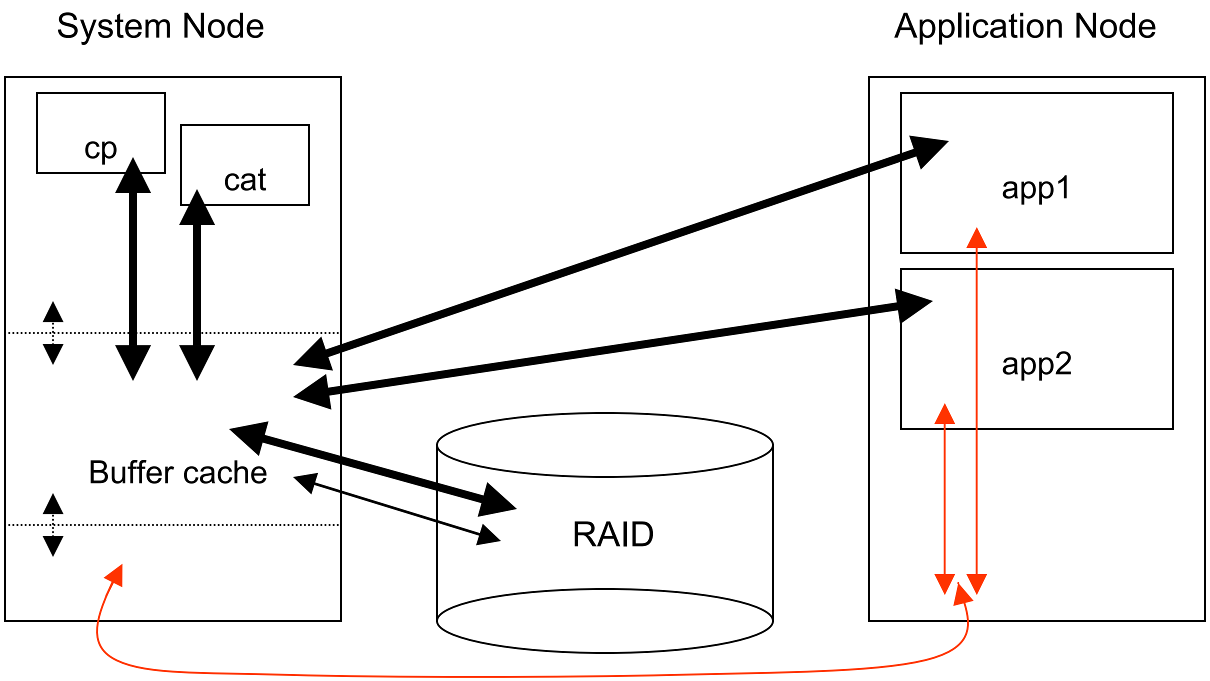
Cray X1 I/O overview

Buffered I/O



I/O system calls from application nodes are migrated to OS node.

Some additional cost.

Standard Unix I/O buffer cache

- **read/write system call I/O can be any size**
- **provides blocking for block devices, cache, readahead and writebehind**

Consumes memory from X1 OS node(s)

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Cray X1 I/O overview

Buffered I/O summary

- Differences from Unicos and previous Cray machines
  - dynamic size, lots of memory
  - faster memory-to-memory transfers
  - mature buffer cache management
- Provides
  - read-ahead, write-behind
    - write-behind important since disk controller cache is disabled
  - xfs allocation ‘sunit’ alignment
- Good for small I/O (up to single digit Gb files)

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Cray X1 I/O overview

Buffered I/O – how it works

systune parameters for flushing dirty buffers illustrate this

- nbuf=256k (buffer headers = osmem / pagesz)
- bdflushr=5 (examine 1/5 of buffers every time)
- bdflush_interval=100 (1 sec.)
- dwcluster=64 (4 Mbytes, collect this much before writing)

Note: little experience with changes other than for ‘nbuf’

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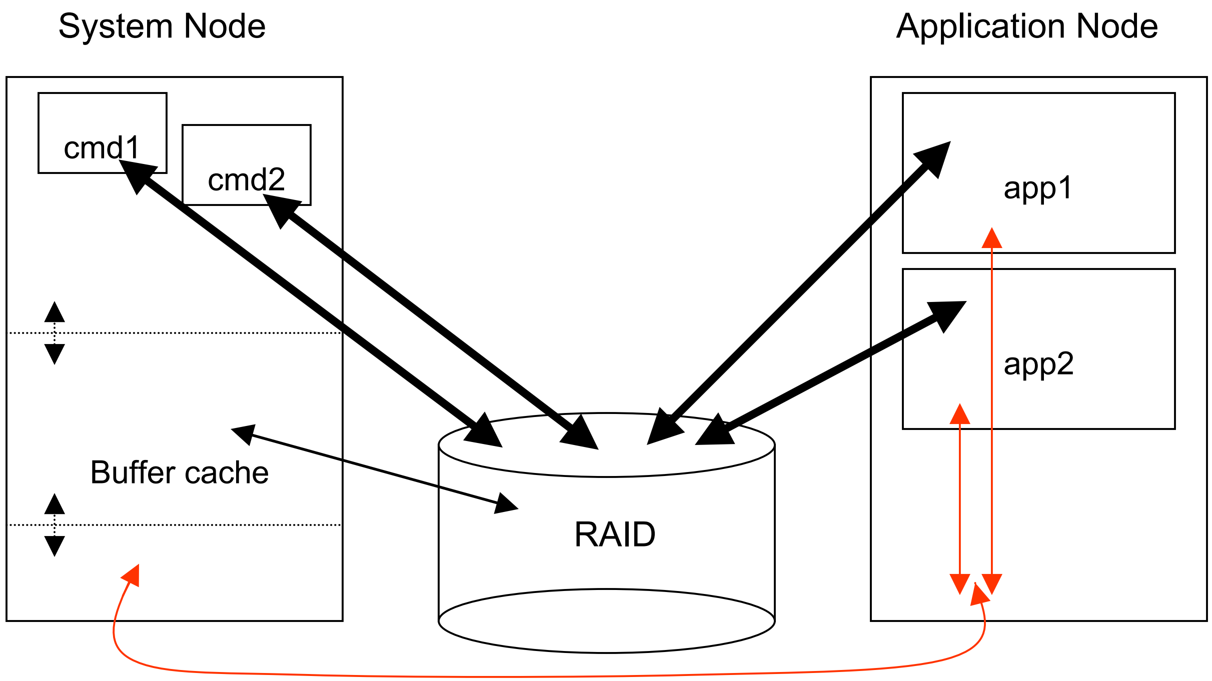
Direct I/O



I/O system calls from application nodes are migrated to OS node.

Some additional cost.

Data flows directly between user space and disk

- **alignment and transfer size restrictions**

Filesystem metadata still flows through buffer cache

Fewer OS node resources (memory, system CPU time) needed

Cray X1 I/O overview

Direct I/O details – how it works

- Data transfers bypass buffer cache
- Writes are synchronous
- XFS allocations are immediate
- User data size and alignment requirements
- Maximum transfer size is 16Mb
  - Higher transfer sizes would require disk driver change

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How to use direct I/O

From C programs:

```
int fd; long datasize;
struct dioattr d;
          .
          .
fd = open("/tmp/outfile",O_DIRECT|…,…);
          .
          .
ret = fcntl(fd, F_DIOINFO, &d);
buf = (unsigned long long *) memalign(d.d_mem, datasize);
          .
          .
write(fd,buf,datasize);   # datasize must be d.d_miniosz multiple
```

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Cray X1 I/O overview

How to use direct I/O with assign and FFIO cachea layer

With FORTRAN programs

With C programs that use ffopen()/ffread()/ffwrite()

```
module load PrgEenv
export FILENV=$HOME/.assign
assign -R
assign -B on -F cachea:4096:8:8 u:21
./my_prog
```

'-B on' enables O_DIRECT open flag

-F selects FFIO layers and options:

cachea asynchronous, cached I/O layer

Buffer size is 4096 512-byte blocks (2Mb)

8 buffers total – allocated with proper alignment for O_DIRECT

8 buffers max. readahead

'u:21' applies to FORTRAN unit 21

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How to use direct I/O – preallocation

Preallocation from C programs

```
struct flock fl;
        …
fl.l_whence = SEEK_SET;
fl.l_start = 0LL;
fl.l_len = (long long) filesize;
fcntl(fd, F_RESVSP, &fl)
```

Preallocation with assign/FFIO

“allocate ahead” feature within cachea layer
planned for Programming Environment 5.2 Update 1 or 2

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Cray X1 I/O overview

Direct I/O summary

- Differences from Unicos O_RAW
  - Not automatic with well formed large I/O
  - Proper alignment of memory buffers required
- Need asynchronous I/O for performance
- xfs allocation/alignment concerns - preallocate
- Consider for large files (> a few Gb)
- Example: Checkpoint/Restart
  - cpr uses direct I/O for checkpoint files as of U/mp 2.3

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Cray X1 I/O overview

I/O from System node vs. Application node

- Some cost/delay associated with migrating I/O system calls from APP nodes to OS node
- #syscalls/second capacity – write(2) example

from OS node	5500	calls/sec.
from APP node	500	calls/sec.

- Alleviate with
  - large I/O sizes, library buffers
  - asynchronous I/O

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Cray X1 I/O overview

Kernel tuning for I/O

- systune changes generally not required
- some sites have reduced ‘nbuf’ to prevent hangs

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Cray X1 Filesystems

“transaction” LUNs – 2x2, 4x2, 4+1

- root
- /opt
- /var
- /var/…
- /tmp
- home filesystem(s)
- swap
- external XFS log devices

“bandwidth” LUNs – 8+1, 4+1

- very fast/large filesystems
- checkpoint filesystem
- dump filesystem

“capacity” LUNs – 13+1

- very large filesystems

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Cray X1 Filesystems

root

- **3-4 copies for shipment**

/var

- **can be separated from root to reduce writes and control root size**

/var/adm

- **Can be separated to contain accounting data**

/var/spool

- **Can be separated to contain PBS spooled data**

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Cray X1 Filesystems

/opt

Could be a small slice on “transaction device” if not used for anything else

/tmp

Could be a small slice on “transaction device” if not used for anything else

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Cray X1 Filesystems

Home filesystems

- NFS-export to CPES

Swap slices

- First swap slice configured in nvram
- Additional slices configured in /etc/fstab

External XFS log devices

- 128Mb appears sufficent
- Recommended with striped XLV devices

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Cray X1 Filesystems

Very fast/large filesystems

- XLV-stripe LUNs on alternate RAID controllers, IOCAs
- External XFS log is recommended
- Communicate best I/O sizes and access methods to users
- Monitor for large files

System dump directory

- Can reside in checkpoint filesystem or on other fast/large device
- Dump files written with FFIO, buffer sizes up to 8Mb
- Typical sizes are 500 Mb per OS node, 55 Mb per APP node

Checkpoint filesystem

- ‘cpr’ uses O_DIRECT and cachea with 8x16Mb buffers
- PBS Pro requires permission bits 0700 on checkpoint directory
  - and 0755 on parent directories within filesystem

I/O tests

Internal Cray Service I/O test

- Used by FTS/SPS as basic I/O diagnostic
- System calls
- Varying I/O sizes
- Buffered or direct I/O

Streams

- General benchmark for user I/O
- Highly configurable
- Supports asynchronous I/O, preallocation

FORTRAN I/O

I/O tests

How to read the graphs

Primary measurements

Write Mb/sec.

Read Mb/sec.

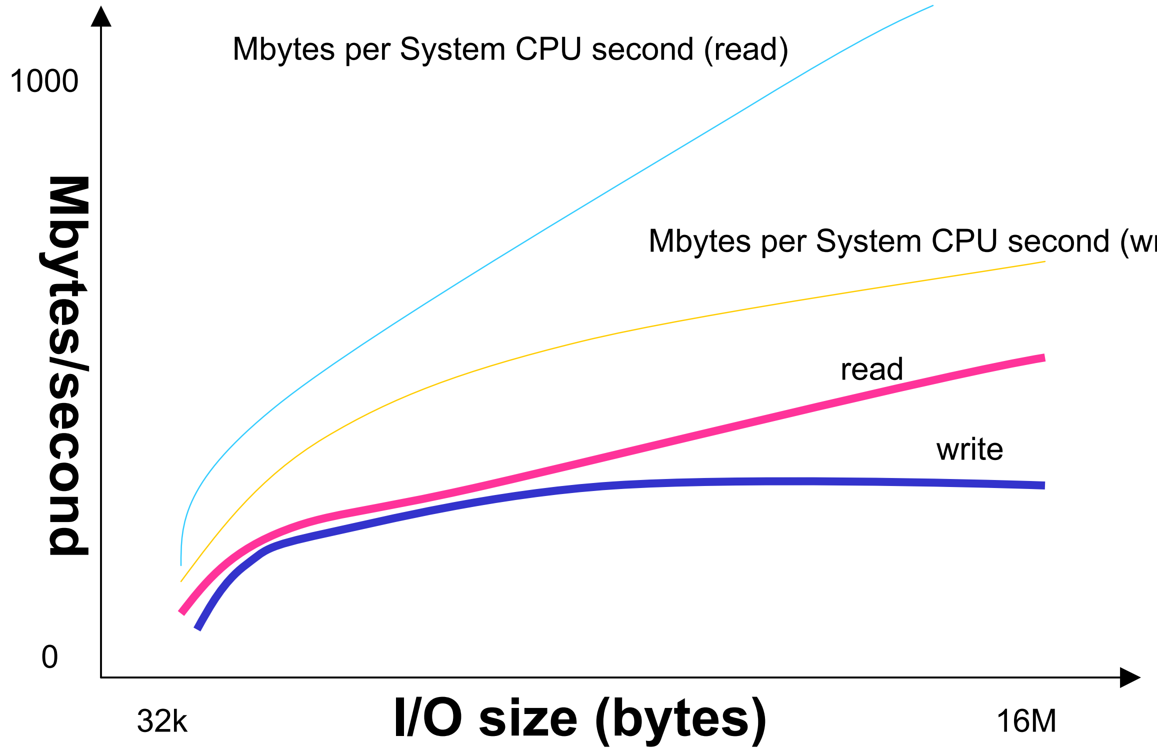
Scenarios shown in next 4 slides

Buffered I/O – OS node

Buffered I/O – APP node

Direct I/O – OS node

Direct I/O – APP node



Mbytes per System CPU second as an unscientific metric for system resources needed to move data

using numbers from 'time' command

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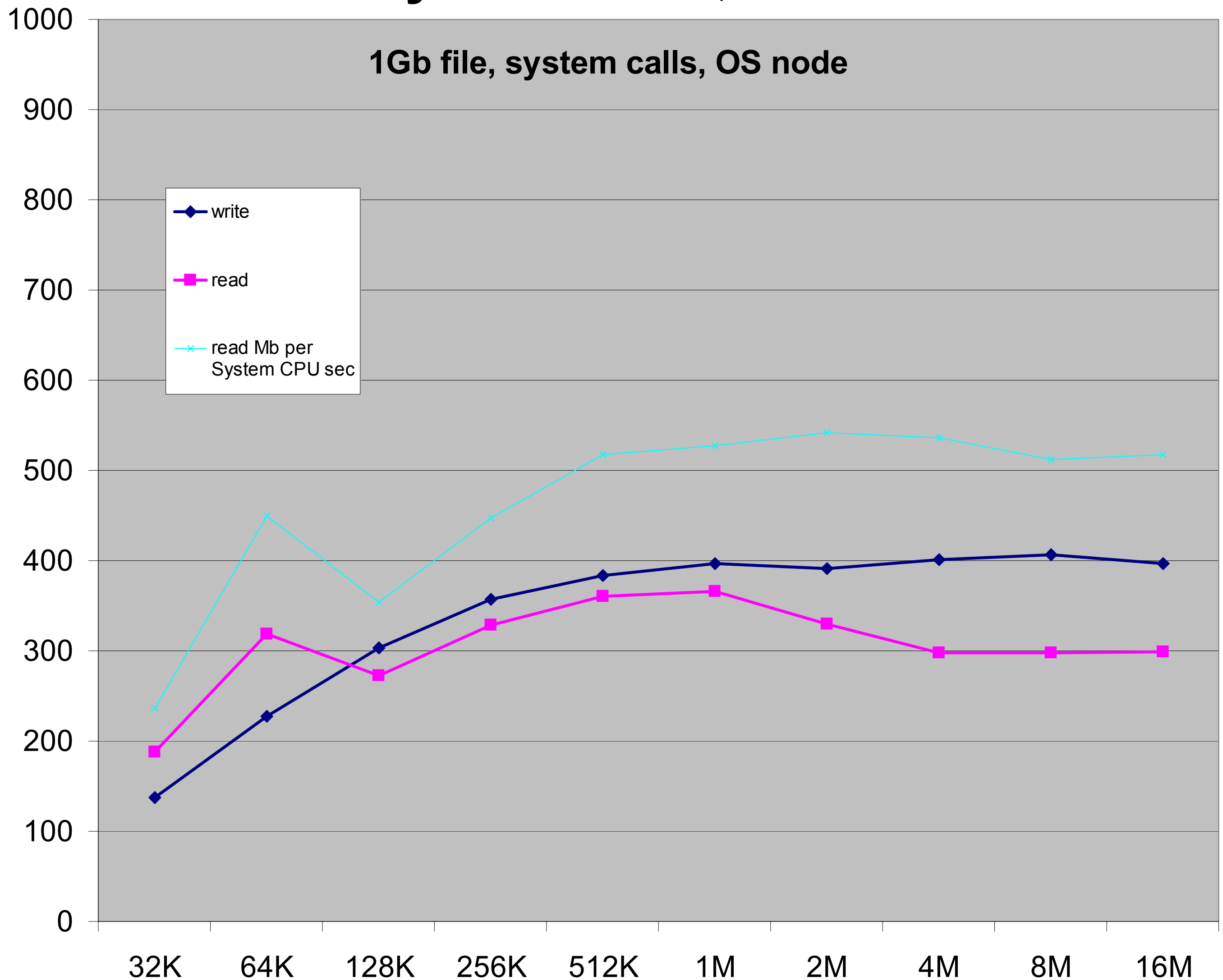
I/O tests

Buffer cache I/O – system calls, OS node



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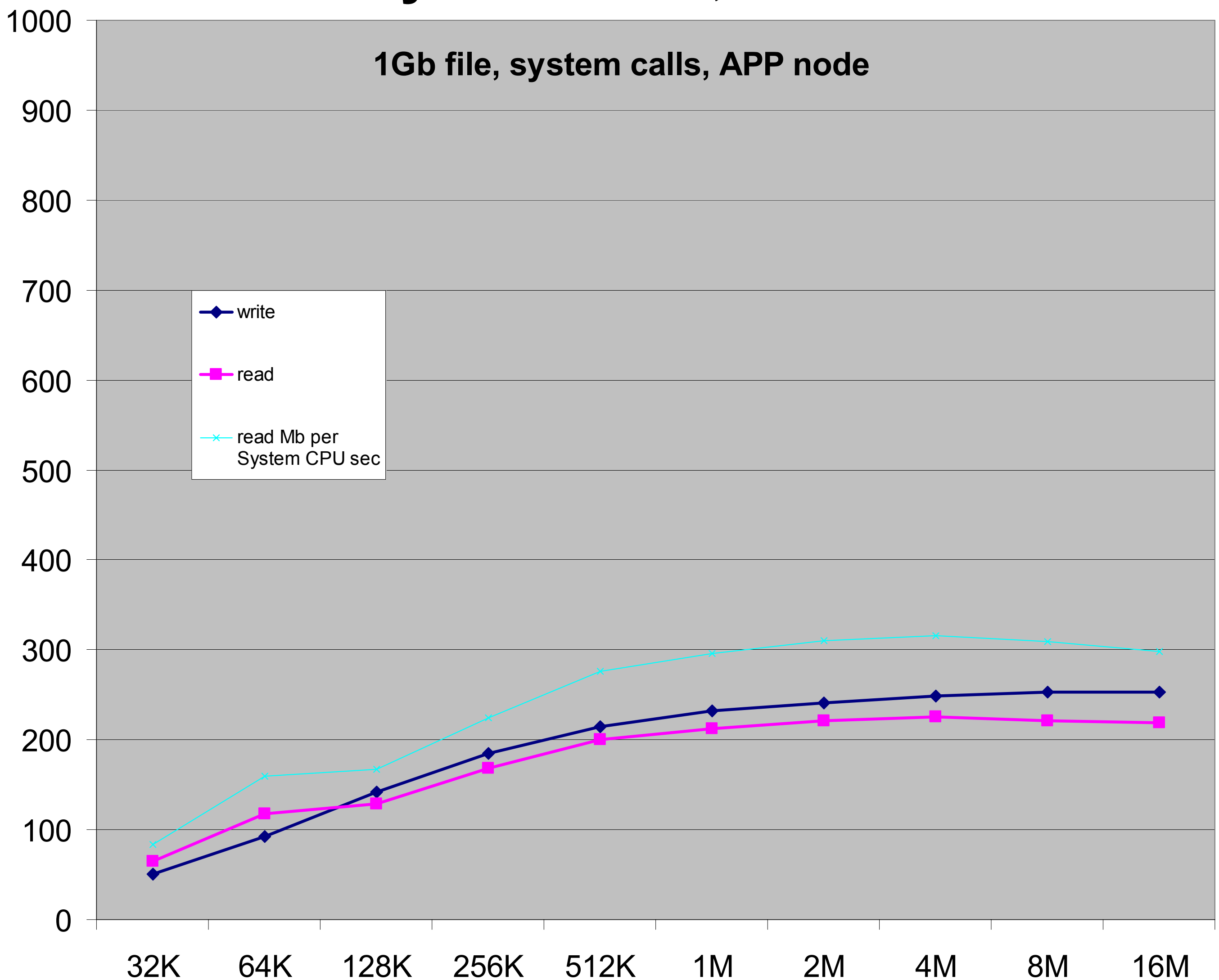
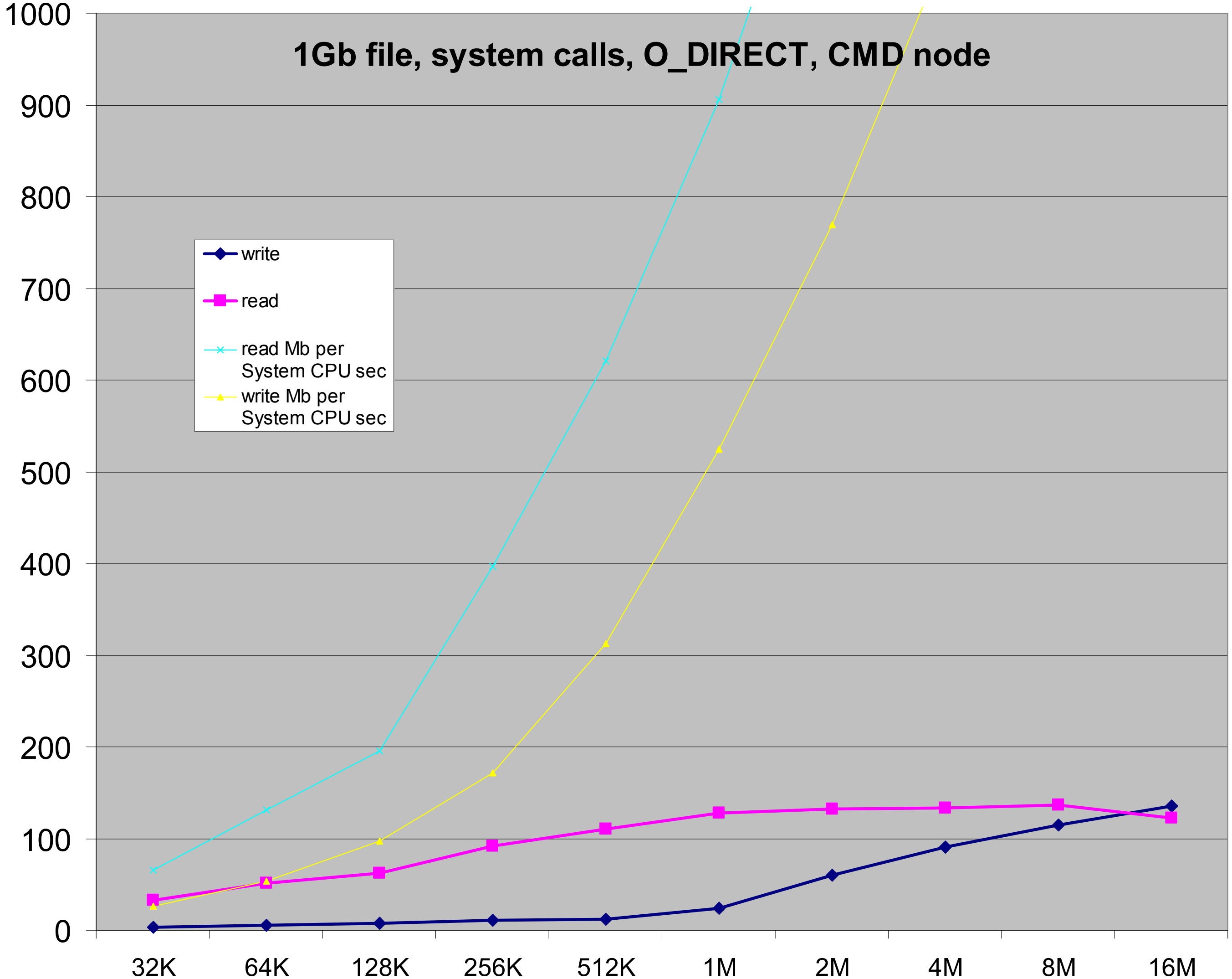
Buffer cache I/O – system calls, APP node



I/O tests

Direct I/O – system calls, OS node



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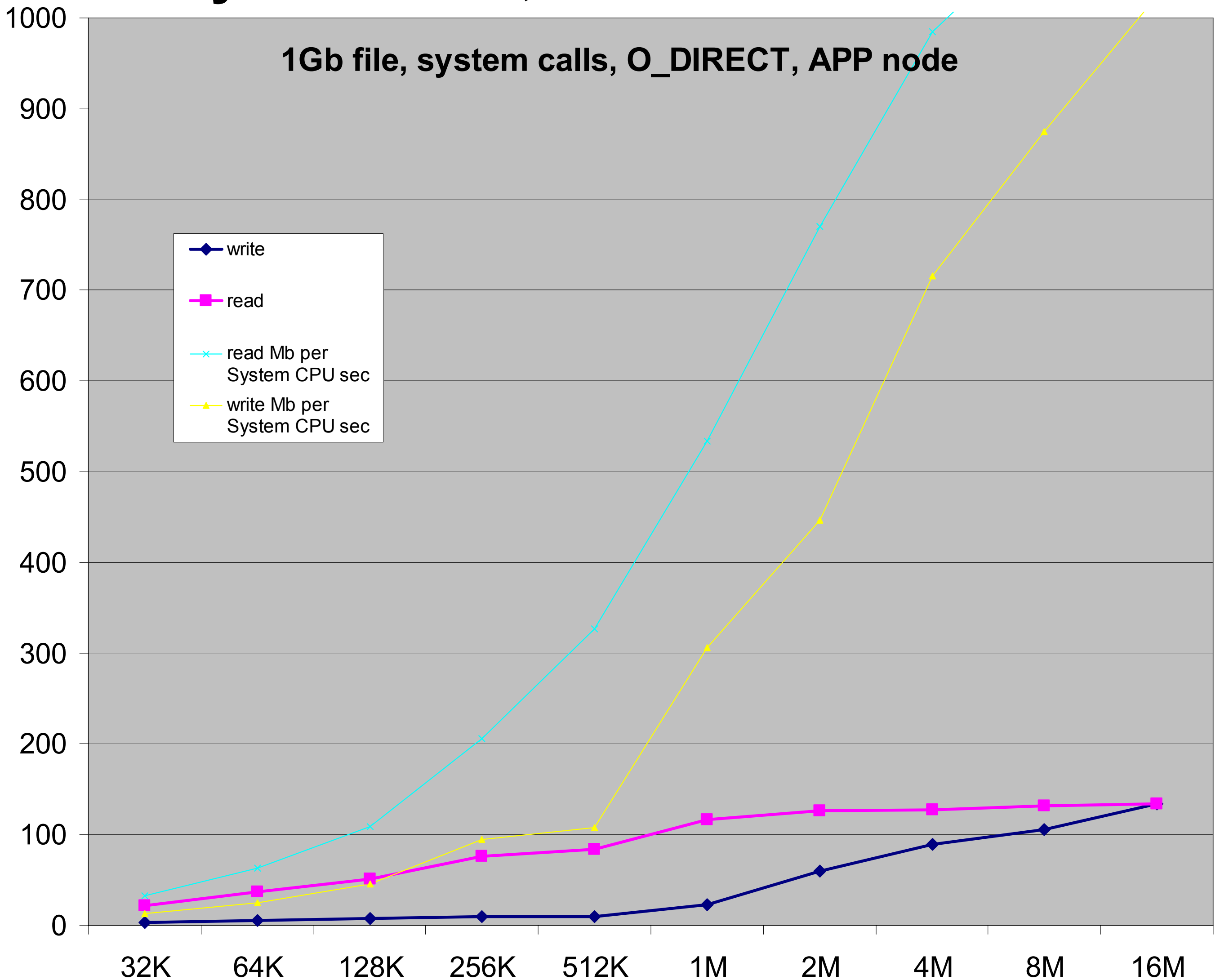
I/O tests

Direct I/O – system calls, APP node



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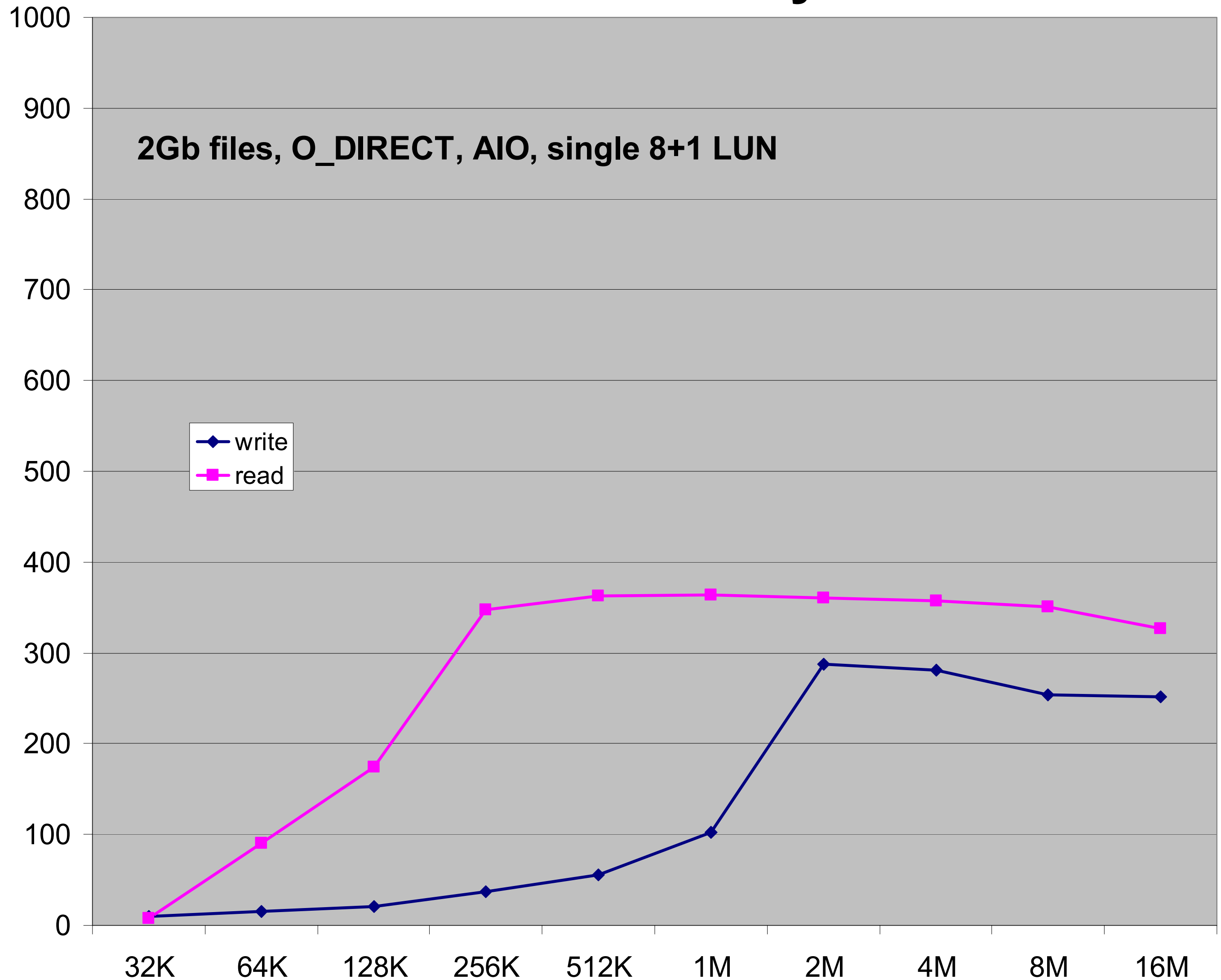
I/O tests

Direct I/O – STREAMS with 16x asynchronous I/O



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I/O tests

STREAMS benchmark – RAID stripe boundary alignment

8+1 LUN (256kb segment size * 8 = 2Mb optimal alignment)

mkfs –s sunit=4096,swidth=4096

Aligned I/O:	**271 Mb/s**	**write**

- 2 Gb file size
- preallocated, contiguous space
- 2Mb I/O transfer size
- async I/O, 8 buffers
- Direct I/O

Non-aligned I/O:	**136 Mb/s**	**write**

- As 1, with offset 256Kb into file

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I/O tests

STREAMS benchmark – large XLV volume

6-wide 8+1 XLV volume, across two RAID controllers

10Gb file size

RAID stripe aligned I/O (2Mb)

Preallocated space

Asynchronous direct I/O, 16 buffers

2Mb I/O size:	362 Mb/s	write
	891 Mb/s	read
12 Mb I/O size:	847 Mb/s	write
	1011 Mb/s	read

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I/O tests

FORTRAN WRITE example

```
      program io
      parameter (n=10000)
      integer a(n)

      do 5 i=1,10000
5     a(i) = i+1

      do 10 i=1,1000              ! 1000 = 40Gb file, 100 = 4Gb file
      do 10 j=1,1000
10     write(21) n, a

       close(21)

      end
```

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I/O tests

FORTRAN WRITE example – results

```
module load PrgEnv
ftn -h command -o io1 io1.f
rm -f fort.21
export FILENV=/users/fi/.filenv
assign -R
assign … u:21
timex ./io1
```

4Gb file	real	user	sys	
Single 8+1 LUN	34.8	5.8	19.0	as-is
32Gb OS node	10.8	6.2	10.0	assign –F cachea:4096:8:8
	19.5	6.1	2.9	assign –B on –F cachea:4096:8:8
40 Gb file	**real**	**user**	**sys**	
Single 8+1 LUN	361	57	228	as-is
32Gb OS node	328	60	134	assign –F cachea:4096:8:8
	184	60	67	assign –B on –F cachea:4096:8:8

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System Administration tasks

- Setting up ‘sar’
- Setting up accounting
- Checking/repairing/reorganizing filesystems (fsr)
- Configuring psched, PBS, limits to manage workload and memory subscription
- Remaking filesystems – moving/shuffling data

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X1 I/O monitoring tools

sar

-d/-D	I/O rates per LUN
-b	Buffer cache vs. direct I/O
-T	I/O totals per LUN, use with –D and -b

bufview

monitoring buffer cache I/O

acctcom

Locating processes doing large I/O, high system CPU time

xfs_db

Allocation/fragmentation details for XFS files

xfs_bmap

scheduled for Unicos/mp 2.5

pm

monitoring I/O paths

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Conclusions

General principles for I/O performance

- Alignment of I/O requests and file allocations
- Avoid Unix buffer cache for large files
- Large transfer sizes
  - 1Mb or more
- Utilize parallelism:
  - asynchronous I/O
  - parallel I/O streams
  - balanced distribution of I/O across available hardware

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Cray X1 System Performance

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