Cloud Vendor Benchmark 2015

Price-Performance Comparison
Among 15 Top IaaS Providers

Part 2.2: Medium VMs Linux

May 2015

CLOUD SPECTATOR

Part 2.2: Medium VMs Linux

CloudSpectator.com

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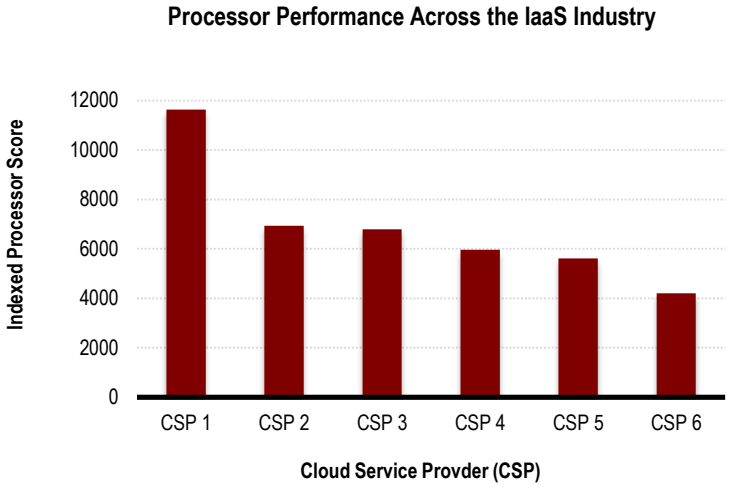
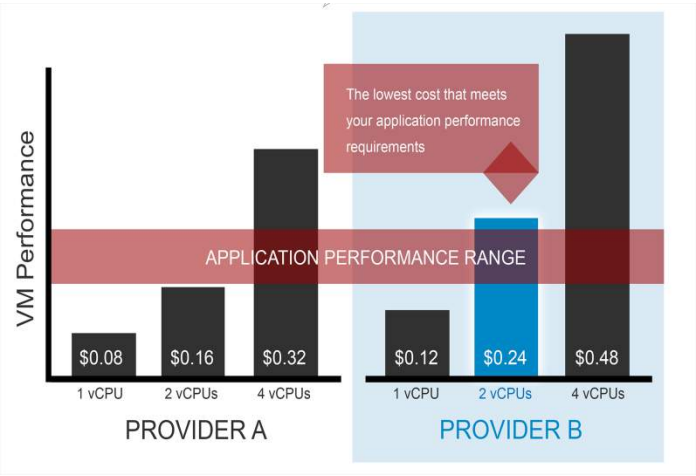
PREFACE

Performance and pricing are both key considerations in the public cloud industry, together having a substantial impact on annual operating costs. Cloud users may need fewer resources on better performing services, which can lower costs depending upon the price-performance ratio. Since many users only consider price and not price-performance, these users may be paying more because they require additional resources to achieve a desired level of performance. While some providers try to differentiate their offerings by cutting prices, others try to differentiate by focusing on improved performance. Recent examples of performance improvement include Rackspace's Performance Servers, Microsoft Azure's D-Series, and most recently, Amazon EC2's C4 family. This report examines the performance and the price-performance of the virtual machines included in the *Cloud Vendor Benchmark 2015 Part 1: Pricing Report*.

Why Does Performance Matter?

Differences in performance outputs of VMs across IaaS providers can greatly impact quality of service as well as annual operating costs. The graph on the right illustrates an example of the average processor performance from a sample of six Cloud Service Providers (CSPs) as studied by Cloud Spectator. CSP 1 has a processor performance three times as high as CSP 6 (names removed), which gives CSP 1 a notable advantage in many processor-intensive workloads. CSPs 2-5 exhibit a closer resemblance in processor performance, but do not offer nearly as much processing power as CSP 1 does.





The performance differences, as a result, will be further reflected in the operating costs of a cloud deployment. The graph on the left depicts a scenario where a 2 vCPU machine of provider B can meet the performance requirement of a certain application while a 2 vCPU machine of provider A cannot. Despite its higher unit price, clients can in fact save cost by deploying Provider B's 2 vCPU machine to run that application instead of a 4 vCPU machine on provider A, which is the lowest priced configuration that meets the application performance requirement for that specific provider. Therefore, understanding the price-performance output of different providers is critical since it allows clients to find the most cost-effective virtual machines that fit their application requirements and saves them money.

About the Cloud Vendor Benchmark 2015 Part 2: Performance and Price-Performance

The *Cloud Vendor Benchmark 2015 Part 1: Pricing* report compares pricing across vendors in the IaaS industry. The document did not assume performance differences across providers; for example, 1 vCPU on Amazon Web Services was considered equivalent to 1 vCPU on Rackspace Cloud. Comparisons were standardized by sets of minimum system requirements defined as Small, Medium, Large, Extra Large, and 2x Large (see

Appendix: VM Sizing for VM configuration information). For detailed information, please refer to the Part 1 report or contact Cloud Spectator at contact@cloudspectator.com.

Part 2 takes the pricing data and server sizes from Part 1 and incorporates CPU and memory performance testing. CPU and memory tests were conducted continuously over a 24-hour period across all of the VMs and providers examined in Part 1. Over the test period, more than 1.1 million data points were collected for the Linux OS (Ubuntu 14.04). By applying the results of the performance testing with the pricing and VM setups in Part 1, this report examines the value of the VMs with respect to performance, price-performance, and performance stability.

THIS REPORT ANALYZES ONLY THE MEDIUM VM SETUP EXAMINED IN PART 1. EXACT VM SIZES USED CAN BE FOUND IN THE APPENDIX UNDER VM SIZES. RELATIVE PERFORMANCE RANKINGS WILL NOT BE THE SAME ACROSS DIFFERENT VM SIZES. FOR PERFORMANCE STUDIES ON ADDITIONAL VM SIZES, PLEASE VISIT CLOUD VENDOR BENCHMARK 2015 REPORTS.

Performance data was collected from CPU and memory tests. The CPU test includes 23 CPU-intensive tasks categorized between integer and floating point tasks. The memory test includes 4 memory-intensive tasks measuring bandwidth. The aggregated CPU & memory test score includes a total of 27 tasks. All 27 tasks were run using the Geekbench 3 Test Suite. Performance results were categorized and analyzed in low, median and high scores. Price-performance was examined using hourly, monthly, annual and 3-year pricing. *The Cloud Vendor Benchmark 2015 Part 2: Performance and Price-Performance* is the largest public-facing performance and price-performance report on the IaaS industry.

Part 2 is divided into 10 separate reports with regard to different VM sizes and operating systems. **This report only examines the Medium machines running Linux.** All data in this report is accurate as of April 1, 2015.

The IaaS Providers

Amazon EC2	DigitalOcean	Google Cloud	Internap	ProfitBricks
CenturyLink Cloud	Dimension Data	HP Helion	Joyent	Rackspace Cloud
CloudSigma	GoGrid	IBM SoftLayer	Microsoft Azure	Verizon Cloud

VM Configurations and Pricing

Provider	Instance	vCPU	RAM	Storage (GB)	Hourly ($)	Monthly ($)	Annual ($)	3-Year ($)
AWS	t2.medium	2	4	EBS only	0.052	37.96	302	607
CenturyLink	customized	2	4	-	0.080	58.40	701	2102
CloudSigma	customized	2	4	50 SSD	-*	40.99	443	1107
DigitalOcean	standard4	2	4	60 SSD	0.060	40.00	480	1440
Dimension Data	customized	2	4	-	0.153	111.69	1340	4021
GoGrid	Standard Large	4	4	200	0.240	131.40	1051	3154
Google	n1-standard-2	2	7.5	-	0.126	64.97	780	2339
HP Helion	Standard Medium	2	4	50	0.120	87.60	1051	3154
IBM SoftLayer	customized	2	4	25	0.118	80.40	965	2894
Internap	B-2	2	8	40 SSD	0.160	116.80	1402	4205
Joyent	standard4	2	7.5	738	0.240	175.20	2102	6307
Microsoft Azure	D2	2	7	100 SSD	0.170	124.10	1489	4468
ProfitBricks	customized	2	4	-	0.057	41.76	501	1503
Rackspace	General1-4	4	4	80 SSD	0.148	108.04	1296	3889
Verizon	4	2	4	-	0.118	86.14	1034	3101

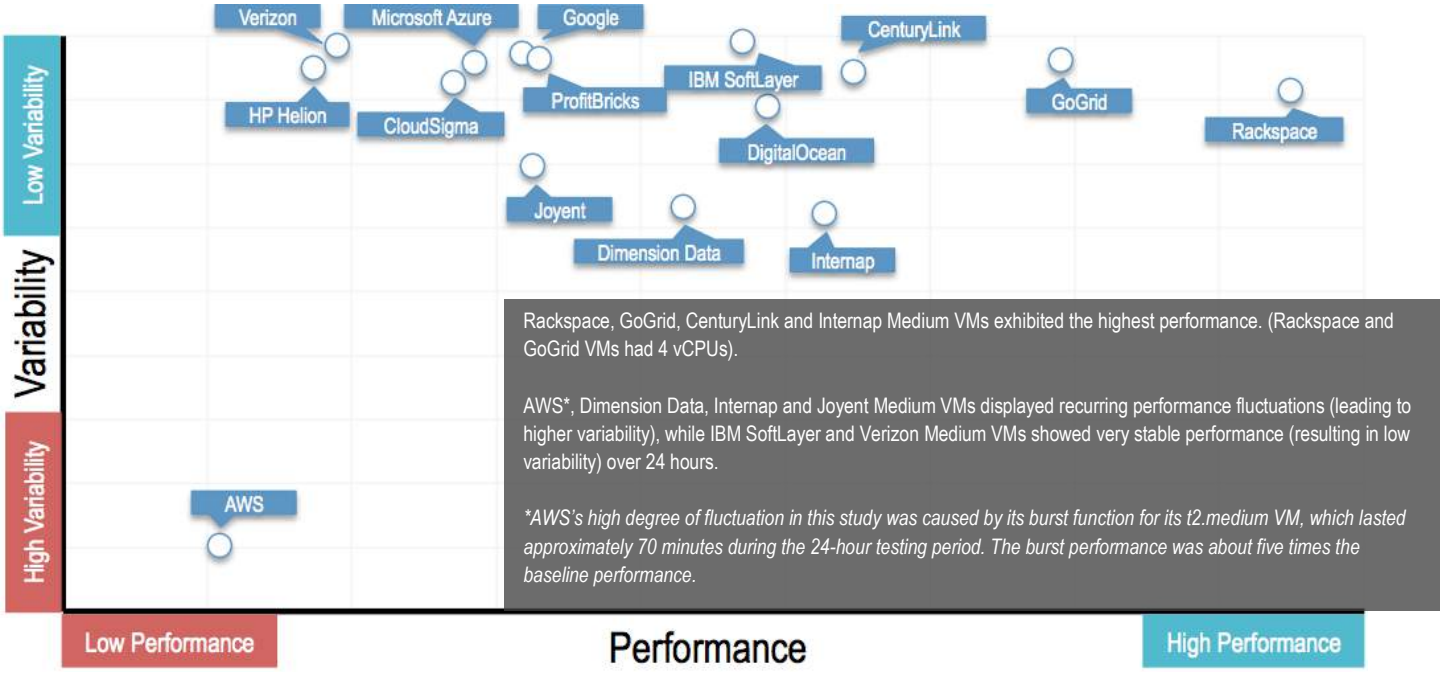
Prices in red are longer-term prices discounted from the hourly pricing.

**CloudSigma uses an algorithm to calculate its hourly pricing – burst pricing, which can be equal to or greater than monthly pricing. The price changes cannot be predicted ahead of time, and therefore CloudSigma's hourly pricing, along with its hourly price-performance values, is not included in this report.*

EXECUTIVE SUMMARY

Key Performance Findings

The following graph shows the relationship between the included VMs' performance and variability. The performance is represented by median aggregated CPU & memory scores, and the variability is the degree of score variation during the 24-hour repeated testing.



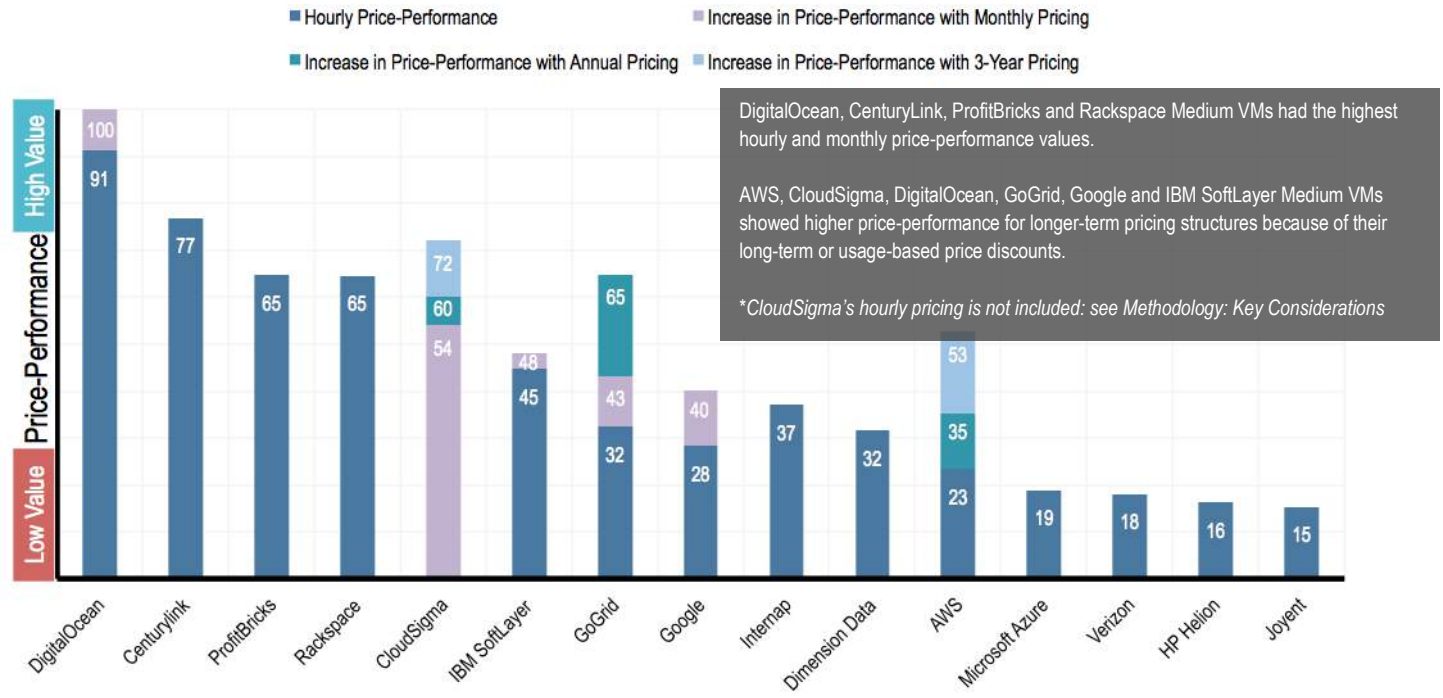
Rackspace, GoGrid, CenturyLink and Internap Medium VMs exhibited the highest performance. (Rackspace and GoGrid VMs had 4 vCPUs).

AWS*, Dimension Data, Internap and Joyent Medium VMs displayed recurring performance fluctuations (leading to higher variability), while IBM SoftLayer and Verizon Medium VMs showed very stable performance (resulting in low variability) over 24 hours.

**AWS's high degree of fluctuation in this study was caused by its burst function for its t2.medium VM, which lasted approximately 70 minutes during the 24-hour testing period. The burst performance was about five times the baseline performance.*

Key Price-Performance Findings

The following graph shows the CloudSpecs Scores™ of all included VMs representing their price-performance values, i.e., performance per unit of price. The scores were calculated using median aggregated CPU & memory performance scores. The VMs are ranked by monthly CloudSpecs Scores™.



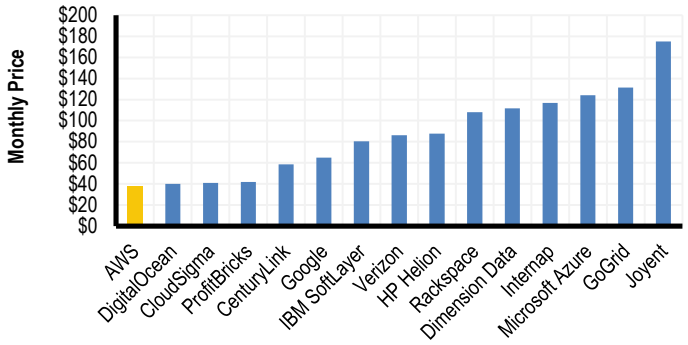
DigitalOcean, CenturyLink, ProfitBricks and Rackspace Medium VMs had the highest hourly and monthly price-performance values.

AWS, CloudSigma, DigitalOcean, GoGrid, Google and IBM SoftLayer Medium VMs showed higher price-performance for longer-term pricing structures because of their long-term or usage-based price discounts.

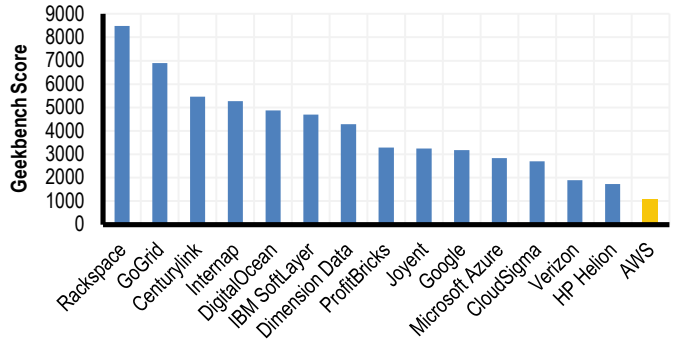
**CloudSigma's hourly pricing is not included: see Methodology: Key Considerations*

Key Takeaway

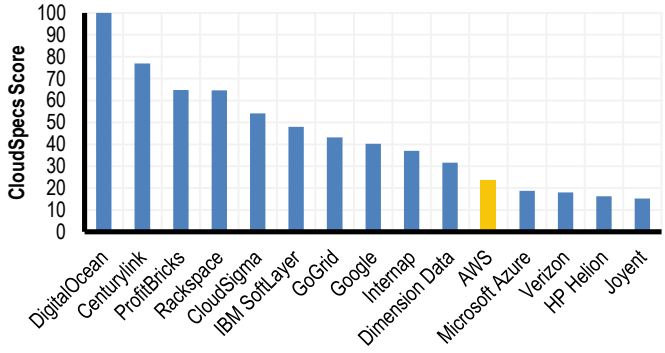
Monthly Pricing Ranking (Low to High) – Medium VMs



Median Performance Ranking (High to Low) – Medium VMs



Monthly Median Price-Performance Ranking (High to Low) – Medium VMs



The three graphs on the left, which display rankings based on price, performance, and price-performance demonstrate the difference that may occur when comparing the same set of provider VMs using different criteria. Using AWS's t2.medium as an example, while the VM ranks first in the monthly pricing comparison, its median performance output ranks last among the 15 providers, and its price-performance calculated using the data supporting the first two graphs ranks 11th. Selecting the right criteria when comparing across the cloud industry is essential in helping users optimize their decision-making process and outcome.

The graphs from the previous page illustrate the differences among the providers in both performance and variability. The differences between VMs can be significant when both performance and variability are taken into account, even though the provider VMs' configurations were relatively controlled.

Understanding both the performance and the severity of performance variation is critical to successfully operating certain applications in the cloud. Just as low-performing virtual machines may not satisfy application performance requirements, high-performing but unstable machines may have diminished performance output periodically, which may fail to sustain the application's ability to run at full capacity. Thorough considerations should be applied to examine performance level and performance variability when users are selecting cloud environments in order to optimize their application operations and IT spend.

Price-performance analysis is critical for choosing the best-fit providers for specific use cases in order to avoid unnecessary IT overspending. Businesses looking for the most economical cloud infrastructure should examine the price and performance output of a target environment together to understand the performance per unit cost value they can expect.

METHODOLOGY

Price

Each provider's pricing information was gathered based on 5 separately sized server configurations. All data on the proceeding pages refer to the specific sizes listed in Table 1.1:

Table 1.1

SERVER	CPU CORES	RAM IN GB
Small	1	2
Medium*	2	4
Large	4	8
XLarge	8	16
2XLarge	16	32

**Only the Medium size is used in this report.*

The above configuration sizes listed are treated as minimum requirements. Any provider server tested in this report must meet or exceed those requirements. The provider server with the lowest price that meets or exceeds the minimum requirements listed above is used. Local storage is not factored into the requirements.

The values within the *Cloud Vendor Benchmark 2015* reports only apply to the listed configurations that are serving as minimum requirements. Different target configurations will yield different results, i.e. the most expensive VMs with the listed configurations in this report may be the least expensive on other target configurations.

Monthly figures are calculated using 730 hours unless discounts apply.

Scaling resources in a Tiered Package structure would require the user(s) to select the next available tier that would fulfill the configuration's requirements. This may mean more resources than necessary.

The application(s) that would hypothetically run on the server configurations listed in Table 1.1 are not assumed to be optimized for cross-server performance; thus, scaling resources in a Tiered Package structure would require the user(s) to select the next available tier that would fulfill the configuration requirements. This may mean more resources than necessary. For example, the 2XLarge Server configuration of 16 vCPU cores and 32GB RAM would require a purchase of HP Helion's closest tiered package (CPU & RAM) that fulfills the requirements, which provides 16 vCPU cores, 120GB RAM, and 1770GB local storage.

Pricing is measured exclusively by the specification of cores and RAM. However, it is valid that vCPU performance, RAM performance, and even overall server performance can alter costs based on each user's application's specific needs.

Performance

CPU and memory performance information was collected and explored using the Geekbench 3 testing suite on Linux Ubuntu 14.04 systems from VMs of the same configurations that were used in the *Cloud Vendor Benchmark 2015 Part 1: Pricing* report. Note that some providers' VMs have more resources (CPU or memory) than others. No storage or network performance is included.

A total of 27 separate tasks were conducted for integer, floating point and memory functions: 13 tasks for integer calculations, 10 tasks for floating point calculations, and 4 tasks for memory function. Python scripts were used, and all providers offered Python 2.7. Screen was used to continue the Python scripts upon terminating an SSH session. All VMs were accessed via SSH; SSH Keys were used when available. An overall weighted performance score for each VM was calculated by aggregating performance results of all 27 tasks. Both single task performance comparisons and aggregated performance comparisons are presented in this report. For specific Geekbench testing, score calculation and score aggregation information, please visit the Geekbench official website: http://www.primatelabs.com/geekbench/.

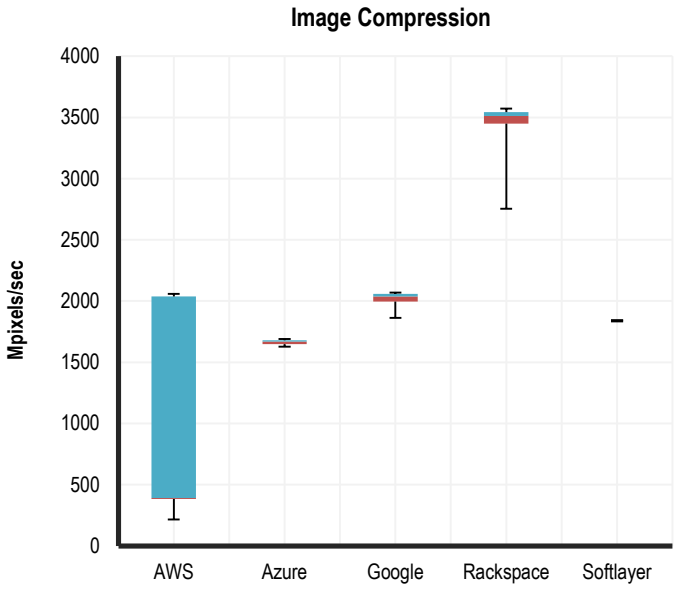
Tests and descriptions related to this report are described in the Table 1.2:

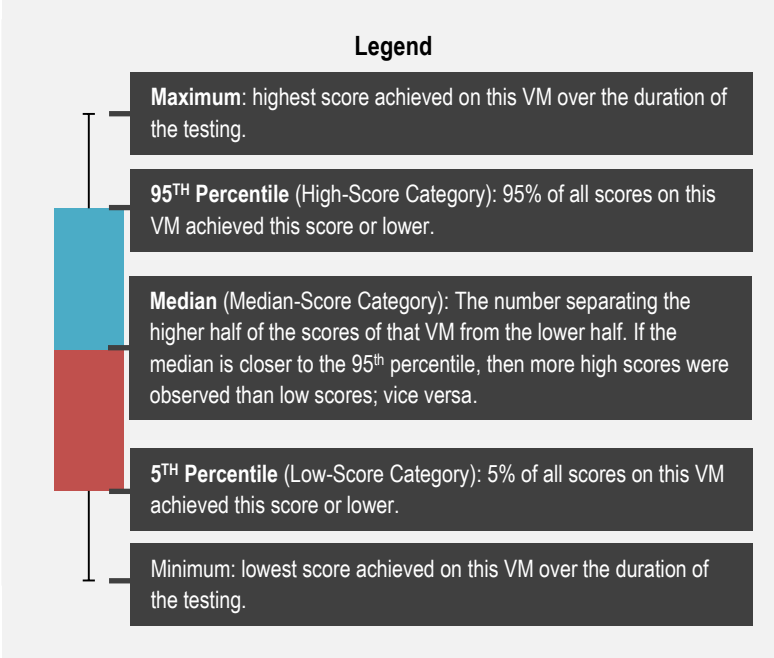
Table 1.2 Performance Tests and Descriptions

TEST	TOOL	TASK	DESCRIPTION
Integer	Geekbench 3	AES, Twofish, SHA1, SHA2, BZip2 Compression, BZip2 Decompression, JPEG Compression, JPEG Decompression, PNG Compression, PNG Decompression, Sobel, Lua, Dijkstra	Integer and Floating Point tasks together represent vCPU performance. The performance of all applications is highly dependent on the vCPU since the vCPU is responsible for the processing and orchestration of all applications.
Floating Point	Geekbench 3	Black Scholes, Mandelbrot, Sharpen Filter, Blur Filter, SGEMM, DGEMM, SFFT, DFFT, N-Body, Ray Trace	
Memory	Geekbench 3	STREAM Copy, STREAM Scale, STREAM Add, STREAM Triad	While memory performance is not considered one of the key bottlenecks in performance for many common applications, a subset of applications—particularly HPC and in-memory databases—is highly dependent on large sustained memory bandwidth.

The Geekbench test suite was installed and run on the same machine continuously for 24 hours in order to capture performance variation. Each round of testing generated one set of data points for every task mentioned above. As a result, 1,121,796 Linux OS data points were collected to examine the value provided across vendors in the market with respect to performance and performance stability.

The virtual machines' performance information was depicted using the minimum, 5th percentile, median, 95th percentile, and maximum scores retrieved from all data points collected for each of the tasks mentioned above during the 24 hours. 5th percentile, median and 95th percentile scores corresponded to low, median and high scores. 5th percentile and 95th percentile scores were used instead of minimum and maximum scores in order to exclude potential outliers. The information was then integrated into percentile graphs and value tables, which were 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 below:





	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	215	384	392	2038	2058	533	28.9%
Azure	1628	1649	1669	1679	1690	10	0.5%
Google	1864	1997	2038	2058	2068	18	1.0%
Rackspace	2755	3451	3512	3543	3574	49	2.7%
Softlayer	1833	1843	1843	1843	1843	1	0.1%

Variability was calculated by taking the percentage of each machine's standard deviation values (Stdev.) from the median of the Medians (median scores) of all VMs. The calculation formula is:

*Variability = [Stdev.] / [median{Median}] * 100%*

Machines with variability scores higher than 5% were considered fluctuating, and their standard deviation (Stdev.) and variability scores (Variability) will be highlighted in red.

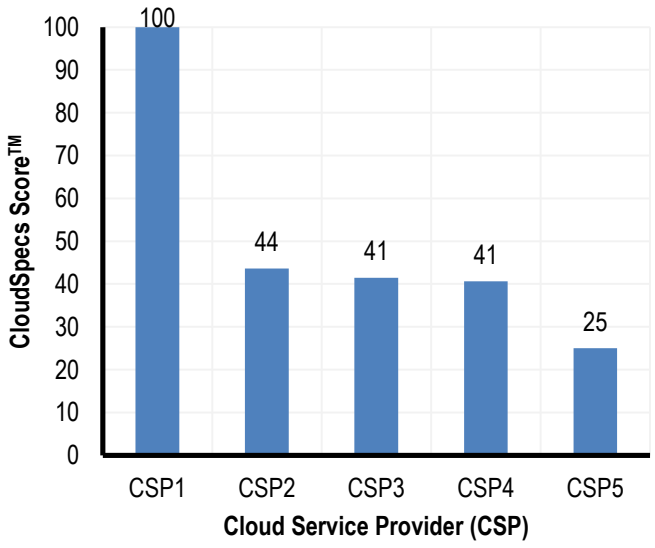
The variability score is designed to reflect the relative fluctuation of a machine in relationship with other VMs included in the same comparison. Therefore, the same variability value of different performance tasks can mean different fluctuation magnitudes. Standard deviation values (Stdev.), alternatively, can be used to compare the fluctuation sizes universally across different VMs and different tasks.

Price-Performance

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 ScoreTM = 100*price-performance_value / best_VM_value*

In this report, Cloud Spectator uses the aggregated performance scores as the [VM performance score] to calculate each machine's CloudSpecs Score™.



The graph on the left is an example of how Cloud Spectator's price-performance analysis is visualized. The closer the score is to 100, the higher price-performance value it indicates. The score 100 represents the best-value VM among all in the comparison. The value is scaled; e.g., the VM from Cloud Service Provider 1 (CSP1) with a score of 100 gives 4x the value of the VM from CSP5 with a score of 25.

The CloudSpecs Scores™ of any VM can change depending on the participants in the comparison. For example, if the highest score in a comparison changes, the price-performance value represented by score 100 will change accordingly, and so will the other CloudSpecs Score™ values.

If you have questions regarding Cloud Spectator's price-performance calculation, please contact us at contact@cloudspectator.com.

Data in this report is accurate as of April 1st, 2015. The report will continue to be accurate for an undetermined duration.

Key Considerations

Listed below are both general and provider-specific notes on how price, performance and price-performance values were calculated and what assumptions were made. The assumptions made for this report may differ from specific use cases, and thus, impact the relevancy of the results.

- This report examines price and performance only. Certain providers may include certain features or services (e.g. 24x7 support) in their price. Features and services comparisons are not included in this report.
- Price figures reflect those of US data centers only, and eastern US data centers were used when there are price differences among US data centers.
- For monthly, annual and 3-year pricing, virtual servers are assumed to be running at 100% utilization of each month.
- There are assumed to be 730 hours in each month.
- Only base virtual machine prices are included. No add-ons that would affect pricing were considered.
- Virtual machine sizes meet or exceed the requirements listed above. The virtual machines with the lowest price that meet or exceed the minimum requirements are used. **Therefore, in this report, 4 vCPU machines were used on GoGrid and Rackspace and 2vCPU machines were used on the remaining providers in order to meet the criteria for selecting Medium VMs according to the listed minimum requirements.** AWS's T2 family burst machine was used.
- CloudSigma uses an algorithm to calculate its hourly pricing – burst pricing, which can be equal to or greater than monthly pricing. At the time Cloud Spectator checked, vCPU burst pricing was roughly 2x the cost of monthly pricing per hour, the RAM price was roughly 3x the cost of monthly pricing per hour, and the storage price was roughly 2x the cost of monthly pricing per hour. The price changes cannot be predicted ahead of time, and therefore CloudSigma's hourly pricing, along with its hourly price-performance values are not included in this report.
- The performance tests were administrated using a Python script written in Python 2.7, which ensured the continuous testing cycles over 24 hours.
- The VMs were deployed using Ubuntu 14.04 64-bit OS images. Using different images may yield different testing results from this report.
- Different provider VMs were based on different physical hardware. The influence of hardware on VM performance was not explored in this report.
- Some providers use more than one type of processor to host their VMs. Since Cloud Spectator only tested one random machine on each provider, the effect of this variable was not explored in this report.
- The CloudSpecs Scores™ cannot be compared against each other numerically over different graphs.

For any further questions or concerns regarding Cloud Spectator's *Cloud Vendor Benchmark 2015 Part 2.2: Performance and Price-Performance (Medium VM, Linux)*, please contact Cloud Spectator at (+1) 617 300 0711 or email us at contact@cloudspectator.com.

PERFORMANCE COMPARISON

Aggregated CPU & Memory Performance Analysis

Table 2.1 shows the Minimum, 5th percentile, median, 95th percentile, and maximum value of the aggregated CPU & memory performance scores for each VM. For test information, please refer to the Methodology: Performance section; for aggregation information, please see Appendix: Score Aggregation.

Table 2.1: Aggregated CPU & Memory Performance Scores – Medium VMs

	AWS	CenturyLink	CloudSigma	DigitalOcean	Dimension Data	GoGrid	Google	HP Helion	IBM SoftLayer	Internap	Joyent	Microsoft Azure	ProfitBricks	Rackspace	Verizon
Min.	868	4664	1906	2836	2411	5517	2386	1358	4576	3470	2309	2336	2587	7674	1816
5th Per.	1044	5234	2417	4508	3060	6833	3082	1639	4661	4356	2668	2730	3132	8195	1854
Median	**1082**	**5462**	**2703**	**4870**	**4288**	**6904**	**3176**	**1732**	**4696**	**5269**	**3250**	**2845**	**3291**	**8489**	**1893**
95th Per.	5409	5561	2847	4993	4637	6948	3226	1855	4722	5679	3746	2899	3360	8718	1938
Max.	5470	5613	2932	5070	4694	6972	3291	1932	4733	5862	3812	3120	3428	8892	1970

Cloud Spectator ranks the VMs by their performance at the 95th percentile and 5th percentile (See *Figure 2.1 and Figure 2.2*), which are referenced as the High-Score Category and the Low-Score Category respectively. Rackspace, GoGrid and CenturyLink VMs display consistent high rankings in both the High-Score Category and the Low-Score Category, while the rankings of Internap, AWS and Dimension Data VMs experience considerable changes in performance values.

Figure 2.1: CPU & Memory Performance Rank by 95th Percentile (High-Score Category) – Medium VMs

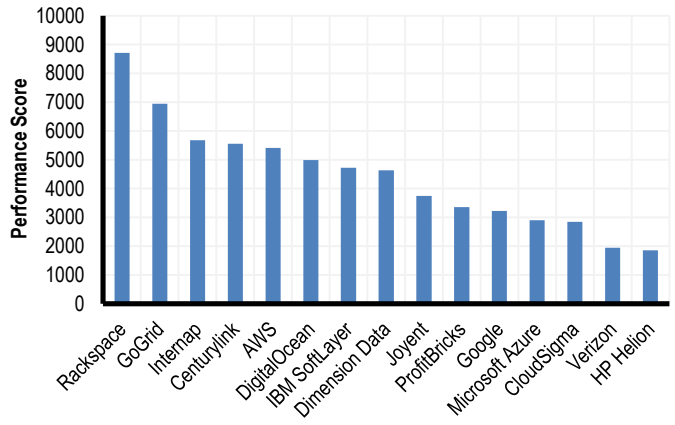
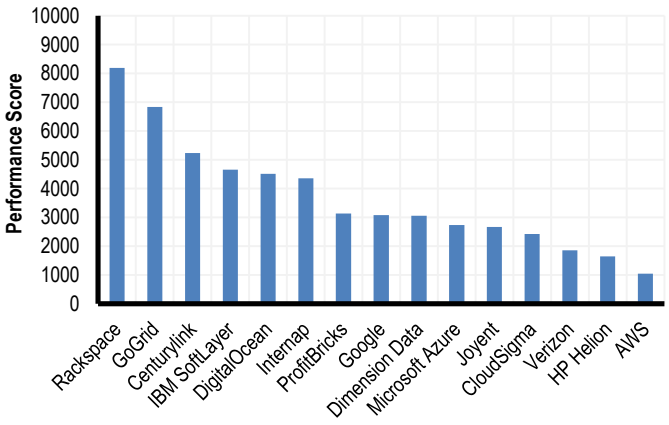


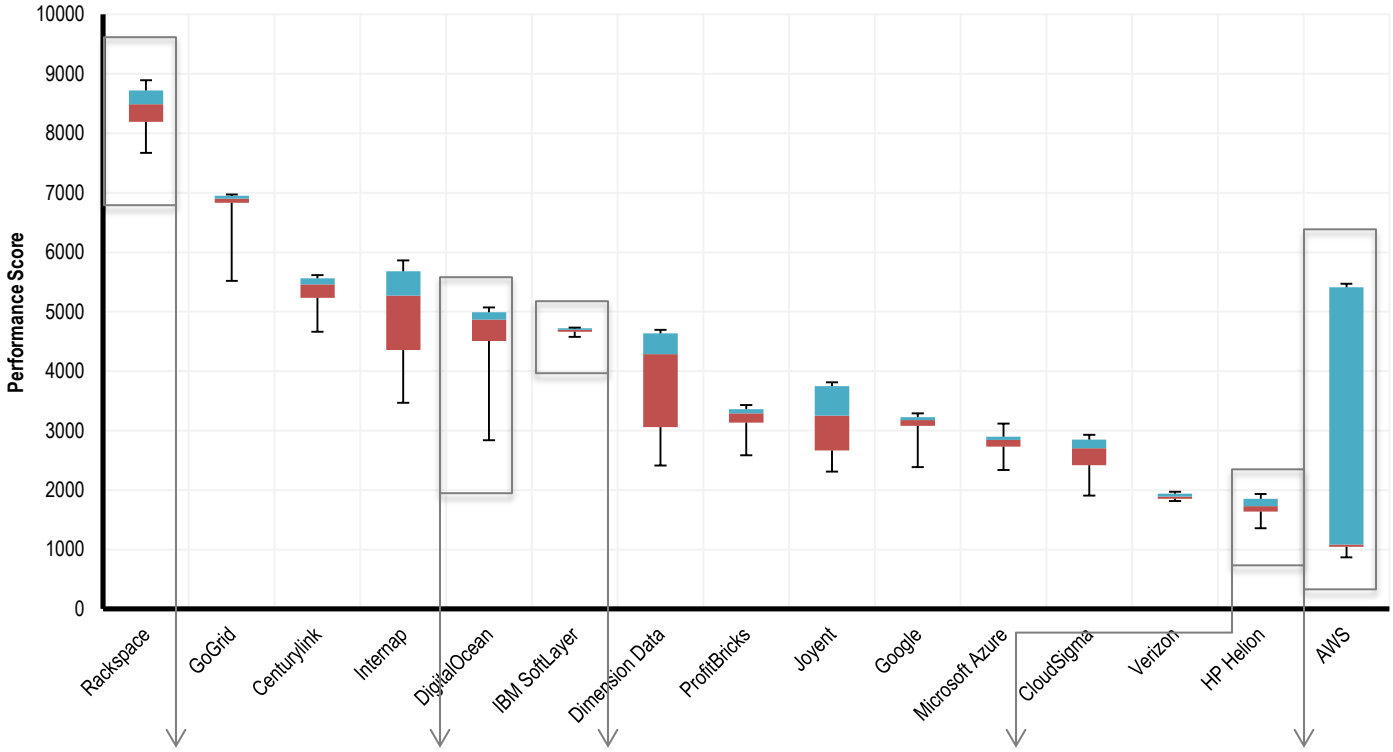
Figure 2.2: CPU & Memory Performance Rank by 5th Percentile (Low-Score Category) – Medium VMs



The changes in performance rankings were due to the performance variations detected during the 24-hour testing period. In order to visualize the performance variations, Cloud Spectator introduces a percentile graph (*See Figure 2.3*). Figure 2.3 ranks the VMs by their median performance while incorporating the minimum, 5th percentile, median, 95th percentile, and maximum scores. For legend and instructions on reading the percentile graph, please refer to the Methodology: Performance section.

The graph indicates that although the DigitalOcean VM maintained high rankings in both the High-Score Category and the Low-Score Category, it experienced relatively large performance variation with some extremely low scores during the testing period. Internap, Dimension Data and AWS VMs had wide ranges of performance levels that covered the performance ranges of their neighboring VMs, which caused their performance rankings to shift in different categories. The percentile graph displays the importance of testing over time to capture a performance range instead of using single point-in-time performance data points to determine a virtual machine's comparative performance level in the market.

Figure 2.3: CPU & Memory Performance Percentile Graph – Medium VMs – Ranked by Median



Rackspace's performance graph shows a median line equally dividing the 95th percentile line and the 5th percentile line, with the minimum line stretching more significantly than the maximum. This shows a **neutral fluctuation**, and one or more points of relatively low scores.

DigitalOcean's performance graph displays a median line closer to the 95th percentile line than the 5th percentile line. The minimum line stretches downward significantly. This indicates a **negative fluctuation**, and one or more points of extremely low scores.

IBM SoftLayer has its 95th percentile line, median line and 5th percentile line closely compact together, and neither the minimum nor the maximum line stretches outward significantly. This indicates a highly stable performance pattern where **very little fluctuation** was detected.

HP Helion's performance graph shows a median line closer to the 5th percentile line than the 95th percentile line, and neither the minimum nor the maximum line stretches outward significantly. This indicates a very slight **positive fluctuation**.

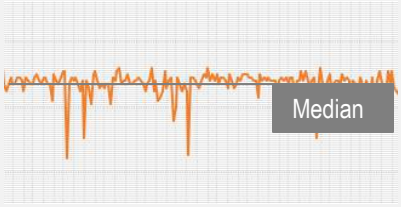
AWS's performance graph exhibits a median line extremely close to the 5th percentile line while the difference between the 95th percentile and median lines is vast. This pattern is caused by AWS T2 family' burst function (see Performance: AWS Burst Analysis on Page 19)

Neutral Fluctuation:
One type of fluctuation where the scores spread evenly above and below median.

Example:

Negative Fluctuation:
One type of fluctuation where the scores below median have a larger magnitude.

Example:



Positive Fluctuation:
One type of fluctuation where the scores above median have a larger magnitude.

Example:

In order to perceive each VM's overall performance fluctuation numerically, Cloud Spectator calculated each VM's aggregated performance variability score by averaging the performance variability scores of the 27 individual tasks (see *Table 2.2*). The variability scores indicate that AWS, Dimension Data, Internap and Joyent VMs exhibited high CPU & memory performance fluctuations, as shown by their relatively large range of performance scores in *Figure 2.3*. For performance variability score calculation information, see Methodology: Performance.

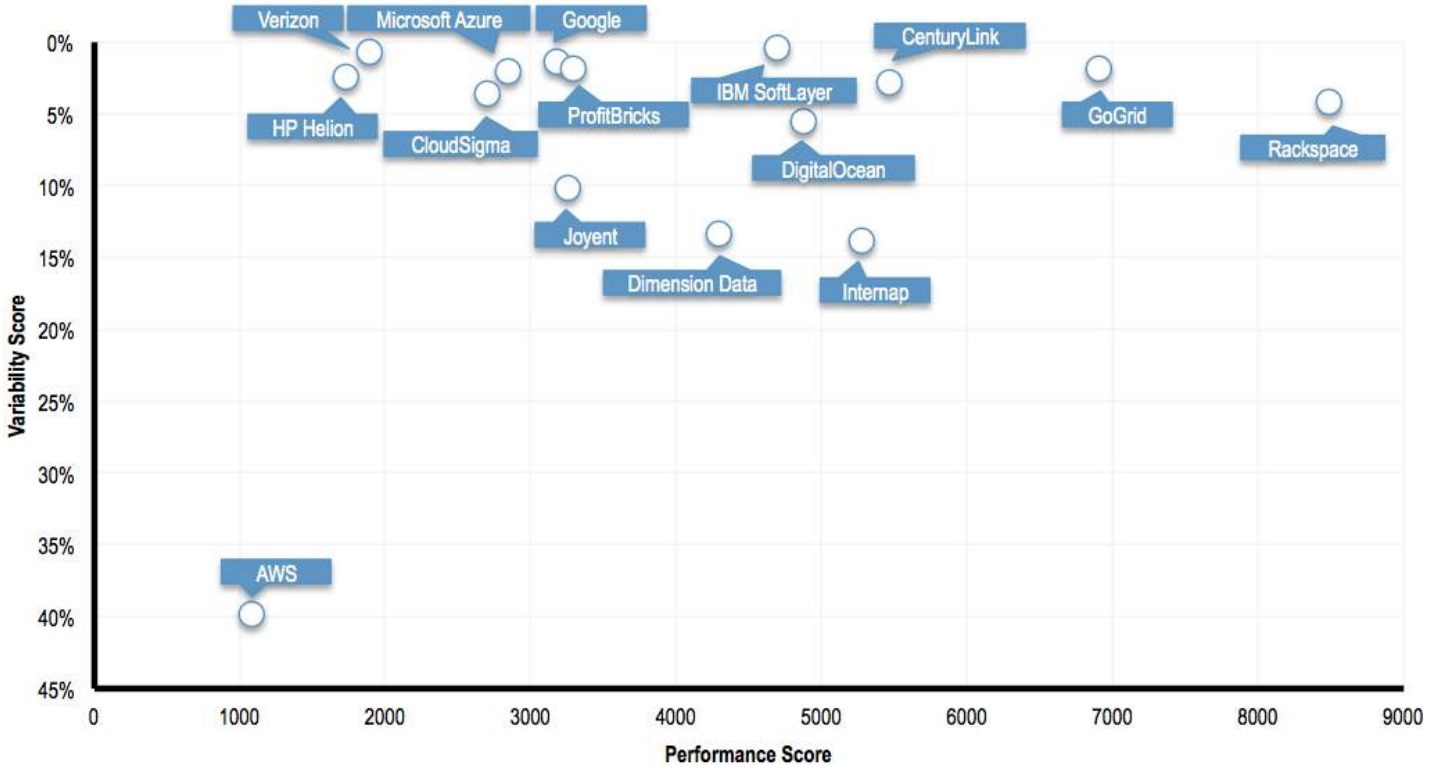
Table 2.2: Aggregated CPU & Memory Performance Variability – Medium VMs

	AWS	CenturyLink	CloudSigma	DigitalOcean	Dimension Data	GoGrid	Google	HP Helion	IBM SoftLayer	Internap	Joyent	Microsoft Azure	ProfitBricks	Rackspace	Verizon
Variability	39.8%	2.8%	3.6%	5.5%	13.3%	1.9%	1.3%	2.4%	0.4%	13.8%	10.2%	2.0%	1.8%	4.2%	0.7%

It is worth noting that since the performance variability scores of different tasks vary within the same VM, an average variability score can only be seen as a rough indication of a provider VM's overall fluctuation. For specific variability information for individual tasks, see Appendix: Individual Tasks. In addition, as is mentioned before, the AWS VM's high variability score was largely due to its bursting function instead of a lack of stability. For AWS burst information, see Performance: AWS Burst Analysis on Page 19.

Figure 2.4 is a matrix incorporating both the performance scores and the variability scores of every VM. The x-axis shows the median CPU & memory performance scores, with higher performance on the right and lower performance on the left. The y-axis shows the CPU & memory performance variability, with the more stable VMs above the less stable VMs. In the top right corner are providers with both high performance and high stability. Most VMs have a performance score between 2000 and 6000 with variability lower than 5%.

Figure 2.4: CPU & Memory Performance-Variability Matrix – Medium VMs



Aggregated CPU Performance Analysis

Cloud Spectator aggregated the scores of all CPU integer and CPU floating point tasks to form the CPU performance scores. Table 2.3 shows the minimum, 5th percentile, median, 95th percentile, and maximum CPU performance scores as well as CPU performance variability scores, which were calculated by averaging the variability scores of all CPU tasks. For test information, please refer to the Methodology: Performance section; for aggregation information, please see Appendix: Score Aggregation; for performance variability score calculation information, see Methodology: Performance.

Table 2.3: Aggregated CPU Performance and Variability Scores – Medium VMs

	AWS	CenturyLink	CloudSigma	DigitalOcean	Dimension Data	GoGrid	Google	HP Helion	IBM SoftLayer	Internap	Joyent	Microsoft Azure	ProfitBricks	Rackspace	Verizon
Min.	896	4948	2005	3039	2665	6411	2517	1481	4854	3679	2418	2699	2832	8761	1813
5th Per.	1086	5572	2608	4732	3412	8004	3377	1814	4934	4524	2809	3182	3379	9356	1845
Median	**1126**	**5733**	**2929**	**5118**	**4783**	**8076**	**3487**	**1844**	**4973**	**5542**	**3508**	**3257**	**3563**	**9669**	**1868**
95th Per.	5693	5847	3095	5240	5102	8125	3538	1944	5004	5966	4105	3293	3631	9872	1891
Max.	5749	5903	3190	5317	5155	8151	3610	2033	5014	6141	4176	3480	3701	10014	1909
Variability	38.1%	2.2%	3.8%	5.2%	12.9%	2.0%	1.4%	1.5%	0.4%	14.4%	11.2%	1.6%	1.8%	3.8%	0.3%

The CPU performance and variability scores are similar to the CPU & memory scores, given that the CPU & memory scores consisted mainly of CPU scores. The CPU & memory performance scores and CPU performance scores are not comparable numerically, i.e., a score of 2000 in CPU & memory performance is not the same as a score of 2000 in CPU performance, because of the difference in calculation process. AWS, Dimension Data, Internap and Joyent VMs exhibited a high degree of CPU performance fluctuation. The performance ranking with variability patterns is shown in *Figure 2.5*.

Figure 2.5: CPU Performance Percentile Graph – Medium VMs – Ranked by Median

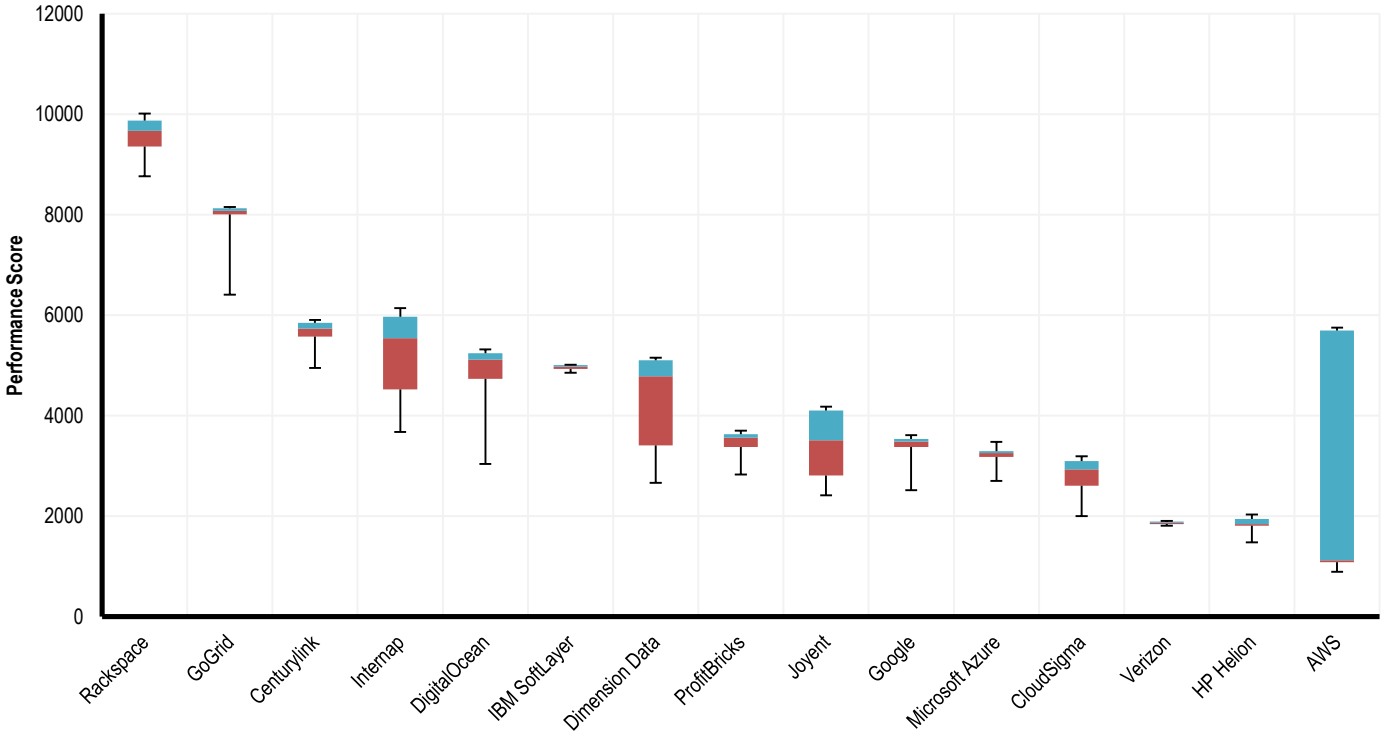
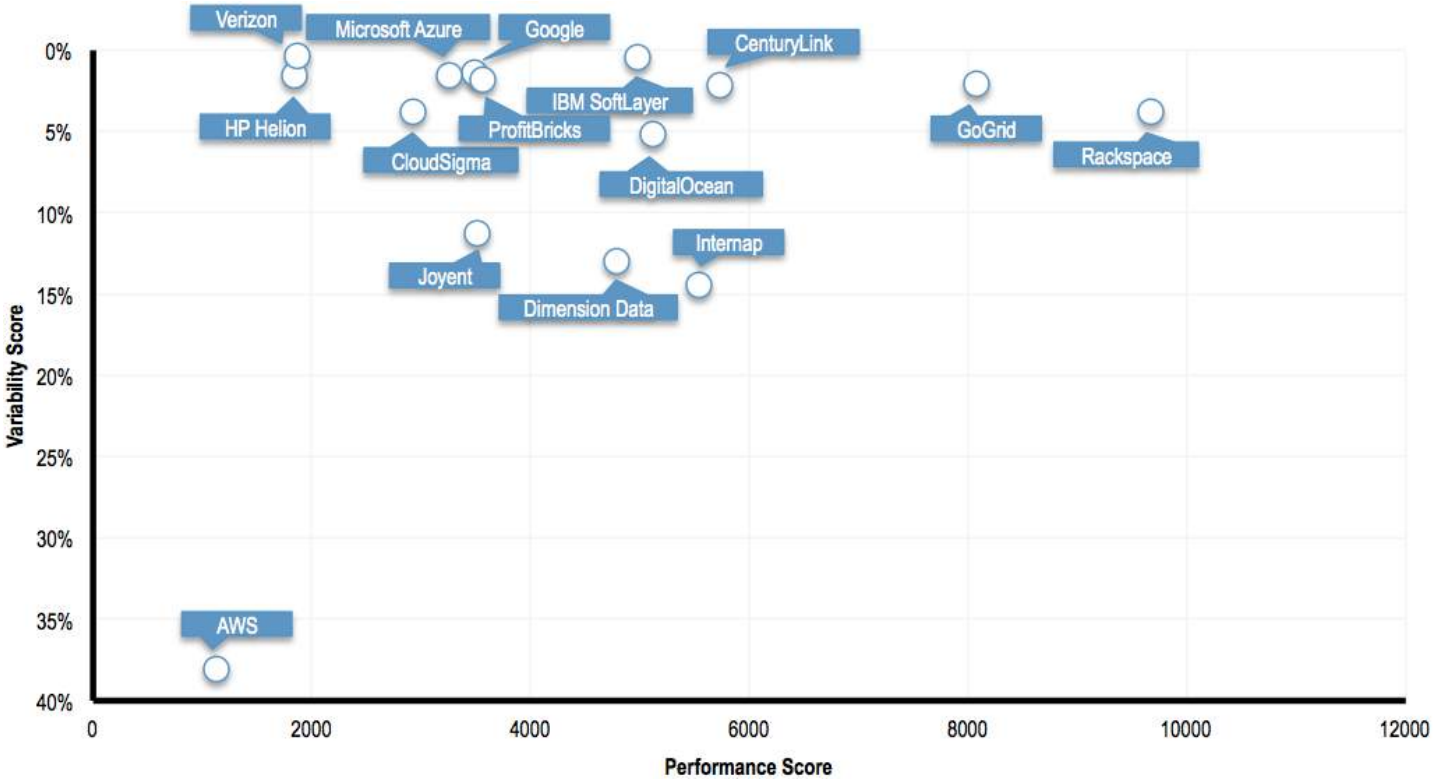


Figure 2.5 shows that Rackspace, GoGrid and CenturyLink are the top three providers for Medium VM CPU performance. It is important to keep in mind that the VMs from GoGrid and Rackspace were 4 vCPU machines, while 2 vCPU machines were used on the remaining providers based on Cloud Spectator's selection criteria consistent with that of the *Cloud Vendor Benchmark 2015 Part 1: Pricing* report. For detailed information, see Preface: VM Configurations and Pricing.

AWS, Dimension Data, Internap and Joyent VMs displayed high CPU performance variability, while Google, HP Helion, IBM SoftLayer and Verizon VMs showed high stability with their variability scores being equal to or lower than 1.5%. Since the performance variability scores of different tasks vary within the same VM, an average variability score can only be seen as a rough indication of a provider VM's overall fluctuation. For specific variability information for individual tasks, see Appendix: Individual Tasks. The AWS VM's high variability score was largely due to its bursting function instead of a lack of stability. For AWS burst information, see Performance: AWS Burst Analysis.

The CPU performance-variability matrix is shown in *Figure 2.6*. The x-axis shows the median CPU performance scores, with higher performance on the right and lower performance on the left. The y-axis shows the CPU performance variability, with the more stable VMs above the less stable VMs. In the top right corner are VMs with both high performance and high stability. Most VMs have a performance score between 2000 and 6000 with variability lower than 5%.

Figure 2.6: CPU Performance-Variability Matrix – Medium VMs



Aggregated Memory Performance Analysis

Cloud Spectator aggregated the scores of all memory tasks to form the memory performance scores. *Table 2.4* shows the minimum, 5th percentile, median, 95th percentile, and maximum memory performance scores as well as memory performance variability scores, which were calculated by averaging variability scores of all memory tasks. For test information, please refer to the Methodology: Performance section; for aggregation information, please see Appendix: Score Aggregation; for performance variability score calculation information, see Methodology: Performance.

Table 2.4: Aggregated Memory Performance and Variability Scores – Medium VMs

	AWS	CenturyLink	CloudSigma	DigitalOcean	Dimension Data	GoGrid	Google	HP Helion	IBM SoftLayer	Internap	Joyent	Microsoft Azure	ProfitBricks	Rackspace	Verizon
Min.	755	3532	1510	2024	1394	1944	1861	865	3463	2633	1873	881	1608	3324	1828
5th Per.	876	3882	1656	3612	1652	2152	1902	937	3571	3686	2104	921	2144	3548	1893
Median	**906**	**4378**	**1795**	**3875**	**2310**	**2215**	**1936**	**1284**	**3589**	**4178**	**2221**	**1195**	**2201**	**3771**	**1990**
95th Per.	4275	4418	1856	4008	2774	2244	1979	1497	3594	4528	2309	1322	2277	4106	2125
Max.	4355	4453	1901	4081	2850	2259	2014	1527	3608	4747	2356	1678	2338	4406	2215
Variability	49.8%	6.1%	2.3%	7.2%	15.7%	1.0%	0.8%	7.6%	0.0%	10.4%	4.2%	4.6%	1.8%	6.6%	2.7%

Similar to what was mentioned in the CPU performance section, the CPU & memory performance scores and memory performance scores are not comparable numerically, i.e., a score of 2000 in CPU & memory performance is not the same as a score of 2000 in memory performance, because of the difference in calculation process. AWS, Dimension Data and Internap VMs exhibited high memory performance fluctuation. The performance ranking with variability patterns is shown in *Figure 2.7*.

Figure 2.7: Memory Performance Percentile Graph – Medium VMs – Ranked by Median

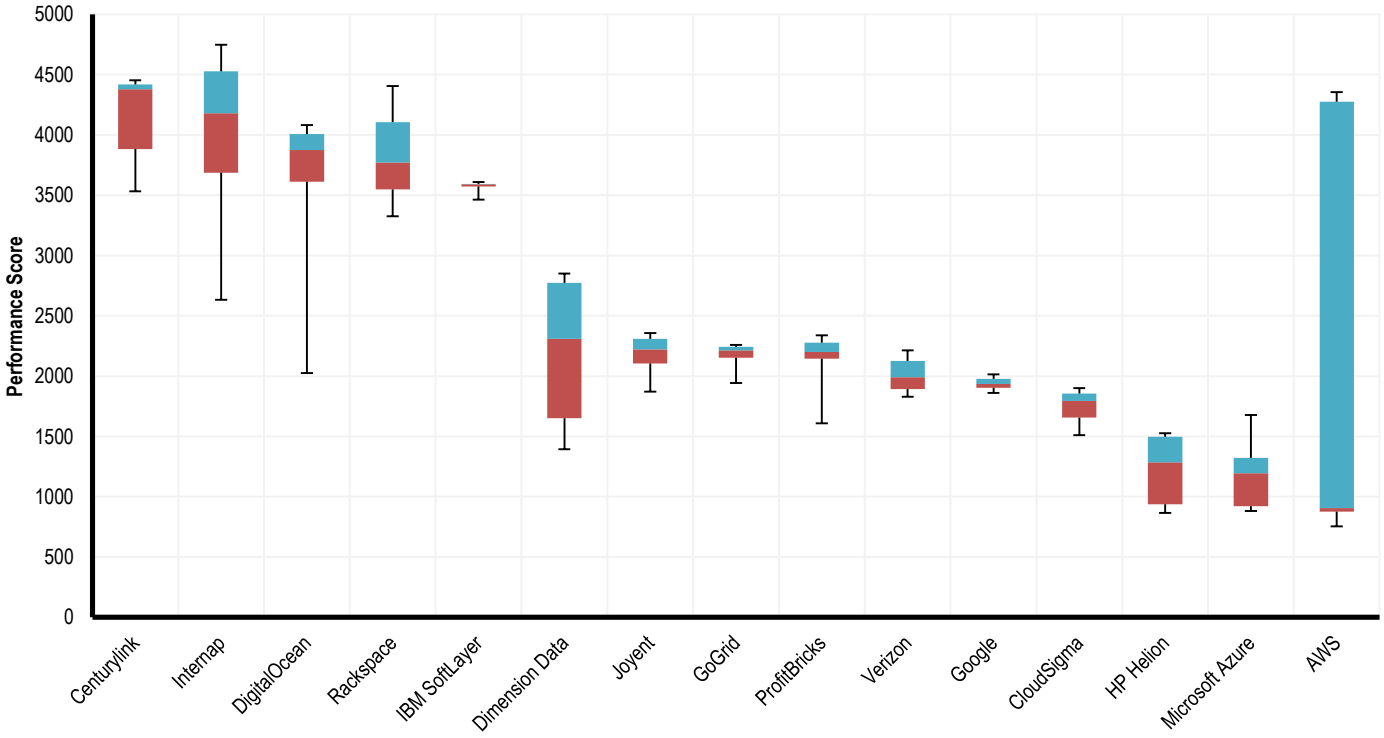
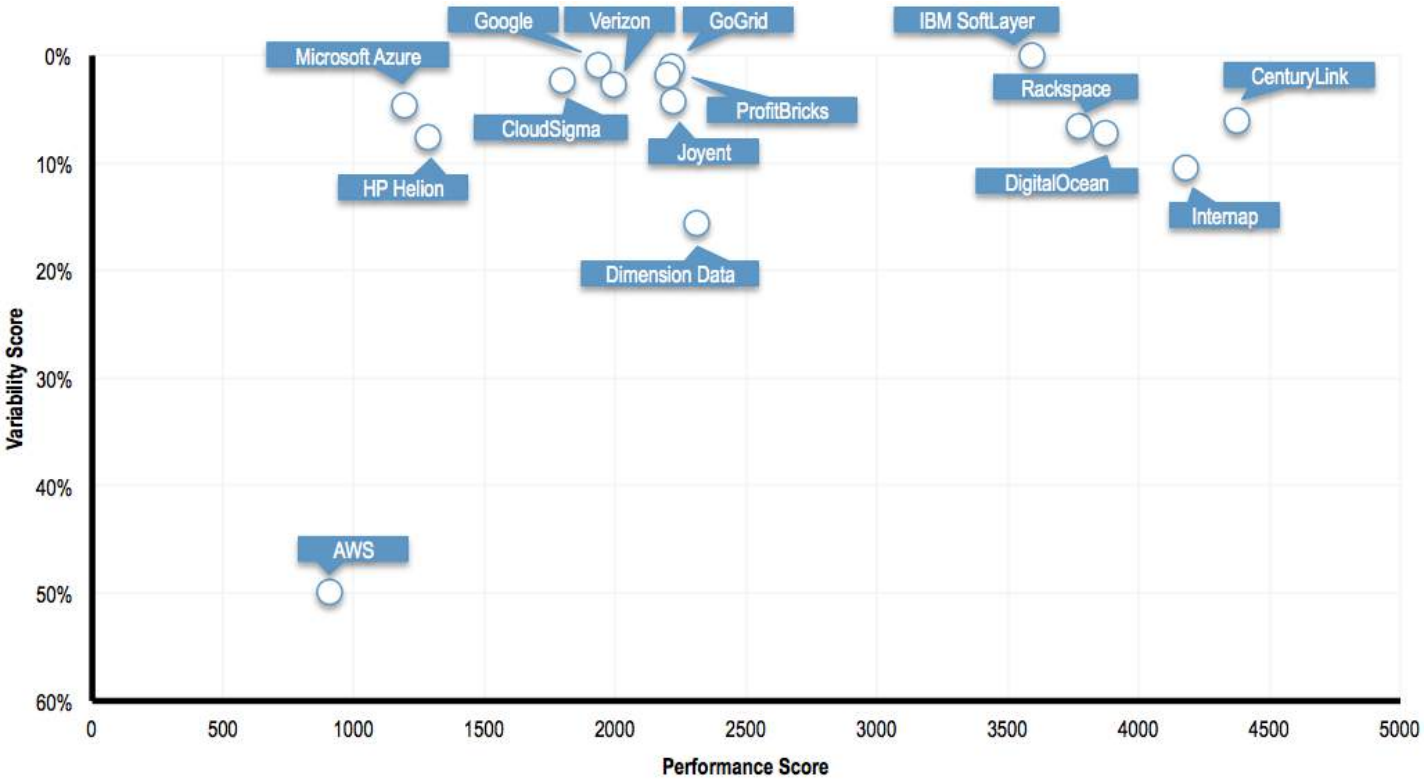


Figure 2.7 shows that CenturyLink, Internap and DigitalOcean are the top three providers for Medium VM memory performance. AWS, Dimension Data and Internap VMs displayed high memory performance variability, while GoGrid, Google and IBM SoftLayer VMs showed high stability with their variability scores being equal to or lower than 1.5%. Since the performance variability scores of different tasks vary within the same VM, an average variability score can only be seen as a rough indication of a provider VM's overall fluctuation. For specific variability information for individual tasks, see Appendix: Individual Tasks. The AWS VM's high variability score was largely due to its bursting function instead of a lack of stability. For AWS burst information, see Performance: AWS Burst Analysis.

The memory performance-variability matrix is shown in *Figure 2.8*. The x-axis shows the median memory performance scores, with higher performance on the right and lower performance on the left. The y-axis shows the memory performance variability, with the more stable VMs above the less stable VMs. In the top right corner are VMs with both high performance and high stability. Most VMs have a performance score between 1000 and 4000 with variability lower than 5%.

Figure 2.8: Memory Performance-Variability Matrix – Medium VMs



Individual Task Performance Analysis

Cloud Spectator conducted analysis for each task tested in this report to show the performance rankings and performance fluctuation for all VMs tested. Percentile graphs and tables can be found in Appendix: Individual Tasks. In general, the AES, Lua, Dijkstra, Black Scholes, SGEMM, DGEMM, STREAM Copy, STREAM Scale, STREAM Add and STREAM Triad tasks yielded larger overall variability within the VMs, while smaller fluctuations were observed for the rest of the tasks. The VM rankings are relatively stable across tasks within the same categories (i.e. integer, floating point or memory), while some changes in rankings can be observed across the categories.

On an individual level, Rackspace, GoGrid, Internap and CenturyLink VMs had the highest performance rankings across all providers for the majority of tasks. Rackspace's VM displayed the highest performance output for 17 out of the 27 tasks, and GoGrid's VM was the top performer for 6 of the remaining tasks. CenturyLink, DigitalOcean, IBM SoftLayer and Internap VMs exhibited the highest performance scores for the memory tasks.

AWS, Dimension Data, Internap and Joyent VMs displayed recurring fluctuations in all tasks included in the testing. A summary of their variability scores is provided in Table 2.5:

Table 2.5: High Variability VM Summary – Medium VMs

	High Variability Score*	Low Variability Score*	Average Variability Score	Variability Pattern
AWS	54.7%	31.0%	39.8%	Mostly positive fluctuations**
Dimension Data	18.6%	2.9%	13.3%	Positive, negative and neutral fluctuations
Internap	19.2%	9.7%	13.8%	Mostly negative fluctuations
Joyent	14.8%	2.1%	10.2%	Positive, negative and neutral fluctuations

**High/low variability scores were obtained by eliminating the max/min scores and selecting the second highest/lowest scores of each VM. This procedure ensures a more realistic score range, which shows general trends without being skewed by extreme scores.*

***AWS VM's performance fluctuation wasn't distributed evenly over time. For specific analysis on AWS VM performance, see AWS Burst Analysis below.*

The AWS VM showed an average variability of 39.8%, with 90% of the variability scores ranging between 31.0% and 54.7%, mostly positive fluctuations; the Internap VM showed an average variability of 13.8%, with 90% of the variability scores ranging between 9.7% and 19.2%, mostly negative fluctuations. The VMs of Dimension Data and Joyent exhibited a mixture of positive, negative, and neutral fluctuations. All variability scores can be viewed in the performance analysis tables. These recurring fluctuations across tasks explain the aggregated performance variations exhibited by AWS, Dimension Data, Internap and Joyent VMs, which resulted in the aggregated performance ranking changes when comparing between the low scores and high scores. For variability calculation information, see Methodology: Performance.

Google, IBM SoftLayer and Verizon VMs showed little fluctuation in all tasks included in the testing. A summary of their performance fluctuation is provided in Table 2.6:

Table 2.6: Low Variability VM Summary – Medium VMs

	High Variability Score (95%)	Low Variability Score (5%)	Average Variability Score	Variability Pattern
Google	3.1%	0.4%	1.3%	-
IBM SoftLayer	2.2%	0.0%	0.4%	-
Verizon	2.7%	0.0%	0.7%	-

The Google VM showed an average variability of 1.3%, with 90% of the variability scores ranging between 0.4% and 3.1%; the IBM SoftLayer VM showed an average variability of 0.4%, with 90% of the variability scores ranging between 0.0% and 2.2%; and the Verizon VM showed an average variability of 0.7%, with 90% of the variability scores ranging from 0.0% and 2.7%. No variability patterns are attributed to VMs with variability scores less than 5%. All variability scores can be viewed in the performance analysis tables. The small degree of variability of these VMs indicates stable aggregate performance outputs during the 24-hour testing. For variability calculation information, see Methodology: Performance.

DigitalOcean, GoGrid, Google, and Joyent VMs exhibited performance outliers on the lower end for the majority of the tasks tested. This implies that some extremely low, but infrequent scores were detected over the course of the 24-hour continuous testing.

AWS Burst Analysis

While the performance variability of other provider VMs was mainly a result of an alternation of high and low scores, the large performance variation of the AWS VM was caused by its T2 family burst function. According to AWS's official description, "T2 instances are designed to provide moderate baseline performance and the capability to burst to significantly higher performance as required by your workload." (See AWS's T2 burst function webpage) AWS allocates a certain number of vCPU credits per 24 hours, and depending on the user's application requirements, the T2 VMs can burst to 100% CPU power instead of the baseline capacity, until the CPU credits are used up within the 24 hours. For specific information, visit AWS's T2 burst function webpage.

During the 24-hour continuous testing, Cloud Spectator detected the AWS t2.medium VM's positive fluctuation, which was recurring across all integer, floating point and memory tasks, the magnitude of which was relatively consistent. In order to analyze the performance pattern, Cloud Spectator calculated the performance difference between the 95th percentile (representing the bursting condition) and 5th percentile (representing the non-bursting condition) performance outputs for each task (see *Table 2.7*):

Table 2.7: AWS Burst and Non-Burst Performance Comparison – t2.medium

	95TH Percentile Performance (Burst)	5TH Percentile Performance (Non-Burst)	Burst Performance Multiplier (=Burst/Non-Burst)
AES (MB/sec)	4263.94	871.76	4.9x
Twofish (MB/sec)	280.64	55.00	5.1x
SHA1 (MB/sec)	632.04	123.80	5.1x
SHA2 (MB/sec)	276.50	54.16	5.1x
BZip2 Compression (MB/sec)	19.10	3.44	5.6x
BZip2 Decompression (MB/sec)	25.00	4.62	5.4x
JPEG Compression (Mpixels/sec)	72.00	14.10	5.1x
JPEG Decompression (Mpixels/sec)	181.54	35.10	5.2x
PNG Compression (Kpixels/sec)	4065.28	706.22	5.8x
PNG Decompression (Kpixels/sec)	63385.60	12083.20	5.2x
Sobel (Mpixels/sec)	256.90	49.40	5.2x
Lua (KB/sec)	4874.24	912.30	5.3x
Dijkstra (Mflops/sec)	15.50	2.47	6.3x
BlackScholes (Mnodes/sec)	19.30	3.77	5.1x
Mandelbrot (Mflops/sec)	5232.64	1024.00	5.1x
Sharpen Filter (Mflops/sec)	3430.40	654.76	5.2x
Blur Filter (Mflops/sec)	3563.52	682.00	5.2x
SGEMM (Mflops/sec)	19968.00	3807.23	5.2x
DGEMM (Mflops/sec)	9973.76	1935.36	5.2x
SFFT (Mflops/sec)	5498.88	1075.20	5.1x
DFFT (Mflops/sec)	5109.76	981.96	5.2x
N-Body (Kpairs/sec)	3194.88	612.56	5.2x
Ray Trace (Kpixels/sec)	8140.80	1587.20	5.1x
STREAM Copy (GB/sec)	14.94	2.92	5.1x
STREAM Scale (GB/sec)	19.40	4.08	4.8x
STREAM Add (GB/sec)	19.10	3.97	4.8x
STREAM Triad (GB/sec)	19.10	3.94	4.8x
			Average = 5.2x

The result shows that on average the VM's burst performance was 5.2 times the baseline performance. The baseline performance is 20% of the full CPU resource performance, as claimed on AWS's T2 burst function webpage. In order to visualize the performance pattern over time, Cloud Spectator produced a line graph with data collected from AWS t2.medium's PNG Compression performance:

Figure 2.9: AWS Performance Line Graph – PNG Compression – t2.medium

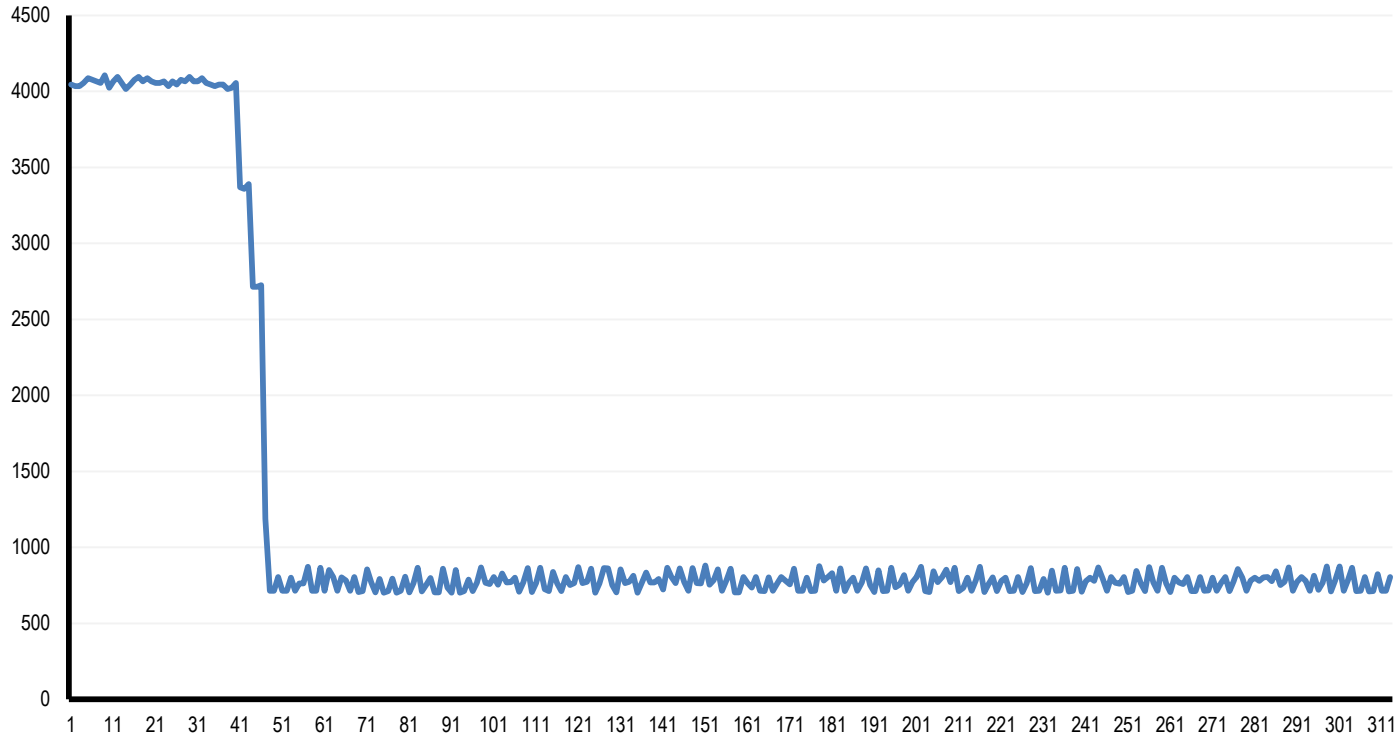


Table 2.8: AWS PNG Compression Performance Statistics – t2.medium

Total Iterations	Burst Iterations	Non-burst Iterations	Burst Average (Kpixels/Sec)	Non-burst Average (Kpixels/Sec)	Total Duration (Hour)	Burst Duration (Minutes)
313.0	47.0	266.0	3867.9	771.4	24.0	69.7

According to the data Cloud Spectator collected, a total of 313 test iterations of the PNG Compression task were completed on the AWS t2.medium VM, among which 266 iterations were operated under the baseline condition and 47 iterations were operated under the burst condition. The AWS VM burst 69.7 minutes during the 24 hours of continuous testing.

The graph indicates that AWS's burst duration was concentrated at the beginning of the 24-hour testing due to the vCPU power demanded by the testing. Operating a different application on the VM may yield different performance patterns from the one shown above.

PRICE-PERFORMANCE COMPARISON

Price-performance value is illustrated by Cloud Spectator's index – the CloudSpecs Score™. The CloudSpecs Score™ is calculated by combining performance scores with hourly, monthly, annual and 3-year pricing. In this study, the aggregated CPU & memory score was used to represent performance. For details on the CloudSpecs Score™ calculation, see Methodology: Price-Performance; for VM performance information, see Performance Comparison; for VM pricing information, see Preface: VM Configurations and Pricing.

Figure 3.1 shows the price-performance comparison of VMs with hourly, monthly, annual and 3-year pricing using the median aggregated CPU & memory performance scores. The CloudSpecs Score™ in *Figure 3.1* was calculated using the equivalent hourly pricing of all pricing commitment durations, and referenced the highest price-performance score of all price-performance values as 100. The VM ranking is based on the monthly CloudSpecs Score™; monthly, annual and 3-year CloudSpecs Score™ increases are added on top of the hourly scores.[1]

Figure 3.1: Median CPU & Memory Aggregated Price-Performance of All Pricing Models – Medium VMs – (Ranked in Monthly Values)

**CloudSigma's hourly price-performance is not calculated because its burst hourly pricing is not a set value. See Methodology: Key Considerations for more details.*

For the median-score performance results, the DigitalOcean VM had the highest price-performance values, outperforming the next highest machine, the CenturyLink VM, by approximately 19%. CenturyLink, ProfitBricks and Rackspace VMs exhibited high price-performance value for hourly pricing, and CloudSigma, GoGrid and AWS VMs exhibited high price-performance values for longer-term pricing where discounts applied. AWS, CloudSigma, DigitalOcean, GoGrid, Google and IBM SoftLayer VMs all showed increased price-performance with long-term discounted pricing. AWS, CloudSigma, GoGrid and Google VMs' long-term price-performance resulted in ranking increases.

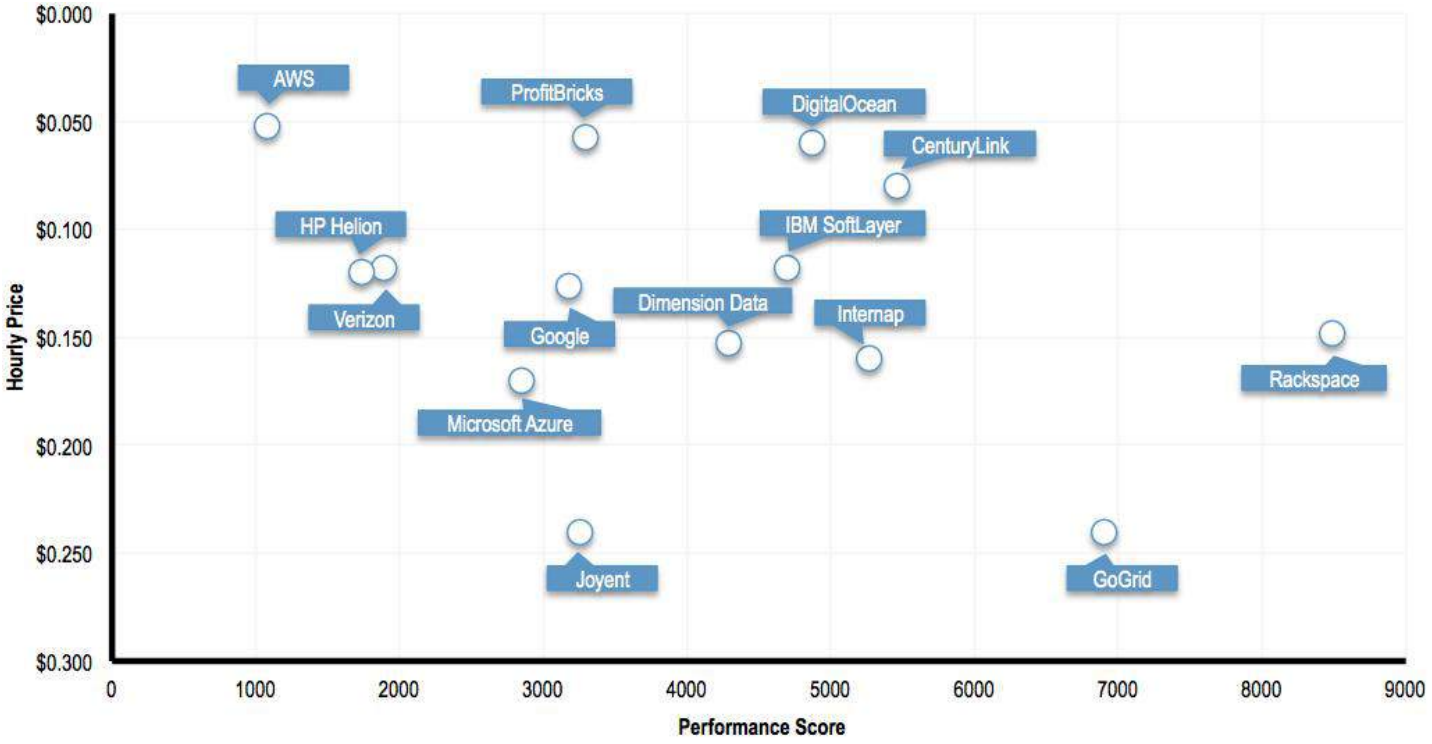
The graphs on the next few pages show the relationship between price and performance for hourly, monthly, annual and 3-year pricing individually, using median performance data, and display the CloudSpecs Score™ price-performance comparison for each pricing model using low scores, median scores and high scores (correspondingly 5th percentile, median and 95th percentile performance values) separately. In each graph, the CloudSpecs Score™ was calculated using the highest price-performance value within the given commitment timeframe (hourly, monthly, annual or 3-year). The CloudSpecs Scores™ of different graphs are not comparable to each other.

[1] In this case, the longer-term pricing models always produce CloudSpecs Scores™ equivalent to larger or than the shorter-term pricing models, because longer-term prices are always equal to or less than shorter-term prices.

Price-Performance with Hourly Pricing

Figure 3.2 presents hourly VM prices and their performance values. The x-axis represents the median CPU & memory performance scores, with lower scores on the left and higher scores on the right. The y-axis represents the hourly cost of the VMs, with lower prices on the top and higher prices on the bottom.

Figure 3.2: Price-Performance Matrix with Hourly Pricing – Medium VMs



**CloudSigma's hourly price-performance is not calculated because its burst hourly pricing is not a set value. See Methodology: Key Considerations for more details.*

Figure 3.3 – 3.5 are price-performance rankings using the CloudSpecs Score™ calculation. The VMs are ranked from high to low by CloudSpecs Score™ calculated using low, median and high CPU & memory performance scores and hourly prices.

Figure 3.3: Low-Score Category Price-Performance – Medium VMs (Hourly)

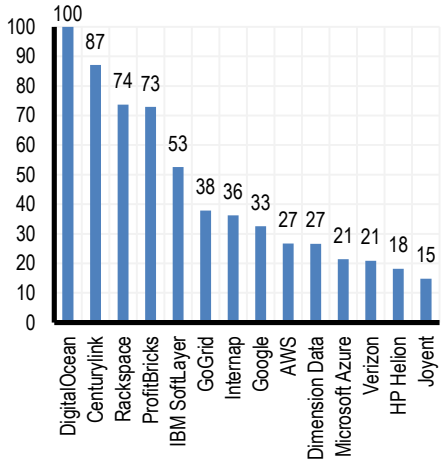


Figure 3.4: Median-Score Category Price-Performance – Medium VMs (Hourly)

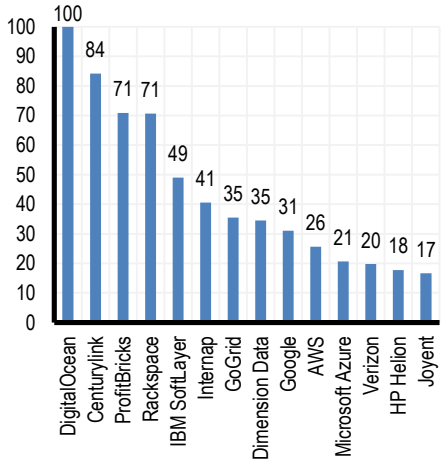
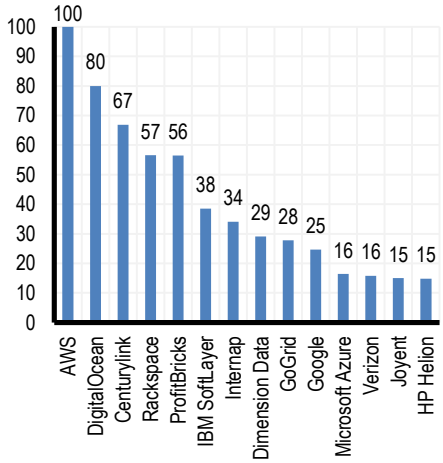


Figure 3.5: High-Score Category Price-Performance – Medium VMs (Hourly)



**CloudSigma's hourly price-performance is not calculated because its burst hourly pricing is not a set value. See Methodology: Key Considerations for more details.*

Price-Performance with Monthly Pricing

Figure 3.6 presents monthly VM prices and their performance values. The x-axis represents the median CPU & memory performance scores, with lower scores on the left and higher scores on the right. The y-axis represents the monthly cost of the VMs, with lower prices on the top and higher prices on the bottom.

Figure 3.6: Price-Performance Matrix with Monthly Pricing – Medium VMs

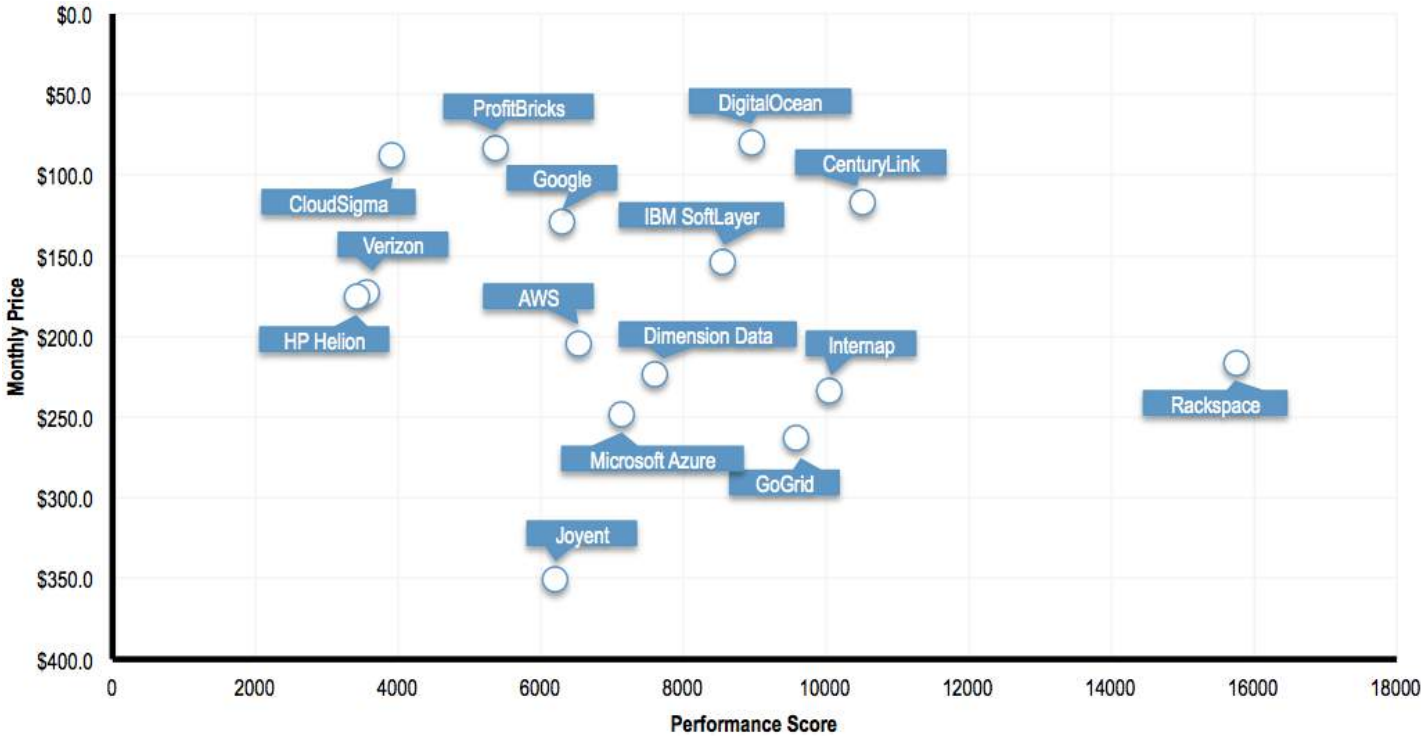


Figure 3.7 – 3.9 are price-performance rankings using the CloudSpecs Score™ calculation. The VMs are ranked from high to low by CloudSpecs Score™ calculated using low, median and high CPU & memory performance scores and monthly prices.

Figure 3.7: Low-Score Category Price-Performance – Medium VMs (Monthly)

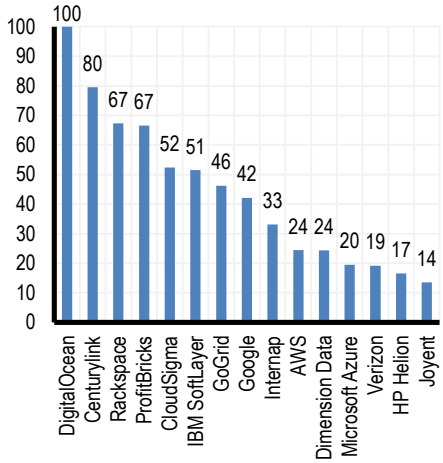


Figure 3.8: Median-Score Category Price-Performance – Medium VMs (Monthly)

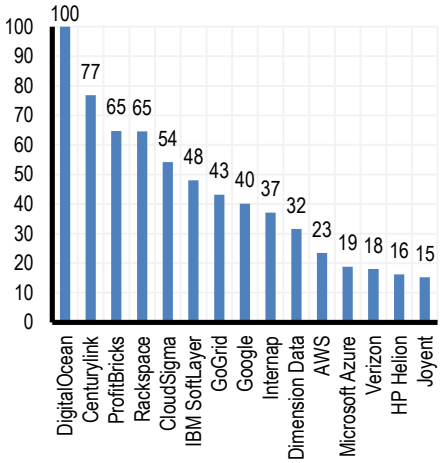
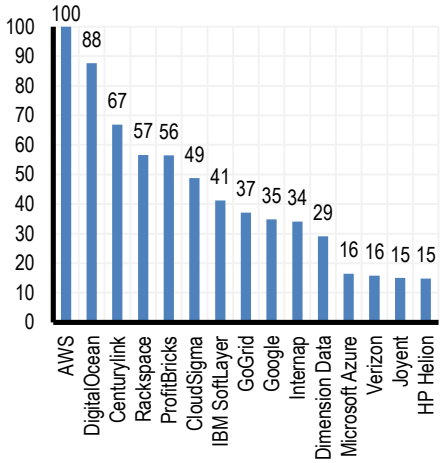


Figure 3.9: High-Score Category Price-Performance – Medium VMs (Monthly)



Price-Performance with Annual Pricing

Figure 3.10 presents annual VM prices and their performance values. The x-axis represents the median CPU & memory performance scores, with lower scores on the left and higher scores on the right. The y-axis represents the annual cost of the VMs, with lower prices on the top and higher prices on the bottom.

Figure 3.10: Price-Performance Matrix with Annual Pricing – Medium VMs

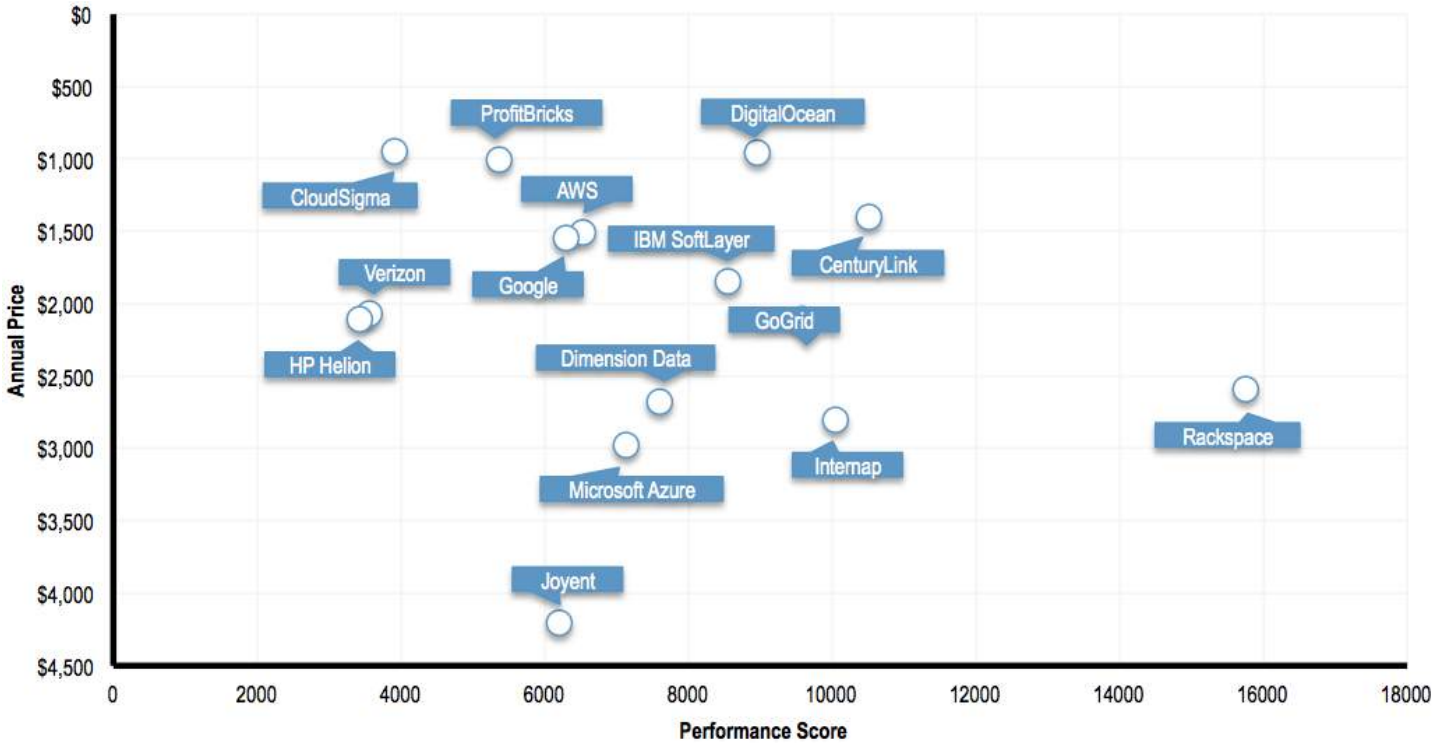


Figure 3.11 – 3.13 are price-performance rankings using the CloudSpecs Score™ calculation. The VMs are ranked from high to low by CloudSpecs Score™ calculated using low, median and high CPU & memory performance scores and annual prices.

Figure 3.11: Low-Score Category Price-Performance – Medium VMs (Annual)

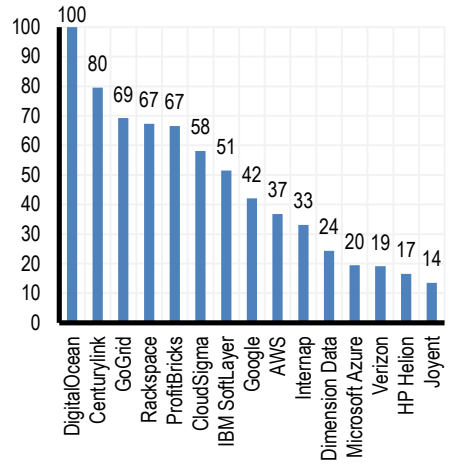


Figure 3.12: Median-Score Category Price-Performance – Medium VMs (Annual)

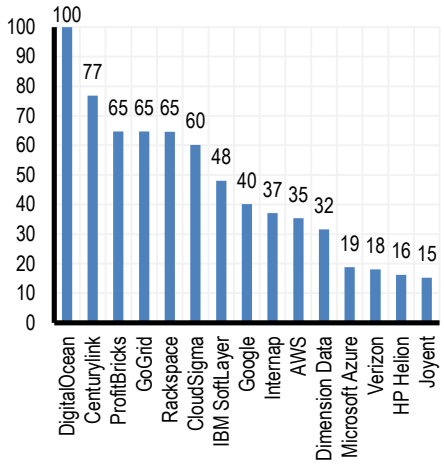
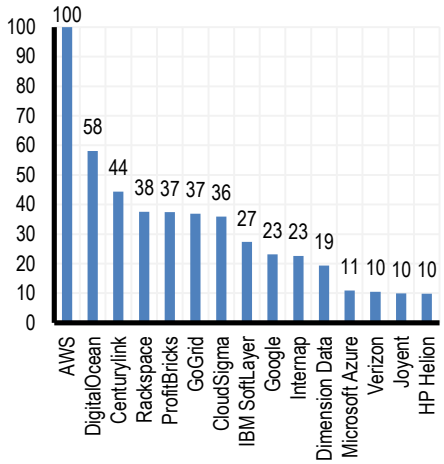


Figure 3.13: High-Score Category Price-Performance – Medium VMs (Annual)



Price-Performance with 3-Year Pricing

Figure 3.14 presents 3-year VM prices and their performance values. The x-axis represents the median CPU & memory performance scores, with lower scores on the left and higher scores on the right. The y-axis represents the 3-year cost of the VMs, with lower prices on the top and higher prices on the bottom.

Figure 3.14: Price-Performance Matrix with 3-Year Pricing

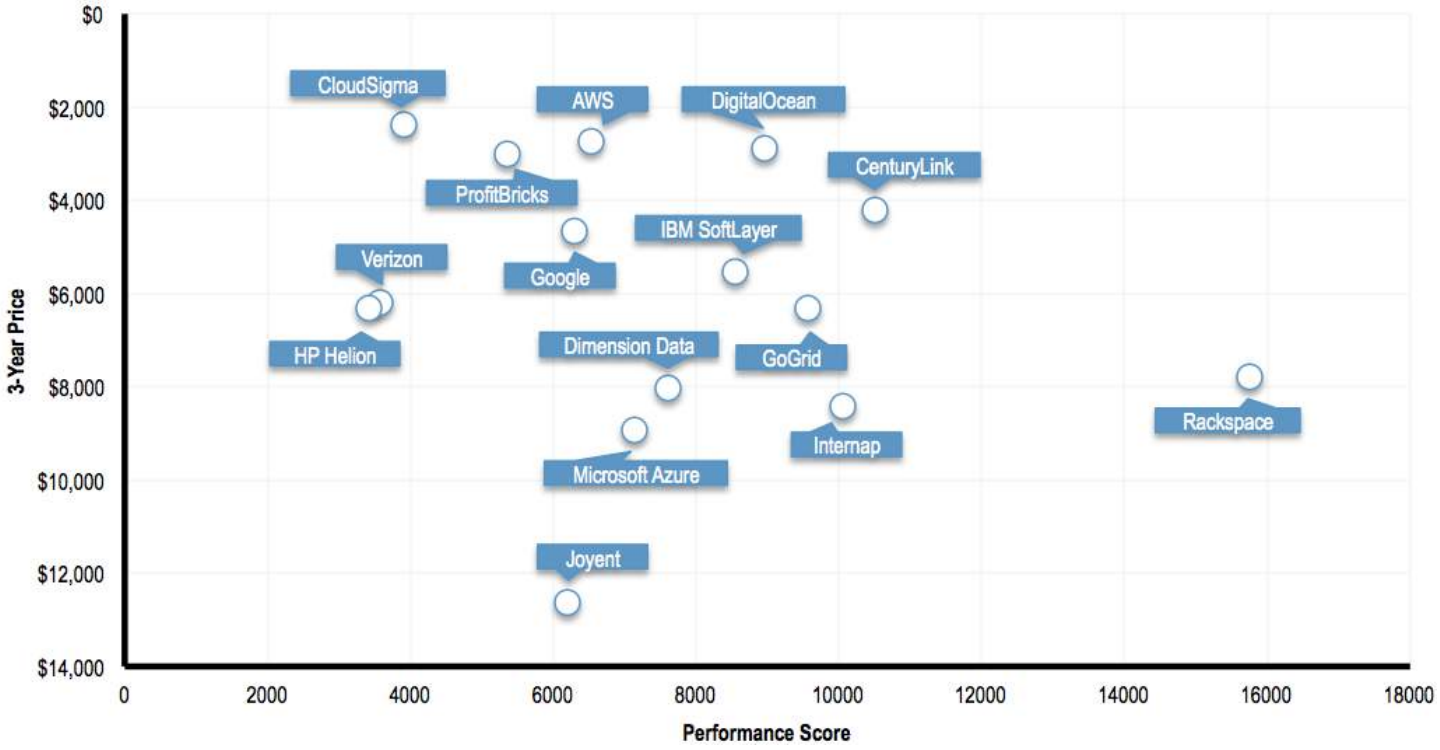


Figure 3.15 – 3.17 are price-performance rankings using the CloudSpecs Score™ calculation. The VMs are ranked from high to low by CloudSpecs Score™ calculated using low, median and high CPU & memory performance scores and 3-year prices.

Figure 3.15: Low-Score Category Price-Performance – Medium VMs (3-Year)

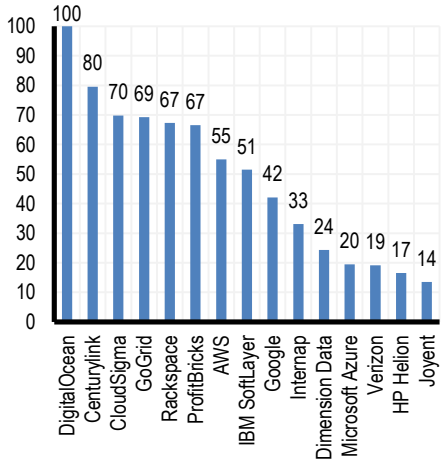


Figure 3.16: Median-Score Category Price-Performance – Medium VMs (3-Year)

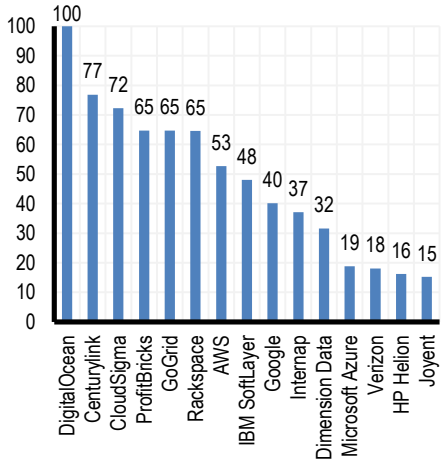
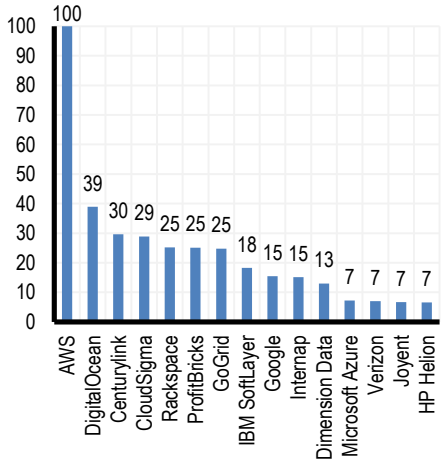


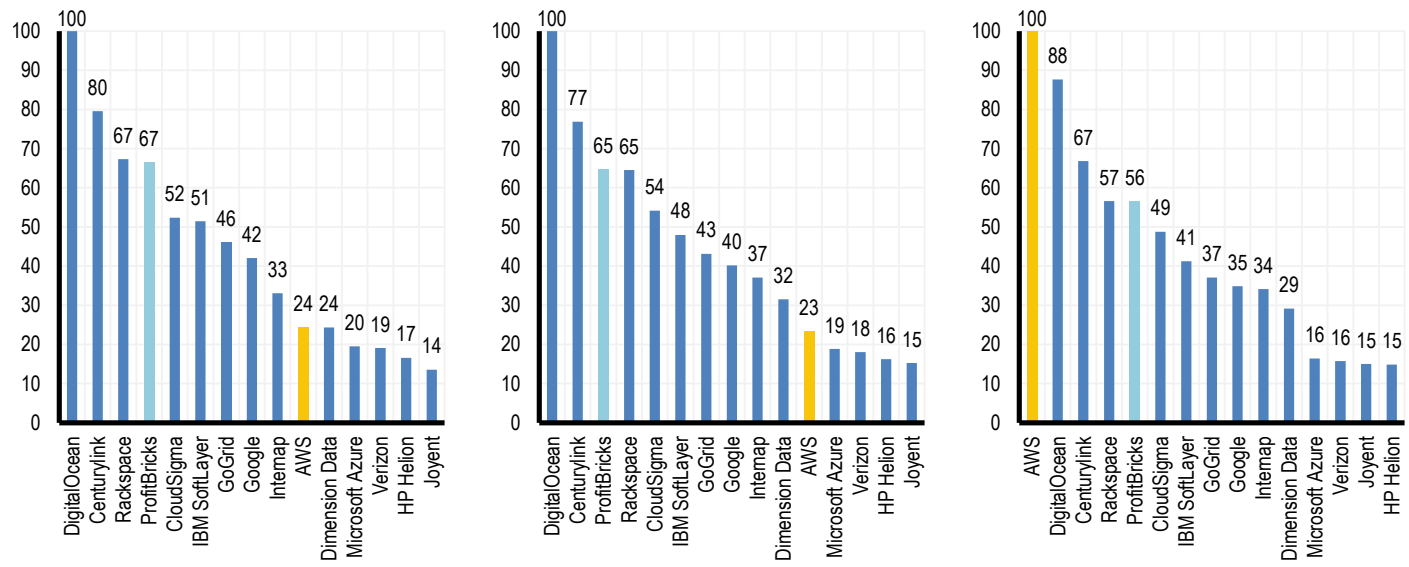
Figure 3.17: High-Score Category Price-Performance – Medium VMs (3-Year)



Overall, DigitalOcean, CenturyLink and Rackspace VMs had the highest rankings in low, median and high CloudSpecs scores of all pricing intervals. The DigitalOcean VM led the price-performance comparisons in Low-Score and Median-Score Categories, and the AWS VM had the highest price-performance values for the High-Score Category where its burst performance was used in the calculation.

Changes in rankings can be seen when switching among the Low-, Median- and High-Score Categories, indicating large price-performance value ranges of some VMs during the testing period.

Figure 3.18: Comparing Price-Performance with Monthly Pricing – Medium VMs



As illustrated above using the monthly examples, the ProfitBricks VM's price-performance ranking in the Median-Score Category was higher than that in the Low- and High-Score Categories, and the AWS VM displayed significantly higher price-performance in the High-Score Category in comparison with the Low- and Median-Score Categories,

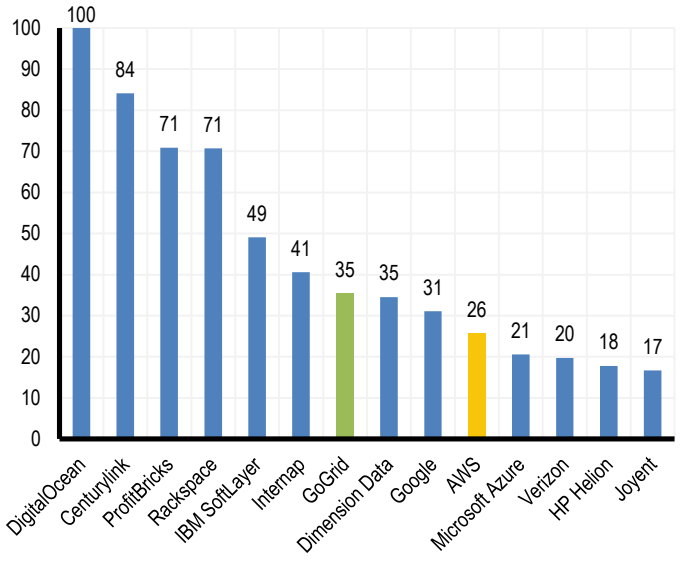
The price-performance value ranges reflected by the three categories are consistent with their performance variations, which are shown in the section titled Performance Comparison.

When viewing the graphs across pages, and as shown in *Figure 3.1*, commitment duration has an impact on price-performance ranking changes as well. In general, AWS, CloudSigma and GoGrid VMs' price-performance rankings increase as the pricing structure changes to longer-term prices, because they offer discounts that increase with longer time commitments (i.e., AWS offers a 34% discount on its annual pricing and a 56% discount on its 3-year pricing[2]; CloudSigma offers a 10% discount on its annual pricing and a 25% discount on its 3-year pricing; GoGrid offers a 25% discount on its monthly pricing and a 50% discount on its annual pricing). The trend is illustrated below using median performance as an example:

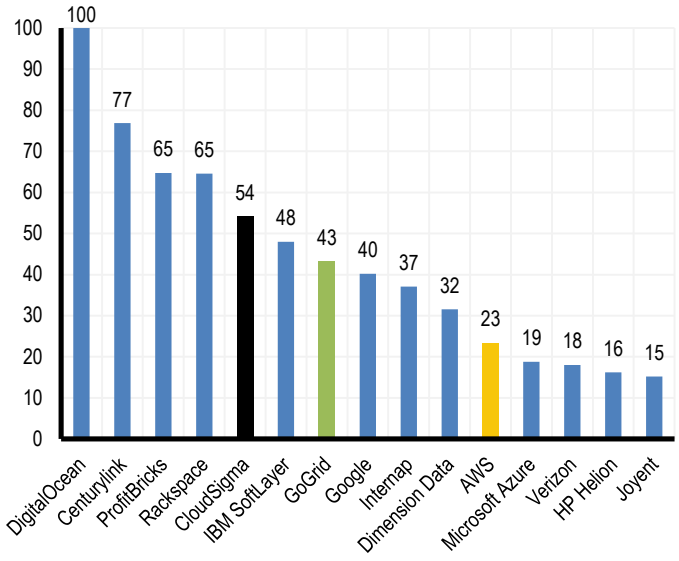
[2] This AWS discount information only applies to the t2.medium instance at their Virginia data center assuming full payment upfront. Any changes in conditions may change the discount information for both annual and 3-year pricing.

Figure 3.19: Price-Performance with Median Scores

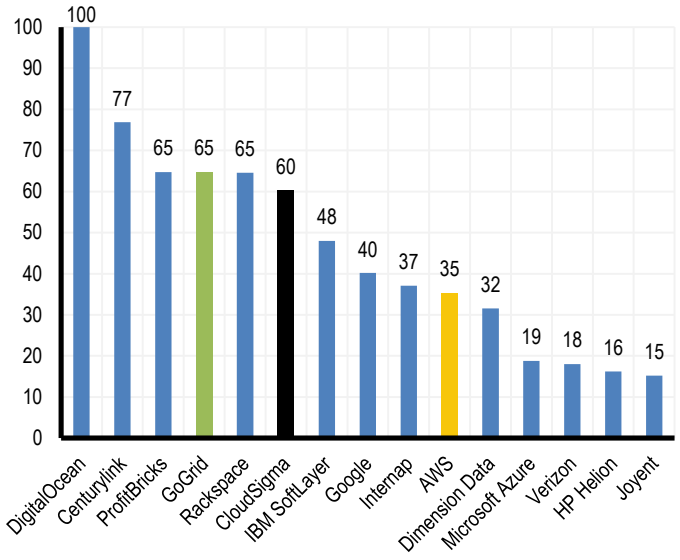
Hourly Price-Performance



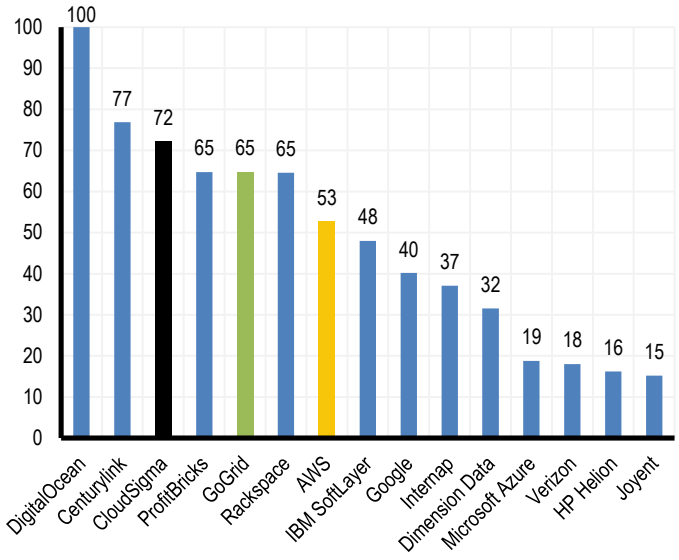
Monthly Price-Performance



Annual Price-Performance



3-Year Price-Performance



AWS, CloudSigma and GoGrid VMs' price-performance rankings increase as the pricing structure changes to longer-term prices, because they offer discounts that increase with longer time commitments.

GENERAL OBSERVATIONS

As cloud adoption increases and more cloud users compare services, considering performance alongside price will help them lower their annual operating costs and achieve greater value. Deploying VMs with outstanding price-performance not only ensures value, but also enables optimized resource allocation and prevents IT overspending. In this report, Cloud Spectator tested the Medium size VMs of 15 top providers in the industry and examined their performance and price-performance values against each other.

The results carry two key messages:

1. Both performance levels and performance variability can vary greatly among provider VMs of similar configurations.

The performance data in this report illustrates the discrepancies among VMs in both performance and variability, and shows that the differences between provider VMs can be significant when both performance and variability are measured, even if the provider VMs are selected with controlled configurations.

Understanding both the performance level and the severity of performance variation is critical to successfully operating certain applications in the cloud. Just as low performing machines may not satisfy application performance requirements, high performing but unstable machines may have diminished performance output periodically, which may fail to support the application's ability to run at full capacity. Thorough considerations should be applied to examine performance levels and performance variability when users are selecting cloud environments in order to optimize their application operations.

2. Comparing cloud provider VMs based on price, performance and price-performance yields different results.

When comparing the same set of provider VMs using price, performance and price-performance, the results may be quite different. Using AWS's t2.medium as an example, while the VM ranks first in the hourly pricing comparison, its median performance output ranks last among the 15 providers, and its price-performance calculated using the data supporting the first two graphs ranks 11th. In this case, selecting the right criteria when comparing across the cloud industry is essential in helping users optimize their decision-making process and outcome.

Price-performance analysis is critical for choosing the best-fit VMs for specific use cases in order to avoid unnecessary IT overspending. Businesses looking for the most economical cloud infrastructure should examine the price and performance output of a targeted VM together to understand the performance per unit cost they can expect.

As the cloud industry continues to become more competitive, it is important to make data-driven decisions with sufficient and accurate information. If you have questions about comparing cloud provider VMs, please call or email Cloud Spectator at +1 617-300-0711 or contact@cloudspectator.com.

RELATED STUDIES

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- Cloud Vendor Benchmark 2015 Part 2.10: Performance and Price-Performance (2XLarge VMs, Windows)

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APPENDIX

VM Sizing

The table below outlines the specific VMs used for each pricing and price-performance comparison. VMs outside the scope of the Medium VM report are also included in the tables. For price-performance comparisons for Small, Large, XLarge and 2XLarge VMs, see Cloud Vendor Benchmark 2015 Reports.

VM Size	Provider	Instance	vCPU	RAM	STORAGE (GB)
Small	AWS	t2.small	1	2	EBS only
	CenturyLink	customized	1	2	-
	CloudSigma	customized	1	2	50 SSD
	DigitalOcean	standard2	2	2	40 SSD
	Dimension Data	customized	1	2	-
	GoGrid	Standard Medium	2	2	100
	Google	n1-standard-1	1	3.75	-
	HP Helion	Standard Small	2	2	10
	IBM SoftLayer	customized	1	2	25
	Internap	B-1	1	4	20 SSD
	Internap (Windows)	A-2	2	2	40 SSD
	Joyent	standard3	1	3.75	123
	Joyent (Windows)	standard4	2	7.5	738
	Microsoft Azure	D1	1	3.5	50 SSD
	Microsoft Azure (Windows)	A2 Basic	2	3.5	60
	ProfitBricks	customized	1	2	-
	Rackspace	General1-2	2	2	40 SSD
	Verizon	3.5	1	3.5	-
Medium	AWS	t2.medium	2	4	EBS only
	CenturyLink	customized	2	4	-
	CloudSigma	customized	2	4	50 SSD
	DigitalOcean	standard4	2	4	60 SSD
	Dimension Data	customized	2	4	-
	GoGrid	Standard Large	4	4	200
	Google	n1-standard-2	2	7.5	-
	HP Helion	Standard Medium	2	4	50
	IBM SoftLayer	customized	2	4	25
	Internap	B-2	2	8	40 SSD
	Joyent	standard4	2	7.5	738
	Microsoft Azure	D2	2	7	100 SSD
	Microsoft Azure (Windows)	A3 Basic	4	7	120

	ProfitBricks	customized	2	4	-
	Rackspace	General1-4	4	4	80 SSD
	Verizon	4	2	4	-
Large	AWS	m3.xlarge	4	15	2 x 40 SSD
	CenturyLink	customized	4	8	-
	CloudSigma	customized	4	8	50 SSD
	DigitalOcean	standard5	4	8	80 SSD
	Dimension Data	customized	4	8	-
	GoGrid	Standard X-Large	8	8	400
	Google	n1-standard-4	4	15	-
	HP Helion	Standard Large	4	8	130
	IBM SoftLayer	customized	4	8	25
	Internap	B-4	4	15	80 SSD
	Joyent	Standard5	4	15	1467
	Microsoft Azure	D3	4	14	200 SSD
	Microsoft Azure (Windows)	A4 Basic	8	14	240
	ProfitBricks	customized	4	8	-
	Rackspace	General1-8	8	8	160 SSD
	Verizon	7	4	8	-
XLarge	AWS	m3.2xlarge	8	30	2 x 80 SSD
	CenturyLink	customized	8	16	-
	CloudSigma	customized	8	16	50 SSD
	DigitalOcean	highvol1	8	16	160 SSD
	Dimension Data	customized	8	16	-
	GoGrid	Standard XX-Large	16	16	800
	Google	n1-standard-8	8	30	-
	HP Helion	Standard 2XL	8	30	470
	IBM SoftLayer	customized	8	16	25
	Internap	B-8	8	30	160 SSD
	Joyent	High Storage1	8	32	7680
	Microsoft Azure	D4	8	28	400 SSD
	Microsoft Azure (Windows)	A7	8	56	605
	ProfitBricks	customized	8	16	-
	Rackspace	Compute1-30	16	30	-
	Verizon	11	8	16	-
2XLarge	AWS	r3.4xlarge	16	122	1 x 320 SSD
	CenturyLink	customized	16	32	-
	CloudSigma	customized	16	32	50 SSD
	DigitalOcean	highvol3	16	48	480 SSD
	Dimension Data	-	-	-	-
	GoGrid	High RAM 4XL	16	64	40

Google	n1-standard-16	16	60	-
HP Helion	Standard 8XL	16	120	1770
IBM SoftLayer	customized	16	32	25
Internap	B-16	16	60	320 SSD
Joyent	-	-	-	-
Microsoft Azure	D14	16	112	800 SSD
ProfitBricks	customized	16	32	-
Rackspace	Compute1-60	32	60	-
Verizon	-	-	-	-

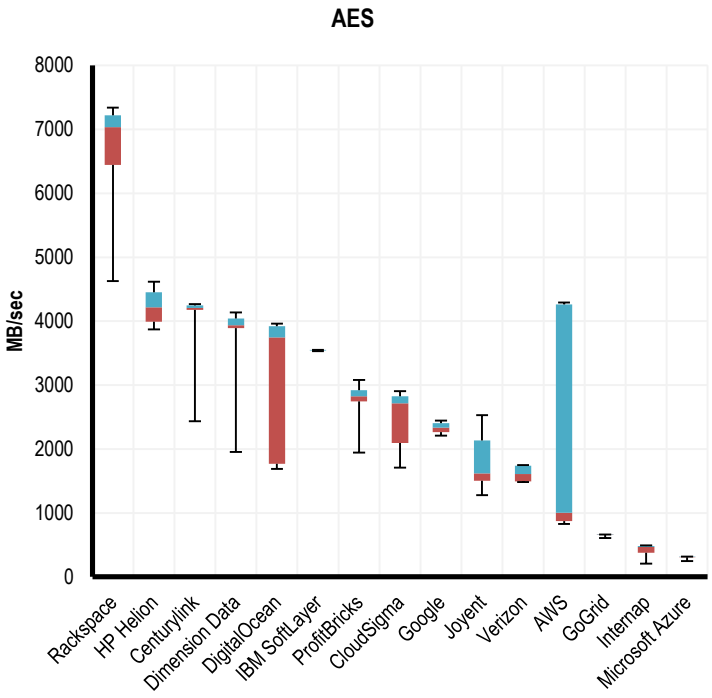
VM Processor Information

Provider	OS	Python Version	Processor (Medium)
AWS	Ubuntu 14.04	2.7	Intel Xeon CPU E5-2670 v2
CenturyLink	Ubuntu 14.04	2.7	Intel Xeon CPU E502650 v2
CloudSigma	Ubuntu 14.04	2.7	AMD Opteron Processor 6380
DigitalOcean	Ubuntu 14.04	2.7	Intel Xeon CPU E5-2630L v2
Dimension Data	Ubuntu 14.04	2.7	Intel Xeon CPU E5-4650
GoGrid	Ubuntu 14.04	2.7	Intel Xeon X5650
Google	Ubuntu 14.04	2.7	Intel Xeon CPU
HP Helion	Ubuntu 14.04	2.7	Intel Core 2 Duo T7700
IBM SoftLayer	Ubuntu 14.04	2.7	Intel Xeon CPU E5-2650 v2
Internap	Ubuntu 14.04	2.7	Common KVM processor
Joyent	Ubuntu 14.04	2.7	Intel Xeon E5645
Microsoft Azure	Ubuntu 14.04	2.7	AMD Opteron Processor 4171 HE
ProfitBricks	Ubuntu 14.04	2.7	AMD Opteron 62xx (Gen 4 Class Opteron)
Rackspace	Ubuntu 14.04	2.7	Intel Xeon CPU E5-2670 v2
Verizon	Ubuntu 14.04	2.7	Intel Xeon CPU E31265L

Individual Tasks

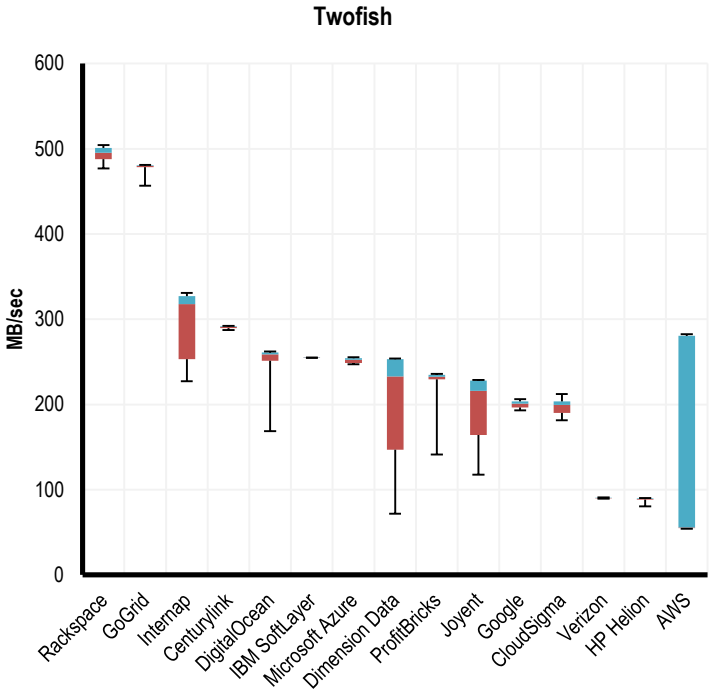
The following tables and graphs describe the performance ranking through each individual task. The rankings are from high to low based on median.

CPU Integer – AES: The AES workload encrypts a generated text string using the advanced encryption standard (AES). AES is used in security tools such as SSL, IPsec, and GPG. Geekbench uses the AES-NI instructions when they are available. When the AES-NI instructions are not available, Geekbench uses its own software AES implementation.



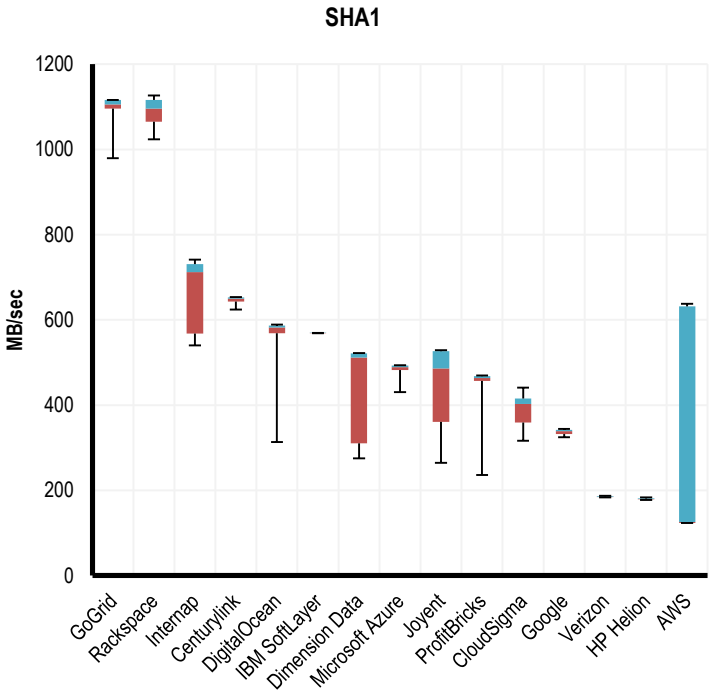
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	829	872	1004	4264	4291	1140	42.0%
CenturyLink	2437	4178	4209	4250	4270	79	2.9%
CloudSigma	1710	2093	2714	2826	2908	250	9.2%
DigitalOcean	1690	1772	3748	3922	3963	729	26.9%
Dimension Data	1956	3891	3937	4045	4137	193	7.1%
GoGrid	610	659	663	665	665	3	0.1%
Google	2212	2264	2335	2406	2447	40	1.5%
HP Helion	3871	3995	4219	4453	4618	146	5.4%
IBM SoftLayer	3533	3543	3543	3553	3553	3	0.1%
Internap	208	379	470	485	495	47	1.7%
Joyent	1280	1505	1618	2134	2529	197	7.3%
Microsoft Azure	249	309	314	316	318	4	0.1%
ProfitBricks	1946	2744	2826	2918	3082	66	2.4%
Rackspace	4628	6445	7035	7219	7342	270	9.9%
Verizon	1485	1495	1608	1741	1751	77	2.8%

CPU Integer – Twofish: The Twofish workload also encrypts a text string, but it uses the Twofish algorithm. Twofish is from the family of encryption algorithms known as "Feistel ciphers." It is included in the OpenPGP standard.



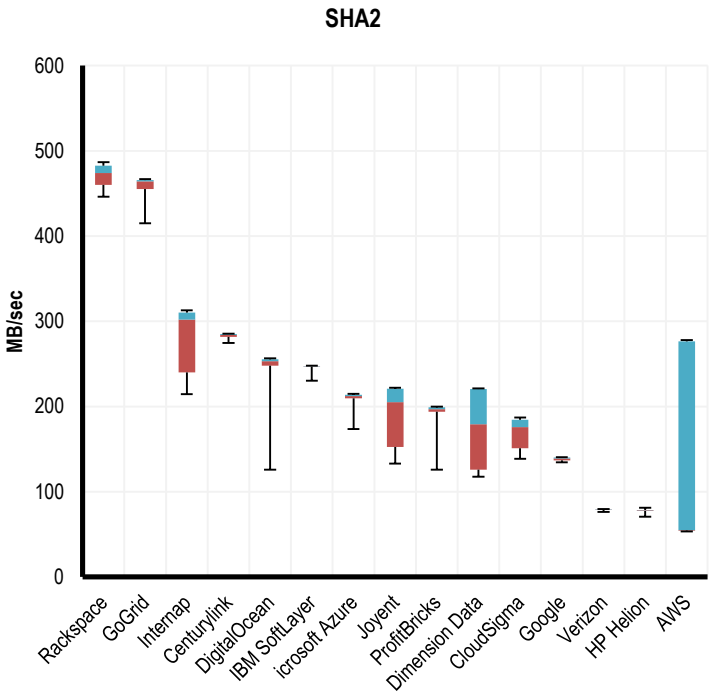
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	54.2	55.0	55.9	280.6	282.6	75.7	32.5%
CenturyLink	287.4	289.6	291.2	291.9	292.4	0.0	0.0%
CloudSigma	181.7	190.0	199.7	203.5	212.4	4.0	1.7%
DigitalOcean	168.6	251.4	259.0	261.1	262.2	5.1	2.2%
Dimension Data	72.0	147.1	233.0	253.3	253.8	36.0	15.5%
GoGrid	456.7	478.4	480.1	480.7	481.1	1.0	0.4%
Google	193.0	196.6	201.1	203.5	206.4	2.0	0.9%
HP Helion	80.5	88.4	89.2	89.8	90.2	0.9	0.4%
IBM SoftLayer	254.6	254.7	255.0	255.1	255.1	0.0	0.0%
Internap	227.5	253.1	317.7	327.1	330.9	29.5	12.7%
Joyent	117.8	164.1	216.1	228.2	228.7	20.7	8.9%
Microsoft Azure	247.4	248.7	252.4	254.5	255.4	1.0	0.4%
ProfitBricks	141.5	229.4	232.8	235.0	236.1	2.3	1.0%
Rackspace	477.0	487.8	495.6	501.0	504.3	4.0	1.7%
Verizon	89.4	89.8	90.3	90.7	91.1	0.0	0.0%

CPU Integer – SHA1: SHA1 is a cryptographic hash algorithm: given a binary input it generates a "hash" or "digest" of the input. SHA1 is designed so that the hash may be computed quickly, but it is difficult to find a string that generates a given hash. SHA1 may be used, for example, to encrypt passwords by storing the hash instead of the password text. The SHA1 workload uses a text string as input.



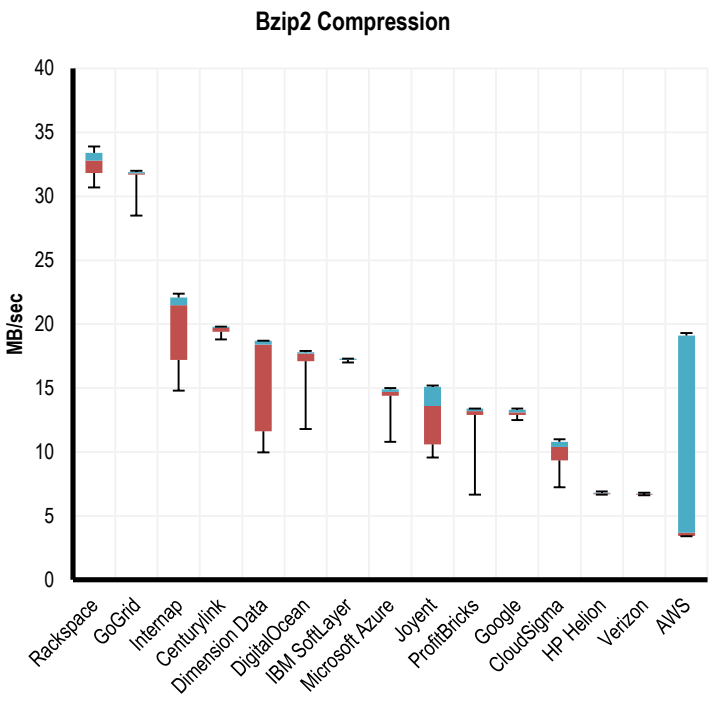
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	123.3	123.8	125.7	632.0	637.6	170.9	34.9%
CenturyLink	624.3	643.2	650.2	652.7	653.9	3.0	0.6%
CloudSigma	316.7	359.7	402.9	415.4	440.8	15.9	3.3%
DigitalOcean	313.7	568.9	582.0	586.8	589.1	17.4	3.6%
Dimension Data	275.0	310.4	511.4	521.7	522.5	69.9	14.3%
GoGrid	979.5	1095.7	1105.9	1116.2	1116.2	8.0	1.6%
Google	325.0	332.3	338.9	342.1	344.4	2.0	0.4%
HP Helion	177.6	178.7	180.0	181.4	183.8	0.0	0.0%
IBM SoftLayer	568.9	569.1	569.5	569.6	569.6	0.0	0.0%
Internap	540.1	568.2	712.3	731.1	741.8	72.4	14.8%
Joyent	264.8	360.4	486.3	526.6	528.8	51.7	10.6%
Microsoft Azure	430.3	482.5	489.0	492.7	493.9	4.0	0.8%
ProfitBricks	235.8	457.0	463.3	468.2	470.0	9.2	1.9%
Rackspace	1023.9	1065.0	1095.7	1116.2	1126.4	10.9	2.2%
Verizon	183.2	184.3	185.1	186.2	187.5	0.0	0.0%

CPU Integer – SHA2: SHA2 solves the same problem as SHA1, but is more secure: SHA1 has a known vulnerability to "collision attacks." Although these attacks are still impractical and SHA1 is still widely used, it is being gradually replaced by SHA2.



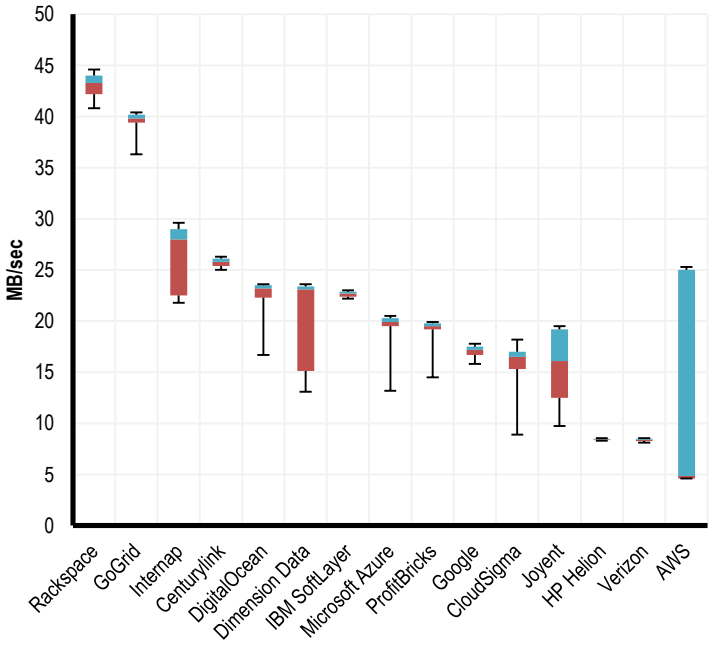
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	53.6	54.2	54.9	276.5	278.1	74.0	36.1%
CenturyLink	274.6	281.7	284.1	285.1	285.6	1.0	0.5%
CloudSigma	138.7	151.2	176.0	184.6	187.0	10.3	5.0%
DigitalOcean	125.9	247.8	253.4	255.3	256.5	5.0	2.4%
Dimension Data	117.7	126.0	179.1	220.4	221.3	33.1	16.1%
GoGrid	415.1	455.2	464.2	465.7	466.9	4.0	1.9%
Google	134.7	136.9	139.2	140.3	140.7	1.0	0.5%
HP Helion	70.9	77.6	78.3	78.8	81.1	0.8	0.4%
IBM SoftLayer	230.5	246.8	247.4	247.6	247.8	0.0	0.0%
Internap	214.4	240.1	302.1	310.2	312.9	30.8	15.0%
Joyent	133.0	152.5	205.2	220.9	222.0	51.6	25.1%
Microsoft Azure	173.5	209.6	212.3	213.8	214.9	2.1	1.0%
ProfitBricks	125.9	193.8	196.8	199.0	200.0	2.0	1.0%
Rackspace	446.1	460.2	474.0	482.5	486.8	4.7	2.3%
Verizon	76.5	78.8	79.1	79.4	79.9	0.0	0.0%

CPU Integer – Bzip2 Compression: BZip2 is a compression algorithm. The BZip2 workloads compress and decompress an ebook formatted using HTML. Geekbench 3 uses bzlib version 1.0.6 in the BZip2 workloads.



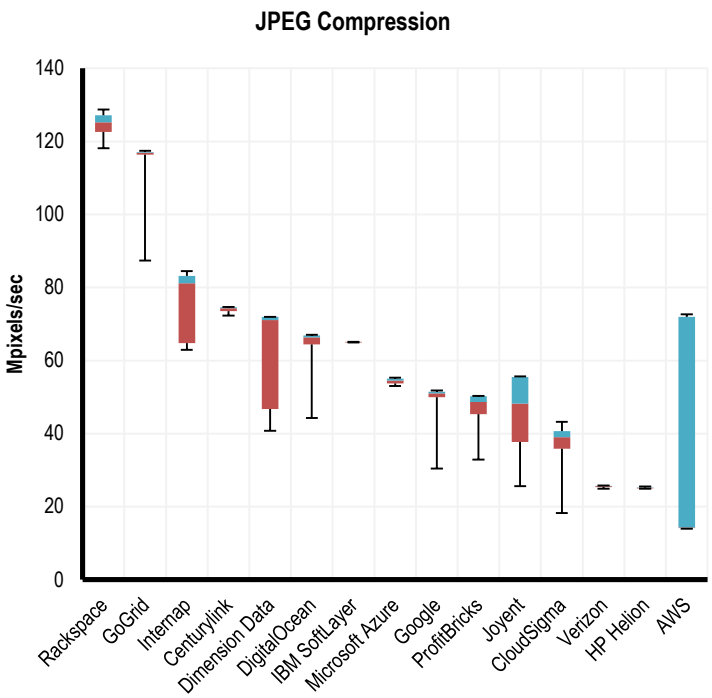
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	3.42	3.44	3.70	19.10	19.30	4.40	29.9%
CenturyLink	18.80	19.40	19.70	19.80	19.80	0.00	0.0%
CloudSigma	7.24	9.35	10.40	10.80	11.00	0.40	2.7%
DigitalOcean	11.80	17.10	17.70	17.80	17.90	0.34	2.3%
Dimension Data	9.97	11.63	18.40	18.70	18.70	2.21	15.0%
GoGrid	28.50	31.70	31.80	31.90	32.00	0.00	0.0%
Google	12.50	12.90	13.10	13.30	13.40	0.00	0.0%
HP Helion	6.66	6.70	6.76	6.82	6.93	0.00	0.0%
IBM SoftLayer	17.00	17.20	17.20	17.30	17.30	0.00	0.0%
Internap	14.80	17.20	21.50	22.10	22.40	1.90	12.9%
Joyent	9.58	10.60	13.60	15.10	15.20	1.43	9.7%
Microsoft Azure	10.80	14.40	14.70	14.90	15.00	0.14	1.0%
ProfitBricks	6.68	12.90	13.20	13.40	13.40	0.26	1.8%
Rackspace	30.70	31.84	32.80	33.40	33.90	0.32	2.2%
Verizon	6.61	6.66	6.71	6.75	6.82	0.00	0.0%

CPU Integer – Bzip2 Decompression: BZip2 is a compression algorithm. The BZip2 workloads compress and decompress an ebook formatted using HTML. Geekbench 3 uses bzlib version 1.0.6 in the BZip2 workloads.



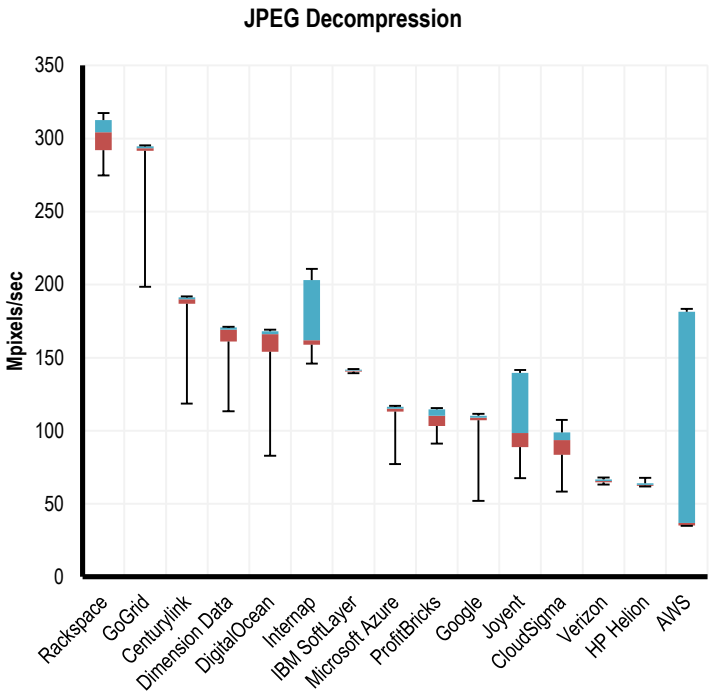
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	4.62	4.62	4.86	25.00	25.30	6.16	31.0%
CenturyLink	25.00	25.40	25.80	26.10	26.30	0.00	0.0%
CloudSigma	8.90	15.30	16.50	17.00	18.20	0.64	3.2%
DigitalOcean	16.70	22.30	23.20	23.50	23.60	0.46	2.3%
Dimension Data	13.10	15.13	23.10	23.40	23.60	2.52	12.7%
GoGrid	36.30	39.40	39.80	40.20	40.40	0.00	0.0%
Google	15.80	16.70	17.20	17.50	17.80	0.17	0.9%
HP Helion	8.29	8.36	8.42	8.50	8.56	0.00	0.0%
IBM SoftLayer	22.20	22.40	22.70	22.90	23.00	0.00	0.0%
Internap	21.80	22.50	28.00	29.00	29.60	2.60	13.1%
Joyent	9.75	12.50	16.10	19.20	19.50	2.24	11.3%
Microsoft Azure	13.20	19.50	19.90	20.30	20.50	0.38	1.9%
ProfitBricks	14.50	19.20	19.50	19.80	19.90	0.19	1.0%
Rackspace	40.80	42.20	43.30	44.00	44.60	0.43	2.2%
Verizon	8.13	8.27	8.40	8.49	8.55	0.00	0.0%

CPU Integer – JPEG Compression: The JPEG workloads compress and decompress one digital image using lossy JPEG format. The workloads use libjpeg version 6b.



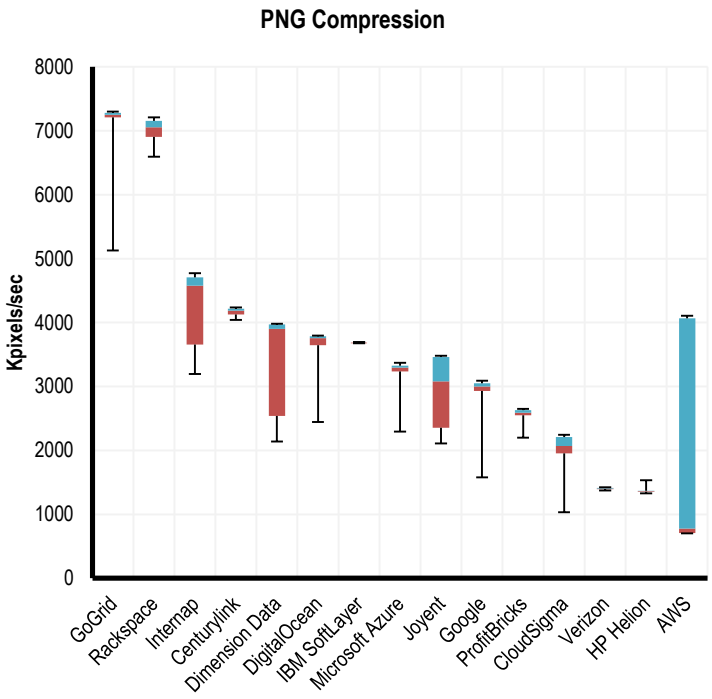
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	14.0	14.1	14.3	72.0	72.7	18.70	34.3%
CenturyLink	72.3	73.5	74.3	74.6	74.7	0.00	0.0%
CloudSigma	18.3	35.9	39.0	40.7	43.2	1.52	2.8%
DigitalOcean	44.3	64.4	66.4	66.9	67.1	1.32	2.4%
Dimension Data	40.8	46.8	71.1	72.0	72.0	7.37	13.5%
GoGrid	87.4	116.4	116.9	117.1	117.4	1.00	1.8%
Google	30.4	50.0	51.0	51.5	51.8	0.50	0.9%
HP Helion	24.9	25.0	25.2	25.3	25.5	0.00	0.0%
IBM SoftLayer	65.0	65.0	65.1	65.1	65.1	0.00	0.0%
Internap	62.9	64.8	81.2	83.2	84.5	7.50	13.8%
Joyent	25.6	37.7	48.2	55.5	55.7	5.64	10.3%
Microsoft Azure	53.0	53.7	54.5	55.1	55.3	0.00	0.0%
ProfitBricks	32.9	45.3	48.7	50.2	50.3	1.44	2.6%
Rackspace	118.1	122.6	125.2	127.2	128.7	1.25	2.3%
Verizon	24.9	25.4	25.6	25.7	25.8	0.00	0.0%

CPU Integer – JPEG Decompression: The JPEG workloads compress and decompress one digital image using lossy JPEG format. The workloads use libjpeg version 6b.



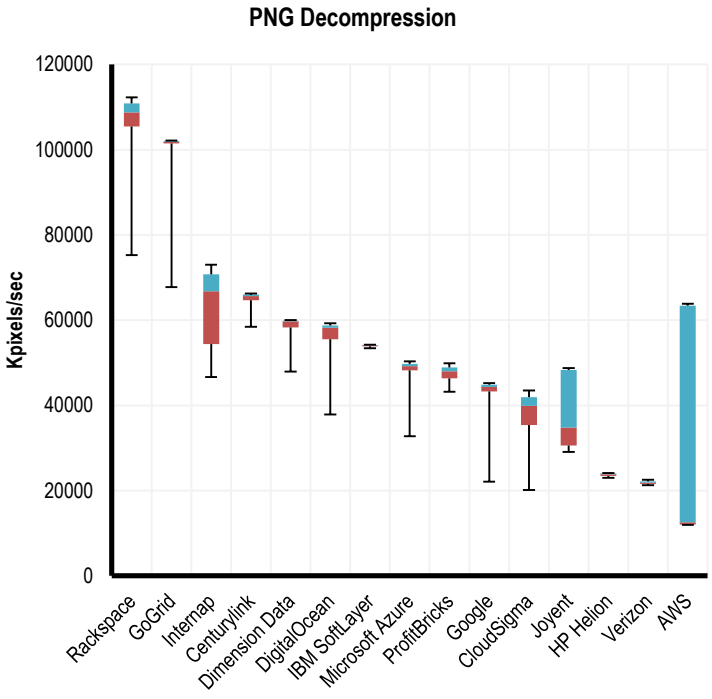
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	35.00	35.10	36.80	181.54	183.50	48.45	42.1%
CenturyLink	118.60	187.00	190.00	191.30	191.90	1.89	1.6%
CloudSigma	58.30	83.50	93.70	98.90	107.50	4.60	4.0%
DigitalOcean	82.90	154.01	166.20	168.03	169.20	6.56	5.7%
Dimension Data	113.40	161.18	169.20	170.70	171.20	3.36	2.9%
GoGrid	198.50	291.65	293.40	294.60	295.40	2.92	2.5%
Google	52.10	107.20	108.90	110.30	111.50	2.16	1.9%
HP Helion	61.80	62.30	62.90	64.00	67.80	0.62	0.5%
IBM SoftLayer	139.50	140.50	141.10	141.70	142.20	0.00	0.0%
Internap	145.90	158.80	162.00	203.16	210.80	15.30	13.3%
Joyent	67.50	88.90	98.40	139.72	141.50	16.64	14.5%
Microsoft Azure	77.20	113.10	115.00	116.40	117.00	2.28	2.0%
ProfitBricks	91.30	103.22	110.30	114.60	115.50	3.27	2.8%
Rackspace	274.70	292.00	304.30	312.70	317.40	6.06	5.3%
Verizon	63.20	64.70	65.60	66.70	67.90	0.00	0.0%

CPU Integer – PNG Compression: The PNG workloads also compress and decompress a digital image, but they do so using the PNG format. The workloads use libpng 1.6.2.



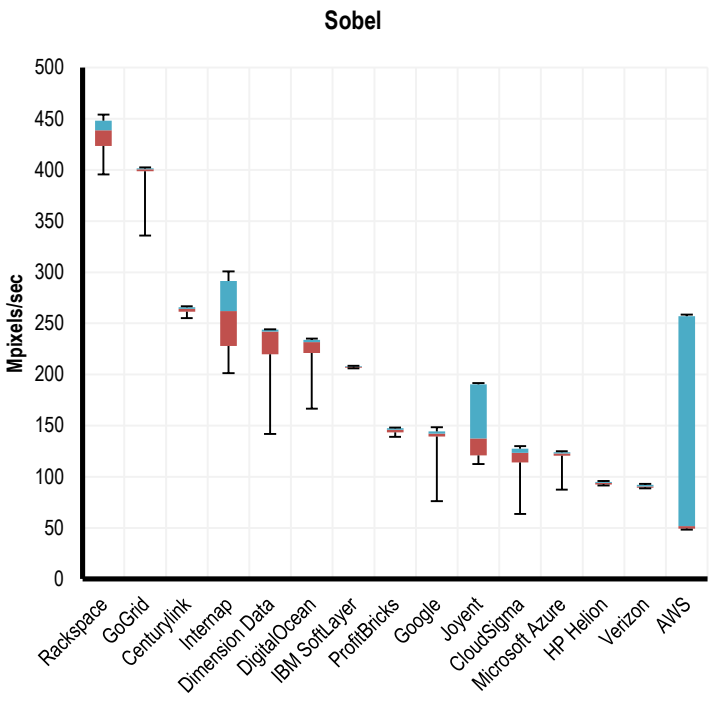
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	701	706	779	4065	4106	1126	34.1%
CenturyLink	4045	4127	4188	4219	4239	26	0.8%
CloudSigma	1034	1956	2068	2212	2243	82	2.5%
DigitalOcean	2447	3645	3758	3789	3799	101	3.1%
Dimension Data	2140	2540	3901	3973	3983	431	13.1%
GoGrid	5130	7209	7250	7281	7301	85	2.6%
Google	1577	2929	3000	3052	3092	63	1.9%
HP Helion	1331	1352	1362	1371	1536	12	0.4%
IBM SoftLayer	3676	3676	3686	3686	3697	2	0.1%
Internap	3195	3656	4577	4710	4772	451	13.7%
Joyent	2109	2353	3082	3461	3482	368	11.2%
Microsoft Azure	2294	3236	3297	3328	3369	66	2.0%
ProfitBricks	2202	2550	2591	2632	2652	20	0.6%
Rackspace	6595	6905	7055	7158	7209	78	2.4%
Verizon	1372	1393	1403	1413	1423	8	0.2%

CPU Integer – PNG Decompression: The PNG workloads also compress and decompress a digital image, but they do so using the PNG format. The workloads use libpng 1.6.2.



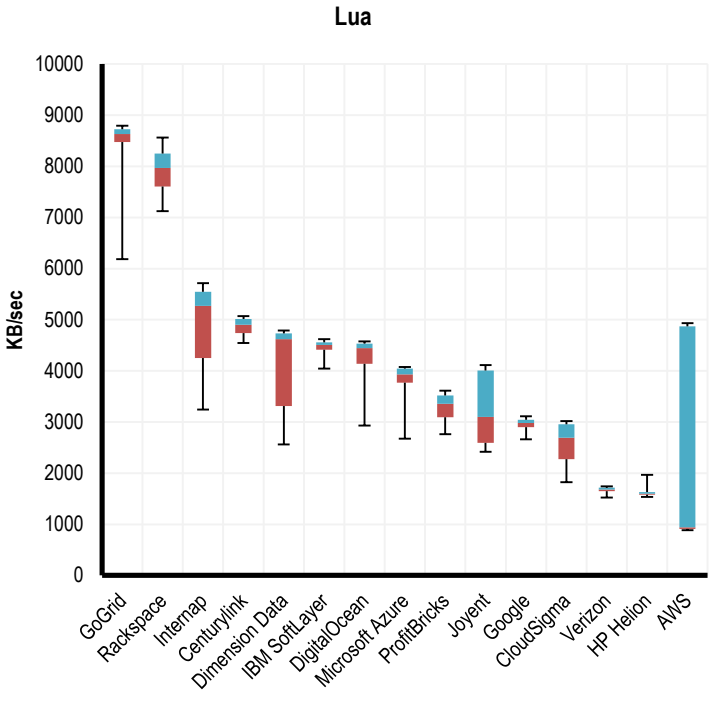
	Min	5th Per.	Median	95th Per.	Max	Stdev.	Variability
AWS	11981	12083	12595	63386	63898	17179	34.9%
CenturyLink	58470	64717	65638	66048	66253	510	1.0%
CloudSigma	20173	35430	39936	41948	43520	1946	4.0%
DigitalOcean	37888	55501	58266	58778	59290	1413	2.9%
Dimension Data	47923	58291	59699	59904	60006	928	1.9%
GoGrid	67789	101478	101888	102093	102195	1296	2.6%
Google	22118	43315	44339	44846	45261	933	1.9%
HP Helion	23040	23450	23859	24064	24166	178	0.4%
IBM SoftLayer	53453	53862	54067	54170	54272	122	0.2%
Internap	46694	54374	66765	70758	73011	6246	12.7%
Joyent	29082	30618	34816	48333	48742	5938	12.1%
Microsoft Azure	32768	48230	49254	49766	50381	1072	2.2%
ProfitBricks	43213	46387	48026	48947	49869	471	1.0%
Rackspace	75264	105472	108749	110899	112333	2044	4.1%
Verizon	21299	21606	21914	22221	22528	187	0.4%

CPU Integer – Sobel: The "Sobel operator" is used in image processing for finding edges in images. The Sobel workload uses the same input image as the JPEG and PNG workloads.



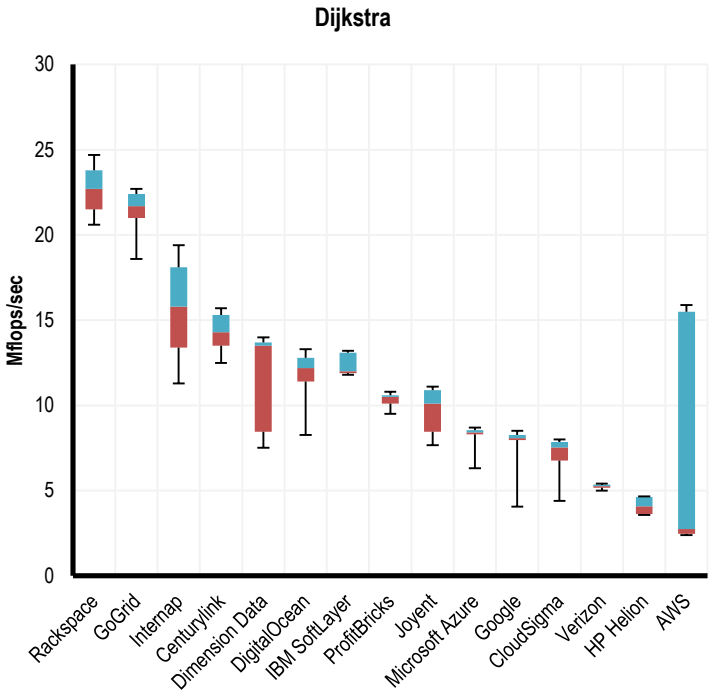
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	48.2	49.4	51.7	256.9	258.5	68.0	46.6%
CenturyLink	255.1	261.3	264.3	265.9	266.8	1.0	0.7%
CloudSigma	63.5	114.0	123.4	127.5	129.9	4.9	3.3%
DigitalOcean	166.6	221.0	231.8	233.9	235.1	4.6	3.2%
Dimension Data	141.9	219.8	242.1	243.8	244.3	16.6	11.4%
GoGrid	335.9	398.8	400.6	401.5	402.5	3.0	2.1%
Google	76.1	139.3	142.3	144.5	148.4	2.8	1.9%
HP Helion	91.4	92.3	93.9	95.0	96.0	0.0	0.0%
IBM SoftLayer	206.1	206.6	207.7	208.3	208.5	0.0	0.0%
Internap	201.4	227.8	261.9	291.6	300.9	25.8	17.7%
Joyent	112.5	120.8	137.6	190.3	191.5	21.6	14.8%
Microsoft Azure	87.3	120.5	122.8	124.1	125.0	1.2	0.8%
ProfitBricks	139.0	143.5	146.0	147.4	148.1	1.0	0.7%
Rackspace	395.7	423.4	438.7	448.2	454.3	4.4	3.0%
Verizon	88.8	89.4	90.6	92.0	93.2	0.9	0.6%

CPU Integer – Lua: Lua is lightweight scripting language. The Lua workload is similar to the code used to display Geekbench results in the Geekbench Browser.



	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	885	912	944	4874	4936	1324	33.7%
CenturyLink	4547	4741	4905	5018	5069	83	2.1%
CloudSigma	1823	2273	2693	2959	3021	219	5.6%
DigitalOcean	2929	4137	4444	4536	4577	164	4.2%
Dimension Data	2560	3313	4618	4731	4792	427	10.9%
GoGrid	6185	8479	8632	8724	8796	152	3.9%
Google	2662	2898	2980	3041	3113	47	1.2%
HP Helion	1536	1577	1597	1628	1966	26	0.7%
IBM SoftLayer	4045	4413	4506	4557	4618	52	1.3%
Internap	3246	4250	5274	5550	5714	535	13.6%
Joyent	2417	2591	3103	4006	4116	485	12.3%
Microsoft Azure	2673	3768	3932	4045	4076	106	2.7%
ProfitBricks	2765	3094	3359	3523	3615	137	3.5%
Rackspace	7127	7608	7967	8250	8561	195	5.0%
Verizon	1526	1649	1679	1717	1741	23	0.6%

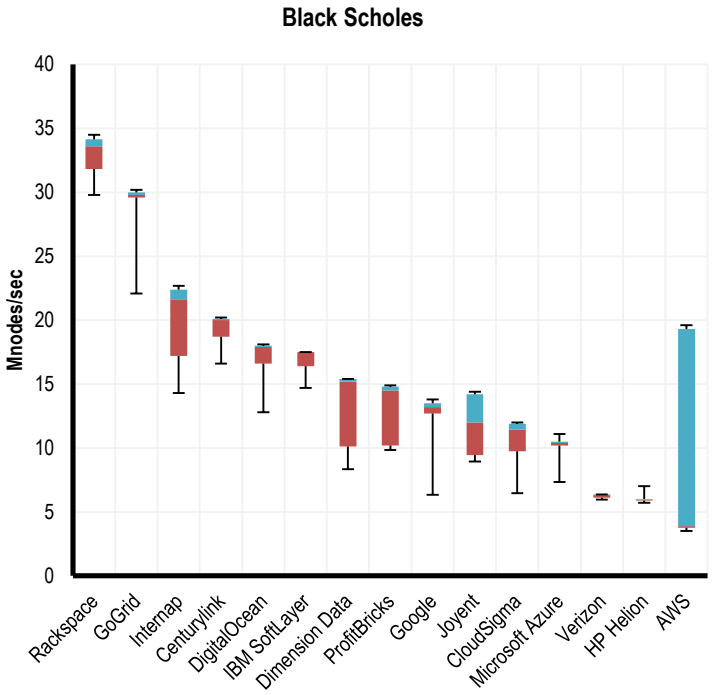
CPU Integer – Dijkstra: The Dijkstra workload computes driving directions between a sequence of destinations. Similar techniques are used by AIs to compute paths in games and by network routers to route computer network traffic.



	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	2.39	2.47	**2.74**	15.50	15.90	3.84	36.6%
CenturyLink	12.50	13.50	**14.30**	15.30	15.70	0.42	4.0%
CloudSigma	4.41	6.76	**7.54**	7.85	8.00	0.28	2.7%
DigitalOcean	8.27	11.40	**12.20**	12.80	13.30	0.36	3.4%
Dimension Data	7.51	8.46	**13.50**	13.70	14.00	1.56	14.9%
GoGrid	18.60	21.00	**21.70**	22.40	22.70	0.42	4.0%
Google	4.06	7.96	**8.09**	8.27	8.52	0.16	1.5%
HP Helion	3.58	3.64	**4.08**	4.62	4.67	0.28	2.7%
IBM SoftLayer	11.80	11.90	**12.00**	13.10	13.20	0.36	3.4%
Internap	11.30	13.40	**15.80**	18.10	19.40	1.50	14.3%
Joyent	7.66	8.45	**10.10**	10.90	11.10	0.63	6.0%
Microsoft Azure	6.32	8.30	**8.42**	8.55	8.70	0.08	0.8%
ProfitBricks	9.50	10.10	**10.50**	10.60	10.80	0.10	1.0%
Rackspace	20.60	21.50	**22.70**	23.80	24.70	0.66	6.3%
Verizon	5.01	5.18	**5.26**	5.35	5.42	0.05	0.5%

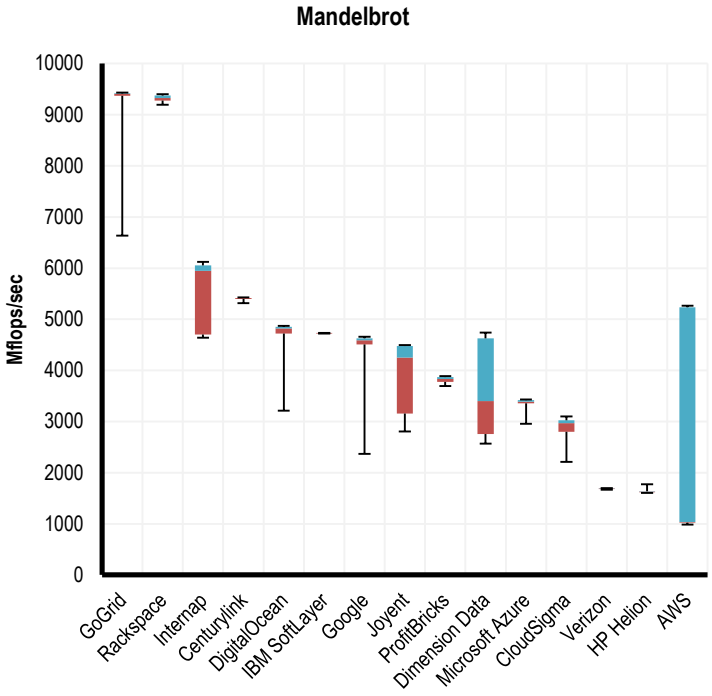
--- End of CPU Integer Results ---

CPU Floating Point – Black Scholes: The Black-Scholes equation is used to model option prices on financial markets. The Black-Scholes workload computes the Black-Scholes formula: a special case solution of the Black-Scholes equation for European call and put options.



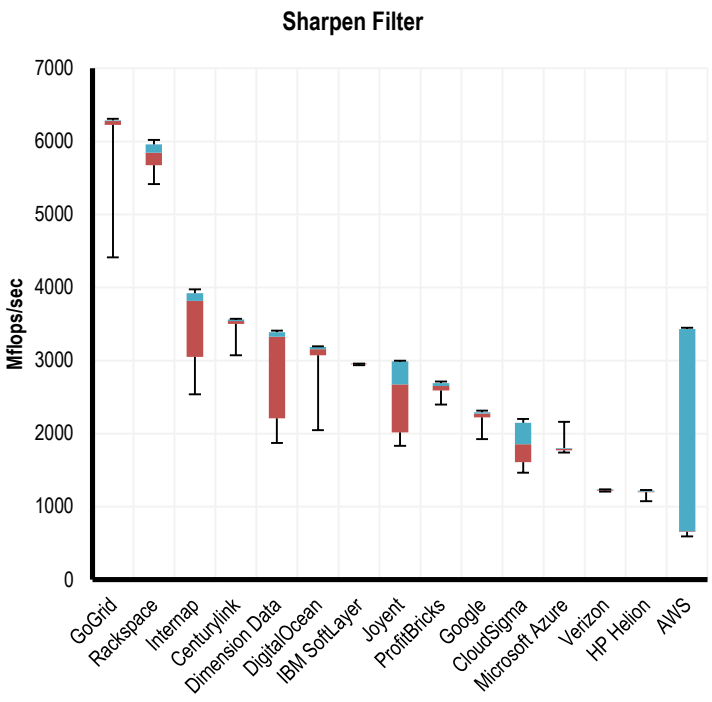
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	3.52	3.77	3.88	19.30	19.60	5.10	35.2%
CenturyLink	16.60	18.70	20.00	20.10	20.20	0.19	1.3%
CloudSigma	6.48	9.76	11.45	11.90	12.00	0.66	4.6%
DigitalOcean	12.80	16.60	17.90	18.00	18.10	0.34	2.3%
Dimension Data	8.34	10.13	15.20	15.40	15.40	1.26	8.7%
GoGrid	22.10	29.60	29.80	30.00	30.20	0.29	2.0%
Google	6.34	12.70	13.20	13.50	13.80	0.26	1.8%
HP Helion	5.73	5.90	5.97	6.01	7.01	0.05	0.3%
IBM SoftLayer	14.70	16.40	17.50	17.50	17.50	0.17	1.2%
Internap	14.30	17.20	21.60	22.40	22.70	2.20	15.2%
Joyent	8.95	9.45	12.00	14.20	14.40	1.56	10.8%
Microsoft Azure	7.35	10.20	10.40	10.50	11.10	0.20	1.4%
ProfitBricks	9.84	10.20	14.50	14.80	14.90	0.98	6.8%
Rackspace	29.80	31.84	33.60	34.17	34.50	0.33	2.3%
Verizon	5.96	6.13	6.32	6.36	6.38	0.06	0.4%

CPU Floating Point – Mandelbrot: The Mandelbrot set is a fractal. It is a useful floating point workload because it has a low memory bandwidth requirement.



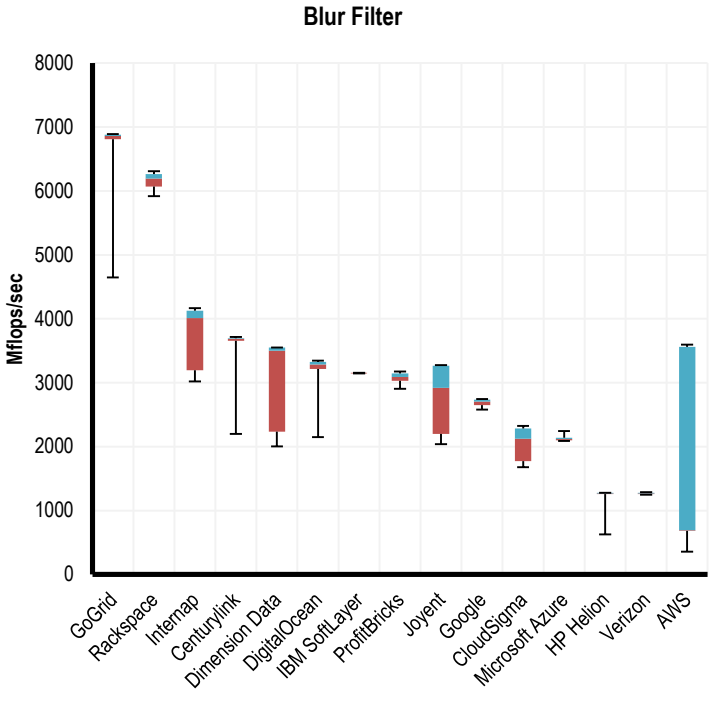
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	988	1024	1034	5233	5263	1410	33.2%
CenturyLink	5315	5396	5417	5417	5427	8	0.2%
CloudSigma	2212	2799	2970	3027	3103	75	1.8%
DigitalOcean	3215	4721	4823	4854	4874	99	2.3%
Dimension Data	2570	2755	3400	4628	4741	630	14.8%
GoGrid	6636	9370	9411	9421	9431	104	2.4%
Google	2365	4506	4588	4628	4659	90	2.1%
HP Helion	1608	1618	1628	1638	1772	17	0.4%
IBM SoftLayer	4721	4721	4731	4731	4731	3	0.1%
Internap	4639	4700	5949	6052	6124	572	13.5%
Joyent	2806	3154	4250	4475	4495	441	10.4%
Microsoft Azure	2959	3359	3389	3420	3430	47	1.1%
ProfitBricks	3697	3779	3830	3871	3891	30	0.7%
Rackspace	9196	9277	9329	9380	9400	31	0.7%
Verizon	1669	1679	1690	1700	1700	6	0.1%

CPU Floating Point – Sharpen Filter: The sharpen image workload uses a standard image sharpening technique similar to those found in Photoshop or Gimp.



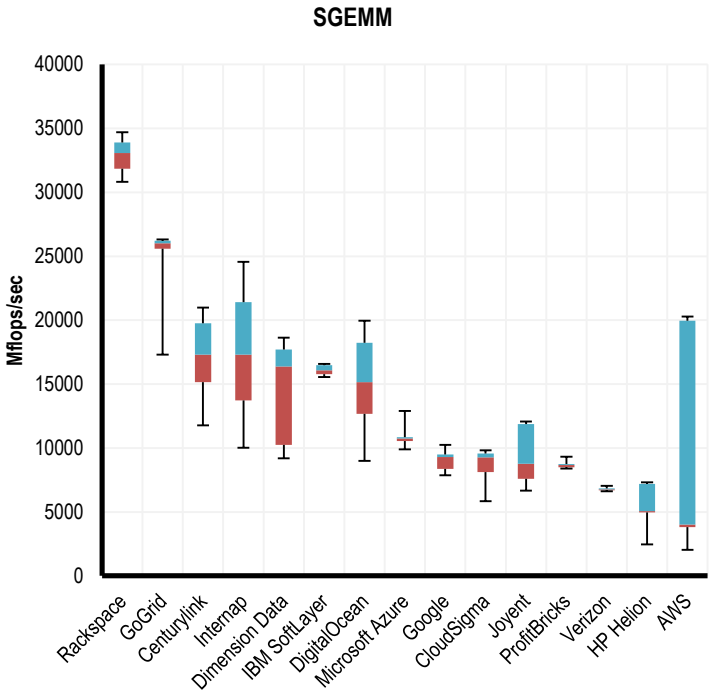
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	593	655	665	3430	3451	926	34.6%
CenturyLink	3072	3502	3543	3564	3574	24	0.9%
CloudSigma	1464	1608	1853	2150	2202	163	6.1%
DigitalOcean	2048	3072	3154	3185	3195	76	2.8%
Dimension Data	1874	2212	3328	3389	3410	376	14.1%
GoGrid	4413	6226	6277	6287	6308	78	2.9%
5Google	1925	2223	2273	2294	2314	25	0.9%
HP Helion	1075	1198	1208	1219	1229	12	0.4%
IBM SoftLayer	2939	2949	2959	2959	2959	5	0.2%
Internap	2540	3052	3820	3922	3973	364	13.6%
Joyent	1833	2017	2673	2990	3000	327	12.2%
Microsoft Azure	1741	1772	1792	1802	2161	38	1.4%
ProfitBricks	2396	2591	2652	2693	2714	33	1.2%
Rackspace	5417	5673	5847	5960	6021	87	3.3%
Verizon	1208	1219	1229	1239	1239	5	0.2%

CPU Floating Point – Blur Filter: Image blurring is also found in tools such as Photoshop. In Geekbench 3, the blur image workload is more computationally demanding than the sharpen workload.



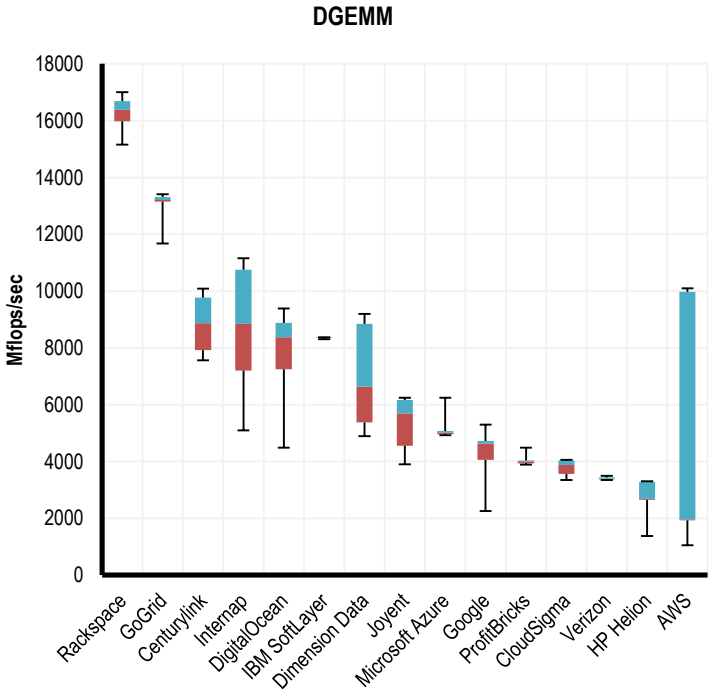
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	360	682	693	3564	3594	965	31.2%
CenturyLink	2202	3656	3686	3697	3717	48	1.6%
CloudSigma	1679	1775	2125	2284	2324	148	4.8%
DigitalOcean	2150	3215	3287	3328	3348	74	2.4%
Dimension Data	2007	2235	3502	3553	3553	432	14.0%
GoGrid	4649	6810	6861	6881	6892	89	2.9%
Google	2580	2652	2703	2734	2744	25	0.8%
HP Helion	626	1260	1270	1280	1280	37	1.2%
IBM SoftLayer	3144	3144	3154	3154	3154	4	0.1%
Internap	3021	3195	4014	4127	4168	393	12.7%
Joyent	2038	2202	2918	3267	3277	353	11.4%
Microsoft Azure	2089	2099	2120	2140	2243	17	0.5%
ProfitBricks	2908	3031	3092	3144	3174	36	1.2%
Rackspace	5919	6072	6195	6267	6308	59	1.9%
Verizon	1249	1260	1270	1280	1290	4	0.1%

CPU Floating Point – SGEMM: GEMM is "general matrix multiplication." Matrix multiplication is a fundamental mathematical operation. It is used in physical simulations, signal processing, graphics processing, and many other areas.



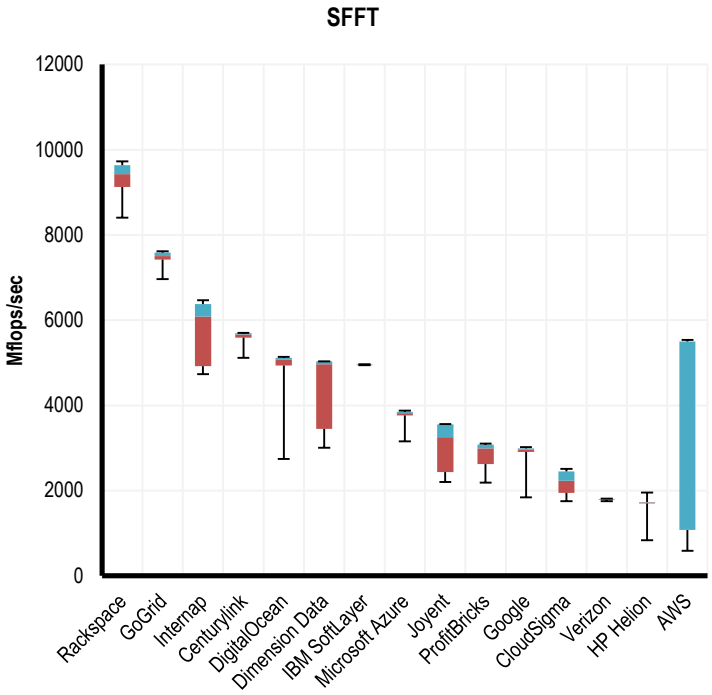
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	2028	3807	4004	19968	20275	5244	48.8%
CenturyLink	11776	15155	17306	19763	20992	1744	16.2%
CloudSigma	5847	8120	9277	9574	9830	452	4.2%
DigitalOcean	8991	12667	15155	18227	19968	1799	16.7%
Dimension Data	9185	10240	16384	17715	18637	2160	20.1%
GoGrid	17306	25600	26010	26214	26317	376	3.5%
Google	7875	8376	9298	9492	10240	332	3.1%
HP Helion	2468	4977	5059	7187	7311	773	7.2%
IBM SoftLayer	15565	15770	16077	16486	16589	239	2.2%
Internap	10025	13722	17306	21402	24576	2067	19.2%
Joyent	6676	7604	8765	11878	12083	1315	12.2%
Microsoft Azure	9902	10547	10752	10854	12902	238	2.2%
ProfitBricks	8407	8499	8663	8755	9329	85	0.8%
Rackspace	30822	31846	33075	33894	34714	596	5.5%
Verizon	6615	6687	6758	6840	7035	47	0.4%

CPU Floating Point – DGEMM: GEMM is "general matrix multiplication." Matrix multiplication is a fundamental mathematical operation. It is used in physical simulations, signal processing, graphics processing, and many other areas.



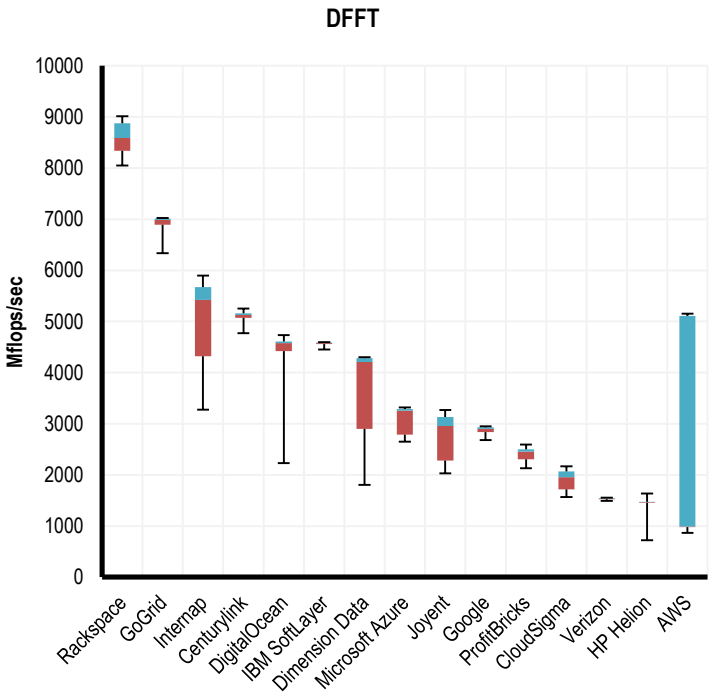
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	1055	1935	1966	9974	10097	2681	47.1%
CenturyLink	7567	7926	8868	9769	10086	612	10.7%
CloudSigma	3348	3564	3881	4035	4055	151	2.7%
DigitalOcean	4485	7250	8376	8878	9390	538	9.4%
Dimension Data	4895	5376	6641	8847	9196	1035	18.2%
GoGrid	11674	13153	13210	13312	13414	100	1.8%
Google	2263	4065	4639	4721	5294	211	3.7%
HP Helion	1382	2652	2683	3287	3308	232	4.1%
IBM SoftLayer	8305	8356	8366	8376	8376	8	0.1%
Internap	5100	7203	8842	10752	11162	989	17.4%
Joyent	3901	4551	5693	6164	6246	464	8.1%
Microsoft Azure	4925	4966	5018	5069	6246	124	2.2%
ProfitBricks	3891	3932	4004	4035	4485	35	0.6%
Rackspace	15155	15974	16384	16691	16998	247	4.3%
Verizon	3348	3369	3400	3441	3502	22	0.4%

CPU Floating Point – SFFT: The fast Fourier transform (FFT) workloads simulate the frequency analysis used to compute the spectrum view in an audio processing application such as Pro Tools.



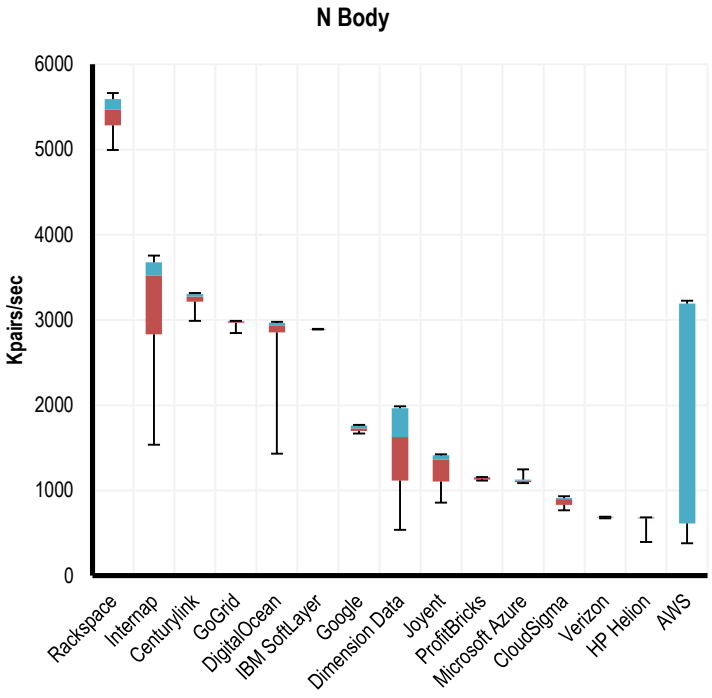
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	587	1075	1096	5499	5540	1479	38.7%
CenturyLink	5120	5591	5663	5693	5704	37	1.0%
CloudSigma	1751	1946	2232	2454	2509	160	4.2%
DigitalOcean	2744	4936	5079	5120	5140	163	4.3%
Dimension Data	3011	3453	4966	5038	5038	471	12.3%
GoGrid	6963	7424	7506	7588	7619	60	1.6%
Google	1843	2908	2959	2990	3021	48	1.3%
HP Helion	837	1700	1720	1731	1956	52	1.4%
IBM SoftLayer	4946	4946	4956	4956	4966	5	0.1%
Internap	4731	4925	6083	6380	6472	651	17.0%
Joyent	2202	2435	3256	3553	3564	371	9.7%
Microsoft Azure	3154	3768	3820	3850	3881	71	1.9%
ProfitBricks	2191	2621	2990	3082	3103	150	3.9%
Rackspace	8407	9124	9431	9636	9728	163	4.3%
Verizon	1751	1782	1792	1802	1812	7	0.2%

CPU Floating Point – DFFT: The fast Fourier transform (FFT) workloads simulate the frequency analysis used to compute the spectrum view in an audio processing application such as Pro Tools.



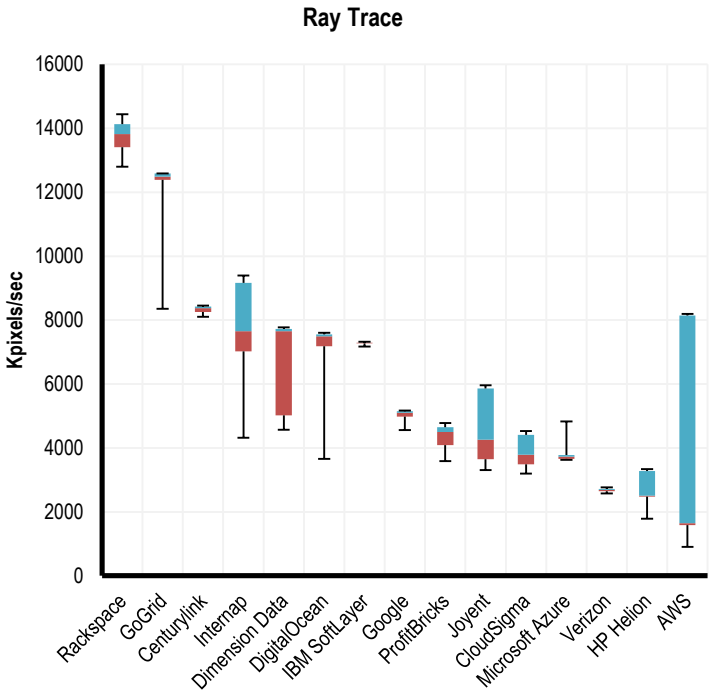
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	866	982	989	5110	5151	1379	42.3%
CenturyLink	4772	5069	5130	5161	5253	32	1.0%
CloudSigma	1567	1720	1956	2068	2171	106	3.3%
DigitalOcean	2232	4421	4577	4611	4731	156	4.8%
Dimension Data	1802	2900	4209	4280	4301	452	13.9%
GoGrid	6339	6892	6984	7014	7025	54	1.7%
Google	2683	2836	2898	2929	2949	27	0.8%
HP Helion	721	1454	1464	1475	1638	45	1.4%
IBM SoftLayer	4454	4557	4577	4588	4598	14	0.4%
Internap	3277	4321	5422	5673	5898	591	18.1%
Joyent	2028	2284	2959	3133	3267	288	8.8%
Microsoft Azure	2652	2785	3256	3287	3318	213	6.5%
ProfitBricks	2130	2304	2458	2499	2591	63	1.9%
Rackspace	8049	8335	8591	8878	9011	162	5.0%
Verizon	1495	1526	1536	1546	1556	6	0.2%

CPU Floating Point – N Body: This workload computes a physical simulation similar to that required for a physics game placed in outer space.



	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	382	613	618	3195	3226	865	53.1%
CenturyLink	2990	3215	3277	3308	3318	28	1.7%
CloudSigma	767	832	900	912	934	27	1.7%
DigitalOcean	1434	2854	2939	2970	2980	80	4.9%
Dimension Data	537	1116	1628	1966	1987	303	18.6%
GoGrid	2847	2970	2980	2990	2990	10	0.6%
Google	1669	1700	1731	1761	1772	17	1.0%
HP Helion	394	674	680	684	686	16	1.0%
IBM SoftLayer	2888	2888	2898	2898	2898	3	0.2%
Internap	1536	2831	3523	3676	3758	338	20.8%
Joyent	860	1106	1362	1413	1423	102	6.3%
Microsoft Azure	1085	1100	1116	1126	1249	15	0.9%
ProfitBricks	1116	1126	1147	1157	1157	0	0.0%
Rackspace	4997	5284	5468	5591	5663	95	5.8%
Verizon	675	686	688	691	694	1	0.1%

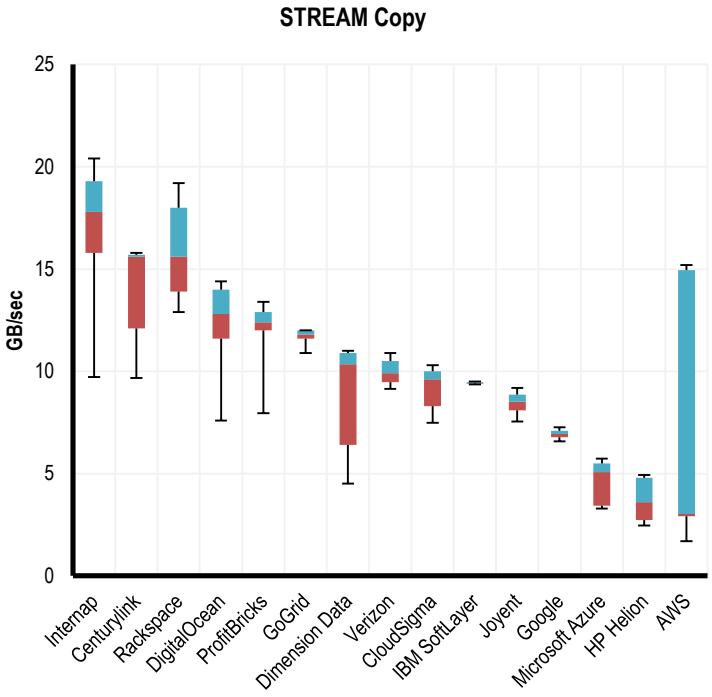
CPU Floating Points – Ray Trace: The ray trace workload renders a 3D scene from a geometric description.



	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	902	1587	1649	8141	8192	2184	42.8%
CenturyLink	8100	8256	8376	8428	8458	54	1.1%
CloudSigma	3195	3492	3789	4413	4526	215	4.2%
DigitalOcean	3656	7185	7496	7557	7608	242	4.7%
Dimension Data	4567	5018	7649	7721	7772	708	13.9%
GoGrid	8356	12390	12493	12595	12595	201	3.9%
Google	4557	4977	5100	5151	5171	56	1.1%
HP Helion	1782	2478	2509	3277	3338	378	7.4%
IBM SoftLayer	7178	7270	7291	7291	7322	10	0.2%
Internap	4321	7025	7654	9165	9400	788	15.5%
Joyent	3308	3645	4260	5857	5960	722	14.2%
Microsoft Azure	3625	3656	3727	3774	4833	115	2.3%
ProfitBricks	3584	4086	4495	4649	4782	164	3.2%
Rackspace	12800	13414	13824	14131	14438	241	4.7%
Verizon	2580	2652	2683	2714	2765	20	0.4%

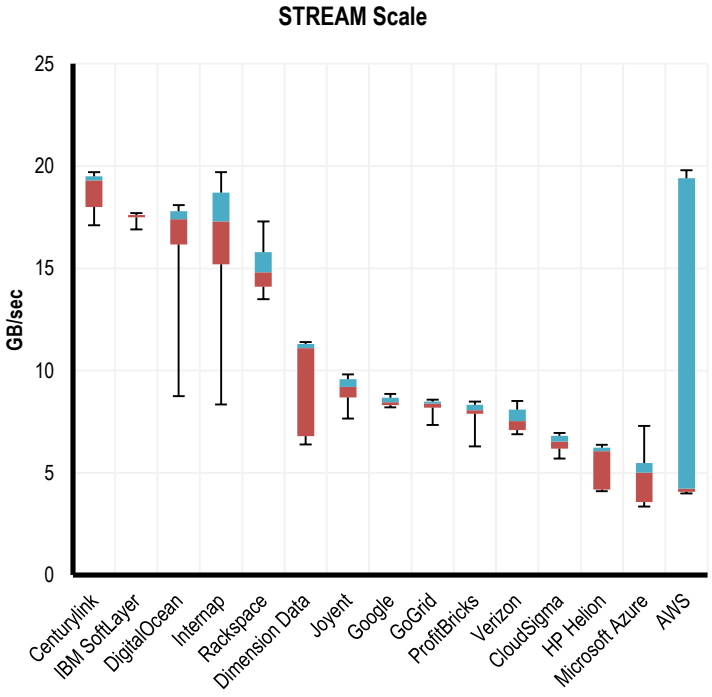
--- End of Floating Point Results ---

Memory – STREAM Copy: The stream copy workload tests how fast your computer can copy large amounts of data in memory. It executes a value-by-value copy of a large list of floating point numbers.



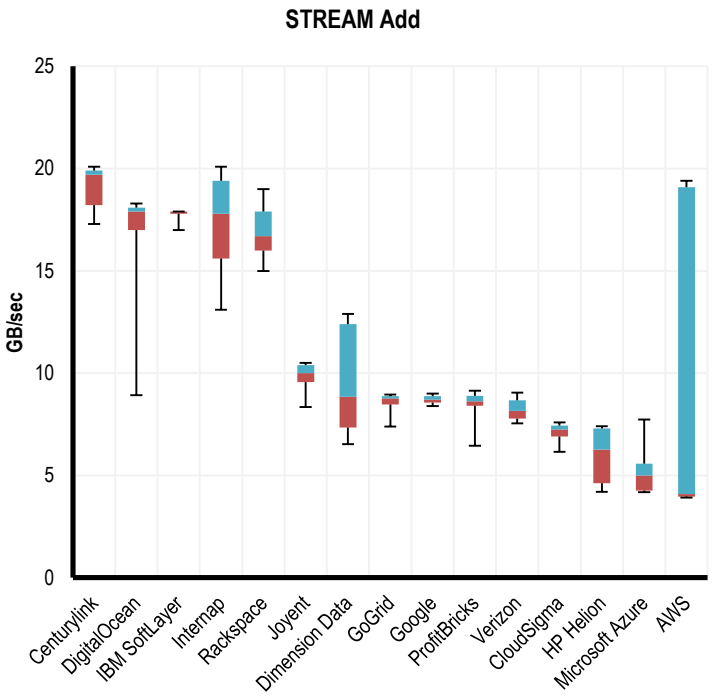
	Min	5th Per.	Median	95th Per.	Max	Stdev.	Variability
AWS	1.69	2.92	3.02	14.94	15.20	3.36	33.9%
CenturyLink	9.68	12.10	15.60	15.70	15.80	1.12	11.3%
CloudSigma	7.49	8.29	9.61	10.00	10.30	0.45	4.5%
DigitalOcean	7.60	11.60	12.80	14.00	14.40	0.72	7.3%
Dimension Data	4.52	6.40	10.35	10.90	11.00	1.53	15.4%
GoGrid	10.90	11.60	11.80	12.00	12.00	0.11	1.1%
Google	6.57	6.78	6.93	7.09	7.26	0.06	0.6%
HP Helion	2.46	2.73	3.61	4.79	4.94	0.48	4.8%
IBM SoftLayer	9.37	9.39	9.42	9.47	9.51	0.00	0.0%
Internap	9.73	15.80	17.80	19.30	20.40	1.02	10.3%
Joyent	7.54	8.09	8.51	8.86	9.19	1.06	10.7%
Microsoft Azure	3.29	3.44	5.07	5.50	5.74	0.44	4.4%
ProfitBricks	7.95	12.00	12.40	12.90	13.40	0.24	2.4%
Rackspace	12.90	13.90	15.60	18.00	19.20	1.05	10.6%
Verizon	9.14	9.47	9.91	10.50	10.90	0.27	2.7%

Memory – STREAM Scale: This workload is similar to stream copy, but each value is multiplied by a constant during the copy.



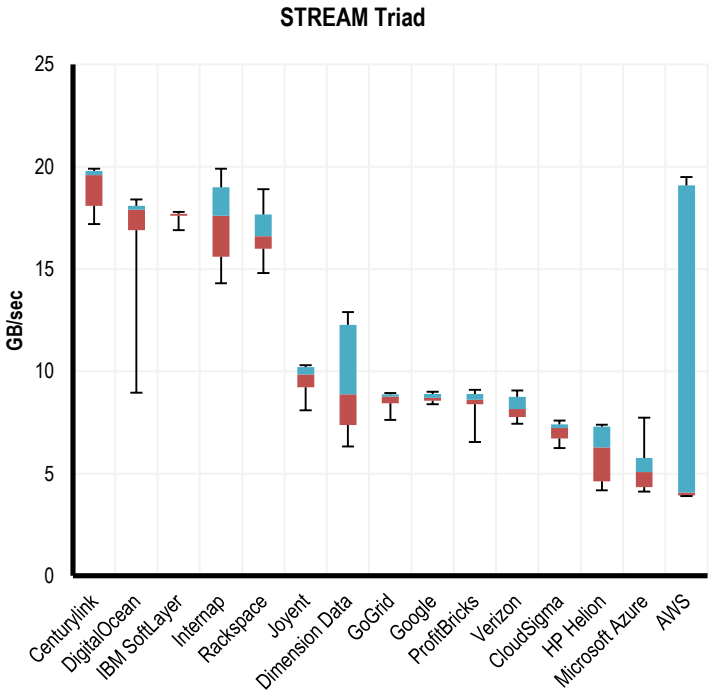
	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	3.99	4.08	4.23	19.40	19.80	4.74	56.0%
CenturyLink	17.10	18.00	19.30	19.50	19.70	0.38	4.5%
CloudSigma	5.70	6.19	6.53	6.81	6.96	0.12	1.4%
DigitalOcean	8.76	16.17	17.40	17.80	18.10	0.68	8.0%
Dimension Data	6.39	6.79	11.10	11.30	11.40	1.30	15.4%
GoGrid	7.35	8.19	8.39	8.49	8.58	0.08	0.9%
Google	8.21	8.32	8.46	8.67	8.86	0.08	0.9%
HP Helion	4.10	4.18	6.06	6.23	6.37	0.60	7.1%
IBM SoftLayer	16.90	17.50	17.60	17.60	17.70	0.00	0.0%
Internap	8.34	15.20	17.30	18.70	19.70	1.02	12.1%
Joyent	7.65	8.69	9.20	9.58	9.81	0.18	2.1%
Microsoft Azure	3.36	3.58	5.02	5.48	7.30	0.44	5.2%
ProfitBricks	6.30	7.89	8.07	8.33	8.49	0.16	1.9%
Rackspace	13.50	14.10	14.80	15.80	17.30	0.42	5.0%
Verizon	6.89	7.10	7.53	8.10	8.51	0.21	2.5%

Memory – STREAM Add: The stream add workload reads two large lists of floating point numbers value-by-value, adds corresponding values, and stores the result in a third list.



	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	3.92	3.97	4.09	19.10	19.40	4.80	54.7%
CenturyLink	17.30	18.23	19.70	19.90	20.10	0.38	4.3%
CloudSigma	6.16	6.91	7.25	7.44	7.60	0.14	1.6%
DigitalOcean	8.92	17.00	17.90	18.10	18.30	0.51	5.8%
Dimension Data	6.53	7.35	8.85	12.40	12.90	1.44	16.4%
GoGrid	7.39	8.46	8.77	8.88	8.95	0.08	0.9%
Google	8.39	8.57	8.70	8.88	9.00	0.08	0.9%
HP Helion	4.20	4.62	6.27	7.30	7.40	0.84	9.6%
IBM SoftLayer	17.00	17.80	17.90	17.90	17.90	0.00	0.0%
Internap	13.10	15.60	17.80	19.40	20.10	0.85	9.7%
Joyent	8.34	9.57	10.00	10.40	10.50	0.18	2.1%
Microsoft Azure	4.19	4.27	5.00	5.58	7.73	0.32	3.6%
ProfitBricks	6.46	8.41	8.62	8.90	9.14	0.16	1.8%
Rackspace	15.00	16.00	16.70	17.90	19.00	0.48	5.5%
Verizon	7.54	7.78	8.17	8.67	9.05	0.24	2.7%

Memory – STREAM Triad: This workload combines stream add and stream scale. It reads two lists of floating point numbers value-by-value, multiplies one of the numbers by a constant, adds the result to the other number, and writes that result to a third list.



	Min.	5th Per.	Median	95th Per.	Max.	Stdev.	Variability
AWS	3.90	3.94	4.08	19.10	19.50	4.80	54.7%
CenturyLink	17.20	18.10	19.60	19.80	19.90	0.38	4.3%
CloudSigma	6.25	6.72	7.23	7.41	7.59	0.14	1.6%
DigitalOcean	8.95	16.90	17.90	18.10	18.40	0.68	7.8%
Dimension Data	6.33	7.37	8.87	12.28	12.90	1.35	15.4%
GoGrid	7.63	8.44	8.77	8.87	8.94	0.08	0.9%
Google	8.39	8.57	8.71	8.89	9.00	0.08	0.9%
HP Helion	4.18	4.62	6.28	7.30	7.39	0.78	8.9%
IBM SoftLayer	16.90	17.60	17.70	17.70	17.80	0.00	0.0%
Internap	14.30	15.60	17.60	19.00	19.90	0.85	9.7%
Joyent	8.09	9.23	9.84	10.20	10.30	0.18	2.1%
Microsoft Azure	4.12	4.34	5.07	5.76	7.74	0.45	5.1%
ProfitBricks	6.54	8.40	8.62	8.90	9.10	0.08	0.9%
Rackspace	14.80	16.00	16.60	17.67	18.90	0.48	5.5%
Verizon	7.44	7.76	8.15	8.75	9.07	0.24	2.7%

--- End of Memory Results ---

Score Aggregation

The performance output of each individual task was converted into Geekbench performance scores using the conversion rates and formulas below. The below conversion rates are consistent with Geekbench's methodology. Information on how specific aggregate scores were calculated appears in the equations below the table.

Category	Task	Conversion Rate
Integer	AES (MB/sec)	1.14
	Twofish (MB/sec)	17.82
	SHA1 (MB/sec)	9.21
	SHA2 (MB/sec)	23.11
	BZip2 Compression (MB/sec)	246.02
	BZip2 Decompression (MB/sec)	184.51
	JPEG Compression (Mpixels/sec)	75.27
	JPEG Decompression (Mpixels/sec)	42.42
	PNG Compression (Kpixels/sec)	1.28
	PNG Decompression (Kpixels/sec)	0.09
	Sobel (Mpixels/sec)	28.82
	Lua (KB/sec)	1.09
	Dijkstra (Mflops/sec)	292.20
Floating Point	BlackScholes (Mnodes/sec)	235.64
	Mandelbrot (Mflops/sec)	1.02
	Sharpen Filter (Mflops/sec)	1.41
	Blur Filter (Mflops/sec)	1.10
	SGEMM (Mflops/sec)	0.37
	DGEMM (Mflops/sec)	0.71
	SFFT (Mflops/sec)	0.99
	DFFT (Mflops/sec)	1.15
	N-Body (Kpairs/sec)	2.76
	Ray Trace (Kpixels/sec)	0.87
Memory	STREAM Copy (GB/sec)	250.66
	STREAM Scale (GB/sec)	250.48
	STREAM Add (GB/sec)	221.14
	STREAM Triad (GB/sec)	227.55

*Task_Performance_Score = Test_Score * Conversion_Rate*

Integer_Performance_Score = Geometric mean {Integer_Task_Performance_Scores}

Floating_Point_Performance_Score = Geometric mean {Floating_Point_Task_Performance_Scores}

CPU_Performance_Score = Average {Integer_Performance_Score, Floating_Point_Performance_Score}

Memory_Performance_Score = Geometric mean {Memory_Test_Performance_Scores}

CPU_&_Memory_Performance_Score = (4 CPU_Performance_Score + Memory_Performance_Score)/5*

About Cloud Spectator

Cloud Spectator is a cloud analyst 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.

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