TCSS 562: SOFTWARE ENGINEERING FOR CLOUD COMPUTING

AWS Demo II, Cloud Enabling Technology

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

TR 5:00-7:00 PM

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OFFICE HOURS – FALL 2021

- **Tuesdays:**
  - 4:00 to 4:30 pm - CP 229
  - 7:15 to 7:45+ pm – ONLINE via Zoom
- **Thursdays**
  - 4:15 to 4:45 pm – ONLINE via Zoom
  - 7:15 to 7:45+ pm – ONLINE via Zoom
- Or email for appointment
- Zoom Link sent as Canvas Announcement

> Office Hours set based on Student Demographics survey feedback

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OBJECTIVES – 11/4

- **Questions from 11/2**
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- Tutorial 5 – Intro to FaaS II – Files in S3, CloudWatch
- Term Project Proposals –
- AWS overview and demonstration

- **2nd hour:**
- AWS overview and demonstration
- Ch. 5: Cloud Enabling Technology
- Team planning

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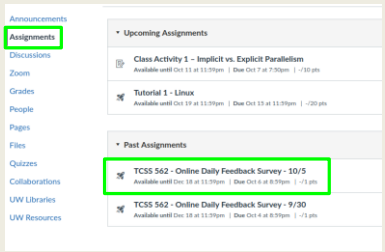
ONLINE DAILY FEEDBACK SURVEY

- Daily Feedback Quiz in Canvas – Take After Each Class
- Extra Credit for completing



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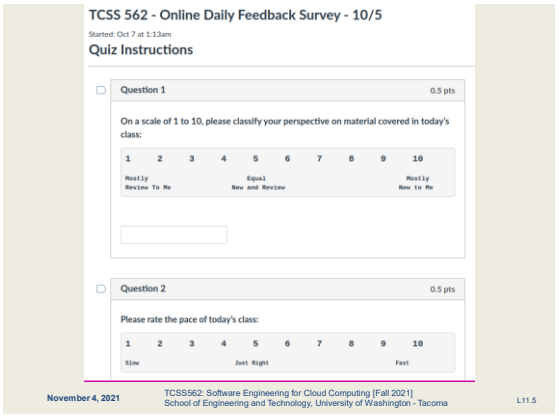

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MATERIAL / PACE

- Please classify your perspective on material covered in today's class (25 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.04 (↓ - *previous 6.52*)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.20 (↓ - previous 5.36)**

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FEEDBACK FROM 11/2

- ***What is burning an image?***
  and why does IS (Instance Storage) need to burn an image?
- "burning an image" is the notion of capturing all of the data contained on a virtual disk and compressing it into an .img file
- A disk image is the full collection of bytes that contains the file system + the data
- In Ubuntu we typically format disks using the ext4 file system
- To recreate a disk in the cloud, we need the image which contains the file system + the data
- IS (Instance Store) are local disks that do not persist
- If you want to save and restore data from an IS disk, image files can be used

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MAKE AN IMAGE FROM A DISK

```
# ***************  ON THE LOCAL COMPUTER ******************
# create 1200 MB virtual disk = 1,258,291,200 bytes
sudo dd if=/dev/zero of=vhd.img bs=1M count=1200
# format the disk using the ext4 filesystem
sudo mkfs.ext4 vhd.img
# mount the disk at "/mnt"
sudo mount -t auto -o loop vhd.img /mnt
# check that the disk is mounted
df -h
# create a hello file (or copy data) to the new virtual disk
cd /mnt
sudo echo "hello world !" > hello.txt
ls -l
cd
# unmount the virtual disk
sudo umount /mnt
```


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COMPRESS IMAGE, PUSH TO S3

```
# compress the disk
bzip2 vhd.img

# push the disk image to S3
aws s3 cp vhd.img.bz2 s3://tcss562-f21-images
```


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RESTORE ON THE CLOUD

```
# ******************  ON THE AWS EC2 VM ******************
# with the awscli installed and configured

# download the image from S3
aws s3 cp s3://tcss562-f21-images/vhd.img.bz2 vhd.img.bz2

# uncompress the image
bzip2 -d vhd.img.bz2

# we need to calculate the number of sectors for the
partition
# disk sectors are 512 bytes each
# divide the disk size by 512 to determine sectors
# sectors = 1258291200 / 512 = 2459648

# create a disk partition for this disk that is
# 2459648 sectors in size using the ephemeral drive or
# a newly mounted EBS volume that is unformatted

sudo fdisk /dev/nvme1n1
```


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PARTITION THE DISK

```
Welcome to fdisk (util-linux 2.34).

Command (m for help): n
Partition type
   p   primary (0 primary, 0 extended, 4 free)
   e   extended (container for logical partitions)

Select (default p): p
Partition number (1-4, default 1): 1
First sector (2048-97656249, default 2048): 2048
Last sector, +/-sectors or +/-size{K,M,G,T,P} (2048-97656249, default
97656249): 2459648

Created a new partition 1 of type 'Linux' and of size 1.2 GiB.

Command (m for help): t
Selected partition 1
Hex code (type L to list all codes): 83
Changed type of partition 'Linux' to 'Linux'.

Command (m for help): w  (to write and exit)
```


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COPY DATA TO NEW DISK PARTITION

```
# now check if the partition has been created.
# it should be listed as /dev/nvme1n1p1:
ls /dev/nvme1n1*

# now copy the data to the partition
sudo dd if=vhd.img of=/dev/nvme1n1p1

# mount the disk
sudo mount /dev/nvme1n1p1 /mnt

# and check if the hello file is there
cat /mnt/hello.txt

# we were able to copy the disk image to the cloud
# and we never had to format the cloud disk
# this examples copies a filesystem from a local disk
# to the cloud disk
```


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FOR MORE INFORMATION

- Example script:
- https://faculty.washington.edu/wlloyd/courses/tcss562/examples/copy-disk-to-cloud.sh

- URLs:
- https://help.ubuntu.com/community/DriveImaging
- https://www.tecmint.com/create-virtual-harddisk-volume-in-linux/

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TERM PROJECTS

- **Team 1:** Cloud Data Streaming Case Study
  Satchit Dahal, Amir Almemar, Alekhya Palle
- **Team 2:** Deep Learning based Face Recognition for Smart Home System
  Zichao Zhang, Zhifei Cheng, Sijin Huang
- **Team 3:** Natural Language Processing pipeline (data preparation → training → inferencing)
  Bob Schmitz, Viktoriya Grishkina, Danielle Lambion
- **Team 4:** – *there is no team 4*
- **Team 5:** Serverless Imaging Processing Pipeline with OpenCV
  Shishir Reddy
- **Team 6:** TLQ Pipeline, Programming Language Comparison
  Guanchen Zhao, Minzhi Qu, Yanliu Wang

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TERM PROJECTS - 2

- **Team 7:** TLQ Pipeline, Service Composition
  Andrew Lim, Di Mo, Solmaz Seyed Monir
- **Team 8:** TLQ Pipeline, Service Composition
  Duy Tran, Pragati Chidanand Patil, Ranjana Bongale Ganesh
- **Team 9:** TLQ Pipeline, Platform Comparison (Azure vs AWS)
  Sri Vibhu Paruchuri, Nischal Khadka, Dev Gandhi
- **Team 10:** TLQ Pipeline, Database Comparison: RDS vs Aurora
  Ashwin Meena Meiyappan, Ayushi Ameta, Ananya Ra
- **Team 11:** Secure Multi-party Computation (MPC)
  Davis Railsback, Trina Pal, Parshva Kotak
- **Team 12:** TLQ Pipeline, Programming Language Comparison
  Shuo Peng, Anmin Huang
- **Team 13:** IoT/Edge Computing Literature Survey Paper
  Anindya Dey

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FUNCTION-AS-A-SERVICE

AWS Lambda Demo

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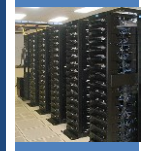
AWS OVERVIEW AND DEMO



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LIST OF TOPICS

- AWS Management Console
- Elastic Compute Cloud (EC2)
- Instance Storage: Virtual Disks on VMs
- Elastic Block Store: Virtual Disks on VMs
- Elastic File System (EFS)
- Amazon Machine Images (AMIs)
- EC2 Paravirtualization
- EC2 Full Virtualization (hvm)
- EC2 Virtualization Evolution
- (VM) Instance Actions
- EC2 Networking
- EC2 Instance Metadata Service
- Simple Storage Service (S3)
- AWS Command Line Interface (CLI)
- Legacy / Service Specific CLIs
- AMI Tools
- Signing Certificates
- Backing up live disks
- Cost Savings Measures

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AMAZON MACHINE IMAGES

- AMIs
- Unique for the operating system (root device image)
- Two types
  - Instance store
  - Elastic block store (EBS)
- Deleting requires multiple steps
  - Deregister AMI
  - Delete associated data (delete snapshot) - (*files actually in S3*)
- Forgetting both steps leads to costly "orphaned" data
  - No way to instantiate a VM from deregistered AMIs
  - Data still in S3 resulting in charges

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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*

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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*)

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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

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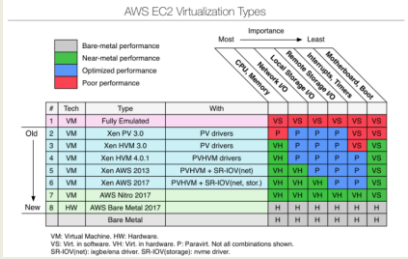
EVOLUTION OF AWS VIRTUALIZATION

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



#	Tech	Type	With					
1	VM	Fully Emulated		VS	VS	VS	VS	VS
2	VM	Xen PV 3.0	PV drivers	P	P	P	VS	VS
3	VM	Xen HVM 3.0	PV drivers	VH	P	P	VS	VS
4	VM	Xen HVM 4.0.1	PVHVM drivers	VH	P	P	P	VS
5	VM	Xen AWS 2013	PVHVM + SR-IOV(net)	VH	VH	P	P	VS
6	VM	Xen AWS 2017	PVHVM + SR-IOV(net, stor.)	VH	VH	VH	P	VS
7	VM	AWS Nitro 2017		VH	VH	VH	VH	VS
8	HW	AWS Bare Metal 2017		H	H	H	H	H
		Bare Metal		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.

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INSTANCE ACTIONS

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

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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

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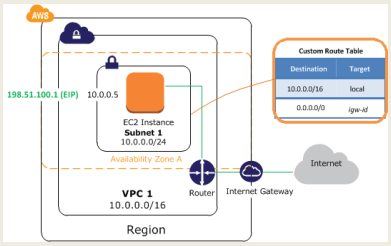
SIMPLE VPC

- Recommended when using Amazon EC2



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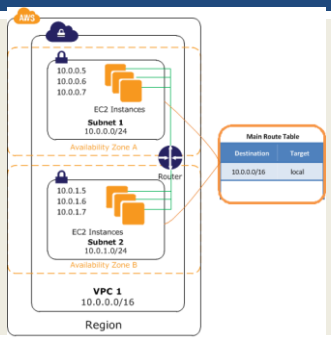
VPC SPANNING AVAILABILITY ZONES



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INSPECTING INSTANCE INFORMATION

- EC2 VMs run a local metadata service
- Can query instance metadata to self discover cloud configuration attributes

- Find your instance ID:

```
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
- Python API that provides easy/formatted access to metadata

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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
- Provides eventual consistency
- Can store Lambda function state for life of container.

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AWS CLI

- Launch Ubuntu 16.04 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-1
```


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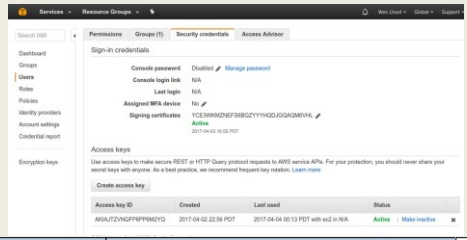
AWS CLI - 2

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



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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

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LEGACY / SERVICE SPECIFIC CLI(S)

- sudo apt install ec2-api-tools
- Provides more concise output
- 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
- Some AWS services have separate CLI installable by package

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AMI TOOLS

- Amazon Machine Images tools
- For working with disk volumes
- Can create live copies of any disk volume
  - Your local laptop, ec2 root volume (EBS), ec2 ephemeral disk
- Installation:
  https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ami-tools-commands.html
- AMI tools reference:
- https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ami-tools-commands.html
- Some functions may require private key & certificate files

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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

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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)**
- An alternative to bundling volumes and storing in S3 is to use a containerization tool such as Docker. . .
- Create image script . . .

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SCRIPT: CREATE A NEW INSTANCE STORE IMAGE FROM LIVE DISK VOLUME

```
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
```


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COST SAVINGS MEASURES

- ***From Tutorial 3:***
- #1: ALWAYS USE SPOT INSTANCES FOR COURSE/RESEARCH RELATED PROJECTS
- #2: NEVER LEAVE AN EBS VOLUME IN YOUR ACCOUNT THAT IS NOT ATTACHED TO A RUNNING VM
- #3: BE CAREFUL USING PERSISTENT REQUESTS FOR SPOT INSTANCES
- #4: TO SAVE/PERSIST DATA, USE EBS SNAPSHOTS AND THEN
- #5: DELETE EBS VOLUMES FOR TERMINATED EC2 INSTANCES.
- #6: UNUSED SNAPSHOTS AND UNUSED EBS VOLUMES SHOULD BE PROMPTLY DELETED !!
- #7: USE PERSISTENT SPOT REQUESTS AND THE "STOP" FEATURE TO PAUSE VMS DURING SHORT BREAKS

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WE WILL RETURN AT ~6:15 PM

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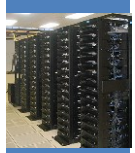
CLOUD ENABLING TECHNOLOGY



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CLOUD ENABLING TECHNOLOGY

- *Adapted from Ch. 5 from Cloud Computing Concepts, Technology & Architecture*
- Broadband networks and internet architecture
- Data center technology
- Virtualization technology
- Multitenant technology
- Web/web services technology

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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**

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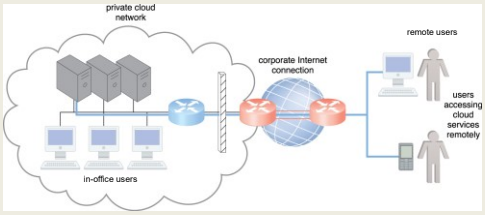
PRIVATE CLOUD NETWORKING

- For institutions with in-house private clouds



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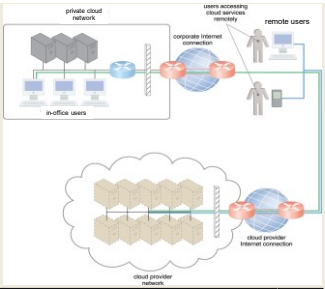
PUBLIC CLOUD NETWORKING

- Resources can be extended by adding public cloud
- Places further dependency on the internet to provide connectivity



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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

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CLOUD ENABLING TECHNOLOGY

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- Data center technology
- Virtualization technology
- Multitenant technology
- Web/web services technology

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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: enable server provisioning, configuration, patching, monitoring without supervision… ***tool/API support is desirable***

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CLUSTER MANAGEMENT TOOLS

Example:
Hyak Cluster
UW-Seattle

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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 HW
- **Secure design**: physical and logical access control
- **Servers**: rackmount, etc.
- **Storage**: hard disk arrays (RAID)
- storage area network (SAN): disk array w/ multiple servers (individual nodes w/ disks) and a dedicated network
- network attached storage (NAS): inexpensive single node with collection of disks, provides shared filesystems, for NFS, etc.
- **Network hardware**: backbone routers (WAN to LAN connectivity), firewalls, VPN gateways, managed switches/routers

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CLOUD ENABLING TECHNOLOGY

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

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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

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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

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KEY VIRTUALIZATION TRADEOFF

- Tradeoff space:

What is the "right" level of abstraction in the cloud for sharing resources with users?

Degree of Hardware Abstraction

Abstraction Concerns:
- **Overhead**
- **Performance**
- **Isolation**
- **Security**

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ABSTRACTION CONCERNS

- **Overhead with too many instances w/ heavy abstractions**
  - Too many instances using a heavy abstraction can lead to hidden resource utilization and waste
  - Example: Dedicated server with 48 VMs each with separate instance of Ubuntu Linux
  - Idle VMs can reduce performance of co-resident jobs/tasks
- **"Virtualization" Overhead**
  - Cost of virtualization an OS instance
  - Overhead has dropped from ~100% to ~1% over last decade
- **Performance**
  - Impacted by weight of abstraction and virtualization overhead

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ABSTRACTION CONCERNS - 2

- **Isolation**
  - From others:
    What user A does should not impact user B in any noticeable way
- **Security**
  - User A and user B's data should be always separate
  - User A's actions are not perceivable by User B

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TYPES OF ABSTRACTION IN THE CLOUD

- **Virtual Machines** – original IaaS cloud abstraction
- **OS and Application Containers** – seen with CaaS
  - **OS Container** – replacement for VM, mimics full OS instance, heavier
  - OS containers run 100s of processes just like a VM
  - **App Container** – Docker: packages dependencies to easily transport and run an application anywhere
  - Application containers run only a few processes
- **Micro VMs** – FaaS / CaaS
  - Lighter weight alternative to full VM (KVM, XEN, VirtualBox)
  - Firecracker
- **Unikernel Operating Systems** – research mostly
  - Single process, multi-thread operating system
  - Designed for cloud, objective to reduce overhead of running too many OS instances

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VIRTUAL MACHINES

- **Type 1 hypervisor**
  - Typically involves a special virtualization kernel that runs directly on the system to share the underlying machine with many guest VMs
  - Paravirtualization introduced to directly share system resources with guests bypassing full emulation
  - VM becomes equal participant in sharing the network card for example
- **Type 2 hypervisor**
  - Typically involves the **Full Virtualization** of the guest, where everything is simulated/emulated
- Hardware level support (i.e. features introduced on CPUs) have made virtualization faster in all respects shrinking virtualization overhead

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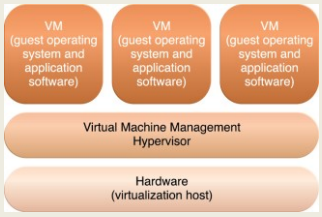
TYPE 1 HYPERVISOR



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

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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)

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COMMON VMMS: PARAVIRTUALIZATION

- **TYPE 1 Hypervisor**
- XEN
- Citrix Xen-server (a commercial version of XEN)
- VMWare ESXi
- KVM (virtualization support in kernel)

- Paravirtual I/O drivers introduced
  - XEN
  - KVM
  - Virtualbox

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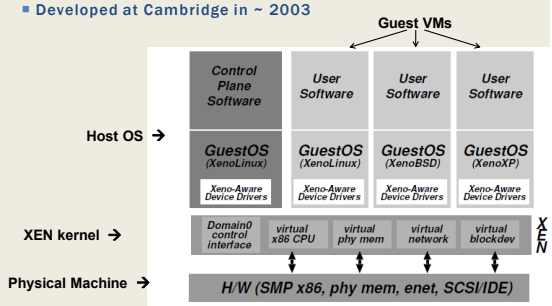
XEN

- Developed at Cambridge in ~ 2003



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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
```


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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

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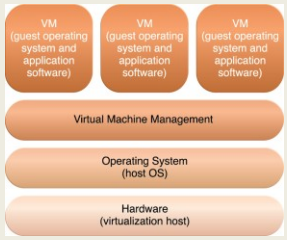
TYPE 2 HYPERVISOR

- Adds additional layer



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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

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CHECK FOR VIRTUALIZATION SUPPORT

- See: https://cyberciti.biz/faq/linux-xen-vmware-kvm-intel-vt-amd-v-support
- # check for Intl VT CPU virtualization extensions on Linux
  `grep –color vmx /proc/cpuinfo`
- # check for AMD V CPU virtualization extensions on Linux
  `grep –color svm /proc/cpuinfo`
- Also see '`lscpu`' → "Virtualization:"
- Other Intel CPU features that help virtualization:
  `ept vpid tpr_shadow flexpriority vnmi`

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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

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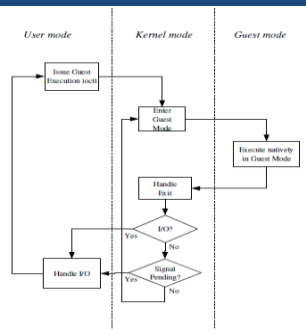
KVM – 2



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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"

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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

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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

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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

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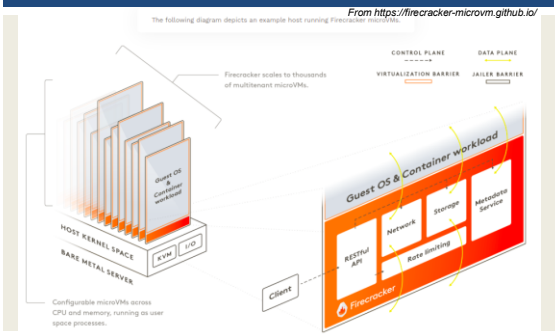
FIRECRACKER MICRO VM

From https://firecracker-microvm.github.io/



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FIRECRACKER MICRO VM

- Provides a virtual machine monitor (VMM) (i.e. hypervisor) using KVM to create and manage microVMs
- Has a minimalist design with goals to improve security, decreases the startup time, and increases hardware utilization
- Excludes unnecessary devices and guest functionality to reduce memory footprint and attack surface area of each microVM
- Supports boot time of <125ms, <5 MiB memory footprint
- Can run 100s of microVMs on a host, launching up to 150/sec
- Is available on 64-bit Intel, AMD, and Arm CPUs
- Used to host AWS Lambda and AWS Fargate
- Has been open sourced under the Apache 2.0 license

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FIRECRACKER - 2

- **Minimalistic**
- MicroVMs run as separate processes on the host
- Only 5 emulated devices are available: virtio-net, virtio-block, virtio-vsock, serial console, and a minimal keyboard controller used only to stop the microVM
- Rate limiters can be created and configured to provision resources to support bursts or specific bandwidth/operation limitations
- **Configuration**
- A RESTful API enables common actions such as configuring the number of vCPUs or launching microVMs
- A metadata service between the host and guest provides configuration information

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FIRECRACKER - 2

- **Security**
- Runs in user space ***(not the root user)*** on top of the Linux Kernel-based Virtual Machine (KVM) hypervisor to create microVMs
- Lambda functions, Fargate containers, or container groups can be encapsulated using Firecracker through KVM, enabling workloads from different customers to run on the same machine, without sacrificing security or efficiency
- MicroVMs are further isolated with common Linux user-space security barriers using a companion program called "jailer" which provides a second line of defense if KVM is compromised

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UNIKERNELS

- Lightweight alternative to containers and VMs
  - Custom Cloud Operating System
  - Single process, multiple threads, runs one program
  - Launch separately atop of hypervisor (XEN/KVM)
  - Reduce overhead, duplication of heavy weight OS
  - OSv is most well known unikernel
  - Several others exist has research projects
  - More information at: http://unikernel.org/
  - Google Trends OSv →

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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

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VIRTUAL INFRASTRUCTURE MANAGEMENT (VIM)

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

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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

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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

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VIM FEATURES - 3

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

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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

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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)

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CLOUD ENABLING TECHNOLOGY

- *Adapted from Ch. 5 from Cloud Computing Concepts, Technology & Architecture*
- Broadband networks and internet architecture
- Data center technology
- Virtualization technology
- Multitenant technology
- Web/web services technology

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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

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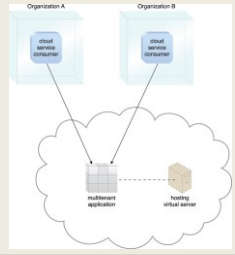
MULTITENANT APPS - 2

- Forms the basis for SaaS (applications)



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

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5. 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

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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*

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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, …

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```
// 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>
```


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```
// 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>
```


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```
// 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>
```


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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
  }
 ]
}
```


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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

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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

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QUESTIONS-

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