CS 524 Homework #2

Due: February 19, 2019

This homework contains both technical and business-related problems, for the total of 100 points.

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.

2. **(10 points)** Explain the advantage that paravirtualization provides for handling timers in virtual machines.

   Answer:

   - All modern OS rely on clock interrupts to maintain their internal timers, a feature that is particularly essential for real time media processing. For this, even an idle virtual machine needs to process the clock interrupts.

   - Without para-virtualization, the VMM needs to continue injecting timer interrupts or to inject back-to-back timer interrupts when the guest operating system is scheduled back to run. This is not a reliable or scalable way of virtualization.

   - With para-virtualization, the virtual machine code is changed to request a notification at the specified time. Then time is re-calculated and restored in the guest, which is the main advantage of para-virtualization.

3. **(10 points)** Explain how paravirtualization helps in minimizing access to APIC.

   Answer:

   - The code sending IPI on the x86-64 based multi – processor architectures using the flat mode needs to access the APIC registers a couple of times. Accessing APIC in the virtual mode is expensive because of the transitions into and out of the hypervisor. Each access to the APIC registers needs to be intercepted for virtualization, causing overhead.

   - With para-virtualization, which has the full view of the code, the multiple APIC access requests can be replaced with a single hypercall, achieving faster, simpler, and more efficient implementations.

4. **(5 points)** Find out if *Linux* (like *Unix*) has both the user-mode and system-mode stacks for each process it runs.

Answer:

- Yes, Linux (like Unix) have one user-mode stack and one system-mode stack for each process it runs. The explicit system requests to switch to the user mode from the system mode. The user -mode stack is for user processes.

- In the system-mode: There is just one common kernel memory. In it each process has its own system stack (by default 8K).

- In the user-mode: Any process which runs in the user mode refers to own stack area that is used for holds local variables, parameters, frame pointers, return address from automatic variables within functions.

5. **(10 points)** 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).

Answer:

- In the description of the Intel LSL, the "unscrambled", means the segment have rules. The limit scaled according to the setting of the G flag in the segment descriptor.

- When the processor accesses any segment it performs a limit check to insure that the offset is within the limit of the segment. Software can perform this limit check using the LSL (load segment limit) instruction.

- The LSL instruction specifies the segment selector for the segment descriptor whose limit is to be checked and a destination register. Segment limit field is used to specify the length of the period.

- When the G flag is clear (G=0), the effective limit is the value of the 20-bit limit field in the segment descriptor. Here, the limit ranges from 0 to 1MByte. When the G flag is set (G=1), the processor scales the value in the limit field by a factor of 4Kbytes. In this case, the effective limit ranges from 4KBytes to 4GBytes.

6. **(25 points)** 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;

Answer:

- The advantages and disadvantages of using I/O MMU are as under:

- Advantages**:** The IOMMU allows the driver in the VM to program device DMA using its virtualized notion of memory addresses, while still allowing the hypervisor to decide where VM memory is actually located in physical machine memory. The I/O MMU also provides a level of safety, ensuring that even buggy driver software in the guest cannot generate DMA accesses to locations outside the VM.A virtual I/O MMU would allow a guest operating system to defend against its own buggy device drivers, as in a native system. On one hand, these results are discouraging: enabling the I/O MMU to get safety and paying up to 60% more in CPU utilization isn't an encouraging prospect. On the other hand, the fact that the throughput is roughly the same when the I/O MMU code doesn't overload the system strongly suggests that software is the culprit, rather than hardware. This is good, because software is easy to fix!

- Disadvantages: Although they provide valuable services, I/O MMUs can impose a performance penalty due to the extra memory accesses required to perform DMA operations. The exact performance degradation depends on the IOMMU design, its caching architecture, the way it is programmed and the workload.

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

Answer:

- A hypervisors virtual machine monitor (VMM) is computer software, firmware, or hardware that creates and runs virtual machines.

- Carrier Grade Linux is a set of specifications which detail standards of availability, scalability, manageability, and service response characteristics which must be met in order for Linux kernel-based operating system to be considered "carrier grade".

- Carrier Grade Linux defines three main types of applications — gateways, signaling servers, and management. Gateway applications provide bridging services between different technologies or administrative domains. Signaling server applications, which includeSS7products, handle control services for calls, such as routing, session control, and status. Management applications handle traditional service and billing operations

7. **(5 points)** Find out what hypervisors *Amazon* is using in EC2, and describe their major characteristics.

Answer:

- Tied up in a recent AWS announcement about a newEC2 high-end instance type (the C5) is a strong suggestion that Amazon's cloud computing giant has begun to shift its hundreds of

thousands of physical servers away from the open source Xen hypervisor that's run them until now, to the open source alternative, KVM.

- Major characteristics**:**

(A) Using a micro-kernel design, providing services that allow multiple computer operating systems to execute on the same computer hardware concurrently.

(B) Xen supports five different approaches to running the guest operating system: HVM (hardware virtual machine), HVM with PV drivers, PVHVM (HVM with PVHVM drivers), PVH (PV in an HVM container) and PV (para - virtualization).

8. **(10 points)** Examine the *Amazon* EC2 VM offer capabilities 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)?

      Answer:

      - The EC2 is using an EC2 compute unite to measure the CPU power of a virtual machine. The amount of CPU that is allocated to a particular instance is expressed in terms of these EC2 Compute Units.

      - It uses several benchmarks and tests to manage the consistency and predictability of the performance from an EC2 Compute Unit. One EC2 Compute Unit provides the equivalent CPU capacity of a 1.0-1.2 GHz 2007 Opteron or 2007 Xeon processor. This is also the equivalent to an early-2006 1.7 GHz Xeon processor referenced in our original documentation.

   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;

      Answer:

      - Amazon EC2 provides a wide selection of instance types optimized to fit different use cases. Instance types comprise varying combinations of CPU, memory, storage, and networking capacity and give you the flexibility to choose the appropriate mix of resources for your applications. Each instance type includes one or more instance sizes, allowing you to scale your resources to the requirements of your target workload.

      - There are in all seven types of General Purpose instances:

1. **Amazon EC2 A1** instances deliver significant cost savings and are ideally suited for scale-out and Arm-based workloads that are supported by the extensive Arm ecosystem. A1 instances are the first EC2 instances powered by AWS Graviton Processors that feature 64-bit Arm Neoverse cores and custom silicon designed by AWS.

   Features:
   - Custom built AWS Graviton Processor with 64-bit Arm Neoverse cores
   - Support for Enhanced Networking with Up to 10 Gbps of Network bandwidth
   - EBS-optimized by default
   - Powered by the AWS Nitro System, a combination of dedicated hardware and lightweight hypervisor

2. **T3 instances** are the next generation burstable general-purpose instance type that provide a baseline level of CPU performance with the ability to burst CPU usage at any time for as long as required. T3 instances offer a balance of compute, memory, and network resources and are designed for applications with moderate CPU usage that experience temporary spikes in use.

   Features:
   - Burstable CPU, governed by CPU Credits, and consistent baseline performance
   - Unlimited mode by default to ensure performance during peak periods and Standard mode option for a predictable monthly cost
   - Powered by the AWS Nitro System, a combination of dedicated hardware and lightweight hypervisor
   - AWS Nitro System and high frequency Intel Xeon Scalable processors result in up to a 30% price performance improvement over T2 instances

3. **T2 instances** are Burstable Performance Instances that provide a baseline level of CPU performance with the ability to burst above the baseline.

   Features:
   - High frequency Intel Xeon processors
   - Burstable CPU, governed by CPU Credits, and consistent baseline performance
   - Lowest-cost general purpose instance type, and Free Tier eligible*
   - Balance of compute, memory, and network resources

4. **M5 instances** are the latest generation of General Purpose Instances. This family provides a balance of compute, memory, and network resources, and is a good choice for many applications.

   Features:
   - Up to 3.1 GHz Intel Xeon® Platinum 8175 processors with new Intel Advanced Vector Extension (AXV-512) instruction set

- New larger instance size, m5.24xlarge, offering 96 vCPUs and 384 GiB of memory
- Up to 25 Gbps network bandwidth using Enhanced Networking
- Requires HVM AMIs that include drivers for ENA and NVMe
- Powered by the AWS Nitro System, a combination of dedicated hardware and lightweight hypervisor
- Instance storage offered via EBS or NVMe SSDs that are physically attached to the host server
- With M5d instances, local NVMe-based SSDs are physically connected to the host server and provide block-level storage that is coupled to the lifetime of the M5 instance

5. **M5a instances** are the latest generation of General Purpose Instances. This family provides a balance of compute, memory, and network resources, and is a good choice for many applications.

   Features:
   - AMD EPYC 7000 series processors with an all core turbo clock speed of 2.5 GHz
   - New larger instance size, m5.24xlarge, offering 96 vCPUs and 384 GiB of memory
   - Up to 20 Gbps network bandwidth using Enhanced Networking
   - Requires HVM AMIs that include drivers for ENA and NVMe
   - Powered by the AWS Nitro System, a combination of dedicated hardware and lightweight hypervisor
   - Instance storage offered via EBS-only
6. **M4 instances** provide a balance of compute, memory, and network resources, and it is a good choice for many applications.

   Features:
   - 2.3 GHz Intel Xeon® E5-2686 v4 (Broadwell) processors or 2.4 GHz Intel Xeon® E5-2676 v3 (Haswell) processors
   - EBS-optimized by default at no additional cost
   - Support for Enhanced Networking
   - Balance of compute, memory, and network resources

7. **T3a instances** are the next generation burstable general-purpose instance type that provide a baseline level of CPU performance with the ability to burst CPU usage at any time for as long as required.

   Features:
   - Burstable CPU, governed by CPU Credits, and consistent baseline performance
   - Unlimited mode by default to ensure performance during peak periods and Standard mode option for a predictable monthly cost
   - Powered by the AWS Nitro System, a combination of dedicated hardware and lightweight hypervisor
   - T3a features 2.5 GHz AMD EPYC 7000 series processors that offer customers a 10% cost savings over T3 instances

- The other EC2 instance types are:

    - Computer Optimized – (C5, C4, C3)
    - Memory Optimized – (X1, R4, R3)
    - Accelerated Computing (P3, P2, G3, F1)
    - Storage optimized-(I3)
    - Dense-storage Instances – (D2)

c. Which operating systems are available on the above systems?

Answer:

- Amazon EC2 currently supports a variety of operating systems including -Amazon Linux, Ubuntu, Windows Server, Red Hat Enterprise Linux, SUSE Linux Enterprise Server, Fedora, Debian, CentOS, Gentoo Linux, Oracle Linux, and FreeBSD.

9. **(10 points)** Find out about the pricing of the EC2 platforms and provide a few examples.

Answer:

- Amazon EC2 is free to try. There are four ways to pay for Amazon EC2 instances: On-Demand, Reserved Instances, and Spot Instances. You can also pay for Dedicated Hosts which provide you with EC2 instance capacity on physical servers dedicated for your use.

    1. **On Demand**: With On-Demand instances you only pay for EC2 instances you use. The use of On-Demand instances 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. On-Demand instances let you pay for compute capacity by the hour or second (minimum of 60 seconds) 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.

    2. **Reserved Instances**: Amazon EC2 Reserved Instances (RI) provide a significant discount (up to 75%) compared to On-Demand pricing and provide a capacity reservation when used in a specific Availability Zone.

3. **Spot Instances**: With Spot instances, You pay the Spot price that's in effect for the time period your instances are running. Spot instance prices are set by Amazon EC2 and adjust gradually based on long-term trends in supply and demand for Spot instance capacity. The following table displays the Spot price for each region and instance type (updated every 5 minutes).Spot instances are available at a discount of up to 90% off compared to On-Demand pricing. To compare the current Spot prices against standard On-Demand rates, visit the Advisor. Spot instances are also available to run for a predefined duration – in hourly increments up to six hours in length – at a discount of up to 30-50% compared to On-Demand pricing.

4. **Dedicated Hosts Pricing**: The price for a Dedicated Host varies by instance family, region, and payment option. Regardless of the quantity or the size of instances that you choose to launch on a particular Dedicated Host you pay hourly for each active Dedicated Host, and you are not billed for instance usage. When you allocate a Dedicated Host for use, you must choose an instance type configuration for the host. This selection will define the number of sockets and physical cores per host, the type of instance you can run on the host, and the number of instances that you can run on each host. After you have allocated a Dedicated Host, you will pay On-Demand unless you have a Dedicated Host Reservation. A Dedicated Host Reservation provides you with a discount of up to 70% compared to On-Demand pricing.

10. **(15 points)** 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;* in particular write down what one needs to do in order to maintain this service **free.**

       Answer:

       - They will apply any Service Credits only against future Amazon EC2 or Amazon EBS payments otherwise due from customer. At their discretion, they may issue the Service Credit to the credit card you used to pay for the billing cycle in which the Unavailability occurred. Service Credits will not entitle customer to any refund or other payment from AWS.

       - A service credit will be applicable and issued only if the credit amount for the application monthly billing cycles is greater than one dollar ($1.00 USD). So, in order to maintain this service free keep the monthly billing cycle less than a dollar.

    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!)

Answer:

- The process to create a free machine instance that could be used as a server is as follows:

1. Select datacenter location :

- ✓ Select the datacenter where your instance will be created. When you are experimenting with a free VPS, you should choose the datacenter closer to your location.

2. Use the Elastic Compute (EC2) service:

- ✓ Access the Elastic Compute service. Click on "EC2" in the upper-left corner of the AWS portal page.

3. Choose base image

- ✓ Click on big "Launch instance" button. You will see the available instance types. Note: you can upload your own if you need to, but that is another topic. Click on the "Free-tier only" check box to show the images available for the free micro-instance option we are using.

- **HVM or PV?** When selecting and instance, pay attention to whether it is an HVM instance or a PV instance. This is usually indicated in parenthesis at the end of the instance name. To understand the difference between HVM instances and PV instances, see the Amazon AWS virtualization types section of the AWS documentation.

  The summary is that HVM is probably the best instance type for most users. Choose HVM.

4. Select instance type

- ✓ Choose the default instance type, t2.micro, which is eligible for the free tier of service. Then, click on the "Next: Configure Instance Details" button at the bottom left of the page. Use all the default settings. Click on the "Review and Launch" button.

5. Launch the instance

- ✓ Review settings and launch the instance. For now, ignore the security warning. Depending on how you plan to use your instance you may wish to set stronger security setting. Click on the "Launch" button.

6. Download private key

- ✓ You will be asked to select a key pair that the instance will use to identify the legitimate user who connects to it via SSH when it is running. A key pair consists of a public key that AWS stores, and a private key file that you store. Together, they allow you to connect to your instance securely. The private key file allows you to securely SSH into your instance. Choose the "Create a new key pair" option from the menu options, then give the key pair a name. Then click on "Download Key Pair". Save the file to your hard drive. Make a note of the directory in which you chose to store the key pair file because you will need it later. In my case, I put it in my Documents folder so the full path of the file is: ~/Documents/Ubuntu-2-keypair.pem. Finally, click on the "Launch Instances" button.

7. Secure key pair file permissions

- ✓ Set permissions for the key. SSH will not allow you to the key pair file unless the file permissions are secure. Navigate to the file in the File Manager, right-click on the file and select Properties from the drop-down menu. In the properties dialogue box, click on the Permissions tab. Change the user permissions to "Read Only". Change group access permissions to "None" and Others access to "None". Then click the "Close" button.
- ✓ Alternatively, use the terminal and enter the command:

```
$ cd ~/Documents

$ sudo chmod 400 Ubuntu-2-keypair.pem
```

8. Manage instances

- ✓ After you clicked on the "Launch Instances" button, the instance started launching. To manage instances, click the "view Instance" button. See the instances you have created in the AWS Console. In my case I have two instances: one I created earlier and the one I created just now, which is initializing. Wait until the status of the instance changes to "running", then log into it.

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?

Answer:

- Yes, one can achieve that by using VM import transfer PC image. To achieve that one need to follow the below steps:

1. One must provide an Amazon S3 bucket and an IAM role named vmimport.
2. VM Import requires a role to perform certain operations in your account, such as downloading disk images from an Amazon S3 bucket. One must create a role named vmimport with a trust relationship policy document that allows VM Import to assume the role, and you must attach an IAM policy to the role.
3. Use the create-role command to create a role named vmimport and give VM Import/Export access to it. Ensure to specify the full path to the location of the trust-policy.jsonfile, and that you prefix file:// to it.
4. Create a file named role-policy.json with the following policy, where disk-image-file-bucket is the bucket where the disk images are stored.
5. Use the following put-role-policy command to attach the policy to the role created above. Ensure that you specify the full path to the location of the role-policy.json file.
6. Upload your VM image file to your Amazon S3 bucket using the upload tool of your choice. For information about uploading files through the S3 console, see Uploading Objects into Amazon S3.
7. After you upload your VM image file to Amazon S3, you can use the AWS CLI to import the image. These tools accept either the Amazon S3 bucket and path to the file or a URL for a public Amazon S3 file. Private Amazon S3 files require a signed GET URL.
8. Use the describe-import-image-tasks command to return the status of an import task.
9. Now that you have an AMI, you can launch it as an instance or copy it to another region.