IaaS Performance Analysis

Processor performance of Amazon EC2 and CenturyLink Cloud

Cloud Spectator & Structure Research – May 2014

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Introduction

Since 2011, Cloud Spectator has tracked the pricing models and performance capabilities of the most recognized cloud infrastructure providers in the industry. One of Cloud Spectator's primary goals is to establish a standard of comparison to help cloud infrastructure users better understand the market landscape so they can make more informed decisions when selecting their provider(s).

Philbert Shih is the Founder and Managing Director of Structure Research, an independent research and consulting firm devoted to the hosting and cloud infrastructure services market. Mr. Shih has covered the hosting infrastructure space for over a decade. Prior to founding Structure Research, Mr. Shih was the first hosting analyst hired after Tier1 Research was sold to The 451 Group (2005) and spent six years as Senior Analyst for Hosting. In this role, Mr. Shih helped launch Tier1's coverage of hosting in international markets and was the lead and contributing author to all of the company's quarterly and bi-annual hosting infrastructure sector reports.

Why we published this report

Recently, CenturyLink Cloud announced lower prices for their cloud instances, claiming to make "a bold cloud move against you-know-who." For this report, Cloud Spectator wanted to see if the claim only held true to CenturyLink Cloud's claim for bandwidth value, or if it meant system value as well. In the case that it did apply, how much did it apply; i.e., was it only a matter of On-Demand pricing, or does the claim hold true for long-term pricing (think Amazon Reserved Instances) as well? And is it only a particular instance size, or does it span a variety of scalable virtual machines?

This report uses data gathered by running the Geekbench 3 benchmark suite, which simulates integer and floating point intensive compute processes to provide an understanding of processor performance. It also leverages STREAM, a recognized memory bandwidth benchmark. STREAM combines with the processor testing to produce the final score output of Geekbench 3 which gives an indexed, comparative value of system performance.

Notes about this study

- Geekbench 3 is a benchmark suite designed to measure and compare performance of machines, but may not reflect the performance of specific applications. Certain applications have complex system requirements (e.g., disk IOPS, network throughput, additional nodes, etc.) and dependencies outside of the scope of Geekbench 3 and this report. Thus, the results in this published report should be viewed as a general, comparative measurement and should not be extrapolated to reflect specific application performance, where bottlenecks may occur independent of processor performance.
- The hypervisor is a central part to controlling and allocating processing power in a public environment. Thus, this is not exclusively a comparison of processor performance across providers, but also a glimpse into hypervisor behavior and processing allocation with respect to scalability, and the costs associated. Amazon EC2 has heavily modified its Xen-based hypervisor, while CenturyLink uses VMware.
- The information on processors in this report are extracted from the system BIOS. As this is a public cloud environment, the system BIOS lists what the hypervisor reports; i.e., the accuracy of the processors reported are dependent on the hypervisor reporting them. It cannot be guaranteed with 100% certainty that the BIOS reports accurate processor information.
    - E.g., on the AWS website, Amazon states the M3 family features Intel Xeon E5-2670 processors (although in the footnote, Amazon states that "M3 instances may also launch as an Intel Xeon E5-2670 v2 (Ivy Bridge) Processor running at 2.5GHz"), while the C3 family features Intel Xeon E5-2670 v2 processors. The BIOS from the tested VMs reported the M3 running on Intel Xeon E5-2670 v2, and the C3's all running on Intel Xeon E5-2680 v2.

- All results from this report can only reflect the scope of this project including but not limited to virtual machine sizes, operating systems, default compilers, physical hosts, costs at the time of experimentation, etc. Thus, results should not be assumed to be reflective of performance outside of the scope of the project; e.g., variations of operating system images may or may not affect performance results. Geekbench 3 measures processor performance and tries to minimize the impact that the compiler and operating system have on the measurement.
    - To standardize comparisons, Cloud Spectator provisioned virtual machines in CenturyLink's Virginia (Sterling) data center. Historically, Cloud Spectator monitors other data centers in the CenturyLink Cloud; hardware may not be not standardized, and performance is also highly dependent on the type of physical machine a virtual server is provisioned inside.
        - E.g., a 4 vCPU, 8GB Memory virtual machine enabled on CenturyLink Cloud's New York data center sustained 193 megapixels per second decompressing a JPEG file, while the same configuration on a Hyperscale enabled machine in CenturyLink Cloud's Virginia data center sustained 305.2 megapixels per second (to see these detailed results, please view Appendix – Raw Scores). The results of the New York data center can be viewed through the Cloud Spectator Portal[1].

The Role of CPU and Memory and Why It Matters

On different levels, all applications and workloads depend on the processor and memory. In public cloud environments, a lack of transparency in performance of virtual cores results in limited understanding of processor capabilities and how it can affect application performance. With the practice of CPU contention common in public cloud environments, it becomes even more important for the user to understand what defines a cloud provider's virtual core, and how that definition equates to expected performance of the application(s).

Geekbench 3 was selected as the benchmark tool for this project due to its versatility, ease-of-use, and variety of practical sample workloads to test the processor and memory through a series of various tasks. Tests are categorized into three sections:

- Integer workloads, including various compression, decompression, and encryption, which are common workload tasks for Internet-accessible servers such as web servers.
- Floating point workloads, including image rendering and financial modeling, which represent more complex and modern CPU tasks.
- Memory tests using STREAM, the industry-standard open source memory bandwidth benchmark. Memory bandwidth is important in the category of high performance computing (e.g., scientific modeling) and in-memory databases

Summary of Results

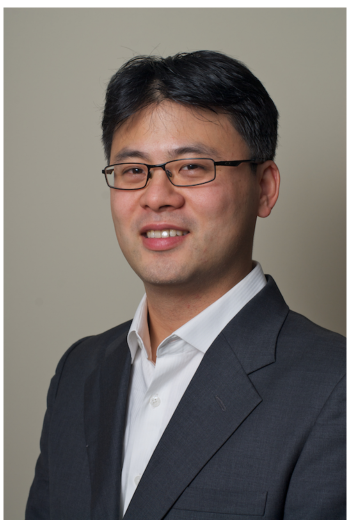
Key Findings and Observations

- From the series of system tests run on increasingly powerful virtual machines, CenturyLink Cloud consistently delivers higher performance against equivalent machines on its competitor, Amazon EC2.
- When factoring in pricing, CenturyLink Cloud also provides more system value per dollar spent. Amazon EC2 provides more value than CenturyLink Cloud with a 3-year commitment.

[1] https://portal.cloudspectator.com

- The single virtual core machine (m3.medium) on Amazon EC2 ran Intel Xeon E5-2670 v2 @ 2.50Ghz. All other virtual machines ran on Intel Xeon E5-2680 v2 @ 2.80GHz. The single core performance difference between the E5-2670 and the E5-2680 was approximately 1.83x.
- All tests run on CenturyLink Cloud virtual machines were conducted on Intel Xeon E5-2650 v2 @ 2.60GHz.
- CenturyLink Cloud scores 1.6x higher than Amazon EC2 on average in the system tests.
- The closest scores between two providers were achieved on the 4 virtual core machine, with CenturyLink scoring 1.43x higher.
- On the single core machine, CenturyLink achieved 2.06x greater score than Amazon EC2 M3's counterpart. While Amazon EC2 C3 multi-core machines scored higher on single core tests, Amazon EC2's C3 Family has no single core offering.
- At a 3-year commitment, Amazon EC2's Heavy Utilization Reserved Instance significantly lowers the cost of the virtual machine, increasing its value to surpass CenturyLink Cloud.

Cloud Industry Overview by Structure Research



Philbert Shih
Managing Director
Structure Research, Ltd.
ps@structureresearch.net

What is going on in the market?

There has been a surge of interest in cloud infrastructure performance over the past few years. This should not come as a surprise in a competitive landscape where Amazon is in a position of strength against the rest of the market. Competing clouds, run by hosters, MSPs and telcos - are looking for ways to compete and differentiate against Amazon and speed and performance is one very effective way of doing that. The performance story is compelling because it is backed by the experience of end users that have found Amazon sometimes comes up a bit short in performance, particularly when it comes to more compute-intensive workloads like databases and high-traffic websites. Data produced by third party performance benchmarking organizations also backs this up. Simply put, clouds run by hosters and other IT service providers have demonstrated – in many cases and to varying degrees – that they can deliver higher performance levels in the cloud by being more targeted and tackling bottlenecks with private layer 2 networks, software-defined networking, enterprise-grade equipment, SSD-based storage and well-constructed architectures.

Performance is also an important variable for determining the true underlying cost of any given cloud infrastructure service – a source of confusion among today's end uers. The common perception in the market is that Amazon is less expensive than competing clouds. That might be true in some cases and certainly scale and resources would put the likes of Amazon at an advantage. But as it turns out perception does not always fit reality. Competing cloud providers are very competitively priced and often have simpler billing models that include a lot of extra costs that are not reflected in Amazon's baseline pricing and are added on later and often unexpectedly. Transaction fees and bandwidth costs are two prominent examples. Third party data also shows that the performance-price ratio can and often does favor hoster-operated clouds that go up against Amazon. When controlling for the extra variable – performance – the cost of competing clouds is brought into clearer light. And as a result, competing clouds can fairly claim on par and even more value than Amazon.

Why is performance important?

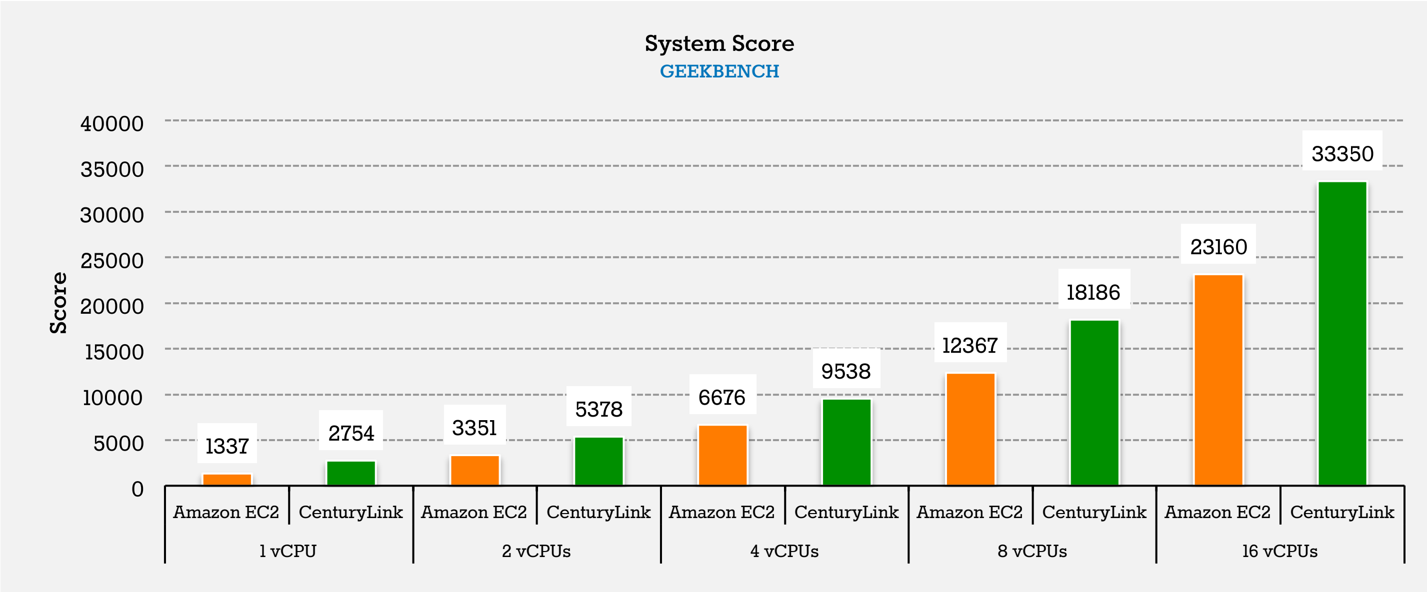
Speed and performance in the cloud is important primarily because it is attached to revenue. If a business is running a production workload or a transactional application, latency issues can degrade the user experience. And that translates directly into customer goodwill and dollars and cents. Performance is also increasingly important because of the rapidly growing expansion of the Internet. Any given website or application can have end users coming from all around the globe. Weak performance can limit an organization's reach and hinder its overall opportunity and addressable market. Again, it boils right down to the bottom line. Performance is a key driver of value that directly impacts a business.

From a competitive standpoint, cloud infrastructure providers need to consider performance as a point of differentiation. Performance is crucial because it can be used as a way to provide and prove value-add, thereby enabling providers to maintain pricing integrity. Performance is also important for providers because it widens the scope of addressable use cases they can compete for and keeps them squarely in the game for production workloads, which are ideal due to stickiness, stability, predictability and long-term growth potential.

Bringing it together

The cloud infrastructure market is accelerating and competition is intensifying. As increasingly diverse and sophisticated workloads move to the cloud, the more variables like performance will be taken into consideration. This has implications for both end users and providers and is sure to spawn a new breed of clouds that will cater to these very specific requirements. The challenge will be how to balance the value-add of performance with cost. In today's market there is no clear leader and various providers offer compelling value when the data analysis is broken down as close to an apples to apples comparison as possible.

PERFORMANCE COMPARISONS



System Performance

CenturyLink scores an average of 1.6x higher than Amazon EC2 on side-by-side virtual machine comparisons. As the virtual machines scaled up in power, CenturyLink consistently achieved higher performance scores. Both cloud providers use modern Intel processors.

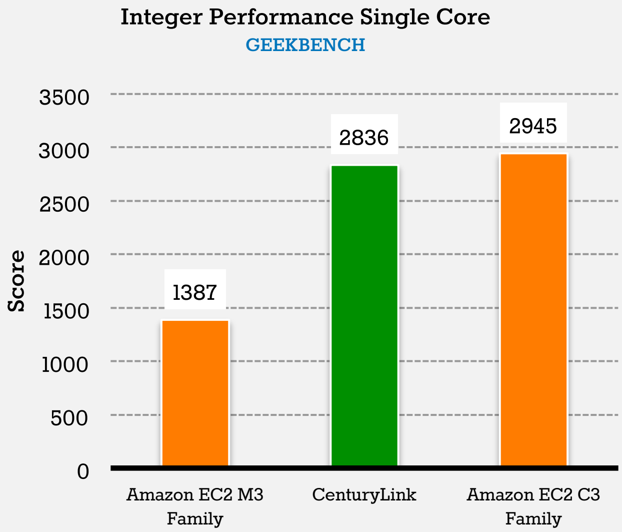
As a reference point, Geekbench 3 uses a Mac Mini (Mid 2011), which has an Intel Core i5-2520M @ 2.50GHz, for its baseline. The baseline score is 2,500. CenturyLink surpasses this baseline at its single virtual core offering, while Amazon EC2 surpasses it with the c3.large dual virtual core offering.

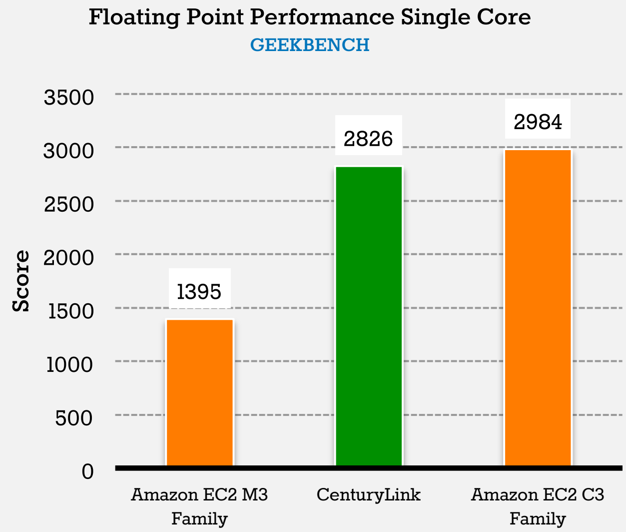
Amazon's low 1vCPU score is due to the CPU allocation of its slightly less powerful Intel Core E5-2670 v2 @ 2.50GHz found in its M3 offering. Beyond the 1vCPU offering, all other tests were run on its latest-generation Compute Optimized C3 instances. According to Amazon, this family provides "customers with the highest performing processors and the lowest price/compute performance available in EC2 currently." The C3 family of machines tested by Cloud Spectator in this study all ran on Intel Xeon E5-2680 v2 @ 2.80GHz.

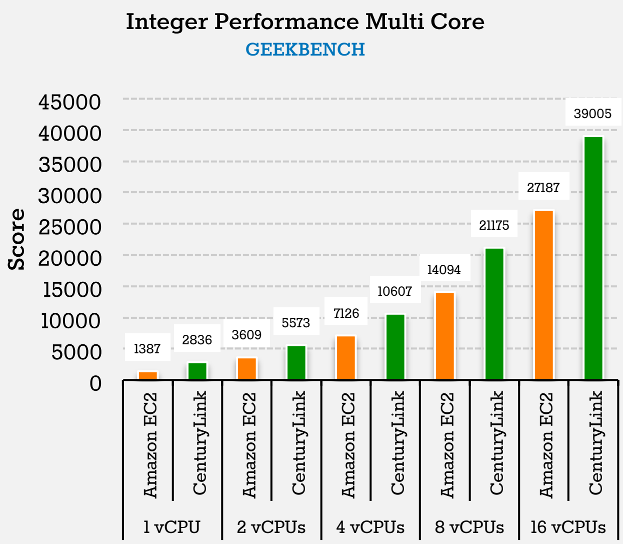
While the C3 family has no single virtual core offering, when running Geekbench 3 on a single core with the C3 family, the single core received an overall score of 2738, surpassing the Geekbench 3 baseline. In other words, a single core on the Amazon EC2 C3 family achieves nearly the same score as CenturyLInk Cloud, and surpasses the Geekbench 3 baseline machine.

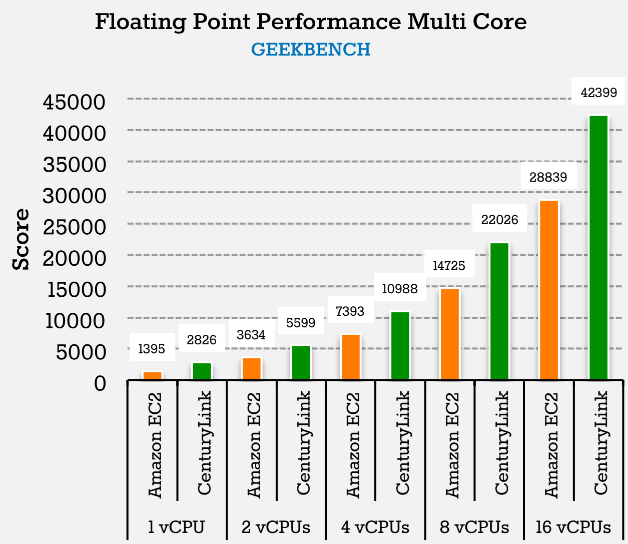
For more information, please see the Appendix.

Integer and Floating Point Performance: Single Core and Multi Core









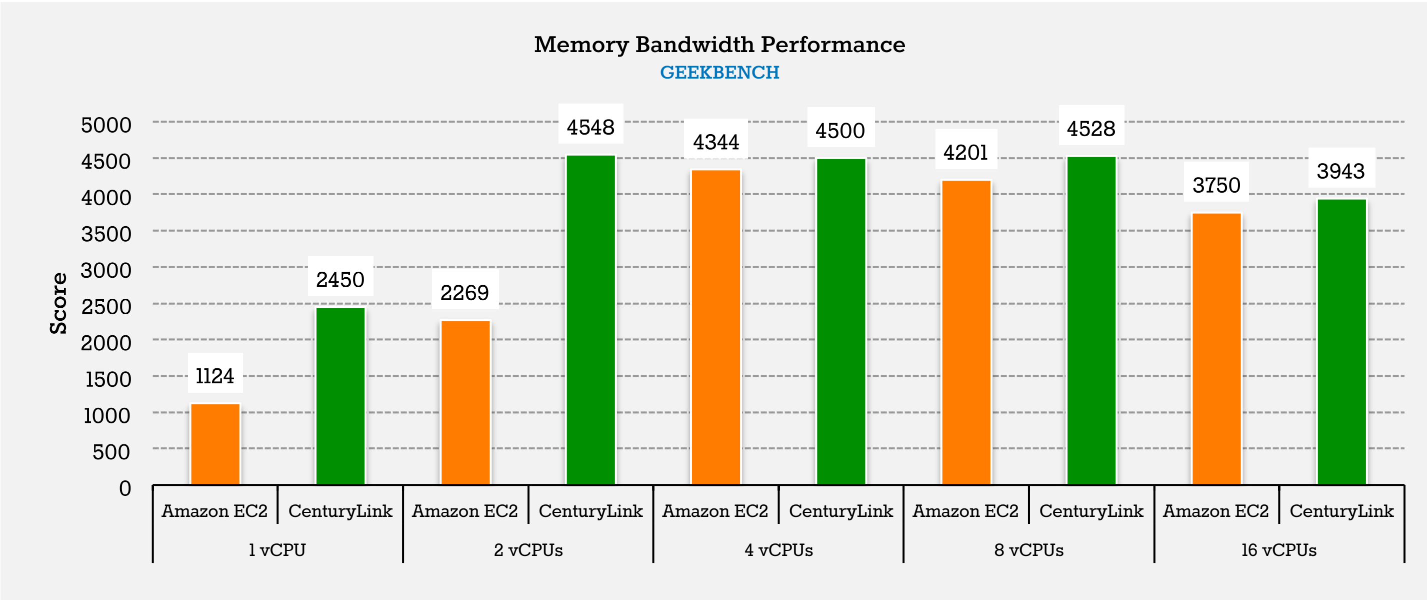
Integer and Floating Point Performance

The charts above separate the scores on the previous page (Overall System Score) into two categories: Integer and Floating Point mathematics. The top row of charts display Geekbench results in single core runs across Amazon EC2's M3 Family, C3 Family, and CenturyLink. Amazon EC2's C3 family, which offers Amazon's highest performing processors, expectedly score higher than its M3 family counterpart on the single core tests.

CenturyLink Cloud's CPU performance falls between the two Amazon families. Its processor, the Intel Xeon E5-2650 v2 (2.6 GHz), has more power than the Amazon M3's family of Intel Xeon E5-2670 v2 (2.5 GHz) and less power than the Intel Xeon E5-2680 v2 (2.8 GHz).

While both companies scaled by an average of 2x from one machine to the next, Amazon EC2 experiences a 2.6x boost in processor power as it scales from its M3 family (m3.medium) 1vCPU machine to its C3 family (c3.large) 2vCPU machine, marking a shift from the Intel Xeon E5-2670 v2 to the Intel Xeon E5-2680 v2.

Memory Bandwidth Performance



Memory access speed was at its fastest in the 2vCPU, 4vCPU, and 8vCPU offerings for CenturyLink; consistent memory access speed was less predictable for Amazon EC2, with the most bandwidth at 4vCPUs and 8vCPUs.

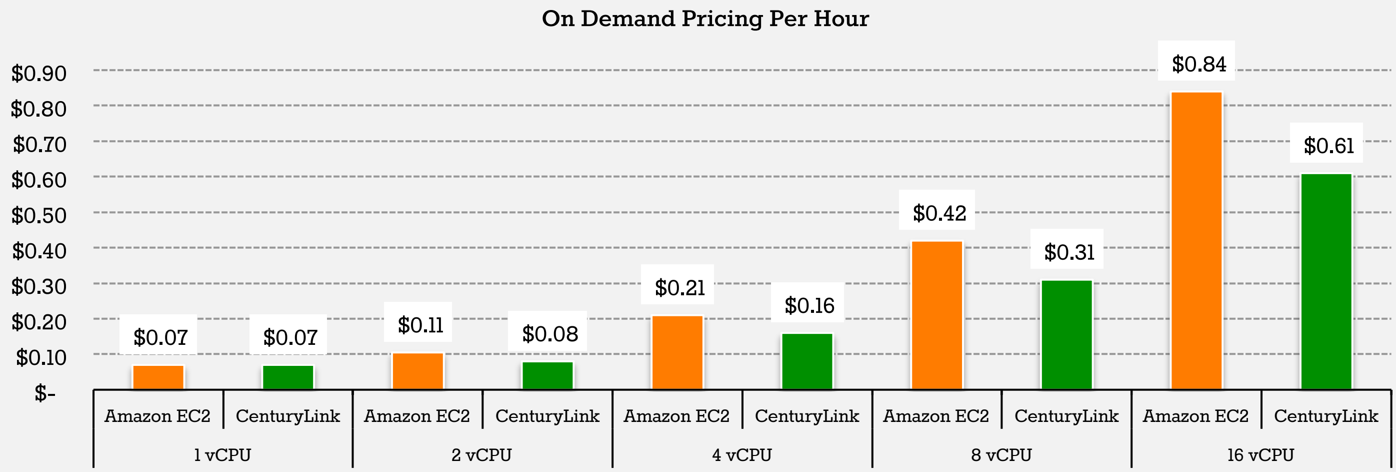
This fluctuation occurred due to performance of microbenchmarks within STREAM: copy, scale, sum, and triad. Copy and Scale are the simplest of the 4 available memory tasks found within STREAM. With Copy, no computation is needed—it is the fastest memory operation in the STREAM benchmark; two values are found in the memory, and one is written to the other. Scale takes the Copy task and performs a mathematical operation on one of the values before writing it to the other.

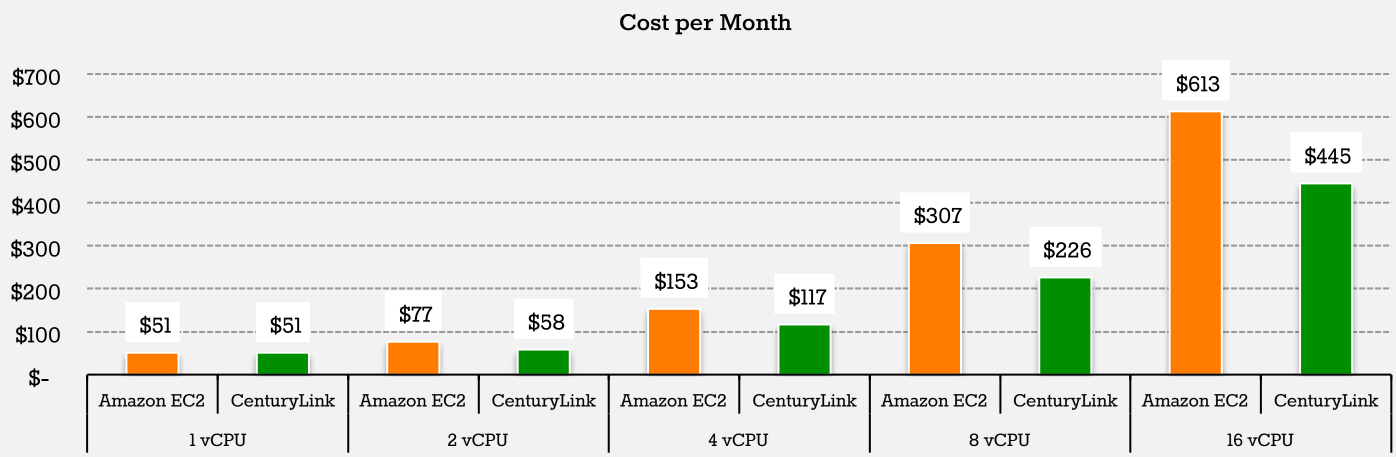
Sum and Triad are the more complex memory tasks, and both Amazon EC2 and CenturyLink experienced similar hardship in sustaining memory bandwidth throughout the process of these operations. Sum was originally used to test vector machines, and is now used to fetch three values from memory so the first two values will be combined and written to the third. Triad, the most complex memory operation, emulates an underlying memory task for matrix multiplication, polynomials, and is directly associated with application performance.

Both Sum and Triad can quickly fill a processor pipeline, leading to poorer throughput performance on the virtual machines, which contend for public resources. More information on STREAM can be found in the appendix, and results from Geekbench 3's Memory test (STREAM) can be found in Appendix – Raw Scores.

PRICING COMPARISONS

On Demand and Monthly Pricing Comparison





This section only accounts for on-demand pricing comparisons across virtual machine offerings, with no inclusion of performance. To understand how cost and performance factor in obtaining a value analysis of each machine, please view the section on Value Comparisons.

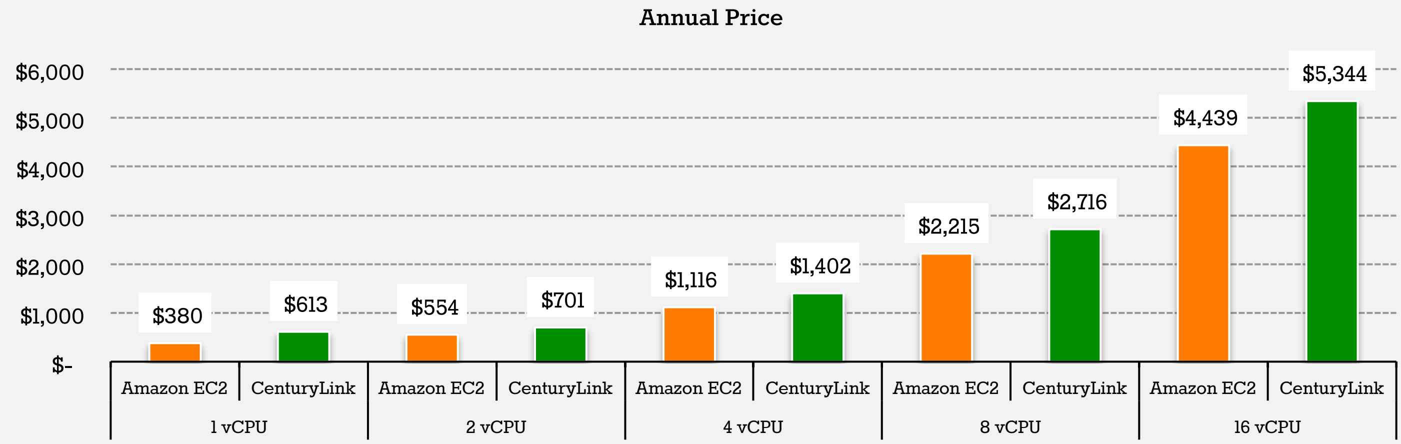
On-Demand and Monthly Pricing

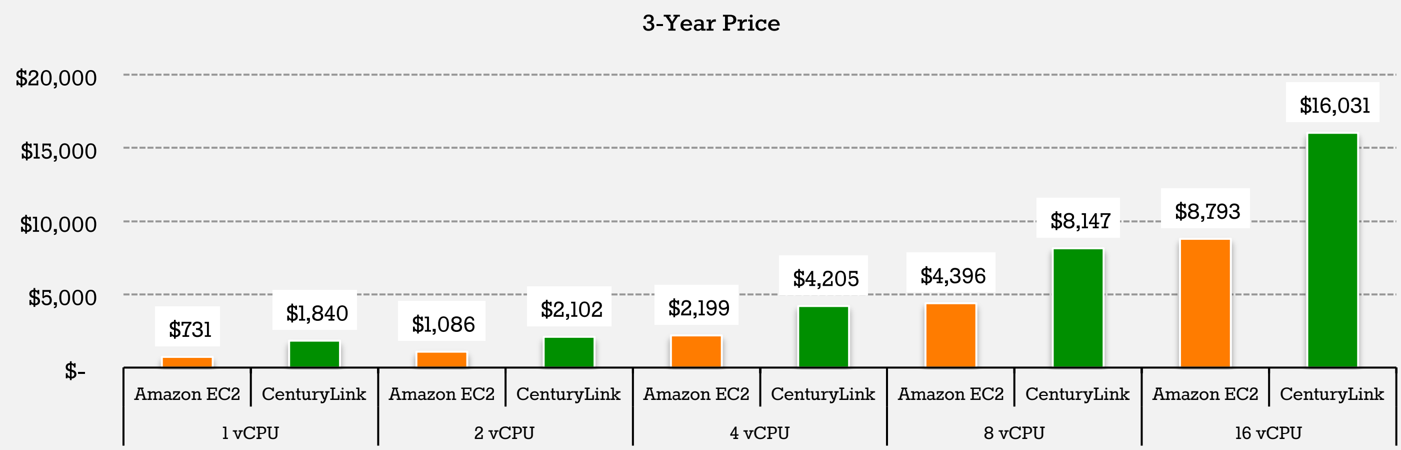
By definition on this comparison, "On-Demand" refers to hourly pricing. Some cloud providers offer minute-by-minute billing intervals, but CenturyLink and Amazon EC2 bill in hourly intervals at the most granular scale offered.

When conducting a basic analysis on pricing, CenturyLink in almost all cases offers a lower price for comparable virtual machine configurations than Amazon EC2 on an on-demand basis. This low cost expands into monthly terms as well. Amazon EC2's single virtual core m3.medium VM and CenturyLink Cloud's single virtual core VM are offered at equivalent costs. The doubled performance scores on CenturyLink tests, though, suggest more value on the CenturyLink VM (for more information, please see the section on Value Comparisons).

Without taking performance into account, if the target duration is less than 1 year, CenturyLink offers a stronger value proposition to the user. Amazon EC2's cost savings outweigh CenturyLink if the target duration is equal to or greater than 1 year. However, to achieve these cost savings, the business must comply with Amazon's terms for Heavy Utilization Reserved Instances.

Annual and 3-year Pricing Comparison





Annual and 3-Year Pricing

Amazon EC2 offers loyal businesses an opportunity to save on the cost of On-Demand Amazon instances by providing a class of Reserved Instance offerings. More information can be found on the Amazon EC2 website or by going to the Appendix at the end of this document.

With a steady rate of utilization, these costs assumed for 24/7 uptime and runtime of virtual machines; thus, the Heavy Utilization Reserved Instance pricing on Amazon EC2 were applied to the total cost for 1 and 3 years. The large upfront financial commitment of purchasing Reserved Instances (which can be analogous to a deposit) is offset by the significantly lowered per-hour cost for the virtual machine(s), resulting in a lower price point when businesses are planning to run the same machines for a longer period of time.

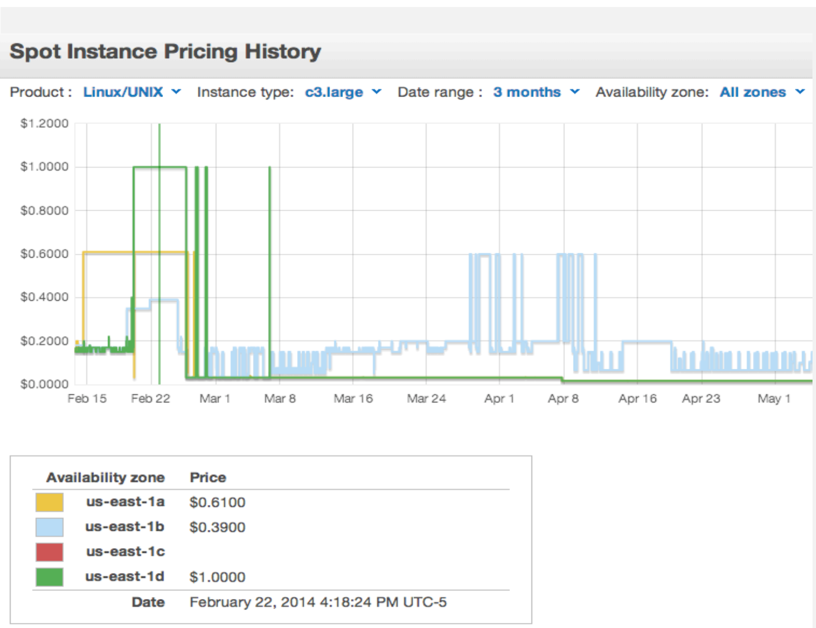
To put into a simple perspective, running Heavy Utilization Reserved Instances on Amazon is the equivalent of receiving more than 5 free months on a 12-month commitment of On-Demand pricing. With 3-year Heavy Utilization Reserved Instance commitment, a business essentially receives the third year of usage free compared to 3 1-year Heavy Utilization Reserved Instances commitments. For more examples, see Table 1.1 and 1.2.

Table 1.1 Amazon Cost Comparison: On Demand VS. Reserved 1 Year Instances	m3.medium	c3.large	c3.xlarge	c3.2xlarge	c3.4xlarge
1 Year of On Demand Total	$612	$924	$1,836	$3,684	$7,356
1 Year Heavy Utilization Reserved Instance Payments Total	$380	$554	$1,116	$2,215	$4,439

Table 1.2 Amazon Cost Comparison: On Demand VS. Reserved 3 Years Instances	m3.medium	c3.large	c3.xlarge	c3.2xlarge	c3.4xlarge
3 Years of Monthly Payments Total	$1,836	$2,772	$5,508	$11,052	$22,068
3 x 1 Year Heavy Utilization Reserved Instance Payments Total	$1,140	$1,662	$3,348	$6,645	$13,317
3 Heavy Utilization Reserved Instance Payments Total	$731	$1,086	$2,199	$4,396	$8,793

The long-term discounts come with advantages and disadvantages. The immediate and apparent advantages are the reductions in price, especially on a 3-year commitment to Amazon EC2 Instances.

A disadvantage, though, is the commitment to such a long period of time in an industry that continues to reduce cost and increase performance. Amazon AWS is an innovative industry leader in the cloud space with no exception in IaaS. Their rate of innovation and aggressively reduced pricing (Amazon EC2 has announced 42 different AWS price reductions since 2008, as stated on their website blog), though, can detract from the value of a 3-year commitment to reserved instances. Also, a reserved instance cannot be resized and the upfront payment is non-refundable; a business must commit to a new reserved instance contract, and it is responsible for disposing the current commitment as well.
That being said, Amazon recognizes this concern and addresses it with the Amazon Marketplace, where users can sell unused reserved instances at a lower price as an alternative to cancelling the contract.



The Spot Instance Pricing graph above shows the historical bid prices of a c3.large (2 vCPUs) Amazon Instance since February 15TH. The fluctuation in Spot Price is not only over time, but across data centers. Also, Spot Instance pricing can exceed On-Demand pricing, as illustrated in the table.

Spot Instance Pricing[2]

Spot instance pricing comparisons were not included in this report for two reasons: spot instances fluctuate on price based on demand, availability, and location, and spot instance pricing does not guarantee availability and are mainly used in batch processing. The comparison of use in this report assumes for high availability virtual machines.

However, this report will briefly describe Spot Instances and their advantages and disadvantages. As an alternative to On-Demand pricing, spot instances are instances operating on a bidding system. Due to the nature of Spot Instances, stopping an instance is not an available feature—only termination; this allows unused Instances to be immediately sent back into the pool of bids. According to Amazon, a user "[bids] on spare Amazon EC2 instances and runs them whenever [the] bid

[2] Amazon Web Services YouTube Channel video – *Deciding on Your Spot Bidding Strategy:* https://www.youtube.com/watch?v=WD9N73F3Fao#t=156

exceeds the current Spot Price, which varies in real-time based on supply and demand."

Below is a summary table of the differences in pricing models on Amazon EC2 and CenturyLink Cloud.

Pricing Model	Available On	Advantages	Disadvantages	Use Cases
Spot Instance Pricing	Amazon EC2	Bid model for VMs Can lower costs	Unstable availability No "stopped" instances	Batch workloads
On Demand Pricing	Amazon EC2 CenturyLink Cloud	Pay-as-you-go Flexibility	Higher costs	Testing/development Fluctuating traffic sites Growing databases High performance computing
Reserved Instance Pricing	Amazon EC2	Lower cost	Limited flexibility	Master servers Stable, steady traffic environments

VALUE COMPARISONS

So far on performance, CenturyLink virtual machines have scored higher than their Amazon EC2 counterparts. With pricing in consideration of frequent machine utilization, Amazon EC2 provides businesses a slight cost advantage with its 1-year Reserved Instance, which is magnified at a 3-year Reserved Instance commitment. When considering the price-performance value of the servers in this report, Cloud Spectator calculated cost with performance to produce the following results seen in the table below:

Virtual Processor Integer Performance

Commitment Term	Who Provides More Value
On Demand	CenturyLink Cloud
Monthly	CenturyLink Cloud
Annually	CenturyLink Cloud
3-Year	Amazon EC2

Virtual Processor Floating Point Performance

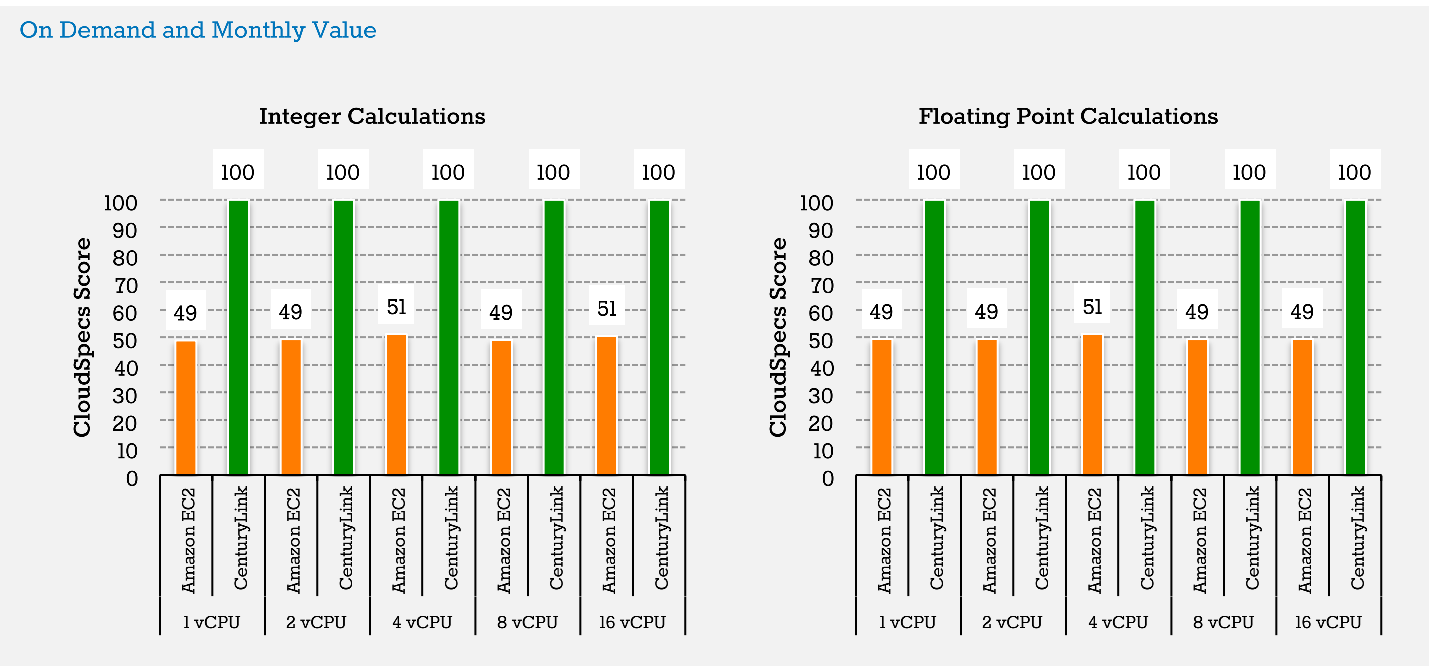
Commitment Term	Who Provides More Value
On Demand	CenturyLink Cloud
Monthly	CenturyLink Cloud
Annually	CenturyLink Cloud
3-Year	Amazon EC2

The CloudSpecs Score Calculation

The CloudSpecs Score is an Indexed, comparable score ranging from 0-100 indicative of value based on a combination of cost and performance. The value is scaled; e.g., a Cloud Service Provider (CSP) with a score of 100 gives 4x the value of a CSP with a score of 25. The CloudSpecs Scores in this report can only be compared with equivalent configurations; e.g., a 1vCPU Instance on Amazon compared to a 1vCPU virtual machine on CenturyLink.

The calculation of the CloudSpecs score:

1. provider_value = [Provider Performance Score] / [Provider Cost]
2. best_provider_value = max(provider_values)
3. CSP's CloudSpecs Score = 100 * provider_value / best_provider_value



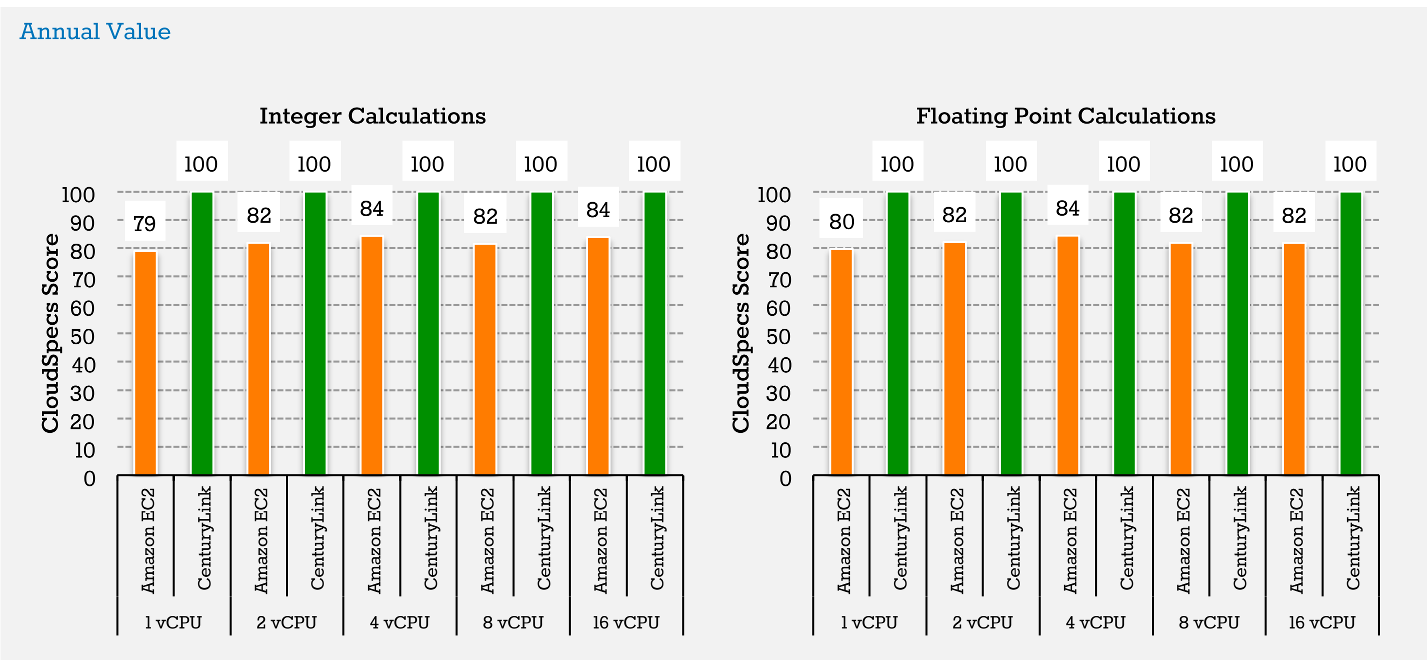
On Demand and Monthly Value

As expected with the combination of higher performance scores and lower on-demand cost, CenturyLink Cloud delivers more price-performance value for on-demand pricing. The value CenturyLink delivers for its processing power is consistently 2x more than Amazon EC2 at On-Demand cost. The value difference applies to both Integer (e.g., compression and decompression) and Floating Point (e.g., financial modeling and image rendering) CPU-intensive calculations.

Because of the linear relationship of monthly cost and hourly cost for both Amazon EC2 and CenturyLink Cloud, the CloudSpecs results can be extrapolated to apply to monthly value as well; i.e., CenturyLink Cloud virtual machines deliver 2x the processor performance value on a month-to-month basis compared to Amazon EC2.

Annual Value

Regarding cost alone, Amazon EC2's Reserved Instance Pricing under conditions of Heavy Utilization makes it the lower-priced option, but when comparing price and performance together in a value score, CenturyLink Cloud still remains as leader in value for processing power on both Integer and Floating Point operations.

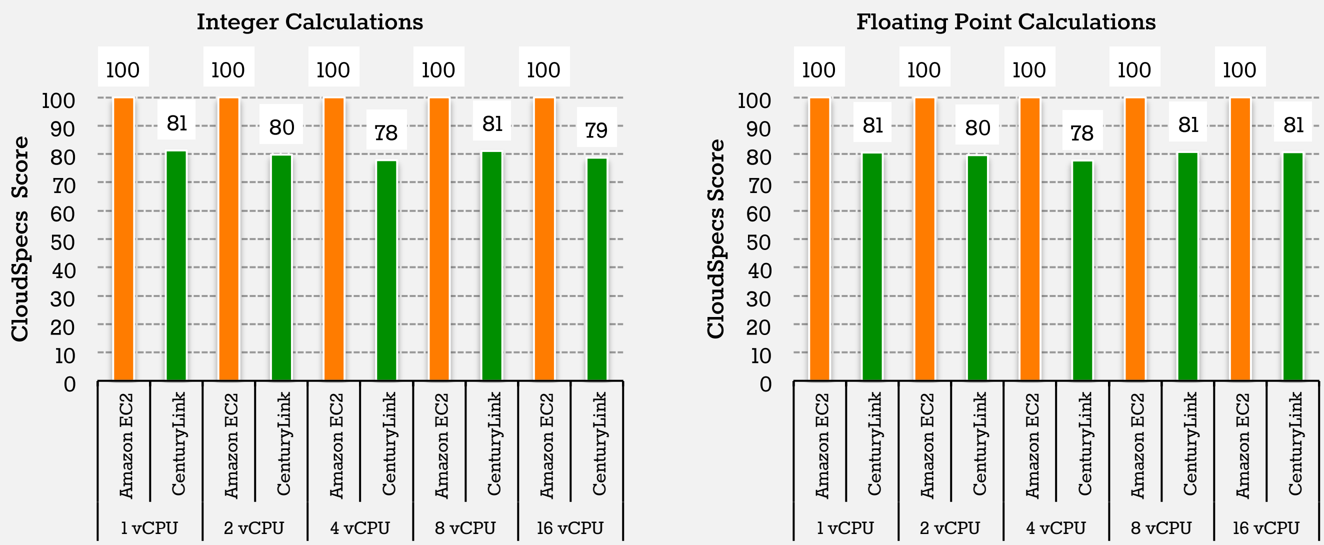


With the cost of Amazon EC2 instances lowered through Reserved Instance pricing, though, the value of CenturyLink Cloud's processor drops from 2x to around 1.2x that of comparable Amazon EC2 offerings.

3-Year Value

With Heavy Utilization Reserved Instances on a 3-year commitment, Amazon EC2 costs are significantly lowered and result in greater price-peformance value than CenturyLink Cloud. Calculating 24/7 uptime for 3 years, Amazon EC2 provides 1.25x more value on average than CenturyLink Cloud for processing power.

3-Year Value



CONCLUSION

CenturyLink's claim to make a "bold cloud move against you-know-who" was a move to decrease costs of their virtual machine offerings to compete against Amazon EC2 in value. Based on the performance and price-performance results obtained in this study, CenturyLink Cloud's decision did, in fact, give it the edge for value against comparable Amazon EC2 servers with respect to processing power.

These value comparisons were conducted under certain conditions and assumed for heavy utilization. Further studies into batch workloads or other low utilization studies can include Amazon EC2 Spot Instance analysis as well to understand performance value that can be obtained from the unique Amazon EC2 bidding system.

Applications and Use Case Comparisons

While not analyzed in detail throughout the report, the Appendix provides a good resource for application use case comparisons run by Geekbench 3. These application scenarios are categorized into Integer (e.g., AES encryption, JPEG compression/decompression) and Floating Point (e.g., Black Scholes financial modeling, Ray tracing for 2-D virtual image rendering) tasks, and descriptions of the specific tasks can be found in the Appendix – About Geekbench 3 as well as the Geekbench 3 website: http://support.primatelabs.com/kb/Geekbench/Geekbench-3-benchmarks.

About Cloud Spectator

Since 2011, Cloud Spectator has tracked the pricing models and performance capabilities of the most recognized cloud infrastructure providers in the industry. One of Cloud Spectator's primary goals is to establish a standard of comparison to help cloud infrastructure users better understand the market landscape so they can make more informed decisions when selecting their provider(s).

http://www.cloudspectator.com

contact@cloudspectator.com

+1 617-300-0711

About Structure Research

Structure Research is an independent research and consulting firm with a specific focus on the hosting and cloud segments within the Internet infrastructure market. They are devoted to understanding, tracking and projecting the future of hosting and cloud infrastructure service providers.

http://www.structureresearch.net

ps@structureresearch.net

+1 647-822-1404

APPENDIX

Pricing Models

CenturyLInk Cloud and Amazon EC2 offer different pricing structures. Amazon EC2 provides a tier-based purchase model for users and business to select pre-configured packages with reserved amounts of virtual cores, memory, and disk space. CenturyLink Cloud provides a basic cost calculation of its services, which are custom server sizes with independently configurable resource allocations.

Amazon EC2 Pricing Model

Spot Instances

The following information is taken from the Amazon EC2 website, and more information can be found at: http://aws.amazon.com/ec2/purchasing-options/spot-instances/

"Spot Instances allow you to name your own price for Amazon EC2 computing capacity. You simply bid on spare Amazon EC2 instances and run them whenever your bid exceeds the current Spot Price, which varies in real-time based on supply and demand. The Spot Instance pricing model complements the On-Demand and Reserved Instance pricing models, providing potentially the most cost-effective option for obtaining compute capacity, depending on your application.

Spot Instances can significantly lower your computing costs for time-flexible, interruption-tolerant tasks. Spot prices are often significantly less than On-Demand prices for the same EC2 instance types…Additionally, for some distributed, fault-tolerant tasks (like web-crawling or Monte Carlo applications), you may be able to simultaneously accelerate your computational task and reduce its overall cost by opportunistically incorporating Spot Instances."

On-Demand Instances

The following information is taken from the Amazon EC2 website, and more information can be found at: http://aws.amazon.com/ec2/pricing/

"On-Demand Instances let you pay for compute capacity by the hour with no long-term commitments. This frees you from the costs and complexities of planning, purchasing, and maintaining hardware and transforms what are commonly large fixed costs into much smaller variable costs."

Reserved Instances

The following information is taken from the Amazon EC2 website, and more information can be found at: http://aws.amazon.com/ec2/purchasing-options/reserved-instances/

"Reserved Instances ("RIs") allow you to make a low, one-time payment to reserve instance capacity and further reduce your on-going Amazon EC2 costs. There are multiple Reserved Instance types shown below that enable you to balance the amount you pay upfront with your effective hourly price:

Light Utilization RIs

Light Utilization RIs offer the lowest upfront payment of all of the Reserved Instance types. Light Utilization RIs allow you to turn off your instance at any point and not pay the hourly fee. Light Utilization RIs are ideal for periodic workloads that only run a couple of hours a day or a few days per week.

Medium Utilization RIs

Medium Utilization RIs are the exact same Reserved Instances that EC2 has offered for the last several years. They have an upfront payment, but a much lower hourly usage fee. Medium Utilization RIs allow you to turn off your instance at any point and not pay the hourly fee. Medium Utilization RIs are best suited for workloads that run most of the time, but have some variability in usage (like web server traffic where demand may increase or decrease throughout the year). Using Medium Utilization RIs, you can save up to 31% for a 1-year term and 54% for a 3-year term vs. running On-Demand Instances. The break-even point for a Medium Utilization Linux RI (vs. On Demand) is 49% for a 1-year term or 22% of a 3-year term. If you expect to use your instance more than that, an RI will save you money.

Heavy Utilization RIs

Heavy Utilization RIs offer the most absolute savings of any Reserved Instance type. They're most appropriate for steady-state workloads where you're willing to commit to always running these instances in exchange for our lowest hourly usage fee. With this RI, you pay a little higher upfront payment than Medium Utilization RIs, a significantly lower hourly usage fee, and you're charged that lower hourly rate for every hour in the Reserved Instance term you purchase. Using Heavy Utilization RIs, you can save up to 37% for a 1-year term and 60% for a 3-year term vs. running On-Demand Instances. The break-even point for a Heavy Utilization Linux RIs (vs. On Demand) is 63% for a 1-year term or 40% of a 3-year term. If you expect to use your instance more than that, an RI will save you money."

CenturyLink Cloud Pricing Model

- CPU Cost: $0.01 per hour per virtual core, scalable up to 16 virtual cores per virtual machine.
- Memory Cost: $0.015 per hour per GB virtual memory, scalable up to 128GB RAM per virtual machine.
- A cost estimator can be found on the CenturyLink Cloud website at http://www.centurylinkcloud.com/estimator/

Virtual Hardware Information

The tables provide the configuration information for the virtual machines that were used in side-by-side comparisons of performance, pricing, and value.

General Hardware	**Amazon EC2**	**CenturyLink Cloud**
Processor(s)	Intel Xeon E5-2670 v2 @ 2.5GHz Intel Xeon E5-2680 v2 @ 2.8GHz	Intel Xeon E5-2650 v2 @ 2.6GHz
Operating System	Ubuntu 14.04 LTS 3.13.0-24-generic x86_64	Ubuntu 12.04.4 LTS 3.2.0-39-generic x86_64
Enhancement Features	HVM AMI	Hyperscale
Hypervisor	Xen-based	VMWare
Data Center Location	US-East (North Virginia)	Virginia (Sterling)

1 vCPU Offering	**Amazon EC2**	**CenturyLink Cloud**
Offering Name	M3.MEDIUM	N/A
# of Virtual Cores	1	1
RAM	3.5GB	4GB
Disk	4GB	14GB
Disk Type	SSD	SSD
Disk Configuration	Local	Local

2 vCPU Offering	**Amazon EC2**	**CenturyLink Cloud**
Offering Name	C3.LARGE	N/A
# of Virtual Cores	2	2
RAM	3.5GB	4GB

Disk	2 x 16GB	14GB
Disk Type	SSD	SSD
Disk Configuration	Local	Local

4 vCPU Offering	**Amazon EC2**	**CenturyLink Cloud**
Offering Name	C3.XLARGE	N/A
# of Virtual Cores	4	4
RAM	7.5GB	8GB
Disk	2 x 40GB	14GB
Disk Type	SSD	SSD
Disk Configuration	Local	Local

8 vCPU Offering	**Amazon EC2**	**CenturyLink Cloud**
Offering Name	C3.2XLARGE	N/A
# of Virtual Cores	2	2
RAM	3.5GB	4GB
Disk	2 x 80GB	14GB
Disk Type	SSD	SSD
Disk Configuration	Local	Local

8 vCPU Offering	**Amazon EC2**	**CenturyLink Cloud**
Offering Name	C3.4XLARGE	N/A
# of Virtual Cores	16	16
RAM	30GB	30GB
Disk	2 x 160GB	14GB
Disk Type	SSD	SSD
Disk Configuration	Local	Local

SSH Commands for Replicating This Study

The process for configuring and running the benchmarks follows a basic process of upgrading the virtual machine OS before proceeding to benchmark the system.

1. Obtain root user privileges (repeat this before step 3; reconnecting the SSH session after a successful reboot)

```
sudo su
```

2. Update and upgrade the system, followed by a reboot

```
apt-get update && apt-get upgrade && reboot
```

3. Reconnect through SSH after the reboot (also re-obtain root user). Download Geekbench 3, unzip the contents, navigate to the unzipped folder, unlock the license, and run the Geekbench test

```
wget http://Geekbench.s3.amazonaws.com/Geekbench-3.1.2-Linux.tar.gz && tar -xvzf Geekbench-3.1.2-Linux.tar.gz && cd dist/Geekbench-3.1.2-Linux/ && ./Geekbench_x86_64 -r [REGISTERED EMAIL ADDRESS] [LICENSE KEY]
```

About Geekbench 3

All of the following information and more can be found on the Geekbench website - http://www.primatelabs.com/Geekbench.

Geekbench 3 is Primate Labs' cross-platform processor benchmark, with a new scoring system that separates single-core and multi-core performance, and new workloads that simulate real-world scenarios.

Integer Performance Workloads

- **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.
- **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.
- **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.
- **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.
- **BZip2 compression and 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.
- **JPEG compression and decompression**: The JPEG workloads compress and decompress one digital image using lossy JPEG format. The workloads use libjpeg version 6b.
- **PNG compression and 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.
- **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.
- **Lua**: Lua is lightweight scripting language. The Lua workload is similar to the code used to display Geekbench results in the Geekbench Browser.
- **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.

Floating Point Performance Workloads

- **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.
- **Mandelbrot**: The Mandelbrot set is a fractal. It is a useful floating point workload because it has a low memory bandwidth requirement.
- **Sharpen image**: The sharpen image workload uses a standard image sharpening technique similar to those found in Photoshop or Gimp.
- **Blur image**: 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.
- **SGEMM and 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.
- **SFFT and 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.
- **N-Body**: This workload computes a physical simulation similar to that required for a physics game placed in outer space.
- **Ray trace**: The ray trace workload renders a 3D scene from a geometric description. The rendered scene is shown below:

Memory Performance Workloads

- **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.
- **STREAM scale**: This workload is similar to stream copy, but each value is multiplied by a constant during the copy.
- **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.
- **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.

Raw Scores

1 vCPU Machine Results				
AMAZON EC2 M3.MEDIUM			**CENTURY LINK 1 VCPU 4GB MEMORY**	
Integer				
AES				
single-core	1565	1.34 GB/sec	2520	2.16 GB/sec
multi-core	1281	1.10 GB/sec	2518	2.16 GB/sec
Twofish				
single-core	1252	70.3 MB/sec	2617	146.9 MB/sec
multi-core	1250	70.2 MB/sec	2619	147.0 MB/sec
SHA1				
single-core	1475	160.1 MB/sec	3035	329.4 MB/sec
multi-core	1454	157.8 MB/sec	3034	329.4 MB/sec
SHA2				
single-core	1586	68.7 MB/sec	3329	144.1 MB/sec
multi-core	1561	67.5 MB/sec	3334	144.3 MB/sec
BZip2 Compress				
single-core	1165	4.74 MB/sec	2452	9.97 MB/sec
multi-core	1143	4.65 MB/sec	2448	9.95 MB/sec
BZip2 Decompress				
single-core	1130	6.13 MB/sec	2428	13.2 MB/sec
multi-core	1143	6.20 MB/sec	2424	13.1 MB/sec
JPEG Compress				
single-core	1292	18.0 Mpixels/sec	2697	37.6 Mpixels/sec
multi-core	1282	17.9 Mpixels/sec	2696	37.6 Mpixels/sec
JPEG Decompress				
single-core	1922	47.5 Mpixels/sec	3805	94.1 Mpixels/sec
multi-core	1883	46.6 Mpixels/sec	3785	93.6 Mpixels/sec
PNG Compress				
single-core	1234	985.8 Kpixels/sec	2601	2.08 Mpixels/sec
multi-core	1222	976.0 Kpixels/sec	2592	2.07 Mpixels/sec
PNG Decompress				
single-core	1374	15.8 Mpixels/sec	2808	32.4 Mpixels/sec
multi-core	1357	15.7 Mpixels/sec	2796	32.2 Mpixels/sec
Sobel				
single-core	1808	65.8 Mpixels/sec	3648	132.8 Mpixels/sec
multi-core	1796	65.4 Mpixels/sec	3641	132.5 Mpixels/sec
Lua				
single-core	1294	1.16 MB/sec	2795	2.51 MB/sec
multi-core	1294	1.16 MB/sec	2752	2.47 MB/sec
Dijkstra				
single-core	1190	4.27 Mpairs/sec	2541	9.12 Mpairs/sec
multi-core	1077	3.87 Mpairs/sec	2268	8.14 Mpairs/sec
Floating Point				
BlackScholes				
single-core	1116	4.97 Mnodes/sec	1947	8.67 Mnodes/sec
multi-core	1095	4.88 Mnodes/sec	1948	8.67 Mnodes/sec
Mandelbrot				
single-core	1254	1.29 Gflops	2589	2.65 Gflops
multi-core	1237	1.27 Gflops	2588	2.65 Gflops
Sharpen Filter				
single-core	1124	833.7 Mflops	2356	1.75 Gflops
multi-core	1126	835.1 Mflops	2357	1.75 Gflops
Blur Filter				

single-core	918	875.0 Mflops
multi-core	913	870.4 Mflops
SGEMM		
single-core	1815	5.09 Gflops
multi-core	1812	5.07 Gflops
DGEMM		
single-core	1683	2.47 Gflops
multi-core	1670	2.45 Gflops
SFFT		
single-core	1290	1.36 Gflops
multi-core	1271	1.34 Gflops
DFFT		
single-core	1371	1.25 Gflops
multi-core	1344	1.22 Gflops
N-Body		
single-core	2099	779.3 Kpairs/sec
multi-core	2080	772.3 Kpairs/sec
Ray Trace		
single-core	1705	2.01 Mpixels/sec
multi-core	1692	2.00 Mpixels/sec
Memory		
Stream Copy		
single-core	1014	4.05 GB/sec
multi-core	1013	4.04 GB/sec
Stream Scale		
single-core	1263	5.04 GB/sec
multi-core	1279	5.11 GB/sec
Stream Add		
single-core	1108	5.01 GB/sec
multi-core	1095	4.95 GB/sec
Stream Triad		
single-core	1128	4.96 GB/sec
multi-core	1125	4.95 GB/sec

Benchmark Summary		
Integer Score	1387	1345
Floating Point Score	1395	1381
Memory Score	1124	1123
Geekbench Score	1337	1315

single-core	1918	1.83 Gflops
multi-core	1915	1.83 Gflops
SGEMM		
single-core	3688	10.3 Gflops
multi-core	3680	10.3 Gflops
DGEMM		
single-core	3315	4.87 Gflops
multi-core	3358	4.93 Gflops
SFFT		
single-core	2659	2.80 Gflops
multi-core	2659	2.80 Gflops
DFFT		
single-core	2860	2.60 Gflops
multi-core	2850	2.60 Gflops
N-Body		
single-core	4374	1.62 Mpairs/sec
multi-core	4372	1.62 Mpairs/sec
Ray Trace		
single-core	3509	4.14 Mpixels/sec
multi-core	3532	4.17 Mpixels/sec
Memory		
Stream Copy		
single-core	2098	8.37 GB/sec
multi-core	2066	8.24 GB/sec
Stream Scale		
single-core	2732	10.9 GB/sec
multi-core	2719	10.9 GB/sec
Stream Add		
single-core	2479	11.2 GB/sec
multi-core	2483	11.2 GB/sec
Stream Triad		
single-core	2539	11.2 GB/sec
multi-core	2547	11.2 GB/sec

Benchmark Summary		
Integer Score	2836	2804
Floating Point Score	2826	2829
Memory Score	2450	2441
Geekbench Score	2754	2741

2 vCPU Machine Results

AMAZON EC2 C3.LARGE

Integer		
AES		
single-core	2647	2.27 GB/sec
multi-core	2920	2.50 GB/sec
Twofish		
single-core	2704	151.7 MB/sec
multi-core	3839	215.5 MB/sec
SHA1		
single-core	3140	340.9 MB/sec
multi-core	3258	353.7 MB/sec
SHA2		
single-core	3401	147.2 MB/sec
multi-core	3307	143.1 MB/sec
BZip2 Compress		
single-core	2541	10.3 MB/sec
multi-core	3373	13.7 MB/sec
BZip2 Decompress		
single-core	2523	13.7 MB/sec
multi-core	3413	18.5 MB/sec
JPEG Compress		
single-core	2788	38.9 Mpixels/sec
multi-core	3705	51.6 Mpixels/sec
JPEG Decompress		
single-core	4014	99.2 Mpixels/sec
multi-core	4507	111.4 Mpixels/sec
PNG Compress		
single-core	2687	2.15 Mpixels/sec

CENTURY LINK CLOUD 2vCPU 4GB MEMORY

Integer		
AES		
single-core	2517	2.15 GB/sec
multi-core	5047	4.32 GB/sec
Twofish		
single-core	2609	146.4 MB/sec
multi-core	5225	293.2 MB/sec
SHA1		
single-core	3026	328.5 MB/sec
multi-core	6060	657.8 MB/sec
SHA2		
single-core	3304	143.0 MB/sec
multi-core	6625	286.6 MB/sec
BZip2 Compress		
single-core	2442	9.93 MB/sec
multi-core	4892	19.9 MB/sec
BZip2 Decompress		
single-core	2424	13.1 MB/sec
multi-core	4853	26.3 MB/sec
JPEG Compress		
single-core	2692	37.5 Mpixels/sec
multi-core	5384	75.0 Mpixels/sec
JPEG Decompress		
single-core	3783	93.5 Mpixels/sec
multi-core	7483	185.0 Mpixels/sec
PNG Compress		
single-core	2595	2.07 Mpixels/sec

multi-core	3750	2.99 Mpixels/sec
PNG Decompress		
single-core	2907	33.5 Mpixels/sec
multi-core	3830	44.2 Mpixels/sec
Sobel		
single-core	3799	138.3 Mpixels/sec
multi-core	4206	153.1 Mpixels/sec
Lua		
single-core	2905	2.61 MB/sec
multi-core	3647	3.28 MB/sec
Dijkstra		
single-core	2652	9.52 Mpairs/sec
multi-core	3445	12.4 Mpairs/sec
Floating Point		
BlackScholes		
single-core	2369	10.5 Mnodes/sec
multi-core	3262	14.5 Mnodes/sec
Mandelbrot		
single-core	2680	2.75 Gflops
multi-core	4500	4.61 Gflops
Sharpen Filter		
single-core	2444	1.81 Gflops
multi-core	3130	2.32 Gflops
Blur Filter		
single-core	1984	1.89 Gflops
multi-core	2888	2.75 Gflops
SGEMM		
single-core	3854	10.8 Gflops
multi-core	3950	11.1 Gflops
DGEMM		
single-core	3513	5.16 Gflops
multi-core	3839	5.64 Gflops
SFFT		
single-core	2756	2.91 Gflops
multi-core	2865	3.02 Gflops
DFFT		
single-core	2964	2.70 Gflops
multi-core	3270	2.98 Gflops
N-Body		
single-core	4538	1.68 Mpairs/sec
multi-core	4881	1.81 Mpairs/sec
Ray Trace		
single-core	3625	4.27 Mpixels/sec
multi-core	4371	5.15 Mpixels/sec
Memory		
Stream Copy		
single-core	2158	8.61 GB/sec
multi-core	2194	8.75 GB/sec
Stream Scale		
single-core	2696	10.8 GB/sec
multi-core	2407	9.61 GB/sec
Stream Add		
single-core	2306	10.4 GB/sec
multi-core	2206	9.98 GB/sec
Stream Triad		
single-core	2372	10.4 GB/sec
multi-core	2279	10.0 GB/sec
Benchmark Summary		
Integer Score	2945	3609
Floating Point Score	2984	3634
Memory Score	2375	2269
Geekbench Score	2846	3351

multi-core	5186	4.14 Mpixels/sec
PNG Decompress		
single-core	2796	32.2 Mpixels/sec
multi-core	5556	64.1 Mpixels/sec
Sobel		
single-core	3576	130.1 Mpixels/sec
multi-core	7114	258.9 Mpixels/sec
Lua		
single-core	2724	2.45 MB/sec
multi-core	5460	4.91 MB/sec
Dijkstra		
single-core	2513	9.02 Mpairs/sec
multi-core	4422	15.9 Mpairs/sec
Floating Point		
BlackScholes		
single-core	1943	8.65 Mnodes/sec
multi-core	3875	17.2 Mnodes/sec
Mandelbrot		
single-core	2587	2.65 Gflops
multi-core	5173	5.30 Gflops
Sharpen Filter		
single-core	2349	1.74 Gflops
multi-core	4689	3.48 Gflops
Blur Filter		
single-core	1915	1.83 Gflops
multi-core	3795	3.62 Gflops
SGEMM		
single-core	3432	9.61 Gflops
multi-core	6984	19.6 Gflops
DGEMM		
single-core	3366	4.95 Gflops
multi-core	6581	9.67 Gflops
SFFT		
single-core	2655	2.80 Gflops
multi-core	5312	5.60 Gflops
DFFT		
single-core	2839	2.59 Gflops
multi-core	5631	5.13 Gflops
N-Body		
single-core	4373	1.62 Mpairs/sec
multi-core	8740	3.24 Mpairs/sec
Ray Trace		
single-core	3519	4.15 Mpixels/sec
multi-core	7070	8.34 Mpixels/sec
Memory		
Stream Copy		
single-core	2090	8.34 GB/sec
multi-core	3997	15.9 GB/sec
Stream Scale		
single-core	2729	10.9 GB/sec
multi-core	5022	20.1 GB/sec
Stream Add		
single-core	2485	11.2 GB/sec
multi-core	4560	20.6 GB/sec
Stream Triad		
single-core	2528	11.1 GB/sec
multi-core	4677	20.6 GB/sec
Benchmark Summary		
Integer Score	2816	5573
Floating Point Score	2806	5599
Memory Score	2446	4548
Geekbench Score	2738	5378

4vCPU Machine Results

AMAZON EC2 C3.XLARGE

Integer

AES

CenturyLink 4vCPUs 8GB MEMORY

Integer

AES

single-core	2636	2.26 GB/sec
multi-core	5814	4.98 GB/sec
Twofish		
single-core	2698	151.4 MB/sec
multi-core	7668	430.3 MB/sec
SHA1		
single-core	3138	340.7 MB/sec
multi-core	6489	704.4 MB/sec
SHA2		
single-core	3389	146.7 MB/sec
multi-core	6631	286.9 MB/sec
BZip2 Compress		
single-core	2540	10.3 MB/sec
multi-core	6590	26.8 MB/sec
BZip2 Decompress		
single-core	2536	13.7 MB/sec
multi-core	6720	36.4 MB/sec
JPEG Compress		
single-core	2790	38.9 Mpixels/sec
multi-core	7410	103.2 Mpixels/sec
JPEG Decompress		
single-core	4090	101.1 Mpixels/sec
multi-core	9151	226.2 Mpixels/sec
PNG Compress		
single-core	2688	2.15 Mpixels/sec
multi-core	7680	6.13 Mpixels/sec
PNG Decompress		
single-core	2917	33.6 Mpixels/sec
multi-core	7740	89.2 Mpixels/sec
Sobel		
single-core	3729	135.7 Mpixels/sec
multi-core	8308	302.4 Mpixels/sec
Lua		
single-core	2952	2.65 MB/sec
multi-core	7274	6.54 MB/sec
Dijkstra		
single-core	2786	10.00 Mpairs/sec
multi-core	5910	21.2 Mpairs/sec
Floating Point		
BlackScholes		
single-core	2361	10.5 Mnodes/sec
multi-core	6509	29.0 Mnodes/sec
Mandelbrot		
single-core	2680	2.75 Gflops
multi-core	8994	9.22 Gflops
Sharpen Filter		
single-core	2443	1.81 Gflops
multi-core	6221	4.61 Gflops
Blur Filter		
single-core	1988	1.89 Gflops
multi-core	5759	5.49 Gflops
SGEMM		
single-core	4070	11.4 Gflops
multi-core	8765	24.5 Gflops
DGEMM		
single-core	3671	5.39 Gflops
multi-core	8249	12.1 Gflops
SFFT		
single-core	2747	2.90 Gflops
multi-core	5729	6.04 Gflops
DFFT		
single-core	2967	2.70 Gflops
multi-core	6597	6.01 Gflops
N-Body		
single-core	4532	1.68 Mpairs/sec
multi-core	9754	3.62 Mpairs/sec
Ray Trace		
single-core	3636	4.29 Mpixels/sec
multi-core	8734	10.3 Mpixels/sec

Memory

single-core	2516	2.15 GB/sec
multi-core	9924	8.49 GB/sec
Twofish		
single-core	2607	146.3 MB/sec
multi-core	10294	577.7 MB/sec
SHA1		
single-core	2989	324.4 MB/sec
multi-core	11459	1.21 GB/sec
SHA2		
single-core	3307	143.1 MB/sec
multi-core	13253	573.4 MB/sec
BZip2 Compress		
single-core	2444	9.94 MB/sec
multi-core	9661	39.3 MB/sec
BZip2 Decompress		
single-core	2406	13.0 MB/sec
multi-core	9588	52.0 MB/sec
JPEG Compress		
single-core	2690	37.5 Mpixels/sec
multi-core	10574	147.3 Mpixels/sec
JPEG Decompress		
single-core	3759	92.9 Mpixels/sec
multi-core	12345	305.2 Mpixels/sec
PNG Compress		
single-core	2586	2.06 Mpixels/sec
multi-core	10136	8.09 Mpixels/sec
PNG Decompress		
single-core	2771	32.0 Mpixels/sec
multi-core	10532	121.4 Mpixels/sec
Sobel		
single-core	3557	129.5 Mpixels/sec
multi-core	13623	495.7 Mpixels/sec
Lua		
single-core	2688	2.42 MB/sec
multi-core	10404	9.35 MB/sec
Dijkstra		
single-core	2357	8.46 Mpairs/sec
multi-core	7583	27.2 Mpairs/sec
Floating Point		
BlackScholes		
single-core	1927	8.58 Mnodes/sec
multi-core	7705	34.3 Mnodes/sec
Mandelbrot		
single-core	2583	2.65 Gflops
multi-core	10301	10.6 Gflops
Sharpen Filter		
single-core	2334	1.73 Gflops
multi-core	9278	6.88 Gflops
Blur Filter		
single-core	1894	1.81 Gflops
multi-core	7596	7.24 Gflops
SGEMM		
single-core	3549	9.94 Gflops
multi-core	13600	38.1 Gflops
DGEMM		
single-core	3212	4.72 Gflops
multi-core	12098	17.8 Gflops
SFFT		
single-core	2645	2.79 Gflops
multi-core	10435	11.0 Gflops
DFFT		
single-core	2811	2.56 Gflops
multi-core	11046	10.1 Gflops
N-Body		
single-core	4366	1.62 Mpairs/sec
multi-core	17303	6.42 Mpairs/sec
Ray Trace		
single-core	3487	4.11 Mpixels/sec
multi-core	13983	16.5 Mpixels/sec

Memory

Stream Copy		
single-core	1540	6.15 GB/sec
multi-core	3903	15.6 GB/sec
Stream Scale		
single-core	2744	11.0 GB/sec
multi-core	4961	19.8 GB/sec
Stream Add		
single-core	2250	10.2 GB/sec
multi-core	4253	19.2 GB/sec
Stream Triad		
single-core	2347	10.3 GB/sec
multi-core	4328	19.0 GB/sec

Benchmark Summary

Integer Score	2959	7126
Floating Point Score	3013	7393
Memory Score	2173	4344
Geekbench Score	2823	6676

Stream Copy		
single-core	2076	8.28 GB/sec
multi-core	3976	15.9 GB/sec
Stream Scale		
single-core	2699	10.8 GB/sec
multi-core	4925	19.7 GB/sec
Stream Add		
single-core	2468	11.2 GB/sec
multi-core	4512	20.4 GB/sec
Stream Triad		
single-core	2520	11.1 GB/sec
multi-core	4642	20.4 GB/sec

Benchmark Summary

Integer Score	2790	10607
Floating Point Score	2788	10988
Memory Score	2429	4500
Geekbench Score	2717	9538

8 vCPU Machine Results

AMAZON C3.2XLARGE

Integer

AES		
single-core	2651	2.27 GB/sec
multi-core	11567	9.90 GB/sec
Twofish		
single-core	2710	152.1 MB/sec
multi-core	15359	861.9 MB/sec
SHA1		
single-core	3147	341.6 MB/sec
multi-core	13046	1.38 GB/sec
SHA2		
single-core	3408	147.5 MB/sec
multi-core	13308	575.8 MB/sec
BZip2 Compress		
single-core	2542	10.3 MB/sec
multi-core	13036	53.0 MB/sec
BZip2 Decompress		
single-core	2534	13.7 MB/sec
multi-core	13308	72.1 MB/sec
JPEG Compress		
single-core	2794	38.9 Mpixels/sec
multi-core	14842	206.8 Mpixels/sec
JPEG Decompress		
single-core	3960	97.9 Mpixels/sec
multi-core	17739	438.5 Mpixels/sec
PNG Compress		
single-core	2692	2.15 Mpixels/sec
multi-core	14935	11.9 Mpixels/sec
PNG Decompress		
single-core	2891	33.3 Mpixels/sec
multi-core	15021	173.2 Mpixels/sec
Sobel		
single-core	3806	138.5 Mpixels/sec
multi-core	16807	611.6 Mpixels/sec
Lua		
single-core	2857	2.57 MB/sec
multi-core	14286	12.8 MB/sec
Dijkstra		
single-core	2454	8.81 Mpairs/sec
multi-core	11411	40.9 Mpairs/sec

Floating Point

BlackScholes		
single-core	2373	10.6 Mnodes/sec
multi-core	13007	57.9 Mnodes/sec
Mandelbrot		
single-core	2685	2.75 Gflops
multi-core	18010	18.5 Gflops
Sharpen Filter		

CENTURYLINK 8vCPUs 15GB MEMORY

Integer

AES		
single-core	2529	2.16 GB/sec
multi-core	19195	16.4 GB/sec
Twofish		
single-core	2610	146.5 MB/sec
multi-core	20868	1.14 GB/sec
SHA1		
single-core	3029	328.8 MB/sec
multi-core	24201	2.57 GB/sec
SHA2		
single-core	3305	143.0 MB/sec
multi-core	26577	1.12 GB/sec
BZip2 Compress		
single-core	2445	9.94 MB/sec
multi-core	19487	79.2 MB/sec
BZip2 Decompress		
single-core	2437	13.2 MB/sec
multi-core	19162	103.9 MB/sec
JPEG Compress		
single-core	2692	37.5 Mpixels/sec
multi-core	21462	299.0 Mpixels/sec
JPEG Decompress		
single-core	3781	93.5 Mpixels/sec
multi-core	23082	570.6 Mpixels/sec
PNG Compress		
single-core	2595	2.07 Mpixels/sec
multi-core	20639	16.5 Mpixels/sec
PNG Decompress		
single-core	2798	32.3 Mpixels/sec
multi-core	21904	252.5 Mpixels/sec
Sobel		
single-core	3577	130.2 Mpixels/sec
multi-core	28001	1.02 Gpixels/sec
Lua		
single-core	2805	2.52 MB/sec
multi-core	21298	19.1 MB/sec
Dijkstra		
single-core	2504	8.99 Mpairs/sec
multi-core	13392	48.1 Mpairs/sec

Floating Point

BlackScholes		
single-core	1941	8.64 Mnodes/sec
multi-core	15485	68.9 Mnodes/sec
Mandelbrot		
single-core	2587	2.65 Gflops
multi-core	20672	21.2 Gflops
Sharpen Filter		

single-core 2443 1.81 Gflops
multi-core 12464 9.24 Gflops
Blur Filter
single-core 1987 1.89 Gflops
multi-core 11542 11.0 Gflops
SGEMM
single-core 4066 11.4 Gflops
multi-core 17062 47.8 Gflops
DGEMM
single-core 3637 5.34 Gflops
multi-core 16144 23.7 Gflops
SFFT
single-core 2757 2.91 Gflops
multi-core 11473 12.1 Gflops
DFFT
single-core 2947 2.68 Gflops
multi-core 13186 12.0 Gflops
N-Body
single-core 4545 1.69 Mpairs/sec
multi-core 19534 7.25 Mpairs/sec
Ray Trace
single-core 3634 4.29 Mpixels/sec
multi-core 17475 20.6 Mpixels/sec

Memory
Stream Copy
single-core 2074 8.28 GB/sec
multi-core 3632 14.5 GB/sec
Stream Scale
single-core 2689 10.7 GB/sec
multi-core 4795 19.1 GB/sec
Stream Add
single-core 2292 10.4 GB/sec
multi-core 4187 18.9 GB/sec
Stream Triad
single-core 2341 10.3 GB/sec
multi-core 4273 18.8 GB/sec

Benchmark Summary
Integer Score 2923 14094
Floating Point Score 3011 14725
Memory Score 2338 4201

Geekbench Score 2841 12367

single-core 2356 1.75 Gflops
multi-core 18512 13.7 Gflops
Blur Filter
single-core 1898 1.81 Gflops
multi-core 14385 13.7 Gflops
SGEMM
single-core 3560 9.97 Gflops
multi-core 26955 75.5 Gflops
DGEMM
single-core 3374 4.96 Gflops
multi-core 25786 37.9 Gflops
SFFT
single-core 2656 2.80 Gflops
multi-core 21080 22.2 Gflops
DFFT
single-core 2860 2.61 Gflops
multi-core 22657 20.6 Gflops
N-Body
single-core 4381 1.63 Mpairs/sec
multi-core 34771 12.9 Mpairs/sec
Ray Trace
single-core 3444 4.06 Mpixels/sec
multi-core 27315 32.2 Mpixels/sec

Memory
Stream Copy
single-core 2097 8.37 GB/sec
multi-core 3992 15.9 GB/sec
Stream Scale
single-core 2737 10.9 GB/sec
multi-core 4975 19.9 GB/sec
Stream Add
single-core 2482 11.2 GB/sec
multi-core 4525 20.5 GB/sec
Stream Triad
single-core 2529 11.1 GB/sec
multi-core 4681 20.6 GB/sec

Benchmark Summary
Integer Score 2825 21175
Floating Point Score 2811 22026
Memory Score 2449 4528

Geekbench Score 2744 18186

16 vCPU Machine Results

Amazon C3.4XLARGE

Integer
AES
single-core 2642 2.26 GB/sec
multi-core 19583 16.8 GB/sec
Twofish
single-core 2701 151.6 MB/sec
multi-core 30584 1.68 GB/sec
SHA1
single-core 3138 340.6 MB/sec
multi-core 25823 2.74 GB/sec
SHA2
single-core 3395 146.9 MB/sec
multi-core 26369 1.11 GB/sec
BZip2 Compress
single-core 2542 10.3 MB/sec
multi-core 26023 105.8 MB/sec
BZip2 Decompress
single-core 2509 13.6 MB/sec
multi-core 26234 142.2 MB/sec
JPEG Compress
single-core 2790 38.9 Mpixels/sec
multi-core 29434 410.1 Mpixels/sec
JPEG Decompress
single-core 4103 101.4 Mpixels/sec

CenturyLink 16vCPUs 30GB MEMORY

Integer
AES
single-core 2531 2.17 GB/sec
multi-core 22497 19.3 GB/sec
Twofish
single-core 2599 145.9 MB/sec
multi-core 41159 2.26 GB/sec
SHA1
single-core 3019 327.8 MB/sec
multi-core 48069 5.10 GB/sec
SHA2
single-core 3297 142.7 MB/sec
multi-core 52687 2.23 GB/sec
BZip2 Compress
single-core 2443 9.93 MB/sec
multi-core 38362 155.9 MB/sec
BZip2 Decompress
single-core 2425 13.1 MB/sec
multi-core 37918 205.5 MB/sec
JPEG Compress
single-core 2686 37.4 Mpixels/sec
multi-core 42556 592.9 Mpixels/sec
JPEG Decompress
single-core 3748 92.7 Mpixels/sec

multi-core	35117	868.1 Mpixels/sec
PNG Compress		
single-core	2690	2.15 Mpixels/sec
multi-core	29565	23.6 Mpixels/sec
PNG Decompress		
single-core	2930	33.8 Mpixels/sec
multi-core	29743	342.9 Mpixels/sec
Sobel		
single-core	3788	137.9 Mpixels/sec
multi-core	33290	1.21 Gpixels/sec
Lua		
single-core	2886	2.59 MB/sec
multi-core	27855	25.0 MB/sec
Dijkstra		
single-core	2796	10.0 Mpairs/sec
multi-core	18899	67.8 Mpairs/sec

Floating Point

BlackScholes		
single-core	2365	10.5 Mnodes/sec
multi-core	25324	112.7 Mnodes/sec
Mandelbrot		
single-core	2681	2.75 Gflops
multi-core	35884	36.8 Gflops
Sharpen Filter		
single-core	2444	1.81 Gflops
multi-core	24762	18.4 Gflops
Blur Filter		
single-core	1990	1.90 Gflops
multi-core	22961	21.9 Gflops
SGEMM		
single-core	4070	11.4 Gflops
multi-core	31025	86.9 Gflops
DGEMM		
single-core	3706	5.45 Gflops
multi-core	30814	45.3 Gflops
SFFT		
single-core	2751	2.90 Gflops
multi-core	22790	24.0 Gflops
DFFT		
single-core	2963	2.70 Gflops
multi-core	26107	23.8 Gflops
N-Body		
single-core	4538	1.68 Mpairs/sec
multi-core	38910	14.4 Mpairs/sec
Ray Trace		
single-core	3471	4.09 Mpixels/sec
multi-core	34808	41.0 Mpixels/sec

Memory

Stream Copy		
single-core	1747	6.97 GB/sec
multi-core	2514	10.0 GB/sec
Stream Scale		
single-core	2473	9.88 GB/sec
multi-core	4696	18.7 GB/sec
Stream Add		
single-core	2295	10.4 GB/sec
multi-core	4063	18.4 GB/sec
Stream Triad		
single-core	2182	9.59 GB/sec
multi-core	4124	18.1 GB/sec

Benchmark Summary

Integer Score	2959	27187
Floating Point Score	3003	28839
Memory Score	2156	3750
Geekbench Score	2816	23160

multi-core	54940	1.36 Gpixels/sec
PNG Compress		
single-core	2589	2.07 Mpixels/sec
multi-core	41088	32.8 Mpixels/sec
PNG Decompress		
single-core	2777	32.0 Mpixels/sec
multi-core	31990	368.8 Mpixels/sec
Sobel		
single-core	3563	129.7 Mpixels/sec
multi-core	53497	1.95 Gpixels/sec
Lua		
single-core	2753	2.47 MB/sec
multi-core	40537	36.4 MB/sec
Dijkstra		
single-core	2457	8.82 Mpairs/sec
multi-core	21282	76.4 Mpairs/sec

Floating Point

BlackScholes		
single-core	1936	8.62 Mnodes/sec
multi-core	30642	136.4 Mnodes/sec
Mandelbrot		
single-core	2583	2.65 Gflops
multi-core	40731	41.7 Gflops
Sharpen Filter		
single-core	2339	1.73 Gflops
multi-core	35677	26.4 Gflops
Blur Filter		
single-core	1893	1.80 Gflops
multi-core	29660	28.3 Gflops
SGEMM		
single-core	3455	9.68 Gflops
multi-core	51815	145.1 Gflops
DGEMM		
single-core	3287	4.83 Gflops
multi-core	48118	70.7 Gflops
SFFT		
single-core	2635	2.78 Gflops
multi-core	38962	41.1 Gflops
DFFT		
single-core	2823	2.57 Gflops
multi-core	42507	38.7 Gflops
N-Body		
single-core	4365	1.62 Mpairs/sec
multi-core	66627	24.7 Mpairs/sec
Ray Trace		
single-core	3516	4.15 Mpixels/sec
multi-core	51678	60.9 Mpixels/sec

Memory

Stream Copy		
single-core	2086	8.33 GB/sec
multi-core	3978	15.9 GB/sec
Stream Scale		
single-core	2703	10.8 GB/sec
multi-core	4820	19.2 GB/sec
Stream Add		
single-core	2465	11.2 GB/sec
multi-core	3511	15.9 GB/sec
Stream Triad		
single-core	2530	11.1 GB/sec
multi-core	3594	15.8 GB/sec

Benchmark Summary

Integer Score	2808	39005
Floating Point Score	2791	42399
Memory Score	2435	3943
Geekbench Score	2726	33350