# TCSS 562: SOFTWARE ENGINEERING FOR CLOUD COMPUTING

## AWS Overview and Demo II, Cloud Enabling Technology

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

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## OFFICE HOURS – FALL 2023

- **THIS WEEK**
- **Tuesdays:**
  - 2:30 to 3:30 pm - CP 229
- ***** Friday *****
  - 1:30 pm to 2:30 pm – ONLINE via Zoom
- Or email for appointment

*> Office Hours set based on Student Demographics survey feedback*

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## APOLOGY

- I accidentally used the Tuesday Office Hours Zoom link for Lecture 10
- The Lecture 10 zoom link accidentally was created for 3:40 ‘am’ instead of ‘pm’
- Initially there were fewer people on Zoom
  - I thought it was due to Halloween
- Many students figured out the Zoom link after awhile
- The lecture 10 recording is unaffected by the Zoom link swap
- I apologize for the error

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## LOOKING FOR CSS GRADUATE STUDENT VOLUNTEER

- The Computer Science & Systems program is looking for a graduate CSS student to volunteer to serve on the CSS hiring committee in the AY 2023-24
- The CSS program is planning to expand and hire 3 new tenure-track professors to start in AY 2024-25.
- Most of the volunteer effort will be in Winter 2024
- We will invite from 9 to 12 new faculty candidates to campus for interviews
- Candidates will give research talks from ~12:30 to 1:20p
- The student volunteer will help advertise the sessions amongst students and survey students to capture feedback regarding the candidates
- The volunteer will work with Toan Nguyen the undergraduate CSS representative
- If interested, contact: **wlloyd@uw.edu**

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## OBJECTIVES – 11/2

- **Questions from 10/31**
- Tutorials Questions
- Tutorial 6 – Serverless Databases
- AWS Overview and demo
- Tutorial 4 Demo
- Ch. 5: Cloud Enabling Technology

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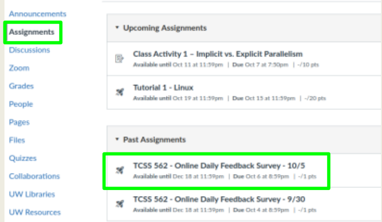
## ONLINE DAILY FEEDBACK SURVEY

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



Announcements
Assignments
Discussions
Zoom
Grades
People
Pages
Files
Quizzes
Collaborations
UW Libraries
UW Resources

▾ Upcoming Assignments

Class Activity 1 – Implicit vs. Explicit Parallelism
Available until Oct 11 at 11:59pm | Due Oct 7 at 7:50pm | -/10 pts

Tutorial 1 - Linux
Available until Oct 19 at 11:59pm | Due Oct 15 at 11:59pm | -/20 pts

▾ Past Assignments

TCSS 562 - Online Daily Feedback Survey - 10/5
Available until Dec 18 at 11:59pm | Due Oct 6 at 8:59pm | -/1 pts

TCSS 562 - Online Daily Feedback Survey - 9/30
Available until Dec 18 at 11:59pm | Due Oct 4 at 8:59pm | -/1 pts

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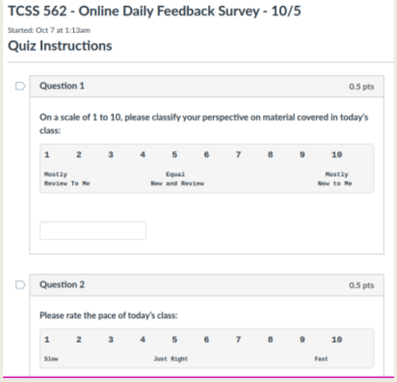

## TCSS 562 - Online Daily Feedback Survey - 10/5

Started: Oct 7 at 1:13am

### Quiz Instructions

**Question 1** 0.5 pts

On a scale of 1 to 10, please classify your perspective on material covered in today's class:

```
1       2       3       4       5       6       7       8       9       10
Mostly                          Equal                                  Mostly
Review To Me               New and Review                           New to Me
```

**Question 2** 0.5 pts

Please rate the pace of today's class:

```
1       2       3       4       5       6       7       8       9       10
Slow                       Just Right                               Fast
```

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## MATERIAL / PACE

- Please classify your perspective on material covered in today's class (**47** respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.23 (↑ - *previous 6.11*)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.77 (↑ - previous 5.31)**

- **Response rates:**
- TCSS 462: 26/44 – 59.1%
- TCSS 562: 21/25 – 84.0%

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## FEEDBACK FROM 10/31

- ***When an ec2 instance associated with a persistent spot request is terminated, does it automatically come back because the spot request is still active?***
- YES, if there is capacity for the instance type, availability zone, etc.
- NO, if there is temporarily no capacity, but once capacity is restored, the instance will be restored

- ***Does the instance stay off until the load on AWS EC2 decreases?***
- Yes, if the termination was due to high demand

- **KEY POINT**: Nothing removes the persistent spot request except the user deleting the spot request.

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## FEEDBACK - 2

- EC2 Spot Instance Advisor:
- https://aws.amazon.com/ec2/spot/instance-advisor/
- Provides sortable list of ec2 instance types with interruption (termination) frequencies
- Helps you choose an instance type that is less likely to be terminated

- Best practices for using spot instances:
- https://docs.aws.amazon.com/whitepapers/latest/cost-optimization-leveraging-ec2-spot-instances/spot-best-practices.html

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## FEEDBACK - 3

- ***What is "bare metal"?***
- A bare metal server is not shared with anyone
- There is no virtualization hypervisor
  *(program the contextualizes and hosts virtual machines)*
- The operating system is installed directly on the root disk and the machine is booted directly like a laptop or desktop computer
- The user can install any operating system and make configurations changes to the machine's base operating system
- The user can then install and control a virtualization hypervisor on bare metal servers
- Bare metal servers were offered on AWS starting in ~2017

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## TERM PROJECT PROPOSALS

- 18 Total term project proposals received
- 14 teams of 4
- 4 teams of 3
- 8 proposals reviewed thus far, 10 remaining
  - 4 proposals accepted
  - 4 proposals – revisions requested
- Application Use Cases (summary to be provided):
  - 5 TLQ pipelines
  - 1 image generation (AI image generation model on ec2)
  - 1 NLP pipeline (sentiment analysis)
  - 1 serverless chatbot

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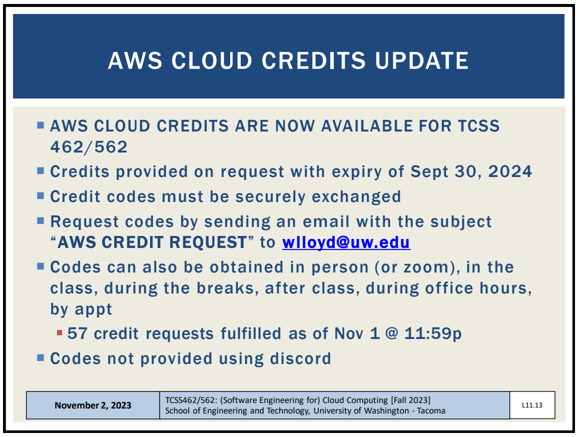

## AWS CLOUD CREDITS UPDATE

- AWS CLOUD CREDITS ARE NOW AVAILABLE FOR TCSS 462/562
- Credits provided on request with expiry of Sept 30, 2024
- Credit codes must be securely exchanged
- Request codes by sending an email with the subject "**AWS CREDIT REQUEST**" to **wlloyd@uw.edu**
- Codes can also be obtained in person (or zoom), in the class, during the breaks, after class, during office hours, by appt
  - 57 credit requests fulfilled as of Nov 1 @ 11:59p
- Codes not provided using discord

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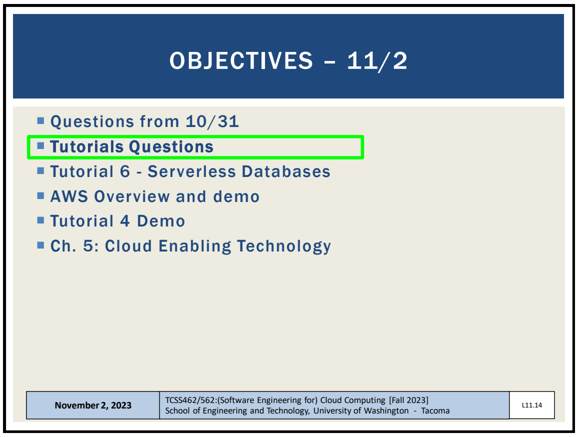

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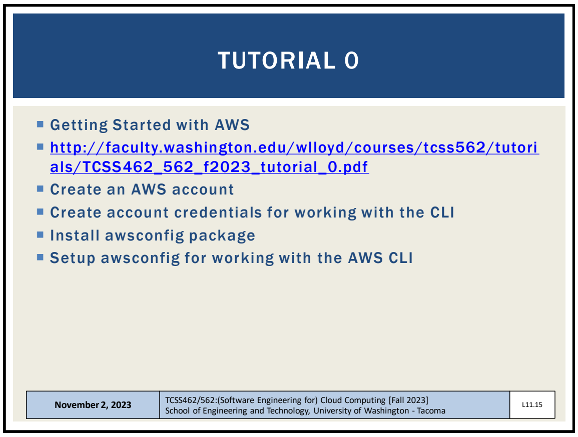

## TUTORIAL 0

- Getting Started with AWS
- http://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2023_tutorial_0.pdf
- Create an AWS account
- Create account credentials for working with the CLI
- Install awsconfig package
- Setup awsconfig for working with the AWS CLI

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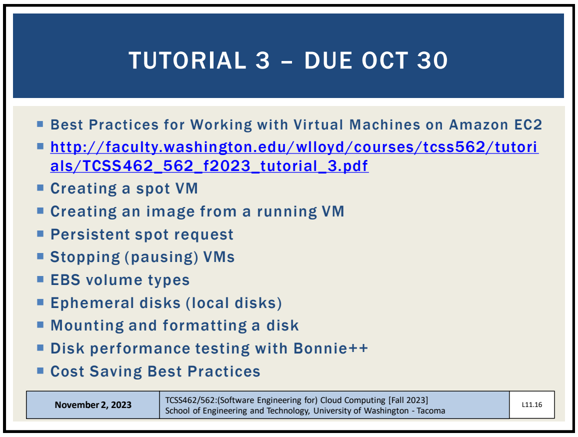

## TUTORIAL 3 – DUE OCT 30

- Best Practices for Working with Virtual Machines on Amazon EC2
- http://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2023_tutorial_3.pdf
- Creating a spot VM
- Creating an image from a running VM
- Persistent spot request
- Stopping (pausing) VMs
- EBS volume types
- Ephemeral disks (local disks)
- Mounting and formatting a disk
- Disk performance testing with Bonnie++
- Cost Saving Best Practices

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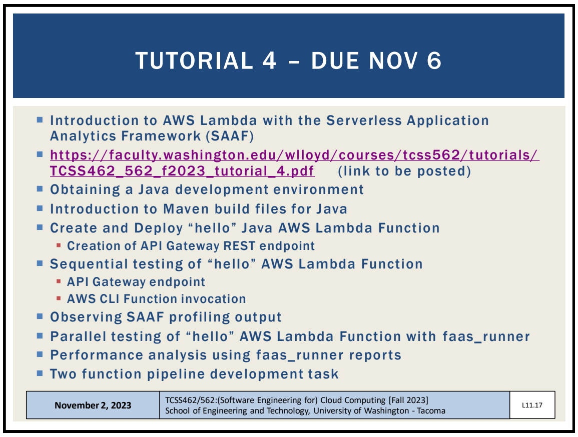

## TUTORIAL 4 – DUE NOV 6

- Introduction to AWS Lambda with the Serverless Application Analytics Framework (SAAF)
- https://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2023_tutorial_4.pdf (link to be posted)
- Obtaining a Java development environment
- Introduction to Maven build files for Java
- Create and Deploy "hello" Java AWS Lambda Function
  - Creation of API Gateway REST endpoint
- Sequential testing of "hello" AWS Lambda Function
  - API Gateway endpoint
  - AWS CLI Function invocation
- Observing SAAF profiling output
- Parallel testing of "hello" AWS Lambda Function with faas_runner
- Performance analysis using faas_runner reports
- Two function pipeline development task

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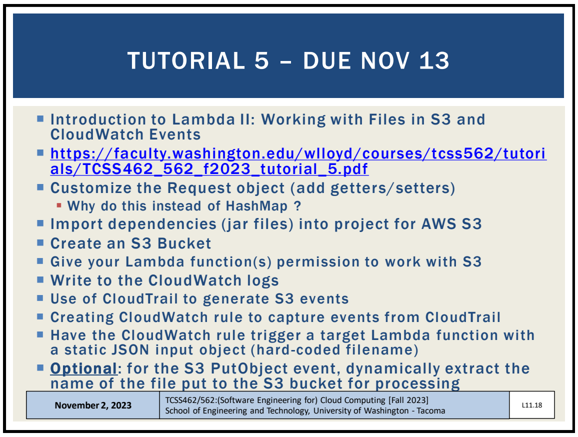

## TUTORIAL 5 – DUE NOV 13

- Introduction to Lambda II: Working with Files in S3 and CloudWatch Events
- https://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2023_tutorial_5.pdf
- Customize the Request object (add getters/setters)
  - Why do this instead of HashMap ?
- Import dependencies (jar files) into project for AWS S3
- Create an S3 Bucket
- Give your Lambda function(s) permission to work with S3
- Write to the CloudWatch logs
- Use of CloudTrail to generate S3 events
- Creating CloudWatch rule to capture events from CloudTrail
- Have the CloudWatch rule trigger a target Lambda function with a static JSON input object (hard-coded filename)
- **Optional**: for the S3 PutObject event, dynamically extract the name of the file put to the S3 bucket for processing

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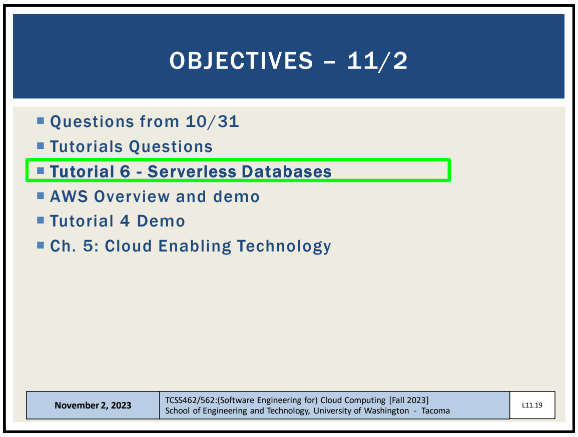

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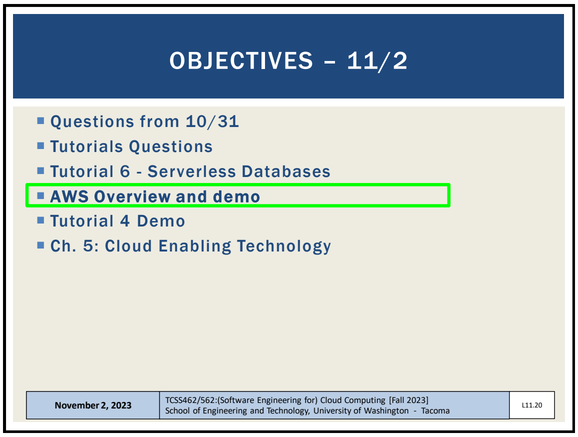

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## AWS OVERVIEW AND DEMO

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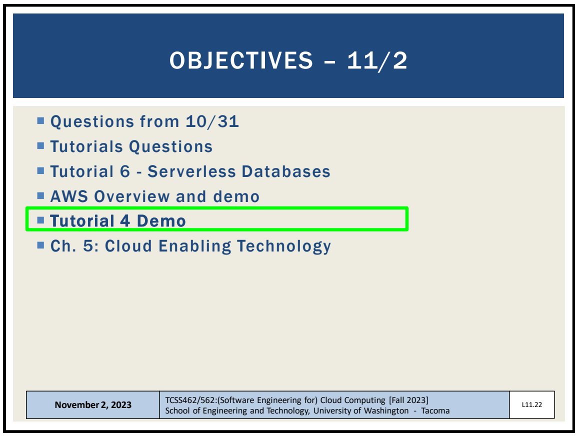

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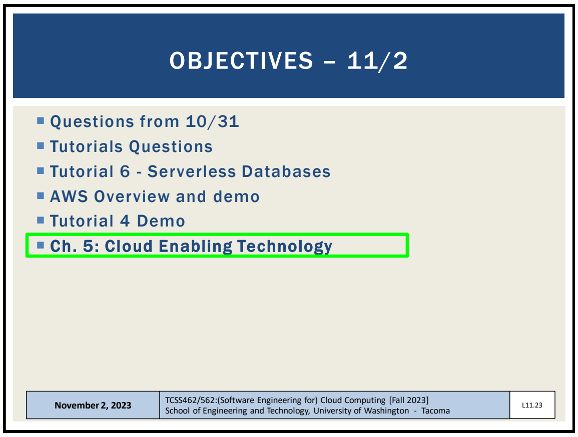

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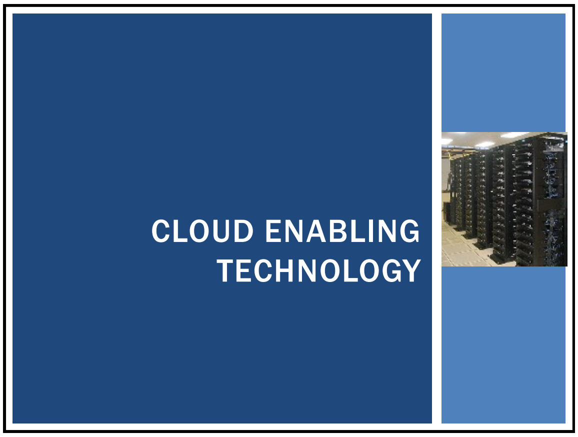

## CLOUD ENABLING TECHNOLOGY

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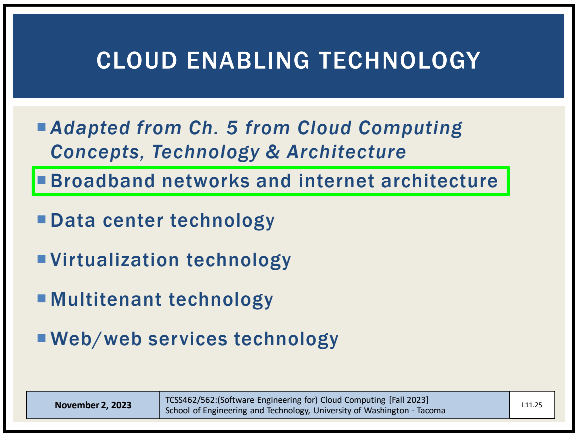

## CLOUD ENABLING TECHNOLOGY

- *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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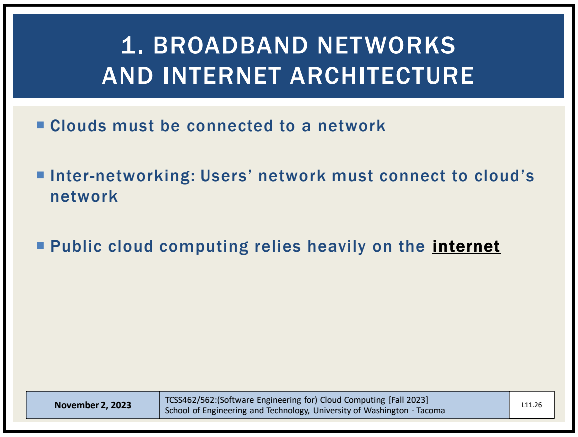

## 1. BROADBAND NETWORKS AND INTERNET ARCHITECTURE

- 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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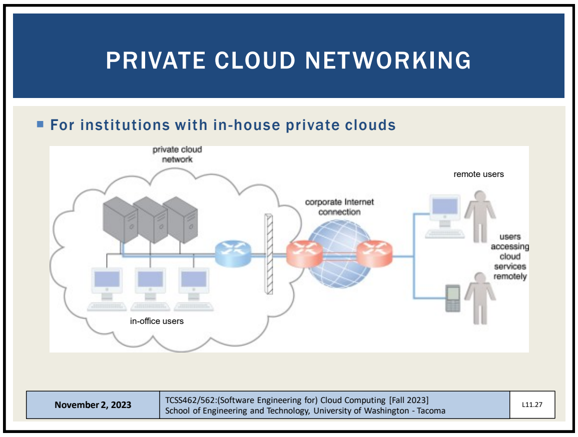

## PRIVATE CLOUD NETWORKING

- For institutions with in-house private clouds

private cloud network
corporate Internet connection
remote users
users accessing cloud services remotely
in-office users

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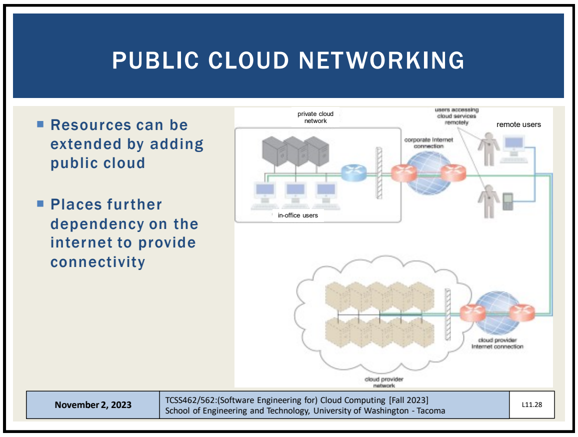

## PUBLIC CLOUD NETWORKING

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

private cloud network
users accessing cloud services remotely
remote users
corporate Internet connection
in-office users
cloud provider Internet connection
cloud provider network

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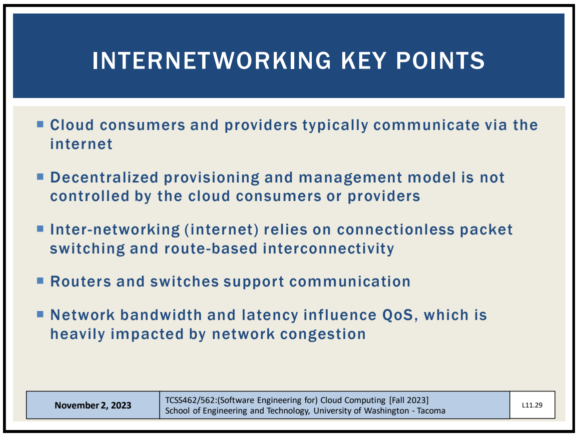

## INTERNETWORKING KEY POINTS

- 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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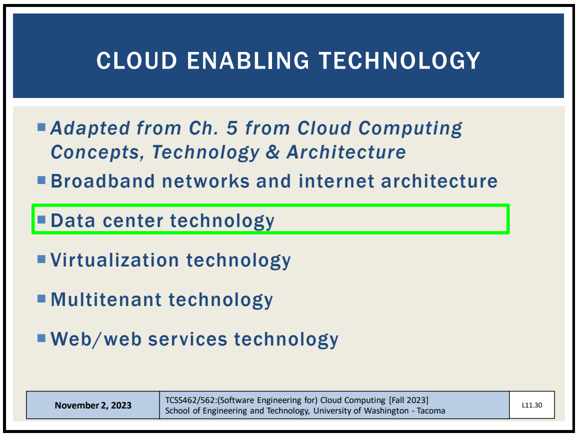

## CLOUD ENABLING TECHNOLOGY

- *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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## 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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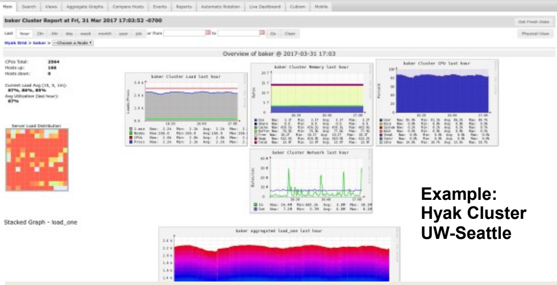
## CLUSTER MANAGEMENT TOOLS



baker Cluster Report at Fri, 31 Mar 2017 17:03:52 -0700

Hyak Grid > baker > --Choose a Node

Overview of baker @ 2017-03-31 17:03

CPUs Total: 2564
Hosts up: 166
Hosts down: 0

Current Load Avg (15, 5, 1m): 87%, 86%, 85%
Avg Utilization (last hour): 87%

Stacked Graph - load_one

**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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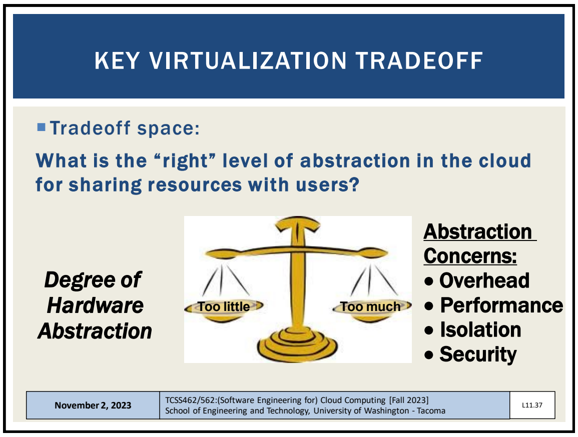

## KEY VIRTUALIZATION TRADEOFF

- Tradeoff space:

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

***Degree of Hardware Abstraction***

Too little
Too much

**Abstraction Concerns:**

- **Overhead**
- **Performance**
- **Isolation**
- **Security**

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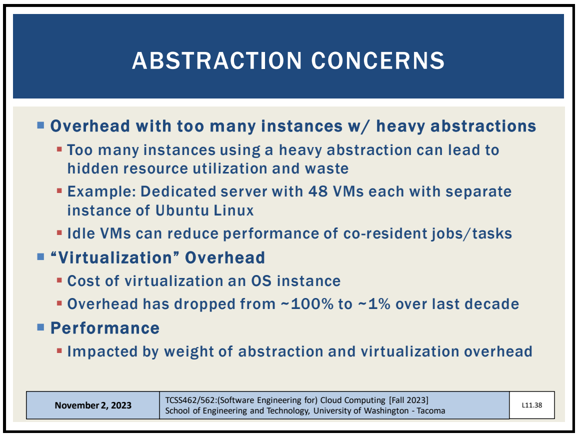

## ABSTRACTION CONCERNS

- **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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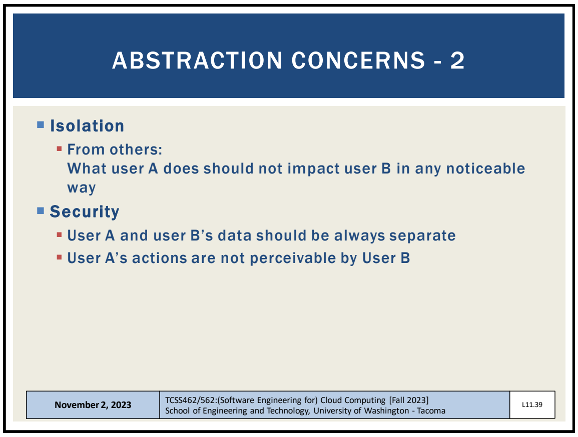

## ABSTRACTION CONCERNS - 2

- **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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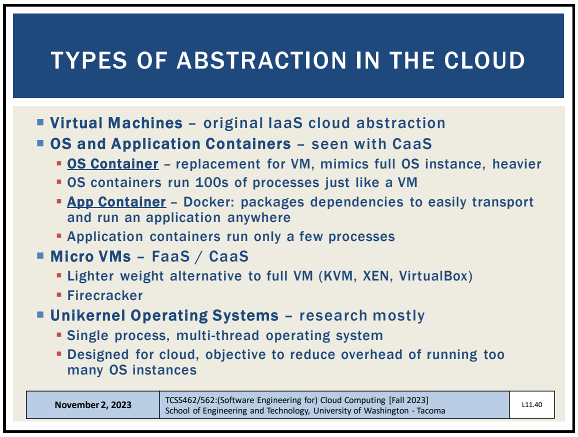

## TYPES OF ABSTRACTION IN THE CLOUD

- **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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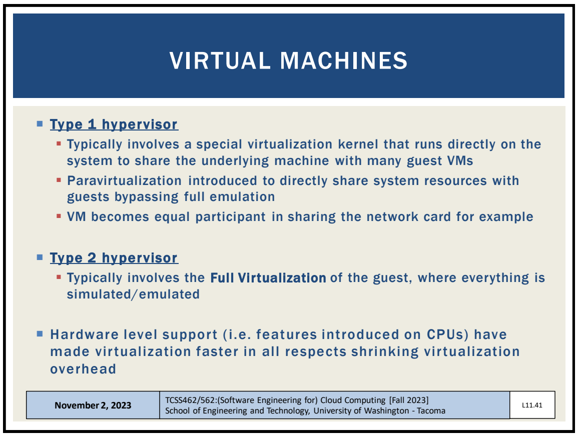

## VIRTUAL MACHINES

- **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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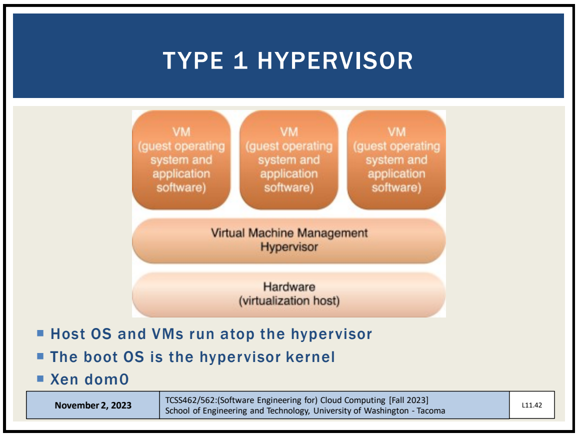

## TYPE 1 HYPERVISOR

VM (guest operating system and application software)

VM (guest operating system and application software)

VM (guest operating system and application software)

Virtual Machine Management Hypervisor

Hardware (virtualization host)

- 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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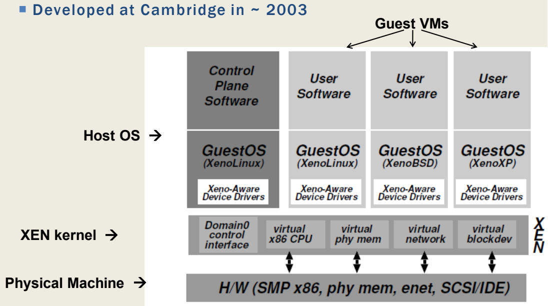
## XEN

- Developed at Cambridge in ~ 2003


Guest VMs

Host OS →

XEN kernel →

Physical Machine →

Control Plane Software | User Software | User Software | User Software

GuestOS (XenoLinux) Xeno-Aware Device Drivers | GuestOS (XenoLinux) Xeno-Aware Device Drivers | GuestOS (XenoBSD) Xeno-Aware Device Drivers | GuestOS (XenoXP) Xeno-Aware Device Drivers

Domain0 control interface | virtual x86 CPU | virtual phy mem | virtual network | virtual blockdev | XEN

H/W (SMP x86, phy mem, enet, SCSI/IDE)

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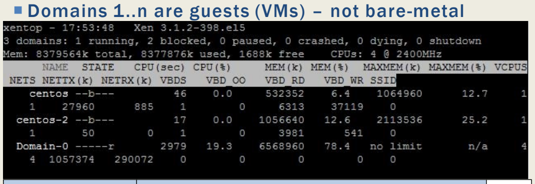
## XEN - 2

- 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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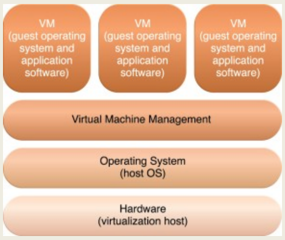
## TYPE 2 HYPERVISOR

- Adds additional layer


VM (guest operating system and application software) | VM (guest operating system and application software) | VM (guest operating system and application software)

Virtual Machine Management

Operating System (host OS)

Hardware (virtualization host)

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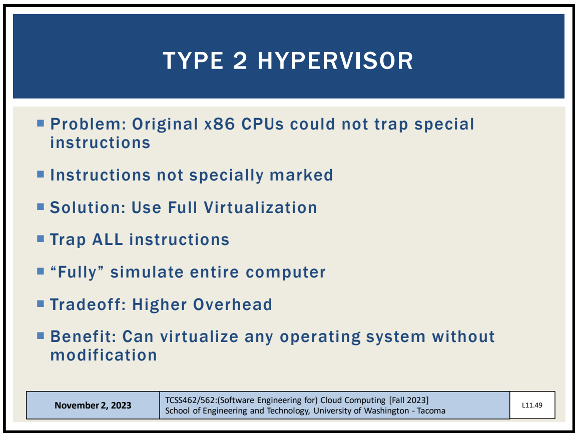
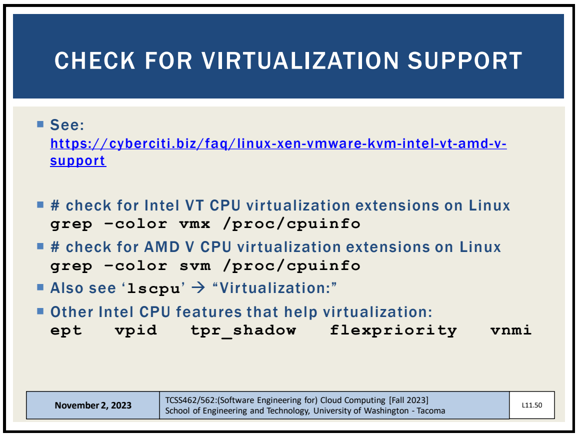


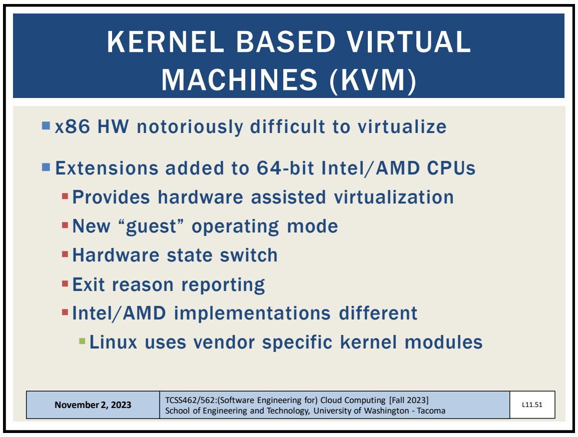
## TYPE 2 HYPERVISOR

- 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



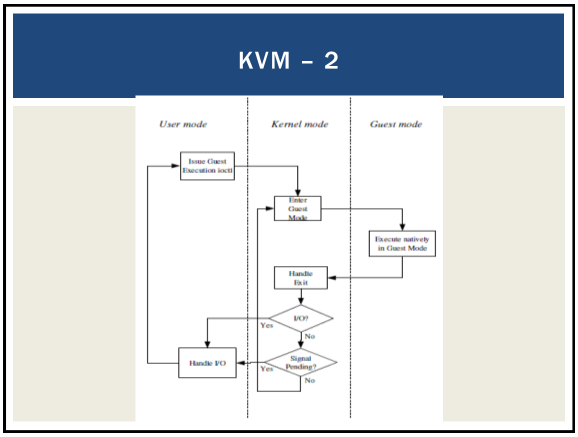
## CHECK FOR VIRTUALIZATION SUPPORT

- See: https://cyberciti.biz/faq/linux-xen-vmware-kvm-intel-vt-amd-v-support
- # check for Intel 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`

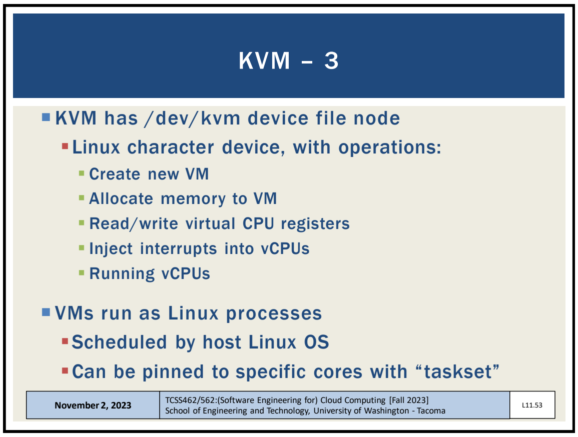


## KERNEL BASED VIRTUAL MACHINES (KVM)

- 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

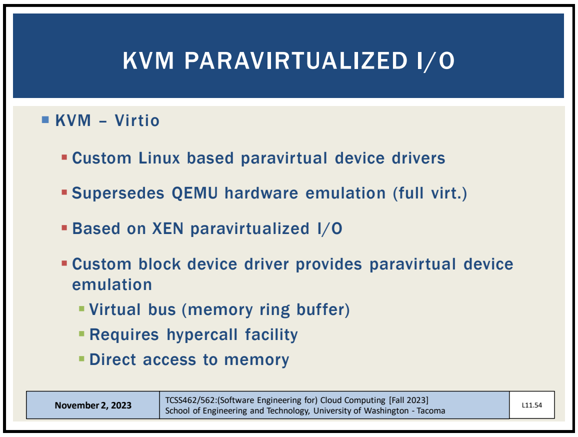


## KVM – 2



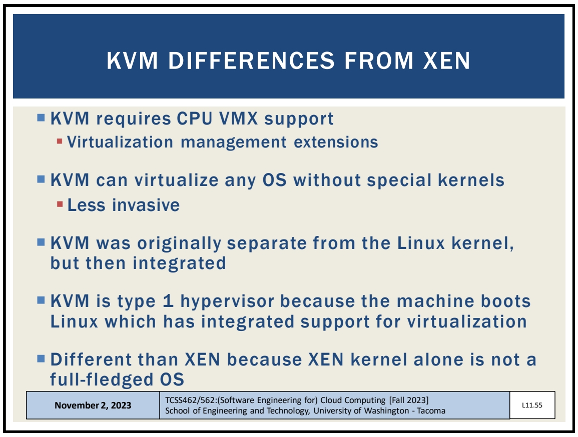
## KVM – 3

- 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”



## 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



## 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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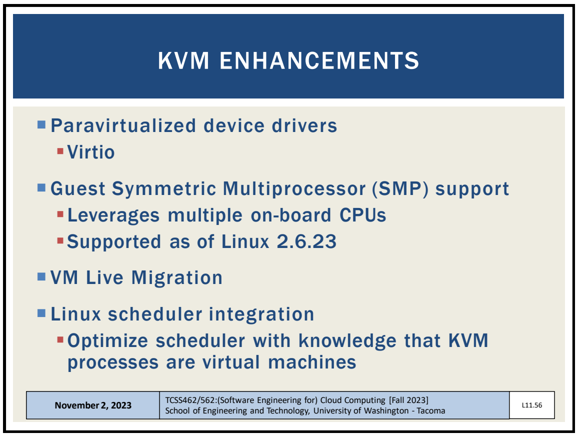

## KVM ENHANCEMENTS

- 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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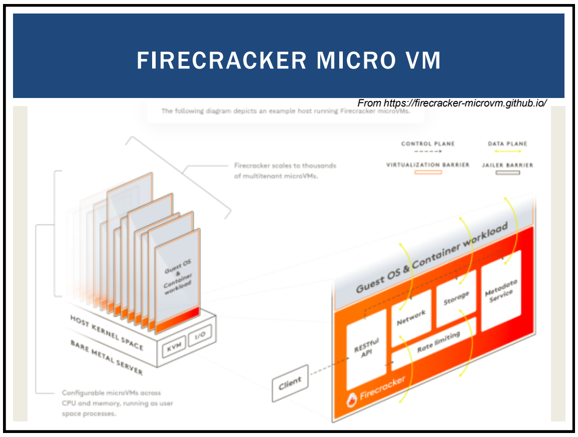

## FIRECRACKER MICRO VM

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

The following diagram depicts an example host running Firecracker microVMs.
CONTROL PLANE
DATA PLANE
VIRTUALIZATION BARRIER
JAILER BARRIER
Firecracker scales to thousands of multitenant microVMs.
Guest OS & Container workload
HOST KERNEL SPACE
BARE METAL SERVER
KVM
I/O
Configurable microVMs across CPU and memory, running as user space processes.
Client
Guest OS & Container workload
RESTful API
Network
Storage
Metadata Service
Rate limiting
Firecracker

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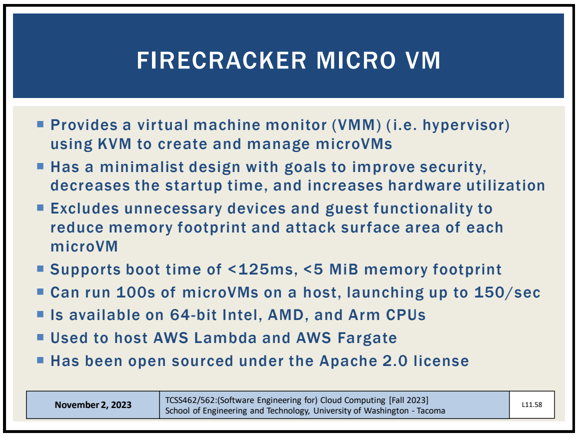

## FIRECRACKER MICRO VM

- 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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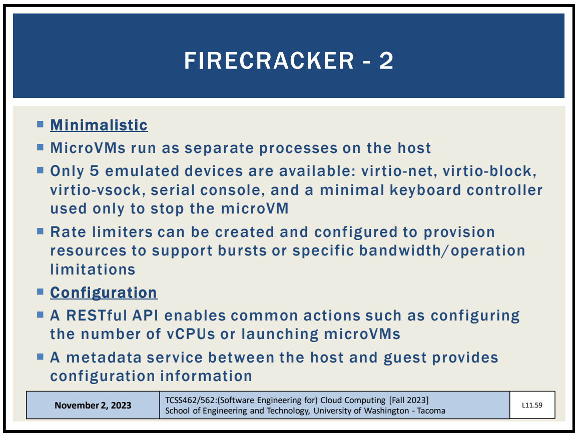

## FIRECRACKER - 2

- **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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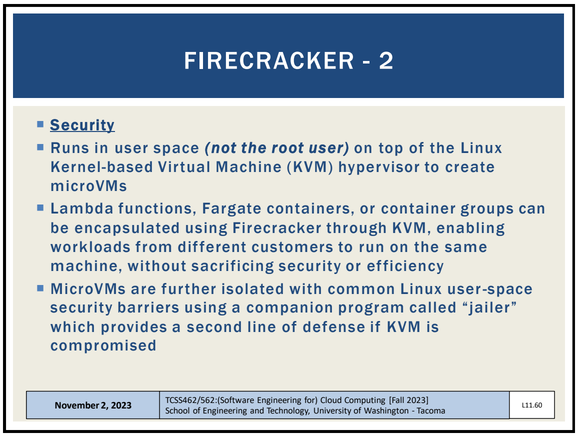

## FIRECRACKER - 2

- **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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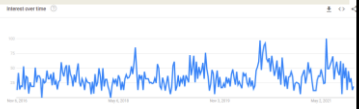
## UNIKERNELS

- 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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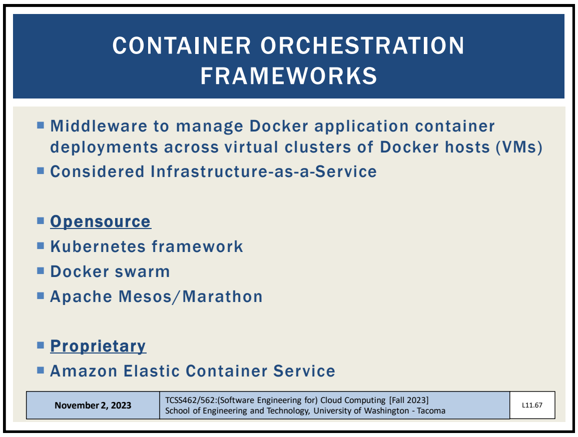

## CONTAINER ORCHESTRATION FRAMEWORKS

- 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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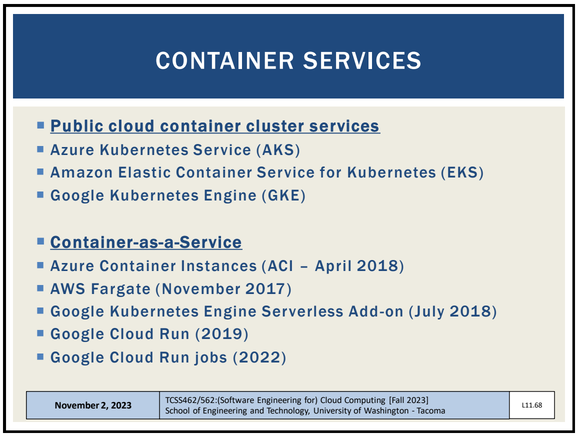

## CONTAINER SERVICES

- **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 (July 2018)
- Google Cloud Run (2019)
- Google Cloud Run jobs (2022)

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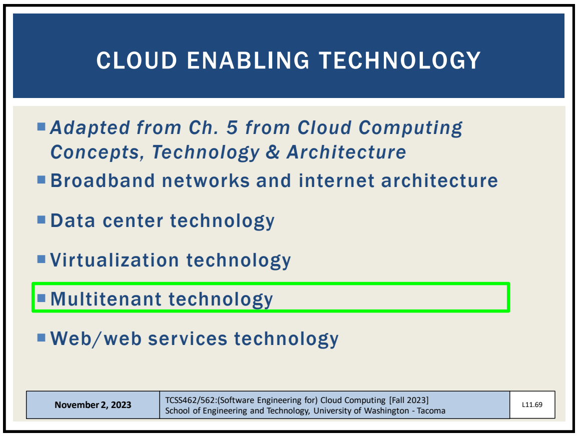

## CLOUD ENABLING TECHNOLOGY

- *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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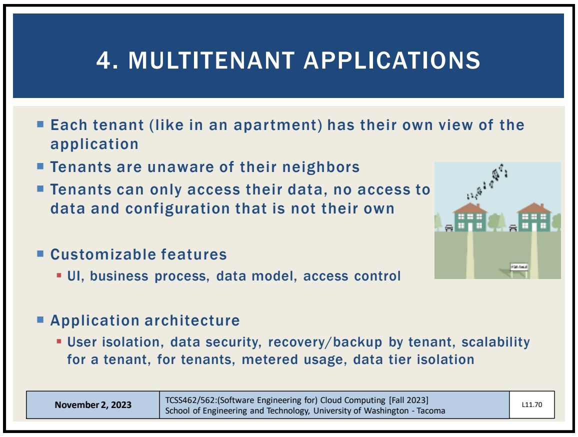

## 4. MULTITENANT APPLICATIONS

- 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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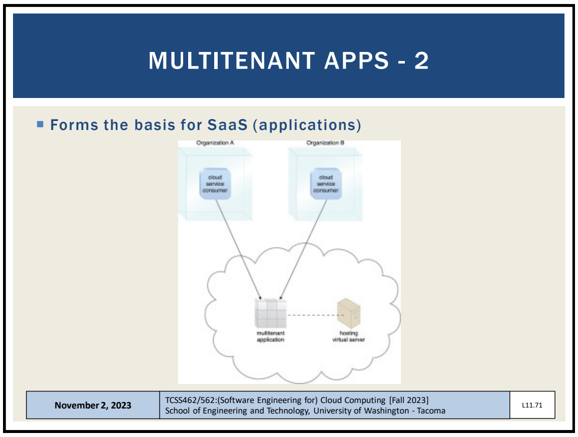

## MULTITENANT APPS - 2

- Forms the basis for SaaS (applications)

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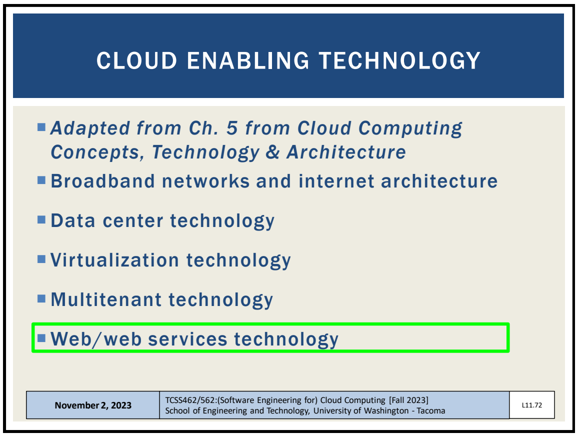

## CLOUD ENABLING TECHNOLOGY

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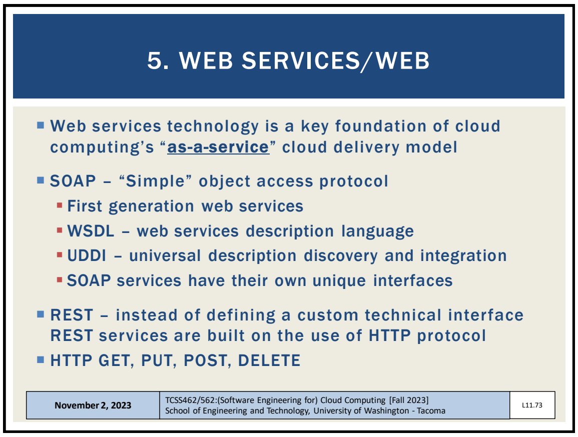

## 5. WEB SERVICES/WEB

- 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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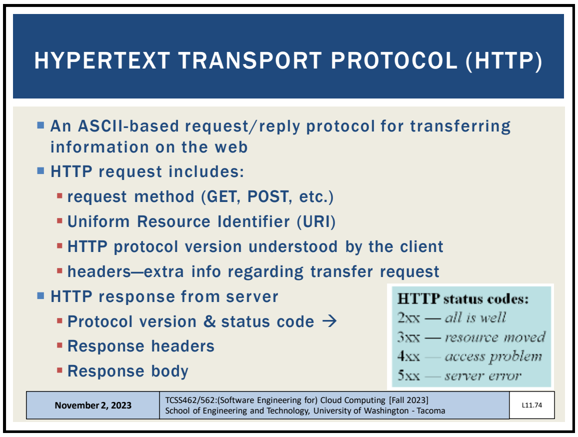

## HYPERTEXT TRANSPORT PROTOCOL (HTTP)

- 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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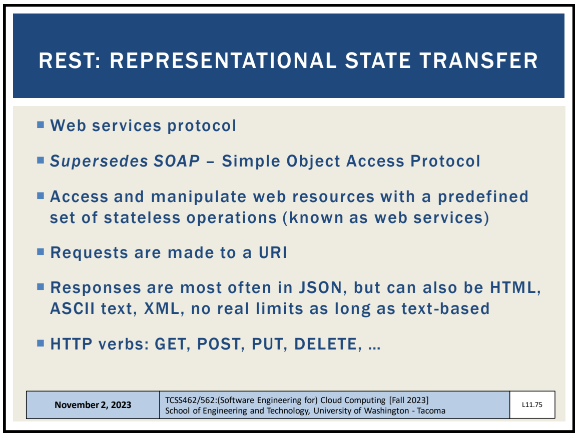

## REST: REPRESENTATIONAL STATE TRANSFER

- 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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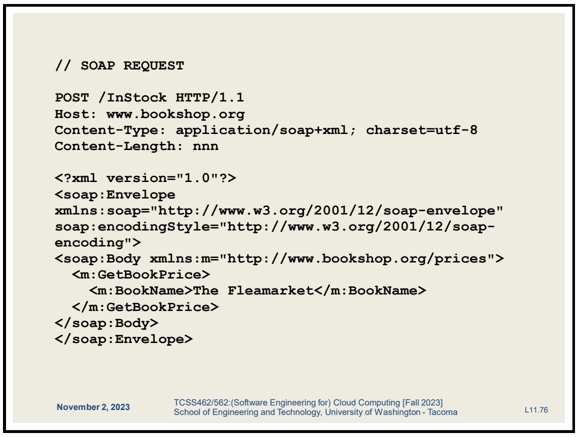

```
// SOAP REQUEST

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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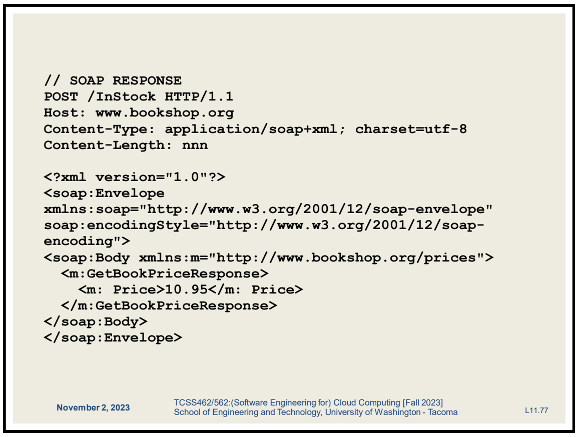

```
// SOAP RESPONSE
POST /InStock HTTP/1.1
Host: www.bookshop.org
Content-Type: application/soap+xml; charset=utf-8
Content-Length: nnn

<?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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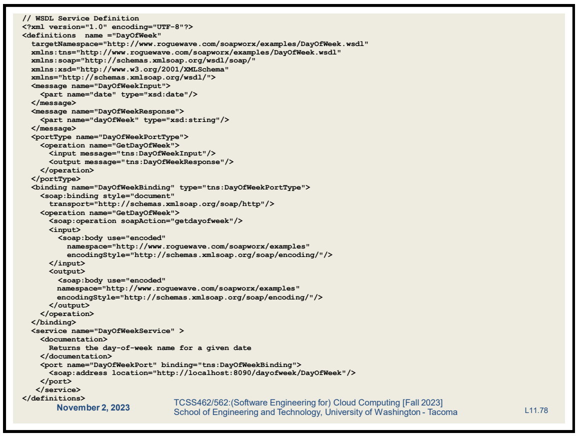

```
// WSDL Service Definition
<?xml version="1.0" encoding="UTF-8"?>
<definitions  name ="DayOfWeek"
  targetNamespace="http://www.roguewave.com/soapworx/examples/DayOfWeek.wsdl"
  xmlns:tns="http://www.roguewave.com/soapworx/examples/DayOfWeek.wsdl"
  xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/"
  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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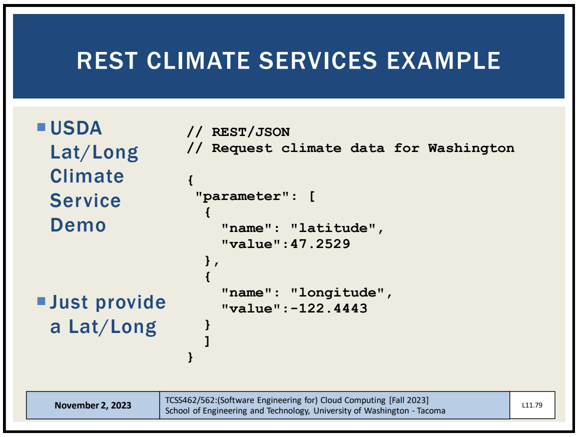

## REST CLIMATE SERVICES EXAMPLE

- 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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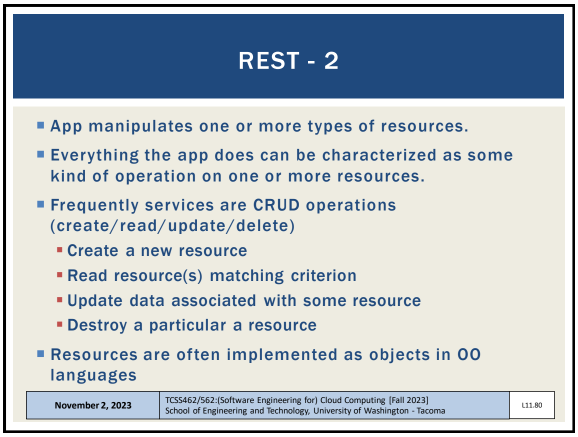

## REST - 2

- 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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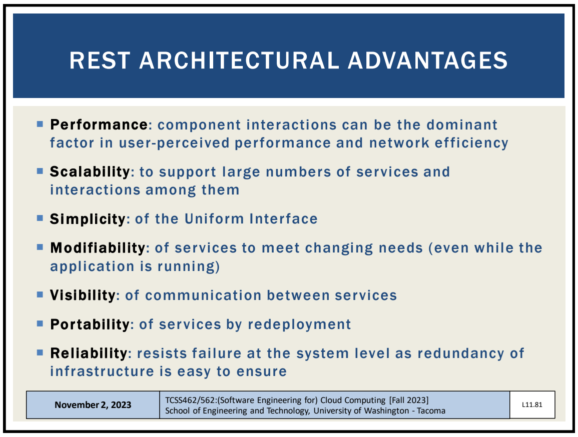

## REST ARCHITECTURAL ADVANTAGES

- **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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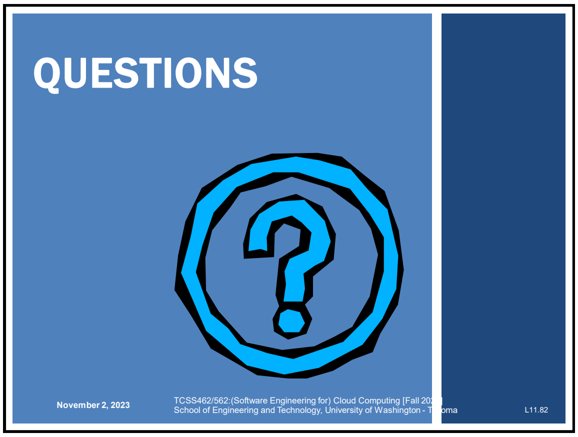

## QUESTIONS

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