The Snow Report: A GPFS Performance & Bottleneck Analysis

snow.llnl.gov
(bldg. 451)

William Loewe
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Lawrence Livermore National Laboratory
Report Outline

- **Background:**
  - Snow Architecture in conjunction with GPFS 1.3
  - RAID Access Patterns

- **File Creation/Removal Rates using NFS, JFS, GPFS 1.2 & GPFS 1.3:**
  - Small Files
  - Large Files
  - Directories

- **IOR_POSIX benchmark tests:**
  - Segmented Access, Varying:
    - Transfer Size
    - Node Number
    - File Size
    - Client-Node Ratio
    - Transfer Size w/Multiple Client
    - Random Size Transfer
  - Strided Access, Varying:
    - Block Size

- **Concluding Summary**
Snow Hardware Specifications

- IBM RS/6000 SP System
- 4 frames
- 4 Nighthawk-1 nodes per frame
- 8 222MHz 64-bit IBM Power3 CPUs per node
  (16 Nodes & 128 CPUs total)
- 4 GBytes RAM per node
  (64 GBytes total memory)
- Peak computing capability of
  ~114 GFLOPS

- 2 I/O nodes (may also be used as compute nodes -- not dedicated)
- 3 SSA adapters per I/O node
- 3 73-GByte RAID sets per SSA adapter (1.3 TBytes total disk space)
- 5 Disks on each RAID (4 + P)
  – parity information is distributed among drives (i.e., not a dedicated parity drive)
- ~250MB/sec maximum transfer
  (14MB/sec per RAID)
Analysis of NH-1 Nodes w/ Santa Cruz adapters

CLIENTS
14 Nighthawk-1 Compute Nodes

SERVERS
2 Nighthawk-1 Server Nodes

Colony Switch

Clients (VSDs) communicate with LAPI protocol (~80% efficient?). Switch comm is client bottleneck: ~294 MB/sec

Colony Adapter:

Point-to-point: ~367 MB/sec
Unidirectional 4 MB buff
~??? MB/sec bidirectional

Each disk is an IBM SSA disk, max 8.5 MB/sec, typical 5.5 MB/sec, total capacity 18.2 GB.

Colony Adapter

222 Mhz Power 3
222 Mhz Power 3
222 Mhz Power 3
222 Mhz Power 3

140MB/sec max write per CPU?

Santa Cruz

Each Santa Cruz Adapter is capable of: 
~48 MB/sec writes
~88 MB/sec reads

Disks are configured into a 4+p Raid Set (73 GB). Each Raid Set is capable of 14 MB/sec.
RAID loops are shared between I/O nodes (5 and 6) so that if a single I/O node fails, another I/O node may cover all eighteen RAID sets.

5 Disks on each RAID set (4 + P)

I/O nodes are not dedicated (i.e., may serve as both compute node and I/O node concurrently.)
- IBM General Parallel File System for AIX (GPFS) version 1.3

- Mohonk PSSP 3.2 GA PTF 1 SubRelease# DV (GPFS)

Primary goal is to allow a single file accessed by multiple clients to be stored (or striped) across multiple disks.
(Of course, several files may be accessed concurrently.)
Testing the creation time of 1000 files (or directories) created on NFS, JFS, and GPFS for Snow and Blue.

Note: Blue runs GPFS 1.2, whereas Snow runs the newer GPFS 1.3

For file tests:

- Machines: snow.llnl.gov
  blue.llnl.gov
- Code used: csh-script
  while ( $nfils < 1000 )
    echo "Sat Jan 01 00:00:00 PDT 2000" > file.$nfils
    @ nfils++
  end

*Nested #1 -- Subdirectory containing one file and one subdirectory, recursively, for a 1000 file/directory total.

**Nested #2 -- Subdirectory containing nine files and one subdirectory, recursively, for a 1000 file/directory total.
GPFS 1.3 is significantly faster for removing files or directories than version 1.2.
The Network File System (NFS) and Journaled File System (JFS) are comparable on Snow and Blue (both using the same version of these file systems.) This shows that despite differences in hardware, the systems behave similarly. Therefore, the notable difference in GPFS performance is likely due to improvements between 1.2 and 1.3, not hardware considerations.
PARAMETERS:

- 1000 29-byte files created on all file systems

Note:

GPFS 1.2 tests run on blue.llnl.gov
GPFS 1.3, NFS, and JFS tests run on snow.llnl.gov
Large File Removal Rate for GPFS 1.2, GPFS 1.3, NFS, JFS

PARAMETERS:
- GPFS 1.2: 128 1G files
- GPFS 1.3: 128 1G files
- NFS: 1000 1M files
- JFS: 1000 _M files

Note:
GPFS 1.2 tests run on blue.llnl.gov
GPFS 1.3, NFS, and JFS tests run on snow.llnl.gov
PARAMETERS:

- 1000 single-nested subdirectories created on all file systems

(e.g., /1, /1/2, 1/2/3 would be three single-nested subdirectories, i.e., a unary tree structure)

Note:

- GPFS 1.2 tests run on blue.llnl.gov
- GPFS 1.3, NFS, and JFS tests run on snow.llnl.gov
The file creation and file removal rates are excellent on GPFS 1.3. Further, they appear scalable for increasing number of clients.

With nested directories, the creation rate on GPFS 1.3 is below that of NFS.
PARAMETERS:

- Client = 1
- Node = 1
- FileSize = 512MB
- TransferSize = 1KB to 512MB

For all subsequent tests:
  Code: ior_posix.c
  Machine: snow.llnl.gov
  PSSP: 3.2
  GPFS: 1.3
  Configuration: 2 * ( 3 * ( 3 * ( 4 + p )))
  ~250MB/sec Max Transfer Rate (14MB/sec per RAID set)
PARAMETERS:

- Client = 1
- Node = 1
- FileSize = 512MB
- TransferSize = 1KB to 512MB

queue_depth = 2
previous run with queue_depth = 40
PARAMETERS:

- Client = 1
- Node = 1
- FileSize = 5GB
- TransferSize = 1KB to 4MB
For reads, the read-ahead algorithm GPFS uses becomes inefficient for larger subblocks, thus causing the bell-curve for reads. The bell-shaped curve is caused by the filling of the L2 cache which bumps out the instruction stream with larger transfer sizes.

Writes can be expected to be slower due to the additional overhead associated with allocation (buffer must be allocated before write request.) But nonetheless for writes, the ceiling of 140MB/sec by one thread (CPU) per Node supposedly causes the poor write performance. Later, we can show that this appears to be the case, but that another bottleneck is creeping up elsewhere.
PARAMETERS:

- Client / Node = 1
- TransferSize = 256KB
- Block = 512MB
- FileSize = Client * 512MB
- Nodes = 1 to 14
PARAMETERS:
- Client / Node = 1
- TransferSize = 256KB
- Block = 512MB
- FileSize = Client * 512MB
- Nodes = 1 to 14

queue_depth = 2
previous run with
queue_depth = 40
PARAMETERS:
- Client / Node = 8
- TransferSize = 256KB
- Block = 512MB
- FileSize = Client * 512MB
- Node = 1 to 14

queue_depth = 2
previous run with
queue_depth = 40

[NOTE: No Summer run of this test for comparison]
PARAMETERS:

- Client / Node = 1
- FileSize = 8400MB
- TransferSize = 256KB
- Block = FileSize / Clients
- Nodes = 1 to 8
PARAMETERS:
- Client / Node = 1
- FileSize = 2100MB
- TransferSize = 256KB
- Block = FileSize / Clients
- Nodes = 1 to 8
PARAMETERS:
- Client / Node = 1
- FileSize = 1470MB
- TransferSize = 256KB
- Block = FileSize / Clients
- Nodes = 1 to 6
It appears from observation of the activity of the I/O nodes that a “read-modify-write” is being performed when using more than 3 clients during this test. As the RAID stripe is 256KB, but the LVM transfer size is 128KB, there is a failure to coalesce the transfer packet to 256KB before writing to disk. Consequently, a read-modify-write is performed, slowing down the write.
PARAMETERS:

- Nodes = 6
- Client / Node = 1
- TransferSize = 256KB
- Block = FileSize / 6
- FileSize = 6 MB to 24GB
PARAMETERS:

- Nodes = 6
- Client / Node = 1
- TransferSize = 256KB
- Block = FileSize / 6
- FileSize = 6 MB to 24 GB

![File Size Variation Graph]

- **Read**
- **Write**
File Size Variation Summary

- Apparently clever use of caching allows for a better read/write rate. But, after a certain blocksize as the file gets larger, the read levels off to around 250MB/sec, but the write rate plummets to 100MB/sec. These are the same bottlenecks we’ve been seeing.

- However, note that writing 32/64MB per node can help boost GPFS through use of caching. As the Page Pool is set to 100MB, we do not see the effects of caching beyond this point.
PARAMETERS:
- Nodes = 1
- FileSize = 512MB * Clients
- TransferSize = 256KB
- Block = 512MB
- Clients = 1 to 8
PARAMETERS:
- Nodes = 8
- TransferSize = 256KB
- Block = 512MB
- FileSize = Client * 512MB
- Client / Node = 1 to 8
PARAMETERS:

- Nodes = 8
- TransferSize = 256KB
- Block = 512MB
- FileSize = Client * 512MB
- Client / Node = 1 to 8
Sensitivity Curve IV-C: 
Client / Node Variation (Segmented)

PARAMETERS:
- Nodes = 8
- FileSize = 8400MB
- TransferSize = 256KB
- Block = FileSize / (total) Clients
- Client / Node = 1 to 8

![Client Number Variation Diagram](image)
With one node, the write rate max of 140 MB/sec increases after one client.

This does not hold true, however, with more nodes. Instead, the write rate stays low. Perhaps a different bottleneck is in effect here.
PARAMETERS:
- Clients = 2
- Nodes = 1
- FileSize = 1024MB
- Block = 512MB
- TransferSize = 16KB – 1024KB
Sensitivity Curve V-B: Multiple Clients with Transfer Size Variation (Segmented)

PARAMETERS:
- Clients = 4
- Nodes = 2
- FileSize = 2048MB
- Block = 512MB
- TransferSize = 16KB – 1024KB
PARAMETERS:
- Clients = 6
- Nodes = 3
- FileSize = 3072MB
- Block = 512MB
- TransferSize = 16KB – 1024KB
PARAMETERS:

- Clients = 8
- Nodes = 4
- FileSize = 4096MB
- Block = 512MB
- TransferSize = 16KB – 1024KB

![Graph](image)

4 Nodes, 8 Clients

- Green diamonds represent Read.
- Red triangles represent Write.

Transfer Rate (MB/sec)

Transfer Size (Kb)
PARAMETERS:

- Clients = 10
- Nodes = 5
- FileSize = 5120MB
- Block = 512MB
- TransferSize = 16KB – 1024KB
PARAMETERS:

- Clients = 12
- Nodes = 6
- FileSize = 6144MB
- Block = 512MB
- TransferSize = 16KB – 1024KB
To determine the effect of the 140MB/sec per CPU bottleneck, the benchmark is run with increasing the number of nodes. With four or few nodes, the write rate is good for any size transfer. After that, however, something slows the write rate. It seems the ‘camel hump’ from Curve II is consistent.
Sensitivity Curve VI-A: Random Transfer Size (Strided)

PARAMETERS:
- Client / Node = 1
- FileSize = Clients * 512MB
- TransferSize = 1KB to 32KB
- Nodes = 1 to 7
As suspected, IOR does not address the problems with random transfer sizes very well. Hopefully MPI-IO will improve these rates.
PARAMETERS:

- Nodes = 2
- Client / Node = 1
- FileSize = Clients * 512MB
- Block = 1KB to 512MB
- (Note: Strided pattern)
PARAMETERS:

- Nodes = 4
- Client / Node = 1
- FileSize = Clients * 512MB
- Block = 1KB to 512MB
PARAMETERS:

- Nodes = 8
- Client / Node = 1
- FileSize = Clients * 512MB
- Block = 1KB to 512MB
PARAMETERS:
- Nodes = 14
- Client / Node = 1
- FileSize = Clients * 512MB
- Block = 8KB to 512MB
PARAMETERS:

- Nodes = 14
- Client / Node = 1
- FileSize = Clients * 512MB
- Block = 32KB to 512MB
For strided reads above ~256KB block size (and corresponding transfer size), the performance is excellent for any number of nodes. In fact, we’ve achieved the theoretical bottleneck of ~250MB/sec.

 Writes, on the other hand, tend to be better with fewer nodes and tend to improve with larger block sizes. Initially (below 256KB) this is the read-modify-write problem. Beyond it, however, probably the large number of client are showing the coalescing problem again.
Concluding Summary

META-DATA (File Create/Delete) Summary:
Changes in GPFS 1.3 have improved meta data performance greatly. Small file creation and large file removal are above that of NFS, JFS, and GPFS 1.2. For directory creation, GPFS 1.3 is strong, but still half that of NFS.

IOR Benchmark Summary:
I. An optimal transfer buffer size seems be ~256KB for reads and writes.

II. Read performance is excellent with a ceiling of ~250MB/sec. Increasing the number of nodes only marginally improves this read performance.
   For writes, there is a coalescing bottleneck.

IOR Benchmark Summary (cont.):
III. The pagepool can improve read/write rates beyond the theoretical ceiling.

IV/V. Increasing the number of nodes using more than one client per node improves write rate, but again the > 4 node bottleneck is present.

VI. Reads/writes for random transfer size is less than desirable. MPI-IO will better address this.

VII. Strided reads greater than 256KB blocks are excellent across the board. Writes tend to ramp us slowly with improvements due to increasing blocksize. Again, writes are better with fewer nodes.
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