Faculty of Informatics

Understanding and Comparing Unsuccessful Executions in Large Datacenters

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Abstract

The project aims at comparing two different traces coming from large datacenters, focusing in particular on unsuccessful executions of jobs and tasks submitted by users. The objective of this project is to compare the resource waste caused by unsuccessful executions, their impact on application performance, and their root causes. We will show the strong negative impact on CPU and RAM usage and on task slowdown. We will analyze patterns of unsuccessful jobs and tasks, particularly focusing on their interdependency. Moreover, we will uncover their root causes by inspecting key workload and system attributes such asmachine locality and concurrency level.

Advisor Prof. Walter Binder Assistant Dr. Andrea Rosá

Advisor's approval (Prof. Walter Binder):

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1 Introduction (including Motivation)

2 State of the Art

2.1 Introduction

TBD

2.2 Rosà et al. 2015 DSN paper

In 2015, Dr. Andrea Rosà, Lydia Y. Chen, Prof. Walter Binder published a research paper titled "Understanding the Dark Side of Big Data Clusters: An Analysis beyond Failures" performing several analysis on Google's 2011 Borg cluster traces. The salient conclusion of that research is that lots of computation performed by Google would eventually fail, leading to large amounts of computational power being wasted.

Our aim with this thesis is to repeat the analysis performed in 2015 on the new 2019 dataset to find similarities and differences with the previous analysis, and ulimately find if computational power is indeed wasted in this new workload as well.

2.3 Google Borg

Borg is Google's own cluster management software. Among the various cluster management services it provides, the main ones are: job queuing, scheduling, allocation, and deallocation due to higher priority computations.

The data this thesis is based on is from 8 Borg "cells" (i.e. clusters) spanning 8 different datacenters, all focused on "compute" (i.e. computational oriented) workloads. The data collection timespan matches the entire month of May 2019.

In Google's lingo a "job" is a large unit of computational workload made up of several "tasks", i.e. a number of executions of single executables running on a single machine. A job may run tasks sequentially or in parallel, and the condition for a job's succesful termination is nontrivial.

Both tasks and jobs lifecyles are represented by several events, which are encoded and stored in the trace as rows of various tables. Among the information events provide, the field "type" provides information on the execution status of the job or task. This field can have the following values:

Type code	Description
QUEUE	The job or task was marked not eligible for scheduling by Borg's scheduler, and
	thus Borg will move the job/task in a long wait queue
SUBMIT	The job or task was submitted to Borg for execution
ENABLE	The job or task became eligible for scheduling
SCHEDULE	The job or task's execution started
EVICT	The job or task was terminated in order to free computational resources for an
	higher priority job
FAIL	The job or task terminated its execution unsuccesfully due to a failure
FINISH	The job or task terminated succesfully
KILL	The job or task terminated its execution because of a manual request to stop it
LOST	It is assumed a job or task is has been terminated, but due to missing data there is
	insufficent information to identify when or how
UPDATE_PENDING	The metadata (scheduling class, resource requirements,) of the job/task was
	updated while the job was waiting to be scheduled
UPDATE_RUNNING	The metadata (scheduling class, resource requirements,) of the job/task was
	updated while the job was in execution

Figure 1 shows the expected transitions between event types.

2.4 Traces contents

The traces provided by Google contain mainly a collection of job and task events spanning a month of execution of the 8 different clusters. In addition to this data, some additional data on the machines' configuration in terms of resources (i.e. amount of CPU and RAM) and additional machine-related metadata.

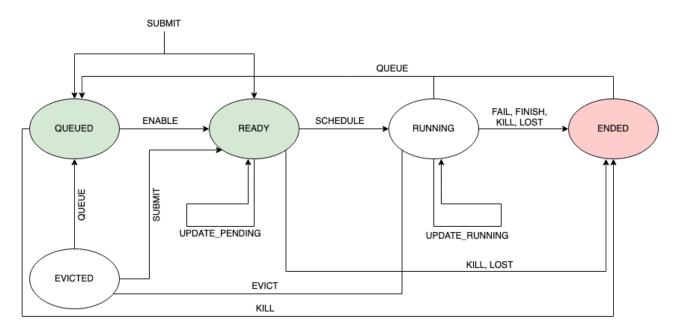


Figure 1. Typical transitions between task/job event types according to Google

Due to Google's policy, most identification related data (like job/task IDs, raw resource amounts and other text values) were obfuscated prior to the release of the traces. One obfuscation that is noteworthy in the scope of this thesis is related to CPU and RAM amounts, which are expressed respetively in NCUs (*Normalized Compute Units*) and NMUs (*Normalized Memory Units*).

NCUs and NMUs are defined based on the raw machine resource distributions of the machines within the 8 clusters. A machine having 1 NCU CPU power and 1 NMU memory size has the maximum amount of raw CPU power and raw RAM size found in the clusters. While RAM size is measured in bytes for normalization purposes, CPU power was measured in GCU (*Google Compute Units*), a proprietary CPU power measurement unit used by Google that combines several parameters like number of processors and cores, clock frequency, and architecture (i.e. ISA).

2.5 Overview of traces' format

The traces have a collective size of approximately 8TiB and are stored in a Gzip-compressed JSONL (JSON lines) format, which means that each table is represented by a single logical "file" (stored in several file segments) where each carriage return separated line represents a single record for that table.

There are namely 5 different table "files":

machine_configs, which is a table containing each physical machine's configuration and its evolution over time;

- instance_events, which is a table of task events;
- collection_events, which is a table of job events;
- machine_attributes, which is a table containing (obfuscated) metadata about each physical machine and its evolution over time;

instance_usage, which contains resource (CPU/RAM) measures of jobs and tasks running on the single machines.

The scope of this thesis focuses on the tables machine_configs, instance_events and collection_events.

2.6 Remark on traces size

While the 2011 Google Borg traces were relatively small, with a total size in the order of the tens of gigabytes, the 2019 traces are quite challenging to analyze due to their sheer size. As stated before, the traces have a total size of 8 TiB when stored in the format provided by Google. Even when broken down to table "files", unitary sizes still reach the single tebibyte mark (namely for machine_configs, the largest table in the trace).

Due to this constraints, a careful data engineering based approach was used when reproducing the 2015 DSN paper analysis. Bleeding edge data science technologies like Apache Spark were used to achieve efficient and parallelized computations. This approach is discussed with further detail in the following section.

3 Project requirements and analysis

TBD (describe our objective with this analysis in detail)

4 Analysis methodology

Due to the inherent complexity in analyzing traces of this size, novel bleeding-edge data engineering tecniques were adopted to performed the required computations. We used the framework Apache Spark to perform efficient and parallel Map-Reduce computations. In this section, we discuss the technical details behind our approach.

4.1 Introduction on Apache Spark

Apache Spark is a unified analytics engine for large-scale data processing. In layman's terms, Spark is really useful to parallelize computations in a fast and streamlined way.

In the scope of this thesis, Spark was used essentially as a Map-Reduce framework for computing aggregated results on the various tables. Due to the sharded nature of table "files", Spark is able to spawn a thread per file and run computations using all processors on the server machines used to run the analysis.

Spark is also quite powerful since it provides automated thread pooling services, and it is able to efficiently store and cache intermediate computation on secondary storage without any additional effort required from the data engineer. This feature was especially useful due to the sheer size of the analyzed data, since the computations required to store up to 1TiB of intermediate data on disk.

The chosen programming language for writing analysis scripts was Python. Spark has very powerful native Python bindings in the form of the *PySpark* API, which were used to implement the various queries.

4.2 Query architecture

4.2.1 Overview

In general, each query written to execute the analysis follows a general Map-Reduce template.

Traces are first read, then parsed, and then filtered by performing selections, projections and computing new derived fields. After this preparation phase, the trace records are often passed through a groupby() operation, which by choosing one or many record fields sorts all the records into several "bins" containing records with matching values for the selected fields. Then, a map operation is applied to each bin in order to derive some aggregated property value for each grouping. Finally, a reduce operation is applied to either further aggregate those computed properties or to generate an aggregated data structure for storage purposes.

4.2.2 Parsing table files

As stated before, table "files" are composed of several Gzip-compressed shards of JSONL record data. The specification for the types and constraints of each record is outlined by Google in the form of a protobuffer specification file found in the trace release package.¹. This file was used as the oracle specification and was a critical reference for writing the query code that checks, parses and carefully sanitizes the various JSONL records prior to actual computations.

The JSONL encoding of traces records is often performed with non-trivial rules that required careful attention. One of these involved fields that have a logically-wise "zero" value (i.e. values like "0" or the empty string). For these values the key-value pair in the JSON object is outright omitted. When reading the traces in Apache Spark is therefore necessary to check for this possibility and insert back the omitted record attributes.

4.2.3 The queries

Most queries use only two or three fields in each trace records, while the original table records often are made of a couple of dozen fields. In order to save memory during the query, a projection is often applied to the data by the means of a .map() operation over the entire trace set, performed using Spark's RDD API.

Another operation that is often necessary to perform prior to the Map-Reduce core of each query is a record filtering process, which is often motivated by the presence of incomplete data (i.e. records which contain fields whose values is unknown). This filtering is performed using the .filter() operation of Spark's RDD API.

¹Google 2019 Borg traces Protobuffer specification on Github

The core of each query is often a groupby() followed by a map() operation on the aggregated data. The groupby() groups the set of all records into several subsets of records each having something in common. Then, each of this small clusters is reduced with a map() operation to a single record. The motivation behind this way of computing data is that for the analysis in this thesis it is often necessary to analyze the behaviour w.r.t. time of either task or jobs by looking at their events. These queries are therefore implemented by groupby()-ing records by task or job, and then map()-ing each set of event records sorting them by time and performing the desired computation on the obtained chronological event log.

Sometimes intermediate results are saved in Spark's parquet format in order to compute and save intermediate results beforehand.

4.3 Query script design

In this section we aim to show the general complexity behind the implementations of query scripts by explaining in detail some sampled scripts to better appreciate their behaviour.

4.3.1 The "task slowdown" query script

One example of analysis script with average complexity and a pretty straightforward structure is the pair of scripts task_slowdown.py and task_slowdown_table.py used to compute the "task slowdown" tables (namely the tables in figure 6).

"Slowdown" is a task-wise measure of wasted execution time for tasks with a FINISH termination type. It is computed as the total execution time of the task divided by the execution time actually needed to complete the task (i.e. the total time of the last execution attempt, successful by definition).

The analysis requires to compute the mean task slowdown for each task priority value, and additionally compute the percentage of tasks with successful terminations per priority. The query therefore needs to compute the execution time of each execution attempt for each task, determine if each task has successful termination or not, and finally combine this data to compute slowdown, mean slowdown and ultimately the final table found in figure 6.

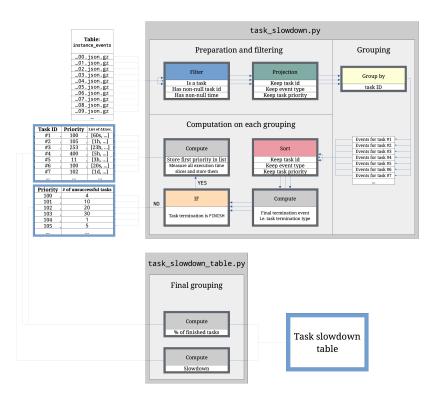


Figure 2. Diagram of the script used for the "task slowdown" query.

Figure 2 shows a schematic representation of the query structure.

The query first starts reading the instance_events table, which contains (among other data) all task event logs

containing properties, event types and timestamps. As already explained in the previous section, the logical table file is actually stored as several Gzip-compressed JSONL shards. This is very useful for processing purposes, since Spark is able to parse and load in memory each shard in parallel, i.e. using all processing cores on the server used to run the queries.

After loading the data, a selection and a projection operation are performed in the preparation phase so as to "clean up" the records and fields that are not needed, leaving only useful information to feed in the "group by" phase. In this query, the selection phase removes all records that do not represent task events or that contain an unknown task ID or a null event timestamp. In the 2019 traces it is quite common to find incomplete records, since the log process is unable to capture the sheer amount of events generated by all jobs in a exact and deterministic fashion.

Then, after the preparation stage is complete, the task event records are grouped in several bins, one per task ID. Performing this operation the collection of unsorted task event types is rearranged to form groups of task events all relating to a single task.

These obtained collections of task events are then sorted by timestamp and processed to compute intermediate data relating to execution attempt times and task termination counts. After the task events are sorted, the script iterates over the events in chronological order, storing each execution attempt time and registering all execution termination types by checking the event type field. The task termination is then equal to the last execution termination type, following the definition originally given in the 2015 Rosá et al. DSN paper.

If the task termination is determined to be unsuccessful, the tally counter of task terminations for the matching task property is increased. Otherwise, all the task termination attempt time deltas are returned. Tallies and time deltas are saved in an intermediate time file for fine-grained processing.

Finally, the task_slowdown_table.py processes this intermediate results to compute the percentage of successful tasks per execution and computing slowdown values given the previously computed execution attempt time deltas. Finally, the mean of the computed slowdown values is computed resulting in the clear and coincise tables found in figure 6.

4.4 Ad-Hoc presentation of some analysis scripts

TBD (with diagrams)

5 Analysis and observations

5.1 Overview of machine configurations in each cluster

Refer to figure 3.

Observations:

- machine configurations are definitely more varied than the ones in the 2011 traces
- some clusters have more machine variability

5.2 Analysis of execution time per each execution phase

Refer to figures 4 and 5.

Observations:

- Across all cluster almost 50% of time is spent in "unknown" transitions, i.e. there are some time slices that are related to a state transition that Google says are not "typical" transitions. This is mostly due to the trace log being intermittent when recording all state transitions.
- 80% of the time spent in KILL and LOST is unknown. This is predictable, since both states indicate that the job execution is not stable (in particular LOST is used when the state logging itself is unstable)
- From the absolute graph we see that the time "wasted" on non-finish terminated jobs is very significant
- Execution is the most significant task phase, followed by queuing time and scheduling time ("ready" state)
- In the absolute graph we see that a significant amount of time is spent to re-schedule evicted jobs ("evicted" state)
- Cluster A has unusually high queuing times

CPU (NCU)	RAM (NMU)	Machine count	% Machines
Unknown	Unknown	8729	1.639218%
1.000000	0.500000	124234	23.329891%
0.591797	0.333496	103013	19.344801%
0.259277	0.166748	78078	14.662260%
0.708984	0.333496	55801	10.478864%
0.386719	0.333496	36237	6.804943%
0.958984	0.500000	31151	5.849843%
0.708984	0.666992	29594	5.557454%
0.386719	0.166748	27011	5.072393%
1.000000	1.000000	12286	2.307187%
0.591797	0.166748	9902	1.859496%
1.000000	0.250000	7550	1.417814%
0.958984	1.000000	3552	0.667030%
0.259277	0.333496	3024	0.567877%
0.591797	0.666992	1000	0.187790%
0.259277	0.083374	634	0.119059%
0.958984	0.250000	600	0.112674%
0.500000	0.062500	54	0.010141%
0.500000	0.250000	34	0.006385%
0.479492	0.250000	12	0.002253%
0.708984	0.250000	6	0.001127%
0.591797	0.250000	4	0.000751%
0.708984	0.500000	2	0.000376%
0.479492	0.500000	2	0.000376%

Unknown	Unknown	1377	1.623170%	CPU (NCU
0.591797	0.333496	29487	34.758469%	Unknown
1.000000	0.500000	13440	15.842705%	0.591797
0.708984	0.333496	12495	14.728764%	1.000000
0.386719	0.333496	9057	10.676144%	0.708984
0.386719	0.166748	5265	6.206238%	0.958984
0.708984	0.666992	4608	5.431784%	0.708984
1.000000	1.000000	4446	5.240823%	1.000000
0.591797	0.166748	2484	2.928071%	0.591797

1143

654

366

6 6

Machine count

% Machines

1.347337%

0.770917%

0.431431%

0.007073% 0.007073%

% Machines

0.794309%

45.288376%

13.401174%

12.791885% 9.260559%

6.986092%

6.258772%

4.064055%

0.679469%

0.465739% 0.006380%

0.003190%

CPU (NCU)

0.386719

0.958984

0.591797

0.386719

CPU (NCU)

Unknown

0.259277

0.708984

0.958984

0.708984 1.000000

0.386719 0.259277

0.259277 0.591797

1.0000001.000000

0.500000

RAM (NMU)

Unknowr

0.333496

0.500000

0.333496

0.500000

0.666992

1.000000

0.166748

0.333496

1.000000

0.666992

RAM (NMU)

Unknown

0.166748

0.333496

0.500000

0.666992

0.500000

0.166748

0.333496

0.083374

0.333496

0.250000 1.000000

0.062500

Machine count

134

16184

9790

8448

5502

3832

2214

2152

816

618

500

412

% Machines

0.264812% 31.982926%

19.347061% 16.694992%

10.873088% 7.572823% 4.375321%

4.252796%

1.612584%

1.221296%

0.988103%

0.814197%

% Machines

0.671915%

48.202377%

14.774608%

10.838389%

9.534674% 7.002457%

5.603470%

1.589530%

0.794765% 0.406158%

0.335957% 0.172993%

0.067693% 0.005014%

RAM (NMU)

0.500000

1.000000

0.250000

0.250000

0.250000

RAM (NMU)

Unknown

0.333496

0.333496

0.166748

0.166748

0.666992

0.333496

0.166748 0.333496

0.500000 0.250000

0.500000

CPU (NCU)

0.958984

0.958984

1.000000

0.479492 0.708984

(b) A c	luster
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498

28394

8402

8020

5806

4380

3924

2548

426

292 4

2

Machine count

(c) Cluster B

536

38452

11786

8646

7606

5586

4470

1268

634 324

268 138

54 4

Machine count

	CPU (NCU)	RAM (NMU)	Machine count	% Machines	
1	Unknown	Unknown	1466	2.274208%	CPU (NCU)
(0.259277	0.166748	15754	24.439204%	Unknown
(0.386719	0.333496	11104	17.225652%	0.591797
(0.591797	0.333496	10404	16.139741%	0.386719
(0.958984	0.500000	6634	10.291334%	0.259277
1	1.000000	0.500000	5654	8.771059%	0.386719
(0.386719	0.166748	3580	5.553660%	0.708984
(0.708984	0.666992	2900	4.498774%	0.708984
1	1.000000	1.000000	2736	4.244361%	0.591797
1	1.000000	0.250000	2132	3.307375%	0.259277
(0.958984	1.000000	766	1.188297%	1.000000
(0.708984	0.333496	620	0.961807%	0.591797
(0.958984	0.250000	600	0.930781%	0.708984
	0.591797	0.166748	112	0.173746%	

(a) All clusters

(d) Cluster C

(e) Cluster D

(f) Cluster E

				CPU (NCU)	RAM (NMU)	Machine count	% Machines				
				Unknown	Unknown	1566	2.261568%				
CPU (NCU)	RAM (NMU)	Machine count	% Machines	0.259277	0.166748	15852	22.892958%	CPU (NCU)	RAM (NMU)	Machine count	% Machines
Unknown	Unknown	1432	2.299958%	1.000000	0.500000	11808	17.052741%	Unknown	Unknown	1720	2.933251%
1.000000	0.500000	41340	66.396839%	0.708984	0.333496	7968	11.507134%	1.000000	0.500000	36324	61.946178%
				0.591797	0.333496	7830	11.307839%				
0.708984	0.333496	6878	11.046866%	0.386719	0.166748	4690	6.773150%	0.591797	0.333496	4826	8.230158%
0.591797	0.333496	5564	8.936430%	0.708984	0.666992	4258	6.149269%	0.708984	0.333496	3682	6.279205%
0.958984	0.500000	2172	3.488484%	0.958984	0.500000	4196	6.059731%	0.958984	0.500000	2858	4.873973%
0.386719	0.166748	1544	2.479843%	0.386719	0.333496	3864	5.580267%	0.386719	0.333496	2596	4.427163%
0.708984	0.666992	1244	1.998008%	0.591797	0.166748	2606	3.763503%	1.000000	1.000000	2030	3.461919%
1.000000	0.250000	792	1.272044%					1.000000	0.250000	1892	3.226577%
0.958984	1.000000	536	0.860878%	1.000000	0.250000	2100	3.032754%	0.386719	0.166748	1244	2.121491%
0.386719	0.333496	398	0.639234%	0.259277	0.333496	1330	1.920744%	0.708984	0.666992	766	1.306320%
1.000000	1.000000	344	0.552504%	0.958984	1.000000	778	1.123563%	0.591797	0.666992	500	0.852689%
0.500000	0.250000	18	0.028910%	1.000000	1.000000	378	0.545896%	0.958984	1.000000	200	0.341076%
0.500000	0.230000	10	0.020/10/0	0.500000	0.250000	12	0.017330%	0.750704	1.000000	200	0.54107070
				0.479492	0.250000	6	0.008665%				
				0.479492	0.500000	2	0.002888%				

(g) Cluster F

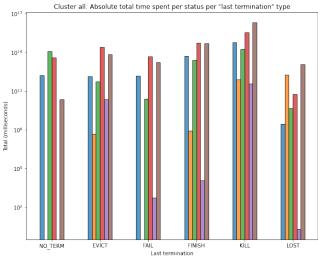
(h) Cluster G

(i) Cluster H

Figure 3. Overview of machine configurations in terms of CPU and RAM resources for each cluster

Color	Execution phase
Blue	Queued
Orange	Ended
Green	Ready
Red	Running
Violet	Evicted
Brown	Unknown

(a) Execution state legend for the graphs



(b) All clusters

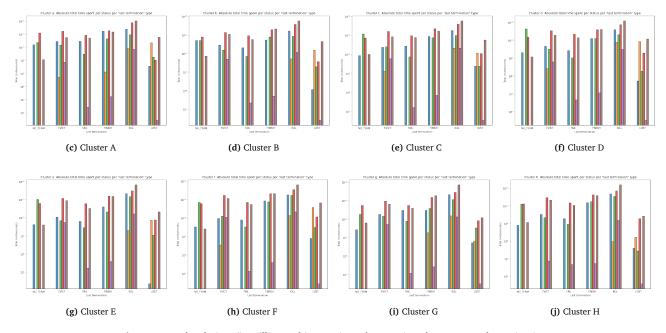
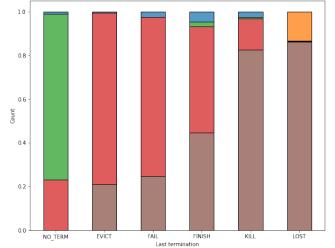


Figure 4. Total task time (in milliseconds) spent in each execution phase w.r.t. task termination.

Color	Execution phase
Blue	Queued
Orange	Ended
Green	Ready
Red	Running
Violet	Evicted
Brown	Unknown

(a) Execution state legend for the graphs



Cluster all: Relative total time spent per status per "last termination" type

(b) All clusters

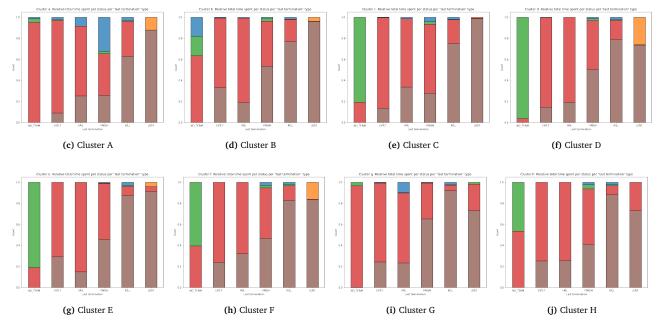


Figure 5. Relative task time (in milliseconds) spent in each execution phase w.r.t. task termination.

Priority	% finished tasks	Mean slowdown	Priority	% finished tasks	Mean slowdown	Priority	% finished tasks	Mean slowdown	Priority	% finished tasks	Mean slowdown
Unknown	10.620113%	1.097556	Filolity			Fliolity			Fliolity		
24	0.000000%	_	0	45.193049%	1.176397	0	50.887820%	1.105787	0	26.522899%	1.116002
25	0.333054%	82.973285	25	0.018094%	133.481864	3	0.000000%	-	5	0.00000%	-
100	0.000000%	-	80	0.000000%	-	10	0.000000%	-	25	16.293068%	65.676400
101	81.917703%	30.798089	100	0.000000%	-	25	22.468276%	8.191258	100	0.00000%	-
102	0.000000%	-	101	66.479321%	433.414195	100	0.000000%	-	101	45.314870%	315.954065
103	14.990678%	1.130579	103	0.106377%	1.645114	101	52.628263%	421.490544	103	0.004540%	1.065721
105	57.678214%	1.078733	105	0.463292%	2.408090	103	0.005336%	2.794339	105	0.051712%	2.897040
107	53.926543%	1.016187	107	0.000000%	-	105	0.023521%	1.372291	107	0.000350%	1.551354
114	0.00000%	-	114	0.676897%	1.003422	107	0.000245%	14.708268	114	0.000000%	-
115	4.108501%	1.004324	115	4.117647%	5.916852	114	0.022221%	1.011266	115	5.189033%	2.186562
116	13.045304%	1.032749	116	8.316438%	1.109652	115	0.281832%	1.980743	116	0.126154%	1.278510
117	0.000000%	-	117	0.000000%	-	116	0.013836%	1.022119	117	85.714286%	1.000000
118	11.907081%	1.003494	118	0.311290%	1.000000	117	93.165468%	1.000000	118	0.054055%	2.048749
119	21.264583%	1.504923	119	0.195997%	2.555160	118	0.004137%	1.100009	119	0.441844%	3.020486
170	0.00000%	-	170	0.000000%	-	119	2.215917%	2.044049	197	0.000000%	-
200	27.211754%	4.116760	199	0.000000%	-	170	0.000000%	-	199	0.000000%	-
205	0.00000%	-	200	30.916717%	9.707524	200	3.606796%	4.139724	200	6.528759%	5.514350
210	0.00000%	-	205	0.000000%	-	205	0.000000%	-	205	0.000000%	-
214	0.000000%	-	210	0.000000%	-	210	0.000000%	_	210	0.000000%	-
215	0.00000%	-	214	0.000000%	-	214	0.000000%	_	214	0.000000%	-
360	0.616372%	2.924018	215	0.000000%	-	215	0.000000%	_	215	0.000000%	-
400	0.000000%	-	360	3.502999%	1.612147	360	4.367418%	2.061085	360	1.594977%	2.476706
450	2.203423%	1.142450	450	0.612913%	1.057515	450	1.512578%	1.066014	450	0.611145%	1.330248
500	0.000000%	-			1.007.010		2.01207070	1.000011			1.000210
	(a) Cluster	Δ		(b) Cluste	r B		(c) Cluster	r C		(d) Cluster	r D

(a) Cluster A

% finished tasks Mean slowdown Priority 42.805214% 1.439544 5.344531% % finished tasks 25 2.676136 % finished tasks Mean slowdown Priority Mean slowdown Priority % finished tasks Mean slowdown Priority 100 0.000000% 27.744380% 1.122458 45.208221% 1.088162 33.612201% 1.138988 0 0 101 103 0.015918% 1 122507 25 0.647505% 2.230960 25 0.233338% 8.692558 19 0.000000% 0.021660% 3.163046 0.000000% 1.042767% 3.064188 100 50 0.000000% 25 105 0.404803% 14.750313 323 858714 101 40 296631% 100 0.000000% 101 100.000000% 76.438090 107 114 0.000000% 0.000000% 0.058418% 101 96.470338% 19.378523 103 0.481256% 1.262067 103 1.167347 1.550453 4.205547 105 0.222372% 103 0.032539% 1.271282 105 1.427256% 115 0.027326% 1.000000 107 114 105 107 107 115 0.060860% 1.012727 0.196286% 1.000738 0.000000% 116 117 0.000000% 0.006958% 5.122494% 1.000000 0.000000% 1.000000 0.000000% 115 3.647104% 5.094215 114 0.000000% 116 1.035309% 73.447995 118 0.000000% 1.000000 1.947121 7.301093 116 117 0.000000% 115 117 7.633588% 1.802068 117 0.000050% 119 0.458256% 10.310893 0.000086% 1.000000 0.000000% 118 1.003331% 170 0.000000% 3.877102 118 0.002082% 1.000000 118 48.969072% 119 0.145214% 200 1 959258% 8 535722 31.354662% 119 0.085944% 3.166077 2.702770% 119 7.608799 200 5.798142 201 0.000000% 3.653528% 5.943247 200 170 201 0.000000% 205 0.000000% 201 360 450 0.000000% 200 360 26.747126% 14.573912 220 0.000000% 210 210 215 0.000000% 7.424790% 0.992623% 2.171524 1.021053 1.618878% 2.737219% 2.119524 4.425746% 2.018441 360 0.000000% 450 450 0 535389% 1 054678 220 0.000000% 360 450 37.157031% 0.548458% 2.873243 1.113283 (f) Cluster F (g) Cluster G (h) Cluster H

(e) Cluster E

Figure 6. Mean task slowdown for each cluster and each task priority

5.3 Task slowdown

Refer to figure 6

Observations:

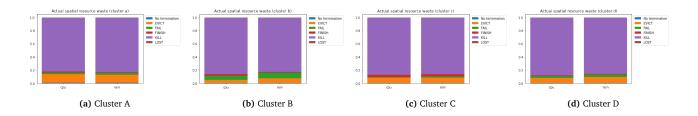
- Priority values are different from 0-11 values in the 2011 traces. A conversion table is provided by Google;
- For some priorities (e.g. 101 for cluster D) the relative number of finishing task is very low and the mean slowdown is very high (315). This behaviour differs from the relatively homogeneous values from the 2011 traces.
- · Some slowdown values cannot be computed since either some tasks have a Ons execution time or for some priorities no tasks in the traces terminate successfully. More raw data on those exception is in Jupyter.
- The % of finishing jobs is relatively low comparing with the 2011 traces.

Reserved and actual resource usage of tasks 5.4

Refer to figures 7 and 8.

Observations:

- Most (mesasured and requested) resources are used by killed job, even more than in the 2011 traces.
- Behaviour is rather homogeneous across datacenters, with the exception of cluster G where a lot of LOSTterminated tasks acquired 70% of both CPU and RAM



Task termination	% CPU	% RAM	Task termination	% CPU	% RAM	Task termination	% CPU	% RAM	Task termination	% CPU	% RAM
No termination	0.6972%	1.0447%	No termination	0.2582%	0.4637%	No termination	0.3376%	0.3812%	No termination	0.4995%	0.4822%
Evict	13.4392%	11.8184%	Evict	4.8340%	7.3120%	Evict	8.2099%	8.0454%	Evict	7.6002%	9.0656%
Fail	2.2792%	2.8387%	Fail	6.2950%	8.3841%	Fail	1.2294%	2.0809%	Fail	3.0288%	3.9214%
Finish	1.3963%	1.1066%	Finish	2.5877%	1.2231%	Finish	2.9399%	3.3249%	Finish	0.8666%	0.8914%
Kill	82.1791%	83.1826%	Kill	86.0215%	82.6144%	Kill	87.2740%	86.1588%	Kill	88.0011%	85.6364%
Lost	0.0091%	0.0091%	Lost	0.0036%	0.0027%	Lost	0.0093%	0.0088%	Lost	0.0039%	0.0030%

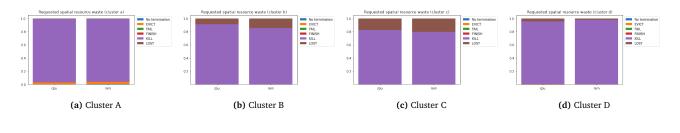
(e) Cluster A (exact values)

(f) Cluster B (exact values)

(g) Cluster C (exact values)

(h) Cluster D (exact values)

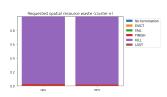
Figure 7. Relative usage of CPU and RAM resources w.r.t. final task termination.



Task termination	% CPU	% RAM	Task termination	% CPU	% RAM	Task termination	% CPU	% RAM	Task termination	% CPU	% RAM
No termination	0.033962%	0.193674%	No termination	0.000094%	0.000191%	No termination	0.000105%	0.000221%	No termination	0.000948%	0.000128%
Evict	2.838362%	3.399075%	Evict	0.003365%	0.004696%	Evict	0.008618%	0.006991%	Evict	0.046057%	0.006352%
Fail	0.058335%	0.069755%	Fail	0.003061%	0.004965%	Fail	0.001261%	0.001459%	Fail	0.023703%	0.002770%
Finish	0.000102%	0.000151%	Finish	0.012696%	0.017647%	Finish	0.015047%	0.017003%	Finish	0.095353%	0.012975%
Kill	96.661332%	95.799104%	Kill	91.094839%	85.573746%	Kill	82.483146%	79.698011%	Kill	95.468127%	97.927565%
Lost	0.407908%	0.538242%	Lost	8.885947%	14.398756%	Lost	17.491823%	20.276314%	Lost	4.365813%	2.050210%
Lost	0.407908%	0.538242%	Lost	8.885947%	14.398756%	Lost	17.491823%	20.276314%	Lost	4.365813%	2.05021

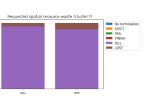
08

(e) Cluster A (exact values)



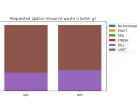
(i) Cluster E

(f) Cluster B (exact values)



(j) Cluster F

(g) Cluster C (exact values)



(k) Cluster G

(h) Cluster D (exact values)

Task termination	% CPU	% RAM	Task termination	% CPU	% RAM	Task termination	% CPU	% RAM	Task termination	% CPU	% RAM
No termination	0.015102%	0.016472%	No termination	0.000114%	0.000306%	No termination	0.001283%	0.000748%	No termination	0.000148%	0.000022%
Evict	0.362088%	0.321274%	Evict	0.007986%	0.013466%	Evict	0.034040%	0.025278%	Evict	0.006021%	0.000751%
Fail	0.051373%	0.047377%	Fail	0.000913%	0.002064%	Fail	0.004384%	0.003918%	Fail	0.000858%	0.000144%
Finish	1.672195%	1.310360%	Finish	0.013296%	0.021751%	Finish	0.176091%	0.166656%	Finish	0.015642%	0.001873%
Kill	97.899179%	98.304482%	Kill	94.396548%	90.227868%	Kill	27.376816%	30.954255%	Kill	78.910066%	97.713322%
Lost	0.000063%	0.000034%	Lost	5.581144%	9.734546%	Lost	72.407386%	68.849146%	Lost	21.067264%	2.283888%

(m) Cluster E (exact values)

(n) Cluster F (exact values)

(o) Cluster G (exact values)

(p) Cluster H (exact values)

Figure 8. Relative request of CPU and RAM resources prior to tasks' execution w.r.t. final task termination.

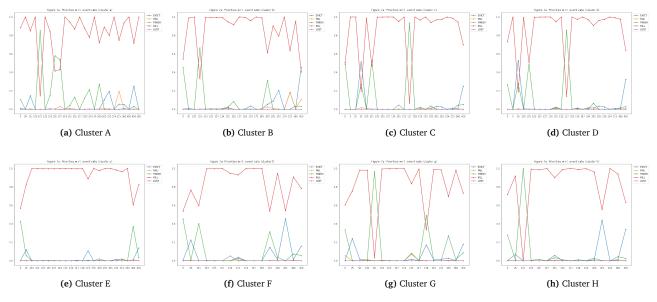


Figure 9. Task event rates vs. task priority and final task termination

5.5 Correlation between task events' metadata and task termination

Refer to figures 9, 10, and 11.

Observations:

- No smooth curves in this figure either, unlike 2011 traces
- The behaviour of curves for 7a (priority) is almost the opposite of 2011, i.e. in-between priorities have higher kill rates while priorities at the extremum have lower kill rates. This could also be due bt the inherent distribution of job terminations;
- Event execution time curves are quite different than 2011, here it seems there is a good correlation between short task execution times and finish event rates, instead of the U shape curve in 2015 DSN
- In figure 10 cluster behaviour seems quite uniform
- Machine concurrency seems to play little role in the event termination distribution, as for all concurrency factors the kill rate is at 90%.

5.6 Correlation between task events' resource metadata and task termination

5.7 Correlation between job events' metadata and job termination

Refer to figures 12, 13, and 14.

Observations:

- Behaviour between cluster varies a lot
- There are no "smooth" gradients in the various curves unlike in the 2011 traces
- Killed jobs have higher event rates in general, and overall dominate all event rates measures
- There still seems to be a correlation between short execution job times and successfull final termination, and likewise for kills and higher job terminations
- Across all clusters, a machine locality factor of 1 seems to lead to the highest success event rate

5.8 Mean number of tasks and event distribution per task type

Refer to figure 15.

Observations:

• The mean number of events per task is an order of magnitude higher than in the 2011 traces

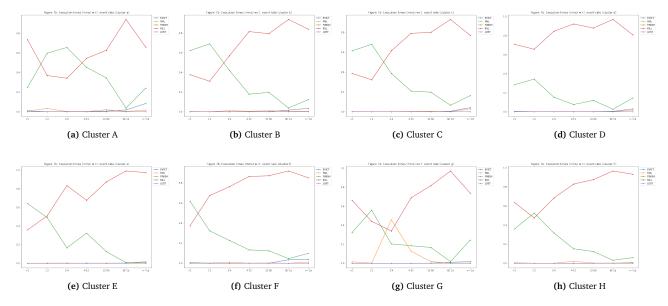


Figure 10. Task event rates vs. event execution time and final task termination

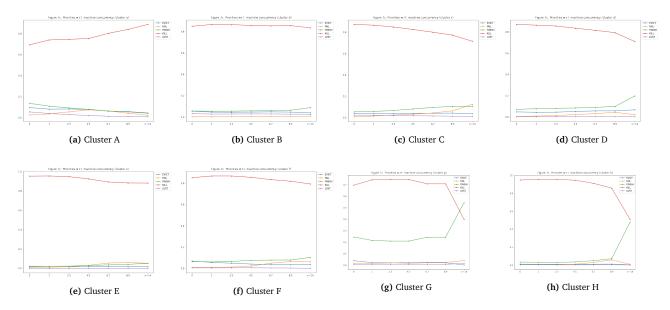


Figure 11. Task event rates vs. machine concurrency and final task termination

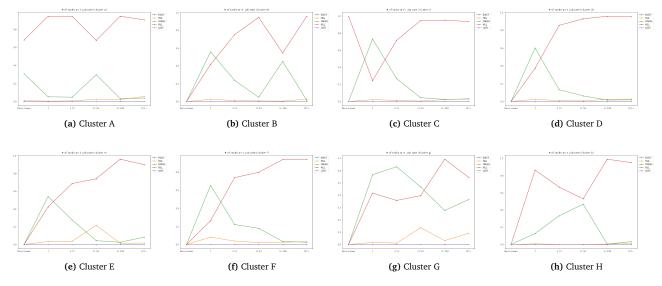


Figure 12. Job event rates vs. job size and final job termination

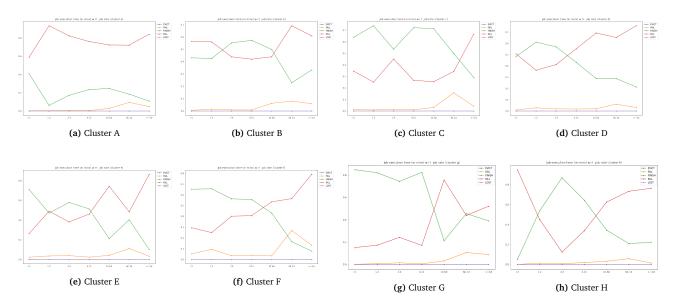


Figure 13. Job event rates vs. event execution time and final job termination

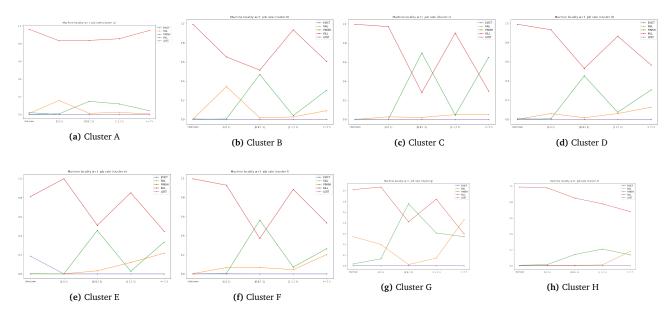


Figure 14. Job event rates vs. machine locality and final job termination

- Generally speaking, the event type with higher mean is the termination event for the task
- The # evts mean is higher than the sum of all other event type means, since it appears there are a lot more non-termination events in the 2019 traces.

5.9 Mean number of tasks and event distribution per job type

Refer to figure 16.

Observations:

- Again the mean number of tasks is significantly higher than the 2011 traces, indicating a higher complexity of workloads
- Cluster A has no evicted jobs
- The number of events is however lower than the event means in the 2011 traces

5.10 Probability of task successful termination given its unsuccesful events

Refer to figure 17.

Observations:

- Behaviour is very different from cluster to cluster
- There is no easy conclusion, unlike in 2011, on the correlation between succesful probability and # of events of a specific type.
- Clusters B, C and D in particular have very unsmooth lines that vary a lot for small # evts differences. This may be due to an uneven distribution of # evts in the traces.

5.11 Potential causes of unsuccesful executions

TBD

6 Implementation issues – Analysis limitations

- 6.1 Discussion on unknown fields
- TBD

No. No. Source of a strain of a s	Task termination	# Evts. 95% p.tile	# Evts. mean	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mean	
BRADEN 9.0 12.465270 0.0001770 2.151832 0.0001790 0.00001790 0.00001790 0.0001									
BAL LOTT 10.00 50.000556 0.000000 <									
DNCT Nermanion 232-06 46.455000 72.05355 0.000107 23.70160 0.000000 Nermanion # Lat 2 UP									
Notermination 94.0 14.3 [252] 0.00000 0.00000 0.00000 0.00000 0.00000 Task termination # Dots 959 public # Dots mean # DOT Text mean # PRD51 Fext mean	LOST	7.0	8.847145	0.083348	0.001821	0.384190	1.329910	1.007933	
(a) Cluster A This termination # Dist, 59% public # Dist, mean # Dist, Brein, mean # Dist, 59% public # Dist, mean # Dist, 59% public # Dist, 59% public <th colspa<="" td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></th>	<td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>								
Taik termination # Dats 9 Port, point # PORT point </td <td>No termination</td> <td>84.0</td> <td>14.818523</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td>	No termination	84.0	14.818523	0.000000	0.000000	0.000000	0.000000	0.000000	
NLL CO.0 40.901041 3.3146 0.27005 0.000565 5.541079 0.013457 PNLN 20.0 87.7219 0.518061 19.666798 0.000560 0.007592 0.000560 0.007592 0.000560 0.007592 0.000560 0.007592 0.000560 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000057 N.015757 0.013677 N.015757 0.013677 N.015757 0.013677 N.015757 N.015757 N.015757				(a)	Cluster A				
NLL CO.0 40.901041 3.3146 0.27005 0.000565 5.541079 0.013457 PNLN 20.0 87.7219 0.518061 19.666798 0.000560 0.007592 0.000560 0.007592 0.000560 0.007592 0.000560 0.007592 0.000560 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000056 0.000057 N.015757 0.013677 N.015757 0.013677 N.015757 0.013677 N.015757 N.015757 N.015757	Task termination	# Fyts 95% n tile	# Evts mean	# FVICT Evts mean	# FAIL Evts mean	# FINISH Evts mean	# KILL Evts mean	# LOST Evts mean	
PRNSH 20.00 17.27756 0.001677 0.001676 0.000606 0.071679 0.011676 Nu 0.14 0.256744 0.021741 0.007420 1.202033 1.315466 1.000579 0.0000000 0.000000 0.000000									
FAIL 12600 66.772419 0.518661 19.56579 0.000500 0.000000 0									
1057 14.0 25.60045 0.425721 0.007420 1.03831 3.31545 2.01133 No termination 32.0 3.31533 0.00000 0.000000 0.000000 0.000000 0.000000 No termination 32.0 3.31533 0.00000 0.000000									
Notermination 32.0 33.018130 0.000000 0.000000 0.000000 0.000000 0.000000 Bitk Fibra Strain # EVIC Evits. mean # EVIC Evits.				0.257231		1.928351			
(b) Cluster B Task termination # Evts. 59% p.th # EVL Fexts. mean # EVL Fexts. mean # FINISH Fexts. mean # HIL Fexts. mean <th< td=""><td>EVICT</td><td>1578.0</td><td>345.705559</td><td>64.816518</td><td>0.240214</td><td>0.000000</td><td>17.961539</td><td>1.028401</td></th<>	EVICT	1578.0	345.705559	64.816518	0.240214	0.000000	17.961539	1.028401	
Task termination # Even. 99% putil	No termination	32.0	13.018130	0.000000	0.000000	0.000000	0.000000	0.000000	
RLL 12.0 24.20887 1.53227 0.116482 0.00994 3.79111 0.013679 PNISH 16.0 15.242028 0.017929 0.01271 2.470544 0.004000 0.006414 PAIL 15.0 15.242028 0.72823 48.445773 2.035376 0.756015 0.13865 PNOT 17.48.0 40.11365 0.000000				(b)	Cluster B				
MLL 92.0 92.423087 1.53227 0.116962 0.00094 3.79911 0.013079 PNISH 18.0 182.02628 0.017929 0.01271 2.470554 0.000614 PALE 18.0 187.03894 0.778213 48.447773 2.033778 0.756115 0.133867 PNIST 2.30 0.411365 0.000000	Task termination	# Evts. 95% p.tile	# Evts. mean	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mean	
FINISH 18.0 15.24228 0.017929 0.012701 2.470554 0.000600 0.000604 FML 15.00 15.003094 0.0773823 0.015699 1.011201 2.735133 0.139647 LOST 17.48.0 0.40110669 7.731537 0.139647 0.000000 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>									
EAUL LOST 135.00 137.038944 0.072823 49.445773 2.033378 0.075015 1.133867 LOST 22.38546 0.411305 0.000006 2.2751353 1.988665 EVICT 1748.0 404.106609 737.15527 1.812816 0.000006 0.2000000 0.000000 Riki 2.325346 0.005551 0.000285 4.682411 0.001785 0.000785 0.0018699 FNISH 18.0 23.05615 0.058551 0.0002377 0.0007285 4.682411 0.0018699 FNISH 18.0 23.05615 0.060000 0.000000									
LGST 22.8 42.384/46 0.411365 0.007569 1.412201 2.731535 1.998655 EVCT 17.460 0.4113056 0.000000									
Ne termination 96.0 21.31516 0.000000 0.000000 0.000000 0.000000 Rikk termination # Exts. 7000 # Exts. 70000 # Exts. 7000 # Exts. 700000000 # Exts. 7000 # Exts. 70		28.0	22.385446	0.411365	0.007569	1.412201	2.751353		
(c) Cluster C Task termination # FIX. 59% p.the # Exts. mean # FIX[Exts. mean # FIX[Exts. mean # FIX[Exts. mean # KILL Evts. mean # KILL Evts. mean # KILL Evts. mean # KILL Evts. mean # FIX[Exts] 0.002355 4.662411 0.0016156 FINISH 18:0 23.106615 0.036961 0.002357 0.002357 0.002735 0.161569 FUXT 20:0 17.05771 0.015700 0.0003377 0.073739 4.653223 0.199794 EVCT 14.652 23.2366130 6.20061510 0.700268 0.0000737 1.455223 0.059979 EVCT 14.65 23.2366130 0.000000									
Task termination # Evts. 95% p.tile # Evts. mean # PAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean KILL 32.0 29.953873 1.960134 0.160521 0.002385 0.009785 0.018699 PINISH 12.0 20.04075 0.0447616 0.0589520 0.039754 0.0389754 PAIL 20.00 21.06515 0.014076 0.003235 1.0807524 4.662431 0.090006 PAIL 20.00 20.000010 0.0700286 0.000000 0.005099 1.1780755 0.18791 1.057951 0.166119 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 </td <td>No termination</td> <td>96.0</td> <td>21.315166</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td>	No termination	96.0	21.315166	0.000000	0.000000	0.000000	0.000000	0.000000	
KILL 1.20 29.93973 1.960134 0.15021 0.002235 4.682411 0.016155 PINSH 1.90 22.105615 0.499316 58.965210 0.299355 0.09755 0.01955 PINSH 2.00 17.065721 0.014766 0.0003577 0.000000 0.000001 0.0000000 0.0000000 0.				(c)	Cluster C				
HLL 12.0 29243873 1.960134 0.150221 0.002382 4.682411 0.016155 PNISH 2690 223.006475 0.0496316 58.05631 0.30951 3.799550 0.000755 0.032757 DIGT 2000 17.065721 0.014760 0.0003577 0.0079289 4.662431 0.652623 1.999794 EVICT 1478.0 223.366130 62.000510 0.700268 0.0000000 0.000000<	Task termination	# Evts. 95% p.tile	# Evts. mean	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mean	
FINISH PAIL 18.0 22.1056/15 0.039651 0.019051 3.789050 0.000765 0.013957 LOST 20.0 17.065721 0.014760 0.0003373 0.465233 1.99774 LOST 1478.0 323.3651.0 0.000000 0.000000 0.000000 0.000000 0.000000 Netermination # Evts. 95%.pd.ll # Evts. resu # VICT Evts. mean # PUCT Evts. mean # PULEvts. mean # PULEvts. mean # PULE vis. mean # PULE vis. mean # PULE vis. mean # VIL Evts. mean	KILL	-							
FAIL LOST 2060 228.004975 0.469316 58.968210 0.809729 2.404396 0.324745 LOST 20.00 17.065721 0.014766 0.003373 0.079289 14.657314 0.627928 EVICT 113.0 27.56743 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000001 0.000024 0.0000241 0.0564905 0.013376 0.054907 0.000241 0.026641 0.026641 0.03377 0.030000 0.000000 0.030000 0.000001 0.000000 0.000001 0.000001 0.000001 0.000000 0.000001 0.000000 0.000001 0.000000									
EVCT 1475.0 323.3661.30 62.000510 0.700268 0.000000 <	FAIL								
No termination 103.0 27.867403 0.000000 0.000000 0.000000 0.000000 Rik First First <th correcorrecorrecorrecorrecorrecorrecorre<="" td=""><td>LOST</td><td>20.0</td><td>17.065721</td><td>0.014760</td><td>0.003577</td><td>0.079289</td><td>4.636283</td><td>1.999794</td></th>	<td>LOST</td> <td>20.0</td> <td>17.065721</td> <td>0.014760</td> <td>0.003577</td> <td>0.079289</td> <td>4.636283</td> <td>1.999794</td>	LOST	20.0	17.065721	0.014760	0.003577	0.079289	4.636283	1.999794
(d) Cluster D Task termination # Evrs. 95% p.tlle # Evrs. mean # EVICT Evrs. mean # FAIL Evrs. mean # KILL Evrs. mean # KILL Evrs. mean # LOST Evrs. mean KILL 2550 55.877475 1.237917 0.056909 0.008455 1.2379889 0.0054997 FNISH 136.0 405.259977 0.457703 1.1471047 0.000000 0.433776 0.187991 LOST 14.0 11.359098 0.000000 0.000000 0.000000 0.000000 0.000000 No termination 34.0 7.349165 0.000000 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>									
Task termination # Evts. 95% p.tile # Evts. mean # FULT Evts. mean # FULSH Evts. mean # KUL Evts. mean # LOST Evts. mean KILL 258.0 55.877475 1.287917 0.059099 0.009135 12.159880 0.0320641 PNINSH 14.0 11.97906 0.013379 0.009435 1.099076 0.032641 PNINSH 13.80 450.526937 0.013379 0.00000 0.030000 0.030000 0.455705 0.187991 LOST 13.00 84.645199 11.780754 0.16111 0.000000 0.00001783 0.002733 0.002733 0.002734 0.002795 0.02397 0.01783 0.002795 0.023977 0.017839 0.007783 <td>No termination</td> <td>103.0</td> <td>27.867403</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td> <td>0.000000</td>	No termination	103.0	27.867403	0.000000	0.000000	0.000000	0.000000	0.000000	
KILL 258.0 55.877475 1.287917 0.056909 0.000185 12.159880 0.054997 FINISH 14.0 11.976806 0.013879 0.008435 1.998677 0.008241 0.026641 LOST 14.0 11.89908 0.000000 0.033976 3.131007 1.792164 LOST 14.0 11.89908 0.000000 0.000000 0.000000 0.600000 0.600000 No termination 34.0 7.349165 0.000000 0.0023707 0.03783 0.07733 0.023707 0.03667 7.28354 2.000428 0.023707 0.023707 0.023707 0.023707 0.023707 0.023707 0.023707 0.023707 0.023707 0.023707 0.023707 0.023707 0.0237489 0.023747 <				(d)	Cluster D				
FINISH 14.0 11.976806 0.018379 0.008435 1.99677 0.008245 0.008267 PAL 138.0 450.5526937 0.457703 0.00000 0.033976 3.131007 1.792164 EVICT 31.00 84.645189 0.000000 0.002707 0.03733 0.007334 0.002707 0.03735 0.007334 0.002707 0.03735 0.007334 0.00023 1.54975 0.003216 1.54975 0.003736 0.2339765 0.037435 0.00023 1.54975 0.00323 1.54975 0.003783 0.007334 0.002377 1.03757 0.004789 0.135075 0.037458 </td <td>Task termination</td> <td># Evts. 95% p.tile</td> <td># Evts. mean</td> <td># EVICT Evts. mean</td> <td># FAIL Evts. mean</td> <td># FINISH Evts. mean</td> <td># KILL Evts. mean</td> <td># LOST Evts. mean</td>	Task termination	# Evts. 95% p.tile	# Evts. mean	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mean	
EAIL LOST 138.0 450.526937 0.457703 111.471047 0.000000 0.455705 1.187991 LOST 310.0 84.645189 11.780754 0.106119 0.000000 0.600000 0.600000 0.000									
LOST 14.0 11.899908 0.000000 0.000000 0.033976 3.13100 1.792164 EVICT 310.0 84.645189 11.780754 0.000000 0.000733 0.037733 0.002707 0.00230 1.54975 0.0037783 0.002707 0.00023 1.54975 0.000732 1.54975 0.000270 0.037783 0.002707 0.00000 0.000000 0.000000 0.000000 1.54975 0.000783 0.023707 0.000783 1.24975 0.000783 1.24975 0.000783 1.24975 0.000783 1.24975 0.000783 1.24975 0.000783 1.24975 1.03785 1.03785 1.									
EVICT No termination 310.0 84.645189 7.349165 11.780754 0.000000 0.106119 0.000000 0.000000 0.000000 5.790960 0.000000 0.654955 0.000000 No termination 34.0 7.349165 0.000000 0.000000 0.000000 0.000000 0.000000 Task termination # Evts. 95% p.tile # Evts. mean # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean KILL 162.0 45.039557 0.384065 0.098430 0.001178 9.804287 0.037783 FINISH 220.0 164.043073 0.279752 39.257407 0.000002 1.549795 0.203977 COST 50.0 320.262347 23.973621 0.192394 0.000004 45.5979997 0.374789 No termination # Evts. 95% p.tile # Evts. mean # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean FINISH 140.00 10.054143 6.090204 0.135073 0.000033 25.27759 0.131106 FINISH									
No termination 34.0 7.349165 0.000000 0.000000 0.000000 0.000000 Res Cluster E									
(e) Cluster E Task termination # Evts. 95% p.tile # Evts. mean # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # I.OST Evts. mean KILL 162.0 45.039557 0.384065 0.098430 0.001178 9.804287 0.037783 FINISH 20.0 164.043073 0.279352 39.257407 0.0000023 1.549795 0.203976 COST 36.0 25.002219 0.011815 0.000000 0.149586 7.283534 2.000428 EVICT 51.0.0 302.262347 23.973621 0.192394 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000003 25.275769 0.13106 FINISH 16.10 130.054143 6.909204 0.135073 0.000003 25.275769 0.13106 FAIL 40.00 40.121553 0.016111									
KILL 162.0 45.039557 0.384065 0.098430 0.001178 9.804287 0.037783 FINISH 20.0 19.899709 0.019381 0.003510 3.007839 0.097934 0.023097 PAIL 220.0 16.4043073 0.279352 39.257407 0.0000023 1.549795 0.20397 LOST 36.0 25.002219 0.011815 0.000909 0.149586 7.283534 2.000428 EVICT 510.0 302.262347 23.973621 0.192394 0.000000									
KILL 162.0 45.039557 0.384065 0.098430 0.001178 9.804287 0.037783 FINISH 20.0 19.899709 0.019381 0.003510 3.007839 0.097934 0.023097 PAIL 220.0 16.4043073 0.279352 39.257407 0.0000023 1.549795 0.20397 LOST 36.0 25.002219 0.011815 0.000909 0.149586 7.283534 2.000428 EVICT 510.0 302.262347 23.973621 0.192394 0.000000	Task termination	# Fyts 95% n tile	# Fyts mean	# FVICT Fyts mean	# FAIL Fyts mean	# FINISH Evts mean	# KILL Evts mean	# LOST Evts mean	
FINISH 20.0 19.899709 0.019381 0.003510 3.007839 0.097934 0.023707 FAIL 22.00 164.043073 0.279352 39.257407 0.0000023 1.549795 0.203997 LOST 53.00 25.002219 0.011815 0.000909 0.149586 7.283534 2.000428 EVICT 510.0 302.262347 23.973621 0.192394 0.000000 45.979997 0.374789 No termination 24.0 7.784905 0.000000 0.0013130 0.36515 48.094421 35.56567 3.534335 0.016113 0.5292780 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.00000									
FAIL 220.0 164.043073 0.279352 39.257407 0.000023 1.549795 0.203997 LOST 36.0 25.002219 0.011815 0.000090 0.149386 7.283334 2.000428 EVICT 30.2 30.2.262347 23.973621 0.192394 0.000000 <td< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>									
LOST 36.0 25.002219 0.011815 0.000909 0.149586 7.283534 2.000428 EVICT 510.0 302.262347 23.973621 0.192394 0.000000 <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>									
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(f) Cluster F Task termination # Evts. 95% p.tile # Evts. mean # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean KILL 641.00 130.054143 6.909204 0.135073 0.000033 25.275769 0.131106 FINISH 18.00 105.240418 0.015228 0.001655 14.153775 0.004879 0.158300 PAIL 460.02 576.384120 1.931330 0.360515 48.094421 35.596567 3.534335 EVICT 2015.00 555.574743 77.429054 0.303127 0.000000		510.0	302.262347	23.973621	0.192394	0.000094	45.979997	0.374789	
Task termination # Evts. 95% p.tile # Evts. mean # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean KILL 641.00 130.054143 6.909204 0.135073 0.000033 25.275769 0.131106 FNISH 18.00 105.240418 0.015228 0.001655 14.153775 0.004879 0.13803 FAIL 40.00 40.121553 0.016111 8.592728 0.000000 0.338883 0.011310 LOST 4602.25 576.384120 1.931330 0.360515 48.094421 35.596567 3.534335 EVICT 555.574743 77.429054 0.303127 0.000000	No termination	24.0	7.784905	0.000000	0.000000	0.000000	0.000000	0.000000	
KILL 64.00 130.054143 6.909204 0.135073 0.000033 25.275769 0.131106 FINISH 18.00 105.240418 0.015228 0.001655 14.153775 0.004879 0.158300 PAIL 40.00 40.121553 0.016111 8.592728 0.000000 0.338883 0.011310 LOST 4602.25 576.384120 1.931330 0.360515 48.094421 35.596567 3.534335 EVICT 2015.00 555.574743 77.429054 0.303127 0.000000 58.299330 0.653819 No termination 30.00 9.503553 0.000000 0.000000 0.000000 0.000000 0.000000 Task termination # Evts. 95% p.tile # Evts. mean # EVICT Evts. mean # FAIL Evts. mean # KILL Evts. mean # LOST Evts. mean KILL 388.0 74.425542 0.633338 0.169666 0.000231 17.172624 0.062799 FINISH 2.0 23.978294 0.023700 0.014129 3.632529 0.011111 0.028482				(f)	Cluster F				
FINISH 18.00 105.240418 0.015228 0.001655 14.153775 0.004879 0.158300 FAIL 40.00 40.121553 0.016111 8.592728 0.000000 0.338883 0.011310 LOST 460.225 576.3841120 1.931330 0.360515 48.094421 35.596567 3.534335 EVICT 2015.00 555.574743 77.429054 0.303127 0.000000 58.299330 0.653819 No termination 30.00 9.503553 0.000000 0.000000 0.000000 0.000000 0.000000 Task termination #Evts.95% p.tile # Kets.mean #EVICT Evts.mean # FAIL Evts.mean # FINISH Evts.mean # KILL Evts.mean # LOST Evts.mean KILL 388.0 7.4425542 0.633383 0.166666 0.000231 17.172624 0.062799 FINISH 2.0 23.978294 0.023700 0.014129 3.632529 0.011111 0.028482 FAIL 487.0 170.153701 0.600483 37.599942 0.000000 2.866647 0.343806 LOST 386.4 9.4666667 1.493333<	Task termination	# Evts. 95% p.tile	# Evts. mean	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mean	
FINISH 18.00 105.240418 0.015228 0.001655 14.153775 0.004879 0.158300 FAIL 40.00 40.121553 0.016111 8.592728 0.000000 0.338883 0.011310 LOST 460.225 576.3841120 1.931330 0.360515 48.094421 35.596567 3.534335 EVICT 2015.00 555.574743 77.429054 0.303127 0.000000 58.299330 0.653819 No termination 30.00 9.503553 0.000000 0.000000 0.000000 0.000000 0.000000 Task termination #Evts.95% p.tile # Kets.mean #EVICT Evts.mean # FAIL Evts.mean # FINISH Evts.mean # KILL Evts.mean # LOST Evts.mean KILL 388.0 7.4425542 0.633383 0.166666 0.000231 17.172624 0.062799 FINISH 2.0 23.978294 0.023700 0.014129 3.632529 0.011111 0.028482 FAIL 487.0 170.153701 0.600483 37.599942 0.000000 2.866647 0.343806 LOST 386.4 9.4666667 1.493333<	KILL	641.00	130.054143	6.909204	0.135073	0.000033	25.275769	0.131106	
FAIL 40.00 40.121553 0.016111 8.592728 0.000000 0.338883 0.011310 LOST 4602.25 576.384120 1.931330 0.306015 48.094421 35.596567 3.534335 EVICT 2015.00 555.574743 77.429054 0.303127 0.000000 58.599330 0.653819 No termination 30.00 9.503553 0.000000									
EVICT 2015.00 555.574743 77.429054 0.303127 0.000000 58.299330 0.653819 No termination 30.00 9.503553 0.000000 17.172624 0.002700 0.014129 3.632529 0.01111 0.026482 FAIL 487.0 17.153701 0.600483 37.599942 0.000000 2.866647 0.3438000 LOST 3.480000 2.421745 0.4201700 0.573333 1.4040000 3.480000 2.4021745 0.000000 7.64722 0.421745 0.000000 7.64722 0.421745 0.000000 7.6472	FAIL	40.00		0.016111			0.338883	0.011310	
No termination 30.00 9.503553 0.000000 0.000000 0.000000 0.000000 L <thl< th=""> L L</thl<>									
(g) Cluster G Task termination # Evts. 95% p.tile # Evts. mean # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean KILL 388.0 74.425542 0.633338 0.169666 0.000231 17.172624 0.062799 FINISH 22.0 23.978294 0.023700 0.014129 3.632529 0.011111 0.028482 FAIL 487.0 170.153701 0.600483 37.599942 0.000000 2.866647 0.343806 LOST 386.4 94.6666667 1.493333 2.400000 0.573333 14.040000 3.480000 EVICT 206.0 75.65864 6.732544 0.837154 0.000000 7.164722 0.42174									
KILL 388.0 74.425542 0.633338 0.169666 0.000231 17.172624 0.062799 FINISH 22.0 23.978294 0.023700 0.014129 3.632529 0.011111 0.028482 FAIL 487.0 170.153701 0.600483 37.599942 0.000000 2.866647 0.343806 LOST 386.4 94.6666667 1.493333 2.400000 0.573333 14.040000 3.48000 EVICT 206.0 75.658064 6.732544 0.837154 0.000000 7.164722 0.421745	No termination	30.00	9.503553			0.00000	0.000000	0.00000	
KILL 388.0 74.425542 0.633338 0.169666 0.000231 17.172624 0.062799 FINISH 22.0 23.978294 0.023700 0.014129 3.632529 0.011111 0.028482 FAIL 487.0 170.153701 0.600483 37.599942 0.000000 2.866647 0.343806 LOST 386.4 94.6666667 1.493333 2.400000 0.573333 14.040000 3.48000 EVICT 206.0 75.658064 6.732544 0.837154 0.000000 7.164722 0.421745									
FINISH 22.0 23.978294 0.023700 0.014129 3.632529 0.011111 0.028482 FAIL 487.0 170.153701 0.600483 37.59942 0.00000 2.866647 0.343806 LOST 3864 94.666667 1.493333 2.400000 0.573333 14.040000 3.48000 EVICT 206.0 75.658064 6.732544 0.837154 0.000000 7.164722 0.421745									
FAIL 487.0 170.153701 0.600483 37.59942 0.00000 2.866647 0.343806 LOST 386.4 94.666667 1.493333 2.40000 0.573333 14.04000 3.48000 EVICT 206.0 75.658064 6.732544 0.837154 0.00000 7.164722 0.42175									
LOST 386.4 94.666667 1.493333 2.40000 0.573333 14.04000 3.48000 EVICT 206.0 75.658064 6.732544 0.837154 0.00000 7.164722 0.421745									
EVICT 206.0 75.658064 6.732544 0.837154 0.00000 7.164722 0.421745									

(h) Cluster H

Figure 15. Mean number of tasks and event distribution per task type

Normalization 92350436 174.3 23250531 3.45444 212047977 94.556076 0.001507 NULL 0.00000 1.0 N.N								
NEME 1.000000 1.00 NEM NEM NEM NEM NEM NEM NULL 0.233171 1.00 1.04519 0.077807 1.463197 0.00000 NULL 0.233171 1.00 1.04519 0.077807 1.463197 0.00000 NULL 2.23.25071 1.5000 1.05419 0.077807 1.463197 0.00000 NULL 2.23.25071 1.000 1.077150 #NULLEN.mem #INLEDS.mem #	Job termination	# Tasks mean	# Tasks 95% p.tile	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mean
Nut. Dist. 99.79773 1.80581 99.09 1.004406 0.049452 0.07920 0.069597 0.44138 1.365987 1.365987 0.009597 0.04946 Nut. Dist. 1.033117 1.00 1.04440 0.071900 0.44138 1.38598 0.009597 Nut. Dist. 1.033117 1.00 1.04440 0.071900 0.44138 1.38598 0.009597 Nut. Dist. 1.033117 1.00 1.054409 2.071000 0.44138 0.135973 0.135973 0.017197 Nuternianion Plank mem	No termination		174.3	23.263951	3.454474	23.047597	34.565608	0.707709
BERSII LOT 1.10702 2.23,0057 1.0 0.004969 0.00000 0.001341 0.00000 1.072623 0.00000 0.002098 0.002098 LOT 2.23,0057 1.06 0.004969 0.00000 0.00000								Nal
NULL COT 1.533171 2.23.2657 1.00 (1.895.8 0.00300 0.00300 0.00400 0.00400 COT 2.23.2657 1.00.8730 0.0046 0.00000								
Ling matrix 22.2.00597 1.699.5 0.00000								
(a) Cluster A Adol termination # Data mean # Mak 99% guile # VOLT Text, mean # PALL Pits, mean # ALOFT Ext, mean # ALOFT Ex	LOST							0.97459
No.emainate 112.42239 196.8 34.461161 0.711242 13.379333 39.74188 0.07996 NERT 73.37943 37.40 2.033253 1.992765 0.266384 0.494145 0.03929 0.004000 NENSI 6.304299 1.0 1.004649 0.137243 0.01729 0.0164 NENSI 6.304299 1.0 1.004649 0.137243 0.017292 0.0164 NENSI 6.304299 1.0 1.004649 0.137233 0.03725 0.03726 NEW NEW NEW NEW PINISI Prs.mean # RULE Drs.mean # RULE Drs.mean # RULE NEW 0.0372 NEW 1.0 1.006229 0.000000 0.000000 0.000000 0.04615 0.0461 NEWT 1.000000 5.276773 7.55296 0.376433 3.984569 0.0464 NEWT 1.030200 3.48460 0.000001 0.04615 0.0464 NEWT 1.030200 3.48460 0.000001 0.04621 0.01741 <td< td=""><td></td><td></td><td></td><td>(a)</td><td>Cluster A</td><td></td><td></td><td></td></td<>				(a)	Cluster A			
ENET 1.000000 1.0 1.000000 0.00	Job termination	# Tasks mean	# Tasks 95% p.tile	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mear
ENET 1.000000 1.0 1.000000 0.00	No termination	112.422759	169.8	34.681161	0.711242	13.379533	38,794188	0.78048
NINSH 6.3042399 10.0 0.022380 0.006447 0.305783 0.435746 0.030576 0.030576 List 6.303202 459.8 0.00000 0.000	EVICT							0.00000
NILL DGT 29.052320 214.0 1.056449 0.127233 0.6.13748 3.00678 0.01202 LGT 3.00.00202 459.8 0.000000 0.000000 0.000000 0.000000 3.00078 0.12723 LGT 450.8 Fluxters Fl	FAIL	74.367804	374.0	2.003355	1.993765	0.266584	4.944145	0.03452
LOAT 230.02020 459.8 0.00000 0.00000 0.00000 2.959946 1.9696 LOAT F <th< td=""><td>FINISH</td><td></td><td></td><td></td><td></td><td></td><td></td><td>0.00648</td></th<>	FINISH							0.00648
(b) Cluster B (c) Cluster C (c) Cluster C <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>								
No remnantano 99.399541 100.0 55.29973 7.5.32006 23.448667 41.7576669 0.60040 PNCT 10.00000 0.000415 0.00003 0.000000 0.000000 0.000040 PNL 41.952201 200.0 3.4483666 0.997592 0.376438 3.998369 0.0464 PNISH 1.991485 1.0 0.021366 0.016974 1.5.55034 0.017401 0.0018 RUL 1106.69088 6.52.0 0.627334 0.039976 0.6.56426 2.2.66794 0.0002 (c) Cluster C 364 termination # Tasks mean # Tasks 95% p.tile # EVICT Evts. mean # FINLSH Evts. mean # KUL Evts. mean # #LOST Evts. mean # FINLSH Evts. mean # LOST Evts. mean # FINLSH Evts. mean # KUL Evts. mean # LOST Evts. mean # LOST Evts. mean # FINLSH Evts. mean # KUL Evts. mean # LOST Evts. mean # LOST Evts. mean # FINLSH Evts. mean # KUL Evts. mean # LOST Evts. mean # LOST Evts. mean # FINLSH Evts. mean # KUL Evts. mean # LOST Evts. mean # LOST Evts. mean # FINLSH Evts. mean # KUL Evts. mean # LOST Evts. mea	1001	520.020202				0.000000	2.737740	1.77007
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PAIL 41.982301 20.00 3.483666 0.979722 0.276438 3.089369 0.00018 NILL 110.668088 652.0 0.023186 0.030076 0.656422 2.266794 0.00021 LOST 38.69009 48.6 0.00001 0.00001 0.00001 0.00000 2.266794 0.0026 LOST TENES FULL	No termination							0.66410
FNISH 1.991485 1.0 0.021806 0.016914 1.55634 0.01401 0.00000 LIST 1.0568088 652.0 0.022733 0.03031 0.00001 0.00000 2.262774 0.00002 LOST 1.0568088 # Table S%P.p.III # EVICT Evits. mean # ENISHEVS. mean # KILL Evits. mean # LOST Evits. mean # LOS								
KILL DGST 110.6680808 652.0 (6.2) 0.627334 0.000031 0.005000 2.266794 2.266794 0.00000 LOST 38.97091 # Baks 95% p.10 # FAILS PTS. mean # FAILS PTS. mean # FAILS PTS. mean # KILL PTS. mean # KILL PTS. mean # COTT PTS. mean Notemination 103.889080 103.89080 10.00000 14.42153 7.604080 0.000000 0.	FINISH							0.04643
LOST 38.870091 48.6 0.000031 0.000000 2.620721 1.8388 LOST 38.870091 48.6 0.000031 0.000000 2.620721 1.8388 Lob termination # Tasks 95% p.tile # EVICT Exts. mean # FINISH Exts. mean # KILL Exts. mean # LOST Exts. mean	KILL							0.00625
Job termination # Tasks 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # FINSH Evts. mean # KUL Evts. mean # LOST Evts. me No termination 103.899987 120.00 14.121352 7.064608 18.179476 47.603562 0.66618 VEICT 10.00000 0.000000								1.83387
No termination 10.88997 10.00 41.421522 7.604808 18.17947/5 47.603502 0.0618 NML 43.955692 2.00 0.203757 0.012614 0.723352 0.019567 0.00557 NISH 2.109200 2.000 0.203757 0.010567 0.00557 RUL 89.647948 283.00 1.013114 0.054374 0.233333 3.255675 0.00660 LOST 271.441748 2620.75 0.000000 0.000000 0.000000 5.93869 1.6470 Job termination # Tasks 95% p.tile # FINCT Fvts. mean # FAL Evts. mean # KUL Evts. mean # KUL Evts. mean # KUL Evts. mean # LOST Evts. me No termination 330.929407 596.0 7.204391 2.074423 0.136290 0.06696 FUCT 1.000000 1.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.0000000 0.0000000 0				(c)	Cluster C			
EVECT 1.000000 1.00 0.000000 0	Job termination	# Tasks mean	# Tasks 95% p.tile	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mea
PAIL 43.355682 250.00 6.111993 0.049602 0.031310 6.497784 0.0018567 0.0018567 NISH 2109260 2.00 0.268375 0.010614 1.723392 0.018567 0.0018567 NILL 89.647948 2620.75 0.00000 0.000000 0.000000 5.938069 1.6470 NILT PAILS exp # Tasks mean # Tasks 95% p.tile # EVICT Evrs. mean # FINISH Evrs. mean # KILL Evrs. mean # KILL Evrs. mean # KILL evrs. mean # KILL evrs. mean # Contentionantion 350.29407 0.595.0 0.020000 0.000000	No termination	103.889987	120.00	41.421532	7.604808	18.179476	47.603502	0.66182
FNISH 2.00260 2.00 0.268375 0.012614 1.723323 2.325675 0.00060 LOST 271.441748 2620.75 0.000000 0.000000 0.000000 5.938069 1.6470 LOST 271.441748 2620.75 0.000000 0.000000 0.000000 5.938069 1.6470 LOST FTASK PENISH FTASK 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LUST Evts. mean No termination 350 929407 5.96.0 7.014391 2.074423 0.126290 46.646065 0.3782 VEXT 1.000000 0.1000000 0.000000	EVICT							0.00000
KILL 99.447948 283.00 1.013114 0.054374 0.283313 3.255675 0.00000 LOST 271.41748 2620.75 0.00000 0.000000 0.000000 5.338069 1.6470 Lob termination # Tasks mean # Tasks 95% p.tile # EVICT Evrs. mean # FAIL Evrs. mean # FINISH Evrs. mean # KILL Evr								0.04107
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(d) Cluster D Job termination # Tasks 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean No termination # Tasks 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean No termination 217.71840 9.79.4 4.304676 1.315021 4.9771122 48.118465 0.042009 No termination 21.71840 9.79.4 4.304676 1.315021 4.9771122 48.118465 0.042009 No termination 21.71840 9.0 0.014704 0.051014 1.659866 0.162042 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>								
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EVICT 1.000000 1.0 1.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.0202929 0.0649 KILL 88.790215 309.0 0.706293 0.028618 0.461084 7.572301 0.02979 LOST 5.0 0.000000 0.000000 0.000000 0.000000 3.234494 1.8139 LOST 5.0 0.000000	Job termination	# Tasks mean	# Tasks 95% p.tile	# EVICT Evts. mean	# FAIL Evts. mean	# FINISH Evts. mean	# KILL Evts. mean	# LOST Evts. mea
FAIL 23.081125 25.0 0.246529 0.6665546 0.716720 1.588119 0.00649 FNISH 7.776085 2.0 0.018677 0.029073 1.934488 0.02029 0.00649 KIL 88.790215 309.0 0.0706293 0.028618 0.410184 7.572301 0.02973 LOST 5.374150 5.0 0.000000 0.000000 0.000000 3.234494 1.8139 Job termination # Tasks mean # Tasks 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # KILL Evts. mean # LOST Evts. mean	No termination	350.929407	596.0	7.204391	2.074423	0.126290	46.646065	0.37827
FINISH 7.776085 2.0 0.018677 0.029073 1.934488 0.020929 0.06649 KLL 88.790215 309.0 0.766393 0.020000 0.000000 0.000000 3.234494 1.8139 LOST 5.374150 5.0 0.000000 0.000000 0.000000 0.000000 3.234494 1.8139 LOST V.S. F Ce) Cluster E KILL Even # KILL Evts. mean # KILL Evts. mean # LOST Evts. me No termination 217.718640 379.4 4.304676 1.315021 4.971122 48.118465 0.4644 EVICT 1.000000 1.000000 0.00000	EVICT		1.0					0.00000
KILL LOST 88.790215 5.374150 309.0 0.706293 0.000000 0.02818 0.000000 0.461084 7.572301 0.0291 0.2324494 LOST 5.374150 5.0 0.000000 0.000000 0.200000 3.234494 1.8139 LOST S.374150 5.0 0.000000 0.000000 3.234494 1.8139 LOST VE VE VE VE VE VE VE VE Job termination 217.718640 379.4 4.304676 1.315021 4.971122 48.118465 0.04644 VE/UCT 1.000000 0.000014	FAIL	23.081125	25.0	0.246529	0.665546	0.716720	1.588119	0.06646
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(e) Cluster E Job termination # Tasks mean # Tasks 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean No termination 217.718640 379.4 4.304676 1.315021 4.971122 48.118465 0.46445 VICT 1.000000 1.0 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.00022 0.0026 7.559244 0.0014 1.669860 0.162042 0.0026 0.0026 0.000000 6.298140 1.4296 LOST 3736.500000 18823.4 0.001491 0.000003 0.000000 6.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.0000								
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No termination 217.718640 379.4 4.304676 1.315021 4.971122 48.118465 0.4644 EVICT 1.000000 1.0 1.000000 0.000000 0.000000 0.000000 0.000000 EAIL 17.161251 8.0 0.621327 0.546356 0.426265 7.559244 0.0026 KILL 103.888843 361.0 0.182630 0.063914 0.416684 5.824311 0.0141 LOST 3736.50000 18823.4 0.001491 0.000038 0.000000 6.298140 1.4296 Job termination # Tasks mean # Tasks 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean No termination 342.090034 599.10 1.4.184405 0.626136 23.836017 46.002917 0.7358 EVICT 1.000000 1.000000 0.000000 0.000000 0.000000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.000000 0.00000 0.00	Job termination	# Tasks mean	# Tasks 05% p tile	# EVICT Eute mean	# FAIL Fute mean	# EINICH Euts mean	# KII I Eute mean	# LOST Eute mag
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(f) Cluster F Job termination # Tasks 95% p.tile # EVICT Evts. mean # FAIL Evts. mean # FINISH Evts. mean # KILL Evts. mean # LOST Evts. mean No termination 342.090034 599.10 14.184405 0.626186 23.836017 46.002917 0.7358 EVICT 1.000000 1.00 0.000000 0.000000 0.000000 0.000000 EVICT 1.000000 0.000000 0.000000 0.000000 0.000000 0.000000 EVICT 1.000000 0.555532 3.334848 0.607560 20.351992 0.1762 EVICT 190.50000 358.35 0.000000 0.000000 0.000000 1.904751 1.9947 LOST 190.50000 358.35 0.000000 0.000000 1.994751 1.9947 LOST 190.500000 358.35 0.000000 0.000000 1.994751 1.9947 LOST 190.500000 358.35 0.000000 0.000000 1.994751 1.9947 LOST 190.500000 358.35								0.01416
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No termination 321.133053 546.9 3.470078 0.907801 3.316902 44.535824 0.3151 EVICT 1.000000 1.0 1.000000 0.000000 0.000000 0.000000 FAIL 20.504293 1.0 0.114090 2.300036 0.980635 12.833466 0.0468 FINISH 4.278193 14.0 0.005406 0.152814 1.778038 0.013567 0.0126 KILL 11.022705 3.0 0.235500 0.102899 0.287701 11.336956 0.0311				0.000000	0.000000			1.99475
No termination 321.133053 546.9 3.470078 0.907801 3.316902 44.535824 0.3151 EVICT 1.000000 1.0 1.000000 0.000000 0.000000 0.000000 0.000000 FAIL 20.504293 1.0 0.114090 2.300036 0.980635 12.833466 0.0468 FINISH 4.278193 14.0 0.005406 0.152814 1.778038 0.013567 0.0126 KILL 11.022705 3.0 0.235500 0.102899 0.287701 11.336956 0.0311								
EVICT 1.000000 1.0 1.000000 0.000000 0.000000 0.00000 0.00000 FAIL 20.504293 1.0 0.114090 2.30036 0.980635 12.833466 0.0468 FINISH 4.278193 14.0 0.05406 0.152814 1.778038 0.013567 0.0126 KILL 11.022705 3.0 0.235500 0.102899 0.287701 11.336956 0.0311								# LOST Evts. mea
FAIL 20.504293 1.0 0.114090 2.300036 0.980635 12.833466 0.0468 FINISH 4.278193 14.0 0.005406 0.152814 1.778038 0.013567 0.0126 KILL 11.022705 3.0 0.235500 0.102899 0.287701 11.336956 0.0311								
FINISH 4.278193 14.0 0.005406 0.152814 1.778038 0.013567 0.0126 KILL 11.022705 3.0 0.235500 0.102899 0.287701 11.336956 0.0311								
KILL 11.022705 3.0 0.235500 0.102899 0.287701 11.336956 0.0311								
	KILL							0.03114
	LOST							1.70588

(h) Cluster H

Figure 16. Mean number of tasks and event distribution per job type

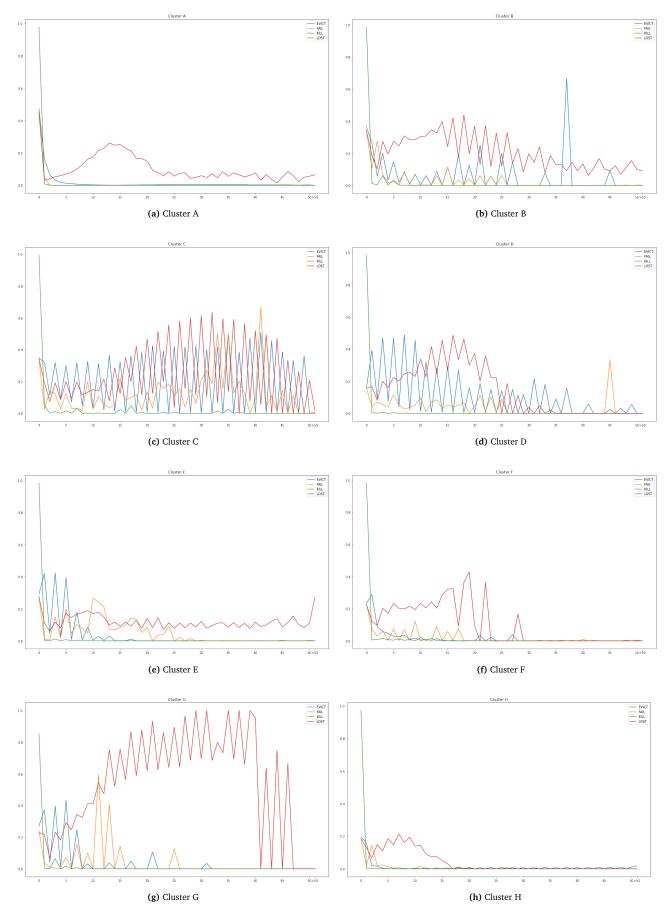


Figure 17. Conditional probability of task success given a number of specific unsuccesful events observed, i.e. eviction, fail, kill or lost.

6.2 Limitation on computation resources required for the analysis

TBD

6.3 Other limitations ...

TBD

7 Conclusions and future work or possible developments

TBD