Lustre usage and compression at DKRZ

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1. DKRZ’s Mistral

2. Cost efficiency
About us: Scientific Computing

- Analysis of parallel I/O
- I/O & energy tracing tools
- Middleware optimization

- Alternative I/O interfaces
- Data reduction techniques
- Cost & energy efficiency

We are an Intel Parallel Computing Center for Lustre
(“Enhanced Adaptive Compression in Lustre”)
HLRE3 – Mistral¹

- Went into operation in two phases
  - Spring 2015 and spring 2016
- Currently number 33 on the TOP500
- Approximately 3,000 nodes
  - 1,500 nodes: $2 \times$ Intel Xeon E5-2680v3 12C 2.5 GHz (Haswell)
  - 1,600 nodes: $2 \times$ Intel Xeon E5-2695V4 18C 2.1 GHz (Broadwell)
- 2.5 PFLOPS (3.14 PFLOPS peak)
- 240 TB RAM
- InfiniBand FDR
  - Fat tree with 2:2:1 blocking

¹With a lot of information from Carsten Beyer.
HLRE3 – Mistral…

- Lustre with a capacity of 54 PiB
  - Split into two file systems, due to phases
- One of the largest storage systems
  - Storage development is a problem
  - CPU factor 20, storage speed factor 15, storage capacity factor 9.5
- Based on Seagate ClusterStor
  - Scalable Storage Units (SSU) and Expansion Storage Units (ESU)
- Throughput of 450 GB/s
  - 5.9 GB/s per node
  - Single-stream performance: 1 GB/s
HLRE3 – Mistral...
HLRE3 – Mistral…

- **Phase 1 (CS9000)**
  - Lustre 2.5.1 (Seagate)
  - 62 OSSs with 124 OSTs
  - 5 MDSs with DNE
  - Per SSU/ESU: Two trays with $41 \times 6$ TB HDDs each
    - One SSD for parity
  - 80,000 metadata operations per second

- **Phase 2 (L300)**
  - Lustre 2.5.1 (Seagate)
  - 74 OSSs with 148 OSTs
  - 7 MDSs with DNE
  - Per SSU/ESU: Two trays with $41 \times 8$ TB HDDs each
    - One SSD for parity
HLRE3 – Mistral...

- File system is separated into Home, Work and Scratch
  - Home for code, configuration files etc.
    - 24 GB quota per user
    - Backup
  - Work for input and output data
    - Project-specific quotas (TBs)
    - No backup
  - Scratch for temporary data
    - 15 TB quota per user
    - No backup
    - Data is deleted 14 days after last access
Policies are implemented using Robinhood
  - Quota reporting, planned for cleaning up Scratch
Currently five instances, one per MDS (phase 1)
  - Planned: Two instances for phase 1, three for phase 2
2× RAID1 with two SSDs (500 GB each)
  - One for OS (ext4), one for MariaDB (XFS)
256 GB RAM, 128 GB dedicated to Robinhood
Performance is satisfactory
  - Can scan 6,000,000 entries per hour
  - 60,000,000 entries per MDS
HLRE3 – Mistral...

- Tape system with a capacity of 200 PB
  - 15 GB/s throughput
  - No automatic HSM
- System is stable, everything works
  - Failover etc.
- Client upgrade to 2.7 is planned (October)
  - Server upgrade is currently not planned
Workflow

- Climate applications often use CDI/NetCDF/HDF
  - Supports parallel I/O via MPI-IO
- Scientists have application- and domain-specific solutions
  - I/O servers such as XIOS
- Performance is problematic
  - Most applications use serial I/O
  - Data is shipped to master process that performs I/O
  - Simply turning on parallel I/O makes it slower
Gap between computation and storage

- Capacity and performance continue to increase exponentially
  - Different components improve at different speeds
- I/O is becoming an increasingly important problem
  - Data can be produced faster but it becomes harder to store it
- Consequence: Spend more money on storage
  - Results in less available money for computation
  - Or more expensive systems overall
- Storage becomes a considerable portion of the TCO
  - Around 20% of total costs for DKRZ
- Left: Compression is only performed on the servers (status quo)
- Right: Compression can be performed on the clients (goal)
Investigated compression across the whole I/O stack [1]
  - Main memory, network, storage
  - Both performance and costs

Compression and HPC usually do not mix well
  - Modern algorithms can provide high performance

Some interesting results regarding cost efficiency
  - Still have to analyze performance impact in more detail
<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Compression</th>
<th>Decompression</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>lz4fast</td>
<td>2,945 MB/s</td>
<td>6,460 MB/s</td>
<td>1.825</td>
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<tr>
<td>lz4</td>
<td>1,796 MB/s</td>
<td>5,178 MB/s</td>
<td>1.923</td>
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<tr>
<td>lz4hc</td>
<td>258 MB/s</td>
<td>4,333 MB/s</td>
<td>2.000</td>
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<td>lzo</td>
<td>380 MB/s</td>
<td>1,938 MB/s</td>
<td>1.887</td>
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<tr>
<td>xz</td>
<td>26 MB/s</td>
<td>97 MB/s</td>
<td>2.632</td>
</tr>
<tr>
<td>zlib</td>
<td>95 MB/s</td>
<td>610 MB/s</td>
<td>2.326</td>
</tr>
<tr>
<td>zstd</td>
<td>658 MB/s</td>
<td>2,019 MB/s</td>
<td>2.326</td>
</tr>
</tbody>
</table>

- Measured using lzbench on a climate data set
- lz4 and lz4fast are suspiciously good
  - Additional benchmarks confirm results are realistic
- zstd is also interesting
  - Higher compression ratio with decent performance
- Several good candidates for archival
- **zram** can be used to compress main memory
  - lzo and lz4, multiple compression streams
  - Reach a per-node capacity of 128 GB
    - Compress as much as necessary to reach capacity target, leave remaining main memory uncompressed
    - Not possible with 64 GB (leave 4 GB uncompressed)
- Leads to more data that we have to store
I/O performance not optimal due to network layout
- Per-node throughput could be improved to roughly 100 Gbit/s (lz4fast) or 125 Gbit/s (zstd)
  - zstd limits throughput for networks faster than 54 Gbit/s
- Alternatively, FDR InfiniBand network could be replaced with QDR InfiniBand when using lz4fast, decreasing costs by 15%
Assumption: 50 PB of storage with 650 GB/s throughput

- Costs approximately €6,000,000
- Distributed across 60 SSU/ESU pairs
- Results in 833 TB and 10.8 GB/s per pair

Costs of €100,000 per SSU/ESU pair

- Assume base costs of €10,000
- Up to €90,000 for HDDs

Additional costs of €1,500 for compression

- Each pair currently equipped with two 8-core CPUs
- Dedicated or faster CPUs for compression
Scenario 1: Purchase as many fully equipped SSU/ESU pairs as necessary for 50 PB
- Lower costs: Buy the minimal amount of hardware
- Decreased throughput: Missing pairs impact performance

Scenario 2: Purchase as many HDDs as necessary for 50 PB and distribute them across 60 SSU/ESU pairs
- Slightly higher costs: Base costs for pairs
- Higher throughput: No pairs are missing
- LZ4 and LZ4Fast do not degrade performance, costs are decreased to roughly €3,500,000
- ZSTD decreases throughput by 20 GB/s and costs to €3,000,000
Conclusion

- DKRZ has one of the largest storage systems
  - Using it efficiently is sometimes problematic
- Storage systems lag behind computation
  - Problem will only get worse over time
  - Compression can help alleviate it
- We are working on compression in Lustre
  - https://wr.informatik.uni-hamburg.de/research/projects/ipcc-l/start