

Comparative Performance Evaluation of Hadoop on PaaS Proposals by Leveraging HiBench

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Abstract

Big Data's advent emerged in any data-driven domain and scaled up the extent and depth of data and its handling. New approaches leaning on enhanced distributed storage and computing paradigms are invented in an ongoing maturing process to overcome management and running analytics challenges. Within the given context, Hadoop is embraced on a wide scale by beneficiaries from industry and academia since its first release in 2005. Cloud Computing's commercialization started a grand migration movement towards the cloud, impacting Hadoop to transfer its presence from on-premises to virtual machines stored and tamed in extensive data center facilities by global Cloud Service Providers. The CSPs' response to result-focused analytics purposes emerged a service called managed systems where the contractor overtakes the demanding workload of multi-node cluster implementation by providing a pre-configured Hadoop package simplifying the installation process to a matter of property selection, thus eliminating technical know-how requirements on such an implementation. Converting the concept of cloud-based Hadoop from IaaS to PaaS reduced costs commercially presented as pay-as-you-go or pay-per-use. However, there is a payoff; managed Hadoop systems do present a black-box behavior to the end-user who cannot be clear on the inner performance dynamics, hence the benefits by leveraging

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them. In the study, we selected three global providers (GCP, Azure, and Alibaba Cloud), activated their Hadoop PaaS services (Dataproc, HDInsight, and e-MapReduce, respectively) within the same geographical region and by promise same computing specifications, and executed several Hadoop workloads of the HiBench Benchmark Suite. The results yield that the same computation specs among CSPs' services do not necessarily guarantee equal or close performance outputs to each other. We assume that the pre-configuration work of managed systems done by the contractor plays a weighing role in their performance.

Keywords: `elsarticle.cls`, Benchmark Hadoop PaaS, HiBench, Performance evaluation

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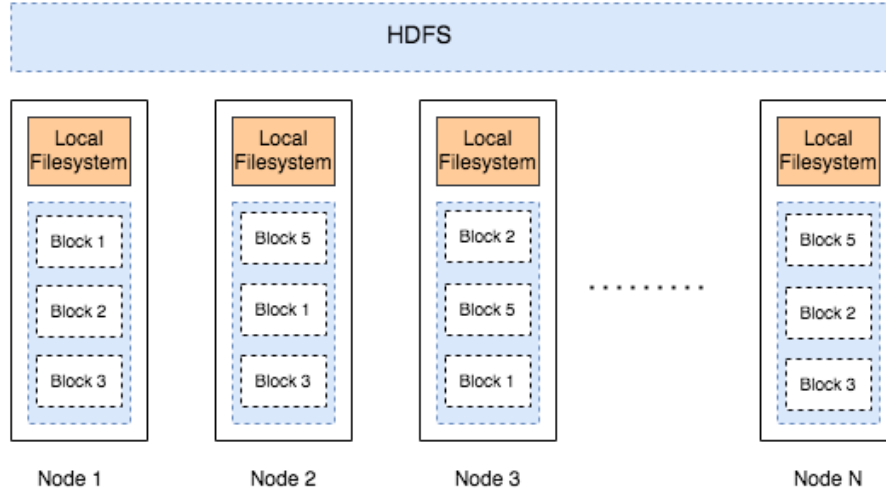
1. Introduction

Big Data. An indispensable aspect for enterprises and academia of the information era is Big Data. As the estimated global internet access rate covers a weighing majority of roughly 63% of the global human population by 2020
5 [1], mobile technology devices become more democratized, sensors and IoT devices the more occupy daily life, and ongoing scientific researches produce vast amounts of data outputs, the Big Data phenomenon gathered itself utilizing overwhelming size with Volume, ever-accelerating growth rate with Velocity, and diverse data structures with Variety, new approaches were forced to mature
10 in order to ease the maintenance of Big Data and enable extracting valuable insights from it leveraging complex statistical formulae.

Hadoop [2]. Frameworks for distributed storage and computation sparked up first by web indexing engines were inherited and developed further by the open-source community yielding what is known as Hadoop and its ecosystem today.
15 Considering the complexity of dealing with big data, Hadoop represents a modern analytics framework decreasing management efforts and analytics operations' duration to an acceptable level employing affordable commodity computers. Hadoop comprises three for its core functionality:

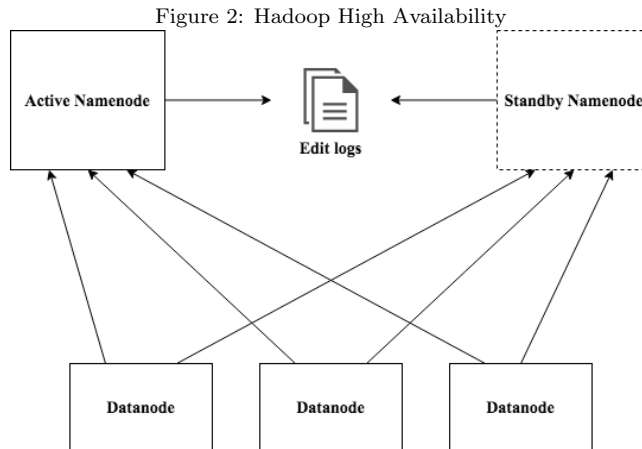
- HDFS filesystem for storing extensive data across a cluster of nodes,
- the MapReduce framework developed for distributed computation, and
- YARN for allocating available resources for the requested tasks.

Figure 1: Hadoop Distributed File System



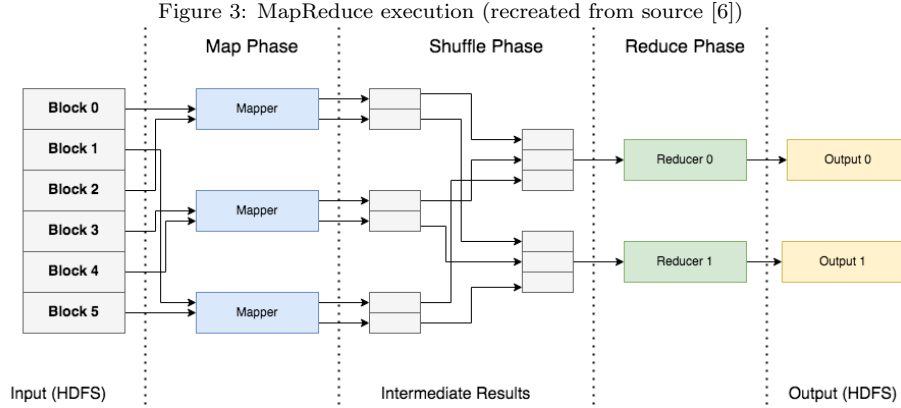
HDFS. Hadoop Distributed File System, which stands for HDFS, is developed with inspiration from the guidelines described in a whitepaper about Google's Filesystem (GFS), a distributed storage paradigm to handle petabytes and larger-scale data volumes within a cluster robust to machine failures, published in 2003 [3]. Significant data volumes are chunked and stored within 128 MB blocks, and each block is replicated to different nodes by a factor of 3, these values are the defaults and can be changed. When the data file is requested, related blocks are constructed from the nodes across the cluster. The redundancy of the blocks guarantees availability; in a case where one or more nodes become out of service, requested data blocks are gathered from the available redundant copies stored on other nodes. HDFS is a co-existing file system on the nodes it is installed, it provides a global distributed view to the files across the cluster, thus listing an HDFS directory is possible from within all nodes, the files on

35 HDFS are listed as they exist on a local filesystem, but the physical parts of the
 files reside on other physical locations. Figure 1 depicts an overview of HDFS.
 The architecture of HDFS comprises Namenode, which is a dedicated machine
 to keep track of the files and folders and respective metadata like block locations
 across the cluster, and a number of data nodes on which the data blocks are
 40 residing [4]. Namenode is a single-point-of-failure, meaning if the namenode is
 down, the whole Hadoop system is down. To overcome this issue, starting with
 version 2, Hadoop matured to a High Availability configuration depicted in Fig-
 ure 2 where there exist two namenodes, one active namenode and one standby
 namenode communicating with the data nodes and storing edit logs in a shared
 45 folder. As their naming convention refers, the active namenode is in charge,
 whereas the standby node behaves more like a shadow system. Whenever the
 active namenode breaks down, the standby namenode gets activated, resulting
 in no service breakage for the end-user.



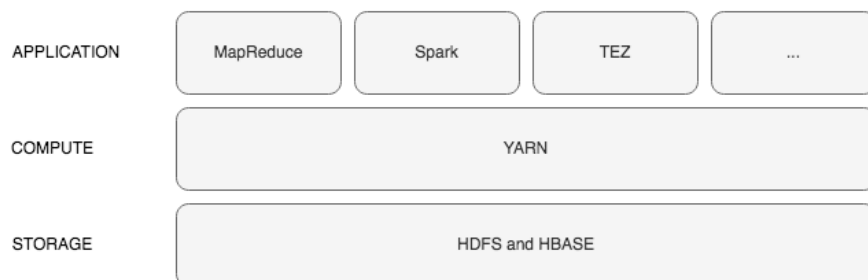
MapReduce. Similar to HDFS, Hadoop's MapReduce is the open-source imple-
 50 mentation of the MapReduce framework described in a paper [5] published in
 2004. An MR flow, as depicted in Figure 3, starts with assigning blocks from
 HDFS as input splits to mappers, computed intermediate results are then shuf-
 fled and passed to reducers where outputs are sent back to the client. Nodes

running mappers and reducers provide parallel processing, which can be scaled
 55 by simply adding new commodity computers. The computation is made on
 nodes where related data blocks reside, which explains the term data locality;
 bringing computation to the data eliminates the need for moving data across
 nodes for computation.



YARN. Hadoop version 2.x includes significant architectural improvements in
 60 terms of resource management. Version 1.x of Hadoop suffered shortcomings
 due to an overload of its resource management duties, which was handled within
 MRv1, where job tracker node and task tracker nodes were running the orga-
 nizational load of MapReduce executions. *YARN* standing for "Yet Another
 Resource Negotiator", emerged as an intermediate layer between HDFS and
 65 MapReduce by taking over some of the load that was previously carried out
 by MRv1, also become a gate to batch, stream, interactive, and graph process-
 ing engines to leverage HDFS file system (Figure 4). After *YARN*, MRv1 has
 become MRv2 isolated from resource managerial duties regarding the previous
 version hence more efficient with processing oriented focus. *YARN* innovates
 70 Hadoop by bringing the architectural elements resource manager, which is one
 node dedicated to tracking resources across the cluster by availability, and node
 managers who reside inside each worker node and monitor containers.

Figure 4: YARN (recreated from source [5])



Cloud Computing. The commercialization of Cloud Computing in the midst
 2000s [7] delivered utilization of storage and computing resources to the end-
 75 users saving them high investments in hardware technology that is soon going
 to be obsolete and is expensive to maintain. As the migration to the cloud is an
 ongoing process, Hadoop also slips out from its residence on on-prem infrastruc-
 ture to the cloud by being implemented on virtual machine instances provided as
 IaaS platforms by many providers. The Cloud Service Providers embraced the
 80 need of eliminating Hadoop's complex implementation process on multi-node
 VMs by providing managed Hadoop systems, commercially packaged as PaaS,
 which are pre-installed and pre-configured Hadoop clusters allowing the instal-
 lation of tens to hundreds of nodes in a matter of minutes by merely determining
 some settings like hardware specs and node numbers prior the installation. The
 85 Managed Hadoop system is both a blessing and a curse; by leaving the hard
 implementation part, which is not necessarily related to the primary analysis
 objective, to a contractor, the end-user saves time and efforts; including a pay-
 off, though: By definition, managed systems are prepackaged solutions provided
 in black-box nature. CSPs apply behind-the-scenes tweaks in terms of reach-
 90 ing better performance results on selected approaches like memory-intensive or
 compute-intensive applications. However, from the end-user's point of view, the
 performance of a managed system's user defined specifications remains uncer-
 tain.

GCP Dataproc [8]. Google’s managed Spark and Hadoop solution, namely Dataproc, is a pre-configured Hadoop on PaaS service built upon pre-installed VM instances on Compute Engine [9], which is another service of GCP. An OS spectrum comprising Debian and/or ubuntu was offered at the date of the study, which are proposed as pre-installed images during the Dataproc installation process. While Hadoop core elements HDFS, YARN, and MapReduce reside as default frameworks, a variety of elements belonging to the Hadoop ecosystem are offered as well. The end-user is also offered to leverage Cloud Storage [10], Google’s proprietary cloud storage service, to keep data in the long term where the Dataproc cluster is meant to be terminated after usage. By means of Web UI or local CLI via API, the end-user can access the Dataproc cluster as well as single VM instances within Compute Engine. Google offers a large number of data centers around the globe.

Azure HDInsight [11]. Azure’s solution to managed Hadoop and Spark platform is a product of the collaboration with Hortonworks bringing Hortonworks Data Platform (HDP) to a cloud platform [12]. As being so, HDInsight differs in architecture with respect to its conjugates by not being a Hadoop cluster installed on the cloud VM service layer, namely Azure Virtual Machines; instead, it is an HDP platform optimized for the cloud. Another difference is that HDInsight obligates WASB, the Azure blob system, as the storage system, including an option to leverage Data Lake Storage, excluding Hadoop’s native file system HDFS from the options. At the date of the study, Azure was obligating Hadoop to use in High Availability mode with two master nodes hence leaving hardware selection to the end-user.

Alibaba Cloud e-MapReduce [13]. Alibaba Cloud’s managed Hadoop service e-MapReduce leveraging Apache Hadoop and Apache Spark is placed as a service layer on its Elastic Compute Service (ECS) [14], a similar approach to the one of GCP’s. Alibaba’s number of provided data center locations beyond Mainland China are not as numerous as its conjugates hence available in the United States, Europe, Middle East, and the Asia Pacific. Alibaba Cloud’s managed service

distinct in that its pre-installed Operating System, Aliyun Linux 2, is developed by Alibaba Cloud, a Linux distribution based on CentOS, the open-source version of RedHat Linux. AliyunOS is claimed to provide a stable and reliable environment optimized for the Alibaba Cloud infrastructure and be open source at its GitHub repository [15]. e-MapReduce offers a wide scale of machine types with different specifications for specific purposes like CPU intensive or memory-intensive tasks. As with GCP, on Alibaba Cloud e-MapReduce, the type of storage, whether it shall be HDFS or leverage Alibaba cloud storage, can be specified by the end-user.

HiBench [16]. The open-source HiBench implementation, introduced to the community in 2010 [17], is motivated by the aim of providing a comprehensive and representative benchmark for Hadoop, helping evaluate different big data frameworks in terms of speed, throughput, and system utilization. At the date of the study, the current version of HiBench is 7.1, comprising 29 benchmarks categorized in 6 sections (Micro, Machine Learning, SQL, Websearch, Graph, and Streaming). Table 1 lists the Hadoop related workloads in HiBench 7.1 [18] executed in the study. *Sort*: The workload sorts the input data generated by RandomTextWriter. *Wordcount*: Counts the occurrence of words generated by RandomTextWriter. *Terasort*: Subject to sort is the input data generated by the Hadoop TeraGen program. *Dfsioe*: The enhanced version of Hadoop’s Dfsio benchmark generating a large number of simultaneous write and read tasks. The enhancement calculates the average IO rate, and average throughput of each map task, and aggregated throughput of the cluster.

HiBench data scales

Here is another HiBench citation [19]

2. Related Work

HiBench is a tool to measure a specific system’s performing behavior during execution. The conceptualization of conducting a benchmark may arise from different soils. Based on the conductor’s motivation, a benchmark’s use case

Table 1: HiBench 7.1 - Hadoop-related Workloads

Category	Workload	Dominant Character
Micro	Sort	IO bound
	Terasort	CPU (map), IO (reduce)
	Wordcount	CPU bound
	Dfsioe	IO bound
SQL	Scan	IO bound
	Join	IO bound
	Aggregation	IO bound
ML	Bayes	IO bound (CPU bound in map)
	Kmeans	CPU (iterations), IO (clustering)
Websearch	Nutchindexing	IO bound
	Pagerank	CPU bound

could be an inner evaluation of a system’s performance before and after some configuration tweaks are set, a comparison of rival / complementary systems, or
155 putting CSP’s cloud infrastructure services on a scale. The following literature has been searched with finding different use cases of the HiBench benchmarking suite in mind.

Poggi et al. [20] Characterizing BigBench

Poggi et al. [21] the state of SQL on Hadoop [53]

160 Samadi et al. [22] conduct an experimental comparison between Spark and Hadoop installed on virtual machines on Amazon EC2 by leveraging nine among the provided HiBench workloads. Accuracy reasons led the conductors to run the workloads three times, concluding input data scales of 1, 3, and 5 GB, respectively. Based on the outputs comprising duration, throughput, speed up, and CPU/memory consumption, the conclusion draws Spark consuming less
165 CPU and performing better on all workload results over Hadoop.

Ahn et al. [23] put Spark on YARN’s performance on the test with HiBench in terms of handling a deluge of data generated by IoT devices. The experiment is run on a cluster with one master and three worker nodes, each node possessing

170 an Intel Xeon processor with 20 cores and 128GB main memory meaning 60
cores and 384GB memory in total. HiBench workloads Micro (comprising Sort,
TeraSort, and Wordcount), SQL (comprising Aggregation, Join, and Scan), and
Machine Learning (comprising Bayes, Logistic Regression, Gradient Boosting
Tree, Random Forest, and Linear Regression) are leveraged by a chosen data
175 scale of 30 GB. Spark occupies memory during the whole job execution, which
reduces IOs' negative impact on processor performance. For optimizing resource
usage, the conductors modified YARN's minimum memory allocation and Spark
executor settings so that the Spark executors' overall loads remain below total
system memory. Alongside with HiBench's duration and throughput report,
180 CPU / memory utilization and disk throughput are profiled as well. The finding
of this paper points out that Spark guarantees performance when provided with
enough memory.

Han et al. [24] study the impact of memory size on big data processing
by means of Hadoop and Spark performance comparison leveraging HiBench's
185 k-Means workload as the only benchmark. For each of the specified memory
sizes of 4, 8, and 12 GB, iterating through a data scale of 1 to 8 GB, with 1GB
increment in between, k-Means benchmark for Hadoop and Spark is executed.
The results depict Spark's overperforming Hadoop unless the total input data
size is smaller than 33.5% of the total memory size assigned to worker nodes.
190 After reaching that ratio, Spark suffers from insufficient memory resources and
is led to interoperate with HDFS causing a sharp decrease in its performance
and brings Hadoop in throughput and duration performance to the front. The
conductors make a second experiment to find out if Spark's performance can
be improved by tweaking the allocation setting for storage memory and shuffle
195 memory while remaining within the specified memory limitations of 4, 8, and
12 GB. Executing HiBench's k-means benchmark outputs a report interpreted
by the conductors as Spark show a 5-10% and 15% maximum improvement in
processing time.

Ivanov et al. [25] compare the performances of two enterprise-grade applica-
200 tions, DataStax Enterprise (DSE), a production-level implementation of Apache

Cassandra with extended features like in-memory computing and advanced security, to name but two, and Cloudera’s Distribution of Hadoop (CDH) comprising core Hadoop elements HDFS and YARN integrated with elements belonging to the Hadoop ecosystem. DSE’s HDFS compatible file system CSF lets Hadoop applications run without any modification. The conductors installed the latest stable releases of both software on equal CPU, memory, and network infrastructure configuration; for both installations, default system parameters have been left with their defaults. HiBench’s three chosen workloads (CPU-bound wordcount, IO-bound dfsioe, and mixed HiveBench) are executed three times; furthermore, the average values have been taken for representativeness. Several conclusions of their study proclaim linearly scaling of both systems by the increase of data size, while CDH outperforms DSE in read-intensive workloads, DSE performs better in write-intensive workloads. Leveraging HiBench is where the study differs in approach related to other studies using the YCSB benchmark suite. HiBench’s results confirm the latter’s output as well.

3. Method

In the study, we benchmarked Hadoop on PaaS services of three CSPs in terms of comparing their performances accompanied by respective resource utilization across the worker nodes: GCP Dataproc, Azure HDInsight, and Alibaba Cloud e-MapReduce, each recognized in Gartner’s 2020 Magic Quadrant for Cloud Infrastructure and Platform Services [26] either in leading or in niche section.

We constructed the benchmark study in two use cases: Use Case 1 aims to map the overall performance behaviors of respective CSP’s service within HiBench’s predefined data scales, huge and gigantic. The following benchmarks have been executed on the clusters of the respective providers: Micro (Sort, Terasort, Wordcount, and Dfsioe), SQL (Scan, Join, and Aggregation), ML (Bayes and Kmeans), and Websearch (Pagerank).

Use Case 2. We picked one benchmark of IO-bound character (Sort), one

230 benchmark of CPU bound character (Wordcount) and executed these in increasing data scales delivered by HiBench: Tiny, Small, Large, Huge, and Gigantic. The largest predefined HiBench data scale, namely Bigdata, would cross the storage limits of the installed clusters; hence we left it off the execution.

Bound by the availability of their respective hardware and software options, 235 we selected by providers' promise apparently same or close settings. With respect to our aim to benchmark managed systems as they come out-of-the-box, we put two basic rules to stick for each provider in order to align initial circumstances prior to benchmark execution: Among the CSPs, the respective data center's geographic location shall be the same or close (1), processor number and 240 memory capacity (by providers' promise) shall be same or as close as possible. Thus Frankfurt is selected as the location for all providers' data centers; within the given options, we selected 8 CPUs/64GB RAM for the master node and 4 CPU's/32 GB RAM for each worker node totaling 12 CPUs and 96GB worker compute power for the cluster. Specified cluster installation options and details 245 are given in Table 2. Without applying any performance tweak operation to the respective configurations, we immediately executed several Hadoop benchmarks from HiBench's Micro, SQL, ML, and Websearch categories. We only modified the default cluster's configuration in cases where the benchmark was detained from running, which is reported in the Discussion section.

250 We collected system utilization records addressing CPU, Memory, and IO behavior on each worker node of the cluster during the benchmark execution. This approach enabled us to visualize the system utilization on each worker node within the cluster over the respective benchmark's execution time. To provide data locality, if a specific data block to process does not reside on the same 255 node where there is an available map slot, YARN transfers the respective block to the node with a free slot requiring a network activity, a possible decreasing impact over the performance. However, due to the small cluster size consisting of 3 nodes, we excluded the network activity track with the assumption data locality condition is provided during the benchmark's executions and is likely 260 to have the least impact on the performance.

Table 2: Selected configurations on CSPs’ managed Hadoop services

	GCP	Azure	Alibaba Cloud
Service	Dataproc	HDInsight	e-MapReduce
Region	europe-west3-a	Germany West Central	eu-central-1
Location	Frankfurt	Frankfurt	Frankfurt
Image	1.4-ubuntu18	HDI 3.6	EMR-3.32.0
OS	ubuntu18.04	ubuntu 16.04	Aliyun Linux 2
Hadoop v.	2.9	2.7.3	2.8.5
Java	1.8.0_275	1.8.0_275	1.8.0_252
MASTER NODE			
Machine Type	e2-highmem-8	A8m v2	ecs.se1.2xlarge
Processors	8 vCPU	8 cores	8 vCPU
Memory	64 GB RAM	64 GB RAM	64 GB RAM
Extras	–	1 Master Node clone for HA, 3 extra nodes for Zookeeper	–
WORKER NODES			
# of Nodes	3	3	3
Machine Type	e2-highmem-4	A4m v2	ecs.se1.xlarge
Processors	4 vCPU	4 cores	4 vCPU
Memory	32 GB RAM	32 GB RAM	32 GB RAM
Storage	HDFS 1000 GB	WASB	HDFS 1000 GB
Replication	2	<i>Azure blob storage</i>	2
Block size	128 MB		128 MB

4. Results

HiBench’s Hadoop related benchmarks in groups Micro (Sort, Terasort, Dfsioe, and Wordcount), SQL (Scan, Join, and Aggregation), ML (Bayes and Kmeans), and Websearch (Pagerank) have been executed on all three CSPs managed Hadoop services. Table 3 lists HiBench 7.1 benchmark reports for Use Case 1, Table 4 lists reports for Use Case 2.

Plots. During benchmark runtime, resource utilization on worker nodes has been captured. The plots are suggested to be perceived as follows: Top-left, top-right, and bottom-left plots represent CPU (user%), memory (%memused), and IO utilization (read transfers and write transfers per second) on each worker node of the respective cluster over time. CPU utilization lines are given in blue tones; memory utilization lines are given in fuchsia tones, IO-read and IO-write tps’ are represented with orange tones and green tones, respectively. Even though the coloring convention might sound confusing, it gives a clear overview of the utilization behavior of the entire benchmark process over time. The left-hand side x-axis measures CPU/Memory usage in percent; the right-hand side x-axis measures IO-read and IO-write transfers per second. The bottom-right plot represents the comparative benchmark performance outputs of the respective CSPs. Duration measure in seconds is expected to be perceived as ”lower is better” while throughput, which is the amount of processed data per second in bytes, is expected to be perceived as ”higher is better”.

For each use case, we provided spider charts, a.k.a. radar plots, to give a comparative overview for system utilization vs. benchmark performances of relevant CSPs. In these plots, normalized average values of the captured CPU, Memory, and IO data on the worker nodes have been taken and averaged a second time in order to get scalar CPU, Memory, and IO values representing the cluster’s average performance. Combining the aforementioned values with normalized Duration and Throughput report values of HiBench resulting the spider plots of the paper. Nevertheless, for the spider plots, our recommendation for both perceptions of Throughput and Duration shall be ”Higher is better”.

Table 3: Use Case 1 benchmark results

Data Scale: Huge

Benchmark	IDS	Dataproc		HDInsight		e-MapReduce	
		$D_{(s)}$	$T_{(MB/s)}$	$D_{(s)}$	$T_{(MB/s)}$	$D_{(s)}$	$T_{(MB/s)}$
Sort	3.28	70	47.11	131	25.08	111	29.42
Terasort	32.00	667	47.99	858	37.28	1054	30.37
Wordcount	32.85	978	33.60	1470	22.34	889	36.95
Dfsioe-r	26.99	294	91.77	662	40.79	245	110.21
Dfsioe-w	27.16	379	71.73	658	41.30	281	96.49
Scan	2.01	73	27.63	157	12.83	74 (*)	27.19 (*)
Join	1.92	181	10.61	356	5.39	175 (*)	10.95 (*)
Aggregation	0.37	97	3.86	215	1.73	97 (*)	3.85 (*)
Bayes	1.88	2604	0.72	6120	0.31	3017	0.62
Kmeans	20.08	2321	8.65	2313	8.68	2070	9.70
Pagerank	2.99	1544	1.94	3334	0.90	2458	1.22

Data Scale: Gigantic

Benchmark	IDS	Dataproc		HDInsight		e-MapReduce	
		$D_{(s)}$	$T_{(MB/s)}$	$D_{(s)}$	$T_{(MB/s)}$	$D_{(s)}$	$T_{(MB/s)}$
Sort	32.85	715	45.94	787	41.72	896	36.68
Terasort	320.00	9821	32.58	—(**)	—(**)	9660	33.13
Wordcount	328.49	10131	32.42	13596	24.16	8671	37.88
Dfsioe-r	216.03	915	236.11	1886	114.54	660	327.29
Dfsioe-w	217.33	1347	161.39	1914	113.57	1060	205.12
Scan	20.10	457	43.96	514	39.09	407 (*)	49.38 (*)
Join	19.19	595	32.27	761	25.24	594 (*)	32.32 (*)
Aggregation	3.69	523	7.05	594	6.20	565 (*)	6.52 (*)
Bayes	3.77	5350	0.70	12589	0.30	6363	0.60
Kmeans	40.16	4541	8.84	4042	9.94	4034	9.96
Pagerank	19.93	8371	2.38	11779	1.70	13893	1.43

IDS: Input Data Size (GB); $D_{(s)}$: Duration (sec); $T_{(MB/s)}$: Throughput (MB/sec)

(*) Benchmark succeeds after modifying preconfiguration, more on this in Discussion

(**) System failure due to insufficient space on HDFS, more on this in Discussion

Table 4: Use Case 2 benchmark outputs

Benchmark	Dataproc			HDInsight		e-MapReduce	
	IDS	$D_{(s)}$	$T_{(MB/s)}$	$D_{(s)}$	$T_{(MB/s)}$	$D_{(s)}$	$T_{(MB/s)}$
Sort (t)	39.30 KB	36	0.0012	69	0.0006	32	0.0012
Sort (s)	3.28 MB	36	0.09	70	0.0471	31	0.105
Sort (l)	328.50 MB	42	7.86	81	4.07	42	7.74
Sort (h)	3.28 GB	70	47.08	141	23.36	107	30.69
Sort (g)	32.85 GB	694	47.30	699	47.00	883	37.20
Wordcount(t)	38.65 KB	38	0.001	68	0.0006	31	0.0012
Wordcount (s)	348.29 MB	50	6.51	98	3.34	47	7.06
Wordcount (l)	3.28 GB	129	25.45	269	12.20	120	27.27
Wordcount (h)	32.85 GB	952	34.51	1487	22.10	888	37.00
Wordcount (g)	328.49 GB	9749	33.70	13286	24.73	8622	38.10

IDS: Input Data Size; $D_{(s)}$: Duration (sec); $T_{(MB/s)}$: Throughput (MB/sec)
(t): tiny, (s): small, (l): large, (h): huge, (g): gigantic

Even though the duration is of lower is better nature, for the sake of proper visualization, we needed to display the shortest duration as the most visible among other CSPs.

4.1. Use Case 1 Results

Sort - Huge (Figure 5). CPU utilization in GCP and Alibaba condense around 80% to 98%, whereas in Azure, the range widens up between 50% to 90%. Memory loads in GCP and Alibaba among the worker nodes display a harmonic behavior between 20% to 40% and 90% to 100%, respectively, whereas the memory load in Azure’s worker nodes varies between 10% and 50%. In the second half of the benchmark execution, IO write transfers in GCP and Alibaba show peaks at about 500 tps, wherein Azure IO transfer s limited with 100 tps. GCP carrying out the highest throughput, thus reaching the shortest duration of 70 seconds.

Sort - Gigantic (Figure 6). Switching the data scale for Sort benchmark to gigantic, GCP’s processor load condenses around 80% - 95% where its memory

load rises to range 80% - 100%; IO write transfers behave at about 500 tps where IO reads reach 1000 tps in the second half of the benchmark process. Azure's processor and memory performances depict a looser behavior not utilizing the maximum potential, whereas IO-read and IO-write tps' reach their maximum at 200 and 350, respectively. Alibaba's resource utilization depicts a high memory load of 90% - 100% dropping to 70% and about 83% on partial nodes in the second half. As so with the processor load behaving between 80% and 100% in the first half dropping to about 50% in the second half where IO write reaches the peak at 800 tps., which results in GCP embarking highest and Azure the second highest throughput, respective Durations output in 715 and 758 seconds.

Terasort - Huge (Figure 7). GCP depicts a high utilization on processors at a range of 80% - 100%, memory moving from 80% to 100%, and IO behavior 500 tps in overall and peaking at 1000 tps in IO-read, resulting in the highest throughput in 667 seconds response time among other CSPs. Azure's processor and memory utilization fluctuate in overall execution where memory performance incrementally reaches 100% in one node, a stable IO-write in overall process at about 70 tps peaking at 250 tps reaches the second highest throughput in 858 seconds. Alibaba, with high memory and processor utilization and varying IO tps's in the overall process, falls back in embarking throughput and resulting in 1054 seconds response time.

Terasort - Gigantic (Figure 8). Switching the scale to gigantic causes dramatic changes in resource utilization on all CSPs. During all benchmark processes, GCP depicts very condensed high utilization on the processor at a broad range of 30% to about 95%, memory consumption between 95% and 100%, and IO read transfer varying between 800 to 1100 tps. Azure, on the other side, fails to complete the benchmark on three attempts, suffering from YARN insufficient HDFS allocation requested for bringing the job further. IO scores drop to null, and task raises failure. Alibaba Cloud's resource utilization goes within maximum levels where processor utilization depicts a consumption of 80% to 90% in the overall, memory utilization at it highest during all process, and IO

reads and writes moving along the 600 tps' and peaking around 1600 tps. With a slightly higher value in throughput, Alibaba performs best with 9660 seconds, followed by GCP with 9821 seconds. Azure disqualifies this session.

Wordcount - Huge (Figure 9). GCP performing processor utilization of 75%
340 to 100% with a memory consumption between 80% to 95% where IO transfers move along 60 tps peaking at about 150 tps reaches second-highest throughput with 978 seconds response time. Azure's processor utilization moving along 70% to about 100%, where memory depicts 30% to 50% utilization and lower IO transfers peaking at about 60 tps reaches the lowest throughput hence the
345 most extended duration of 1470 seconds. Alibaba depicting high processor and memory load moving in ranges 70% to 100% and 80% to slightly over 90% with IO transfers moving along 200 tps peaking at 300tps to 350tps reaches the highest throughput hence shortest execution time of 889 seconds.

Wordcount - Gigantic (Figure 10). GCP utilizing processor and memory sources
350 at their maximum during the overall process, for CPU within 60% up to pushing 100%, memory utilization varying between 60% to 100%, and IO-read and IO-write transfers moving along 90 tps and 250 tps, respectively, reaches second-highest Throughput load resulting in 10131 seconds response time. Azure shows a dens processor utilization varying between 40% and close to 100%, memory
355 consumption is somehow oppressed to stay within the range of 20% up to 50%, IO behavior seldomly reacts over 60 tps resulting in the lowest throughput and most extended duration of 13596 seconds. Alibaba depicting a high processor utilization within range 85%-100%, relatively more stable memory consumption in the range 85% to 100%, and IO transfers mostly about 300 tps, thus
360 performing highest throughput hence shortest response time of 8671 seconds.

Dfsioe-read - Huge (Figure 11). GCP's processor utilization is moving roughly between 80% to 95%, accompanied by memory utilization within range slightly below and over 70%, IO transfers peaking at 400 tps mostly go along 100 tps to 250 tps performs second highest throughput resulting in 294 seconds of duration.

365 Azure's processor utilization is somewhat limited to between 60% and 90%,
whereas the memory utilization behaves between 10% to 50%, generally low
IO transfers with two markable IO-read and IO-write condenses reaching peaks
at 2000 tps and 1500 tps, respectively, results in the lowest throughput and
662 seconds of response time. Alibaba, with 245 seconds duration, displays a
370 similar resource utilization pattern with GCP where it differentiates in memory
utilization, moving around 90%.

Dfsioe-read - Gigantic (Figure 12). Processor utilization in GCP cloud con-
centrates within the range of 80% to 90%; memory utilization moves around
95% to 100%, whereas IO read transfers moving along about 500 tps brings its
375 performance to second highest throughput with 915 seconds Duration. Azure
performs within a range of 55% up to 90% in CPU utilization, 20% to 55% in
memory utilization, and IO-write activity moving along 70 tps, IO-read showing
a peak at about 470 tps, which results in throughput outputting 1886 seconds
response time. Alibaba system utilization moves along 80%-90% range for pro-
380 cessing performance, 90%-100% for memory load, and behavior up to 1700 tps
IO-write placing its performance to the highest throughput with 660 seconds
duration.

Dfsioe-write - Huge (Figure 13). In GCP, processor utilization moves between
70% and 90%, memory load increments from 20% up to 70%, whereas IO-write
385 transfers move along 500 tps resulting in the second shortest response time 379
seconds. Azure's CPU utilization around 60% to 90%, memory load moves
between 20% and 40%, whereas IO-write transfers vary about 20 tps to 80 tps
peaking at about 120 tps by a Duration output of 658 seconds. Alibaba, with
processor utilization 80% and 95%, incrementing memory load from about 40%
390 up to 90%-100%, and IO-write transfers at about 100 tps to 600 tps peaking
at about 800 tps performs the heaviest throughput, thus reaching the shortest
response time with 281 seconds.

Dfsioe-write - Gigantic (Figure 14). GCP processor utilization moves along a broad range hitting up to 90% load, memory load quickly rises to 95%-100% range and keeps its position in overall execution, IO-writes move along 500 tps to 600 tps placing GCP to the second-best performance with 1347 seconds response time. Azure shows a CPU utilization in a range of 60% up to 90% until it drops to about 25% in the 2/3th of the overall process, memory load moves along lower 20% to upper 50% until its sudden drop to upper 15% simultaneously with CPU utilization where IO-write transfers peak at about 120 tps resulting in 1914 seconds response time. Alibaba performing the shortest response time with 1060 seconds displays a similar memory and processor utilization behavior with GCP where it differs in IO-write transfers peaking at about 900 tps.

Scan - Huge (Figure 15). GCP processor utilization condenses between about 80% and 90% during benchmark execution; memory load depicts movement between 20% and 40% accompanied by an IO-write transfer reaching over 500 tps, which brings GCP to the top performance within this benchmark with 73 seconds. On Azure's side, processor utilization moves along 80%-90% range whereas memory load increments from the 15% to the 30%, relatively low IO-write transfer peaking at about 85 tps results in lowest Throughput and 157 seconds Duration. Alibaba follows a similar pattern like GCP in resource utilization with about 90% CPU load, 15% to below 40% memory utilization but a less dense IO-write transfer peaking at about 550 tps and so reaching a close Throughput to GCP resulting in 74 seconds response time.

Scan - Gigantic (Figure 16). GCP's CPU utilization varying between 50% and 90% with convergence at about 80%, memory load showing similar range with utilization reaching up to 100% and IO-write transfers moving between 500 tps and 600 tps results in second-highest throughput by a 457 seconds response time. Azure's CPU utilization condenses between 80% and 90% and memory load incrementing two times from 20% to 40%, IO-write transfer moving along 50 tps to 60 tps peaking at about 200 tps results in 514 seconds Duration. Alibaba's processor utilization moves in a relatively higher range between 80%

and 95%, incrementing memory load range from 40%_s-50%_s to 80%_s-100%_s during runtime, and IO-write transfers peaking at about over 500 tps results in
425 the highest throughput, thus the shortest duration of 407 seconds.

Join - Huge (Figure 17). GCP processor load moves mainly between 80%_s and over 90%_s; memory utilization moves along about 20%_s and 30%_s, IO-writes behaving at about 150 tps brings outputs 181 seconds response time. Azures resource utilization shows a range between 80% and 90% for CPU, varying
430 memory loads moving along below 20%_s and below 60%_s, IO-write transfers behave below 60 tps with a peak of 100 tps resulting in a lower throughput and response time of 356 seconds. Resource utilization at Alibaba behaves similarly to GCP in processor and memory load, whereas IO-write peaks at about 260 tps, reaching the highest throughput and a duration of 175 seconds.

435 *Join - Gigantic (Figure 18).* CPU load in GCP moves along 70% to 90% overall whereas RAM utilization among worker nodes takes a path within 50% to 90% range, IO-write transfers observed in behavior about 100 tps resulting in a Throughput outputting 595 seconds of response time. Azure's performance dynamics show a load of 80% to 90% with decreasing utilization on some worker
440 nodes in a later stage, memory utilization moving along the range of 20% up to 60%, and IO-write transfer observations peaking at 120 tps provide the lowest throughput hence the longest response time of 761 seconds. Alibaba is performing a processor utilization of about below 90% to below 100%, memory load behavior moving along 50% to below 70%, and IO-write observation peaking
445 at 350 tps performs a slightly higher Throughput than GCP hence a slightly shorter duration of 594 seconds.

Aggregation - Huge (Figure 19). GCP processor utilization moving around 80% to about 95%, memory load behaving between 15% to 40%, and IO-write transfer observed at about 150 tps result in 97 seconds Duration. Azure's CPU
450 utilization behaves between 80% and 90%, whereas memory load moves along from 10% to varying utilization among worker nodes up to 30% and below 60%,

and IO-write transfers peaking at about 180 tps performs a relatively small
Throughput resulting in 215 seconds completion time. Alibaba resource uti-
lization moving along between 80% and 90% for CPU, 10% to 40% in memory,
455 and IO-write transfer average of 26 tps show comparable performance to GCP
resulting in the same completion time of 97 seconds.

Aggregation - Gigantic (Figure 20). Processor utilization moving between 80%
and 90% in overall execution, memory load between 50% and 70% peaking to
below 100%, IO-write transfers reaching a dense behavior at the end reaching
460 500 tps results in highest throughput and 523 seconds response time. Azure
displays a CPU utilization of below 80% to above 90%, mild RAM utilization
moving along 30% to 60%, IO-write transfers behaving about 100 tps resulting
in a relative low throughput, and 594 seconds of duration to complete. Alibaba's
processor load moves along 80% to below 100%, IO-write transfer behavior
465 scaling from about 50 tps to 400 tps results in 565 seconds response time.

Bayes - Huge (Figure 21). GCP in processor behavior moving along about
70% to below 100%, memory load at about 30% with a short peak to below
100% at the first half, an IO-write transfer behavior about 500 tps resulting in
highest throughput thus fastest response time of 2604 seconds. Azure displays a
470 split behavior in CPU utilization among worker nodes, where one load moves at
about 80% to lower 100% and one node depicts a movement on the minimum at
about 20%; memory load on worker nodes also vary from each other by about
20% load difference at the beginning however meeting the similar range starting
at the second half, IO observations depict a low range with the exception at
475 the high IO-write transfer at about 3200 tps at the initial state of the execution
result in a relatively low throughput hence the most prolonged duration of 6120
seconds. Alibaba CPU utilization shows varieties among worker nodes in load
ranges; RAM utilization condenses at higher levels of 80%, IO transfers moving
along 100tps to observable 450 tps resulting in 3017 seconds response time.

480 *Bayes - Gigantic (Figure 22).* GCP's processor utilization moving along 70% to below 100%, accompanied by memory load incrementing from 40% to 70% becoming stable at 50%, and IO-write transfers moving along 500 tps results in the highest throughput and 5350 seconds of response time. Azure's resource utilization shows the distinction in CPU and memory among worker nodes while
 485 two nodes depict higher utilization at about 70% to below 100% for processing and 40%-50% for memory, one node staying at lower levels for respective resources, the observed IO-write transfer move along 100 tps where IO-read transfer peaks at about 650 tps resulting in the lowest performance of 12589 seconds Duration. Alibaba depicting different utilization ranges among worker
 490 nodes for processing, the memory consumption follows a more balanced load among worker nodes with IO-write transfer moving along 200 tps a relatively lower Throughput hence the relatively long duration of 6363 seconds, with respect to GCP.

Kmeans - Huge (Figure 23). GCP's CPU performance behaves in the range
 495 of about 60% to below 100%, whereas memory utilization moves about 60%, increasing at the reduce phase where IO-write activity also condenses 500 tps. The utilization in Azure depicts itself in a high CPU behavior of about 80% and 90%, a moderate memory consumption moving along 20% up to below 60%, and IO transfers moving along 40 tps results in the second shortest duration. Alibaba
 500 utilizing processor and memory in high levels, including drops in processors on particular worker nodes, with an increased IO-write transfer in reduce phase reaches the highest throughput hence shortest duration.

Kmeans - Gigantic (Figure 24). In the gigantic data scale, all three services remain their previous utilization behavior in a more condensed manner in IO
 505 transfers. Alibaba and Azure competing in throughputs, the resulting outcome is 4034 seconds for Alibaba and 4042 seconds for Azure, GCP's duration does not stand far apart by 4541 seconds.

Pagerank - Huge (Figure 25). GCP's processor utilization behavior moves in a higher range at about 70% and below 100%; RAM utilization follows a midlevel path moving along to 50%, including peak points at below 100%, IO transfers vary in the heights at about 500 tps resulting in the best performance by 1544 seconds. Azure performs a high utilization behavior in the processor at about 80% to over 90%, memory load changes between about 20% up to 60%, a lower level range of 100 tps to 150 tps characterizes its IO transfer utilization resulting in 3334 seconds duration. Alibaba's both CPU and memory utilization across worker nodes move between 80% and lower 100%, and IO transfer behavior pushing upper limits at about 600 tps reaches second-highest throughput resulting in 2458 seconds.

Pagerank - Gigantic (Figure 26). Switching to a gigantic scale, the CPU load of GCP becomes more condense in a range of about 60% up to below 100%, a fluctuating RAM utilization behavior incrementing three times to 100% over the execution time, and an IO transfer at about 500 tps performs the highest throughput and shortest duration of 8,371 seconds. Azure's processor load varies between 70% up to below 100%, showing fluctuating memory utilization incrementing from 40% to below 100%, general IO transfers limited to about 200 tps with peak exceptions at about 5000 tps performing the second shortest duration of 11,779 seconds. Alibaba's resource utilization draws condense load for CPU and memory, pushing the limits in a fluctuating style; IO transfers mostly stay below about 300 tps, peaking at 600 tps to 1200 tps several times during execution, performing the lowest throughput result in the longest duration of 13,893 seconds.

Overview to benchmarks executed in Use Case 1 (Figures 27 and 28).

4.2. Use Case 2 Results

Sort - Tiny, Small, Large, Huge, Gigantic (Figures 29, 30, 31, 32, 33).

Wordcount - Tiny, Small, Large, Huge, Gigantic (Figures 34, 35, 36, 37, 38).

Figure 5: UC1 - Sort (Huge; 3.2 GB)

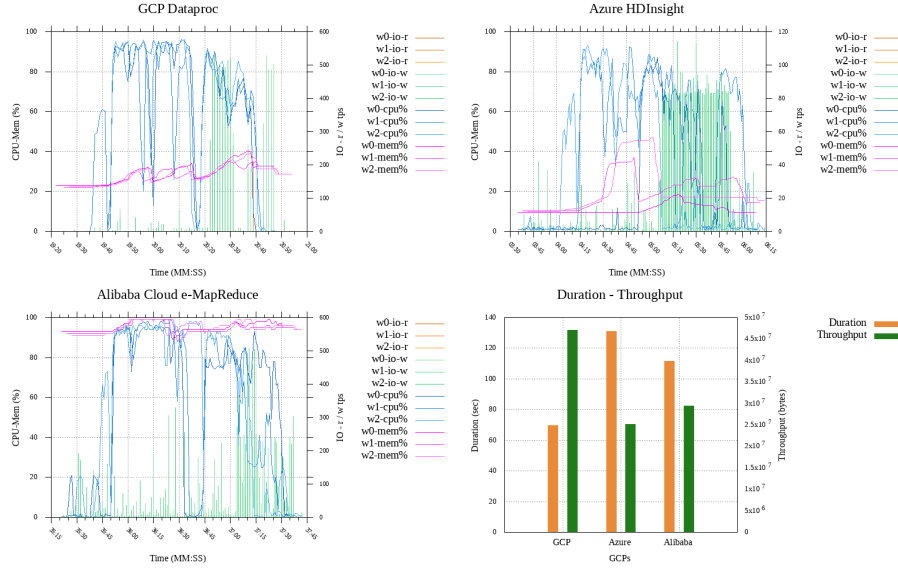


Figure 6: UC1 - Sort (Gigantic; 32 GB)

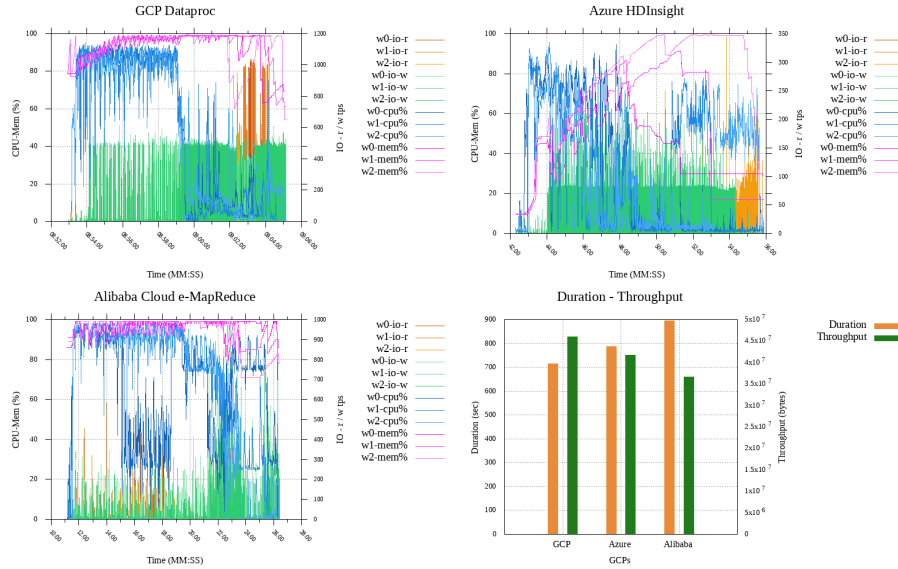


Figure 7: UC1 - Terasort (Huge; 320 MB)

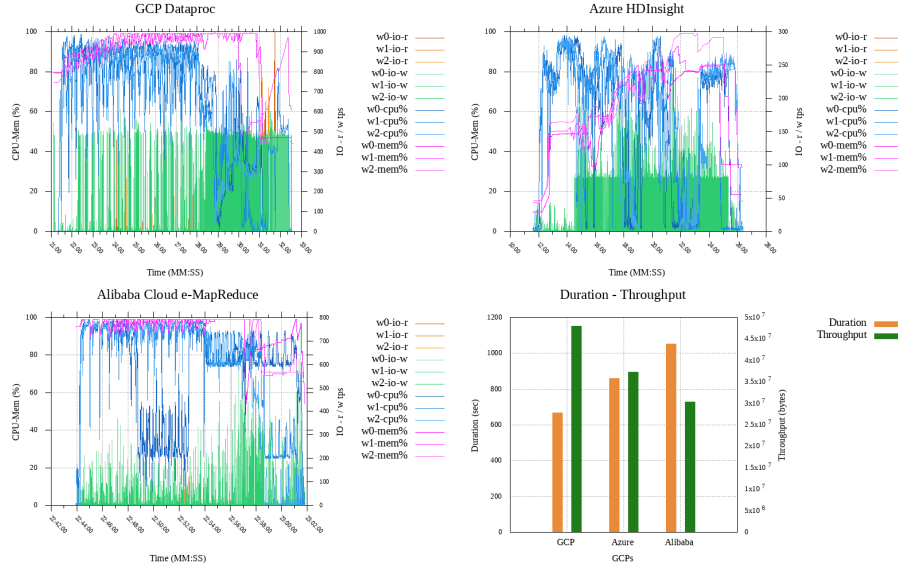


Figure 8: UC1 - Terasort (Gigantic; 3.2 GB)

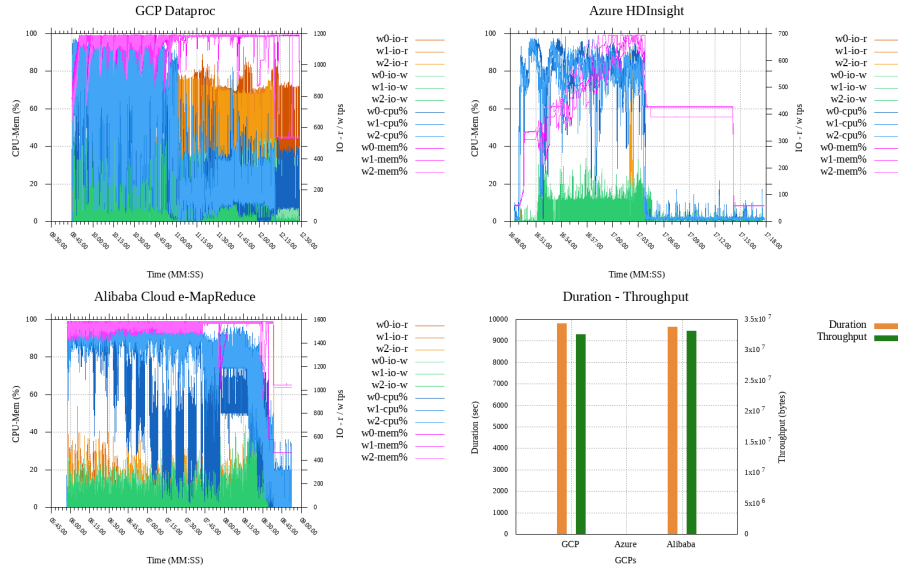


Figure 9: UC1 - Wordcount (Huge; 32 GB)

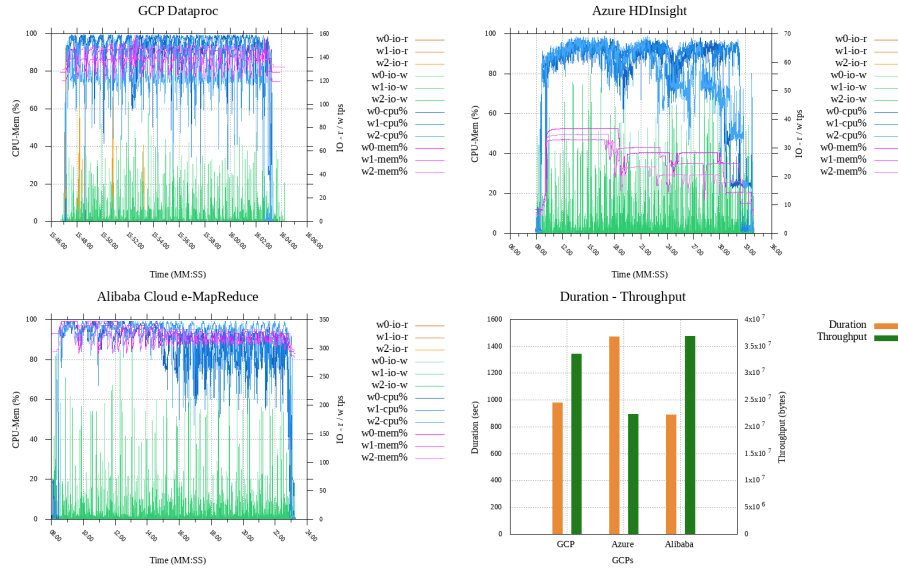


Figure 10: UC1 - Wordcount (Gigantic; 320 GB)

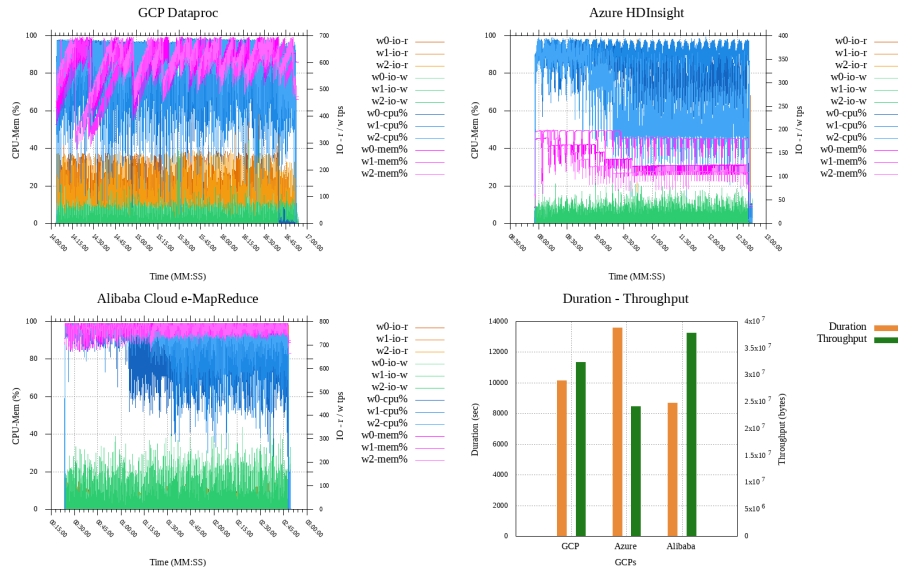


Figure 11: UC1 - Dfsioe-read (Huge; No of Files: 256, File size: 100 MB)

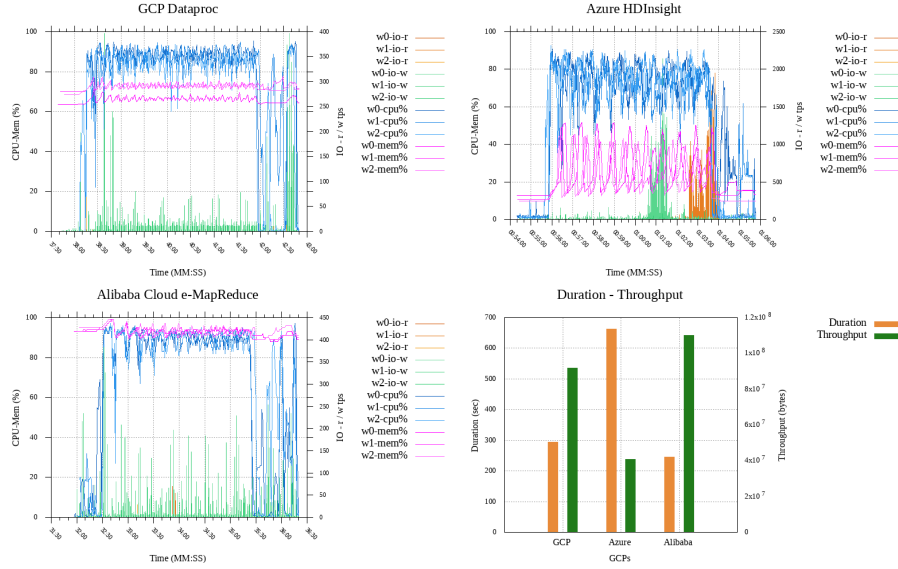


Figure 12: UC1 - Dfsioe-read (Gigantic; No of Files: 512, File size: 400 MB)

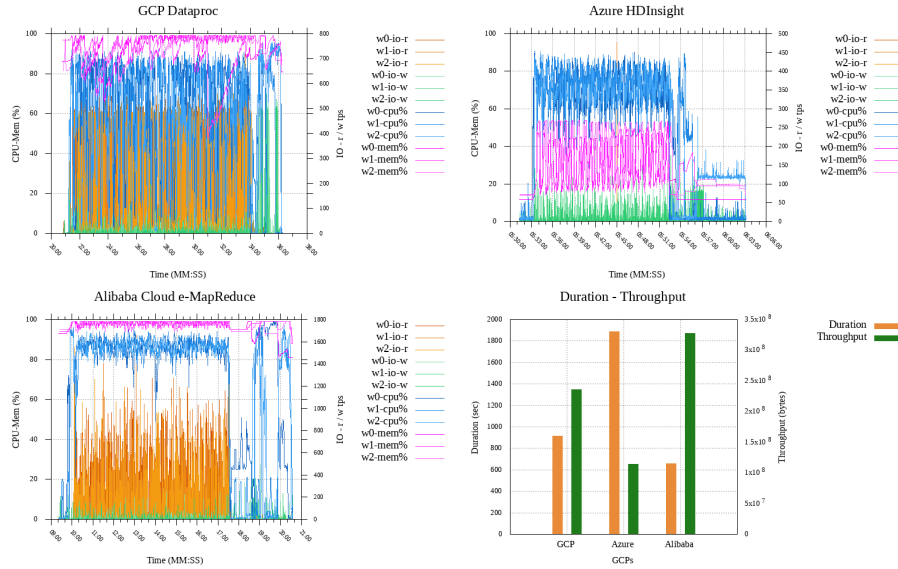


Figure 13: UC1 - Dfsioe-write (Huge; No of Files: 256, File size: 100 MB)

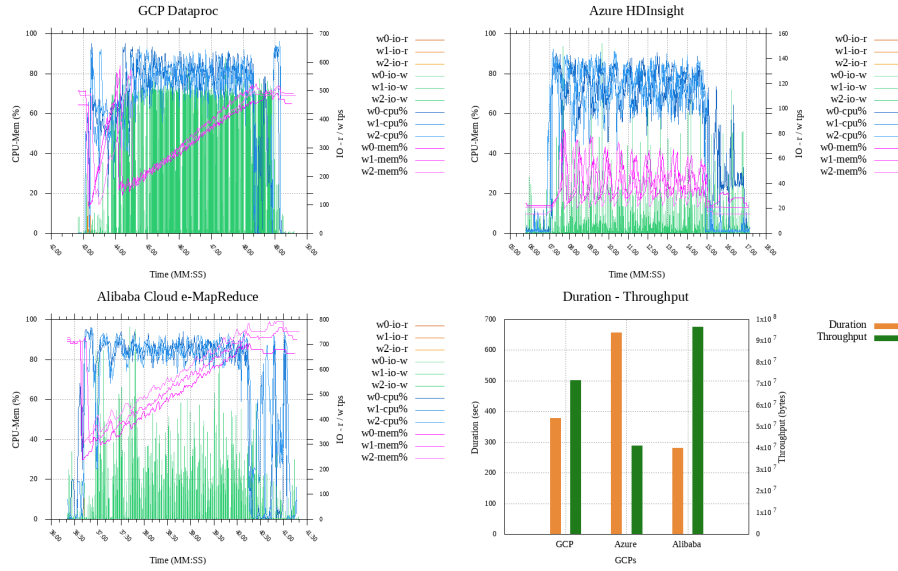


Figure 14: UC1 - Dfsioe-write (Gigantic; No of Files: 512, File size: 400 MB)

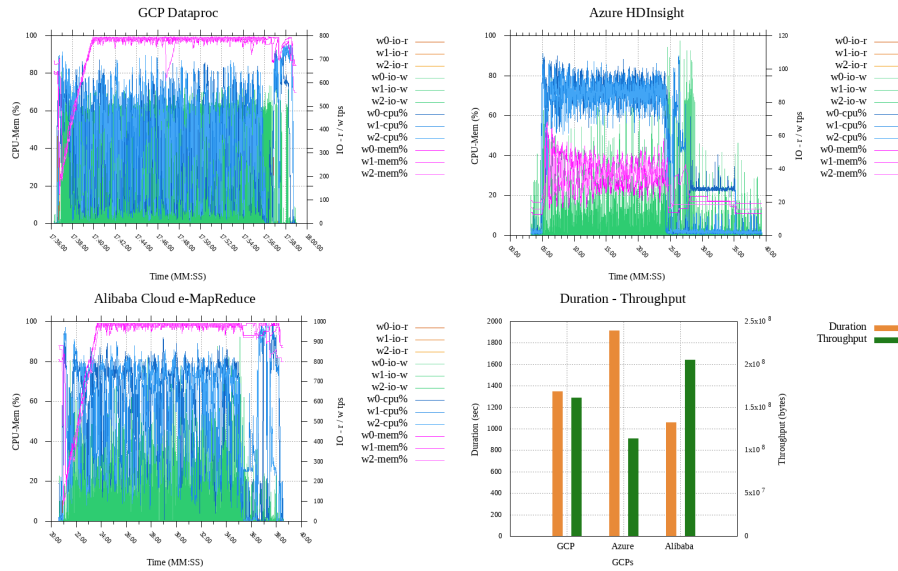


Figure 15: UC1 - Scan (Huge; USERVISITS: 10,000,000 PAGES: 1,200,000)

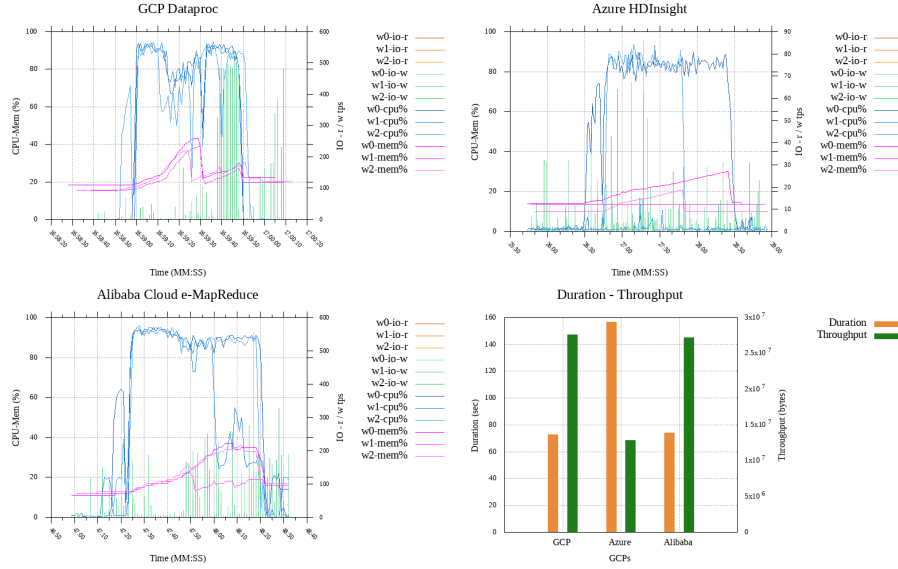


Figure 16: UC1 - Scan (Gigantic; USERVISITS: 100,000,000 PAGES: 12,000,000)

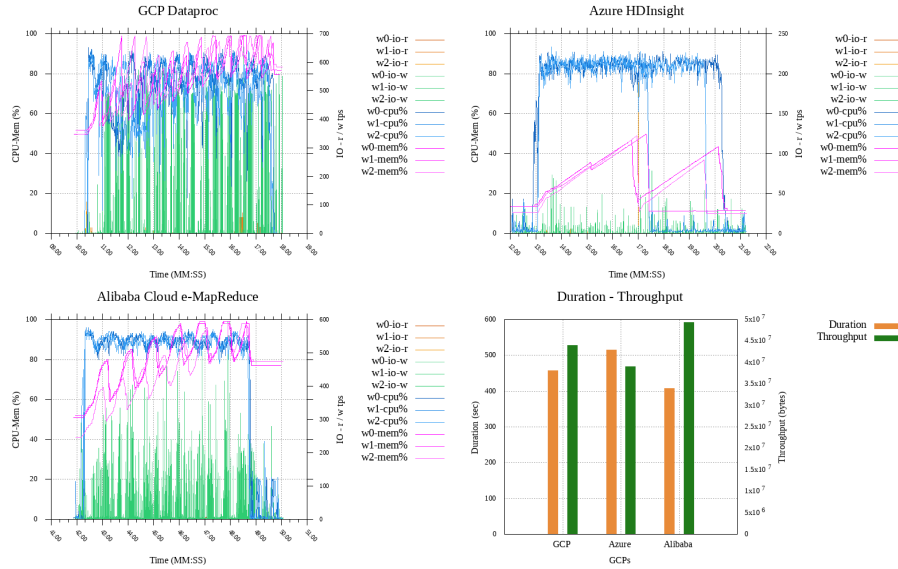


Figure 17: UC1 - Join (Huge; USERVISITS: 10,000,000 PAGES: 1,200,000)

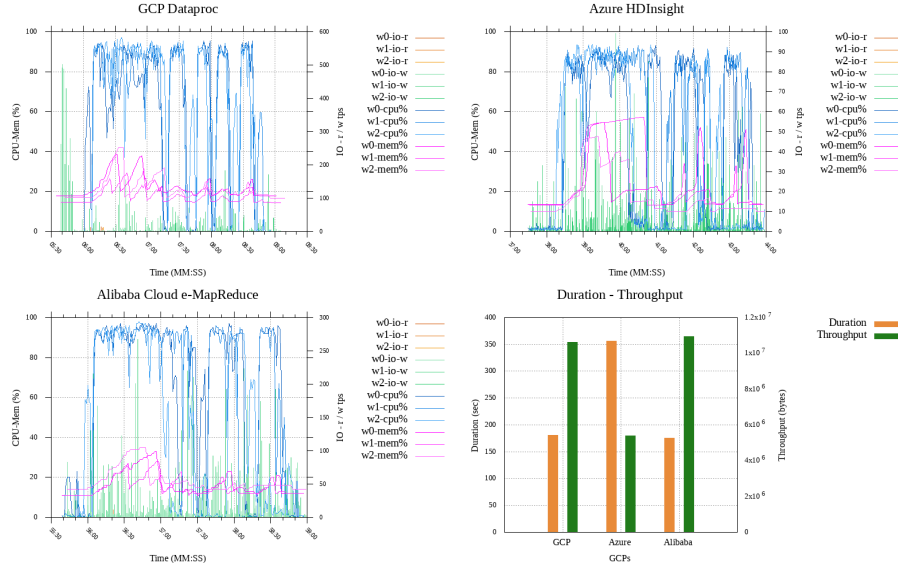


Figure 18: UC1 - Join (Gigantic; USERVISITS: 100,000,000 PAGES: 12,000,000)

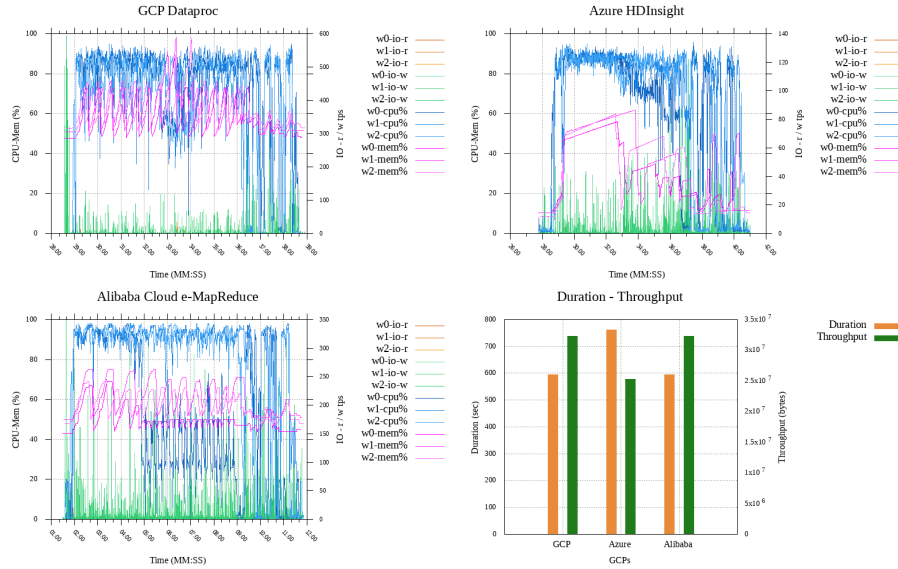


Figure 19: UC1 - Aggregation (Huge; USERVISITS: 10,000,000 PAGES: 1,200,000)

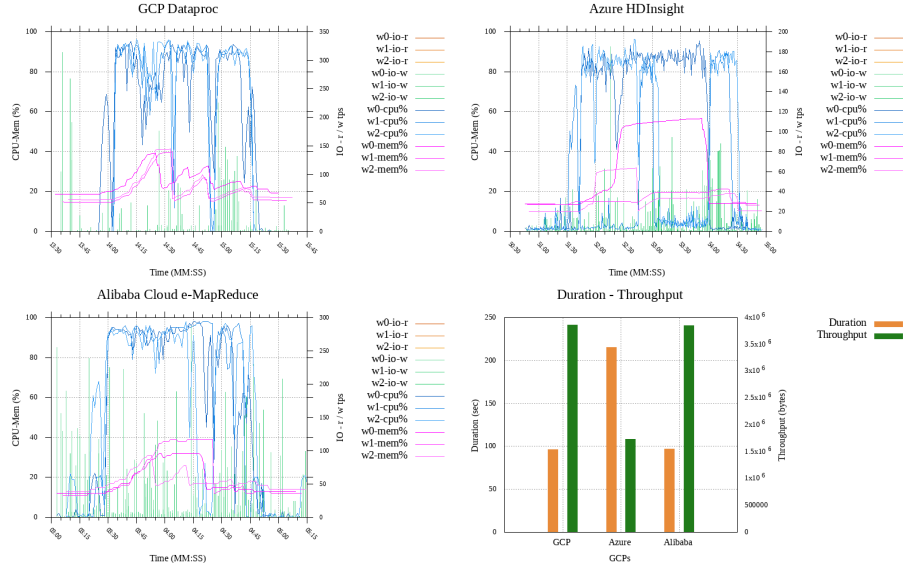


Figure 20: UC1 - Aggregation (Gigantic; USERVISITS: 100,000,000 PAGES: 12,000,000)

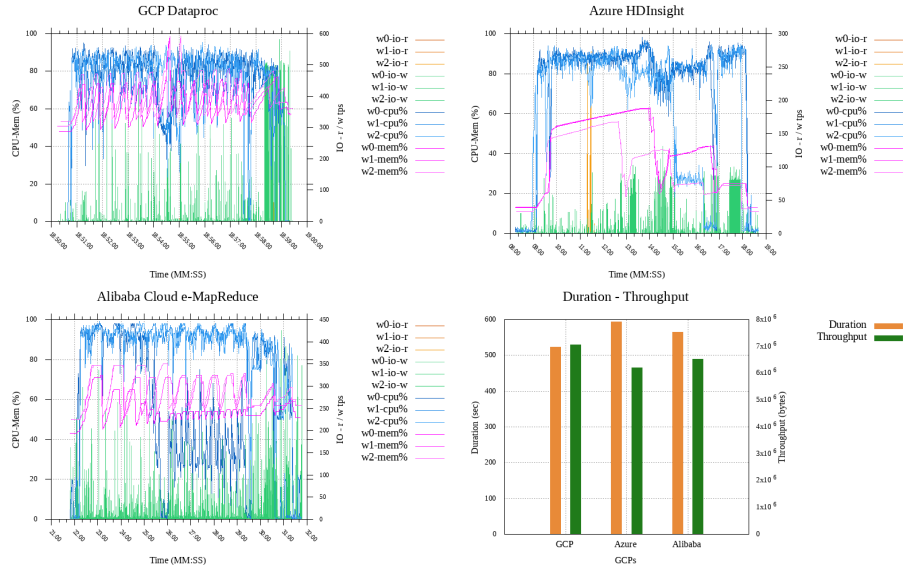


Figure 21: UC1 - Bayes (Huge; PAGES: 500,000 CLASSES: 100 NGRAMS: 2)

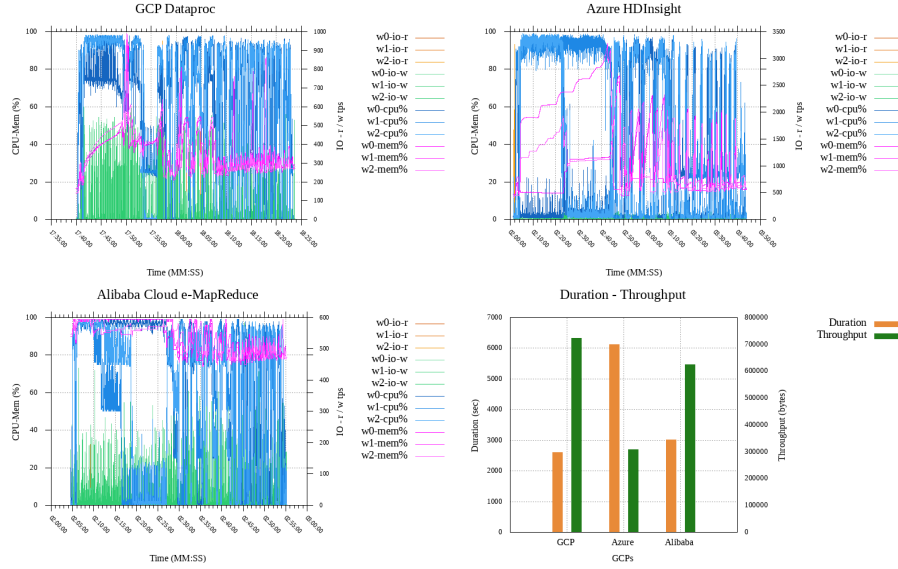


Figure 22: UC1 - Bayes (Gigantic; PAGES: 1,000,000 CLASSES: 100 NGRAMS: 2)

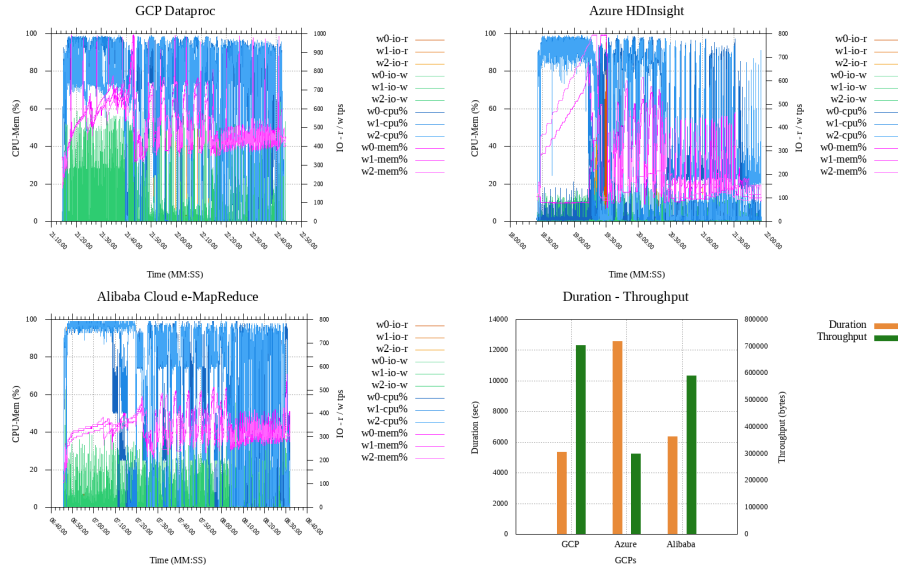


Figure 23: UC1 - Kmeans (Huge; CLUSTERS: 5 DIMENSIONS: 20 SAMPLES: 100,000,000
SAMP PER INPUT: 20,000,000 MAX IT: 5 K: 10 CONVERGEDIST: 0.5)

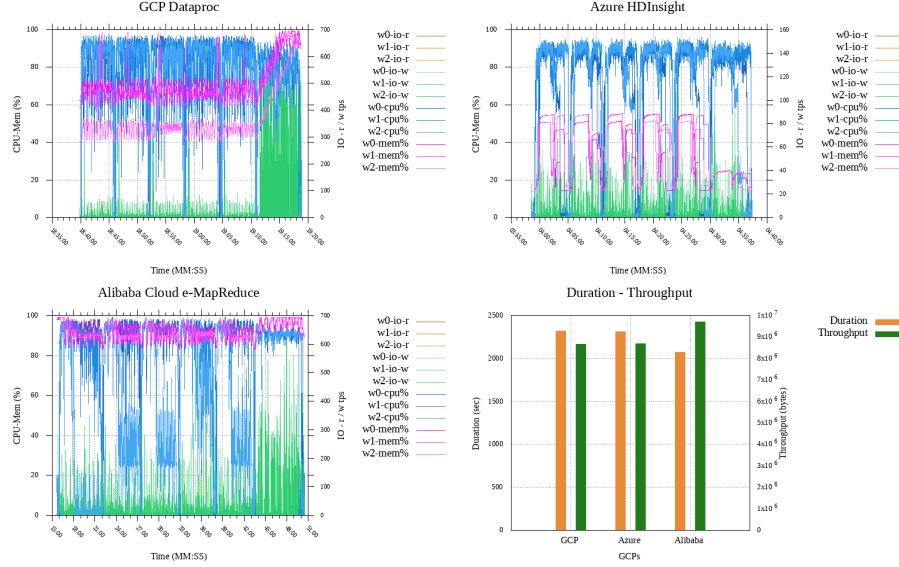


Figure 24: UC1 - Kmeans (Gigantic; CLUSTERS: 5 DIMENSIONS: 20 SAMPLES: 200,000,000 SAMP PER INPUT: 40,000,000 MAX IT: 5 K: 10 CONVERGEDIST: 0.5)

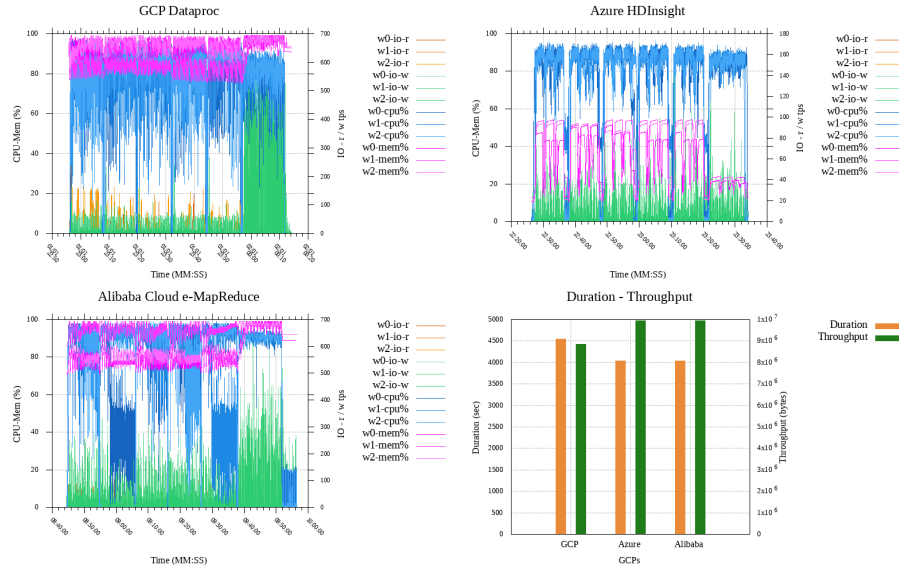


Figure 25: UC1 - Pagerank (Huge; PAGES: 5,000,000 NUM ITERATIONS: 3 BLOCK: 0
BLOCK WIDTH: 16)

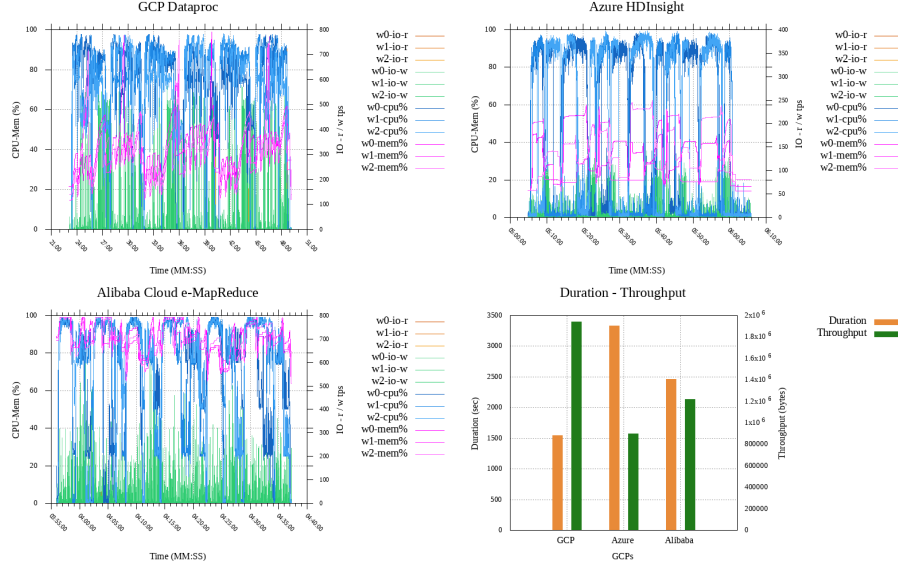


Figure 26: UC1 - Pagerank (Gigantic; PAGES: 30,000,000 NUM ITERATIONS: 3 BLOCK:
0 BLOCK WIDTH: 16)

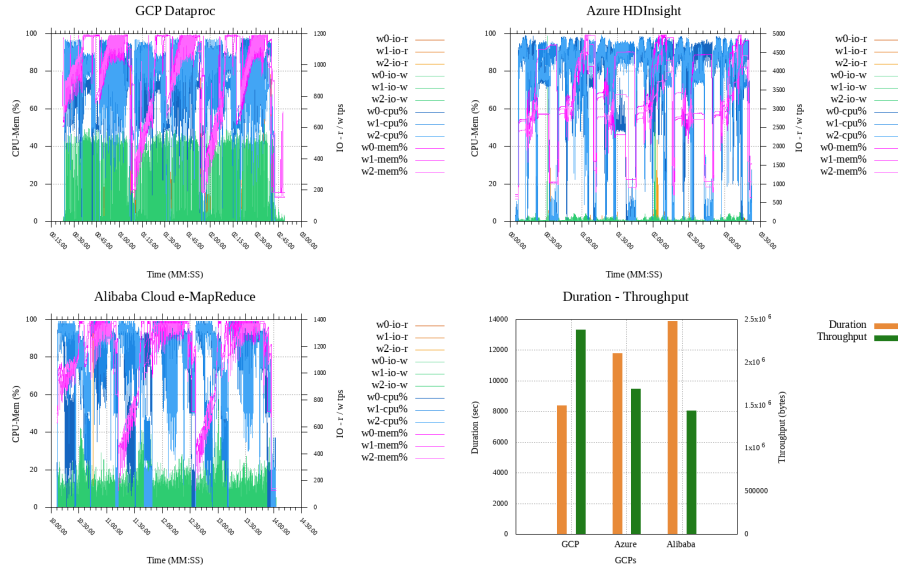


Figure 27: Use Case 1 - Hadoop benchmark comparisons in huge data scale

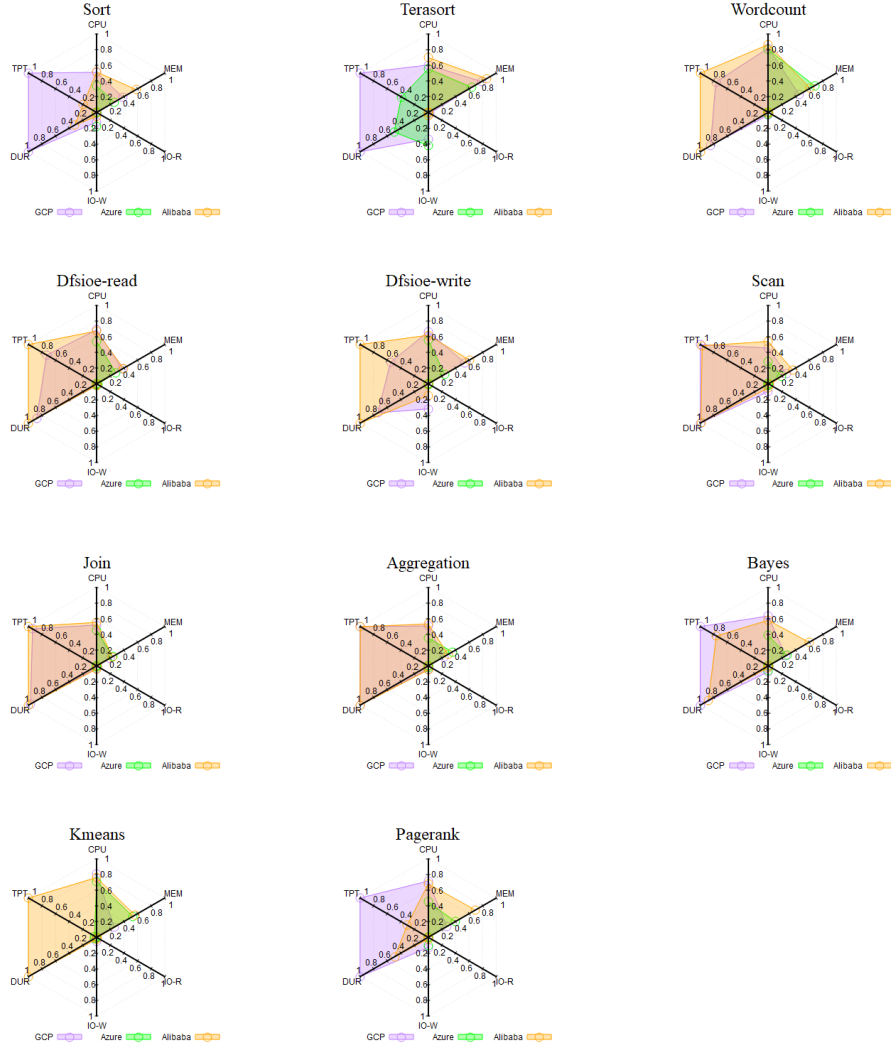


Figure 28: Use Case 1 - Hadoop benchmark comparisons in gigantic data scale

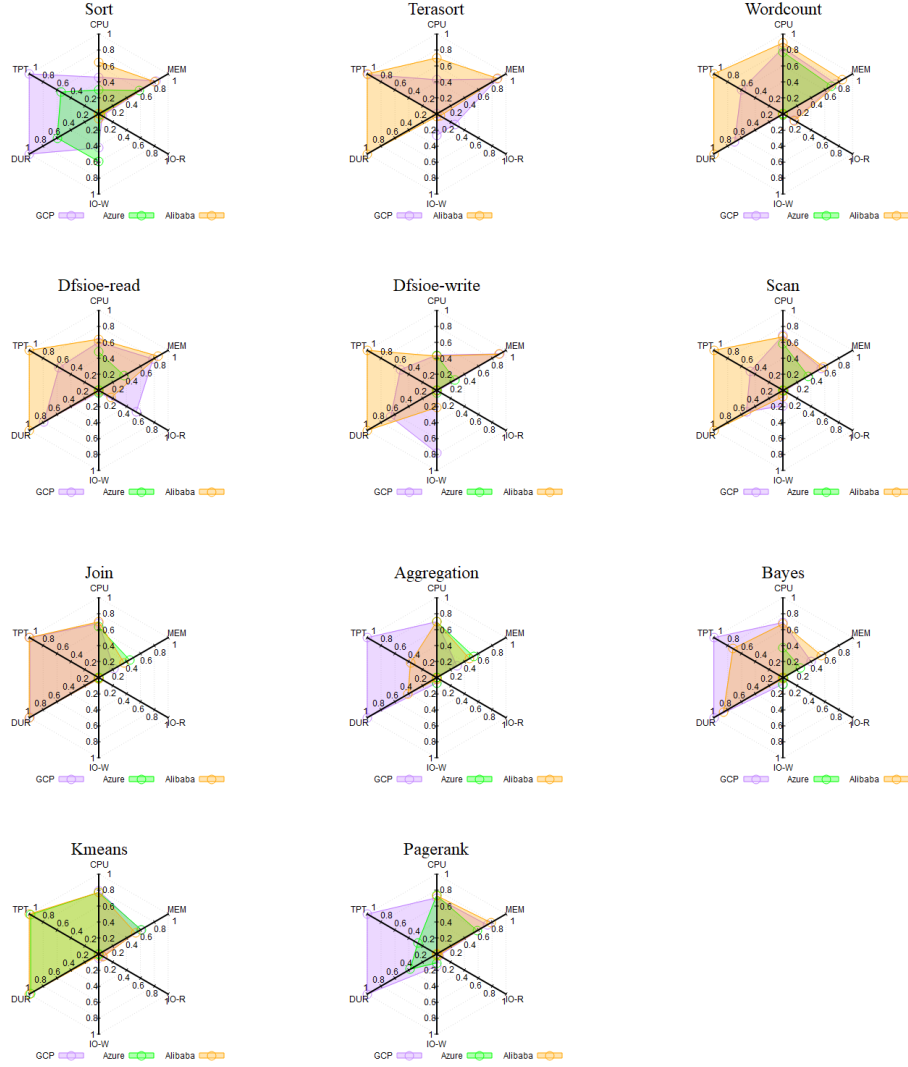


Figure 29: UC2 - Sort (Tiny; 32 KB)

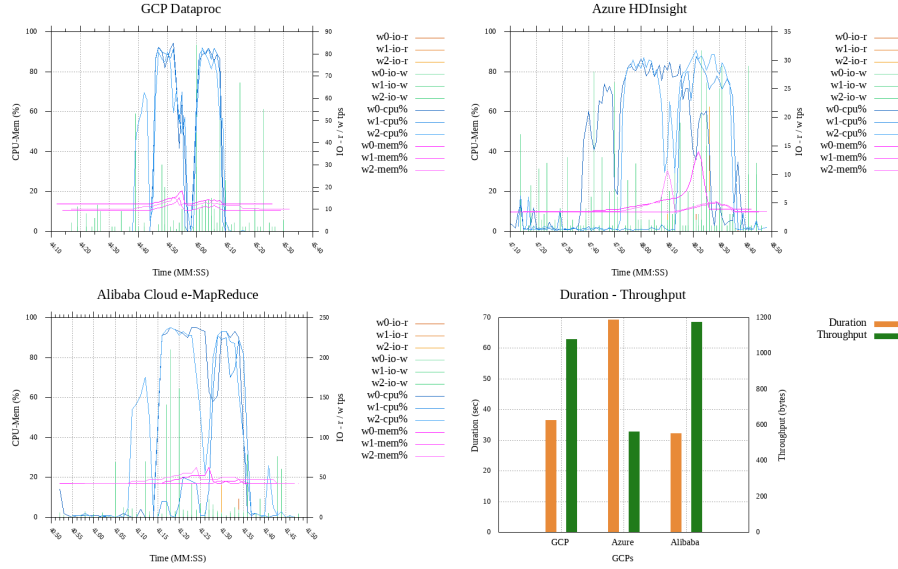


Figure 30: UC2 - Sort (Small; 3.2 MB)

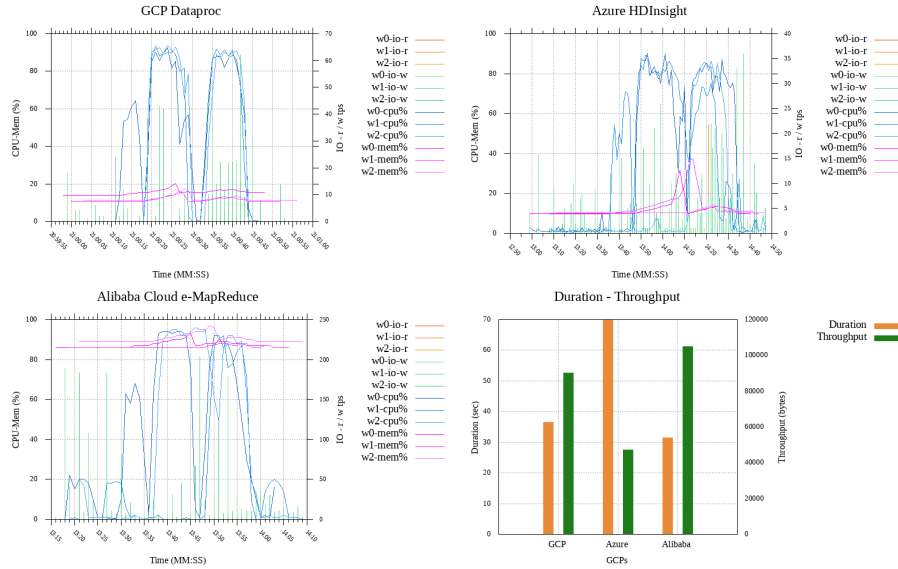


Figure 31: UC2 - Sort (Large; 320 MB)

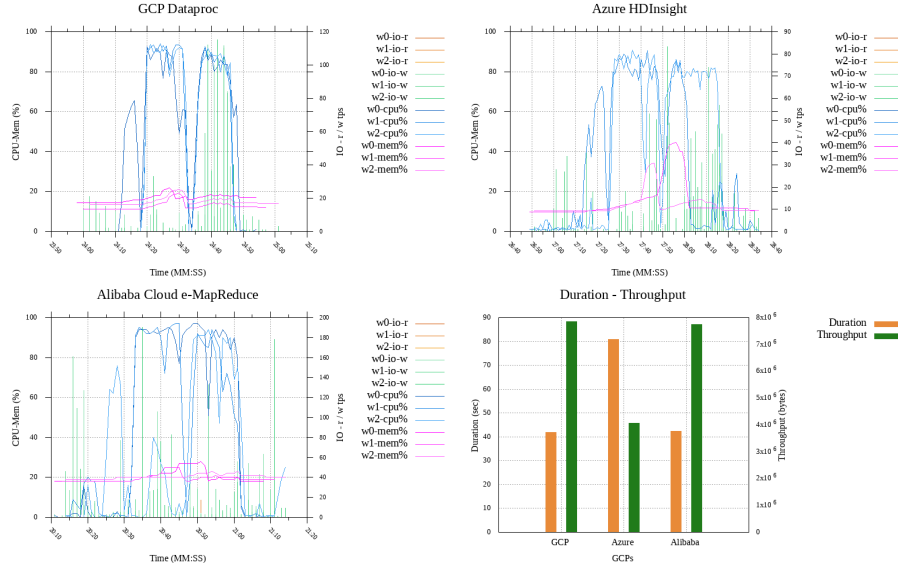


Figure 32: UC2 - Sort (Huge; 3.2 GB)

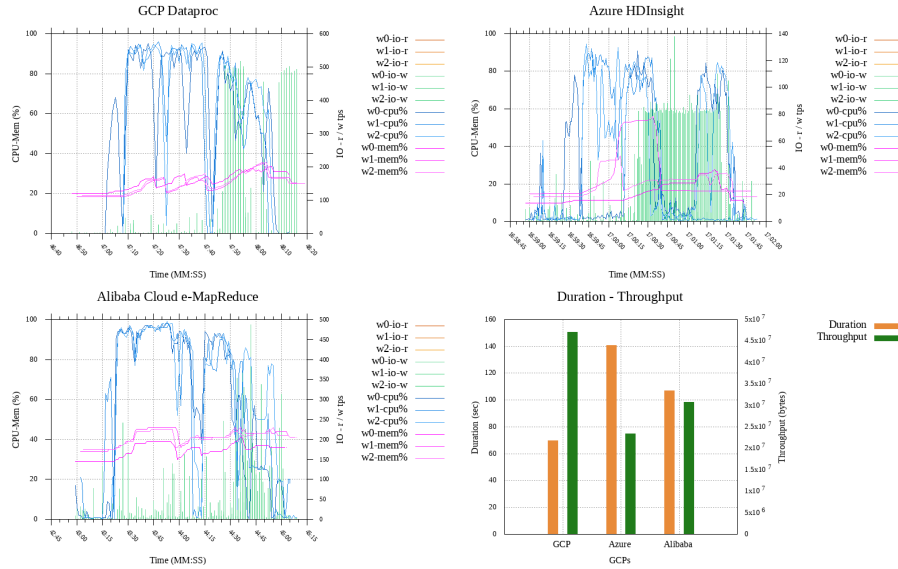


Figure 33: UC2 - Sort (Gigantic; 32 GB)

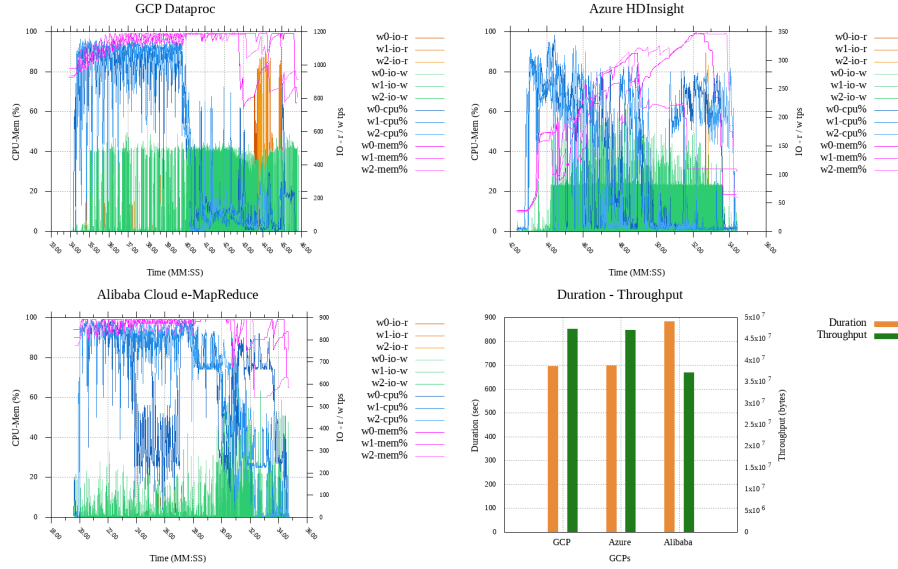


Figure 34: UC2 - Wordcount (Tiny; 32 KB)

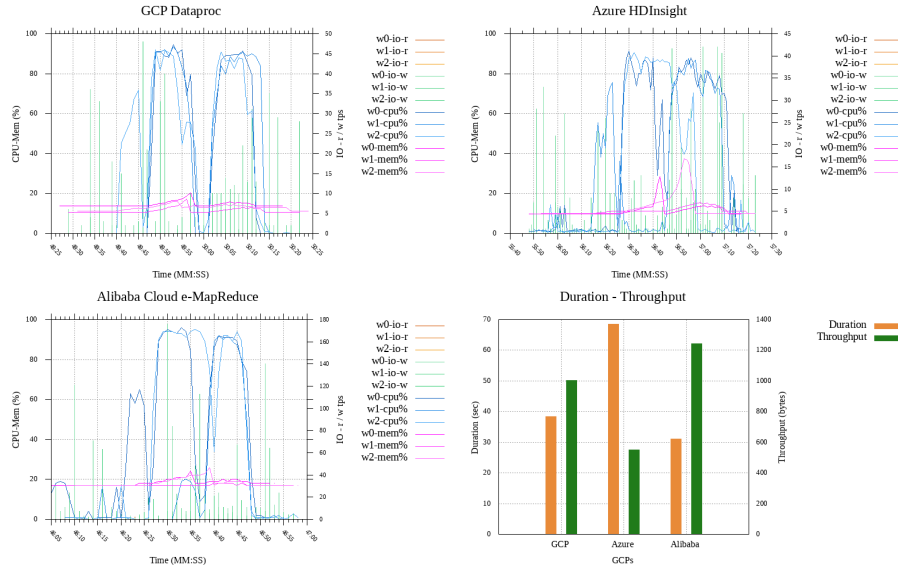


Figure 35: UC2 - Wordcount (Small; 320 MB)

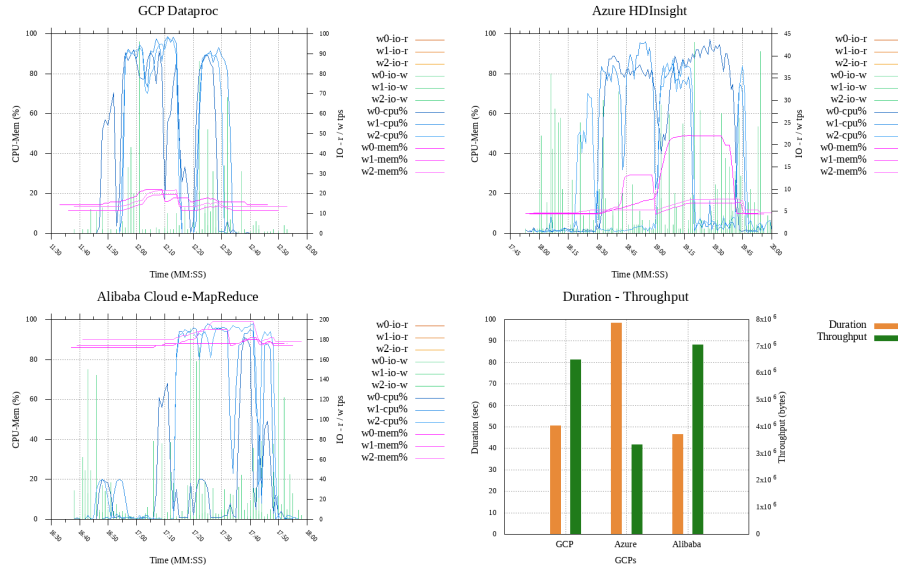


Figure 36: UC2 - Wordcount (Large; 3.2 GB)

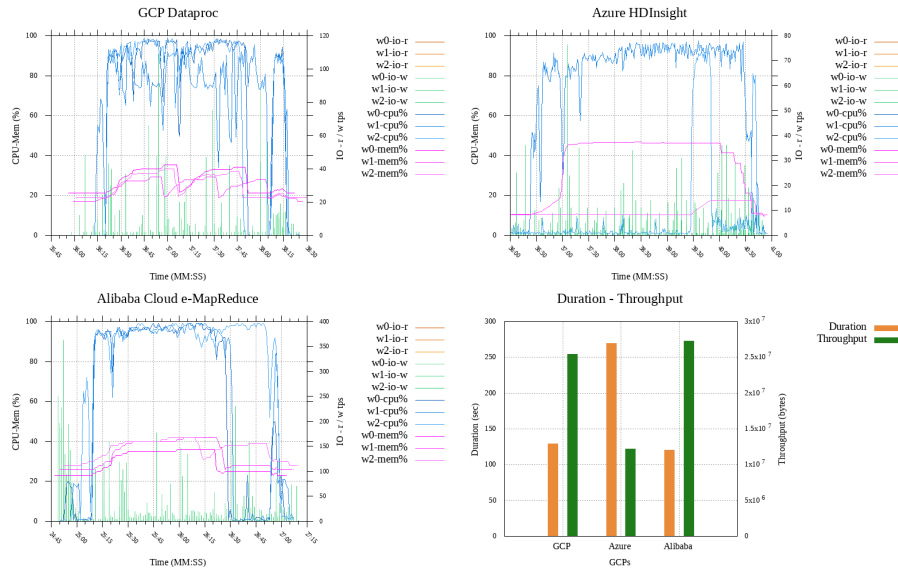


Figure 37: UC2 - Wordcount (Huge; 32 GB)

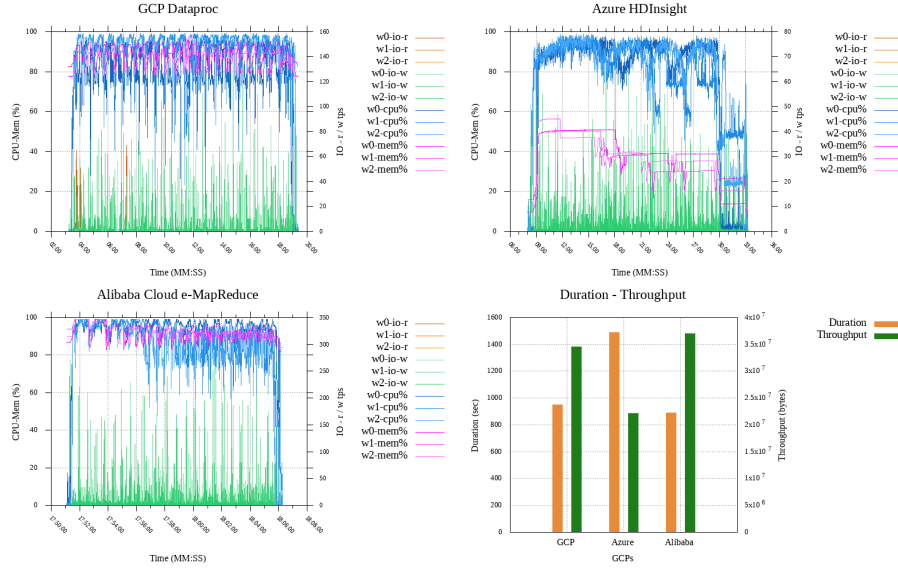
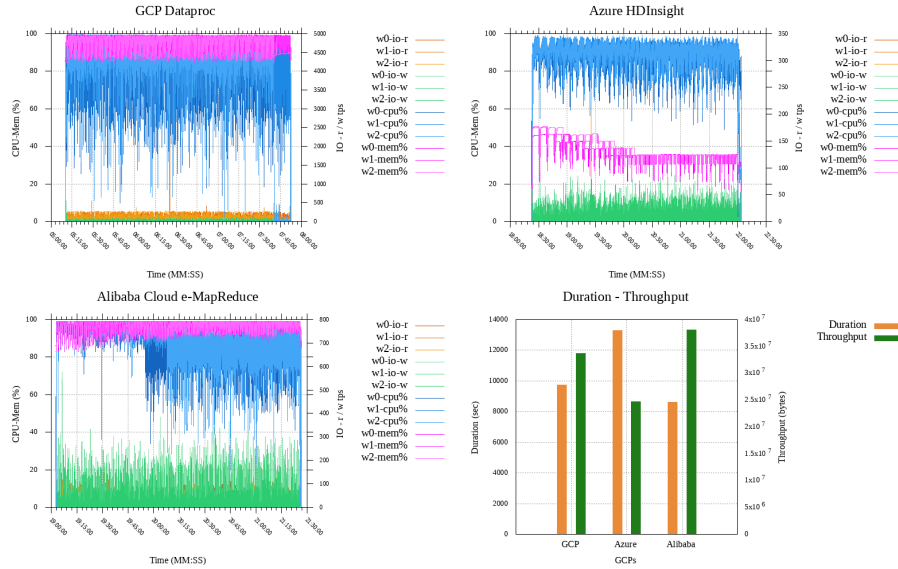


Figure 38: UC2 - Wordcount (Gigantic; 320 GB)



Overview of Sort benchmark varying data scales (Figure 39).

Overview of Wordcount benchmark varying data scales (Figure 40).

5. Discussion

Limitations, workarounds, failures. One major limitation of the study has been the high-cost of benchmark executions' total running time charged in a pay-per-use manner, which led the conductors to keep benchmarks at only one successful execution for each workload, which is not fitting the best practice; executing each benchmark thrice and taking the average would have provided more stable outcomes, especially in cases where there occurs a very tiny difference between successive performances of respective providers. Another result of the limitation mentioned above is that we also left off the largest predefined data scale of HiBench, namely Bigdata. Execution of this benchmark would have provided us performance outputs in a vast data scale like 300 GB for Sort, 1.6 TB for Wordcount, and 12.000.000 pages by 1.000.000.000 user visits for Aggregation, to name but three. Hence, we recommend the study to be understood in terms of an attempt to bring more clarity to black-box nature managed Hadoop proposals' performance behavior using resource utilization dynamics and as the managed services come out-of-the-box without any performance tweaking configurations applied. We do not recommend the study to be understood as a grading board for the business values of respective managed Hadoop systems.

HiBench comes with dependencies downloaded during its compilation process by Apache Maven. The Hive engine is one of those dependencies leveraged by HiBench for running SQL workloads Scan, Join, and Aggregation. Alibaba's e-Mapreduce comprises a ready-made Hive hook triggering a Java file to run post-execution transactions for other services within the package. However, this configuration prevented HiBench from starting with respective benchmarks' execution since the HiBench based Hive engine does not include the jar file mentioned above defined for e-MapReduce's specific environment. A workaround

Figure 39: Use Case 2 - Sort performances along with data scales

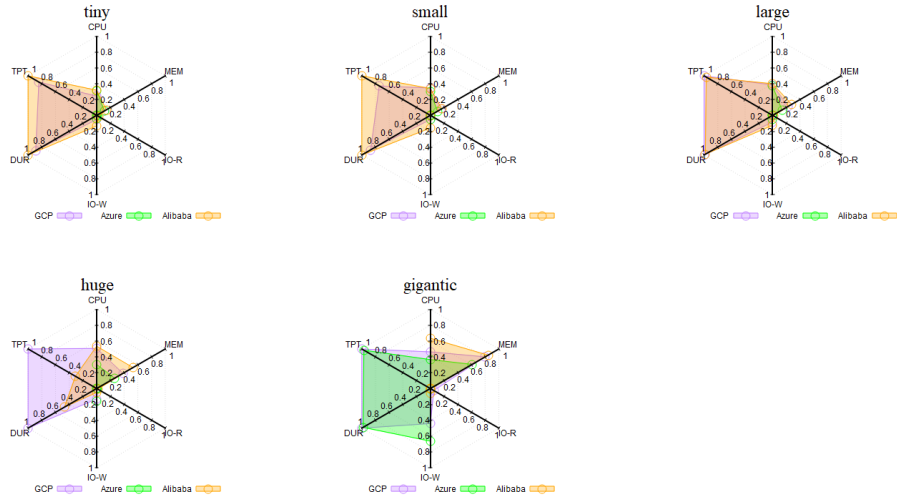
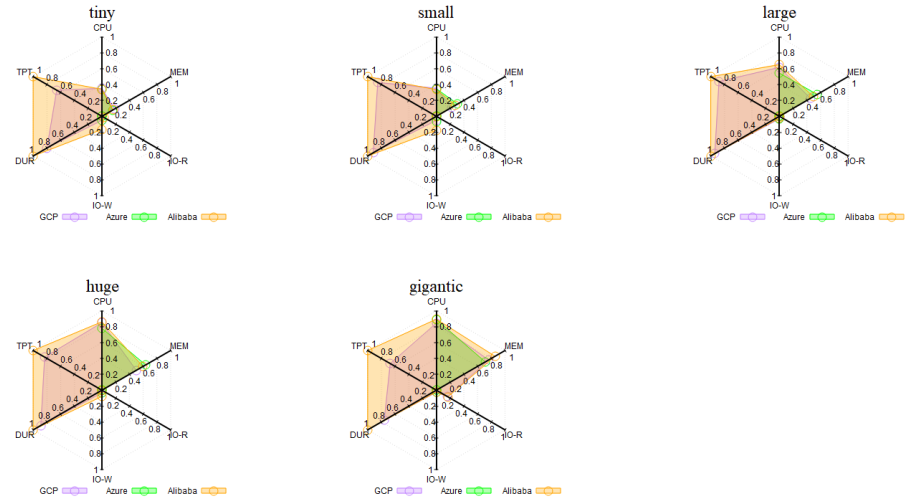


Figure 40: Use Case 2 - Wordcount performances along with data scales



attempt, copying the related jar file to an appropriate directory within Hi-
565 Bench, made the jar file available; however, this time, HiBench’s Hive engine
of an older version did not support the hook `”hive.exec.post.hooks”` defined
in Alibaba’s Hive configuration. At this point, disabling the respective Hive
hook from Alibaba e-MapReduce’s UI management console apparently solved
this issue and enabled HiBench’s SQL workloads to run, but its impact on the
570 respective performance values remains unknown, hence the need to annotate it
here. With GCP and Azure, issues of this kind did not occur.

In the Azure environment, the Terasort benchmark running in data scale
gigantic failed to complete in all three attempts we conducted where about 20%
of map operations were reached. Showing distinction to GCP and Alibaba where
575 the end-user is liberated in choosing HDFS or the respective provider’s cloud
storage service as the cluster’s file system, Azure obligates the user to go with
WASB file system among other Azure storage services with a promise to Peta-
scale. However, after inspecting the failure, it turned out that the exception
is not due to the WASB file system. Even though WASB is predefined as the
580 cluster’s file system, during the application’s run time, YARN still leverages the
cluster’s HDFS file system for storing intermediary results failing to allocate
free space on HDFS reaching specific levels of maps operators. The conductors
marked this failure as a structural bottleneck since all end users running Terasort
operation at this scale would face the same error, and since resource utilization
585 can be tracked up to the failure point and after, we kept this benchmark by
marking it as incomplete. Figure 8 displays system resource utilization on Azure,
including the point where the failure occurs.

Along with the resource utilization vs. performance plots both for Use Case
1 and Use Case 2, it is easily recognizable how likely architectures, namely
590 GCP Dataproc and Alibaba Cloud e-MapReduce, both leveraging a more con-
ventional Hadoop installation and infrastructure, follow a similar pattern in
utilization over time whereas a different architectural approach distinct in its
performance behavior as in Azure’s HDP based HDInsight. To better under-
stand the relative performance dynamics, we gathered and processed the CSPs’

595 HiBench performances in duration (seconds) in Table 5 and Table 6. Column
 "Benchmark" refers to the respective benchmark executed, column "First" con-
 tains the best-performing provider, column "Second" points out the provider
 service with the second shortest duration, column "Third" lists the provider of
 the longest duration for the respective benchmark. Columns "-Perf%" display
 600 the relatively low performance of the respective provider's service listed to their
 left with respect to the best performing service's value. *Relative Performance*
Rate = (Shortest Duration - Current Duration) / Shortest Duration. Relative
 Performance Rates indicate that in overall alike architectures are close in their
 results and competitive like performing the same Duration in UC1-Aggregation
 605 or as close as 0.17% time difference. The farthest distance between GCP and
 Alibaba is 65.97% in UC2-PageRank.

On the other hand, the Relative Performance Rates in Table 5 and Table 6
 depicts numerous samples where Azure's performance falls back the best dura-
 tion by more than 100%, meaning that performing at least two times slower in
 610 the respective benchmarks. A possible reason for the -170.20% and -134.16%
 low performances in UC1's Dfsioe's and -185.76% and -80.57% low performances
 in UC2's Dfsioe's might be the replacement of the native Hadoop filesystem by
 Azure blob. HDI performances for SQL benchmarks (Scan, Join, and Aggre-
 gation) move between -103% and -121% in UC1, whereas in UC2, a better
 615 performance moving along -13% and -28% occurs. Another contradictory case
 for Azure is in its ML performances, especially in gigantic data scale where for
 Bayes it low performs at -135.31% whereas for Kmeans it almost scores the best
 performance, getting the second place by a performance slightly less than -0.20%
 with respect to the shortest duration. Why is it so? Our attempt to understand
 620 this situation consists of digging into execution plans of the benchmark tasks,
 which are generated initially by Hadoop during execution but also captured and
 stored by HiBench inside the Reports folder. Table 7 and Table 8 comprising
 the allocated map and reduce slots by their respective Hadoop cluster for the
 relevant benchmarks.

Table 5: Use Case 1 Relative Performance Rates
Data Scale: Huge

Benchmark	First	Second	-Perf.%	Third	-Perf.%
Sort	GCP	Alibaba	-58.57%	Azure	-87.14%
Terasort	GCP	Azure	-28.64%	Alibaba	-58.02%
Wordcount	Alibaba	GCP	-10.01%	Azure	-65.35%
Dfsioe-r	Alibaba	GCP	-20.00%	Azure	-170.20%
Dfsioe-w	Alibaba	GCP	-34.88%	Azure	-134.16%
Scan	GCP	Alibaba	-1.37%	Azure	-115.07%
Join	Alibaba	GCP	-3.43%	Azure	-103.43%
Aggregation	GCP-Alibaba	—	—	Azure	-121.65%
Bayes	GCP	Alibaba	-15.86%	Azure	-135.02%
Kmeans	Alibaba	Azure	-11.74%	GCP	-12.13%
Pagerank	GCP	Alibaba	-59.20%	Azure	-115.93%

Data Scale: Gigantic					
Benchmark	First	Second	-Perf.%	Third	-Perf.%
Sort	GCP	Azure	-10.07%	Alibaba	-25.31%
Terasort	Alibaba	GCP	-1.67%	Azure	—
Wordcount	Alibaba	GCP	-16.84%	Azure	-56.80%
Dfsioe-r	Alibaba	GCP	-38.64%	Azure	-185.76%
Dfsioe-w	Alibaba	GCP	-27.08%	Azure	-80.57%
Scan	Alibaba	GCP	-12.29%	Azure	-26.29%
Join	Alibaba	GCP	-0.17%	Azure	-28.11%
Aggregation	GCP	Alibaba	-8.03%	Azure	-13.58%
Bayes	GCP	Alibaba	-18.93%	Azure	-135.31%
Kmeans	Alibaba	Azure	-0.20%	GCP	-12.57%
Pagerank	GCP	Azure	-40.71%	Alibaba	-65.97%

Table 6: Use Case 2 Relative Performance Rates

Benchmark	First	Second	-Perf.%	Third	-Perf.%
Sort (t)	Alibaba	GCP	-12.50%	Azure	-115.63%
Sort (s)	Alibaba	GCP	-16.13%	Azure	-125.81%
Sort (l)	GCP-Alibaba	—	—	Azure	-92.86%
Sort (h)	GCP	Alibaba	-52.86%	Azure	-101.43%
Sort (g)	GCP	Azure	-0.72%	Alibaba	-27.23%
Wordcount (t)	Alibaba	GCP	-22.58%	Azure	-119.35%
Wordcount (s)	Alibaba	GCP	-6.38%	Azure	-108.51%
Wordcount (l)	Alibaba	GCP	-7.50%	Azure	-124.17%
Wordcount (h)	Alibaba	GCP	-7.21%	Azure	-67.45%
Wordcount (g)	Alibaba	GCP	-13.07%	Azure	-54.09%
(t): tiny, (s): small, (l): large, (h): huge, (g): gigantic					

Table 7: Allocated map and reduce slots in SQL benchmarks of Use Case 1

Benchmark	GCP		Azure		Alibaba		Ref.
	Maps	Reduces	Maps	Reduces	Maps	Reduces	
Scan * (h)	24	—	12	—	24	—	<i>Fig.15</i>
Scan * (g)	144	—	36	—	144	—	<i>Fig.16</i>
Join (h)	60	25	48	25	60	25	<i>Fig.17</i>
Join (g)	180	25	72	25	180	25	<i>Fig.18</i>
Aggregation (h)	24	12	12	12	24	12	<i>Fig.19</i>
Aggregation (g)	144	12	36	12	144	12	<i>Fig.20</i>
(h): huge, (g): gigantic							
* No reduce operation							

Table 8: Allocated map and reduce slots in Use Case 2

Benchmark	GCP		Azure		Alibaba		Ref.
	Maps	Reduces	Maps	Reduces	Maps	Reduces	
Sort (t)	11	12	12	12	11	12	<i>Fig.29</i>
Sort (s)	11	12	12	12	11	12	<i>Fig.30</i>
Sort (l)	12	11	12	12	11	11	<i>Fig.31</i>
Sort (h)	24	12	12	12	23	12	<i>Fig.32</i>
Sort (g)	251	12	60	12	252	12	<i>Fig.33</i>
Wordcount (t)	11	12	12	12	11	12	<i>Fig.34</i>
Wordcount (s)	12	11	12	12	12	11	<i>Fig.35</i>
Wordcount (l)	24	11	12	12	23	12	<i>Fig.36</i>
Wordcount (h)	250	11	60	12	252	12	<i>Fig.37</i>
Wordcount (g)	2447	12	612	12	2447	11	<i>Fig.38</i>

(h): huge, (g): gigantic

6. Conclusion and Future Work

Managed Hadoop systems are by CSPs provided cloud service proposals comprising pre-installed and pre-configured Hadoop clusters in order to eliminate the hard work on planning and installing Hadoop clusters manually on VM instances hence reducing the cluster installation to a matter of property selection and letting end users focus only to applications that will run on the cluster. As managed systems come in a black-box nature, respective pre-configurations and their impacts on the cluster performance remains unclear to the end-user. In the study, we conducted HiBench benchmarks against Hadoop clusters on PaaS in their proposed form as they come out-of-the-box, provided by respective CSPs. For each CSP, among the proposed installation specifications, we selected the same geographical location as region and by-promise apparently the same CPU and Memory properties. Our aim is to compare those systems' performance behaviors by leveraging HiBench Benchmark Suite. We executed Hadoop related benchmarks on all three Hadoop on PaaS services and captured system resource utilization data in the meanwhile. The results yield that Hadoop PaaS

offerings by vendors' promise do not necessarily utilize system resources in similar ways hence may highly distinct in some cases. Our assumption is that the pre-configuration choices applied by CSPs impact performance result even with apparently the same hardware settings. The end-users shall be aware of their use cases' requirements and truly understand what CSPs configuration proposals and their respective outcome.

Based on the gained experience, the study might be varied in an approach more sensitive in balancing small performance differences among CSPs. As HiBench offers benchmarks for Spark, graph, and streaming frameworks as well, the comparison can be made from within the respective perspective, also putting other global CSP players into the scope.

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