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CS-524 Homework 2

1. Complete reading Chapter 3 of the textbook and the lecture materials. Please note the errata: The references to [19] on p. 56 of the book should be replaced with references to [20]! Please also read [20] (available free) at https://www.kernel.org/doc/ols/2007/ols2007v2-pages-87-96.pdf .

Ans: Completed reading Textbook Chapter 3 and the lecture materials.

2. Explain the advantage that paravirtualization provides for handling timers in virtual machines.

Ans: In regards to Cloud Computing, for para-virtualization pre-processing is necessary. All privileged instructions are replaced with so-called hypercalls, which are system calls that trap directly into the hypervisor, during pre-processing. Para-virtualization allows virtual machines to be accessed via interfaces similar to the underlying hardware. This capability reduces overhead and improves system performance by allowing the use of VMs that would otherwise go unused in traditional or full hardware virtualization. Other advantages include, Direct communication between the guest kernel and the hypervisor enhances overall performance. The thin software layer generated by para-virtualization manages virtual server traffic by enabling a single guest OS to access the physical hardware device while blocking access to all other guest OS. Because para-virtualization does not attempt to completely rebuild the hardware, the virtualization overhead is smaller. Because it uses the drivers already existing in the guest OS, paravirtualization does not require device drivers. As a result, businesses can take full advantage of the server's hardware rather than being confined to hardware with available drivers, as is the case with full virtualization.

(Reference: Cloud Computing: Business Trends and Technologies)

3. Explain how paravirtualization helps in minimizing access to APIC.

Ans: Another advantage of para-virtualization is the ability to operate with multi-processor architectures. Until now, we have assumed that our simplified computer design has only one CPU, although this is not always the case with modern devices. In theory, an operating system treats several CPUs the same way it treats one; with modular architecture, only the scheduler and interrupt handlers need to be aware of the variances. Without going into detail, x86-based multi-processor systems employ the Advanced Programmable Interrupt Controller (APIC) for interrupt redirection in support of Symmetric Multi-Processing (SMP). Because of the transitions into and out of the hypervisor, accessing APIC in virtual mode is costly. Multiple APIC access requests can be replaced with a single hypercall using para-virtualization, which has a full view of the code.

(Reference: Cloud Computing: Business Trends and Technologies)

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4. Find out if Linux (like Unix) has both the user-mode and system-mode stacks for each process it runs.

Ans: Yes, Linux (like Unix) has user-mode and system-mode or kernel-mode stacks for each process that runs.
There may be more than one set of identical registers on the CPU. The operating system will only work if one set of registers is reserved for user mode, where application programs run, and another for system mode, where only the operating system software runs.
The CPU will not be able to switch between modes automatically. When an interrupt occurs in the CPU, the interrupt handler changes between user mode and system mode.

(Reference: Cloud Computing: Business Trends and Technologies)

5. Find out what "unscrambled" means in the description of the Intel LSL instruction (you can, for example, use the Intel manual referenced in the lecture).

Ans: The term "unscrambled" in the Intel Load Segment Limit (LSL) instruction refers to the limit being scaled based on the setting of the G flag in the segment descriptor. When the privilege level and type checks pass into the destination register and set a ZF flag in the EFLAGS register, the unscrambled limit is loaded. If the segment selector is not visible at the current privilege level or is an incorrect type for the LSL instruction, the instruction ignores the destination register and clears the ZF flag. When the processor accesses a segment, it uses a limit check to ensure that the offset is within the segment's limit. The LSL (Load Segment Limit) instruction can be used by the program to perform limit checking.
The LSL instruction specifies the segment selector for the segment descriptor whose limit is to be checked, as well as a destination register. Depending on the G flag. The restrictions are viewed differently. When the G flag is clear, the effective limit is the value of the segment descriptor's 20-bit limit. The limit in this case ranges from 0 to 1MB. When the G flag is set to 4KB page granularity, the processor adjusts the value in the limit field by a factor of 212. (4KBytes). In this situation, the effective limit ranges from 4KB to 4GB.

(Reference: https://www.intel.com/content/www/us/en/architecture-and-technology/64-ia-32-architectures-software-developer-instruction-set-reference-manual-325383.html (Pg: 646))

6. Read the following two papers:
• Carl Waldspurger and Rosenblum, M. (2012) I/O Virtualization. Communications of the ACM, vol. 55, No 1. January 2012. Pages 66-72; and
• Muli Ben-Yehuda; Xenidis, J.; Ostrowski, M.; Rister, K.; Bruemmer, A.; Van Doorn, L. (2007). The Price of Safety: Evaluating IOMMU Performance. Proceedings of the Linux Symposium on June 27th–30th, 2007. Ottawa, Ontario. Pages 225-230.
1) Explain the advantages and disadvantages of using I/O MMU by citing the appropriate text from the paper;

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2) Research the Web to find what is meant by "carrier-grade hypervisors". What products are available?

Ans: 1) Advantages of I/O MMU:

- The I/O MMU converts the I/O virtual memory address to the corresponding physical memory, making direct device access safe and efficient. It also allows the VM driver to program device DMA using its virtualized notion of memory address, while allowing the hypervisor to decide where VM memory is actually located.
- The huge region of memory can be allocated without the necessity for physical memory to be contiguous – the IOMMU maps contiguous virtual addresses to the underlying fragmented physical addresses.
- Devices that do not provide memory addresses long enough to address the complete physical memory can still address the entire memory via the IOMMU, eliminating the overheads associated with copying buffers to and from the addressable memory space of the peripheral.
- Decoupling allows I/O devices to be multiplexed in time and space, allowing several logical devices to be realized by a lower number of physical devices.
- Because of the ability to multiplex logical I/O devices onto physical ones, administrators and automated systems can drive I/O devices at higher utilization and achieve improved hardware efficiency. Much of the rapid adoption of virtualization over the last decade can be ascribed to the huge cost reductions realized as a result of such basic partitioning and server consolidation.
- Decoupling allows for more flexible mappings between logical and physical devices, allowing for more seamless portability. Virtualization makes VMs portable, even across heterogeneous systems, by facilitating mappings of logical I/O devices to physical devices with varied but semantically comparable interfaces.
- Decoupling also enables common VM capabilities such as the ability to suspend and resume a VM as well as the ability to live migrate a running VM between physical computers.
- Even if the VM does not move, this virtualization layer may change mappings to physical devices. A VM's virtual disk, for example, can be transferred transparently across network storage units by altering mappings while copying storage contents, even while the VM remains operational. The same feature can be utilized to boost availability or balance load across many I/O channels.
- I/O virtualization enables several novel and valuable modifications to logical I/O devices.
- Device aggregation is a beneficial capability enabled by I/O virtualization, in which numerous physical devices can be merged into a single more capable logical device that is exported to the VM. Combining numerous disk storage devices and exporting them as a single bigger disk is one example.

The disadvantages of an I/O MMU.

- Some translation performance degradation and management overhead (e.g., page table walks).
- By interposing and modifying virtual I/O requests, new features can be added to existing systems, invisibly improving unmodified software with new capabilities.

A disk write, for example, can be turned into duplicated writes to several drives, allowing the system to endure disk-device failures.

- Physical memory is consumed for the additional I/O page (translation) tables. If the tables can be shared with the processor, this can be minimized.
- Another disadvantage of this optimization is that it protects other guests and the hypervisor from the guest but not the guest itself.

(References: I/O Virtualization by Carl Waldspurger, Mendel Roseblum, https://en.wikipedia.org/wiki/Input%E2%80%93output_memory_management_unit , http://www.linuxpundit.com/documents/CGV_WP_Final_FN.pdf)

2) Carrier Grade virtualization services are those that meet some or all of the required qualities found in edge and core network elements such as IP Multimedia Systems nodes.
Real-time behavior, flexible security, availability, high performance scaling, upgrade possibilities, fault tolerance, and ease of analysis are among the features.

BareMetal Xen Hypervisors, Oracle Solaris, and NEC CGHV are among the products available.

7. Find out what hypervisors Amazon is using in EC2, and describe their major characteristics.

Ans: In Xen, Amazon EC2 use bare-metal hypervisors. The primary qualities are:

- Memory Overcommit: By sharing unused server RAM between VMs on the host server, you can save money while improving application speed and security.
- Live Storage Migration: Move active virtual machines and their associated virtual disk images within and between resource pools using local and shared storage.
- Host Failure Protection: Provide high availability by restarting virtual machines automatically whenever a failure occurs at the VM, hypervisor, or server level. Link aggregation connects network interfaces to boost network redundancy and throughput.
- Live VM Migration: It offers live virtual machine migration from one host to another, allowing for workload balance and the avoidance of downtime.
- Host Power Protection: Utilize integrated hardware characteristics to reduce datacenter electricity consumption by dynamically consolidating VMs on fewer systems and then turning off unneeded servers as service demand changes.
- Site Recovery: Site-to-site disaster recovery planning and services for virtual environments are provided. Site recovery is simple to set up, quick to recover from, and can be tested on a regular basis to verify disaster recovery plans remain relevant.

(References: https://en.wikipedia.org/wiki/Amazon_Elastic_Compute_Cloud , https://en.wikipedia.org/wiki/Xen , http://xenserver.org/overview-xenserver-open-source-virtualization/open-source-virtualizationfeatures.html)

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8. Examine the Amazon EC2 VM offer capabilities and particularly the Amazon Machine Image (AMI) ((
https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/AMIs.html **) and answer the following questions:**
a. How (i.e., in what units) does EC2 measure the CPU power of a virtual machine and how is the unit in question translated into the power of the physical processors)?
b. What kinds of machine instances are there as characterized by the power of their respective CPUs, platform (i.e., 32-bit or 64-bit), memory, storage, etc.? Please list all the instances in the nomenclature along with their respective characteristics;
c. Which operating systems are available on the above systems?
d. What is an AMI and what is its relationship to an instance?
e. What are the components of an AMI?

Ans:
a. The CPU power of a virtual machine is measured by EC2 in ECU (EC2 Computing Units). ECU is said to equate to a specific number of computation cycles in a way that is independent of the actual hardware. As a result, numerous benchmarks and tests are utilized to assess how the Computing Units convert into physical processor power. A single ECU, according to the specification, is described as the computing power of a 1.0 to 1.2 GHz 2007 server CPU capacity.

(References:
https://aws.amazon.com/ec2/faqs/#What_is_an_EC2_Compute_Unit_and_why_did_you_introduce_it , https://www.datadoghq.com/blog/are-all-aws-ecu-created-equal/)

b. Amazon EC2 allows you to pick between several instance types and the flexibility to choose the combination of instances that best meets your computing needs, and these sets of instance combinations can be modified at any time if your business needs change. Each instance delivers a known amount of dedicated computation resources and is priced by the hour. The various sorts of instances are as follows:
General Purpose: Because of the variety of CPU size ranges, this instance family comprises T2, M3, and M4, which are frequently the first choice. Furthermore, the resource balance makes them perfect for running small and medium-sized databases, more memory-intensive data processing workloads, caching fleets, and backend servers.
Compute-Optimized: This instance family, which comprises the C3 and C4 instance types, is designed for applications that require a lot of compute capacity.
Memory Optimized: This instance family, which contains the X1, R3, and R4 instance types, is intended for memory-intensive applications. Instances are the least expensive instance type in terms of cost per GB of RAM.
Accelerated Computing/GPU: This instance family, which contains the P2, G2, and F1 instance types, enables you to take use of the parallel capabilities of the NVIDIA Tesla GPU via CUDA or OpenCL programming models for GPGPU.

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Storage Optimized: This instance family, which includes the I2 and D2 instance types, offers direct attached storage solutions that are targeted for applications that have specific disk I/O and storage capacity requirements. There are now two types of storage-optimized instances.

(References: https://aws.amazon.com/blogs/aws/choosing-the-right-ec2-instance-type-foryour-application/ , https://aws.amazon.com/ec2/instance-types/ , https://aws.amazon.com/ec2/previous-generation/)

c. Currently, Amazon EC2 supports the following operating systems: Amazon Linux, CentOS, CoreOS, Debian, Fedora, FreeBSD, Gentoo, Genymotion, Oracle Linux, RancherOS, Red Hat Enterprise Linux (RHEL), SUSE, SUSE Linux Enterprise Server, TurnKey Core, Windows Server, and Ubuntu Server 14.04 LTS (HVM)

(References:
http://docs.aws.amazon.com/opsworks/latest/userguide/workinginstances-oslinux.html ,
https://aws.amazon.com/marketplace/b/2649367011?ref_=header_nav_category_2649367011)

d. An Amazon Machine Image (AMI) is a form of virtual appliance used to generate virtual machines in the Amazon Elastic Compute Cloud ("EC2"). It is the fundamental unit of deployment for services supplied via EC2. It is also a type of instance offered by AWS.

e. The components of an AMI are:
- Storage for the Root Device
- Determining the Root Device Type of Your AMI
- Stopped State
- Default Data Storage and Persistence
- Boot Times
- AMI Creation

9. Find out about the pricing of the EC2 platforms and provide a few examples.

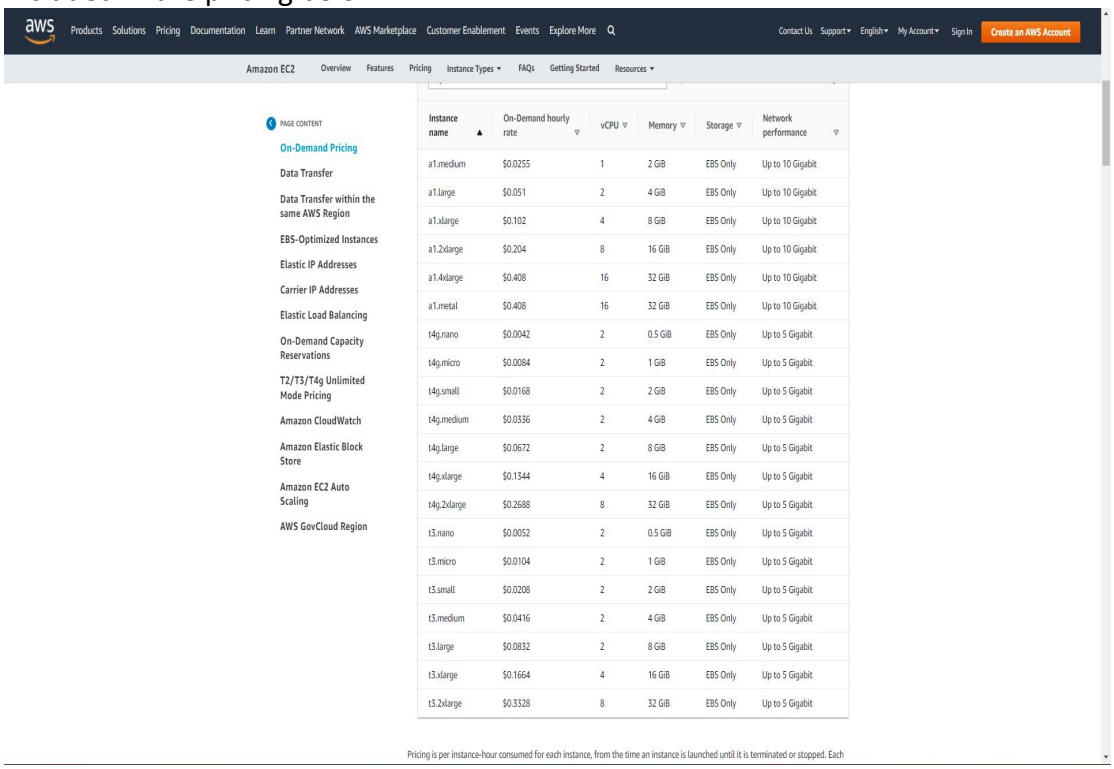
Ans: The Amazon EC2 platform is accessible to use for free. There are no hidden or minimum prices, and users must pay based on their needs and utilization of the services. A monthly calculator is also available to compute the projected monthly bill.

Amazon EC2 instances can be purchased in four ways: On-Demand, Reserved Instances, Spot Instances, and Dedicated Hosts.
- On-Demand Instances are excellent for unanticipated or short-term demand because the customer pays for computing resources by the hour with no long-term obligations or upfront expenditures.
- Reserved Instances are beneficial for reserving capacity for predictable workloads and are available at large discounts of up to 75% off when compared

to On-Demand Instances. All normal reserved instances are always available (i.e. 24x7) and allow the reserved instances to be launched when needed.

- Spot Instances are useful for urgent computing demands for huge quantities of extra capacity, and they allow you to bid on spare computing resources for up to 90% off the price of On-Demand Instances.
- Dedicated Hosts assist in meeting compliance requirements and lowering costs by permitting the use of current server-bound software licenses (subject to the conditions of the user's license). Dedicated Hosts can be hired on an hourly basis or as a reservation for up to 70% off the On-Demand pricing.

For example:
1) <u>On-Demand Pricing:</u> You must pay for computing resources utilized each hour or minute for On-demand instances, with no long-term obligations.
The cost of running public and private AMIs on the given operating system is included in the pricing below.



Amazon EC2 on-demand instance in Ohio area for General purpose- Current generation is mentioned above for Linux operating system.

2) <u>Amazon EC2 Spot Instances:</u> You pay the spot pricing for the time your instances are running in spot instances. When spot instances are compared to Ondemand pricing, discounts of up to 90% are achievable.

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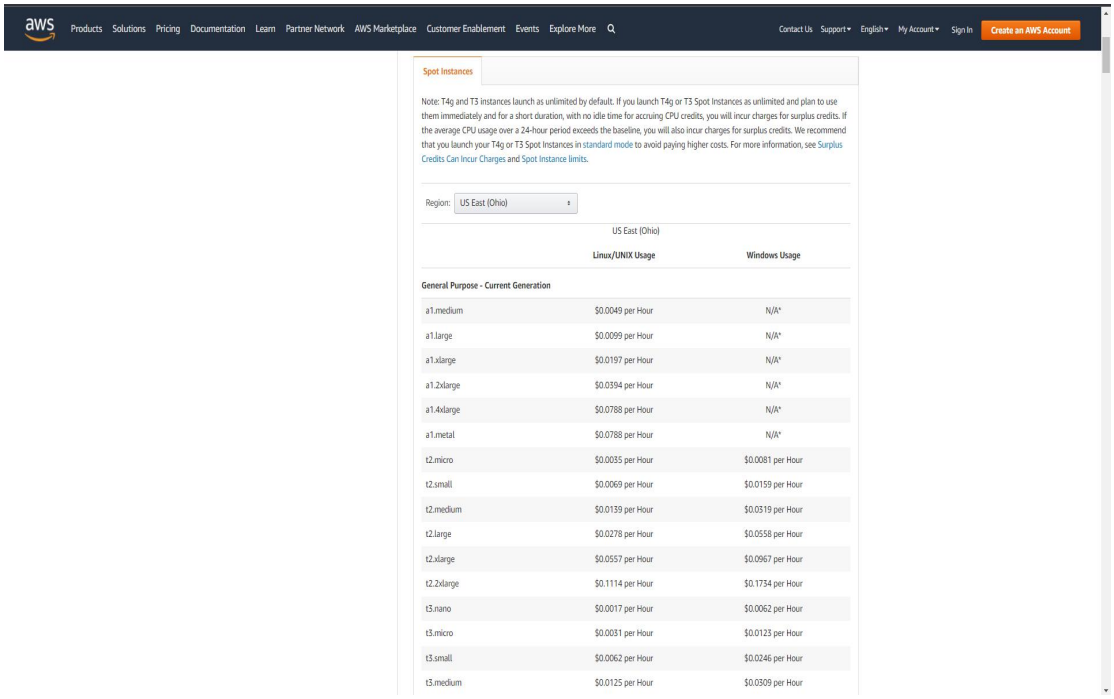
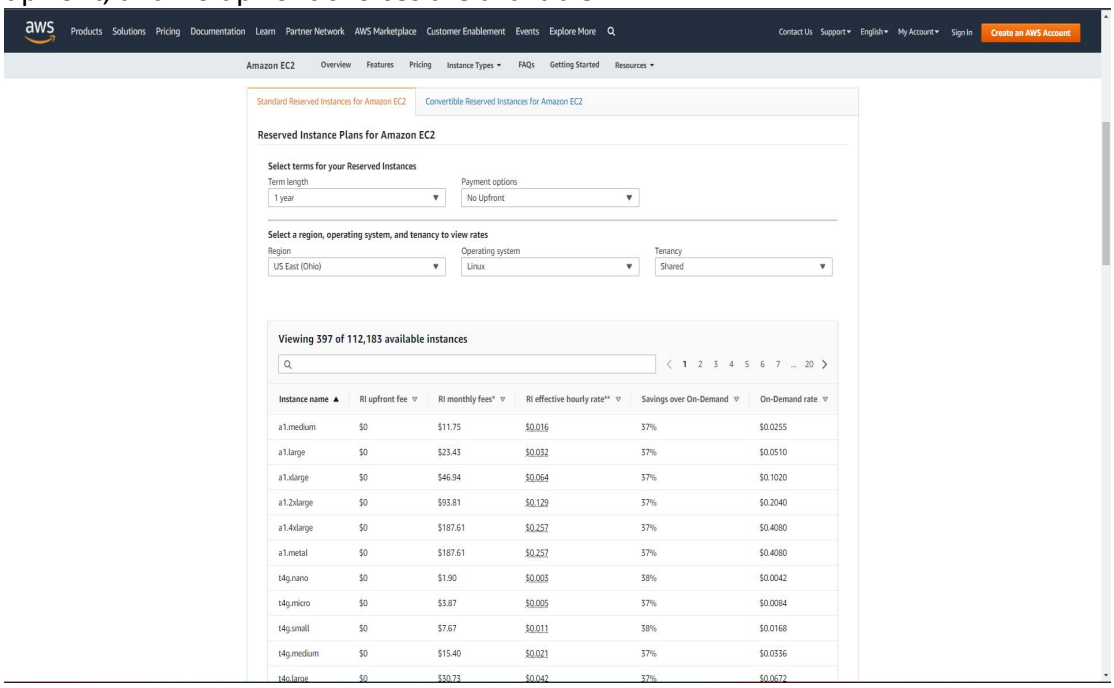


3) <u>Amazon EC2 Reserved Instances:</u> When compared to on-demand instances, reserved instances offer a large reduction of up to 75%. When you buy a standard or converted reserved instance, you have three payment options: All upfront, Partial upfront, and No upfront choices are available.



4) <u>Dedicated Host Pricing:</u> Dedicated host pricing varies each instance family, independent of the amount or size of the instance that you want to run. On-demand pricing allows you to scale up or down without committing to a long-term contract.

(References: https://aws.amazon.com/ec2/pricing/)

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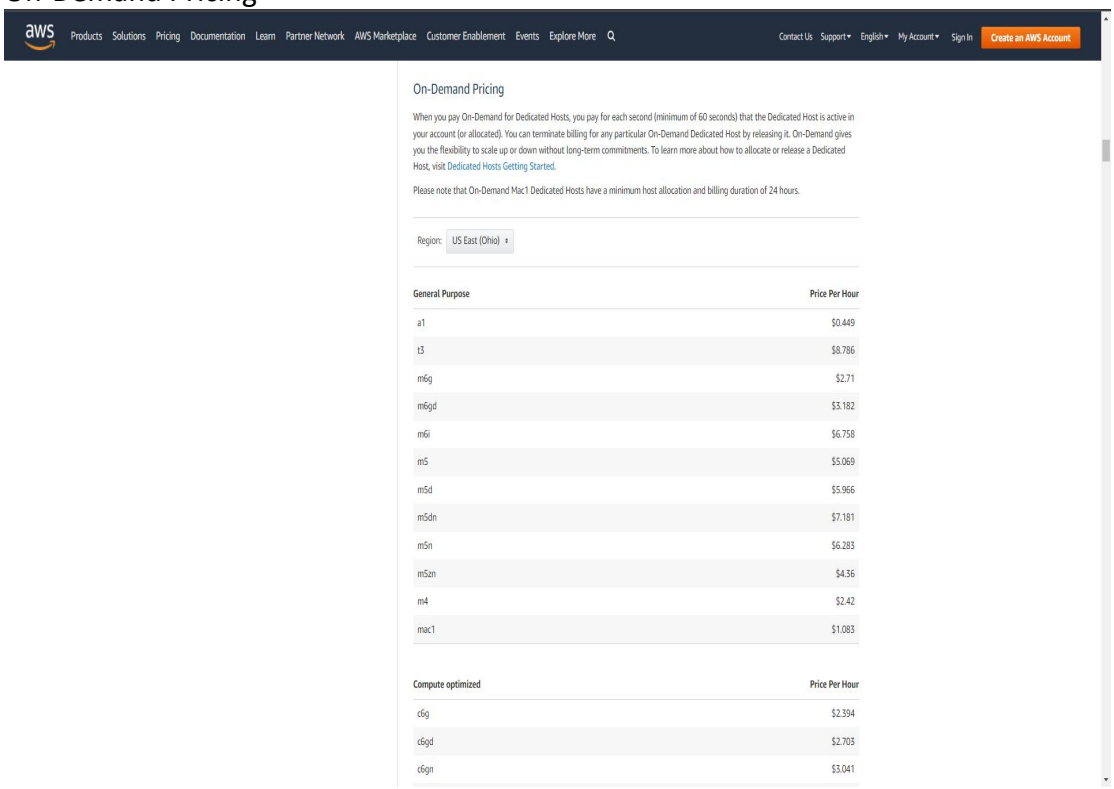
On-Demand Pricing



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On-Demand Pricing

When you pay On-Demand for Dedicated Hosts, you pay for each second (minimum of 60 seconds) that the Dedicated Host is active in your account (or allocated). You can terminate billing for any particular On-Demand Dedicated Host by releasing it. On-Demand gives you the flexibility to scale up or down without long-term commitments. To learn more about how to allocate or release a Dedicated Host, visit Dedicated Hosts Getting Started.

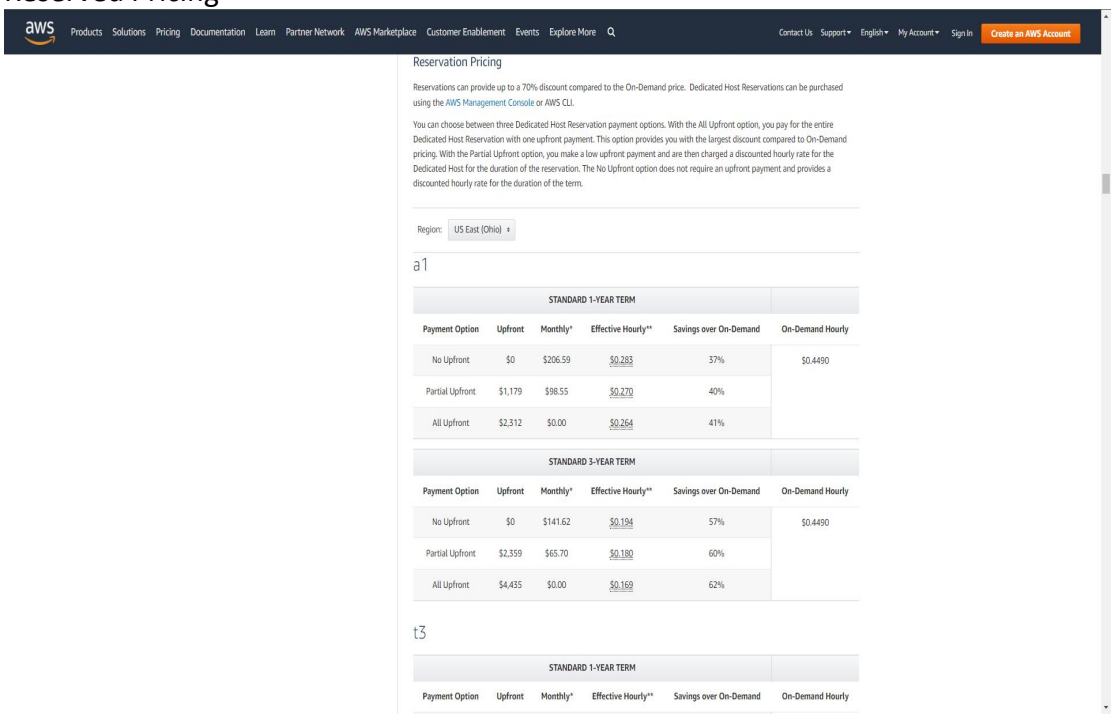
Please note that On-Demand Mac1 Dedicated Hosts have a minimum host allocation and billing duration of 24 hours.

Region: US East (Ohio)

General Purpose	Price Per Hour
a1	$0.449
t3	$8.786
m6g	$2.71
m6gd	$3.182
m6i	$6.758
m5	$5.069
m5d	$5.966
m5dn	$7.181
m5n	$6.283
m5zn	$4.36
m4	$2.42
mac1	$1.083

Compute optimized	Price Per Hour
c6g	$2.394
c6gd	$2.703
c6gn	$3.041

Reserved Pricing



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Reservation Pricing

Reservations can provide up to a 70% discount compared to the On-Demand price. Dedicated Host Reservations can be purchased using the AWS Management Console or AWS CLI.

You can choose between three Dedicated Host Reservation payment options. With the All Upfront option, you pay for the entire Dedicated Host Reservation with one upfront payment. This option provides you with the largest discount compared to On-Demand pricing. With the Partial Upfront option, you make a low upfront payment and are then charged a discounted hourly rate for the Dedicated Host for the duration of the reservation. The No Upfront option does not require an upfront payment and provides a discounted hourly rate for the duration of the term.

Region: US East (Ohio)

a1

STANDARD 1-YEAR TERM					
Payment Option	Upfront	Monthly*	Effective Hourly**	Savings over On-Demand	On-Demand Hourly
No Upfront	$0	$206.59	$0.283	37%	$0.4490
Partial Upfront	$1,179	$98.55	$0.270	40%	
All Upfront	$2,312	$0.00	$0.264	41%	

STANDARD 3-YEAR TERM					
Payment Option	Upfront	Monthly*	Effective Hourly**	Savings over On-Demand	On-Demand Hourly
No Upfront	$0	$141.62	$0.194	57%	$0.4490
Partial Upfront	$2,359	$65.70	$0.180	60%	
All Upfront	$4,435	$0.00	$0.169	62%	

t3

STANDARD 1-YEAR TERM					
Payment Option	Upfront	Monthly*	Effective Hourly**	Savings over On-Demand	On-Demand Hourly

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10. From the above exercise, you will learn that it is possible to create a free machine instance. Please, do the following:

a. Find out and document the essence of the respective Service Level Agreement (SLA) on ; in particular write down what one needs to do in order to maintain this service free;

b. Describe the process (i.e., what exactly one needs to do) to create a free machine instance that could be used as a server. (Do not, however, create anything yet!)

c. Can you create a machine instance equivalent to your own PC and then transfer your own PC image there? If so, how would you achieve that?

Ans:

a. A Service Level Agreement (SLA) is a contract between a cloud provider (internal or external) and the service user that defines duties, quality, and scope on both sides. The most typical component of a SLA is that the services shall be given to the client in accordance with the terms of the contract. To continue receiving free Amazon EC2 services, sign up for the Free Tier and gain hands-on experience for a 12-month period. Then, subject specific use limits, the user must register an account and access the services supplied.

The need to follow the steps:

i. Sign up for an AWS account,

ii. Credit card details and billing address must be provided. You would not be charged for the services until your free usage exceeded the restrictions.

iii. Choose any of the items offered under the Free Tier service to get started with AWS Cloud services.

(References: http://searchcloudcomputing.techtarget.com/essentialguide/Breaking-down-whats-inyour-cloud-SLA, https://en.wikipedia.org/wiki/Service-level_agreement, https://aws.amazon.com/ec2/sla/)

b. The steps to take in order to build a free machine instance that can be used as a server are as follows:

i. First, have to construct an instance of Amazon EC2 which can be utilized as a server for hosting an \sapplication on the cloud.

ii. Next, a database instance must be created as a server for the database.

iii. After completing the preceding stages, a web app can be deployed on the server.

iv. After then, load balancing and scaling are required to spread traffic across the number of servers or application servers.

v. Finally, a name can be associated or used by the user with your online application.

(References: http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/AMIs.html)

c. Yes, we can establish a machine instance that is identical to my own PC and then transfer our own PC image to it. All of this is possible simply launching an Amazon Cloud EC2 instance and hosting it as a server. Following that, we must connect our own PC to the server and transmit the picture.

(References: https://aws.amazon.com/premiumsupport/knowledge-center/)