TCSS 462/562: (SOFTWARE ENGINEERING FOR) CLOUD COMPUTING

Containerization

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

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OFFICE HOURS – FALL 2024

- **THIS WEEK**
- **Tuesdays:**
  - 2:30 to 3:30 pm - CP 229
- **Thursday*:**
  - 6:00 pm to 7:00 pm – CP 229 and via Zoom*
- Or email for appointment

> Office Hours set based on Student Demographics survey feedback
** - Four Friday faculty meetings have moved office hours to a 5pm starting time*

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OBJECTIVES – 11/14

- **OBJECTIVES – 11/12**
- Tutorials Questions
- Class Presentations Schedule - Cloud Technology or Research Paper Review
- Quiz 1
- Tutorial 7
- Containerization
- Container Profiler

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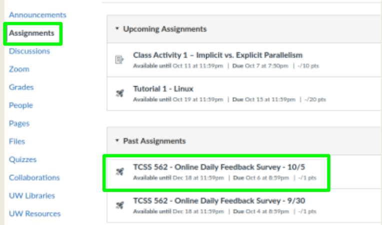
ONLINE DAILY FEEDBACK SURVEY

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



▾ Upcoming Assignments

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

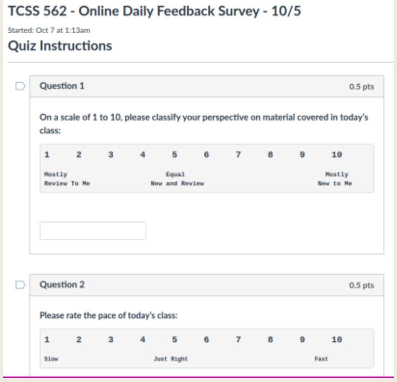
Tutorial 1 - Linux
Available until Oct 19 at 11:59pm | Due Oct 15 at 11:59pm | -/20 pts

▾ 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

4



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 (**42** respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 5.60 (↓ - *previous 5.84*)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.42 (↓ - previous 5.13)**

- **Response rates:**
- TCSS 462: 30/42 – 71.43%
- TCSS 562: 12/20 – 60.00%

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FEEDBACK FROM 11/12

- ...

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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
  - 56 credit requests fulfilled as of Nov 13 @ 11:59p
- Codes not provided using discord

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Don't Forget to Terminate (Shutdown) all EC2 instances for Tutorials 3

Spot instances:
c5d.large instance @ ~3.2 cents / hour

$0.78 / day
$5.48 / week
$23.78 / month
$285.42 / year

AWS CREDITS → → → → → → → → →

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TUTORIAL SUBMISSION TIME

- Tutorials can now be submitted on the due date until the very last minute of the day **Anywhere-on-Earth (AOE)**
  - **Equivalent to 4:59 AM Pacific Standard Time (PST)**
- Anywhere-on-Earth timezone: **Baker Island, Pacific Ocean**
- https://www.timeanddate.com/time/zones/aoe
- Uninhabited island in Pacific Ocean

Coordinates	0°11′45″N 176°28′45″W
Area	2.1 km2 (0.81 sq mi)
Length	1.81 km (1.125 mi)
Width	1.13 km (0.702 mi)
Coastline	4.8 km (2.98 mi)
Highest elevation	8 m (26 ft)
Population	0 (2000)

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TUTORIAL 5 – DUE NOV 14

- Introduction to Lambda II: Working with Files in S3 and CloudWatch Events
- https://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2024_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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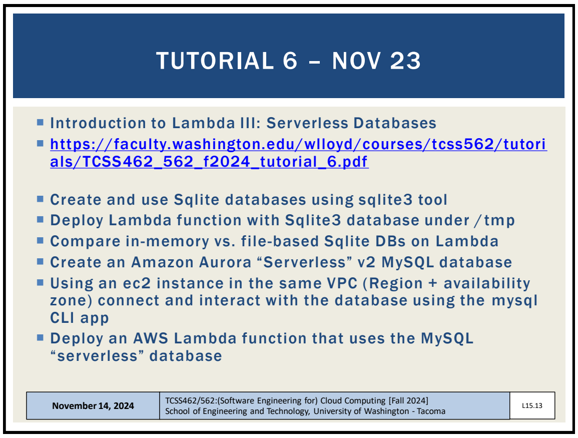

TUTORIAL 6 – NOV 23

- Introduction to Lambda III: Serverless Databases
- https://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2024_tutorial_6.pdf
- Create and use Sqlite databases using sqlite3 tool
- Deploy Lambda function with Sqlite3 database under /tmp
- Compare in-memory vs. file-based Sqlite DBs on Lambda
- Create an Amazon Aurora "Serverless" v2 MySQL database
- Using an ec2 instance in the same VPC (Region + availability zone) connect and interact with the database using the mysql CLI app
- Deploy an AWS Lambda function that uses the MySQL "serverless" database

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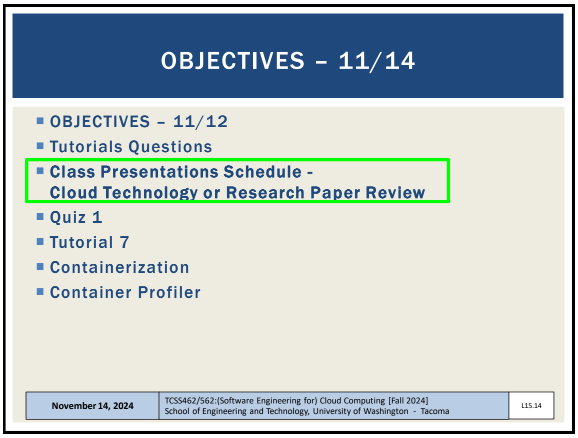

OBJECTIVES – 11/14

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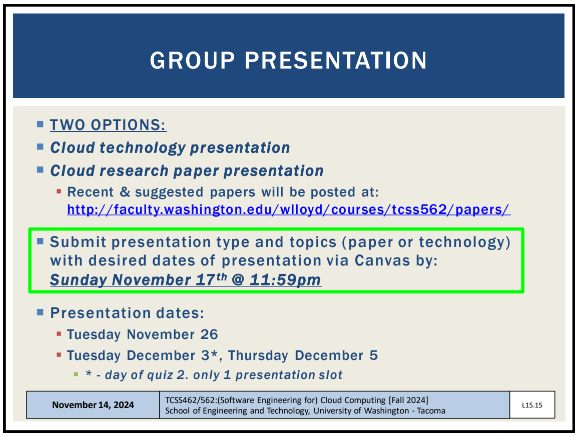

GROUP PRESENTATION

- TWO OPTIONS:
- ***Cloud technology presentation***
- ***Cloud research paper presentation***
  - Recent & suggested papers will be posted at: http://faculty.washington.edu/wlloyd/courses/tcss562/papers/
- Submit presentation type and topics (paper or technology) with desired dates of presentation via Canvas by: ***Sunday November 17th @ 11:59pm***
- Presentation dates:
  - Tuesday November 26
  - Tuesday December 3*, Thursday December 5
    - ** - day of quiz 2. only 1 presentation slot*

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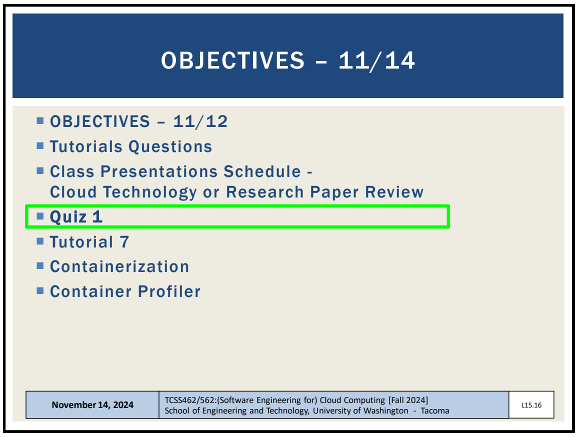

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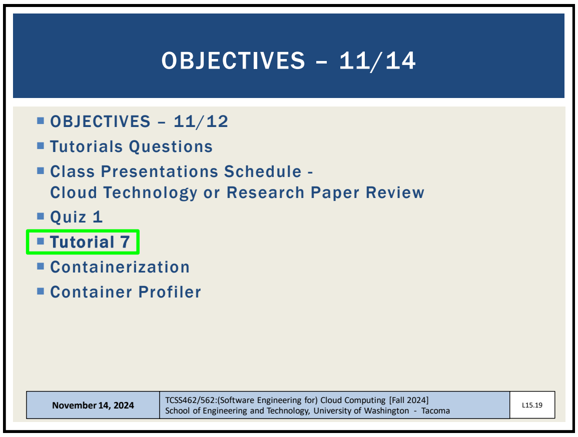

OBJECTIVES – 11/14

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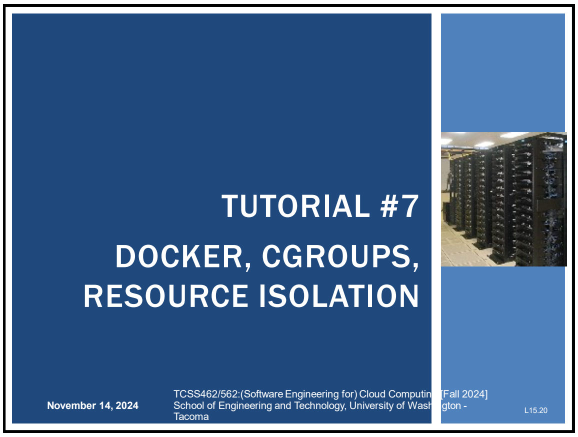

TUTORIAL #7

DOCKER, CGROUPS, RESOURCE ISOLATION

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TUTORIAL 7 – DEC 1

- Introduction to Docker
- https://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2024_tutorial_7.pdf
- Complete tutorial using Ubuntu 24.04 (for cgroups v2)
- Complete using **c6i.large ec2 instance** (for consistency)
- Use DOCX file for copying and pasting Docker install commands
- Topics:
  - Installing Docker
  - Creating a container using a Dockerfile
  - Using cgroups virtual filesystem to monitor CPU utilization of a container
  - Persisting container images to Docker Hub image repository
  - Container vertical scaling of CPU/memory resources
  - Testing container CPU and memory isolation

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TUTORIAL COVERAGE

- **Docker CLI → Docker Engine (dockerd) → containerd → runc**
- Working with the docker CLI:
- docker run   create a container
- docker ps -a   list containers, find CONTAINER ID
- docker exec --it   run a process in an existing container
- docker stop   stop a container
- docker kill   kill a container
- docker help   list available commands
- man docker   Docker Linux manual pages

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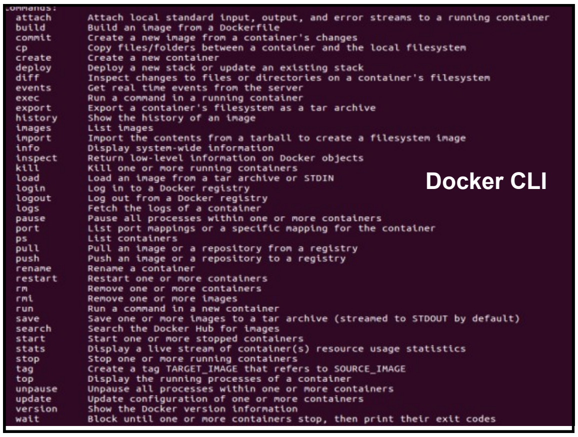

```
Commands:
  attach      Attach local standard input, output, and error streams to a running container
  build       Build an image from a Dockerfile
  commit      Create a new image from a container's changes
  cp          Copy files/folders between a container and the local filesystem
  create      Create a new container
  deploy      Deploy a new stack or update an existing stack
  diff        Inspect changes to files or directories on a container's filesystem
  events      Get real time events from the server
  exec        Run a command in a running container
  export      Export a container's filesystem as a tar archive
  history     Show the history of an image
  images      List images
  import      Import the contents from a tarball to create a filesystem image
  info        Display system-wide information
  inspect     Return low-level information on Docker objects
  kill        Kill one or more running containers
  load        Load an image from a tar archive or STDIN
  login       Log in to a Docker registry
  logout      Log out from a Docker registry
  logs        Fetch the logs of a container
  pause       Pause all processes within one or more containers
  port        List port mappings or a specific mapping for the container
  ps          List containers
  pull        Pull an image or a repository from a registry
  push        Push an image or a repository to a registry
  rename      Rename a container
  restart     Restart one or more containers
  rm          Remove one or more containers
  rmi         Remove one or more images
  run         Run a command in a new container
  save        Save one or more images to a tar archive (streamed to STDOUT by default)
  search      Search the Docker Hub for images
  start       Start one or more stopped containers
  stats       Display a live stream of container(s) resource usage statistics
  stop        Stop one or more running containers
  tag         Create a tag TARGET_IMAGE that refers to SOURCE_IMAGE
  top         Display the running processes of a container
  unpause     Unpause all processes within one or more containers
  update      Update configuration of one or more containers
  version     Show the Docker version information
  wait        Block until one or more containers stop, then print their exit codes
```

Docker CLI

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TUTORIAL 7

- Tutorial introduces use of two common Linux performance benchmark applications
- stress-ng
- 100s of CPU, memory, disk, network stress tests
- Sysbench
- Used in tutorial for memory stress test

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WE WILL RETURN AT ~4:50 PM

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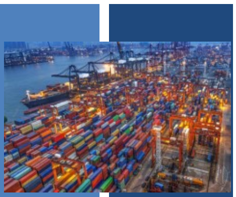

CONTAINERIZATION

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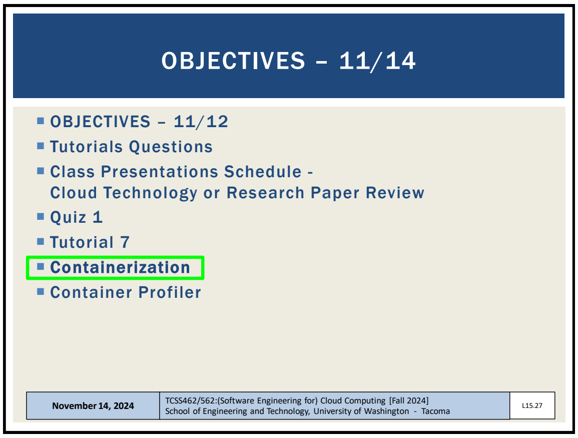

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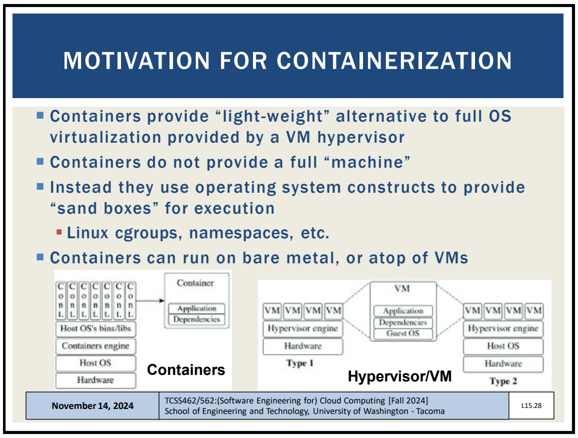

MOTIVATION FOR CONTAINERIZATION

- Containers provide "light-weight" alternative to full OS virtualization provided by a VM hypervisor
- Containers do not provide a full "machine"
- Instead they use operating system constructs to provide "sand boxes" for execution
  - Linux cgroups, namespaces, etc.
- Containers can run on bare metal, or atop of VMs

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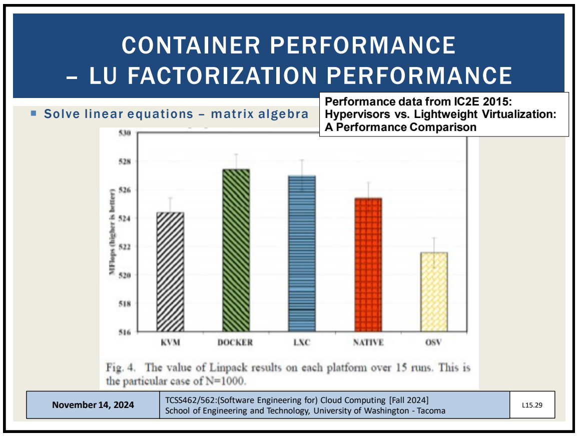

CONTAINER PERFORMANCE – LU FACTORIZATION PERFORMANCE

- Solve linear equations – matrix algebra

Performance data from IC2E 2015: Hypervisors vs. Lightweight Virtualization: A Performance Comparison

Fig. 4. The value of Linpack results on each platform over 15 runs. This is the particular case of N=1000.

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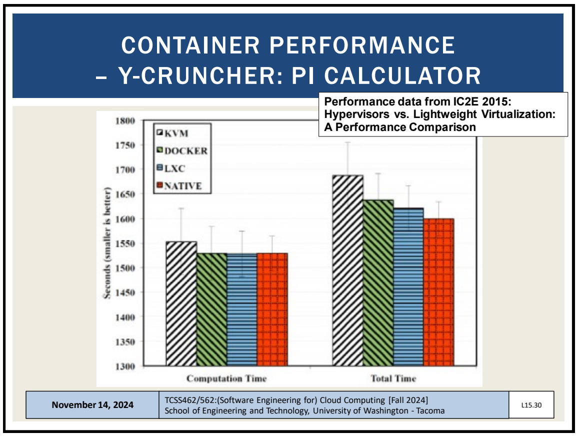

CONTAINER PERFORMANCE – Y-CRUNCHER: PI CALCULATOR

Performance data from IC2E 2015: Hypervisors vs. Lightweight Virtualization: A Performance Comparison

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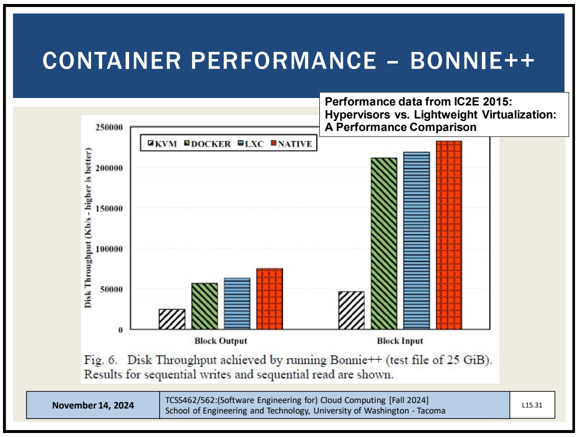

CONTAINER PERFORMANCE – BONNIE++

Performance data from IC2E 2015: Hypervisors vs. Lightweight Virtualization: A Performance Comparison

Fig. 6. Disk Throughput achieved by running Bonnie++ (test file of 25 GiB). Results for sequential writes and sequential read are shown.

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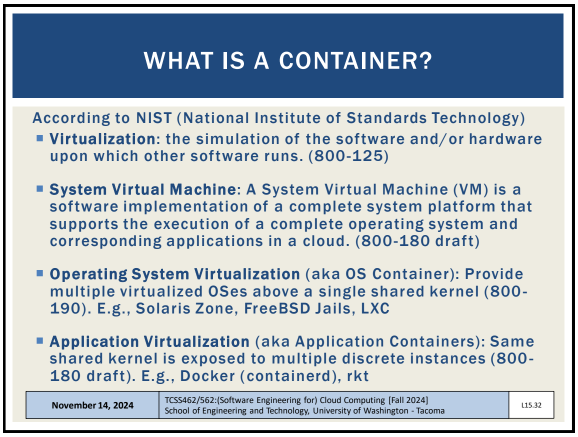

WHAT IS A CONTAINER?

According to NIST (National Institute of Standards Technology)

- **Virtualization**: the simulation of the software and/or hardware upon which other software runs. (800-125)
- **System Virtual Machine**: A System Virtual Machine (VM) is a software implementation of a complete system platform that supports the execution of a complete operating system and corresponding applications in a cloud. (800-180 draft)
- **Operating System Virtualization** (aka OS Container): Provide multiple virtualized OSes above a single shared kernel (800-190). E.g., Solaris Zone, FreeBSD Jails, LXC
- **Application Virtualization** (aka Application Containers): Same shared kernel is exposed to multiple discrete instances (800-180 draft). E.g., Docker (containerd), rkt

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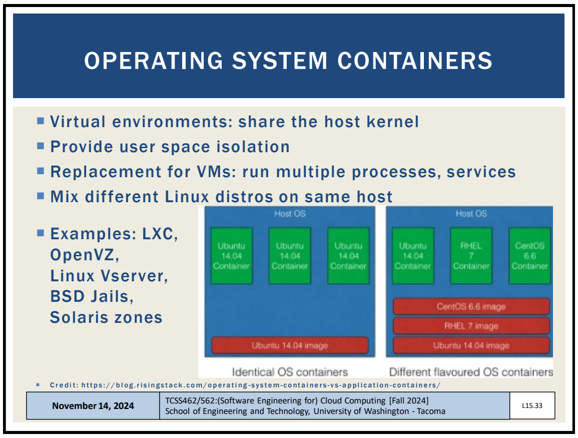

OPERATING SYSTEM CONTAINERS

- Virtual environments: share the host kernel
- Provide user space isolation
- Replacement for VMs: run multiple processes, services
- Mix different Linux distros on same host
- Examples: LXC, OpenVZ, Linux Vserver, BSD Jails, Solaris zones

Identical OS containers   Different flavoured OS containers

- Credit: https://blog.risingstack.com/operating-system-containers-vs-application-containers/

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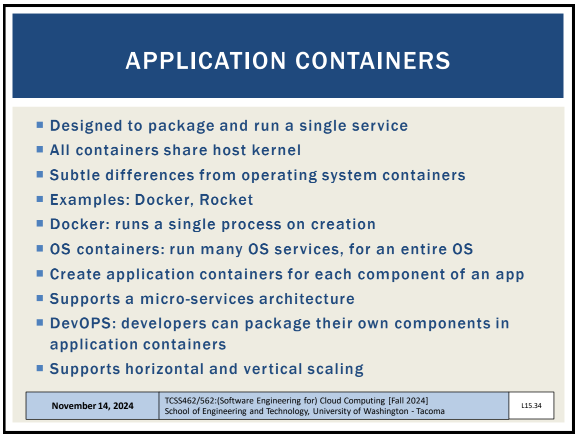

APPLICATION CONTAINERS

- Designed to package and run a single service
- All containers share host kernel
- Subtle differences from operating system containers
- Examples: Docker, Rocket
- Docker: runs a single process on creation
- OS containers: run many OS services, for an entire OS
- Create application containers for each component of an app
- Supports a micro-services architecture
- DevOPS: developers can package their own components in application containers
- Supports horizontal and vertical scaling

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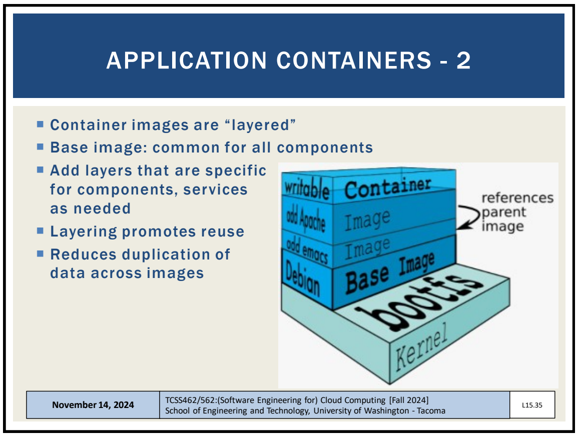

APPLICATION CONTAINERS - 2

- Container images are "layered"
- Base image: common for all components
- Add layers that are specific for components, services as needed
- Layering promotes reuse
- Reduces duplication of data across images

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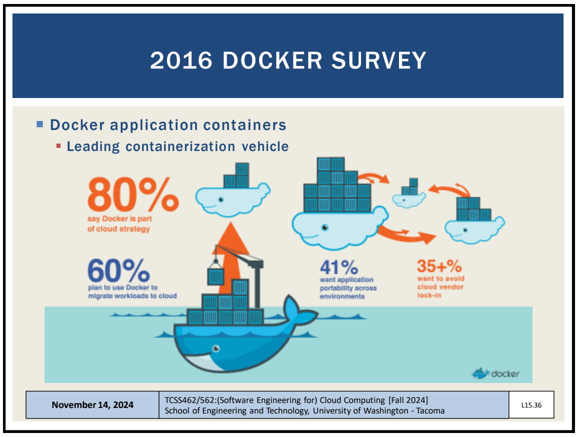

2016 DOCKER SURVEY

- Docker application containers
  - Leading containerization vehicle

80%
say Docker is part of cloud strategy
60%
plan to use Docker to migrate workloads to cloud
41%
want application portability across environments
35+%
want to avoid cloud vendor lock-in
docker

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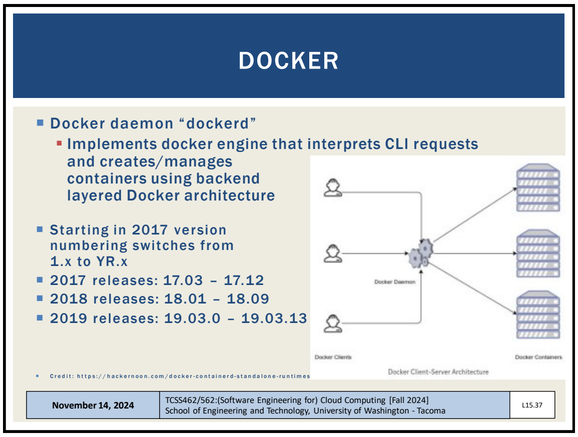

DOCKER

- Docker daemon "dockerd"
  - Implements docker engine that interprets CLI requests and creates/manages containers using backend layered Docker architecture
- Starting in 2017 version numbering switches from 1.x to YR.x
- 2017 releases: 17.03 – 17.12
- 2018 releases: 18.01 – 18.09
- 2019 releases: 19.03.0 – 19.03.13

Docker Client-Server Architecture

- Credit: https://hackernoon.com/docker-containerd-standalone-runtimes

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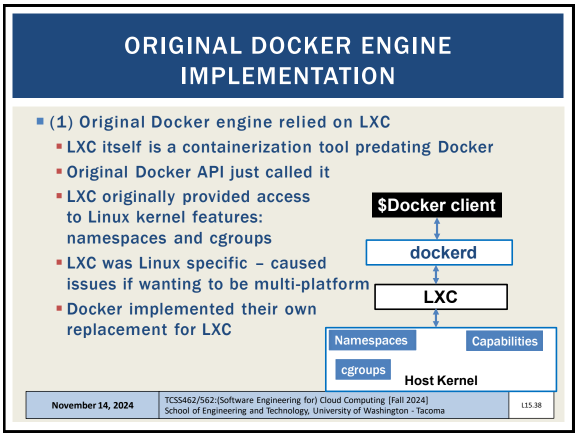

ORIGINAL DOCKER ENGINE IMPLEMENTATION

- (1) Original Docker engine relied on LXC
  - LXC itself is a containerization tool predating Docker
  - Original Docker API just called it
  - LXC originally provided access to Linux kernel features: namespaces and cgroups
  - LXC was Linux specific – caused issues if wanting to be multi-platform
  - Docker implemented their own replacement for LXC

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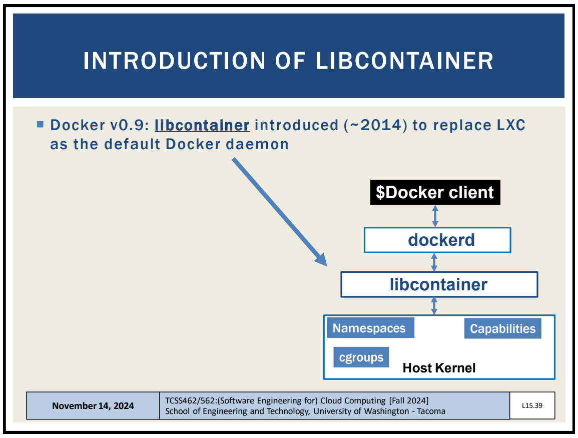

INTRODUCTION OF LIBCONTAINER

- Docker v0.9: **libcontainer** introduced (~2014) to replace LXC as the default Docker daemon

$Docker client
dockerd
libcontainer
Namespaces
Capabilities
cgroups
Host Kernel

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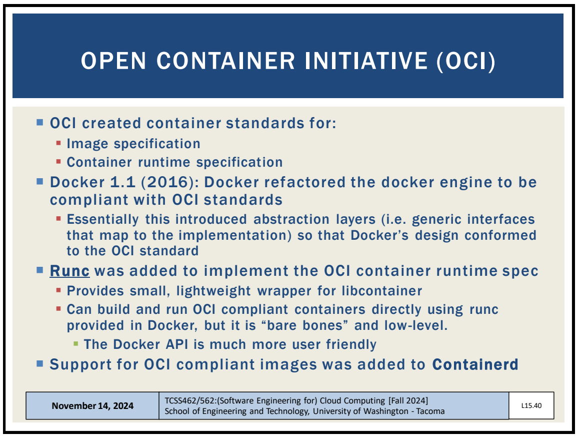

OPEN CONTAINER INITIATIVE (OCI)

- OCI created container standards for:
  - Image specification
  - Container runtime specification
- Docker 1.1 (2016): Docker refactored the docker engine to be compliant with OCI standards
  - Essentially this introduced abstraction layers (i.e. generic interfaces that map to the implementation) so that Docker's design conformed to the OCI standard
- **Runc** was added to implement the OCI container runtime spec
  - Provides small, lightweight wrapper for libcontainer
  - Can build and run OCI compliant containers directly using runc provided in Docker, but it is "bare bones" and low-level.
    - The Docker API is much more user friendly
- Support for OCI compliant images was added to **Containerd**

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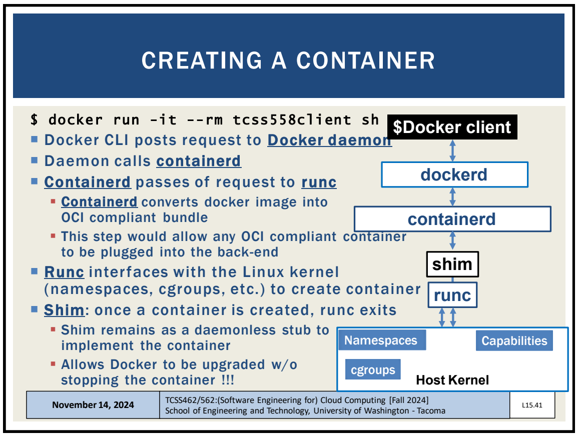

CREATING A CONTAINER

```
$ docker run -it --rm tcss558client sh
```

- Docker CLI posts request to **Docker daemon**
- Daemon calls **containerd**
- **Containerd** passes of request to **runc**
  - **Containerd** converts docker image into OCI compliant bundle
  - This step would allow any OCI compliant container to be plugged into the back-end
- **Runc** interfaces with the Linux kernel (namespaces, cgroups, etc.) to create container
- **Shim**: once a container is created, runc exits
  - Shim remains as a daemonless stub to implement the container
  - Allows Docker to be upgraded w/o stopping the container !!!

$Docker client
dockerd
containerd
shim
runc
Namespaces
Capabilities
cgroups
Host Kernel

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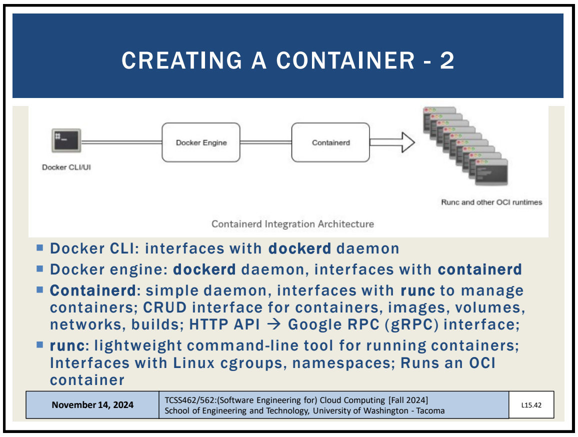

CREATING A CONTAINER - 2

Docker CLI/UI
Docker Engine
Containerd
Runc and other OCI runtimes

Containerd Integration Architecture

- Docker CLI: interfaces with **dockerd** daemon
- Docker engine: **dockerd** daemon, interfaces with **containerd**
- **Containerd**: simple daemon, interfaces with **runc** to manage containers; CRUD interface for containers, images, volumes, networks, builds; HTTP API → Google RPC (gRPC) interface;
- **runc**: lightweight command-line tool for running containers; Interfaces with Linux cgroups, namespaces; Runs an OCI container

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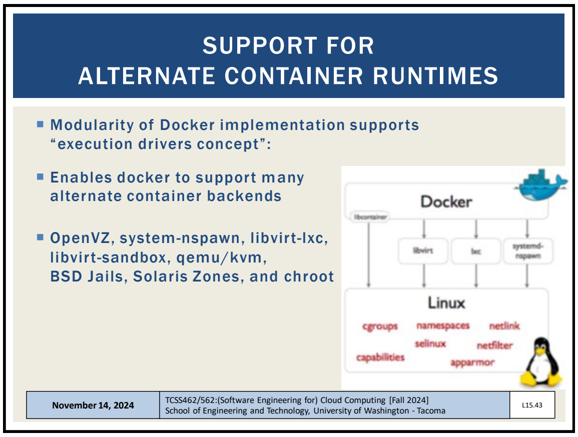

SUPPORT FOR ALTERNATE CONTAINER RUNTIMES

- Modularity of Docker implementation supports "execution drivers concept":
- Enables docker to support many alternate container backends
- OpenVZ, system-nspawn, libvirt-lxc, libvirt-sandbox, qemu/kvm, BSD Jails, Solaris Zones, and chroot

Docker
libcontainer
libvirt
lxc
systemd-nspawn
Linux
cgroups
namespaces
netlink
selinux
netfilter
capabilities
apparmor

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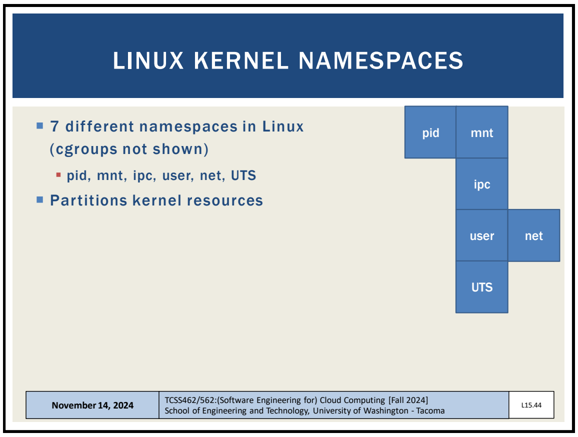

LINUX KERNEL NAMESPACES

- 7 different namespaces in Linux (cgroups not shown)
  - pid, mnt, ipc, user, net, UTS
- Partitions kernel resources

pid
mnt
ipc
user
net
UTS

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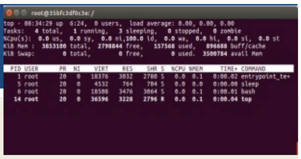
NAMESPACES - 2



```
root@35bfc3df0c3e: /
top - 08:34:29 up  6:24,  0 users,  load average: 0.00, 0.00, 0.00
Tasks:   4 total,   1 running,   3 sleeping,   0 stopped,   0 zombie
%Cpu(s):  0.0 us,  0.0 sy,  0.0 ni,100.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
KiB Mem :  3853100 total,  2798844 free,   157568 used,   896688 buff/cache
KiB Swap:        0 total,        0 free,        0 used.  3500784 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
    1 root      20   0   18376   3032   2780 S   0.0  0.1   0:00.02 entrypoint_te+
    5 root      20   0    4532    704    704 S   0.0  0.0   0:00.00 sleep
    6 root      20   0   18508   3476   3064 S   0.0  0.1   0:00.01 bash
   14 root      20   0   36596   3228   2796 R   0.0  0.1   0:00.04 top
```

- **Provides isolation of OS entities for containers**
- **mnt**: separate filesystems
- **pid**: independent PIDs; first process in container is PID 1
- **ipc**: prevents processes in different IPC namespaces from being able to establish shared memory. Enables processes in different containers to reuse the same identifiers without conflict.
  … provides expected *VM like isolation…*
- **user**: user identification and privilege isolation among separate containers
- net: network stack virtualization. Multiple loopbacks (lo)
- **UTS (UNIX time sharing)**: provides separate host and domain

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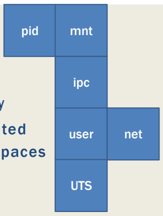
LINUX KERNEL NAMESPACES - 3

- Processes see only their set of resources
- Provides isolation
- Namespaces are hierarchical
- Parent processes can see down the hierarchy
- Each process can only see resources associated with the namespace, and descendent namespaces



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CONTROL GROUPS (CGROUPS)

- Collection of Linux processes
- Group-level resource allocation: *CPU, memory, disk I/O, network I/O*
- **Resource limiting**
  - Memory, disk cache
- **Prioritization**
  - CPU share
  - Disk I/O throughput
- **Accounting**
  - Track resource utilization
  - For resource management and/or billing purposes
- **Control**
  - Pause/resume processes
  - Checkpointing → Checkpoint/Restore in Userspace (CRIU)
  - https://criu.org

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CGROUPS - 2

- Control groups are hierarchical
- Groups inherent limits from parent groups
- Linux has multiple cgroup controllers (subsystems)
- ls /proc/cgroups
- "memory" controller limits memory use
- "cpuacct" controller accounts for CPU usage
- **cgroup filesystem:**
- /sys/fs/cgroup
- Can browse resource utilization of containers…

#subsys_name	hierarchy	num_cgroups	enabled
cpuset	3	2	1
cpu	5	97	1
cpuacct	5	97	1
blkio	8	97	1
memory	9	218	1
devices	6	97	1
freezer	4	2	1
net_cls	2	2	1
perf_event	10	2	1
net_prio	2	2	1
hugetlb	7	2	1
pids	11	98	1

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OVERLAY FILE SYSTEMS

- Docker leverages overlay filesystems
- 1st: AUFS - **A**dvanced multi-layered **u**nification **f**ile**s**ystem
- Now: overlay2
- **Union mount file system**: combine multiple directories into one that appears to contain combined contents
- Idea: Docker uses layered file systems
- Only the top layer is writeable
- Other layers are read-only
- Layers are merged to present the notion of a real file system
- Copy-on-write- implicit sharing
  - Implement duplicate copy
- https://medium.com/@nagarwal/docker-containers-filesystem-demystified-b6ed8112a04a
- https://www.slideshare.net/jpetazzo/scale11x-lxc-talk-1/

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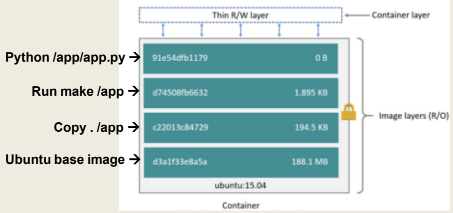
LAYERED FS: BUILDING A CONTAINER

- Dockerfile:

```
FROM ubuntu:18.04
COPY . /app
RUN make /app
CMD python /app/app.py
```



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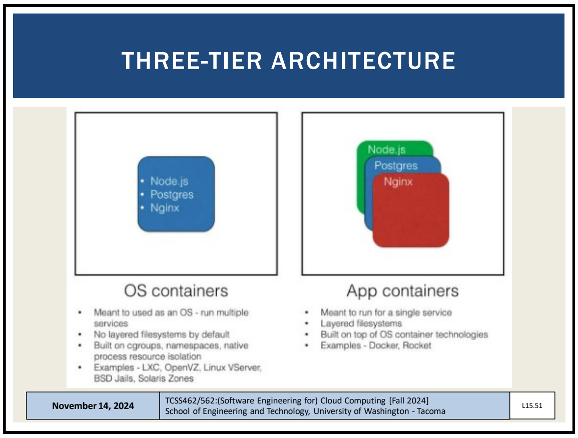


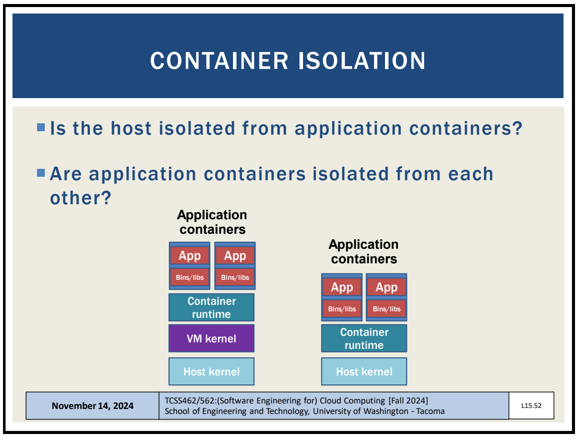
THREE-TIER ARCHITECTURE

OS containers

- Meant to used as an OS - run multiple services
- No layered filesystems by default
- Built on cgroups, namespaces, native process resource isolation
- Examples - LXC, OpenVZ, Linux VServer, BSD Jails, Solaris Zones

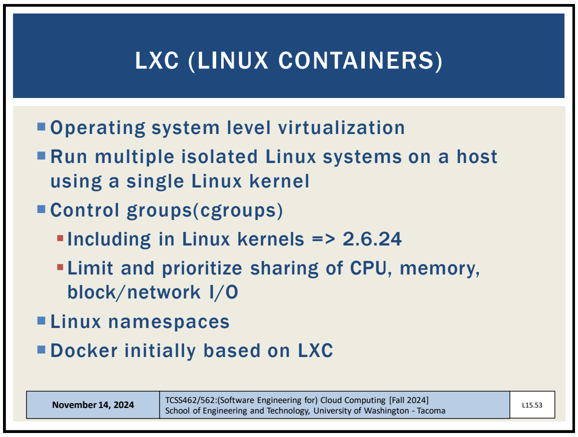
App containers

- Meant to run for a single service
- Layered filesystems
- Built on top of OS container technologies
- Examples - Docker, Rocket



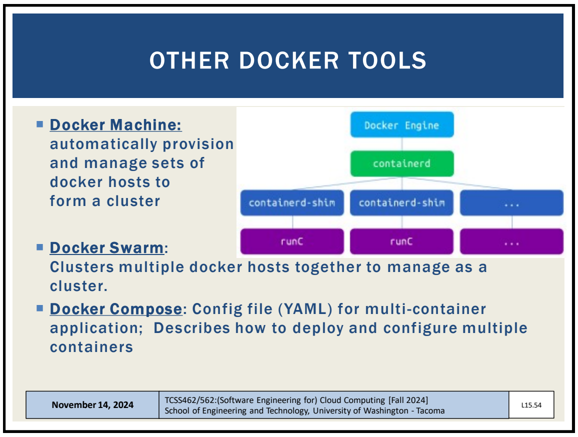
CONTAINER ISOLATION

- Is the host isolated from application containers?
- Are application containers isolated from each other?



LXC (LINUX CONTAINERS)

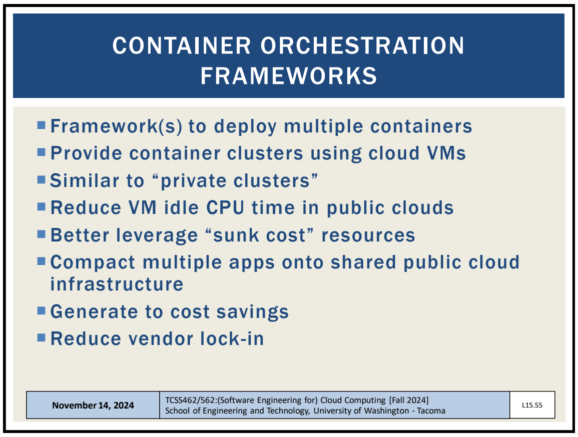
- Operating system level virtualization
- Run multiple isolated Linux systems on a host using a single Linux kernel
- Control groups(cgroups)
  - Including in Linux kernels => 2.6.24
  - Limit and prioritize sharing of CPU, memory, block/network I/O
- Linux namespaces
- Docker initially based on LXC



OTHER DOCKER TOOLS

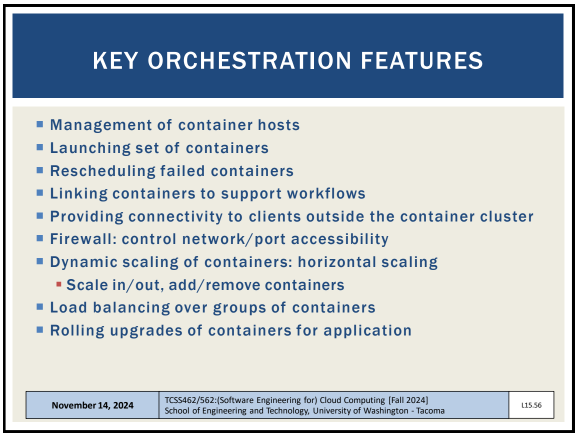
- **Docker Machine:** automatically provision and manage sets of docker hosts to form a cluster

- **Docker Swarm**: Clusters multiple docker hosts together to manage as a cluster.
- **Docker Compose**: Config file (YAML) for multi-container application; Describes how to deploy and configure multiple containers



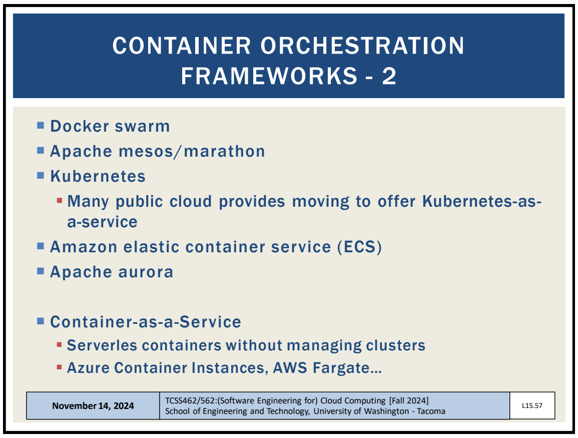
CONTAINER ORCHESTRATION FRAMEWORKS

- Framework(s) to deploy multiple containers
- Provide container clusters using cloud VMs
- Similar to “private clusters”
- Reduce VM idle CPU time in public clouds
- Better leverage “sunk cost” resources
- Compact multiple apps onto shared public cloud infrastructure
- Generate to cost savings
- Reduce vendor lock-in



KEY ORCHESTRATION FEATURES

- Management of container hosts
- Launching set of containers
- Rescheduling failed containers
- Linking containers to support workflows
- Providing connectivity to clients outside the container cluster
- Firewall: control network/port accessibility
- Dynamic scaling of containers: horizontal scaling
  - Scale in/out, add/remove containers
- Load balancing over groups of containers
- Rolling upgrades of containers for application



CONTAINER ORCHESTRATION FRAMEWORKS - 2

- Docker swarm
- Apache mesos/marathon
- Kubernetes
  - Many public cloud provides moving to offer Kubernetes-as-a-service
- Amazon elastic container service (ECS)
- Apache aurora

- Container-as-a-Service
  - Serverles containers without managing clusters
  - Azure Container Instances, AWS Fargate…

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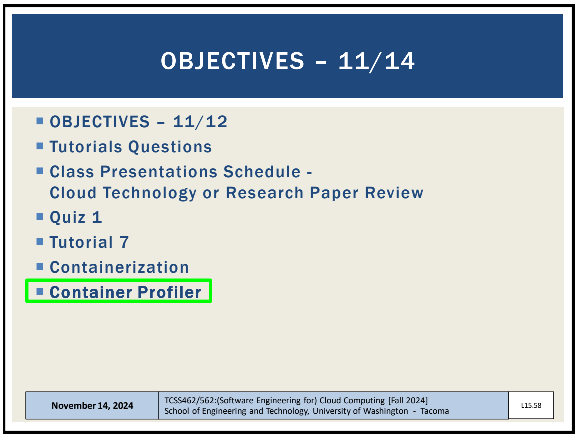

OBJECTIVES – 11/14

- OBJECTIVES – 11/12
- Tutorials Questions
- Class Presentations Schedule - Cloud Technology or Research Paper Review
- Quiz 1
- Tutorial 7
- Containerization
- Container Profiler

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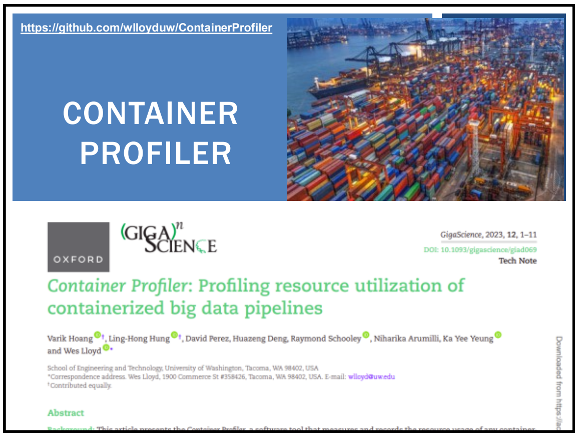

https://github.com/wlloyduw/ContainerProfiler

CONTAINER PROFILER

OXFORD (GIGA)^n SCIENCE

GigaScience, 2023, 12, 1–11
DOI: 10.1093/gigascience/giad069
Tech Note

Container Profiler: Profiling resource utilization of containerized big data pipelines

Varik Hoang†, Ling-Hong Hung†, David Perez, Huazeng Deng, Raymond Schooley, Niharika Arumilli, Ka Yee Yeung and Wes Lloyd*

School of Engineering and Technology, University of Washington, Tacoma, WA 98402, USA
*Correspondence address. Wes Lloyd, 1900 Commerce St #358426, Tacoma, WA 98402, USA. E-mail: wlloyd@uw.edu
†Contributed equally.

Abstract

Background: This article presents the Container Profiler, a software tool that measures and records the resource usage of any container

Downloaded from https://ac

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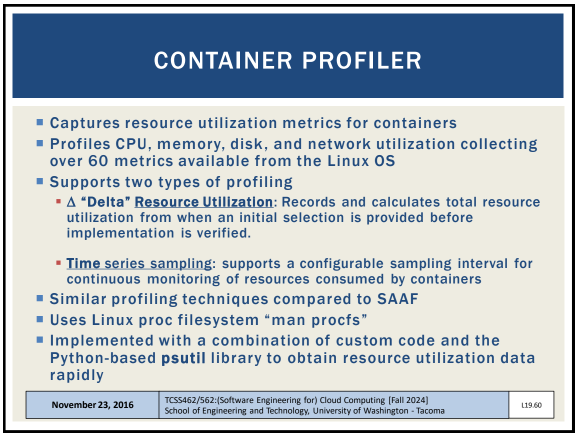

CONTAINER PROFILER

- Captures resource utilization metrics for containers
- Profiles CPU, memory, disk, and network utilization collecting over 60 metrics available from the Linux OS
- Supports two types of profiling
  - Δ "Delta" Resource Utilization: Records and calculates total resource utilization from when an initial selection is provided before implementation is verified.
  - Time series sampling: supports a configurable sampling interval for continuous monitoring of resources consumed by containers
- Similar profiling techniques compared to SAAF
- Uses Linux proc filesystem "man procfs"
- Implemented with a combination of custom code and the Python-based **psutil** library to obtain resource utilization data rapidly

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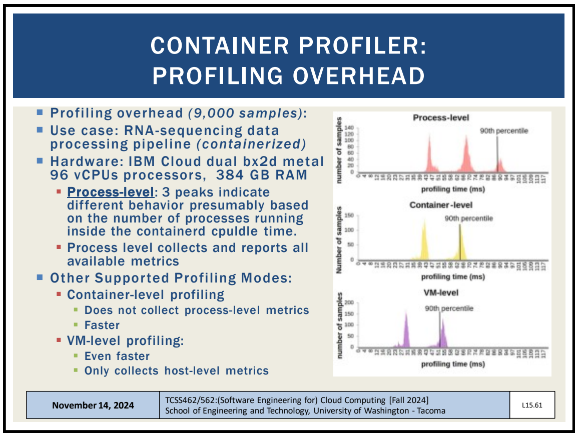

CONTAINER PROFILER: PROFILING OVERHEAD

- Profiling overhead *(9,000 samples)*:
- Use case: RNA-sequencing data processing pipeline *(containerized)*
- Hardware: IBM Cloud dual bx2d metal 96 vCPUs processors, 384 GB RAM
  - Process-level: 3 peaks indicate different behavior presumably based on the number of processes running inside the containerd cpuldle time.
  - Process level collects and reports all available metrics
- Other Supported Profiling Modes:
  - Container-level profiling
    - Does not collect process-level metrics
    - Faster
  - VM-level profiling:
    - Even faster
    - Only collects host-level metrics

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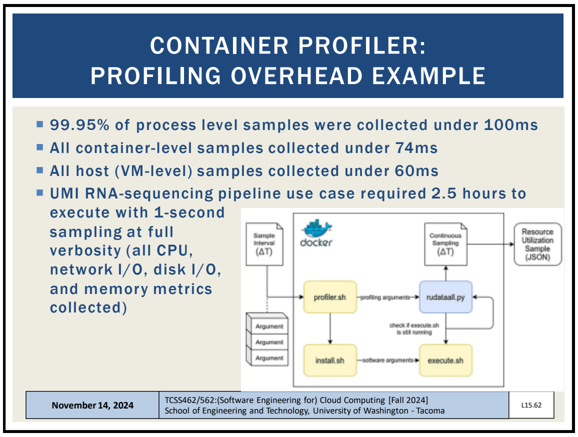

CONTAINER PROFILER: PROFILING OVERHEAD EXAMPLE

- 99.95% of process level samples were collected under 100ms
- All container-level samples collected under 74ms
- All host (VM-level) samples collected under 60ms
- UMI RNA-sequencing pipeline use case required 2.5 hours to execute with 1-second sampling at full verbosity (all CPU, network I/O, disk I/O, and memory metrics collected)

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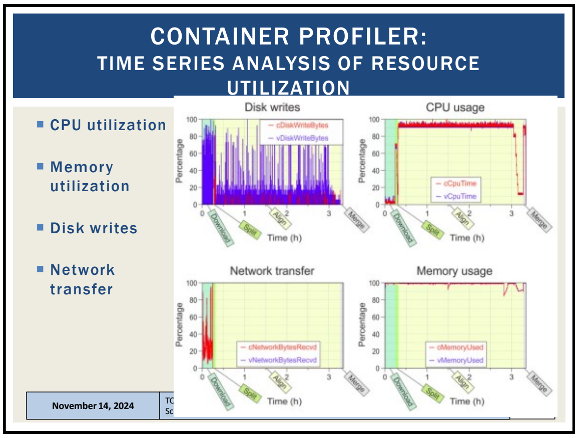

CONTAINER PROFILER: TIME SERIES ANALYSIS OF RESOURCE UTILIZATION

- CPU utilization
- Memory utilization
- Disk writes
- Network transfer

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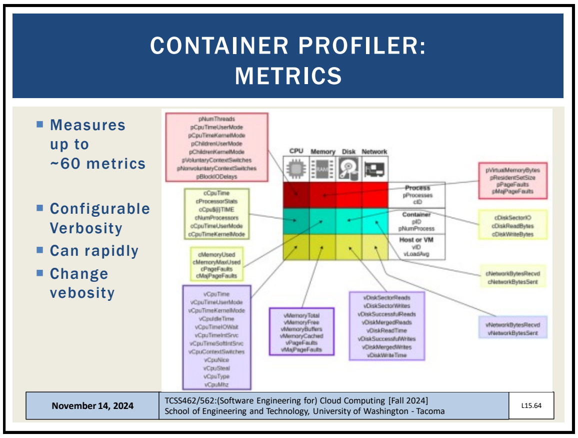

CONTAINER PROFILER: METRICS

- Measures up to ~60 metrics
- Configurable Verbosity
- Can rapidly
- Change vebosity

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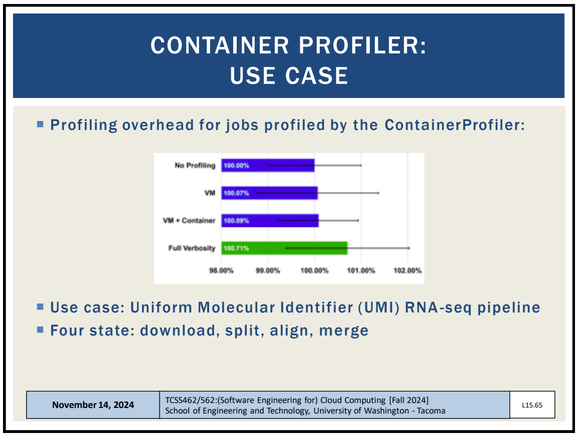

CONTAINER PROFILER: USE CASE

- Profiling overhead for jobs profiled by the ContainerProfiler:

- Use case: Uniform Molecular Identifier (UMI) RNA-seq pipeline
- Four state: download, split, align, merge

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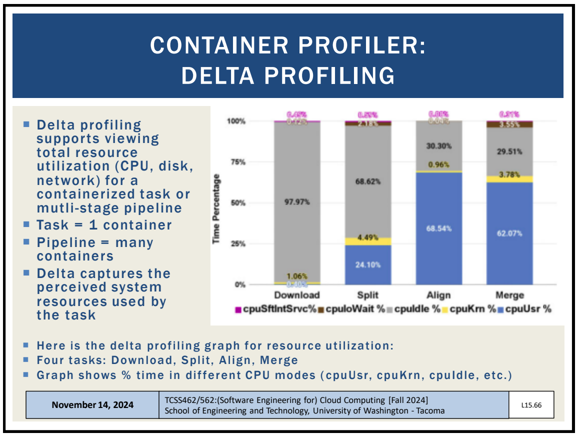

CONTAINER PROFILER: DELTA PROFILING

- Delta profiling supports viewing total resource utilization (CPU, disk, network) for a containerized task or mutli-stage pipeline
- Task = 1 container
- Pipeline = many containers
- Delta captures the perceived system resources used by the task

- Here is the delta profiling graph for resource utilization:
- Four tasks: Download, Split, Align, Merge
- Graph shows % time in different CPU modes (cpuUsr, cpuKrn, cpuIdle, etc.)

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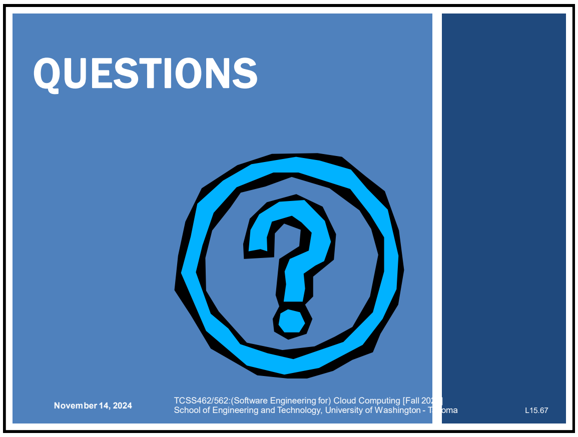

QUESTIONS

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