TOP 10 CLOUD
IaaS Providers Benchmark

2017 NORTH AMERICAN REPORT

Price-Performance Analysis of the Top 10 Public IaaS Providers

CLOUD SPECTATOR

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INTRODUCTION

A public cloud service provider (CSP) offers instantaneous, scalable virtual infrastructure with utility billing. While the public cloud IaaS industry streamlines IT through these advantages, a lack of standardization in performance can lead to businesses overspending in order to obtain the necessary performance requirements for their applications.

Cloud Spectator set out to test 10 of the largest, most well-known public cloud providers with data centers in North America. This report measures and ranks CSPs using a comprehensive performance and price-performance methodology designed by Cloud Spectator specifically for the purpose of measuring cloud environments. The study documented in this report examines the performance of vCPU, memory, and block storage as well as the value (the CloudSpecs™ Score) as defined by the relationship between price and performance.

In conjunction with a proper process for cloud vendor selection, this report serves to assist in the purchasing decision by assessing performance and price-performance in a holistic, industry view. The report is specifically designed to educate readers on the variation in performance and price-performance value across public cloud providers. Performance is a critical and often overlooked component when making a cloud purchase decision, but can have substantial impact on annual operating costs.

WHY IS THIS INFORMATION NECESSARY?

A lack of transparency in the public cloud IaaS marketplace for performance often leads to misinformation or false assumptions. Users and potential users may be led to view cloud computing as a commodity, differentiated mostly by services. The reality of performance in cloud computing impacts the user differently from CSP to CSP, involving everything from the physical hardware (e.g., Intel or AMD, SSD or spinning disk), to the cost of the virtualized resources. By identifying environments based on performance rather than resource count, users are able to maximize value in the cloud.

MISCONCEPTIONS ABOUT PERFORMANCE IN CLOUD

1. VM performance is the same from CSP to CSP.

While CSPs often use the same terms to label resources (i.e., vCPUs, RAM or memory, and block storage), differences in the underlying hardware, architecture, and performance tuning lead to entirely different results from the same terms such as vCPUs. For example, on VM performance alone (the virtual processor and memory), the 10 IaaS providers in this report exhibited differences of up to 1.9x. With block storage performance, differences exceeded 18x.

2. For performance, you get what you pay for.

When it comes to additional services such as support, security, geographical location, and managed services on CSPs, this may be true; however, regarding performance, this study found no correlation between price and performance. The study demonstrated the best-value CSPs in this report (defined as the ratio of price and performance as ranked by the CloudSpecs Score™) offer virtualized resources at the lowest prices. Similarly sized VMs within the 10 IaaS providers

tested displayed a spectrum of prices with up to a 5.8x difference between the least and most expensive CSPs.

3. Resource contention, known colloquially as the Noisy Neighbor Effect, is not a concern with most providers.

A public cloud environment offers multi-tenant physical hosts, which means a business may share the same physical resources with different users on the same hardware. With a lack of understanding of other users' activities, resource-hogging applications can affect the performance of other VMs on the host machine. While resource contention has been addressed by many of the largest providers in an attempt to stabilize VM performance, the block storage offerings still exhibit high levels of performance fluctuations, which may be related to other activity on the same physical host as Cloud Spectator's test VMs. The fluctuation in performance evidenced in some CSPs can significantly affect hosted applications within those environments.

3a. If Noisy Neighbor is a concern, then performance is too unpredictable.

In public cloud environments, some providers, especially major ones such as Microsoft Azure and Amazon Web Services, use performance throttling to deliver a consistent user experience regardless of the actual user load on the physical machine. This means that, while performance may be lower for the VM, the user will not see much change over time. See Performance by VM Size to view the performance variation of different CSPs over the 24-hour period of the study (on disk performance, Google Compute Engine, OVH, and IBM SoftLayer demonstrated very stable performance).

EXECUTIVE SUMMARY

INTRODUCTION

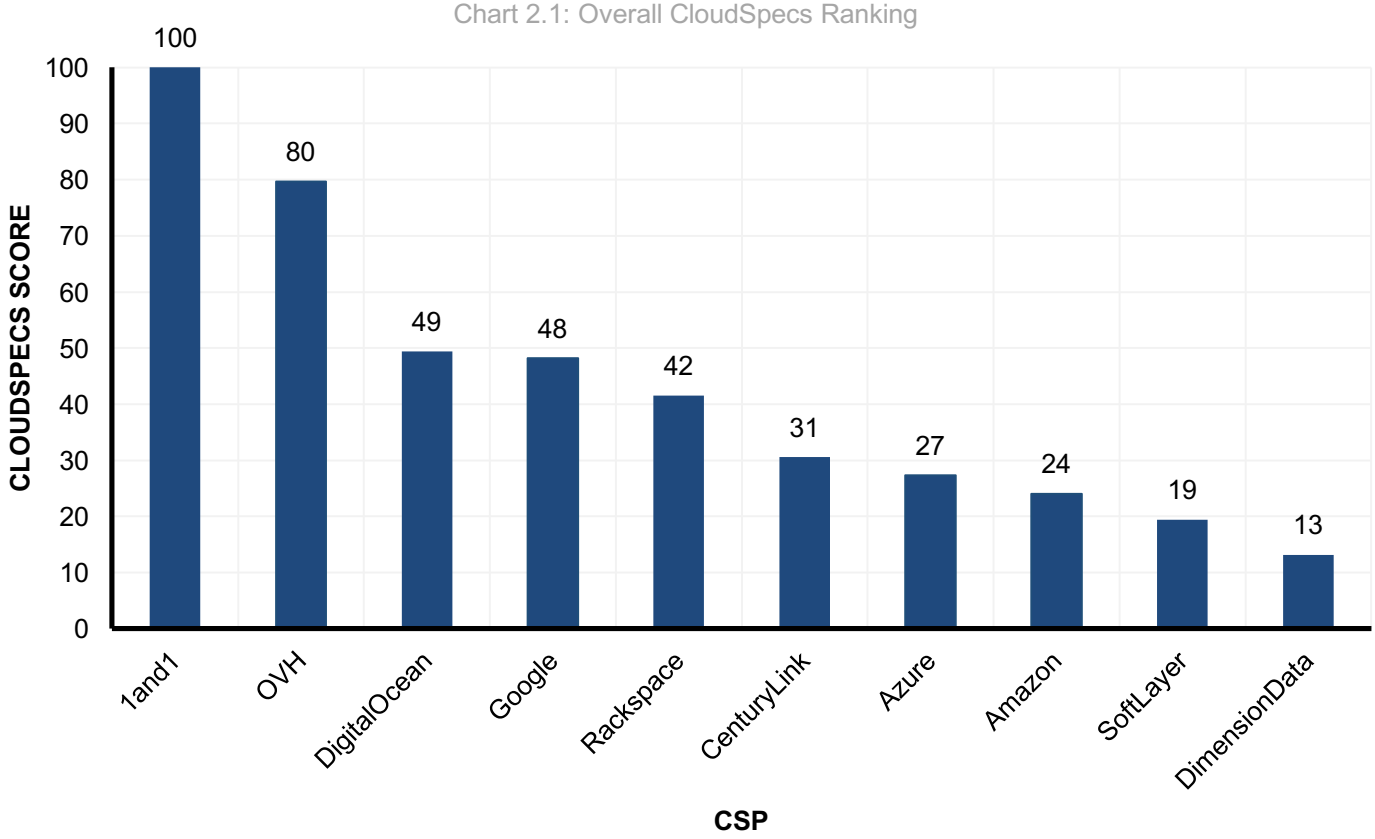
This report examines the results of a study measuring and comparing the performance and price-performance value of 10 CSPs within the North American region. While the CSPs included in the study did not have to be headquartered in North America, they must have at least one data center located within the North American continent (see Methodology page 11).

The list of 10 CSPs included major providers like Amazon AWS, Google Compute Engine, Microsoft Azure, and IBM SoftLayer. Smaller CSPs, some of which specialize in high performance and aggressive pricing, can achieve higher CloudSpecs Scores™.

The performance results are separated into two categories: VM Performance and Block Storage Performance. VM Performance tests the CPU and memory of the virtual machine. This performance data is aggregated into one score including both CPU and memory. Block storage is tested using two different tests detailed in the methodology section (page 11).

PRICE-PERFORMANCE KEY FINDINGS

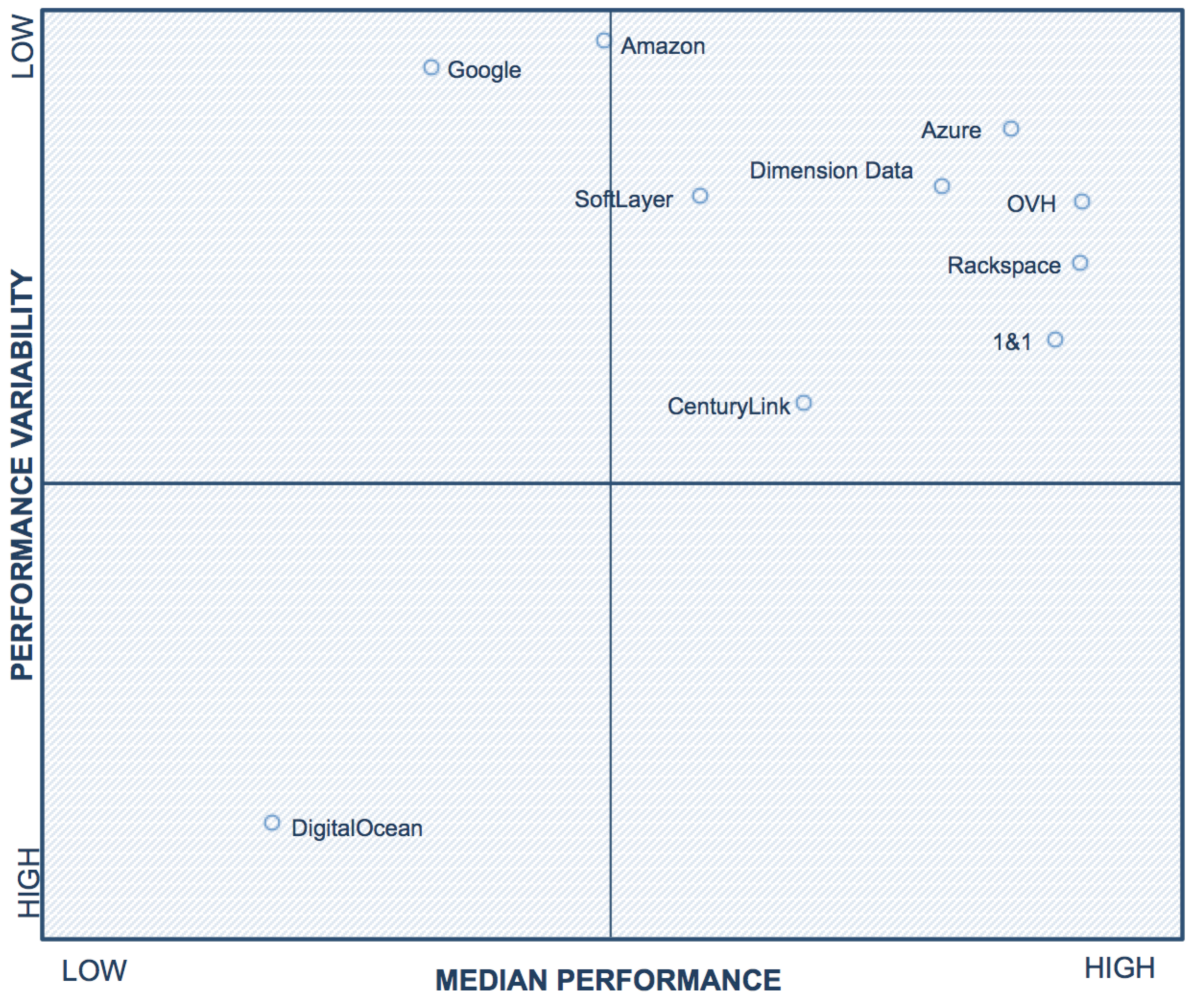
Chart 2.1: Overall CloudSpecs Ranking



- Value, defined as the ratio of price and performance (see Methodology page 16) varies by 7.7x across the compared IaaS providers.
- 1&1 achieves the highest CloudSpecs Score™ in the Top 10 cloud IaaS providers ranking. This is due to strong VM performance and the most inexpensive packaged pricing found in the study.
- While certain providers such as Rackspace may have achieved above-average performance for VM environments, the price-performance value achieved by those types of providers were lower due to higher costs. This study does not account for additional features such as managed services, which are included in Rackspace's pricing.

VM PERFORMANCE KEY FINDINGS

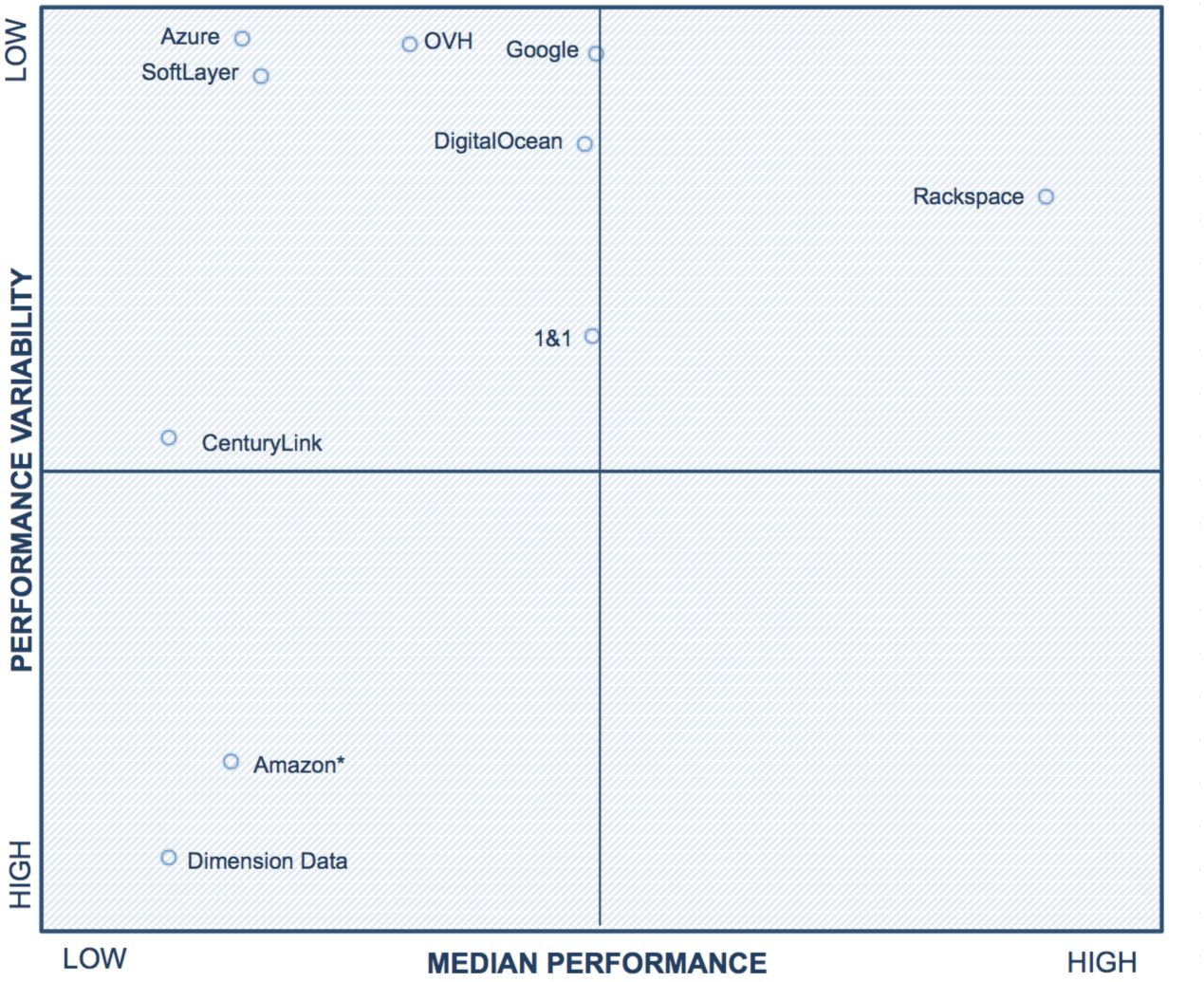
Chart 2.2: VM Performance and Variability Over 24 Hours



- In certain scenarios, providers exhibited a difference of almost 2x in VM (CPU & memory) performance, emphasizing the need for performance testing to understand value.
- The differences in performance across the Top 10 providers illustrate a lack of standardization in public cloud IaaS. Overall, Microsoft Azure's VMs (Performance Index score of 92 with 2% variability) demonstrated the highest median performance and lowest performance variability, while DigitalOcean's VMs demonstrated the lowest median performance and highest performance variability (Performance Index score of 60 with 16% variability) in the study.
- Amazon AWS, Microsoft Azure, and Google Compute Engine showed the least performance variability in the 24-hour testing period.

BLOCK STORAGE PERFORMANCE KEY FINDINGS

Chart 2.3: Block Storage Performance and Variability Over 24 Hours



*Amazon's disk variability is artificially high due to an initial burst period that lasted until the volume ran out of I/O credits.

- Dimension Data's disk performance variability exceeded 66% in certain scenarios.
- Microsoft Azure showed the lowest performance variability over the testing period. Amazon AWS demonstrated controlled performance throttling on disk IOPS as well. The level of throttling on AWS EBS disks is determined by the size of the disk. The high amount of variability on AWS is due to a burst function that is built in to EBS and is not representative of an unstable environment.
- Rackspace tested highest in median disk IOPS performance with moderate performance variability at 12%.

Table 2.1: Performance and Variability of CSPs Over 24 Hours

	VM		Block Disk	
	Performance Index	Variability	Performance Index	Variability
1&1	94	6%	49	21%
Amazon*	75	1%	17	49%
Azure	92	2%	18	2%
CenturyLink	83	8%	11	28%
DigitalOcean	60	16%	48	9%
Dimension Data	89	3%	11	55%
Google	67	1%	50	3%
OVH	96	4%	33	2%
Rackspace	95	5%	90	12%
SoftLayer	79	4%	20	4%

*Amazon's disk variability is artificially high due to an initial burst period that lasted until the volume ran out of I/O credits.

Table 2.1 lists the indexed performance scores and variability percentages by CSP. These numbers are used in generating Charts 2.2 and 2.3.

The Performance Index is calculated by indexing the individual performance scores achieved by each VM category (categorized as Small, Medium, Large and Extra Large; see Methodology for more information) on a scale of 0-100 with 100 as the highest possible score. An average across all VM categories is calculated to represent the Performance Index for each provider.

Variability is calculated as the average coefficient of variation (CV), which is the standard deviation expressed as a percentage of the mean performance for the VM categories of each CSP. Higher CV correlates to more fluctuation in performance (i.e., higher performance variability) over the test period.

METHODOLOGY

The Cloud Spectator team designed this methodology to measure the performance of various public cloud infrastructure services. These results will provide a general insight into the public cloud industry; however, businesses have varying needs when defining performance requirements, so businesses should apply testing methodologies relevant to their business and technical use cases to yield more relevant results.

THE CRITERIA

In order to be considered and tested as one of the IaaS providers in this report, a CSP must deliver the following as part of its IaaS offering:

1. The CSP must have at least one data center located within the North American continent. The CSP does not need to be headquartered in North America.
2. Self sign-up: a user must be able to sign up for a CSP's services online, rather than reaching out to a sales representative. Contact forms that request users to message the CSP for signup are not considered self sign-up.
3. Self-service: a user must be able to log into a portal that allows the user to provision, manage, and terminate virtual machines and other cloud-related services.
4. Hourly billing intervals: the CSP must provide billing by the hour or less. Some CSPs offer billing by the minute.
5. Only providers with persistent block storage offerings are included in this study. Cloud Spectator measured disk performance by running performance tests on block storage.

THE SETUP

The team set up anonymous accounts on all cloud service providers. No CSPs provided the team an account to provision virtual machines. For all VMs, Ubuntu 14.04 images were operating systems of choice. In cases when Ubuntu 14.04 was not available, 12.04 was used; if no Ubuntu images were available, Debian was used. Virtual machines were tested according to four separate categories: Small, Medium, Large and Extra-Large. Each category contained a prerequisite allocation of VM resources.

Table 4A: VM Sizing

SIZE	vCPU COUNT	RAM COUNT (GB)	DISK SIZE (GB)
Small	2	4	100
Medium	4	8	150
Large	8	16	200
Extra Large	16	32	500

CSPs were segmented into two categories: (1) Packaged Offering CSPs and (2) Customizable Offering CSPs. Packaged Offering CSPs include providers such as Amazon AWS and Microsoft Azure, which deliver VMs based on pre-packaged sizes; for example, a customer can purchase an Instance size of c4.xlarge on AWS. Customizable Offering CSPs allow users to define custom VM sizes by setting resources such as vCPUs, RAM, and disk space. Only block storage was tested for disk because of its durability and persistence. This meant that CSPs that only offer local storage were not included in the report. A single block storage size was paired and tested with each VM size. For other CSPs such as Amazon AWS, which offers local and persistent block storage, the local storage was not measured and did not affect the performance or price-performance ranking of the CSP beyond the potential effect on pricing if local storage is included in packaged VM prices. **Please see the Appendix for a specific list showing what was tested on which providers.**

For Packaged Offering CSPs, the team selected VMs that most closely corresponded to the four categories of sizes. For Customizable Offering CSPs, the team provisioned servers designed to the exact requirements of the four categories of sizes when possible.

For each CSP, the team provisioned three copies of VMs for each size; i.e., three Small, three Medium, three Large, and three Extra-Large VMs were provisioned. All VMs were provisioned and tested simultaneously for 24 hours. This means that, for each CSP, twelve various-sized VMs were running from the account on the corresponding provider for 24 hours.

Please note that some CSPs do not offer any VMs with resource allocations that would qualify for the Extra Large size.

SIMULTANEOUS TESTING OVER TIME

Three resources were examined to compare performance: vCPU, memory, and storage. Performance tests were run in continuous, iterative sequence according to the following order: vCPU tests and memory tests followed by block storage tests. Each complete sequence of testing comprised a single cycle, and cycles repeated without pause for the duration of 24 hours. Different providers completed varying numbers of cycles within the 24-hour time limit, and the number of cycles completed was impacted by the performance levels of the resources tested (higher performance allows each test to be completed faster).

Testing over several iterations impacted the ranking of performance for CSPs. In an uncontrollable multi-tenant environment, VM performance can be affected by issues that arise with neighboring VMs. While these issues may be mitigated with resource planning as a responsibility of the CSP, sometimes performance levels cannot be guaranteed or sustained in the public cloud; therefore, measuring to examine sustainable performance is just as important on a public cloud as measuring to

examine achieved performance. This is why the Cloud Spectator team chose to test over a period of 24 hours.

Three VMs of each category size were tested in parallel. Single-VM performance may not necessarily be reflective of the potential performance a CSP's VMs can achieve if the provisioned VM is faulty for any number of reasons. Measuring more than a singular VM of each size mitigates the possibility that the performance may be an unusual outlier due to a VM provisioning issue, so results are a more accurate reflection of a VM type's potential performance.

At other times, the physical host itself may experience issues, affecting all VMs residing on it. By provisioning all VMs simultaneously, Cloud Spectator may increase the possibility of measuring on multiple physical hosts with different users and resource contention issues, which would be more representative of a VM size's performance. While all of these processes are implemented to increase the accuracy of the measurements, it should be noted that these practices cannot guarantee 100% accuracy. Even by provision three of the same VMs of each category, the VMs still have the possibility of residing on the same physical host depending on the provider's capacity.

DATA COLLECTION

Throughout the 24-hour period of testing across all qualified and tested providers in this report, a total of 1,503,285 data points were collected to measure and compare performance variation. Testing was conducted in January, 2017.

The rankings were produced based on the CloudSpecs Score™, which is a price-performance ratio of the cost and median performance output of the VM. Each VM size category received a VM CloudSpecs Score™ and a block storage CloudSpecs Score™, which were averaged to calculate a

CloudSpecs Score™ for the VM. The CSPs with the highest average CloudSpecs Scores™ across all VMs were then ranked. All 10 tested CSPs were ranked according to price-performance.

TESTING USED

Table 4B: Testing Tools

TEST	TOOL	TASKS
vCPU Testing	Geekbench 3	Integer and Floating Point
Memory	Geekbench 3 (using STREAM)	Reads and writes
Block Disk	Fio	Reads and writes

vCPU and Memory

vCPU performance was measured with integer and floating point tasks from the Geekbench 3 benchmark suite. The Geekbench 3 benchmark suite was also used in collecting memory bandwidth data, which was used to measure the performance of the system memory (RAM).

Table 4C: Testing Specifics

CATEGORY	TYPE 1	TYPE 2
Block Size	4KB	128KB
File Size	5GB	128MB

Table 4D: Total Files Used in Block Storage Testing

SIZE	TYPE 1	TYPE 2
Small	1	2
Medium	2	4
Large	4	8
Extra Large	8	16

Storage

Storage performance was measured using fio. Two storage scenarios were run to capture performance data: Type 1 and Type 2. In both scenarios, random and sequential IOPS were recorded as the indicator of performance over a test period of 60 seconds. Type 1 used a large file size with a small block size, while Type 2 used a small file size with a large block size. The total number of files used in testing varied with the category of VM.

In both testing scenarios, the number of parallel jobs run were set equal to the number of virtual processors in the VM. Each test scenario was run for 12 hours, for a total of 24 hours.

Table 4E: Type 1 Scenario

SCENARIO	BLOCK SIZE	FILE SIZE
Type 1	4KB	5GB
Type 2	128KB	128MB

RANKING CALCULATION

The rankings of the 10 CSPs were determined by calculating the median performance of both vCPU-memory and storage with the monthly cost corresponding to each VM size for two price-performance scores per VM size (one for vCPU-memory and one for storage). The resulting ratios were normalized in relation to the highest-value provider for each resource, which receives a score of 100. Then the two price-performance scores for each VM size were averaged together to get one score per VM size. The providers were then ordered based on their value across all each VM size, and then their scores were averaged for all VM sizes to come up with a final score. The providers that sustained higher ratios across all VM categories ranked highly.

PRICE-PERFORMANCE VALUE (THE CLOUDSPECS SCORE)

Cloud Spectator's price-performance calculation, the CloudSpecs Score™, provides information on how much performance the user receives for each unit of cost. The CloudSpecs Score™ is an indexed, comparable score ranging from 0-100 indicative of value based on a combination of cost and performance. The calculation of the CloudSpecs Score™ is:

price-performance_value = [VM performance score] / [VM cost]

best_VM_value = max{price-performance_values}

*CloudSpecs Score™ = 100*price-performance_value / best_VM_value*

CPU and Memory

Cloud Spectator used the median Geekbench 3 performance scores as the [VM performance score] to calculate each machine's CPU and memory CloudSpecs Score™.

Block Storage

For both storage scenarios, median sequential r/w and median random r/w IOPS are used as the [VM performance score] to calculate each machine's Type 1 and Type 2 storage CloudSpecs Score™. Type 1 and Type 2 scores were averaged to calculate a single block storage CloudSpecs Score™.

Overall

Overall storage CloudSpecs Score™ was calculated by averaging block storage and vCPU-memory price-performance scores together so that they have equal weight for each VM size. Then, all resulting VM size scores were averaged together.

1. For block storage performance, the normalized sequential and random CloudSpecs Scores™ were averaged together. 2.
2. Then, the Type 1 and Type 2 CloudSpecs Scores™ were averaged together to create a single storage CloudSpecs™ score per VM size.
3. Then, the overall CPU, memory and storage CloudSpecs Scores™ were calculated by averaging the CPU and memory CloudSpecs Score™ and overall storage CloudSpecs Score™ for each VM size.
4. All VM size scores were then averaged for each provider and normalized to get the final scores on the scale from 1 to 100.

VARIABILITY

Variability is calculated by taking the coefficient of variation (CV) of each VM size's individual performance data points. The CVs are averaged for all VM sizes per CSP. The coefficient of variation is the standard deviation expressed as a percentage of the mean.

CONSIDERATIONS

Limitations within the Methodology

The IaaS industry lacks a standard methodology for evaluating CSPs. While the most effective methodology for measuring value of a CSP varies among use cases, the methodology developed by Cloud Spectator for this study was designed to capture performance statistics based on synthetic performance uniquely adopted for cloud infrastructure, which requires steps including extended testing over a period of time and running multiple VMs in parallel.

Furthermore, the synthetic testing conducted in this study is for measurement of maximum sustainable performance over a period of 24 hours, and is not representative of any specific workload. Therefore, the results are used for comparison purposes only, and cannot be applied to predict application performance. For example, on AWS, the gp2 block volumes demonstrated periods of burst that were limited due to the continuous bursting over the 24-hour period, but the gp2 would not be a recommended option for applications that demand the continuously high IOPS performance.

VM Sizes

The performance data in this report only applies to the tested VM and block sizes. Larger VMs may yield better results with both VM scores and block storage scores. Larger block sizes may also yield better block storage performance scores. Not all CSPs offered the Extra Large size (see Methodology page 11) for testing. In those cases, the CloudSpecs Score was calculated by averaging the three available sizes.

Pricing Calculations and Discounts

In this report, Cloud Spectator used monthly pricing to calculate the cost of VMs on providers. Some providers offer sustained-use discounts based on a monthly interval, while others discount for monthly commitments. Certain providers offer similar discounts on an annual basis or longer; these longer-term discounts were not factored into the analysis. Where available, monthly discounting was factored into the pricing calculations; therefore, for longer or shorter time commitments, the rankings may change.

The Ranking System

The 10 providers included in this report were ranked based on a calculation that considers both performance and cost of the environments. The performance results of vCPU, memory, and block storage are all included in the calculation. While some providers may exhibit high performance on vCPU, memory, and/or block storage, those CSPs may not necessarily rank highly depending on the cost of their environments as compared to their competitors.

Additional Features and Costs

Only the VM, block storage, and costs of those two components were examined in this study. Additional features, such as support costs (where applicable), public and private networks, traffic, and other services that may increase the overall cost of a CSP's offering, were not examined in the report. Depending on the types of use cases, the features not examined may impact the overall rankings. However, if a user can select between different base infrastructure options that have a difference in performance (e.g. SSD vs. magnetic storage), the options yielding higher performance outputs were chosen with exception to the pay-to-scale IOPS option, such as Provisioned IOPS. The amount and cost of the pay-to-scale IOPS option can affect a provider's ranking.

DATA CENTER LOCATIONS

All VMs were provisioned in the North American data centers of each CSP. Specific locations, as described by each CSP, are listed in Table 4E.

Table 4F: Data Center Locations

Provider	Data Center Location
1&1	US
Amazon	US East
Azure	US East 2
CenturyLink	Virginia
DigitalOcean	New York
Dimension Data	US East
Google	US East
OVH	BHS
Rackspace	Northern Virginia
SoftLayer	Washington DC

PRICE-PERFORMANCE VALUE

This section examines the price-performance value (i.e., the CloudSpecs Score™) of the 10 IaaS providers, which is used in determining each CSP's ranking in this report. The CloudSpecs Score™ is calculated as the ratio between the price, defined as the monthly cost of the VM and block storage, and median performance of the VM and block storage. For more information on the calculation of the CloudSpecs Score™, please see the Methodology.

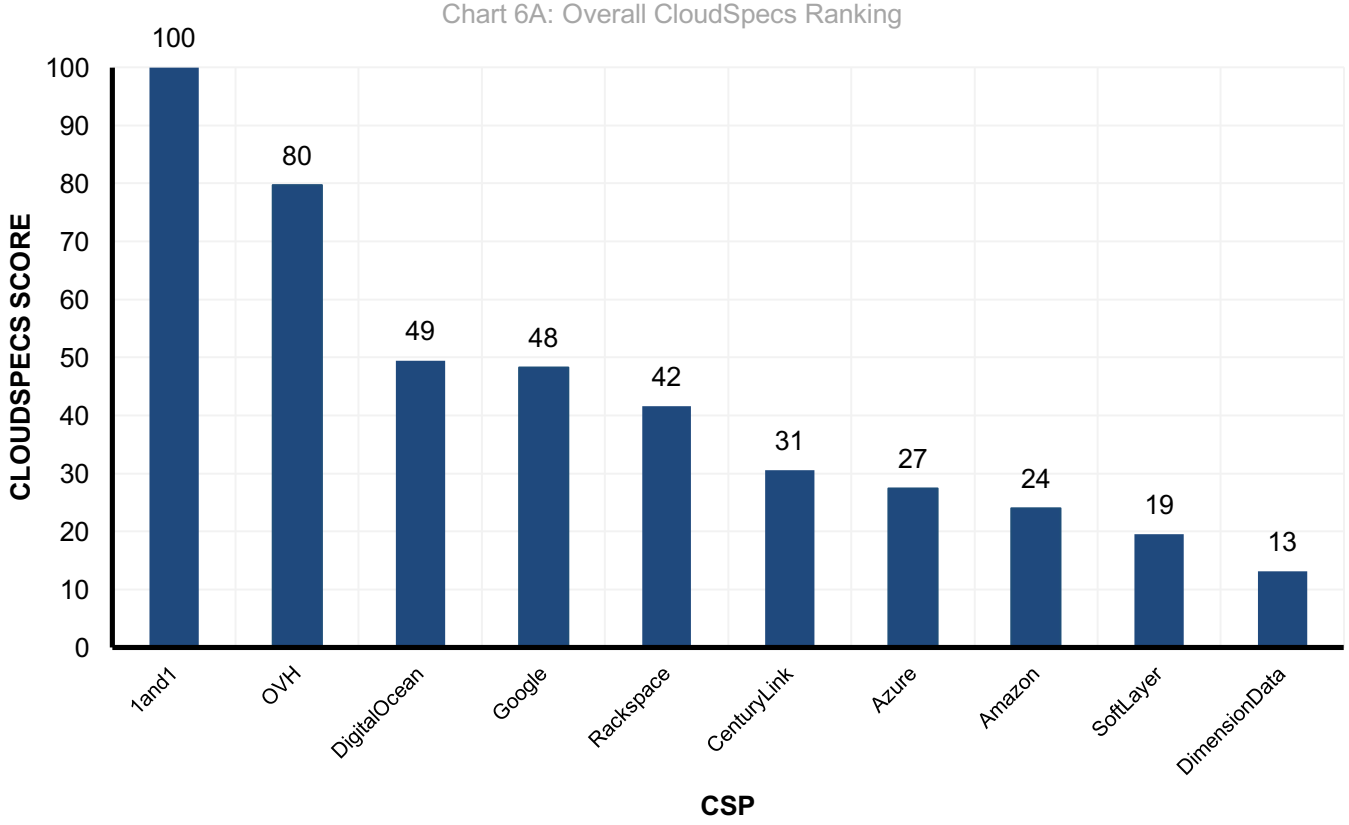
1&1's Cloud Server achieves the highest CloudSpecs Score™ in this study (a CloudSpecs Score of 100). CSPs such as Rackspace, which achieved high performance scores in the previous section, ranked lower overall due to higher costs of infrastructure.

OVERALL CLOUDSPECS RANKING

The ranking of the Top 10 CSPs based on CloudSpecs Score™ is displayed in Chart 6A.

Value based on price-performance in this study is ranked in relation to the highest-value CSP, 1&1. A difference in value of 7.7x exists between 1&1, the highest-ranked CSP, and Dimension Data, the lowest-ranked CSP in the Top 10.

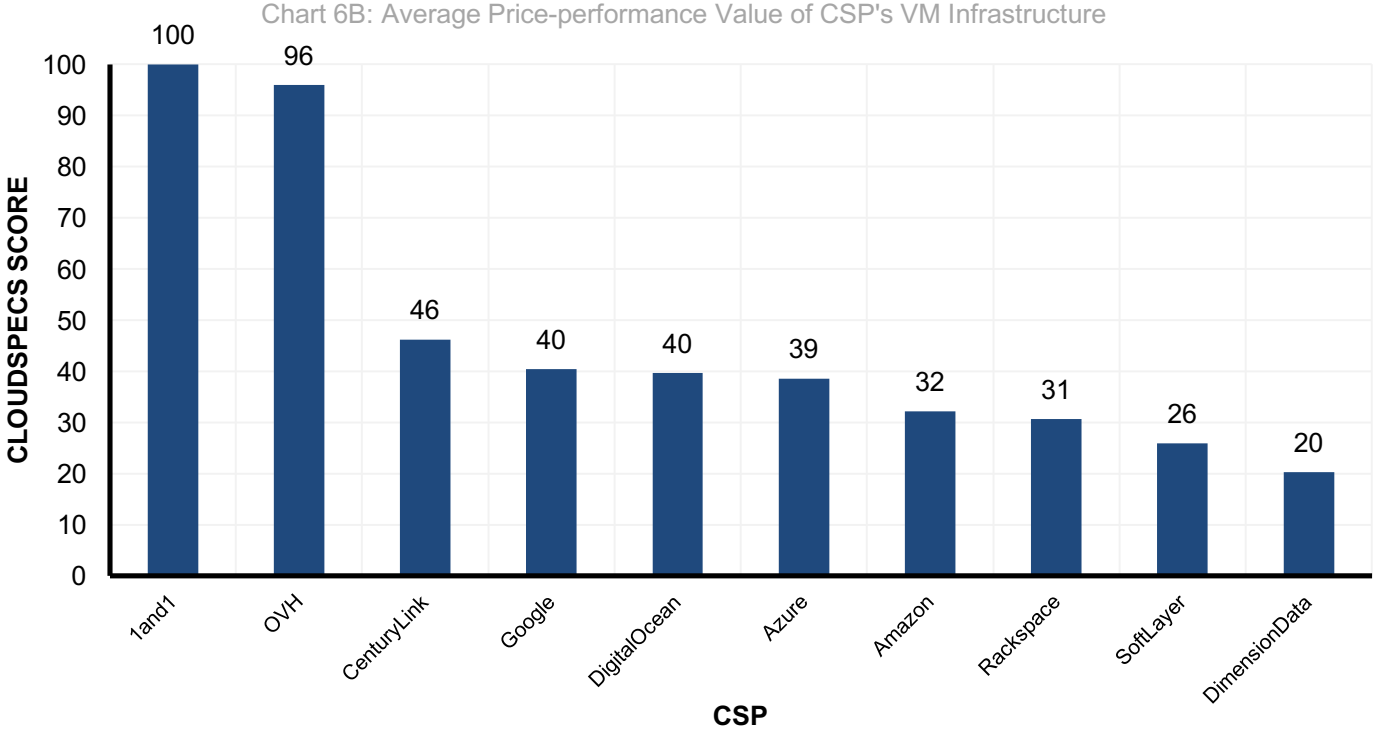
Chart 6A: Overall CloudSpecs Ranking



The following sections (vCPU and Memory Value and Block Storage Value) illustrate the individual Value scores segregated by section, which are the scores used to calculate the overall CloudSpecs ranking. 1&1 achieves the highest CloudSpecs ranking in both the vCPU and Memory Value category as well as the Block Storage Value category.

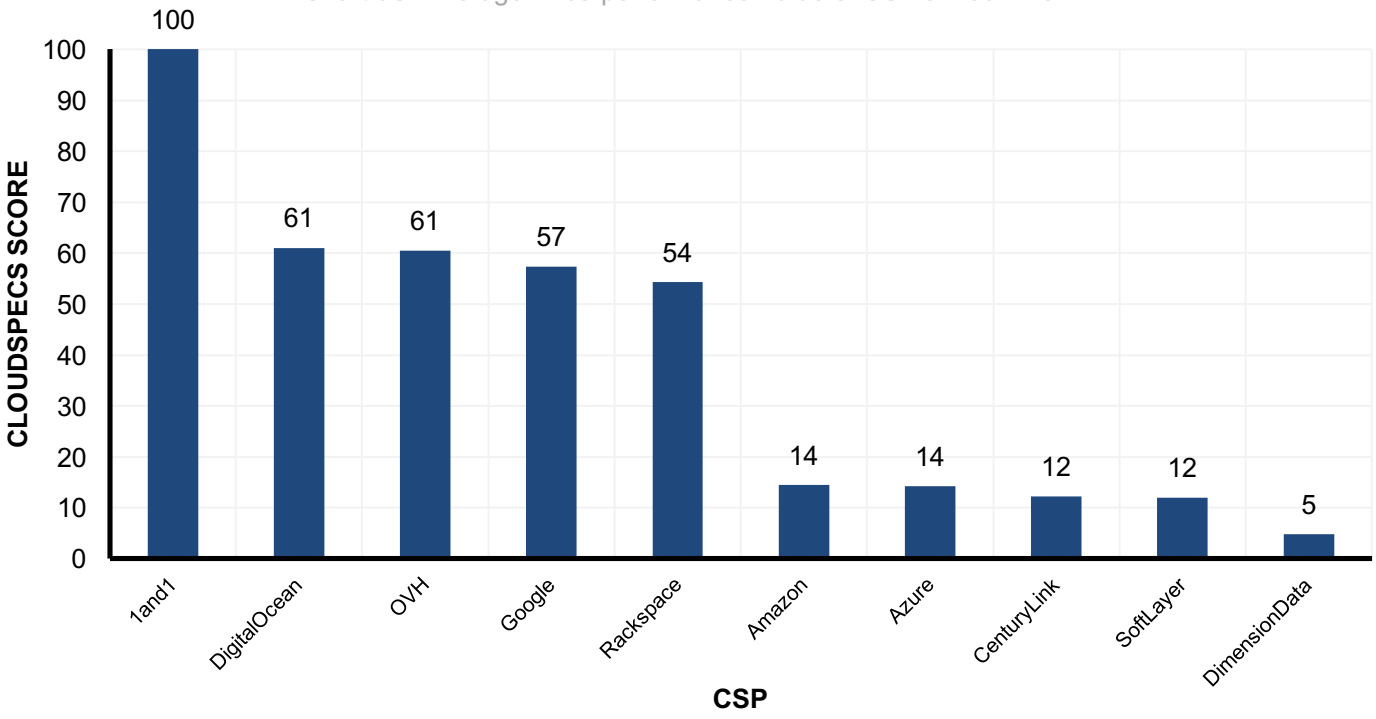
VCPU AND MEMORY VALUE

Chart 6B: Average Price-performance Value of CSP's VM Infrastructure



BLOCK STORAGE VALUE

Chart 6C: Average Price-performance Value of CSP's Block Disk



PERFORMANCE

This section examines the performance of the 10 IaaS providers ranked in this report. This section does not use the CloudSpecs Score™, which is used to rank providers and can be found in the Price-Performance section of the report.

The period of 24-hour testing across 3 parallel machines for each category of VMs demonstrated much higher overall stability of performance in the vCPU and memory components for all providers, as compared to block storage performance over the same period. Performance differences are more noticeable as VMs scale up in size (e.g., the XL size), although a noticeable difference exists in the small VM category as well.

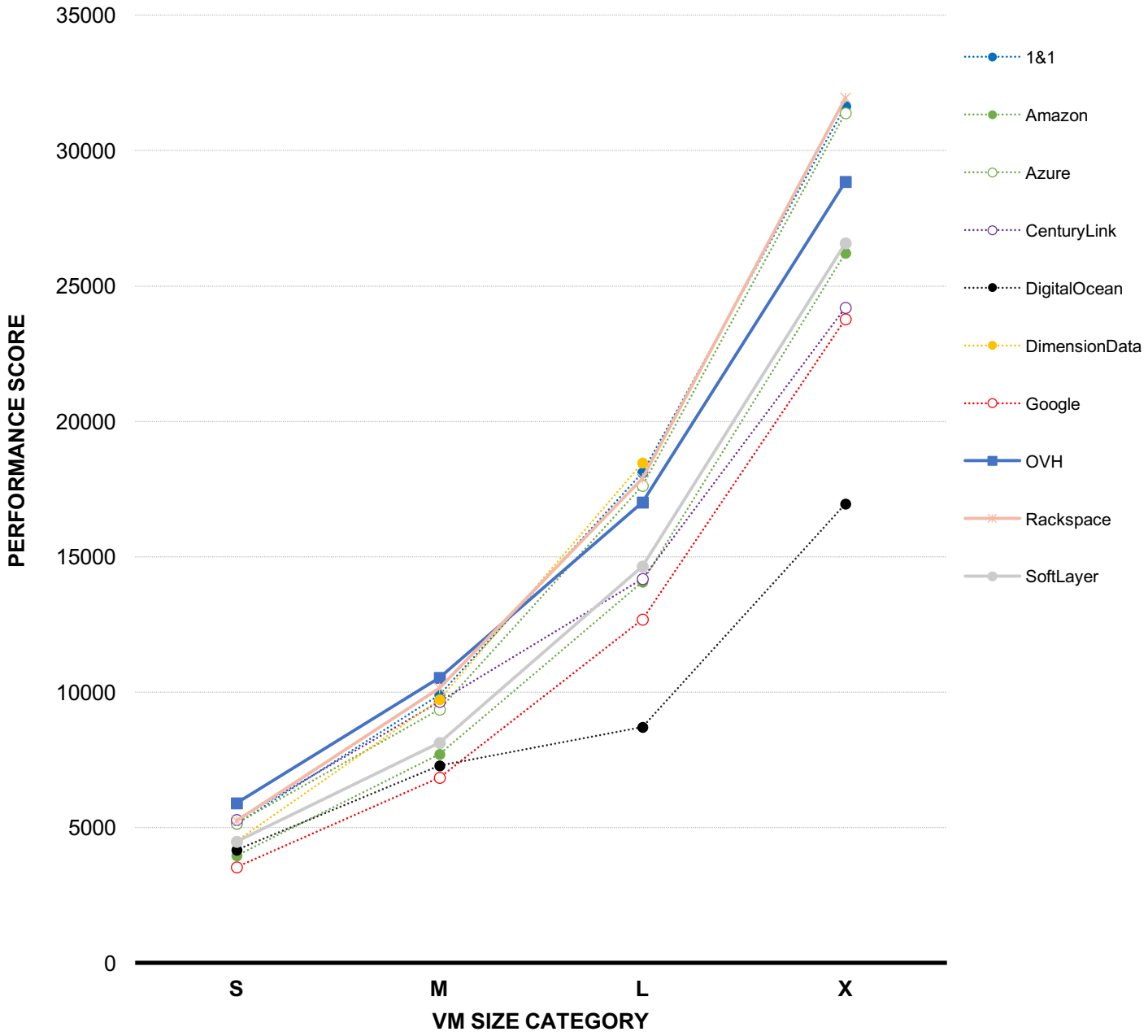
For detailed information on performance scores by VM size, see Performance by VM Size on page 32.

VCPU AND MEMORY PERFORMANCE

Performance differences between CSPs on vCPU and memory increase with the size of the VM:

- The Small VM category exhibits a difference of 1.7x between the highest and lowest-performing CSP VMs.
- The Extra Large VM category exhibits a difference of 1.9x between the highest and lowest-performing CSP VMs.

Chart 5A: vCPU and Memory Performance (Median Scores Displayed)



BLOCK STORAGE PERFORMANCE

Because the relationship in performance between providers remained similar with both the random and sequential operations, only results from the sequential tests are displayed in this section. Detailed results and random results can be found in the Performance by VM Size on page 32. Each varying disk size corresponded with a VM category (see Methodology page 11). Two disk scenarios were measured: Type 1 and Type 2. More information on the two scenarios can be found in the Methodology (page 11).

- Block storage is not created equally across CSPs in regards to hardware, architecture, or performance. A difference of more than 18x can exist between highest and lowest-performing block storage offerings across CSPs.
- While Amazon AWS's Small, Medium, and Large VMs show performance fluctuation, the variance is controlled. On AWS, block storage is allocated a limit of burst-performance time; the limit is dependent on the size of the block storage volume—the larger the volume, the longer the limit for burst performance. After the burst time limit expires, performance is throttled also based on the size of the volume. The burst-limit on volumes smaller than 1TB is 3,000 IOPS. The extra-large block volume on AWS shows no performance variance, indicating the stability of AWS block storage. The burst-model on AWS block storage is specific to the gp2 type. Other models of block storage can yield higher performance without burst, such as the Provisioned IOPS offering. Provisioned IOPS demonstrates a similar level of high stability in performance.

Chart 5B: Scenario Type 1 - Sequential Performance (Median Scores Displayed)

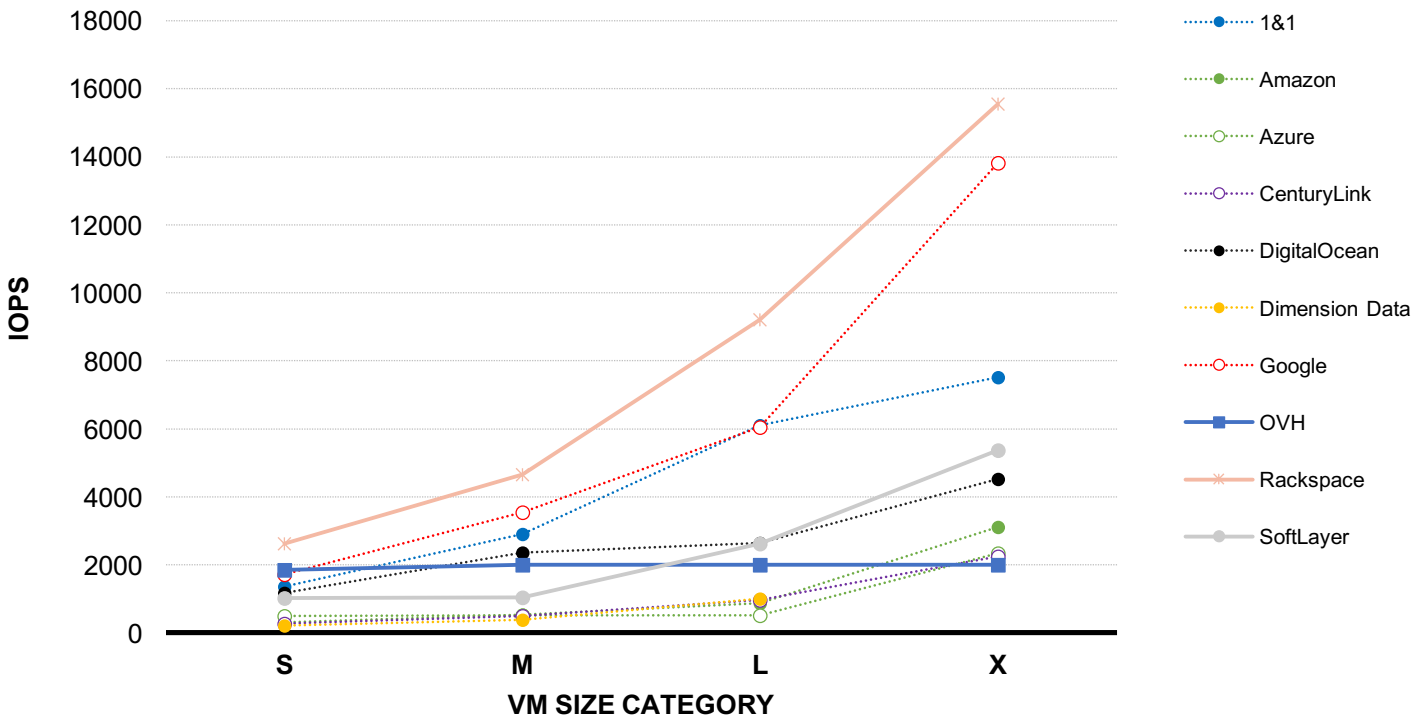
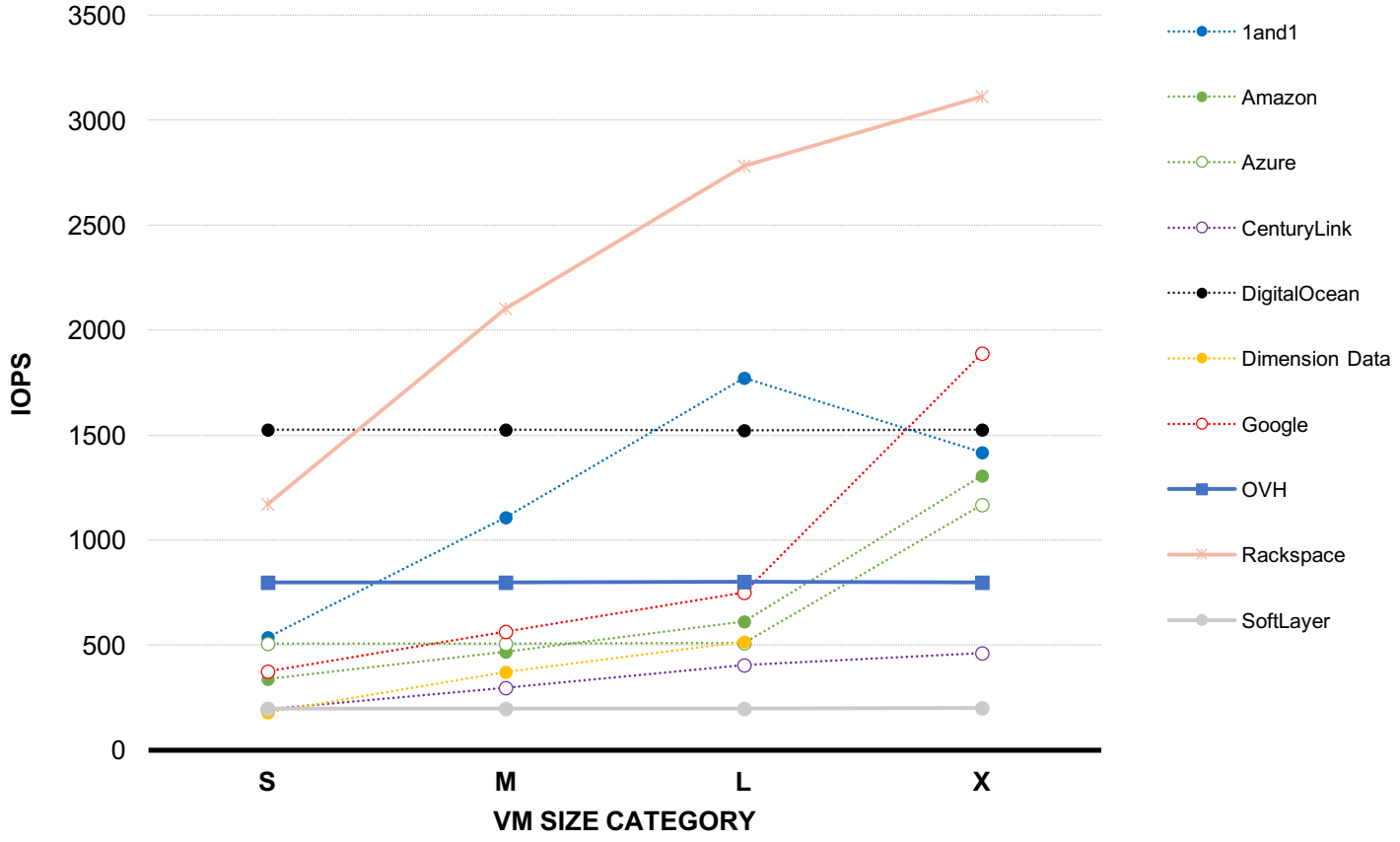


Chart 5C: Scenario Type 2 - Sequential Performance (Median Scores Displayed)



PRICING

This section outlines the cost of the VMs and block storage for each size examined in the study across all CSPs. Additional services, unless required (such as Rackspace Managed Services), are not included in the final cost of the VMs. Only the cost of the VM and tested block storage were factored into the final cost. Please keep in mind that some providers may charge for add-on services such as support, while other providers include it into the cost of the VMs.

OVERALL PRICING

The final monthly cost of each VM category for each CSP is calculated as the cost of the VM and the cost of the attached block storage. 1&1 and OVH maintained top ranks as the least-expensive providers in the price ranking. While DigitalOcean offers lost-cost VMs, its extra-large VM is more expensive than the alternatives on Google Compute Engine and CenturyLink Cloud.

Chart 7A: Monthly Cost of VMs Across CSPs

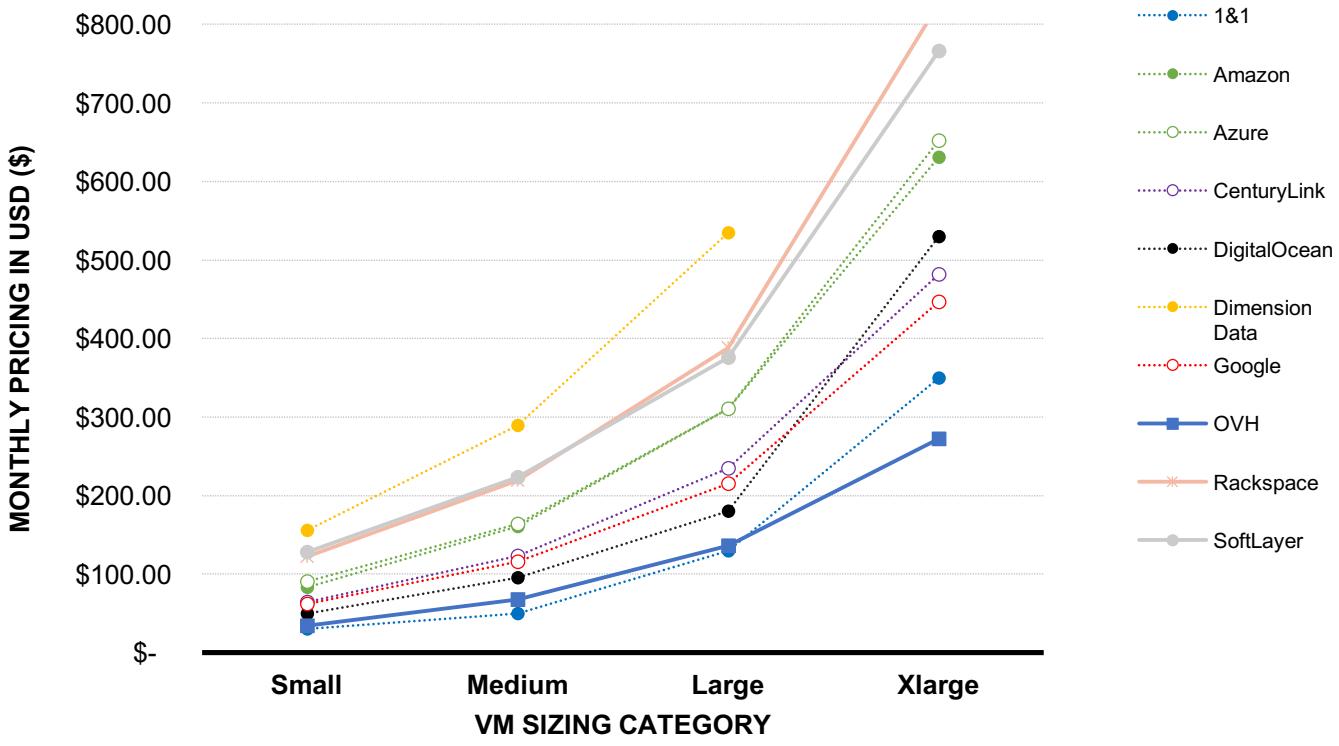


Table 7A: Monthly Cost of VMs Across CSPs

	Small	Medium	Large	Extra Large
1&1	$29.99	$49.99	$129.99	$349.99
Amazon	$83.00	$160.27	$310.54	$631.08
Azure	$90.19	$163.92	$310.65	$652.02
CenturyLink	$64.75	$123.41	$234.62	$481.44
DigitalOcean	$50.00	$95.00	$180.00	$530.00
Dimension Data	$155.49	$289.08	$534.36	
Google	$62.24	$115.98	$214.96	$446.92
OVH	$34.00	$68.00	$136.00	$272.00
Rackspace	$122.27	$219.54	$388.35	$826.70
SoftLayer	$128.00	$223.00	$376.00	$766.00

PRICING BY VM CATEGORY

From small to large-sized VMs, the provider rankings remained the same from the least to most expensive provider. On the extra-large VMs, sizing allocation is less standardized, with differences in the amount of memory and local disk (if available) on the VM. The lack of standardization results in ranking changes on the extra-large VMs: OVH offers the least-expensive VM, and Google Compute Engine and CenturyLink Cloud offer less-expensive VMs than DigitalOcean. Dimension Data does not have a VM that fits in the extra-large VM category.

Chart 7B: Monthly Cost of Small VMs

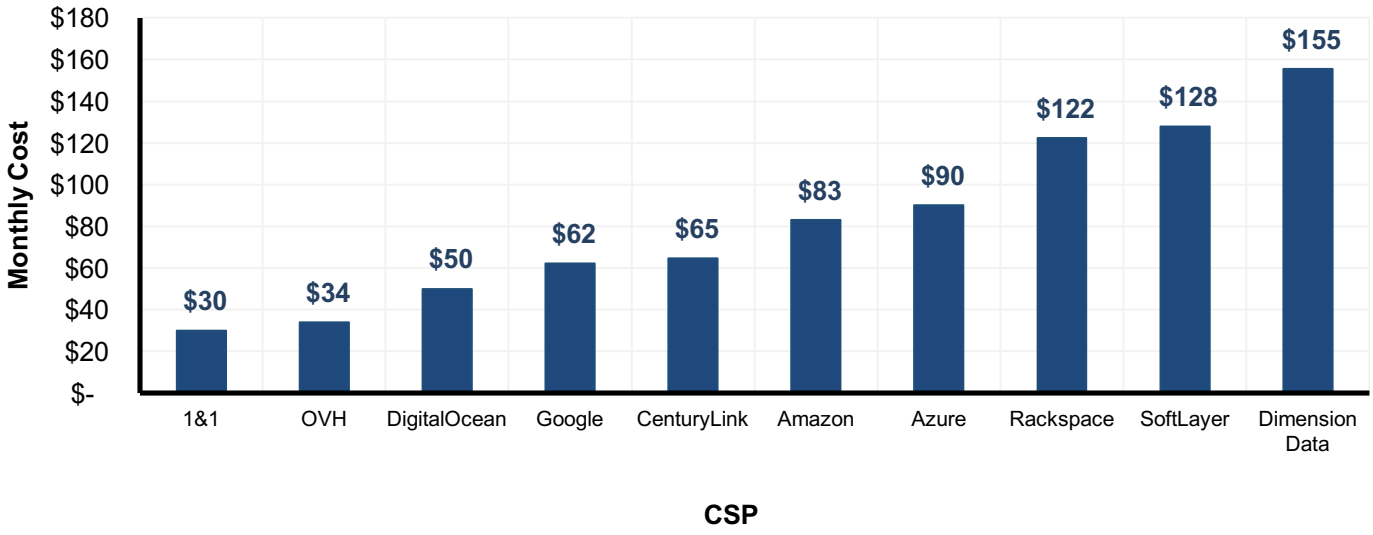


Chart 7C: Monthly Cost of Medium VMs

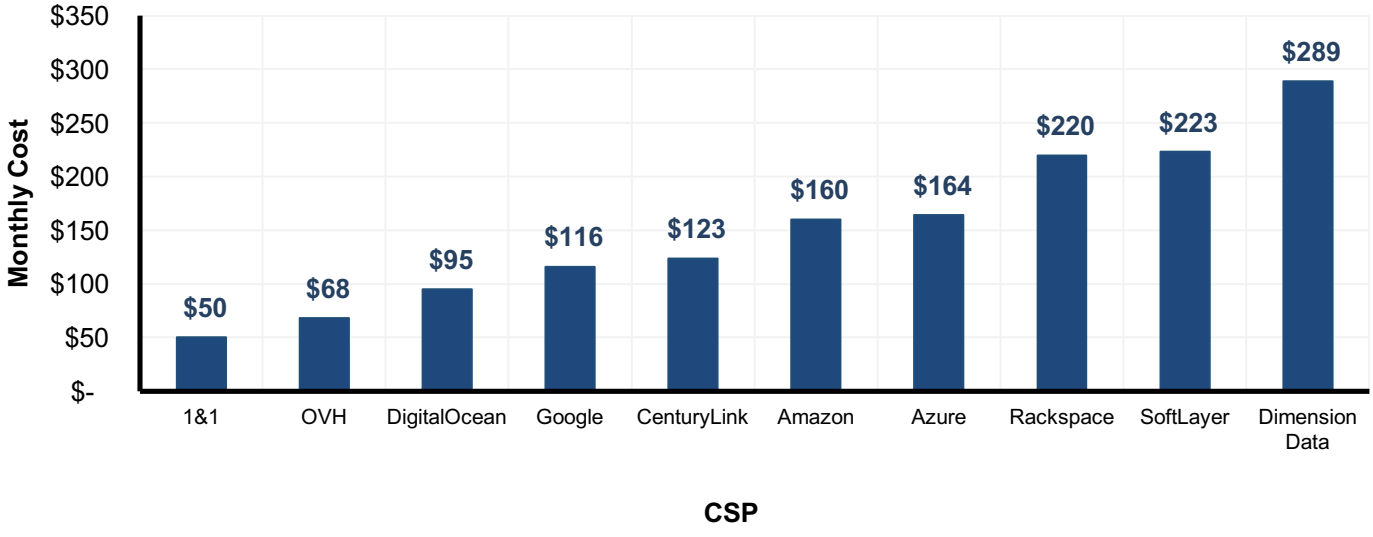


Chart 7D: Monthly Cost of Large VMs

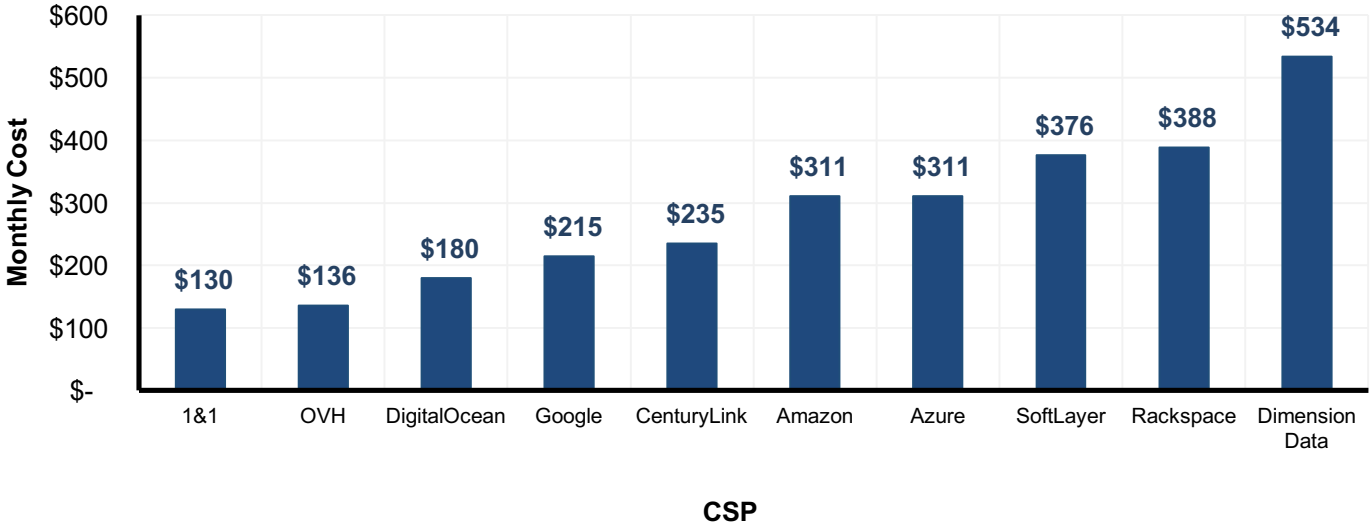
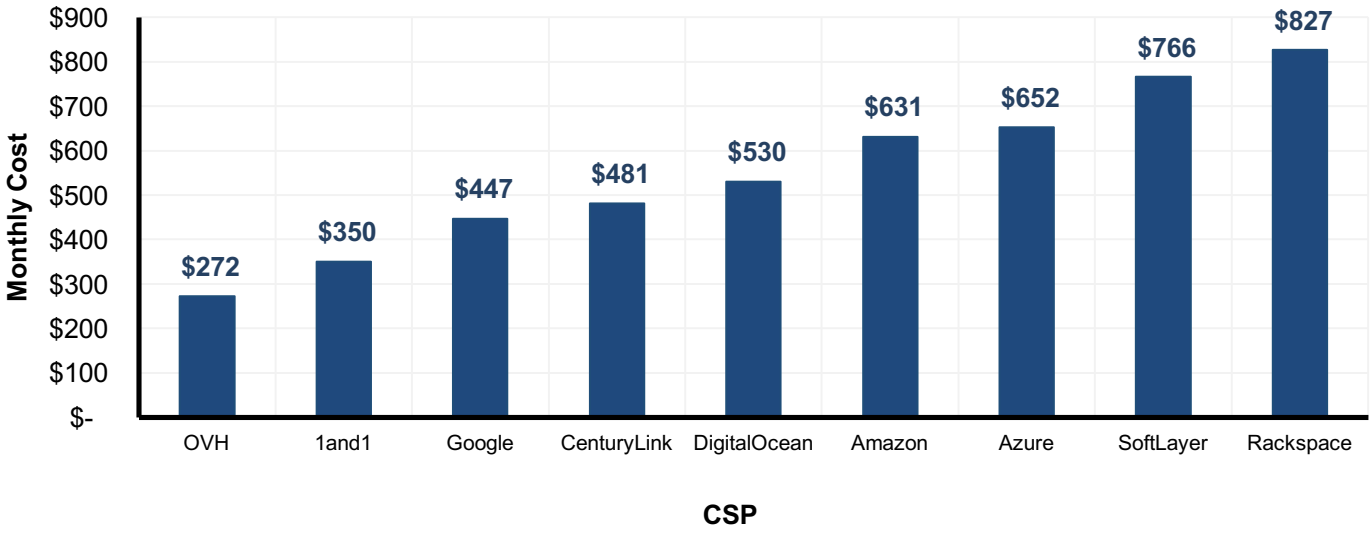


Chart 7E: Monthly Cost of Extra Large VMs

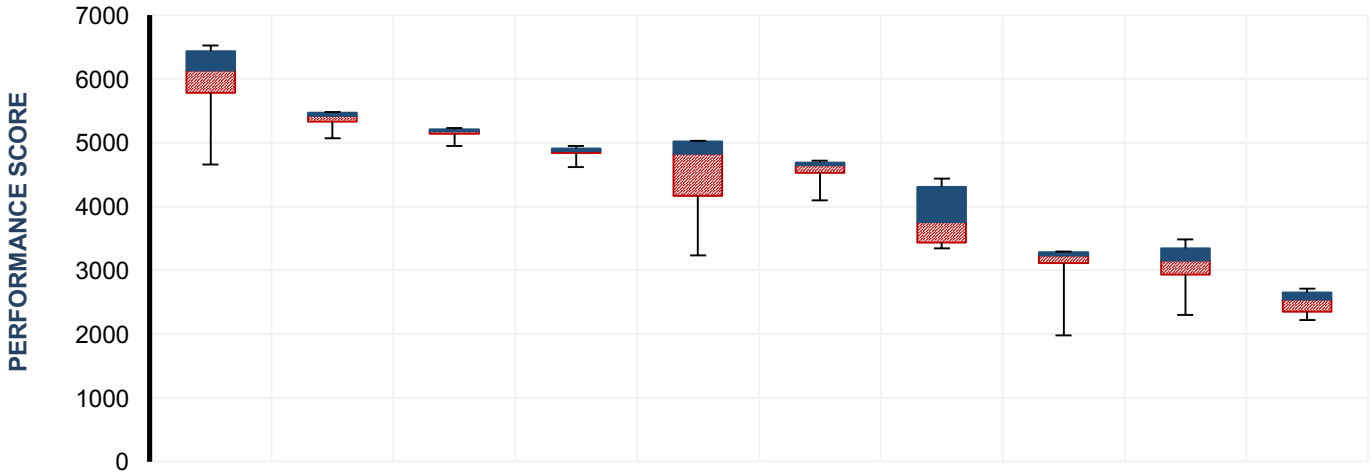


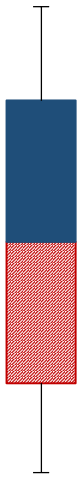
PERFORMANCE BY VM SIZE

UNDERSTANDING THE CHARTS

VM performance is illustrated using percentile scores retrieved from all data points collected. 5th percentile and 95th percentile scores are often used instead of minimum and maximum scores in order to exclude potential outliers. Median scores are used instead of mean to avoid values being skewed by outliers. The information has been integrated into percentile graphs and value tables designed to visualize performance variation captured while testing over time. An example of the performance percentile graph along with a corresponding value table is displayed in Chart 8:

Chart 8: Sample Chart Guide





- **Maximum (MAX)**: The highest performance score(s) achieved on the VM over the course of the study.
- **95TH Percentile (95TH)**: 95% of all scores on the VM achieved this performance score or lower.
- **Median (MED)**: The number separating the higher and lower half of scores. If the median is closer to the 95TH percentile, then more high performance scores were observed than low performance scores (and vice versa).
- **5TH Percentile (5TH)**: 5% of all scores on the VM achieved this performance score or lower.
- **Minimum (MIN)**: The lowest performance score(s) achieved on the VM over the course of the study.

SMALL VMs

Chart 8A.1: VM Performance (Small VMs)

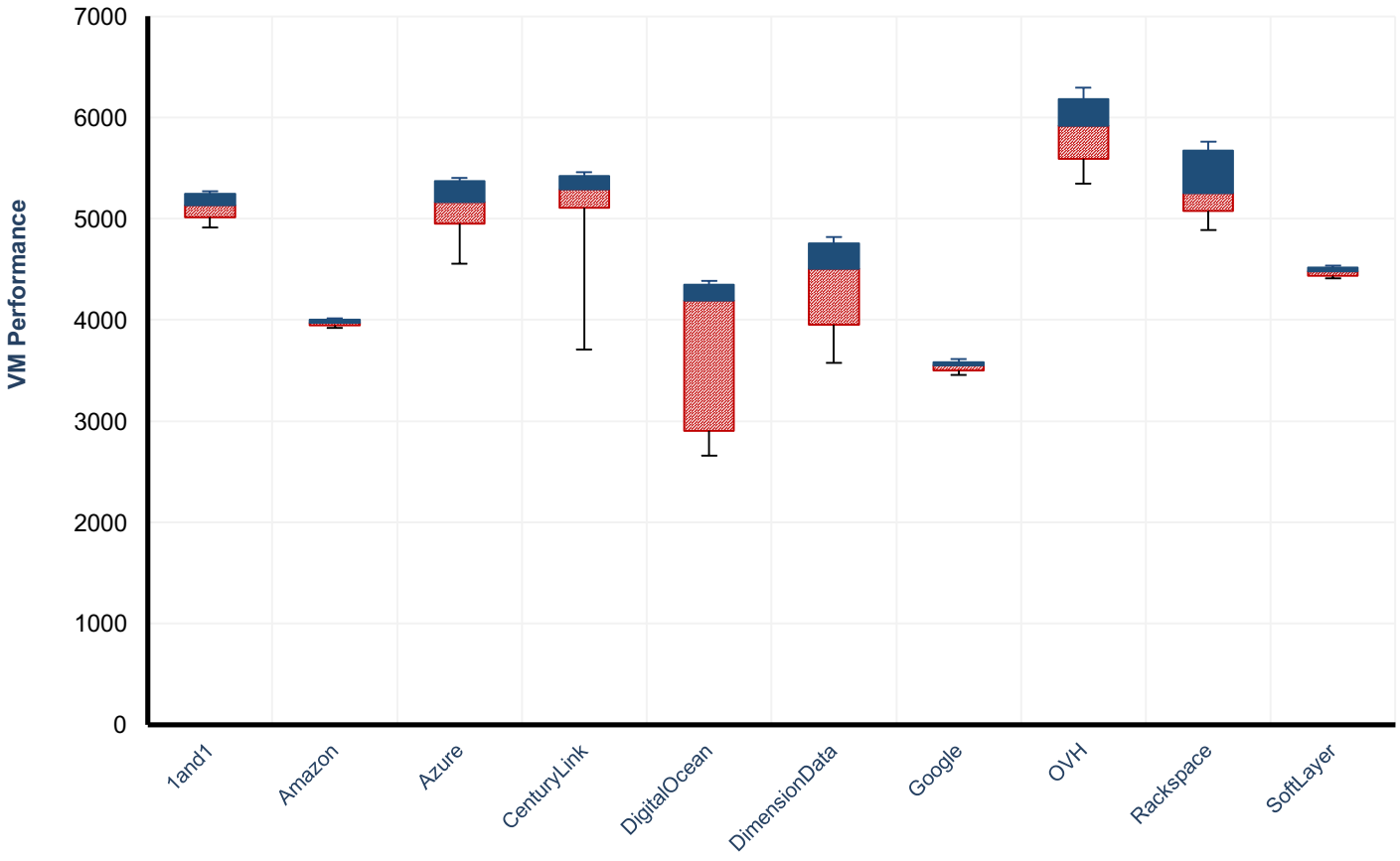


Table 8A.1: VM Performance (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1&1	4912	5013	5131	5244	5272	66	1%
Amazon	3921	3945	3973	4000	4018	17	0%
Azure	4556	4949	5163	5371	5402	162	3%
CenturyLink	3708	5108	5293	5422	5461	160	3%
DigitalOcean	2656	2905	4189	4346	4386	550	14%
Dimension Data	3573	3952	4504	4757	4822	248	6%
Google	3455	3502	3550	3581	3611	25	1%
OVH	5350	5593	5918	6184	6295	180	3%
Rackspace	4887	5079	5255	5671	5764	200	4%
SoftLayer	4410	4439	4481	4515	4534	23	1%

Chart 8A.2: Sequential Block Disk Performance Type 1 (Small VM)

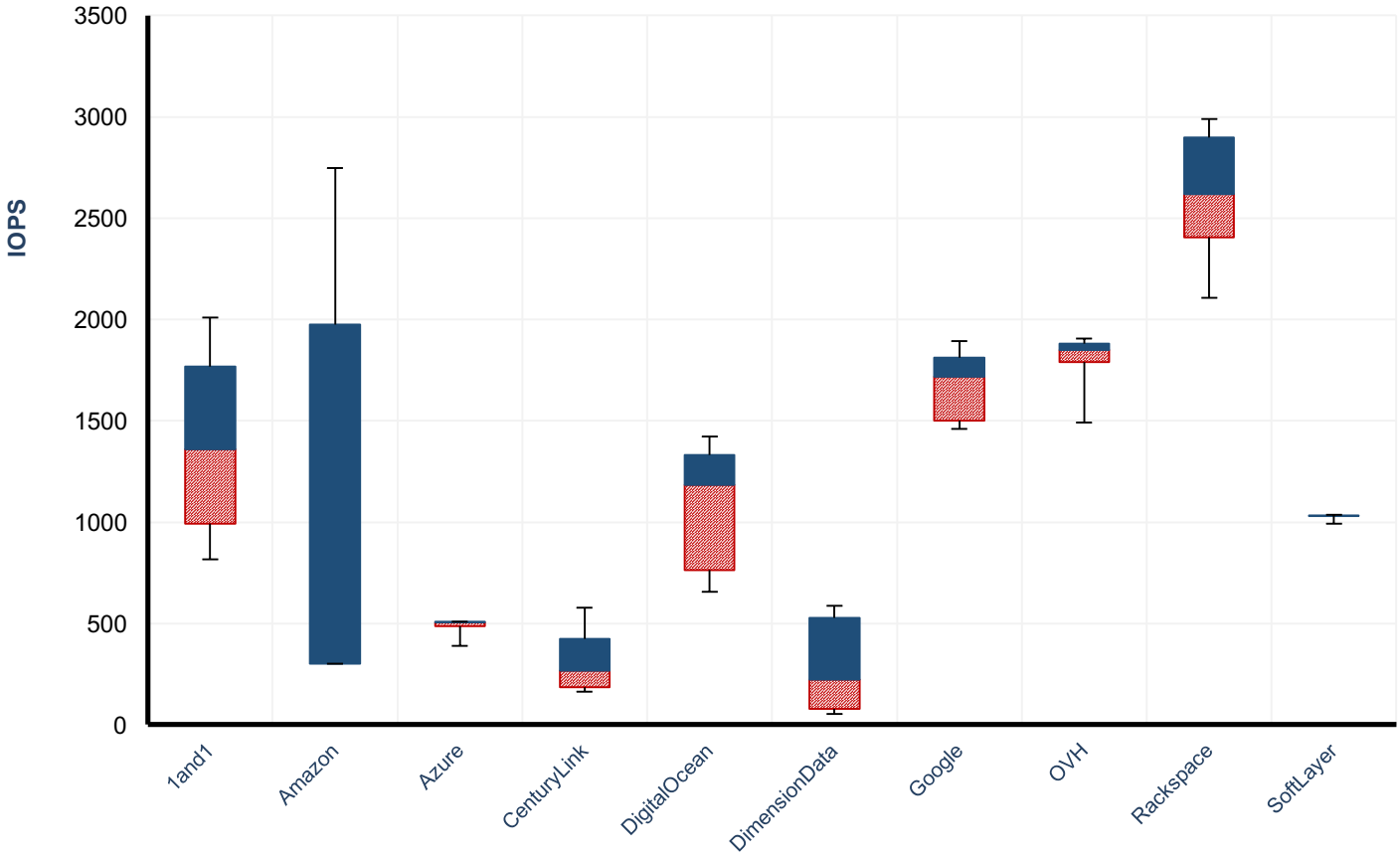


Table 8A.2: Sequential Block Disk Performance Type 1 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1&1	818	993	1361	1767	2011	227	16%
Amazon	301	301	301	1974	2747	473	114%
Azure	389	487	506	507	508	15	3%
CenturyLink	162	186	267	424	577	81	29%
DigitalOcean	656	764	1184	1331	1423	204	18%
Dimension Data	52	80	222	526	586	127	53%
Google	1461	1500	1717	1812	1893	97	6%
OVH	1493	1791	1849	1882	1906	40	2%
Rackspace	2108	2404	2619	2898	2990	172	7%
SoftLayer	991	1029	1029	1030	1037	3	0%

Chart 8A.3: Random Block Disk Performance Type 1 (Small VM)

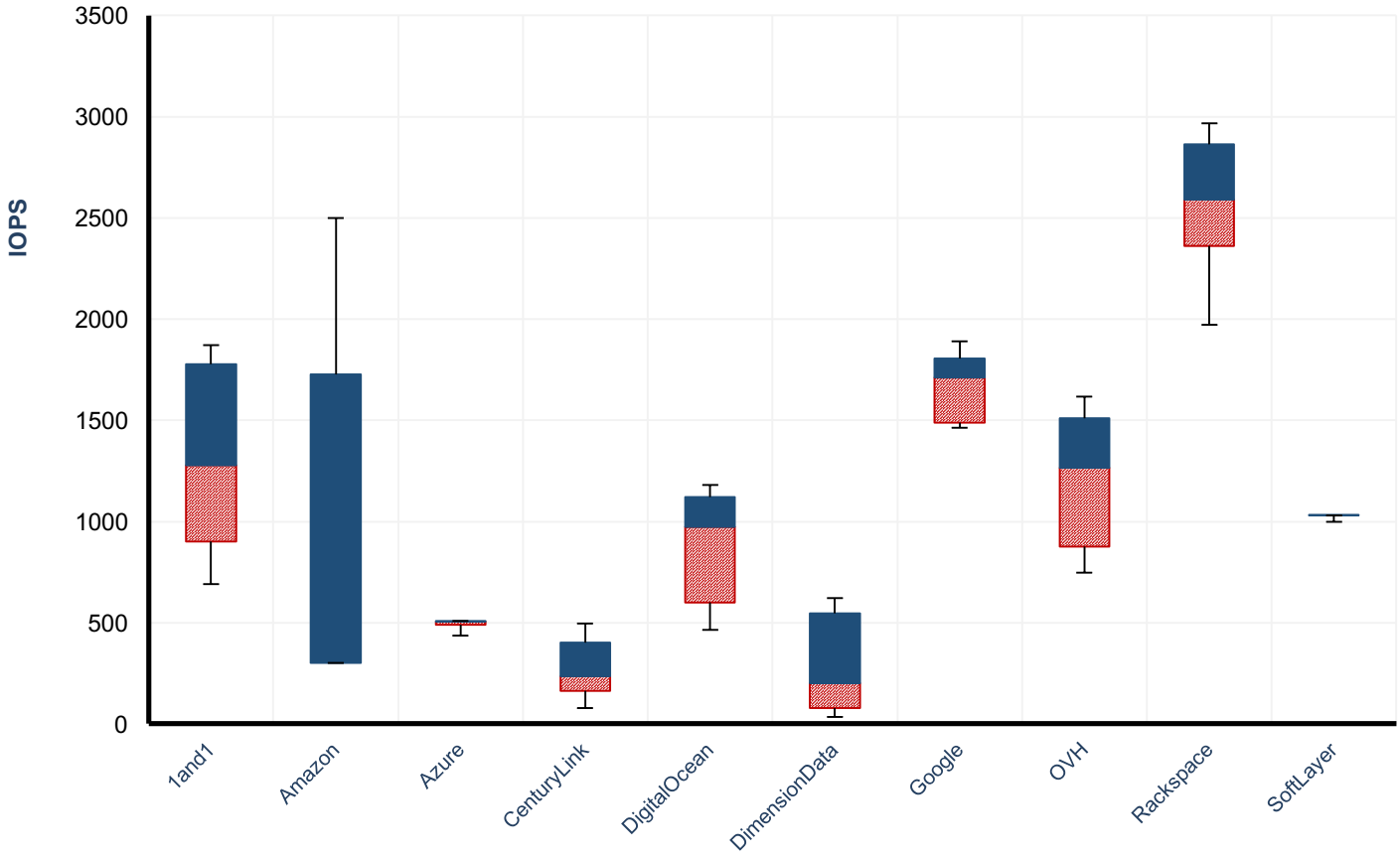


Table 8A.3: Random Block Disk Performance Type 1 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	692	902	1278	1776	1873	255	20%
Amazon	301	301	301	1728	2499	419	104%
Azure	436	490	506	507	510	8	2%
CenturyLink	80	164	237	403	496	80	31%
DigitalOcean	464	601	974	1121	1180	181	20%
Dimension Data	35	79	200	545	622	135	56%
Google	1463	1489	1710	1806	1891	97	6%
OVH	746	877	1267	1512	1618	181	15%
Rackspace	1971	2360	2592	2864	2968	173	7%
SoftLayer	999	1029	1029	1030	1030	3	0%

Chart 8A.4: Sequential Block Disk Performance Type 2 (Small VM)

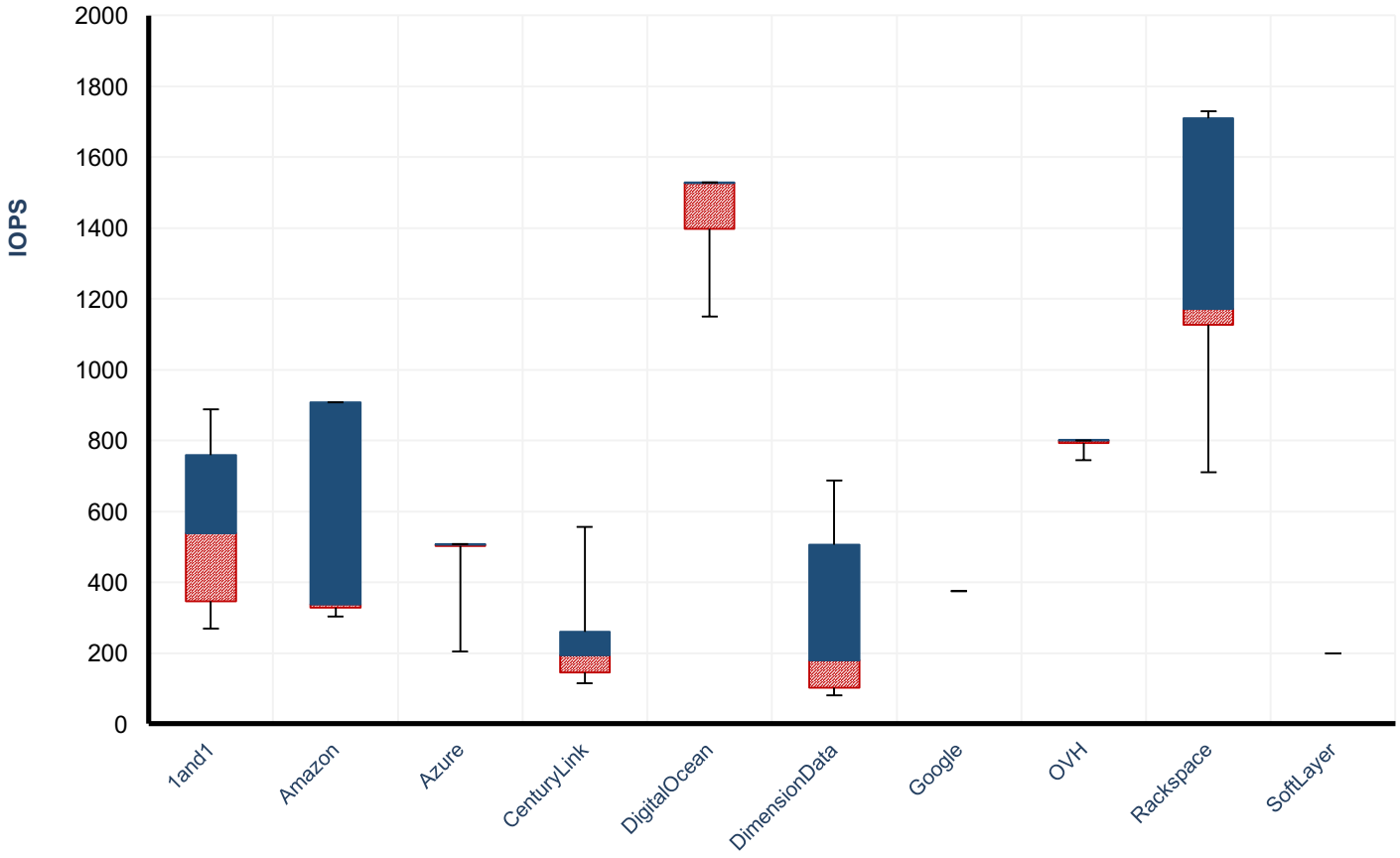


Table 8A.4: Sequential Block Disk Performance Type 2 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	269	347	538	759	889	125	23%
Amazon	304	328	338	908	908	259	52%
Azure	205	502	506	508	508	28	6%
CenturyLink	114	145	194	261	557	48	24%
DigitalOcean	1151	1398	1527	1528	1528	57	4%
Dimension Data	81	102	180	506	688	133	56%
Google	375	375	375	375	375	0	0%
OVH	744	793	800	801	801	5	1%
Rackspace	711	1127	1171	1710	1729	234	18%
SoftLayer	199	199	199	199	199	0	0%

Chart 8A.5: Random Block Disk Performance Type 2 (Small VM)

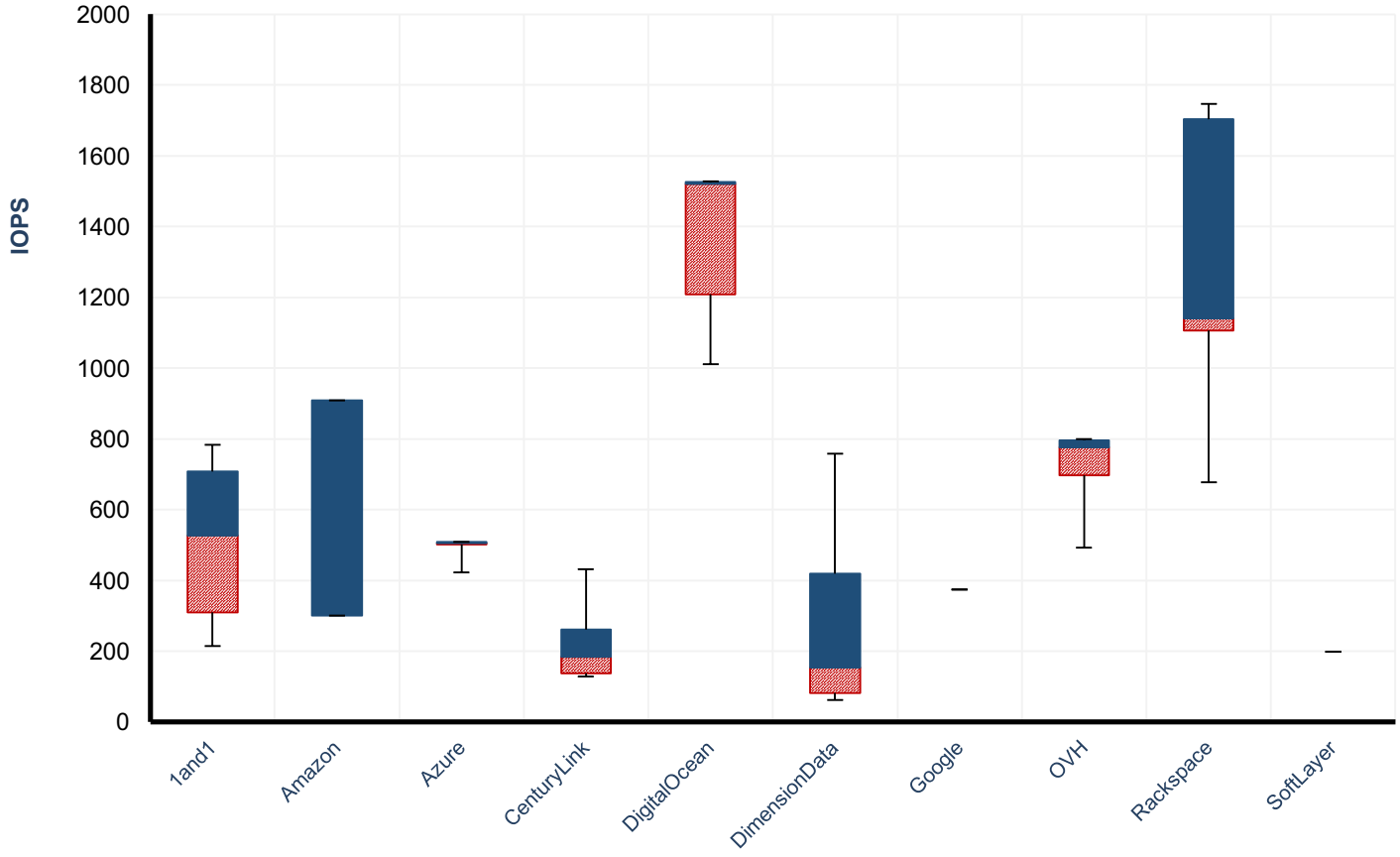


Table 8A.5: Random Block Disk Performance Type 2 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	214	310	527	707	784	121	23%
Amazon	300	300	300	908	908	269	58%
Azure	422	502	506	508	508	11	2%
CenturyLink	128	138	184	261	431	48	25%
DigitalOcean	1011	1209	1521	1527	1528	117	8%
DimensionData	62	82	153	419	759	125	66%
Google	375	375	375	375	375	0	0%
OVH	493	696	776	796	799	40	5%
Rackspace	677	1107	1140	1703	1746	245	19%
SoftLayer	199	199	199	199	199	0	0%

MEDIUM VMs

Chart 8B.1: VM Performance (Medium VMs)

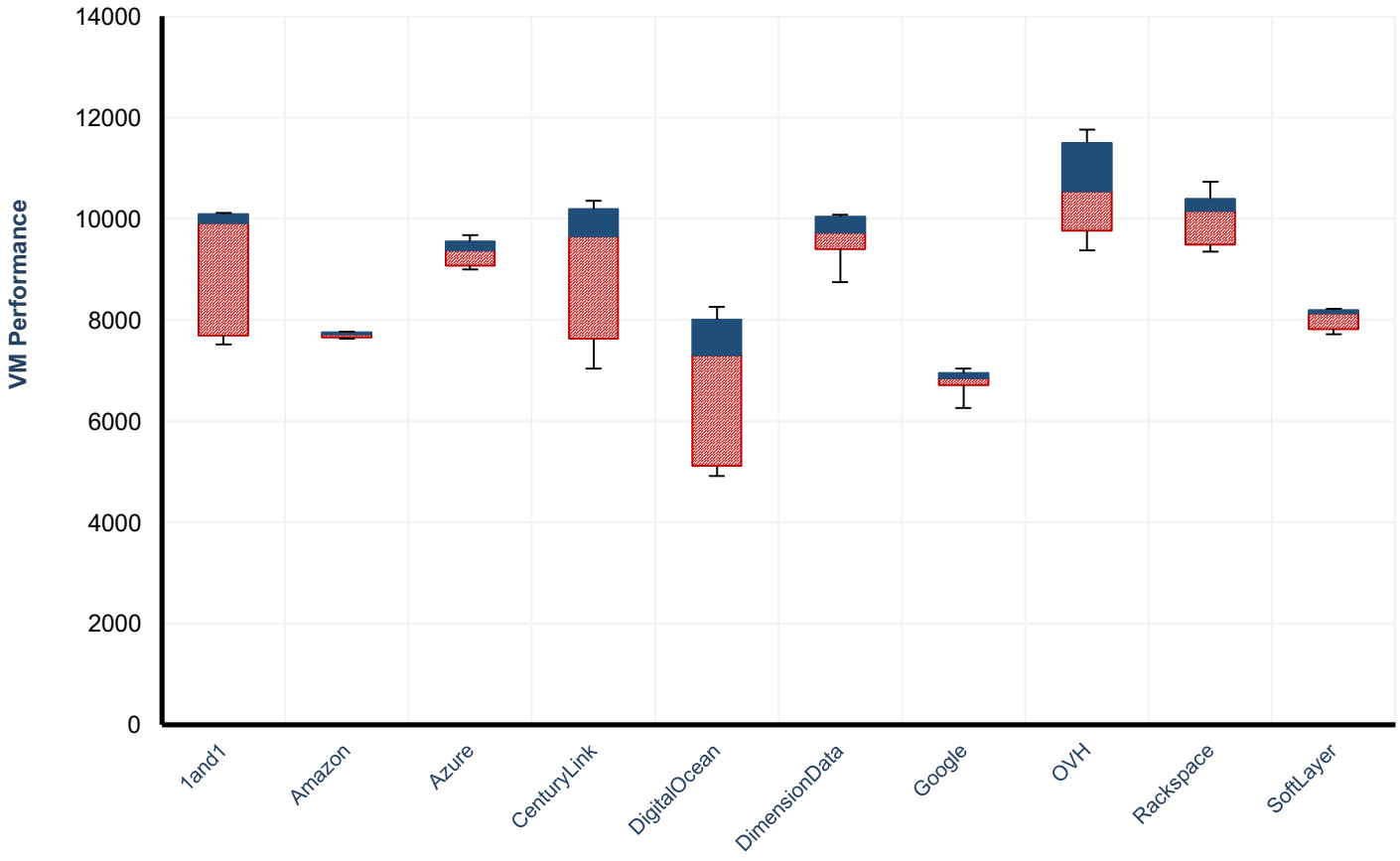


Table 8B.1: VM Performance (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	7518	7686	9911	10089	10116	995	11%
Amazon	7627	7655	7718	7751	7771	29	0%
Azure	8993	9072	9376	9553	9672	156	2%
CenturyLink	7038	7625	9657	10189	10358	833	9%
DigitalOcean	4918	5122	7299	8000	8257	1119	16%
DimensionData	8743	9402	9726	10039	10075	201	2%
Google	6261	6716	6854	6947	7033	80	1%
OVH	9376	9762	10545	11496	11764	524	5%
Rackspace	9352	9483	10158	10386	10732	332	3%
SoftLayer	7720	7819	8131	8190	8214	136	2%

Chart 8B.2: Sequential Block Disk Performance Type 1 (Medium VM)

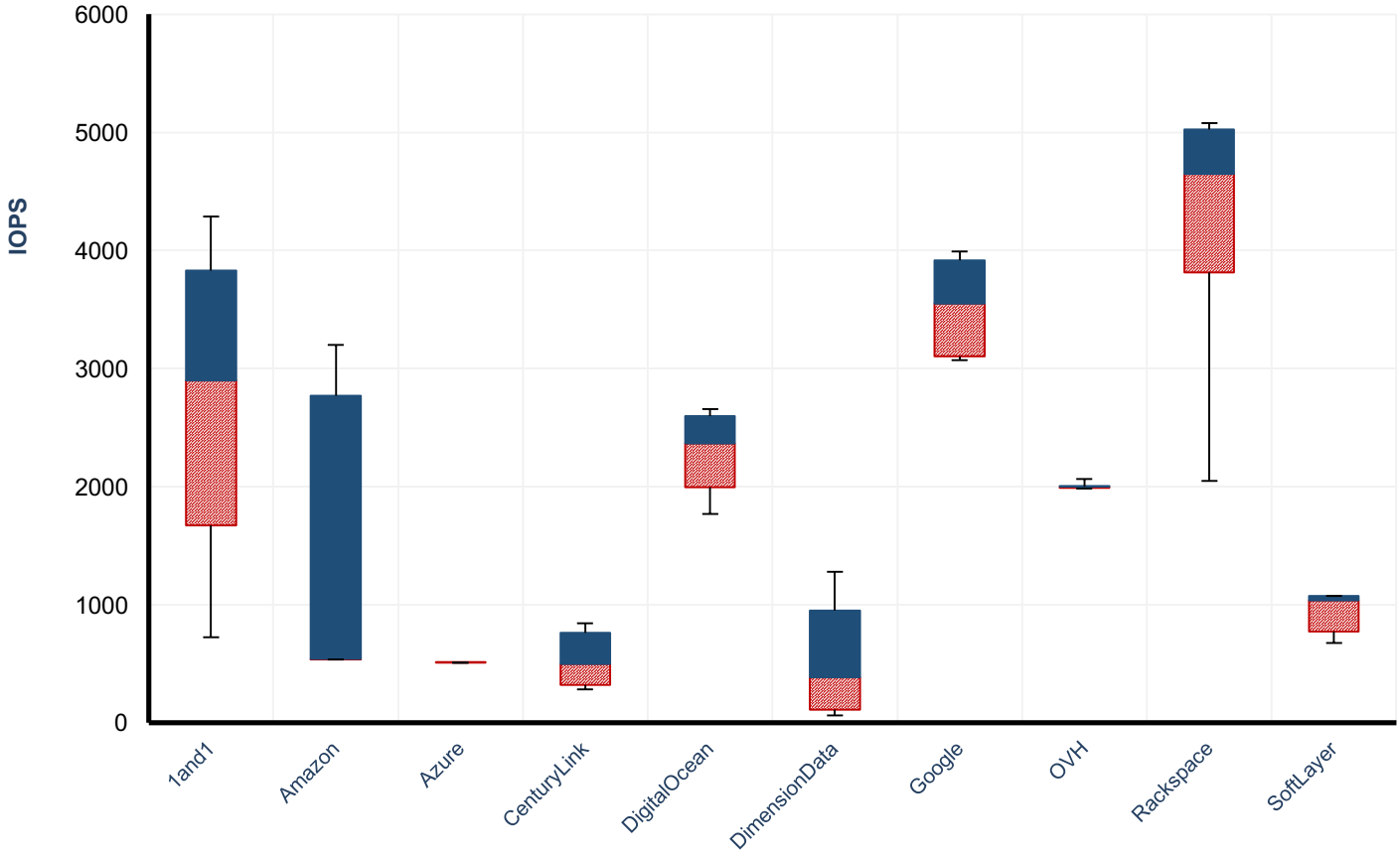


Table 8B.2: Sequential Block Disk Performance Type 1 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	725	1672	2900	3833	4288	733	26%
Amazon	538	538	539	2768	3198	617	87%
Azure	507	507	509	509	509	1	0%
CenturyLink	281	319	500	762	841	145	28%
DigitalOcean	1766	1995	2369	2596	2659	208	9%
DimensionData	62	109	385	950	1276	279	63%
Google	3069	3104	3550	3918	3991	263	7%
OVH	1983	1989	1998	2001	2062	9	0%
Rackspace	2047	3813	4649	5026	5080	453	10%
SoftLayer	675	771	1035	1072	1075	97	10%

Chart 8B.3: Random Block Disk Performance Type 1 (Medium VM)

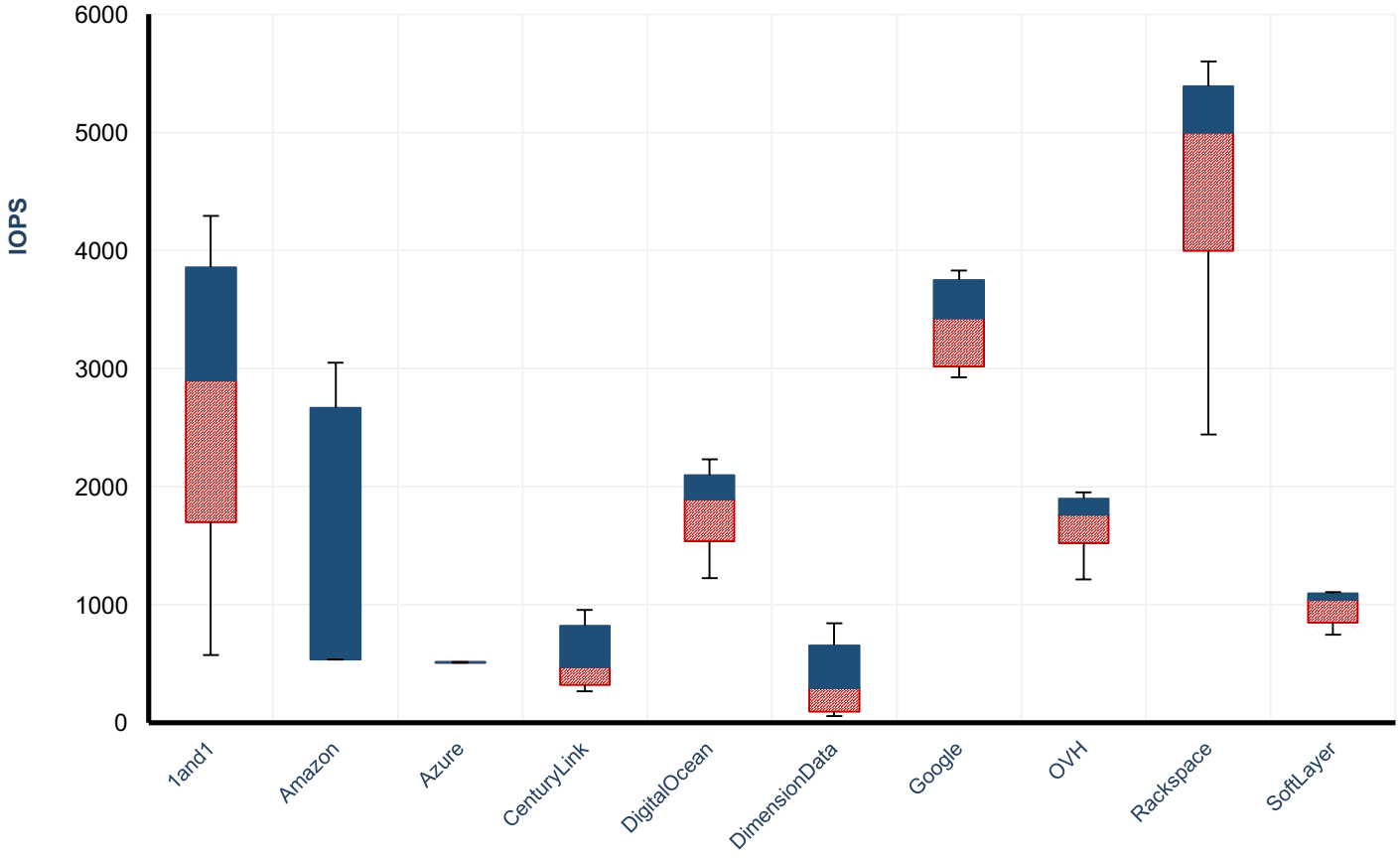


Table 8B.3: Random Block Disk Performance Type 1 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	575	1697	2899	3857	4295	725	26%
Amazon	537	537	537	2666	3052	597	85%
Azure	507	507	511	515	516	3	1%
CenturyLink	265	322	471	823	956	151	30%
DigitalOcean	1225	1537	1891	2099	2231	196	11%
DimensionData	54	95	293	655	840	177	57%
Google	2924	3017	3428	3747	3831	247	7%
OVH	1215	1523	1764	1897	1952	136	8%
Rackspace	2441	3995	4997	5389	5601	437	9%
SoftLayer	746	845	1044	1097	1105	85	8%

Chart 8B.4: Sequential Block Disk Performance Type 2 (Medium VM)

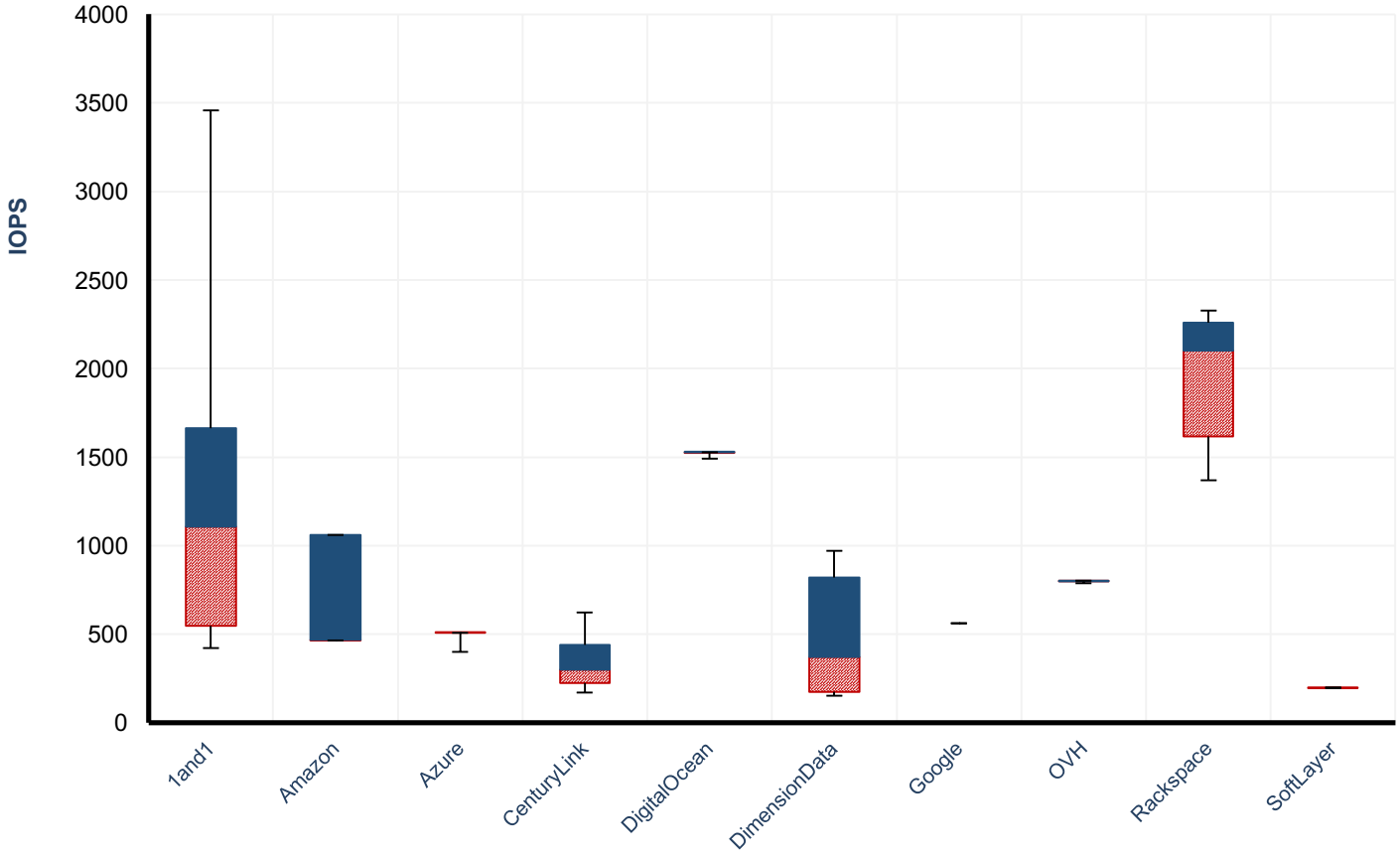


Table 8B.4: Sequential Block Disk Performance Type 2 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	420	549	1109	1662	3457	379	34%
Amazon	463	465	467	1061	1061	288	42%
Azure	399	506	508	508	509	9	2%
CenturyLink	172	226	298	439	623	72	23%
DigitalOcean	1491	1525	1527	1528	1528	4	0%
DimensionData	154	175	372	818	969	217	49%
Google	562	563	563	563	563	0	0%
OVH	787	797	800	801	801	2	0%
Rackspace	1369	1615	2103	2260	2327	262	13%
SoftLayer	196	197	199	199	199	1	0%

Chart 8B.5: Random Block Disk Performance Type 2 (Medium VM)

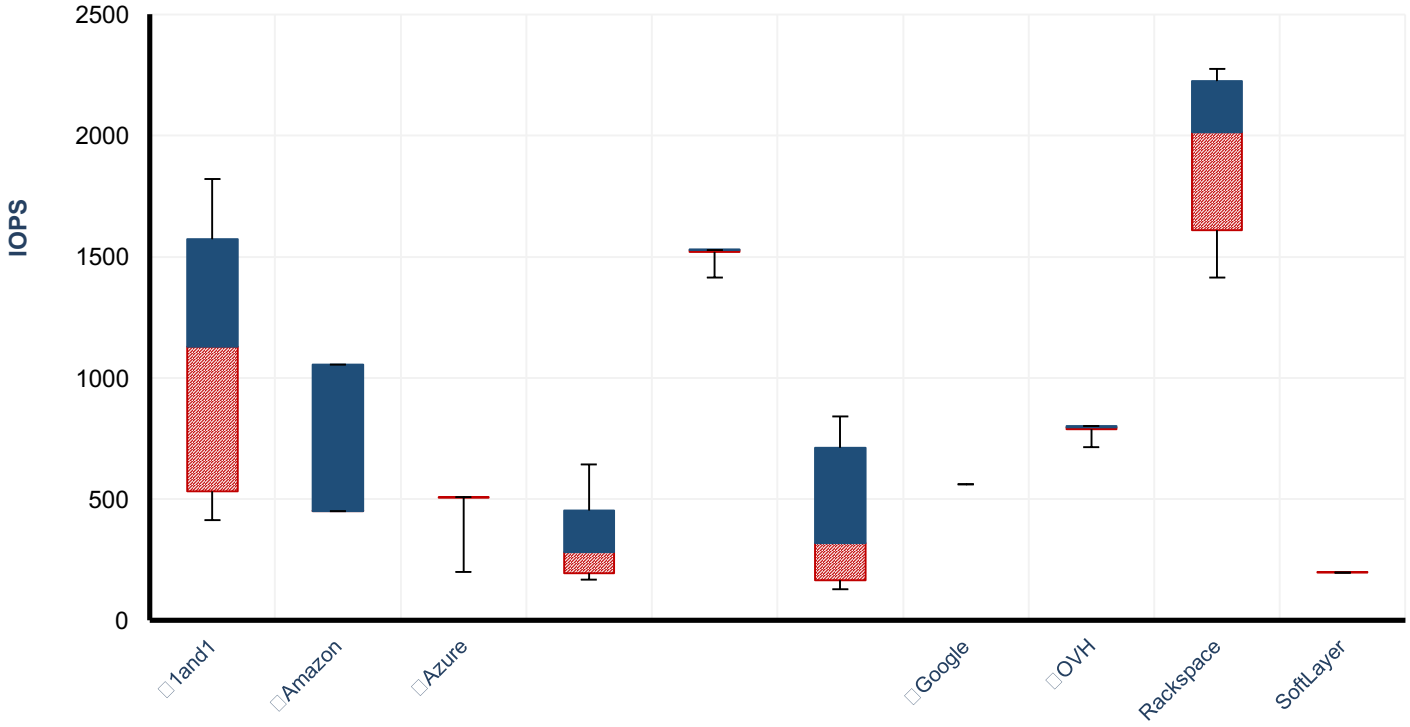


Table 8B.5: Random Block Disk Performance Type 2 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	414	533	1130	1572	1821	316	29%
Amazon	450	450	451	1056	1056	294	43%
Azure	200	506	508	508	509	25	5%
CenturyLink	169	196	282	453	643	84	28%
DigitalOcean	1416	1520	1527	1528	1528	14	1%
DimensionData	129	167	320	713	843	180	48%
Google	562	563	563	563	563	0	0%
OVH	716	789	798	801	801	9	1%
Rackspace	1414	1611	2014	2226	2275	240	12%
SoftLayer	197	197	199	199	199	1	0%

LARGE VMs

Chart 8C.1: VM Performance (Large VMs)

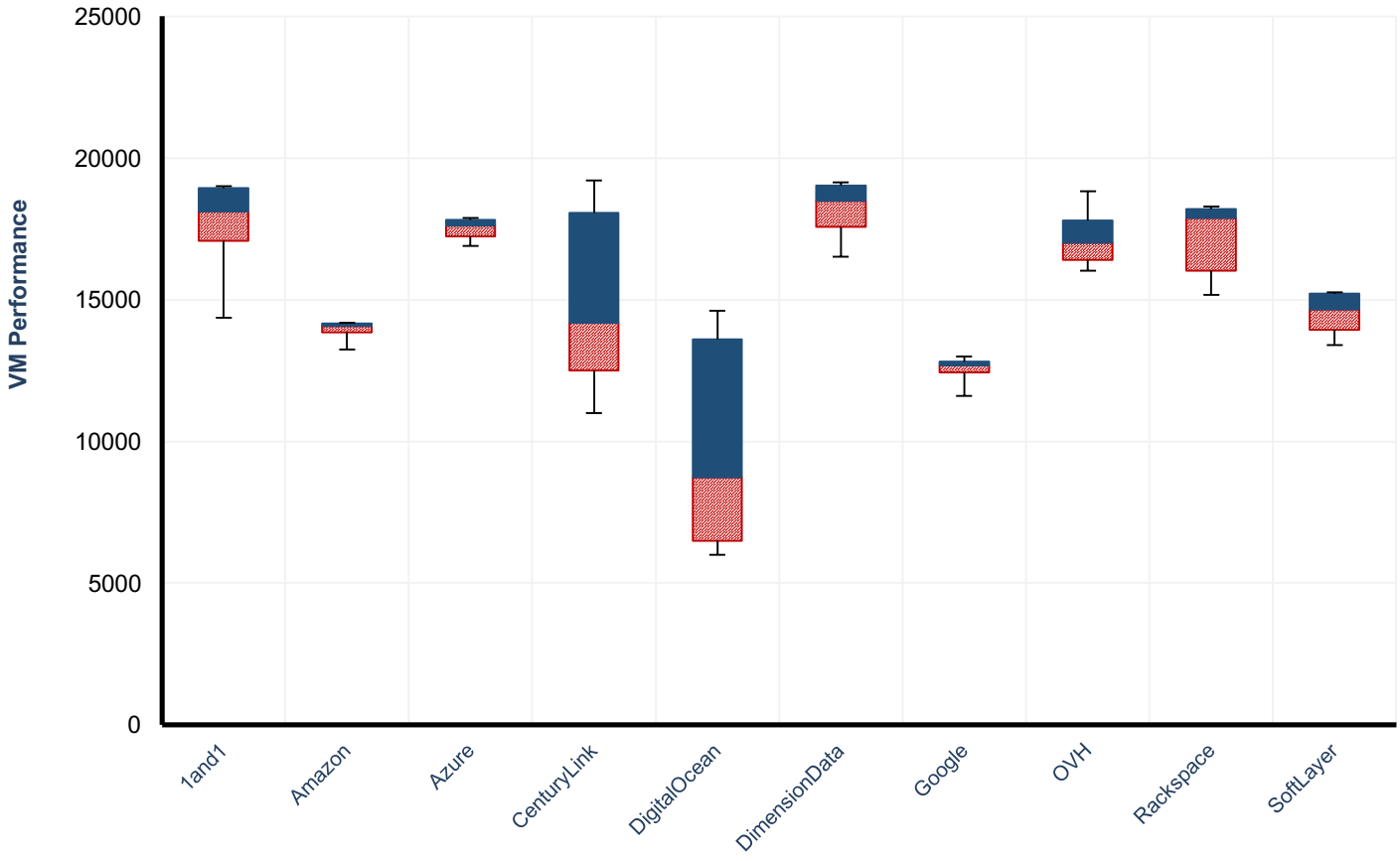


Table 8C.1: VM Performance (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	14356	17087	18105	18935	19004	624	3%
Amazon	13237	13840	14079	14157	14178	121	1%
Azure	16891	17243	17625	17819	17895	219	1%
CenturyLink	10993	12512	14186	18073	19205	2028	14%
DigitalOcean	5994	6486	8724	13609	14618	2091	23%
DimensionData	16518	17570	18480	19037	19135	478	3%
Google	11600	12438	12692	12822	12990	175	1%
OVH	16012	16405	17012	17802	18826	450	3%
Rackspace	15167	16021	17895	18208	18286	734	4%
SoftLayer	13409	13930	14646	15215	15263	426	3%

Chart 8C.2: Sequential Block Disk Performance Type 1 (Large VM)

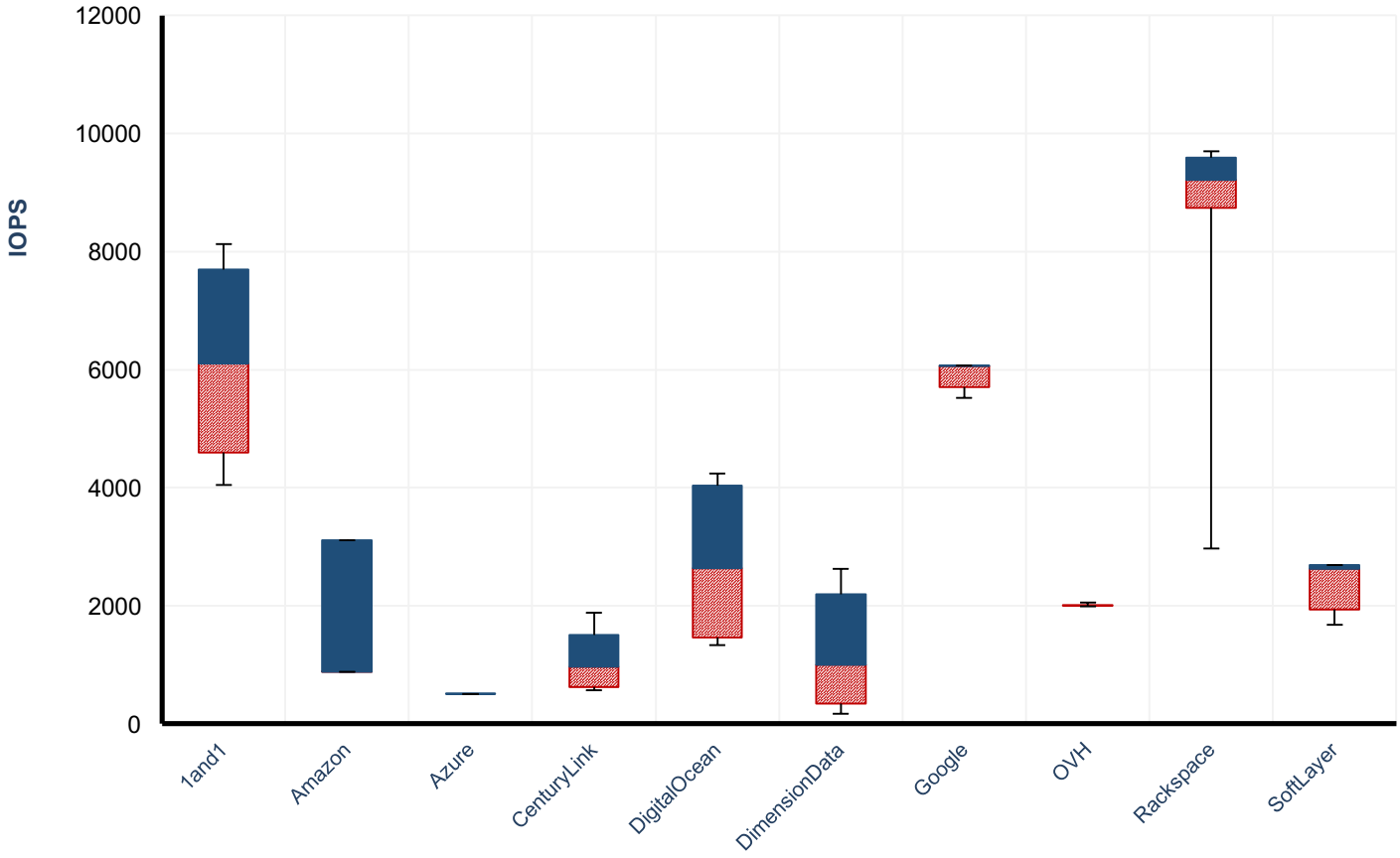


Table 8C.2: Sequential Block Disk Performance Type 1 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	4046	4593	6100	7695	8129	1013	17%
Amazon	878	878	879	3109	3110	644	60%
Azure	507	508	508	509	509	1	0%
CenturyLink	570	628	965	1503	1882	287	28%
DigitalOcean	1331	1469	2641	4032	4245	744	29%
DimensionData	173	345	1003	2197	2629	559	55%
Google	5519	5708	6057	6060	6067	110	2%
OVH	1991	1999	2002	2002	2056	9	0%
Rackspace	2976	8741	9219	9597	9701	668	7%
SoftLayer	1682	1943	2623	2692	2695	269	11%

Chart 8C.3: Random Block Disk Performance Type 1 (Large VM)

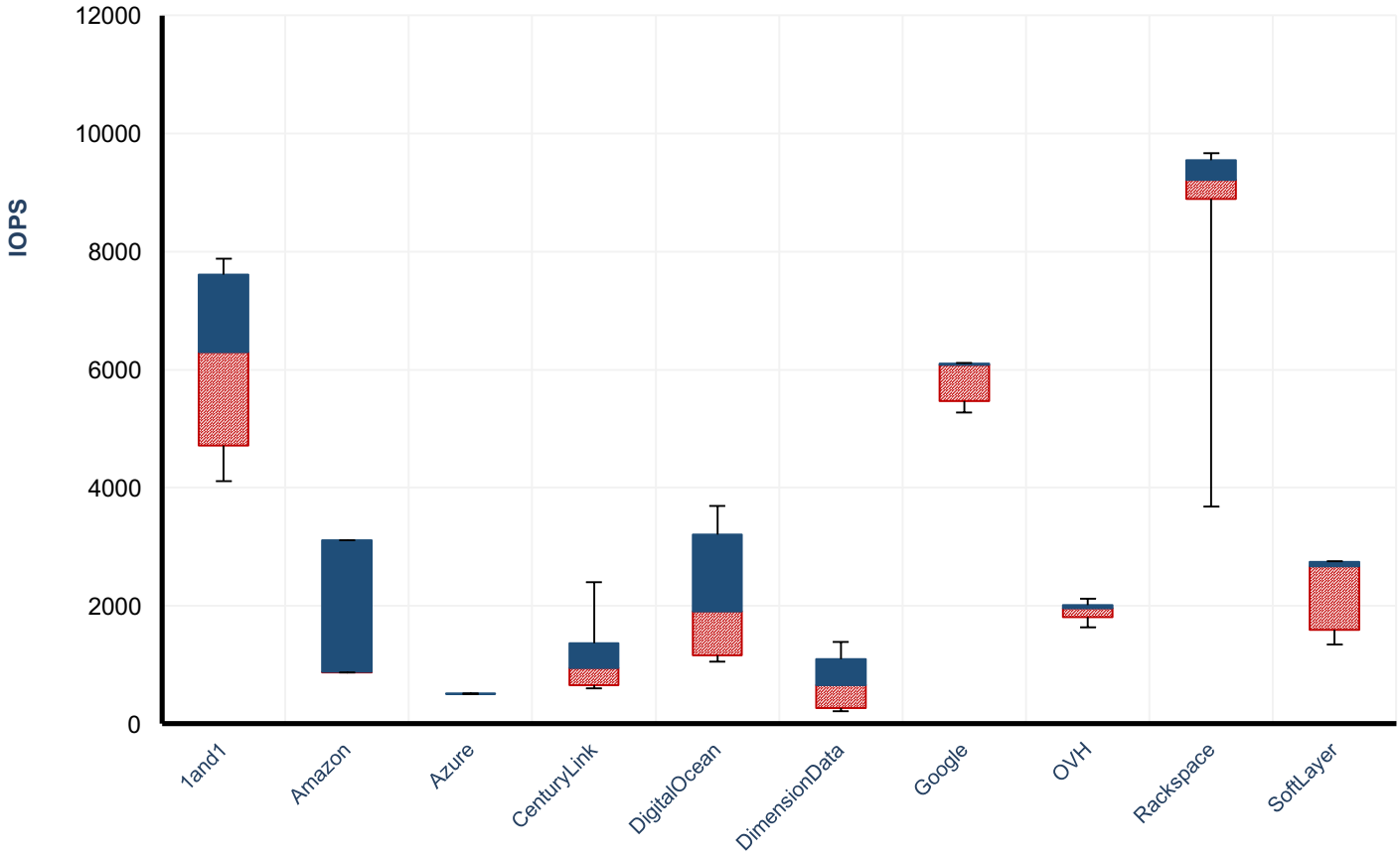


Table 8C.3: Random Block Disk Performance Type 1 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	4109	4714	6298	7610	7886	934	15%
Amazon	875	877	878	3109	3110	645	60%
Azure	508	510	510	512	514	1	0%
CenturyLink	604	654	947	1366	2402	286	29%
DigitalOcean	1056	1164	1908	3211	3690	632	31%
Dimension Data	215	265	662	1098	1394	282	43%
Google	5272	5468	6081	6102	6120	207	3%
OVH	1641	1806	1965	2010	2120	73	4%
Rackspace	3686	8888	9219	9554	9669	582	6%
SoftLayer	1346	1593	2666	2748	2754	422	17%

Chart 8C.4: Sequential Block Disk Performance Type 2 (Large VM)

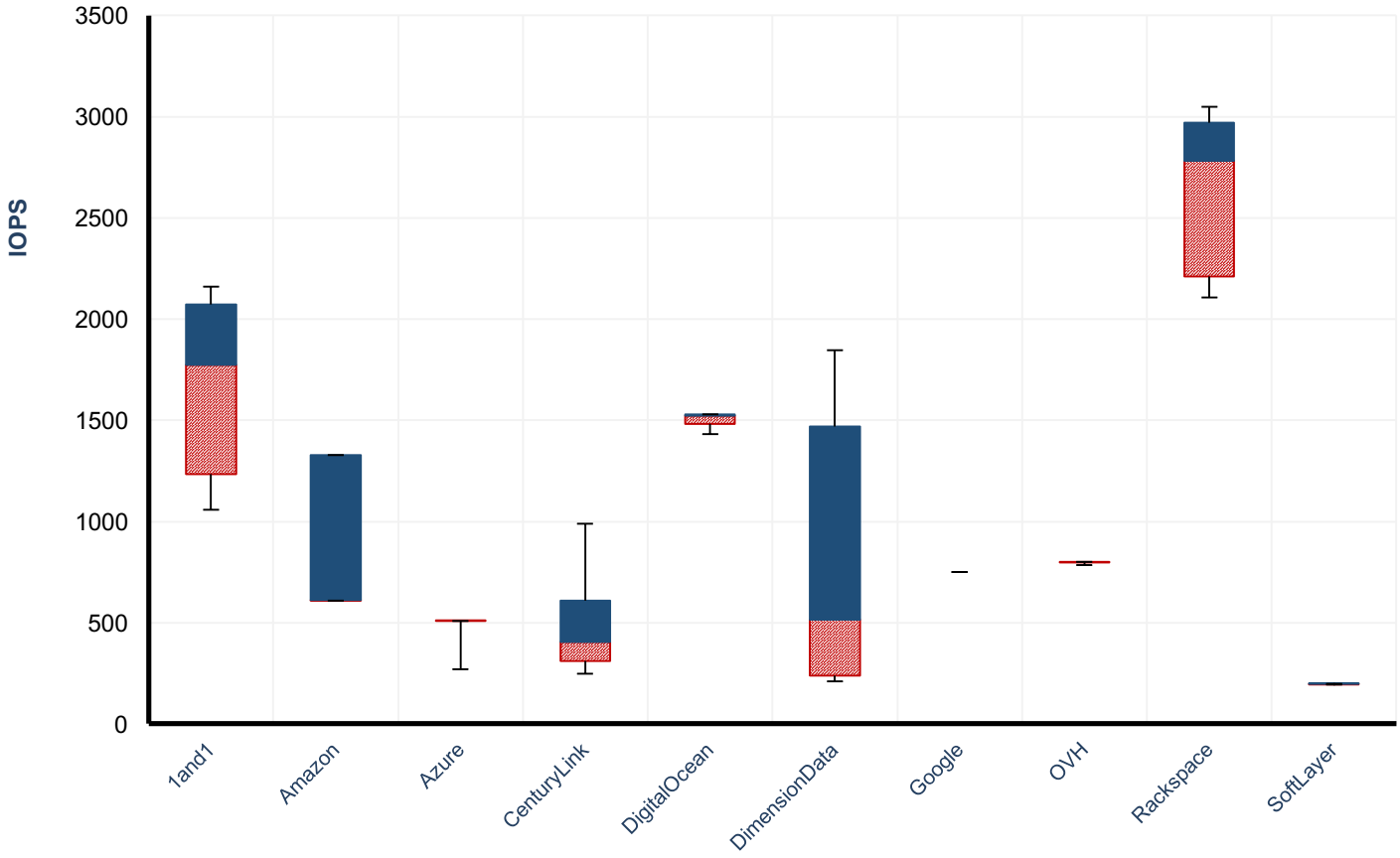


Table 8C.4: Sequential Block Disk Performance Type 2 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	1059	1233	1773	2072	2161	247	14%
Amazon	610	610	612	1327	1327	351	39%
Azure	270	508	509	509	509	19	4%
CenturyLink	247	312	405	608	989	109	25%
DigitalOcean	1431	1482	1523	1528	1528	19	1%
Dimension Data	209	239	516	1470	1845	409	61%
Google	751	751	751	751	751	0	0%
OVH	784	797	801	801	801	2	0%
Rackspace	2106	2211	2782	2971	3050	240	9%
SoftLayer	195	196	197	198	199	1	0%

Chart 8C.5: Random Block Disk Performance Type 2 (Large VM)

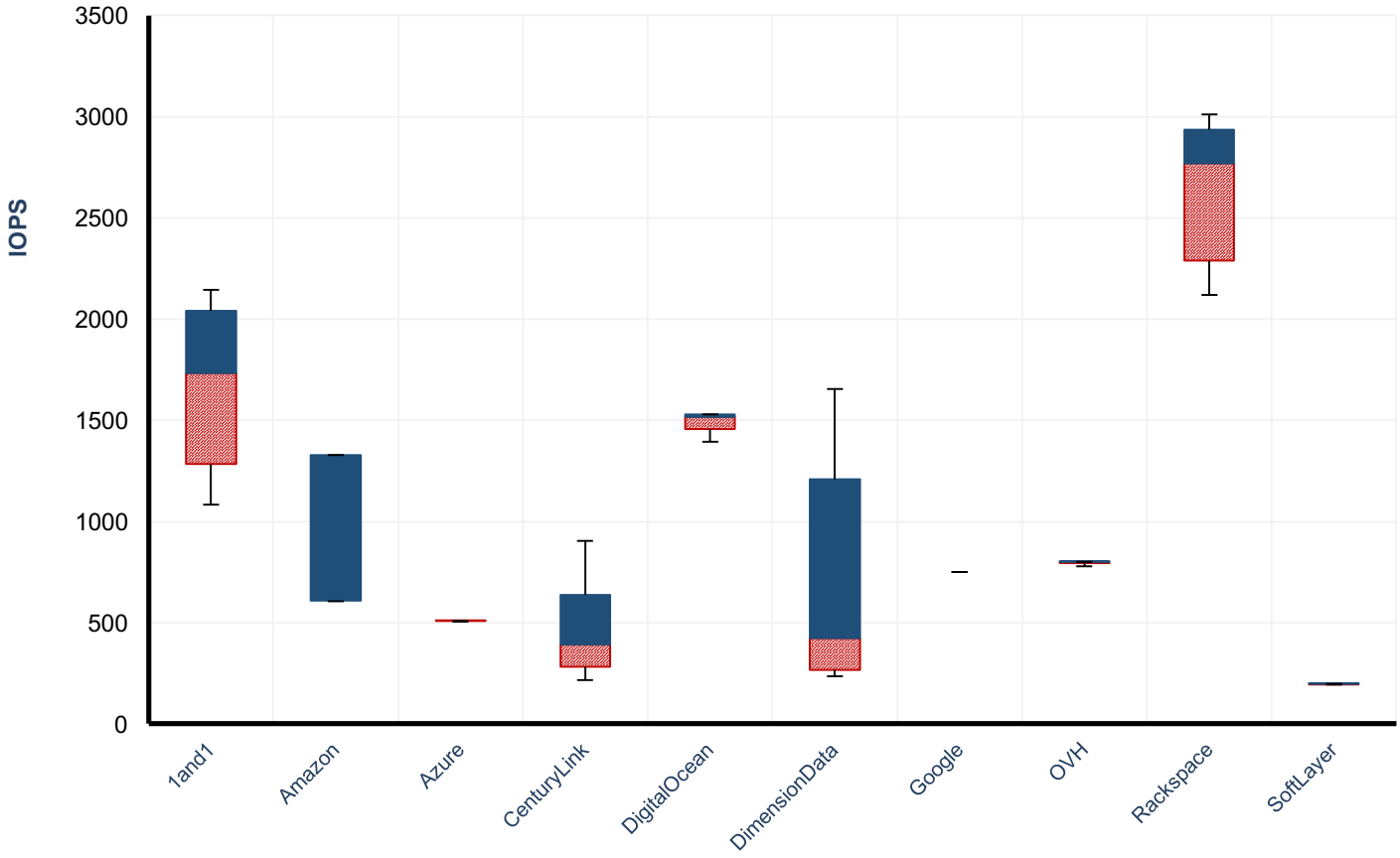


Table 8C.5: Random Block Disk Performance Type 2 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	1083	1284	1734	2040	2144	236	14%
Amazon	606	608	608	1327	1327	354	39%
Azure	504	508	509	509	509	1	0%
CenturyLink	218	282	391	638	903	124	30%
DigitalOcean	1395	1456	1518	1528	1528	25	2%
Dimension Data	234	266	425	1208	1654	299	55%
Google	751	751	751	751	751	0	0%
OVH	779	795	800	801	801	3	0%
Rackspace	2120	2288	2771	2937	3012	218	8%
SoftLayer	195	196	197	198	199	1	0%

EXTRA LARGE VMs

Chart 8D.1: VM Performance (Extra Large VMs)

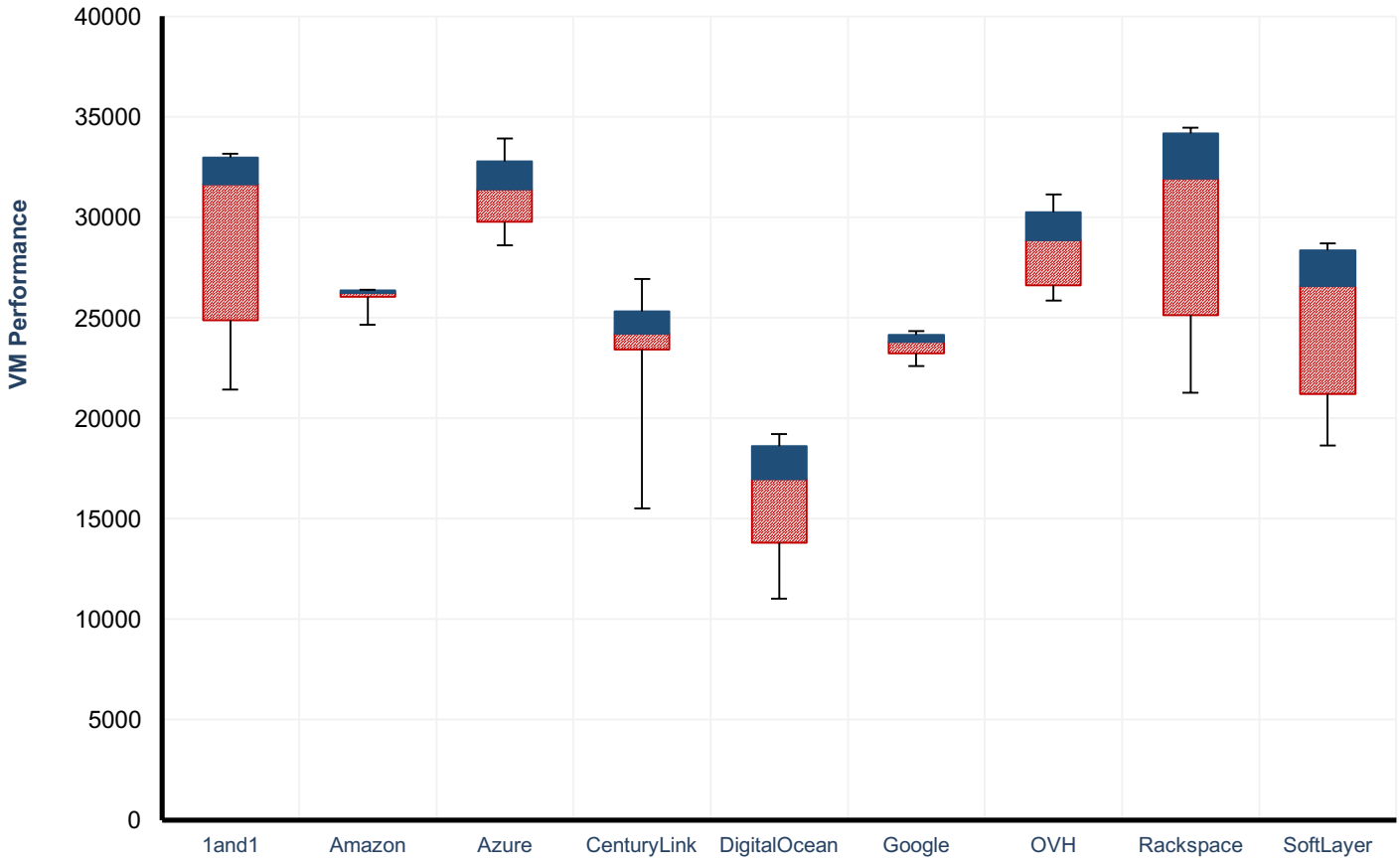


Table 8D.1: VM Performance (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	21417	24861	31636	32978	33168	3031	10%
Amazon	24650	26047	26224	26362	26401	184	1%
Azure	28609	29766	31388	32770	33911	967	3%
CenturyLink	15510	23407	24197	25309	26933	1173	5%
DigitalOcean	11005	13803	16968	18601	19218	1547	9%
Google	22584	23231	23790	24158	24333	285	1%
OVH	25868	26605	28845	30239	31127	1219	4%
Rackspace	21274	25136	31942	34182	34447	2619	8%
SoftLayer	18636	21201	26579	28360	28704	2375	9%

Chart 8D.2: Sequential Block Disk Performance Type 1 (Extra Large VM)

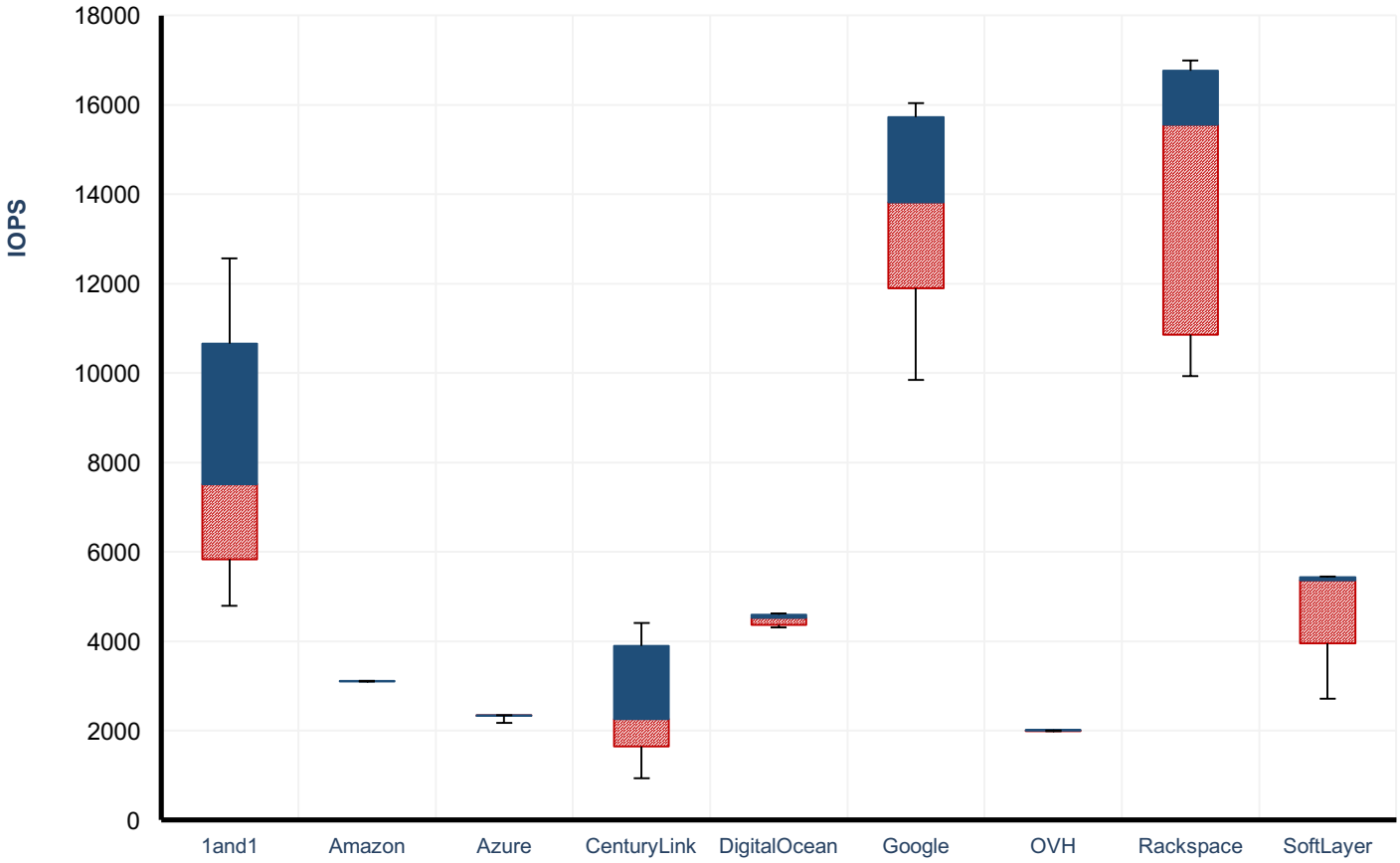


Table 8D.2: Sequential Block Disk Performance Type 1 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	4794	5833	7512	10662	12568	1626	21%
Amazon	3106	3109	3109	3110	3110	1	0%
Azure	2171	2333	2336	2346	2346	21	1%
CenturyLink	937	1644	2255	3894	4408	806	32%
DigitalOcean	4310	4369	4521	4598	4620	76	2%
Google	9847	11898	13817	15727	16040	1141	8%
OVH	1990	1997	2001	2002	2011	3	0%
Rackspace	9929	10854	15561	16761	16996	2036	14%
SoftLayer	2715	3960	5364	5439	5444	762	15%

Chart 8D.3: Random Block Disk Performance Type 1 (Extra Large VM)

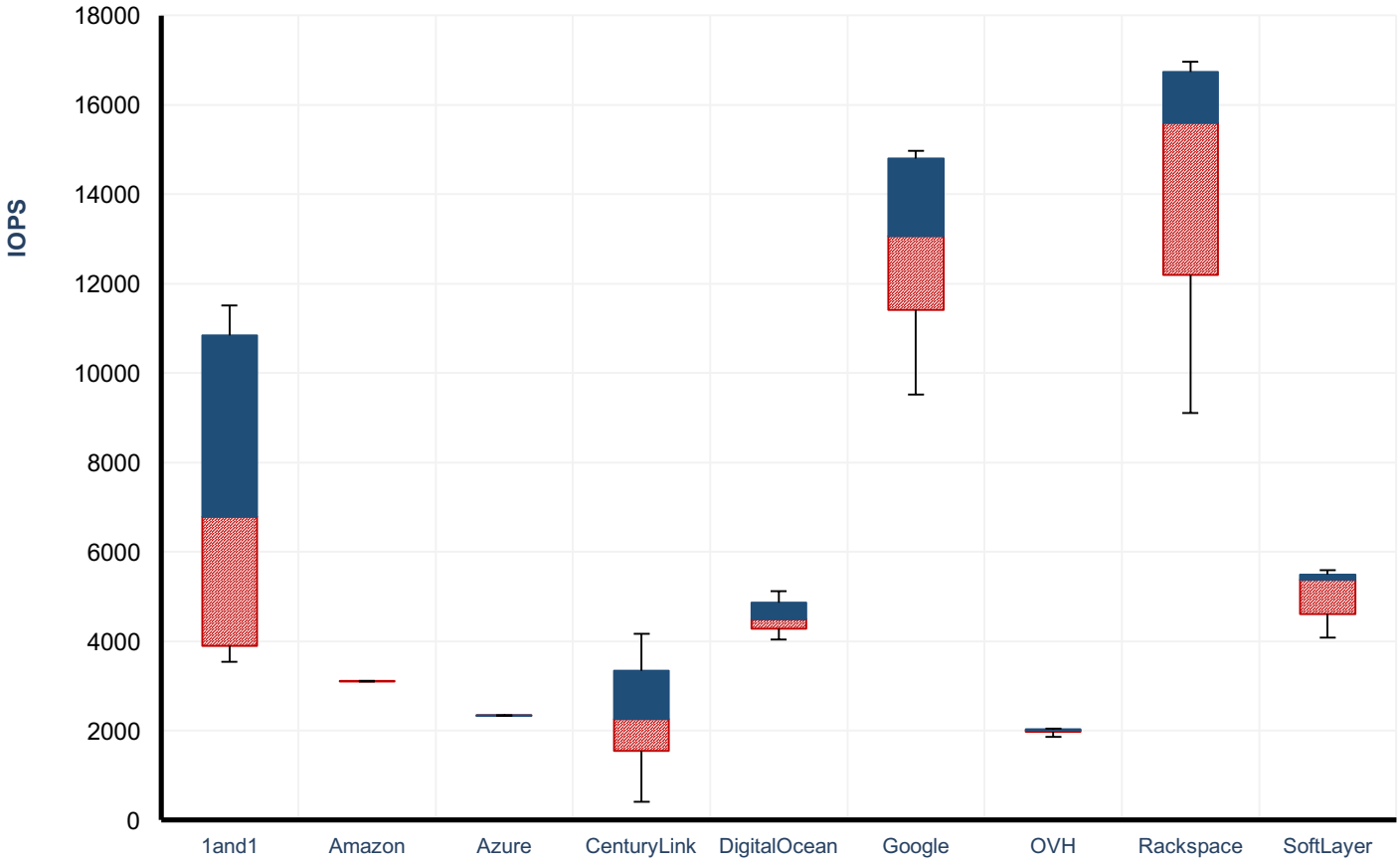


Table 8D.3: Random Block Disk Performance Type 1 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	3546	3896	6784	10840	11511	2159	31%
Amazon	3109	3109	3110	3110	3110	1	0%
Azure	2332	2334	2336	2346	2352	5	0%
CenturyLink	417	1552	2259	3340	4172	655	28%
DigitalOcean	4046	4278	4494	4862	5118	187	4%
Google	9526	11420	13071	14809	14968	986	8%
OVH	1859	1975	2009	2038	2054	29	1%
Rackspace	9110	12194	15594	16741	16968	1688	11%
SoftLayer	4084	4608	5375	5490	5592	392	7%

Chart 8D.4: Sequential Block Disk Performance Type 2 (Extra Large VM)

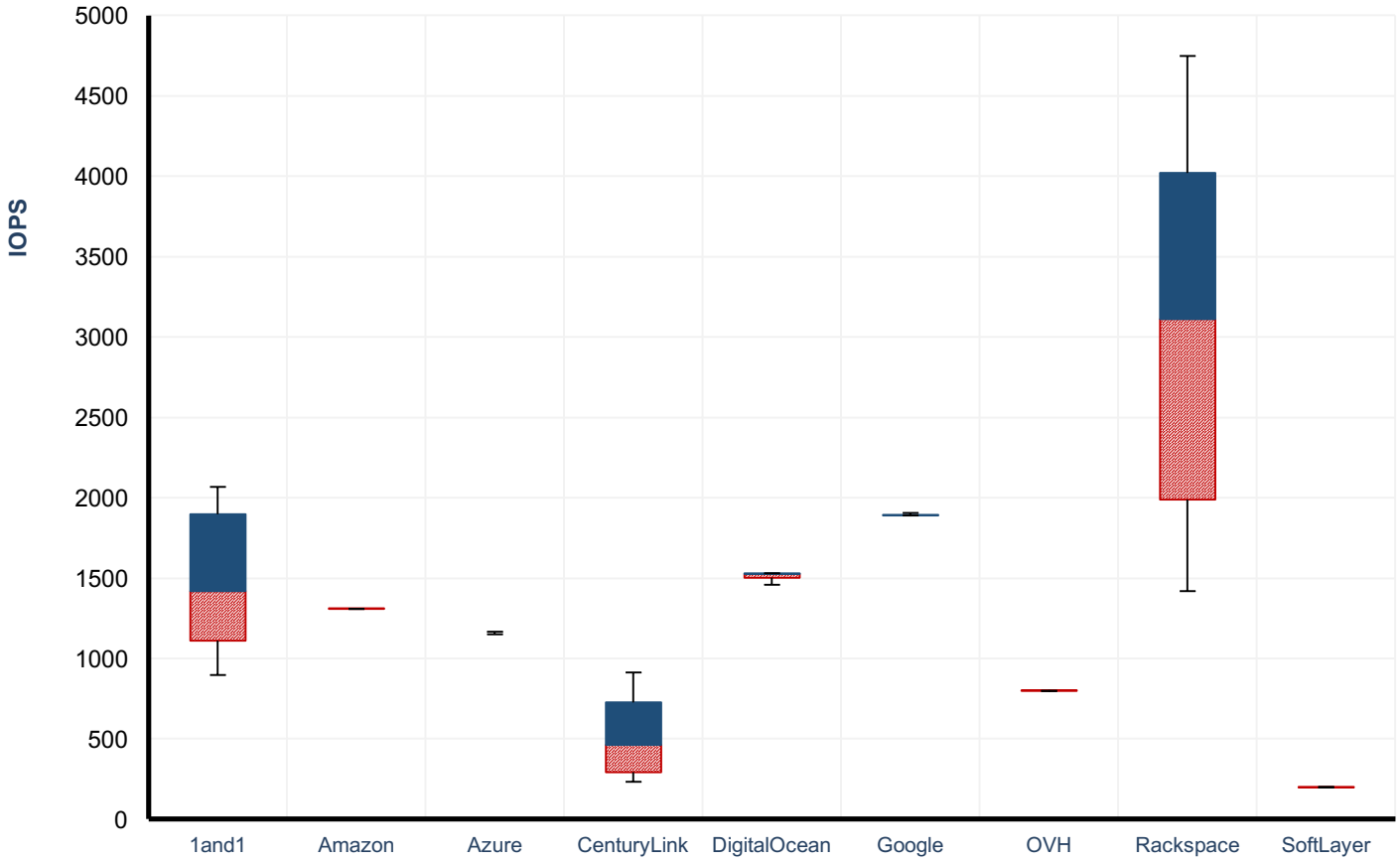


Table 8D.4: Sequential Block Disk Performance Type 2 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	896	1112	1419	1897	2069	250	17%
Amazon	1307	1307	1308	1308	1308	0	0%
Azure	1149	1167	1167	1167	1167	2	0%
CenturyLink	231	294	464	729	914	148	30%
DigitalOcean	1458	1501	1526	1528	1528	11	1%
Google	1890	1891	1891	1895	1907	2	0%
OVH	797	798	800	800	800	1	0%
Rackspace	1418	1989	3113	4021	4750	675	23%
SoftLayer	196	198	200	200	200	1	0%

Chart 8D.5: Random Block Disk Performance Type 2 (Extra Large VM)

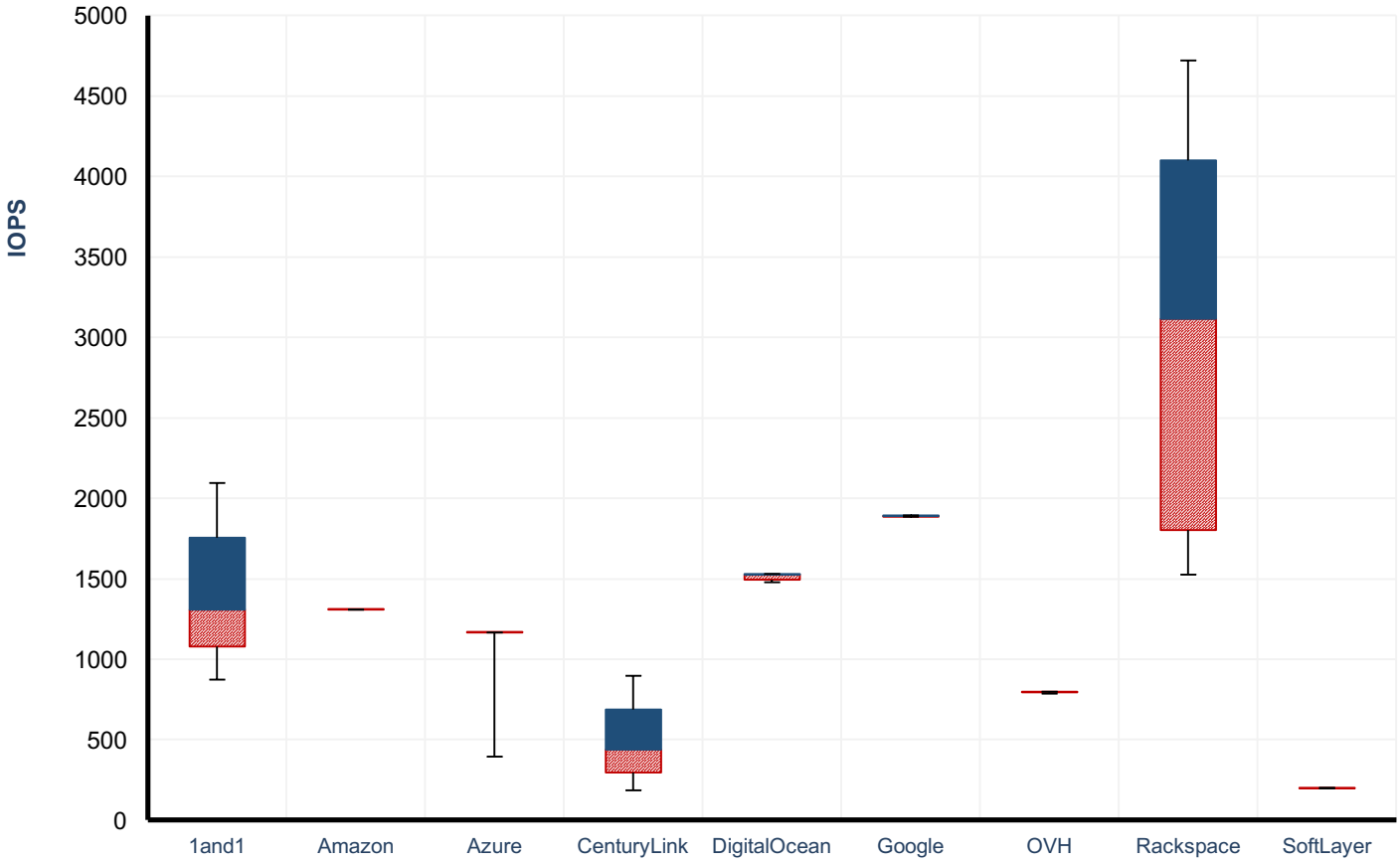


Table 8D.5: Random Block Disk Performance Type 2 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	874	1078	1310	1756	2096	216	16%
Amazon	1307	1307	1308	1308	1308	0	0%
Azure	394	1165	1167	1167	1167	81	7%
CenturyLink	184	295	439	688	896	136	29%
DigitalOcean	1477	1496	1526	1528	1528	11	1%
Google	1885	1886	1888	1893	1895	2	0%
OVH	787	796	800	800	800	2	0%
Rackspace	1524	1803	3114	4101	4722	716	24%
SoftLayer	196	198	200	200	200	1	0%

ABOUT CLOUD SPECTATOR

Cloud Spectator is a cloud benchmarking and consulting agency focused on cloud Infrastructure-as-a-Service (IaaS) performance. The company actively monitors several of the largest IaaS providers in the world, comparing VM performance (i.e., CPU, RAM, disk, internal network, and workloads) and pricing to achieve transparency in the cloud market. The company helps cloud providers understand their market position and helps business make intelligent decisions in selecting cloud providers and lowering total cost of ownership. The firm was founded in early 2011 and is located in Boston, MA.

For questions about this report, to request a custom report, or if you have general inquiries about our products and services, please contact Cloud Spectator (www.cloudspectator.com) at +1 (617) 300-0711 or contact@cloudspectator.com.

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APPENDIX

Tested VM & Storage Configurations

VM Size	Provider	Instance	Storage Type	vCPU	RAM	Storage	Data Center
Small	1and1	Cloud Server XL	SSD Storage	2	4	120	US
	Amazon	c4.large	SSD EBS	2	3.75	100	US East (N. Virginia)
	Azure	FS2	Premium Storage P10 (128GB)	2	4	128	US East 2
	CenturyLink	Customized	Block Storage	2	4	100	Virginia
	DigitalOcean	4GB	SSD Block Storage	2	4	100	US East (New York)
	Dimension Data	Customized	High Performance Storage	2	4	100	US East
	Google	Customized	SSD Persistent Disk	2	4	100	US East
	OVH	HG-7	High Availability	2	7	200	BHS
	Rackspace	Compute1-4	SSD Block Storage	2	3.75	100	N. Virginia
	SoftLayer	Customized	Endurance Block Storage 10 IOPS/GB	2	4	100	Washington DC
Medium	1and1	Cloud Server XXL	SSD Storage	4	8	160	US
	Amazon	c4.xlarge	SSD EBS	4	7.5	150	US East (N. Virginia)
	Azure	FS4	Premium Storage P10 (128GB)	4	8	128	US EAST 2
	CenturyLink	Customized	Block Storage	4	8	150	Virginia
	DigitalOcean	8GB	SSD Block Storage	4	8	150	US East (New York)
	Dimension Data	Customized	High Performance Storage	4	8	150	US East
	Google	Customized	SSD Persistent Disk	4	8	150	US East
	OVH	HG-15	High Availability	4	15	400	BHS
	Rackspace	Compute1-8	SSD Block Storage	4	7.5	150	N. Virginia
	SoftLayer	Customized	Endurance Block Storage 10 IOPS/GB	4	8	150	Washington DC
Large	1and1	Cloud Server 3XL	SSD Storage	8	16	240	US
	Amazon	c4.2xlarge	SSD EBS	8	15	200	US East (N. Virginia)
	Azure	FS8	Premium Storage P10 (128GB)	8	16	128	US East 2
	CenturyLink	Customized	Block Storage	8	16	200	Virginia
	DigitalOcean	16GB	SSD Block Storage	8	16	200	US East (New York)
	Dimension Data	Customized	High Performance Storage	8	16	200	US East
	Google	Customized	SSD Persistent Disk	8	16	200	US East
	OVH	HG-30	High Availability	8	30	800	BHS
	Rackspace	Compute1-15	SSD Block Storage	8	15	200	N. Virginia
	SoftLayer	Customized	Endurance Block Storage 10 IOPS/GB	8	16	200	Washington DC

Extra Large	1and1	Cloud Server 5XL	SSD Storage	16	48	500	US
	Amazon	c4.4xlarge	SSD EBS	16	30	500	US East (N. Virginia)
	Azure	FS16	Premium Storage P20 (512GB)	16	32	512	US East 2
	CenturyLink	Customized	Block Storage	16	32	500	Virginia
	DigitalOcean	48GB	SSD Block Storage	16	48	500	US East (New York)
	Dimension Data	N/A	N/A	N/A	N/A	N/A	N/A
	Google	Customized	SSD Persistent Disk	16	32	500	US East
	OVH	HG-60	High Availability	16	60	1600	BHS
	Rackspace	Compute1-30	SSD Block Storage	16	30	500	N. Virginia
	SoftLayer	Customized	Endurance Block Storage 10 IOPS/GB	16	32	500	Washington DC