Machine Learning of I/O Behavior

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Goals

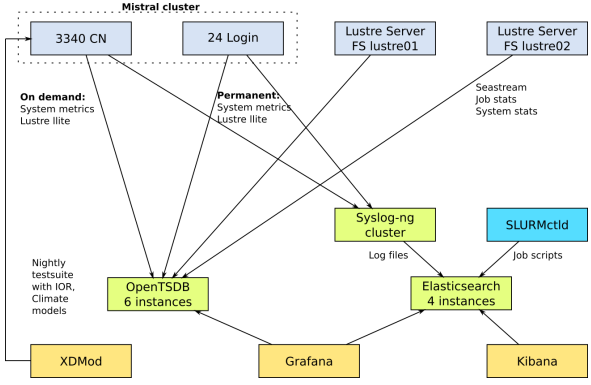
Motivation

- Understanding the workload of the Mistral Supercomputer.

Goals

- Monitoring system development
  - A flexible and extensible monitoring system
  - A portable solution for the next HPC generation
- Establishing analysis workflows
  - Identification of problematic applications and key workloads
  - Understanding of typical I/O patterns
- Tooling
  - **Automatic identification of inefficient applications** (long term goal)

DKRZ Supercomputer and Monitoring



- The Mistral Supercomputer
  - 3,340 client nodes
  - 24 login nodes
  - 2 Lustre file systems
  - Slurm workload manager
- Monitoring System is built of
  - open source components
  - a self-developed data collector
- **Provides statistics about**
  - **login nodes**
  - **user jobs**
  - **workload manager queue**

Captured I/O Metrics

- I/O metrics are captured and archived by default for each job
- Some metadata metrics are cumulated
- Relevant Lustre metrics are captured (focus on key aspects)

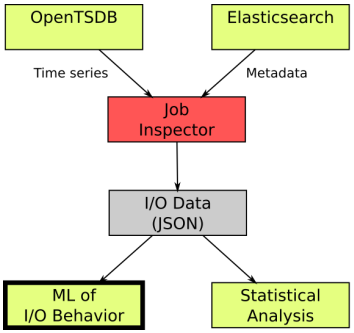
Source file: /proc/fs/lustre/llite/lustre*-*/stats

```
md_read = getattr + getxattr + readdir + statfs + listxattr + open + close
md_mod = setattr + setxattr + mkdir + link + rename + symlink + rmdir
md_file_create = create
md_file_delete = unlink
md_other = truncate + mmap + ioctl + fsync + mknod
```

Source file: /proc/fs/lustre/llite/lustre*-*/read_ahead_stats

```
osc_read_bytes, osc_read_calls
osc_write_bytes, osc_write_calls
read_bytes, read_calls
write_bytes, read_calls
seek
```

Analysis Workflow



- A daemon process iterates over all jobs
- Each job is fetched and analysed
  - Elasticsearch provides meta data
  - OpenTSDB provides I/O time series
- Output
  - I/O data is stored in separate JSON files
  - Job statistics
  - Sequence of I/O behaviour
- The tool is in an early development stage

Aggregated Data in JSON format: a Sample


```
{
 "metadata": {
   "_source": {
     "time_limit": 5400,
     "@end": "2018-12-04T11:32:23",
     "cpu_hours": 0.057778,
     "cpus_per_task": 1,
     "total_cpus": 8,
     "@eligible": "2018-12-04T11:31:23",
     "elapsed": 26,
     "jobid": 14407,
     "state": "COMPLETED",
     "jobname": "mkmpost",
     "ntasks_per_node": 8,
     "@start": "2018-12-04T11:31:57",
     "ntasks": 8,
     "groupname": "mpis",
     "nodes": " m11515 ",
     "job_name": "mkmpost",
     "user_id": 237,
     "group_id": 210,
     "exit_code": "0:0",
     "total_nodes": 1,
     "account": "ba09",
     "username": "m3"
   }}}
```

```
"ts": {
 "read_bytes": [
   {
     "metric": "host.lustre.stats.read.bytes",
     "dps": {
       "1515756295": 5104980744214,
       "1515756305": 5104980753366,
       "1515756310": 5104980867566,
       "1515756290": 5104980741946,
       "1515756300": 5104980753366
     },
     "aggregateTags": [],
     "tags": {
       "name": "lustre01",
       "system": "mistral",
       "host": "m10753"
     }
   }
 ]
}
```

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Statistical Analysis: Derived Metrics

- New metrics
  - that **provide more information**
  - e.g. "bytes/call" for read and write
- Other job characteristic metrics
  - to **identify I/O intensive jobs**
  - e.g. data read and written by a node
- Independent metrics
  - that can be used to **compare jobs**
  - e.g. average call rate done by a process

Examples: write metrics

metric	Description
'write_bytes'	Data written (job)
'write_bytes_nn'	Data written (node)
'write_bytes_ppn'	Data written (process)
'write_bytes_rate'	I/O performance (job)
'write_bytes_nn_rate'	I/O performance (node)
'write_bytes_ppn_rate'	I/O performance (process)

Statistical Analysis: Overview Dashboard

General information

Nodes	4
Processes	7
Elapsed time	4.8h

Metadata access

Metadata read ops	27 Mops
Metadata read frequency	**1537 ops/s**

Read

(Avg.) Bytes/op	**4 MB**
Total data	78 TB
(Avg.) Performance (job)	4.5 GB/s
(Avg.) Performance (node)	**1.1 GB/s**
(Avg.) Performance (process)	0.2 GB/s
Operations	19.3 Mops
(Avg.) Operation frequency	1108 ops/s

Write

(Avg.) Bytes/op	**3.3 MB**
Total data	71 TB
(Avg.) Performance (job)	4.1 GB/s
(Avg.) Performance (node)	**1.0 GB/s**
(Avg.) Performance (process)	0.1 GB/s
Operations	21.2 Mops
(Avg.) Operation frequency	1218 ops/s

Statistical approach

Cans

- Provides understandable representation of job data
- Shows many useful information, that allows
  - Identify high work loads and responsible users
  - Compare jobs

Cant's

- Provides average I/O values only
  - can't always identify bad I/O performance
  - e.g. I/O phases can be short, but fast
- Doesn't consider execution phases
  - e.g. creating checkpoints, computing, reading/writing data, ...

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Goal: Mathematical Representation of I/O Data

- Mapping of captured job data to a fixed length vector
- Each element represents weighted I/O behaviour

Goal

$$\text{footprint}(\text{jobid}) = \vec{v}_{\text{jobid}} \tag{1}$$

with $\vec{v}$ is a fixed length numeric vector

Goal: Mathematical Representation of I/O Data

- Mapping of captured job data to a fixed length vector
- Each element represents weighted I/O behaviour

Example

$$\text{footprint}(14400233) = \begin{pmatrix} X1:3 \\ X2:1 \\ X3:3 \\ X4:1 \end{pmatrix} \quad (1)$$

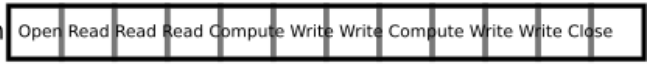
I/O Behavior

X1:	Metadata intensive
X2:	Using I/O node
X3:	Highly parallel I/O
X4:	No I/O

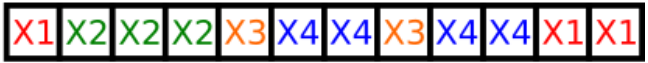
Basic Approach

1. Capturing

2. Segmentation



3. Classification



4. Labeling

X1 : 4 (Meta Data Access)

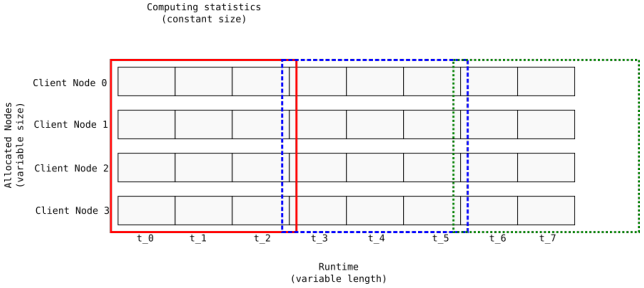
X2 : 2 (Read Intesity)

X3 : 2 (No I/O Phase)

X4 : 4 (Write Intesity)

Segmentation

- Problem
  - Number of nodes is variable
  - Segment size to large / too many segments
- Solution
  1. Split data in 2D segments
  2. Convert to $n \times n$ matrix
     - for each segment and
     - for each metric

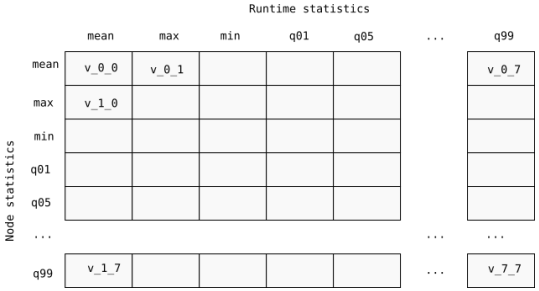


Conversion of Variable Length Vectors to Fixed Length Statistics

$$\text{stats}\left(\vec{v}\right) = \begin{pmatrix} \text{min} \\ \text{max} \\ \text{mean} \\ \text{q01} \\ \text{q10} \\ \text{q05} \\ \text{q25} \\ \text{q50} \\ \text{q75} \\ \text{q90} \\ \text{q95} \\ \text{q99} \end{pmatrix} \tag{2}$$

Computing statistics

- Statistics are organized as a 2D-matrix
- stats $(\vec{v})$ is applied to both axis
  - x-axis combines runtime
  - y-axis combines nodes
- The computation is done
  - for each segment
  - for each of 13 metrics



Resulting segment size after conversion

12 stats on x-axis * 12 stats on y-axis * 13 metrics = 1872 floating point values

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General Information about the Test Dataset

- Data from 5 days
  - from 2018-12-07 to 2018-12-13
- 70846 jobs statistics downloaded in JSON format
  - uncompressed size is 360GB
- **33193 (47%) jobs are evaluated**, that
  - contain non-empty time series and
  - and have exit status `COMPLETED`

Exit status statistics

JOBS	EXIT STATUS
1,026	CANCELLED
63,636	**COMPLETED**
5,753	FAILED
3	NODE_FAIL
426	TIMEOUT

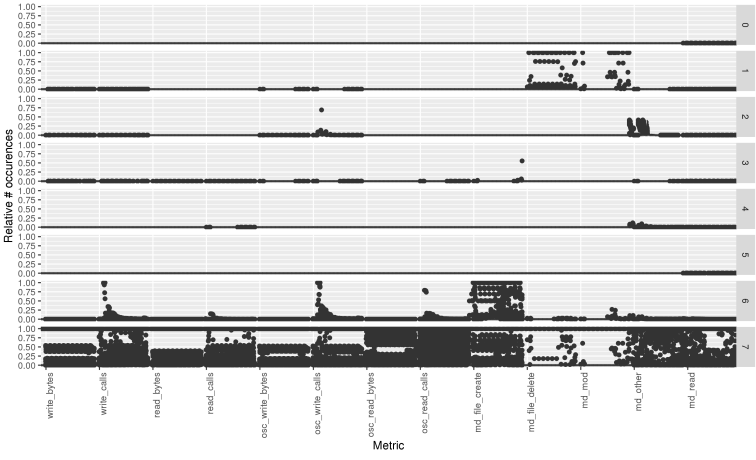
Slurm statistics

JOBS	SLURM PARTITION
37,989	**compute,compute2**
241	gpu
828	miklip
34	minerva
31,752	shared,prepost

Segmentation Parameters

- Data from 33,193 jobs is converted to 3,231,014 segments
  - Each segment is 1 minute long
  - Shorter segments are dropped
- Algorithm: kMeans (batch mode)
  - Input: segments (segment size is 1,872)
  - Output: 8 clusters

Segmentation Categories



Cat	Percent	Jobs
0	25.55	825,650
1	0.10	3,163
2	0.74	24,060
3	0.01	253
4	0.02	574
5	5.97	193,000
6	53.14	1,717,006
7	14.46	467,315

Cat	Description
0	No I/O
1	MD delete/modify
2	MD other intensive
3	Light read/write
4	Light MD other
5	No I/O
6	File create/inefficient write
7	Intensive I/O

Footprints (Example)

- Now a job can be represented as a sequence of I/O behavior.

Example

- Sequence of I/O behavior

```
[6 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 7 7 7 6 6 6 6 6 6 6 7
6 6 6 6 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
6 6 6 7 6 6 6 6 6 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 1 6 6 6 7 6 6 6 6 7 7 7 0 6 0 5 6 6 6 6 6 6
6 6 6 6 6 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 7 0 6 6 0 0 6 0 6 0 7 6 5
6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 7 6 6 6 6 6 7 6 6 6 7 6 6 6 6 6 6
6 7 6 6 6 6 6 6 6 6 6 7 6 6 6 7 6 6 6 6 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
7 6 6 6 6 7 6 6 7 6 6 7 6 6 6 6 5 0 0 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
6 6 7 0 6 0 7 0 6 0 0 0 0 6 6 6 5 0 0 5 7 5 5 7 0 0 0 0 0 5 5 6 0 0 0 7 0
7 0 0 0 5 0 0 0 7 0 0 0 0 0 0 0 0 0 5 0 0 5 0 5 0 5 0 0 5 0 0 0 0 0 0 0 0
0 7 0 0 7 5 0 7 5 0 0 5 0 0 5 0 5 0 0 5 0 0 0 0 5 0 0 5 0 0 0 5 0]
```

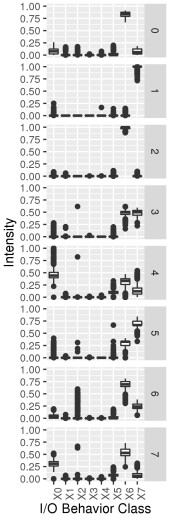
- Footprint

```
footprint(14461299) = [78, 1, 0, 0, 0, 24, 299, 38]
```

Footprint Clustering Parameters

- Footprints for each of 33193 jobs are created
- Footprints are normalized, to make them independent to job length
  - e.g. norm([78, 1, 0, 0, 0, 24, 299, 38]) = norm([156, 2, 0, 0, 0, 48, 598, 76])
- Algorithm: kMeans
  - Input: Footprints
  - Output: 8 clusters

Footprint Categories and Distribution



Footprint statistics

Cat	Percent	Jobs
0	13.32	4,192
1	6.06	1,906
2	39.34	12,384
3	7.27	2,290
4	6.25	1,968
5	9.75	3,069
6	8.91	2,805
7	9.10	2,864

I/O behavior

Cat	Description
X0	No I/O
X1	MD delete/modify
X2	MD other intensive
X3	Light read/write
X4	Light MD other
X5	No I/O
X6	File create/inefficient write
X7	Intensive I/O

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Summary

- DKRZ monitoring system
  - **Open source** components + self-developed collector
  - **Portable** to the next HPC and other machines
- Statistical approach is a good way to
  - **Identify large workloads**
  - **Find users** who create large workloads
  - **Compare jobs**
- Job-Footprinting
  - **Categorization** of jobs