TCSS 562: SOFTWARE ENGINEERING FOR CLOUD COMPUTING

**AWS Demo,
Cloud Enabling Technology**

Wes J. Lloyd
School of Engineering and Technology
University of Washington - Tacoma

1

FEEDBACK FROM 10/28

- Perspective on material: 6.87 (→ *mostly new to me*)
- Pace: 5.4 (~ just right)
- 15 respondents
- **Could you please introduce virtualization more specifically?**
  - More today in AWS Demo, and in "Cloud Enabling Technology" talk coming up...

2

FEEDBACK - 2

- ***The mechanics of a snapshot are unclear***
  - Demo...
- ***How do you extract the compressed snapshot volume?***
  - *From a user's perspective, snapshots are "extracted" when creating a **new** EBS volume. The snapshot ID is selected, and data is transferred from the snapshot to the **new** EBS volume.*

3

FEEDBACK - 2

- ***How does Amazon boot VMs?:***
  - EBS root "/" volume:
    root volume not transferred to physical host
    - Root volume needs to be available to the host via EBS network storage – (transfer may be required)
  - Instance store root volume (legacy):
    root volume transferred to physical host and cached
    - First launch on HW is slow, subsequent launches are faster
- 1^{st}-4^{th} gen: AWS XEN hypervisor boots VM on host
- 5^{th} gen: AWS KVM Nitro hypervisor boots VM on host
- Network must set up (public/private)
- Hypervisor limits VM resources: # vCPUs, RAM

4

FEEDBACK - 3

- **VM placement**: cloud provider must decide where to place newly requested VMs
  - **Greedy placement**: fill entire server w/ VMs, then move to the next
  - **Round-robin placement**: place on VM on each server in round-robin fashion to distribute and load-balance VM placements
- VM placement evaluates available server resources to determine if sufficient capacity (CPU/RAM) exists to host a VM on a given physical host
  - CPU cores can be shared with many VMs
  - Memory is generally not overbooked.
  - For example: if a machine has 256 GB, then only 256 GB of VMs are allowed to be created on the host...
  - C5d.large VM → 64 x 4GB VMs on 256 GB host

5

FEEDBACK - 4

- ***Does round-robin VM placement across hosts guarantee load balancing (even distribution) of cloud workloads?***
  - Why / why not?
  - DOES every VM behave the same?

6

AWS DEMO

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.7

7

EC2 VIRTUALIZATION - PARAVIRTUAL

- **1st, 2nd, 3rd, 4th generation → XEN-based**
- **5th generation instances → AWS Nitro virtualization**

- XEN - two virtualization modes
- XEN Paravirtualization "paravirtual"
  - 10GB Amazon Machine Image – base image size limit
  - Addressed poor performance of old XEN HVM mode
  - I/O performed using special XEN kernel with XEN paravirtual mode optimizations for better performance
  - Requires OS to have an available paravirtual kernel
  - PV VMs: will use common **AKI** files on AWS – ***Amazon kernel image(s)***
    - *Look for common identifiers*

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.8

8

EC2 VIRTUALIZATION - HVM

- XEN HVM mode
  - Full virtualization – no special OS kernel required
  - Computer entirely simulated
  - MS Windows runs in "hvm" mode
  - Allows work around: 10GB instance store root volume limit
  - Kernel is on the root volume (under /boot)
  - No AKIs (kernel images)
  - Commonly used today (*EBS-backed instances*)

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.9

9

EC2 VIRTUALIZATION - NITRO

- Nitro based on Kernel-based-virtual-machines
  - Stripped down version of Linux KVM hypervisor
  - Uses KVM core kernel module
  - I/O access has a direct path to the device
- Goal: provide indistinguishable performance from bare metal

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.10

10

EVOLUTION OF AWS VIRTUALIZATION

From http://www.brendangregg.com/blog/2017-11-29/aws-ec2-virtualization-2017.html

VS: Virtualization in software

P: Paravirtual

VH: Virtualization in Hardware

H: Hardware

AWS EC2 Virtualization Types

Bare-metal performance
Near-metal performance
Optimized performance
Poor performance

Importance: Most → Least

	#	Tech	Type	With	CPU, Memory	Network I/O	Local Storage I/O	Remote Storage I/O	Interrupts, Timers	Motherboard, Boot
	1	VM	Fully Emulated		VS	VS	VS	VS	VS	VS
Old	2	VM	Xen PV 3.0	PV drivers	P	P	P	P	VS	VS
	3	VM	Xen HVM 3.0	PV drivers	VH	P	P	P	VS	VS
	4	VM	Xen HVM 4.0.1	PVHVM drivers	VH	P	P	P	P	VS
	5	VM	Xen AWS 2013	PVHVM + SR-IOV(net)	VH	VH	P	P	P	VS
	6	VM	Xen AWS 2017	PVHVM + SR-IOV(net, stor.)	VH	VH	VH	P	P	VS
	7	VM	AWS Nitro 2017		VH	VH	VH	VH	VH	VS
New	8	HW	AWS Bare Metal 2017		H	H	H	H	H	H
			Bare Metal		H	H	H	H	H	H

VM: Virtual Machine. HW: Hardware.
VS: Virt. in software. VH: Virt. in hardware. P: Paravirt. Not all combinations shown.
SR-IOV(net): ixgbe/ena driver. SR-IOV(storage): nvme driver.

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.11

11

AWS VIRTUALIZATION - 2

- **Full Virtualization - Fully Emulated**
  - Never used on EC2, before CPU extensions for virtualization
  - Can boot any unmodified OS
  - Support via slow emulation, performance 2x-10x slower
- **Paravirtualization: Xen PV 3.0**
  - Software: Interrupts, timers
  - Paravirtual: CPU, Network I/O, Local+Network Storage
  - Requires special OS kernels, interfaces with hypervisor for I/O
  - Performance 1.1x – 1.5x slower than "bare metal"
  - Instance store instances: 1ST & 2nd generation- m1.large, m2.xlarge
- **Xen HVM 3.0**
  - Hardware virtualization: **CPU**, **memory** (CPU VT-x required)
  - Paravirtual: network, storage
  - Software: interrupts, timers
  - EBS backed instances
  - m1, c1 instances

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.12

12

AWS VIRTUALIZATION - 3

- XEN HVM 4.0.1
  - Hardware virtualization: CPU, memory **(CPU VT-x required)**
  - Paravirtual: network, storage, interrupts, timers
- XEN AWS 2013 *(diverges from opensource XEN)*
  - Provides hardware virtualization for CPU, memory, network
  - Paravirtual: storage, interrupts, timers
  - Called Single root I/O Virtualization (SR-IOV)
  - Allows sharing single physical PCI Express device (i.e. network adapter) with multiple VMs
  - Improves VM network performance
  - 3rd & 4th generation instances (c3 family)
  - Network speeds up to 10 Gbps and 25 Gbps
- XEN AWS 2017
  - Provides hardware virtualization for CPU, memory, network, local disk
  - Paravirtual: remote storage, interrupts, timers
  - Introduces hardware virtualization for EBS volumes (c4 instances)
  - Instance storage hardware virtualization (x1.32xlarge, i3 family)

13

AWS VIRTUALIZATION - 4

- AWS Nitro 2017
  - Provides hardware virtualization for CPU, memory, network, local disk, remote disk, interrupts, timers
  - All aspects of virtualization enhanced with HW-level support
  - November 2017
  - Goal: provide performance indistinguishable from "bare metal"
  - 5th generation instances – c5 instances (also c5d, c5n)
  - Based on KVM hypervisor
  - Overhead around ~1%

14

INSTANCE ACTIONS

- Stop
  - Costs of "pausing" an instance
- Terminate
- Reboot
- Image management
- Creating an image
  - EBS (snapshot)
- Bundle image
  - Instance-store

15

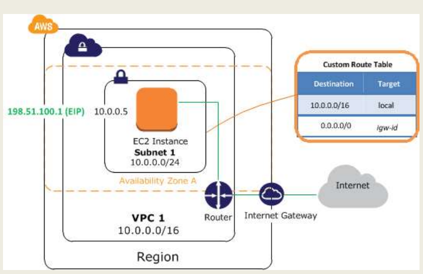
EC2 INSTANCE: NETWORK ACCESS

- Public IP address
- Elastic IPs
  - Costs: in-use FREE, not in-use ~12 ₵/day
  - Not in-use (e.g. "paused" EBS-backed instances)
- Security groups
  - E.g. firewall
- Identity access management (IAM)
  - AWS accounts, groups
- VPC / Subnet / Internet Gateway / Router
- NAT-Gateway: appliance that provides internet connectivity to private subnets

16

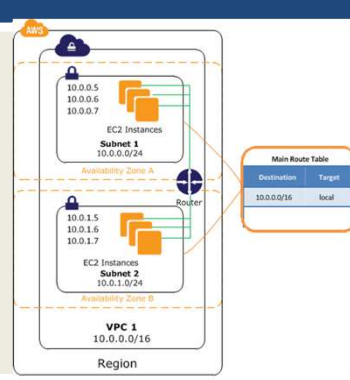
SIMPLE VPC

- Recommended when using Amazon EC2



17

VPC SPANNING AVAILABILITY ZONES



18

SIMPLE STORAGE SERVICE (S3)

- Key-value blob storage
- What is the difference vs. key-value stores (NoSQL DB)?
- Can mount an S3 bucket as a volume in Linux
  - Supports common file-system operations, but with some performance limitations
  - Uses s3fs (leverages FUSE- file system in user space)
  - https://github.com/s3fs-fuse/s3fs-fuse
- S3 replicates data, and provides eventual consistency
- Can be used to persist data for AWS Lambda functions

19

AWS CLI

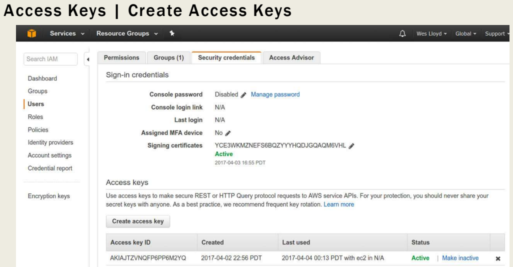
- Launch Ubuntu 18.04 VM
  - Instances | Launch Instance
- Install the general AWS CLI
  - sudo apt install awscli
- Create config file

```
[default]
aws_access_key_id = <access key id>
aws_secret_access_key = <secret access key>
region = us-east-2
```


20

AWS CLI - 2

- Creating access keys: IAM | Users | Security Credentials | Access Keys | Create Access Keys



21

AWS CLI - 3

- Export the config file
  - Add to /home/ubuntu/.bashrc

```
export AWS_CONFIG_FILE=$HOME/.aws/config
```

- Try some commands:
  - `aws help`
  - `aws command help`
  - `aws ec2 help`
  - `aws ec2 describes-instances --output text`
  - `aws ec2 describe-instances --output json`
  - `aws s3 ls`
  - `aws s3 ls vmscaleruw`

22

ALTERNATIVE CLI

- `sudo apt install ec2-api-tools`
- Predates "awscli" package
- API specifically for ec2 (not all amazon web services)
- Provides more concise output (generally no JSON)
- Additional functionality
- Define variables in .bashrc or another sourced script:
- `export AWS_ACCESS_KEY={your access key}`
- `export AWS_SECRET_KEY={your secret key}`
- `ec2-describe-instances`
- `ec2-run-instances`
- `ec2-request-spot-instances`
- EC2 management from Java:
- http://docs.aws.amazon.com/AWSJavaSDK/latest/javadoc/index.html

23

INSPECTING INSTANCE INFORMATION

- Find your instance ID (from any EC2 VM):

```
curl http://169.254.169.254/
curl http://169.254.169.254/latest/
curl http://169.254.169.254/latest/meta-data/
curl http://169.254.169.254/latest/meta-data/instance-id
; echo
```

- ec2-get-info command (if available on VM??)

24

PRIVATE KEY AND CERTIFICATE FILE

- Install openssl package on VM

\# generate private key file
$openssl genrsa 2048 > mykey.pk

\# generate signing certificate file
$openssl req -new -x509 -nodes -sha256 -days 36500 -key mykey.pk -outform PEM -out signing.cert

- Add signing.cert to IAM | Users | Security Credentials | *- - new signing certificate - -*
- From: http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/set-up-ami-tools.html?icmpid=docs_iam_console#ami-tools-create-certificate

25

PRIVATE KEY, CERTIFICATE FILE

- These files, combined with your AWS_ACCESS_KEY and AWS_SECRET_KEY and AWS_ACCOUNT_ID enable you to publish new images from the CLI
- Objective:

1. Configure VM with software stack
2. Burn new image for VM replication **(horizontal scaling)**

- Some folks may just install Docker. . .
- Create image script . . .

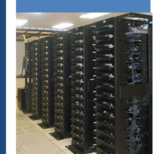
26

CREATE, UPLOAD, AND REGISTER NEW INSTANCE STORE AMI SCRIPT:

```
# for legacy instance store images - requires ec2-ami-tools package
image=$1
echo "Burn image $image"
echo "$image" > image.id
mkdir /mnt/tmp
AWS_KEY_DIR=/home/ubuntu/.aws
export EC2_URL=http://ec2.amazonaws.com
export S3_URL=https://s3.amazonaws.com
export EC2_PRIVATE_KEY=${AWS_KEY_DIR}/mykey.pk
export EC2_CERT=${AWS_KEY_DIR}/signing.cert
export AWS_USER_ID={your account id}
export AWS_ACCESS_KEY={your aws access key}
export AWS_SECRET_KEY={your aws secret key}
ec2-bundle-vol -s 5000 -u ${AWS_USER_ID} -c ${EC2_CERT} -k ${EC2_PRIVATE_KEY}
--ec2cert /etc/ec2/amitools/cert-ec2.pem --no-inherit -r x86_64 -p $image -i
/etc/ec2/amitools/cert-ec2.pem
cd /tmp
ec2-upload-bundle -b tcss562 -m $image.manifest.xml -a ${AWS_ACCESS_KEY} -s
${AWS_SECRET_KEY}  --url http://s3.amazonaws.com --location US
ec2-register tcss562/$image.manifest.xml --region us-east-1 --kernel aki-
88aa75e1
```


27

CLOUD ENABLING TECHNOLOGY



28

CLOUD ENABLING TECHNOLOGY

- Broadband networks and internet architecture
- Data center technology
- Virtualization technology
- Multitenant technology
- Web/web services technology

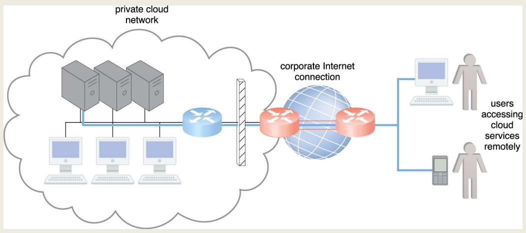
29

1. BROADBAND NETWORKS AND INTERNET ARCHITECTURE

- Clouds must be connected to a network
- Inter-networking: Users' network must connect to cloud's network
- Public cloud computing relies heavily on the **internet**

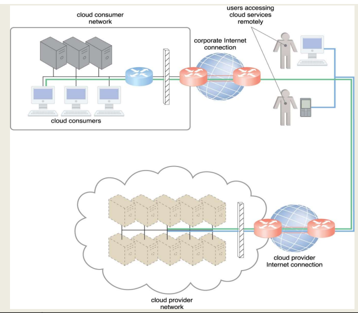
30

PRIVATE CLOUD NETWORKING



31

PUBLIC CLOUD NETWORKING



32

INTERNETWORKING KEY POINTS

- Cloud consumers and providers typically communicate via the internet
- Decentralized provisioning and management model is not controlled by the cloud consumers or providers
- Inter-networking (internet) relies on connectionless packet switching and route-based interconnectivity
- Routers and switches support communication
- Network bandwidth and latency influence QoS, which is heavily impacted by network congestion

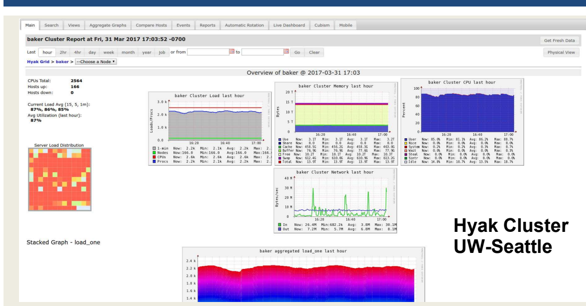
33

2. DATA CENTER TECHNOLOGY

- Grouping servers together (clusters):
- Enables power sharing
- Higher efficiency in shared IT resource usage (less duplication of effort)
- Improved accessibility and organization
- Key components:
  - Virtualized and physical server resources
  - Standardized, modular hardware
  - Automation support: ease server provisioning, configuration, patching, monitoring without supervision… ***tools are desirable***

34

CLUSTER MANAGEMENT TOOLS



35

DATA CENTER TECHNOLOGY – KEY COMPONENTS

- Remote operation / management
- **High availability support**: **redundant everything** Includes: power supplies, cabling, environmental control systems, communication links, duplicate warm replica hardware
- **Secure design**: physical and logical access control
- **Servers**: rackmount, etc.
- **Storage**: hard disk arrays (RAID), storage area network (SAN): disk array with dedicated network, network attached storage (NAS): disk array on network for NFS, etc.
- **Network hardware**: backbone routers (WAN to LAN connectivity), firewalls, VPN gateways, managed switches/routers

36

3. VIRTUALIZATION TECHNOLOGY

- Convert a physical IT resource into a virtual IT resource
- Servers, storage, network, power (virtual UPSs)
- Virtualization supports:
  - Hardware independence
  - Server consolidation
  - Resource replication
  - Resource pooling
  - Elastic scalability
- Virtual servers
  - Operating-system based virtualization
  - Hardware-based virtualization

37

VIRTUAL MACHINES

- Emulation/simulation of a computer in software
- Provides a substitute for a real computer or server
- Virtualization platforms provide functionality to run an entire operating system
- Allows running multiple different operating systems, or operating systems with different versions simultaneously on the same computer

38

KEY VIRTUALIZATION TRADEOFF

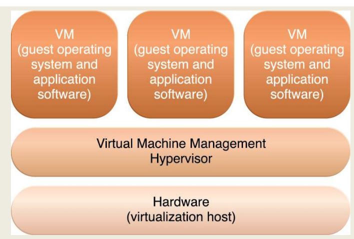
- Tradeoff space:

Degree of Hardware Abstraction

Concerns:
Overhead
Performance
Isolation
Security

39

TYPE 1 HYPERVISOR



- Host OS and VMs run atop the hypervisor
- The boot OS is the hypervisor kernel
- Xen dom0

40

TYPE 1 HYPERVISOR

- Acts as a control program
- Miniature OS kernel that manages VMs
- Boots and runs on bare metal
- Also known as Virtual Machine Monitor (VMM)
- **Paravirtualization**: Kernel includes I/O drivers
- VM guest OSes must use special kernel to interoperate
- Paravirtualization provides hooks to the guest VMs
- Kernel traps instructions (i.e. device I/O) to implement sharing & multiplexing
- User mode instructions run directly on the CPU
- Objective: minimize virtualization overhead
- Classic example is XEN (dom0 kernel)

41

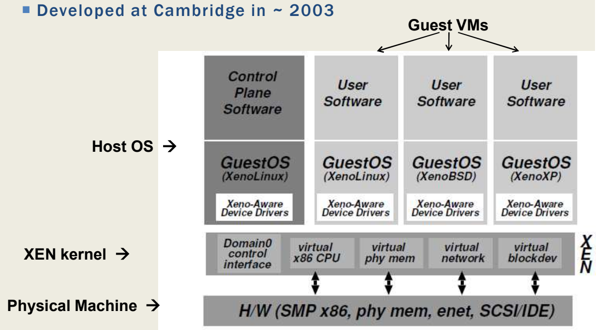
COMMON VMMS: PARAVIRTUALIZATION

- **TYPE 1**
- XEN
- Citrix Xen-server (a commercial version of XEN)
- VMWare ESXi
- KVM (virtualization support in kernel)
- Paravirtual I/O drivers introduced
  - XEN
  - KVM
  - Virtualbox

42

XEN

- Developed at Cambridge in ~ 2003



43

XEN - 2

- VMs managed as "domains"
- Domain 0 is the hypervisor domain
  - Host OS is installed to run on bare-metal, but doesn't directly facilitate virtualization (*unlike KVM*)
- Domains 1..n are guests (VMs) – not bare-metal

```
xentop - 17:53:48   Xen 3.1.2-398.el5
3 domains: 1 running, 2 blocked, 0 paused, 0 crashed, 0 dying, 0 shutdown
Mem: 8379564k total, 8377876k used, 1688k free    CPUs: 4 @ 2400MHz
      NAME  STATE   CPU(sec) CPU(%)     MEM(k) MEM(%)  MAXMEM(k) MAXMEM(%) VCPUS
 NETS NETTX(k) NETRX(k) VBDS   VBD_OO   VBD_RD   VBD_WR SSID
    centos --b---         46    0.0     532352    6.4    1064960      12.7     1
    1    27960      885    1        0     6313    37119    0
  centos-2 --b---         17    0.0    1056640   12.6    2113536      25.2     1
    1       50        0    1        0     3981      541    0
  Domain-0 -----r       2979   19.3    6568960   78.4   no limit       n/a     4
    4  1057374   290072    0        0        0        0    0
```


44

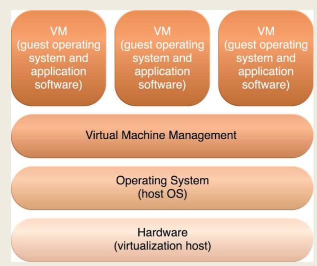
XEN - 3

- Physical machine boots special XEN kernel
- Kernel provides paravirtual API to manage CPU & device multiplexing
- Guests require modified XEN-aware kernels
- Xen supports full-virtualization for unmodified OS guests in hvm mode
- Amazon EC2 largely based on modified version of XEN hypervisor (EC2 gens 1-4)
- XEN provides its own CPU schedulers, I/O scheduling

45

TYPE 2 HYPERVISOR

- Adds additional layer



46

TYPE 2 HYPERVISOR

- Problem: Original x86 CPUs could not trap special instructions
- Instructions not specially marked
- Solution: Use Full Virtualization
- Trap ALL instructions
- "Fully" simulate entire computer
- Tradeoff: Higher Overhead
- Benefit: Can virtualize any operating system without modification

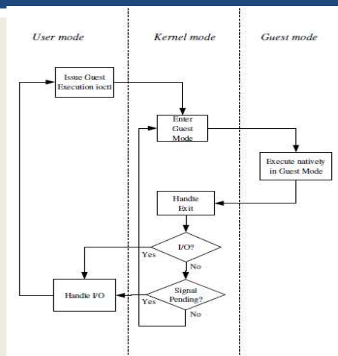
47

KERNEL BASED VIRTUAL MACHINES (KVM)

- x86 HW notoriously difficult to virtualize
- Extensions added to 64-bit Intel/AMD CPUs
  - Provides hardware assisted virtualization
  - New "guest" operating mode
  - Hardware state switch
  - Exit reason reporting
  - Intel/AMD implementations different
    - Linux uses vendor specific kernel modules

48

KVM – 2



49

KVM – 3

- KVM has /dev/kvm device file node
  - Linux character device, with operations:
    - Create new VM
    - Allocate memory to VM
    - Read/write virtual CPU registers
    - Inject interrupts into vCPUs
    - Running vCPUs
- VMs run as Linux processes
  - Scheduled by host Linux OS
  - Can be pinned to specific cores with "taskset"

50

KVM PARAVIRTUALIZED I/O

- KVM – Virtio
  - Custom Linux based paravirtual device drivers
  - Supersedes QEMU hardware emulation (full virt.)
  - Based on XEN paravirtualized I/O
  - Custom block device driver provides paravirtual device emulation
    - Virtual bus (memory ring buffer)
    - Requires hypercall facility
    - Direct access to memory

51

KVM DIFFERENCES FROM XEN

- KVM requires CPU VMX support
  - Virtualization management extensions
- KVM can virtualize any OS without special kernels
  - Less invasive
- KVM was originally separate from the Linux kernel, but then integrated
- KVM is type 1 hypervisor because the machine boots Linux which has integrated support for virtualization
- Different than XEN because XEN kernel alone is not a full-fledged OS

52

KVM ENHANCEMENTS

- Paravirtualized device drivers
  - Virtio
- Guest Symmetric Multiprocessor (SMP) support
  - Leverages multiple on-board CPUs
  - Supported as of Linux 2.6.23
- VM Live Migration
- Linux scheduler integration
  - Optimize scheduler with knowledge that KVM processes are virtual machines

53

VIRTUALIZATION MANAGEMENT

- Virtual infrastructure management (VIM) tools
- Tools that manage pools of virtual machines, resources, etc.
- Private cloud software systems can be considered as a VIM
- Considerations:
- Performance overhead
  - Paravirtualization: custom OS kernels, I/O passed directly to HW w/ special drivers
- Hardware compatibility for virtualization
- Portability: virtual resources tend to be difficult to migrate cross-clouds

54

VIRTUAL INFRASTRUCTURE MANAGEMENT (VIM)

- Middleware to manage virtual machines and infrastructure of IaaS "clouds"
- Examples
  - OpenNebula
  - Nimbus
  - Eucalyptus
  - OpenStack

55

VIM FEATURES

- Create/destroy VM Instances
- Image repository
  - Create/Destroy/Update images
  - Image persistence
- Contextualization of VMs
  - Networking address assignment
    - DHCP / Static IPs
  - Manage SSH keys

56

VIM FEATURES - 2

- Virtual network configuration/management
  - Public/Private IP address assignment
  - Virtual firewall management
  - Configure/support isolated VLANs (private clusters)
- Support common virtual machine managers (VMMs)
  - XEN, KVM, VMware
  - Support via libvirt library

57

VIM FEATURES - 3

- Shared "Elastic" block storage
  - Facility to create/update/delete VM disk volumes
    - Amazon EBS
    - Eucalyptus SC
    - OpenStack Volume Controller

58

CONTAINER ORCHESTRATION FRAMEWORKS

- Middleware to manage Docker application container deployments across virtual clusters of Docker hosts (VMs)
- Considered Infrastructure-as-a-Service
- Opensource
- Kubernetes framework
- Docker swarm
- Apache Mesos/Marathon
- Proprietary
- Amazon Elastic Container Service

59

CONTAINER SERVICES

- Public cloud container cluster services
- Azure Kubernetes Service (AKS)
- Amazon Elastic Container Service for Kubernetes (EKS)
- Google Kubernetes Engine (GKE)
- Container-as-a-Service
- Azure Container Instances (ACI – April 2018)
- AWS Fargate (November 2017)
- Google Kubernetes Engine Serverless Add-on (alpha-July 2018)

60

4. MULTITENANT APPLICATIONS

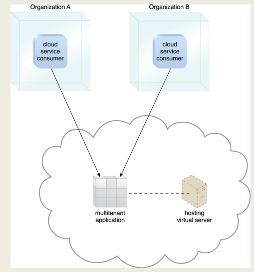
- Each tenant (like in an apartment) has their own view of the application
- Tenants are unaware of their neighbors
- Tenants can only access their data, no access to data and configuration that is not their own
- Customizable features
  - UI, business process, data model, access control
- Application architecture
  - User isolation, data security, recovery/backup by tenant, scalability for a tenant, for tenants, metered usage, data tier isolation

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.61

61

MULTITENANT APPS - 2

- Forms the basis for SaaS (applications)



October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.62

62

WEB SERVICES/WEB

- Web services technology is a key foundation of cloud computing's "as-a-service" cloud delivery model
- SOAP – "Simple" object access protocol
  - First generation web services
  - WSDL – web services description language
  - UDDI – universal description discovery and integration
  - SOAP services have their own unique interfaces
- REST – instead of defining a custom technical interface REST services are built on the use of HTTP protocol
- HTTP GET, PUT, POST, DELETE

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.63

63

HYPERTEXT TRANSPORT PROTOCOL (HTTP)

- An ASCII-based request/reply protocol for transferring information on the web
- HTTP request includes:
  - request method (GET, POST, etc.)
  - Uniform Resource Identifier (URI)
  - HTTP protocol version understood by the client
  - headers—extra info regarding transfer request
- HTTP response from server
  - Protocol version & status code →
  - Response headers
  - Response body

HTTP status codes:
2xx — *all is well*
3xx — *resource moved*
4xx — *access problem*
5xx — *server error*

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.64

64

REST: REPRESENTATIONAL STATE TRANSFER

- Web services protocol
- *Supersedes SOAP* – Simple Object Access Protocol
- Access and manipulate web resources with a predefined set of stateless operations (known as web services)
- Requests are made to a URI
- Responses are most often in JSON, but can also be HTML, ASCII text, XML, no real limits as long as text-based
- HTTP verbs: GET, POST, PUT, DELETE, …

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.65

65

```
// SOAP REQUEST

POST /InStock HTTP/1.1
Host: www.bookshop.org
Content-Type: application/soap+xml; charset=utf-8
Content-Length: nnn

<?xml version="1.0"?>
<soap:Envelope
xmlns:soap="http://www.w3.org/2001/12/soap-envelope"
soap:encodingStyle="http://www.w3.org/2001/12/soap-
encoding">
<soap:Body xmlns:m="http://www.bookshop.org/prices">
  <m:GetBookPrice>
    <m:BookName>The Fleamarket</m:BookName>
  </m:GetBookPrice>
</soap:Body>
</soap:Envelope>
```

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.66

66

```
// SOAP RESPONSE
POST /InStock HTTP/1.1
Host: www.bookshop.org
Content-Type: application/soap+xml; charset=utf-8
Content-Length: nnn

<?xml version="1.0"?>
<soap:Envelope
xmlns:soap="http://www.w3.org/2001/12/soap-envelope"
soap:encodingStyle="http://www.w3.org/2001/12/soap-
encoding">
<soap:Body xmlns:m="http://www.bookshop.org/prices">
  <m:GetBookPriceResponse>
    <m: Price>10.95</m: Price>
  </m:GetBookPriceResponse>
</soap:Body>
</soap:Envelope>
```


67

```
// WSDL Service Definition
<?xml version="1.0" encoding="UTF-8"?>
<definitions  name ="DayOfWeek"
  targetNamespace="http://www.roguewave.com/soapworx/examples/DayOfWeek.wsdl"
  xmlns:tns="http://www.roguewave.com/soapworx/examples/DayOfWeek.wsdl"
  xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns="http://schemas.xmlsoap.org/wsdl/">
  <message name="DayOfWeekInput">
    <part name="date" type="xsd:date"/>
  </message>
  <message name="DayOfWeekResponse">
    <part name="dayOfWeek" type="xsd:string"/>
  </message>
  <portType name="DayOfWeekPortType">
    <operation name="GetDayOfWeek">
      <input message="tns:DayOfWeekInput"/>
      <output message="tns:DayOfWeekResponse"/>
    </operation>
  </portType>
  <binding name="DayOfWeekBinding" type="tns:DayOfWeekPortType">
    <soap:binding style="document"
      transport="http://schemas.xmlsoap.org/soap/http"/>
    <operation name="GetDayOfWeek">
      <soap:operation soapAction="getdayofweek"/>
      <input>
        <soap:body use="encoded"
          namespace="http://www.roguewave.com/soapworx/examples"
          encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"/>
      </input>
      <output>
        <soap:body use="encoded"
        namespace="http://www.roguewave.com/soapworx/examples"
        encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"/>
      </output>
    </operation>
  </binding>
  <service name="DayOfWeekService" >
    <documentation>
      Returns the day-of-week name for a given date
    </documentation>
    <port name="DayOfWeekPort" binding="tns:DayOfWeekBinding">
      <soap:address location="http://localhost:8090/dayofweek/DayOfWeek"/>
    </port>
   </service>
</definitions>
```


68

REST CLIMATE SERVICES EXAMPLE

- USDA Lat/Long Climate Service Demo
- Just provide a Lat/Long

```
// REST/JSON
// Request climate data for Washington

{
 "parameter": [
  {
    "name": "latitude",
    "value":47.2529
  },
  {
    "name": "longitude",
    "value":-122.4443
  }
 ]
}
```


69

REST - 2

- App manipulates one or more types of resources.
- Everything the app does can be characterized as some kind of operation on one or more resources.
- Frequently services are CRUD operations (create/read/update/delete)
  - Create a new resource
  - Read resource(s) matching criterion
  - Update data associated with some resource
  - Destroy a particular a resource
- Resources are often implemented as objects in OO languages

70

REST ARCHITECTURAL ADVANTAGES

- **Performance**: component interactions can be the dominant factor in user-perceived performance and network efficiency
- **Scalability**: to support large numbers of services and interactions among them
- **Simplicity**: of the Uniform Interface
- **Modifiability**: of services to meet changing needs (even while the application is running)
- **Visibility**: of communication between services
- **Portability**: of services by redeployment
- **Reliability**: resists failure at the system level as redundancy of infrastructure is easy to ensure

71

QUESTIONS

72

TCSS 562 TERM PROJECT

73

TCSS 562 TERM PROJECT

- Build a serverless cloud native application
- Application provides a case study to design trade-offs:
- Projects will compare and contrast one or more trade-offs:
- **Service composition**
  - **Switchboard architecture**
    - Address COLD Starts
    - Infrastructure Freeze/Thaw cycle of AWS Lambda (FaaS)
  - Full service isolation, full service aggregation
- **Application flow control**
- **Programming Languages**
- **Alternate FaaS Platforms**
- **Data provisioning**

74

EXTRACT TRANSFORM LOAD DATA PIPELINE

- Service 1: **TRANSFORM**
- Read CSV file, perform some transformations
- Write out new CSV file
- Service 2: **LOAD**
- Read CSV file, load data into relational database
- Cloud DB (AWS Aurora), or local DB (Derby/SQLite)
  - Derby DB and/or SQLite code examples to be provided in Java

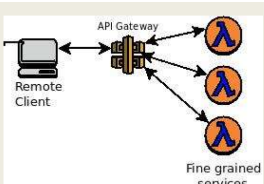
75

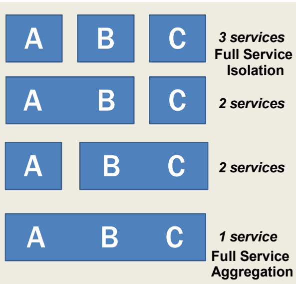
EXTRACT TRANSFORM LOAD DATA PIPELINE 2

- Service 3: **EXTRACT**
- Using relational database, apply filter(s) and/or functions to aggregate data to produce sums, totals, averages
- Output aggregations as JSON

76

SERVICE COMPOSITION

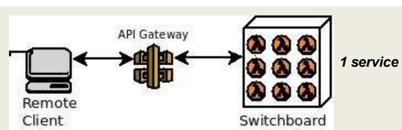




Other possible compositions: group by library, functional cohesion, etc.

77

SWITCH-BOARD ARCHITECTURE



Single deployment package with consolidated codebase (Java: one JAR file)

Entry method contains "switchboard" logic
Case statement that route calls to proper service

Routing is based on data payload
Check if specific parameters exist, route call accordingly

Goal: reduce # of COLD starts to improve performance

78

APPLICATION FLOW CONTROL

- **Serverless Computing:**
- AWS Lambda (FAAS: Function-as-a-Service)
- Provides HTTP/REST like web services
- Client/Server paradigm
- **Synchronous web service:**
- Client calls service
- Client blocks (freezes) and waits for server to complete call
- Connection is maintained in the "OPEN" state
- Problematic if service runtime is long!
  - Connections are notoriously dropped
  - System timeouts reached
- Client can't do anything while waiting unless using threads

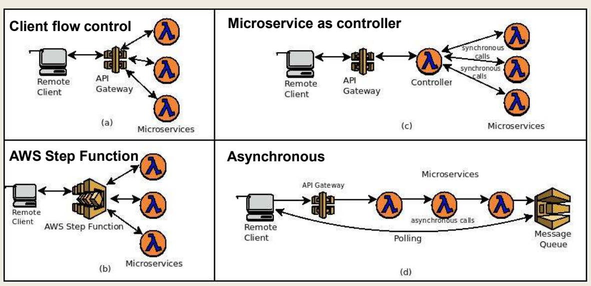
79

APPLICATION FLOW CONTROL - 2

- **Asynchronous web service**
- Client calls service
- Server responds to client with OK message
- Client closes connection
- Server performs the work associated with the service
- Server posts service result in an external data store
  - AWS: S3, SQS (queueing service), SNS (notification service)

80

APPLICATION FLOW CONTROL - 3



81

PROGRAMMING LANGUAGE

- Function-as-a-Service platforms support hosting services code in multiple languages
- AWS Lambda- common: Java, Node.js, Python
  - Plus others: Go, PowerShell, C#, and Ruby
- Also Runtime API ("BASH") which allows deployment of any binary executable in any programming languages
- Jackson D, Clynch G. An Investigation of the Impact of Language Runtime on the Performance and Cost of Serverless Functions. In Proc. Of the 2018 IEEE/ACM International Conference on Utility and Cloud Computing Companion (UCC Companion) 2018 Dec 17 (pp. 154-160).
- http://faculty.washington.edu/wlloyd/courses/tcss562/papers/AnInvestigationOfTheImpactOfLanguageRuntimeOnThePerformanceAndCostOfServerlessFunctions.pdf

82

FAAS PLATFORMS

- Many commercial and open source FaaS platforms exist
- TCSS562 projects can choose to compare performance and cost implications of alternate platforms.
- Supported by SAAF:
- AWS Lambda
- Google Cloud Functions
- Azure Functions
- IBM Cloud Functions

83

DATA PROVISIONING

- Consider performance and cost implications of the data-tier design for the serverless application
- Use different tools as the relational datastore to support service #2 (LOAD) and service #3 (EXTRACT)
- **SQL / Relational:**
- Amazon Aurora (serverless cloud DB), Amazon RDS (cloud DB), DB on a VM (MySQL), DB inside Lambda function (SQLite, Derby)
- **NO SQL / Key/Value Store:**
- Dynamo DB, MongoDB, S3

84

TLQ PIPELINE: 'T' SERVICE

- Transform service
  - Please perform 3 or more data transformations
  - 3 ensures workload is not trivial
  - Groups are free to propose the actual transformation
  - At least one new column should be added
  - Other transformations can reformat data
  - More work is generally good as the goal of the case study is to have access to an application that performs some processing on the data to make comparisons more interesting
- Alternate datasets to be posted
  - (not the customer database)

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.85

85

TLQ PIPELINE DATASETS

- Multiple datasets online at:
  - http://faculty.washington.edu/wlloyd/courses/tcss562/project/etl/
- Sales data
  - Up to 1.5 million rows
- Medical payments data
  - Up to 10.8 million rows (see readme.txt file)
- Performance test:
  - How long does it take to process an entire dataset in the TLQ pipeline?
    - Sequentially
    - In parallel with multiple client threads processing rows (or chunks) of data

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.86

86

TLQ PIPELINE: MEDICARE PAYMENTS DATASET

- Medicare Open payments data in CSV file format
- This example represents a large health payment dataset.
- Open Payments, since 2013, is a federal program that collects information about the payments drug and device companies make to physicians and teaching hospitals for things like travel, research, gifts, speaking fees, and meals.
- The key fields to process in the file include:
  - - Provider ID, integer
  - - Record ID, integer
  - - Date, date
  - - Payer, string
  - - Specialty, string
  - - Amount, decimal
  - - Payment Nature, string
- Other fields can optionally be processed

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.87

87

TLQ PIPELINE: MEDICARE PAYMENTS DATASET - 2

- Medicare Open payments data in CSV file format
- **Interesting filters:**

- Report the count of payments greater than $1000 for different values of [Payment Nature]

- Report the count of payments greater than $500 for different values of [Payment Nature]

- Count the number of payments for each category: [Physician_Specialty]

- Calculate the total payments for the top 10 categories: [Physician_Specialty]

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.88

88

TLQ PIPELINE: LOCAL DBS

- Approach:
  - Shard (split) large CSV files into many small CSV files
  - Process in parallel on AWS Lambda with separate client threads
- Each Lambda holds a small temporary SQLite local database to store a subset of the whole dataset in relational form
- Problem:
  - Medical Payments data is nearly 6 GB, will it fit directly on a single Lambda's 512MB file system in SQLite format???
  - Shard (based on ID) into 20 x 300MB small local SQLite databases
  - Can invoke 20 Lambdas in parallel to search complete DB
  - Need to keep Lambdas from freezing or else data is lost
  - Can backup SQLite files to S3, and retrieve them later once created

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.89

89

TLQ PIPELINE: CENTRALIZED DB

- Can load data to centralized database
- Amazon Aurora Serverless
  - Provides MySQL (cheaper), and PostgreSQL (more expensive) options
  - Aurora Serverless is an alternative to hosting a DB with an always-on VM - - ***but is it cheaper???***
  - Storage is 10¢/GB/month
  - Size of Aurora instance is scalable
  - Amazon Aurora Serverless charges based on reserved or dynamic "**Aurora Capacity** Units"
  - 1 ACU = 2GB memory, 1 vCPU, with corresponding networking
  - Single database instance becomes a processing bottleneck
  - ***How long will it take to load 10 million rows on a 1 vCPU, 2GB DB??***
  - ***How many parallel clients can this DB support?***

October 30, 2019 | TCSS562: Software Engineering for Cloud Computing [Fall 2019] School of Engineering and Technology, University of Washington - Tacoma | L11.90

90