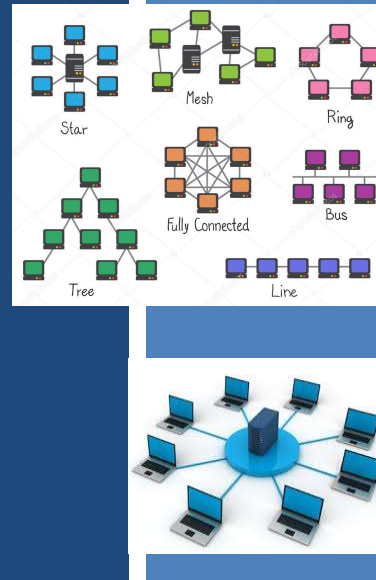


TCSS 558: APPLIED DISTRIBUTED COMPUTING

Processes: Threads & Virtualization, Clients & Servers

Wes J. Lloyd
School of Engineering
& Technology (SET)
University of Washington - Tacoma



OBJECTIVES - 2/4

- **Questions from 1/28**
- **Assignment 1: Key/Value Store**
 - Java Maven project template files posted
- **Midterm Thursday February 11**
 - 2nd hour - Tuesday February 9 - practice midterm questions
- **Chapter 3: Processes**
 - Chapter 3.1: Threads
 - Threading Models
 - Multithreaded clients/servers
 - Chapter 3.2: Virtualization
 - Chapter 3.3: Clients
 - Chapter 3.4: Servers

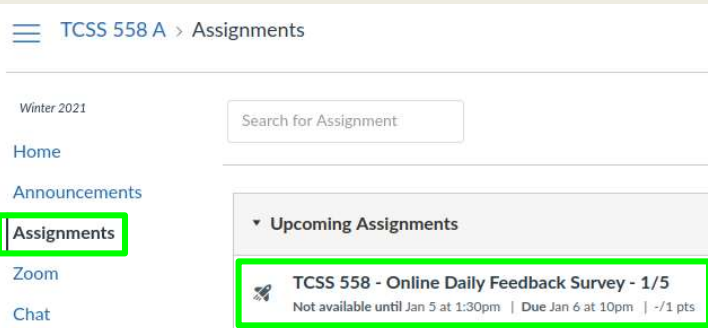
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.2

ONLINE DAILY FEEDBACK SURVEY

- Daily Feedback Quiz in Canvas – Available After Each Class
- Extra credit available for completing surveys **ON TIME**
- Tuesday surveys: due by ~ Wed @ 10p
- Thursday surveys: due ~ Mon @ 10p



TCSS 558 A > Assignments

Winter 2021

Home

Announcements

Assignments

Zoom

Chat

▼ Upcoming Assignments

TCSS 558 - Online Daily Feedback Survey - 1/5
Not available until Jan 5 at 1:30pm | Due Jan 6 at 10pm | -1 pts

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.3
------------------	---	------

SURVEY QUESTIONS

- Survey has two questions:
- Be sure to add your questions about the previous class to the **second question**
- **1st question:** After today's class, comment on any new concepts that you learned about?
 - *Have been getting questions here...*
- **2nd question:** After today's class, what point(s) remain least clear to you?
 - **>> Please add questions HERE**

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.4
------------------	---	------

TCCS 558 - Online Daily Feedback Survey - 1/5

Due Jan 6 at 10pm Points 1 Questions 4
Available Jan 5 at 1:30pm - Jan 6 at 11:59pm 1 day Time Limit None

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 Review To Me				Equal New and Review					Mostly 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

February 4, 2021 TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma L9.5

MATERIAL / PACE

- Please classify your perspective on material covered in today's class (23 respondents):
 - 1-mostly review, 5-equal new/review, 10-mostly new
 - **Average - 6.22** (↓ - *previous 7.29*)

- Please rate the pace of today's class:
 - 1-slow, 5-just right, 10-fast
 - **Average - 5.74** (↓ - *previous 5.81*)

February 4, 2021 TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma L9.6

FEEDBACK FROM 1/28

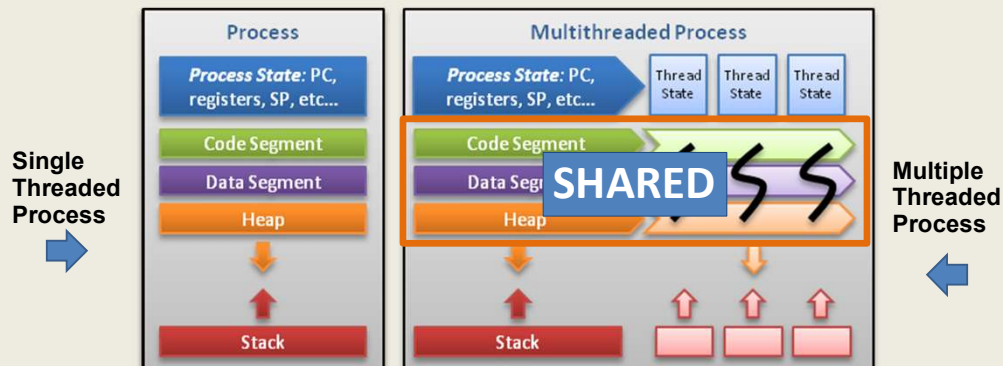
- **QUESTIONS on Processes vs. Threads:**
- *I am confused on process and thread. You went by that part really fast. Would you explain a bit more?*
- *Also: What Process and Thread are, and the difference between them*

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.7

PROCESSES VS. THREADS



©Alfred Park, <http://randu.org/tutorials/threads>

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.8

THREADS - 2

- Enables a single process (program) to have multiple “workers”
 - This supports parallel programming...
 - Threads share the program's memory
 - Programmer must coordinate shared memory access
- Supports independent path(s) of execution within a program *with shared memory* **at the same time** ...
- Each thread has its own Thread Control Block (TCB)
 - PC, registers, SP, and stack
- Threads share code segment, memory, and heap are *shared*

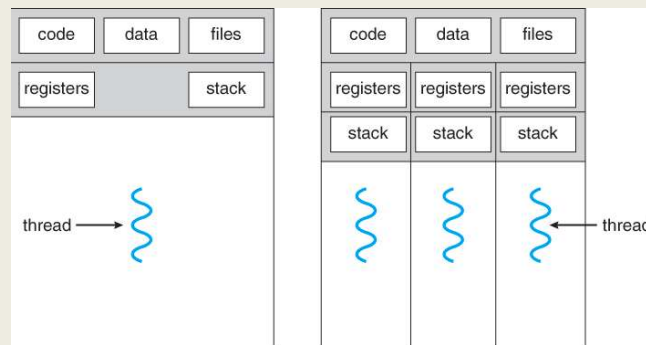
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.9

PROCESS AND THREAD METADATA

- Creating threads (*light-weight*) in the OS is typically faster than creating processes (*heavy-weight*)
- Creating a thread only requires creating a stack and creating a data structure to track thread stated



single-threaded process

multithreaded process

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.10

PROCESSES VS THREADS

- **What is an embarrassingly parallel program?**
 - Program that runs several threads in parallel (at the same time) that works on a problem, where each thread runs independently without any coordination/communication with other threads
 - The parallel tasks doesn't involve any shared data
 - These are MAP REDUCE style problems
- **For further review:**
- See *UC Berkeley Lecture on OS, Processes, Threads (CS 162)*
- <https://youtu.be/KRenWKpfGo4?t=1471>

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.11

FEEDBACK - 2

- **It would be of great help if you could provide an overview of the steps in the assignment and what we hope to achieve through it. It would help us understand the assignment a bit more.**
- Which assignment ?
- Assignment 0 ?
- We will next review assignment 0
- For assignment 1, please submit questions
- I'm happy to provide a "big picture" discussion on the assignment objectives after class, or in office hours
 - *Can also schedule an appointment*

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.12

ASSIGNMENT 0 REVIEW

- *I had some follow-up questions regarding Assignment 0.*
- *I have completed the assignment but few points remained unclear to me.*
- Config #3 has 3 different containers so can we track from which container the response we are getting during a test run for config #3?
 - Tracking which container runs the request is not the goal
 - The idea with haproxy is to **load balance** requests across more vCPUs
 - With testFibPar.sh we orchestrate 10 runs in parallel
 - For config #1 and #2 we load balance 10 requests across 3 containers running on the same VM (c5.large) with 2 vCPU cores and 4 GB of ram: 10 requests / 2 vCPUs = 5 requests / vCPU
 - The VM is **overprovisioned** !
 - The performance we measure for config #1/#2 is not optimal

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.13

ASSIGNMENT 0 REVIEW - 2

- Config #1 and Config #2 run 10 requests across 2 vCPUs
- Each Fibonacci request requires 100% access to 1 vCPU
- Config #1/#2: each vCPU timeshares 5 requests
 - Performance may be only 20% of optimal
- Config #3 runs 10 requests across 3 VMs with 2 vCPUs
 - Config #3 has access to 6 vCPUs
 - Each vCPU will run just 10 requests / 6 vCPUs = 1.667 requests/vCPU
 - This is far better than 5 requests, but still not optimal
- The motivation for using Config #3 vs #1/#2 is performance
- *How many c5.large VMs are required for optimal performance?*

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.14

ASSIGNMENT 0 REVIEW - 3

- What about config #2?
- Config #1, doesn't restrict the container's access to the VM's CPUs
- The Linux CPU scheduler tries to schedule 10 fibonacci service requests on 2 vCPU cores
- In config #2, we apply a vCPU limit
 - Each container is only allowed 0.66% of 1 vCPU
 - This way the VM with 3 containers only uses 2 vCPUs
 - **PROBLEM:** there are now 10 requests sent to 3 containers where each container has 0.66 vCPUs
 - Config #2 PROVISIONING RATIO: $3.33 \text{ requests} / 0.66 \text{ vCPUs} = 5.05$
 - Config #1 PROVISIONING RATIO: $10 \text{ requests} / 2 \text{ vCPUs} = 5.00$
 - **Config #1 and #2 are essentially the same**
- **Question: what is the effect of "restricting CPU time" for the container?**

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.15

OBJECTIVES - 2/4

- Questions from 1/28
- **Assignment 1: Key/Value Store**
 - **Java Maven project template files posted**
- Midterm Thursday February 11
 - 2nd hour - Tuesday February 9 - practice midterm questions
- Chapter 3: Processes
 - Chapter 3.1: Threads
 - Threading Models
 - Multithreaded clients/servers
 - Chapter 3.2: Virtualization
 - Chapter 3.3: Clients
 - Chapter 3.4: Servers

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.16

ASSIGNMENT 1

- TCP/UDP/RMI Key Value Store
- Implement a “GenericNode” project which assumes the role of a client or server for a Key/Value Store
- Recommended in Java (11 or 8)
- Client node program interacts with server node to put, get, delete, or list items in a key/value store

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.17

OBJECTIVES – 2/4

- Questions from 1/28
- Assignment 1: Key/Value Store
 - Java Maven project template files posted
- Midterm Thursday February 11
 - 2nd hour - Tuesday February 9 – practice midterm questions
- Chapter 3: Processes
 - Chapter 3.1: Threads
 - Threading Models
 - Multithreaded clients/servers
 - Chapter 3.2: Virtualization
 - Chapter 3.3: Clients
 - Chapter 3.4: Servers

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.18

OBJECTIVES - 2/4

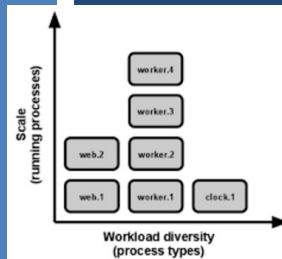
- Questions from 1/28
- Assignment 1: Key/Value Store
 - Java Maven project template files posted
- Midterm Thursday February 11
 - 2nd hour - Tuesday February 9 - practice midterm questions
- Chapter 3: Processes
 - Chapter 3.1: Threads
 - **Threading Models**
 - Multithreaded clients/servers
 - Chapter 3.2: Virtualization
 - Chapter 3.3: Clients
 - Chapter 3.4: Servers

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.19

CH. 3: PROCESSES CH. 3.1: THREADS



L9.20

THREADING MODELS

- **Many-to-one threading:** multiple user-level threads per process
- Thread operations (create, delete, locks) run in user mode
- Multithreaded process mapped to single schedulable entity
- Only run thread per process runs at any given time
- Key take-away: thread management handled by user processes

- **What are some advantages of many-to-one threading?**

- **What are some disadvantages?**

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.21

THREADING MODELS - 2

- **One-to-one threading:** use of separate kernel threads for each user process - also called **kernel-level threads**
- The kernel API calls (e.g. I/O, locking) are farmed out to an existing kernel level thread

- Thread operations (create, delete, locks) run in kernel mode
- Threads scheduled individually by the OS
- System calls required, context switches as expensive as process context switching
- Idea is to have preinitialized kernel threads for user processes
- Linux uses this model...

- **What are some advantages of one-to-one threading?**

- **What are some disadvantages?**

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.22

APPLICATION EXAMPLES

- Google chrome: processes
- Apache tomcat webserver: threads
- Multiprocess programming avoids synchronization of concurrent access to shared data, by providing coordination and data sharing via interprocess communication (IPC)
- Each process maintains its own private memory
- While this approach avoids synchronizing concurrent access to shared memory, what is the tradeoff(s) ??
 - Replication instead of synchronization - must synchronize multiple copies of the data
- Do distributed objects share memory?

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.23

OBJECTIVES - 2/4

- Questions from 1/28
- Assignment 1: Key/Value Store
 - Java Maven project template files posted
- Midterm Thursday February 11
 - 2nd hour - Tuesday February 9 - practice midterm questions
- Chapter 3: Processes
 - Chapter 3.1: Threads
 - Threading Models
 - **Multithreaded clients/servers**
 - Chapter 3.2: Virtualization
 - Chapter 3.3: Clients
 - Chapter 3.4: Servers

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.24

MULTITHREADED CLIENTS

- Web browser
- Uses threads to load and render portions of a web page to the user in parallel
- A client could have dozens of concurrent connections all loading in parallel

- testFibPar.sh
- Assignment 0 client script (GNU parallel)

- Important benefits:
- Several connections can be opened simultaneously
- Client: dozens of concurrent connections to the webserver all loading data in parallel

February 4, 2021

TCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.25

MULTIPLE THREADS

- In Linux, threads also receive a process ID (PID)
- To display threads of a process in Linux:

- Identify parent process explicitly:

- `top -H -p <pid>`
- `htop -p <pid>`
- `ps -iT <pid>`

- Virtualbox process ~ 44 threads
- No mapping to guest # of processes/threads

February 4, 2021

TCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.26

PROCESS METRICS

CPU

- cpuUsr: CPU time in user mode
- cpuKrn: CPU time in kernel mode
- cpuIdle: CPU idle time
- cpuIoWait: CPU time waiting for I/O
- cpuIntSrvc: CPU time serving interrupts
- cpuSftIntSrvc: CPU time serving soft interrupts
- cpuNice: CPU time executing prioritized processes
- cpuSteal: CPU ticks lost to virtualized guests
- contextsw: # of context switches
- loadavg: (avg # proc / 60 secs)

Disk

- dsr: disk sector reads
- dsreads: disk sector reads completed
- drm: merged adjacent disk reads
- readtime: time spent reading from disk
- dsw: disk sector writes
- dswrites: disk sector writes completed
- dwm: merged adjacent disk writes
- writetime: time spent writing to disk

Network

- nbs: network bytes sent
- nbr: network bytes received

LOAD AVERAGE

- Reported by: `top`, `htop`, `w`, `uptime`, and `/proc/loadavg`
- Updated every 5 seconds
- Average number of processes using or waiting for the CPU
- Three numbers show exponentially decaying usage for 1 minute, 5 minutes, and 15 minutes
- One minute average: exponentially decaying average
- Load average = $1 \cdot (\text{avg last minute load}) - 1/e \cdot (\text{avg load since boot})$

- 1.0 = 1-CPU core fully loaded
- 2.0 = 2-CPU cores
- 3.0 = 3-CPU cores . . .

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.28
------------------	---	-------

THREAD-LEVEL PARALLELISM

- Metric – measures degree of parallelism realized by running system, by calculating average utilization:

$$TLP = \frac{\sum_{i=1}^N i \cdot c_i}{1 - c_0}$$

- C_i – fraction of time that exactly i threads are executed
- N – maximum threads that can execute at any one time
- Web browsers found to have TLP from 1.5 to 2.5
- Clients for web browsing can utilize from 2 to 3 CPU cores
- Any more cores are redundant, and potentially wasteful
- **Measure TLP to understand how many CPUs to provision**

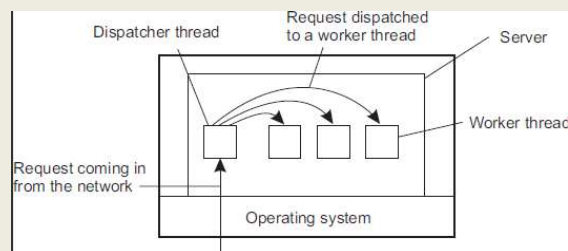
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.29

MULTITHREADED SERVERS

- Multiple threads essential for servers in distributed systems
- Even on single-core machines greatly improves performance
- Take advantage of idle/blocking time
- Two designs:
 - Generate new thread for every request
 - Thread pool – pre-initialize set of threads to service requests



February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.30

SINGLE THREAD & FSM SERVERS

- **Single thread server**
 - A single thread handles all client requests
 - **BLOCKS** for I/O
 - All waiting requests are queued until thread is available
- **Finite state machine**
 - Server has a single thread of execution
 - I/O performing asynchronously (non-BLOCKing)
 - Server handles other requests while waiting for I/O
 - Interrupt fired with I/O completes
 - Single thread “jumps” back into context to finish request

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.31

SERVER DESIGN ALTERNATIVES

- A blocking system call implies that a thread servicing a request synchronously performs I/O
- The thread **BLOCKS** to wait on disk/network I/O before proceeding with request processing
- Consider the implications of these designs for responsiveness, availability, scalability. . .

Model	Characteristics
Multithreading	Parallelism, blocking I/O
Single-thread	No parallelism, blocking I/O
Finite-state machine	Parallelism, non-blocking I/O

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.32

OBJECTIVES – 2/4

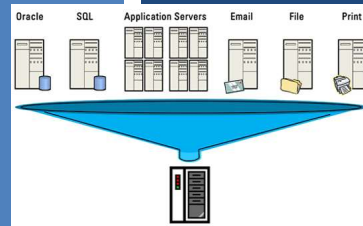
- Questions from 1/28
- Assignment 1: Key/Value Store
 - Java Maven project template files posted
- Midterm Thursday February 11
 - 2nd hour - Tuesday February 9 – practice midterm questions
- Chapter 3: Processes
 - Chapter 3.1: Threads
 - Threading Models
 - Multithreaded clients/servers
 - **Chapter 3.2: Virtualization**
 - Chapter 3.3: Clients
 - Chapter 3.4: Servers

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.33

CH. 3.2: VIRTUALIZATION



L9.34

VIRTUALIZATION



- Initially introduced in the 1970s on IBM mainframe computers
- Legacy operating systems run in mainframe-based VMs
- Legacy software could be sustained by virtualizing legacy OSES
- 1970s virtualization went away as desktop/rack-based hardware became inexpensive
- Virtualization reappears in 2000s to leverage multi-core, multi-CPU processor systems
- VM-Ware virtual machines enable companies to host many virtual servers with mixed OSES on private clusters
- Cloud computing: Amazon offers VMs as-a-service (IaaS)

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

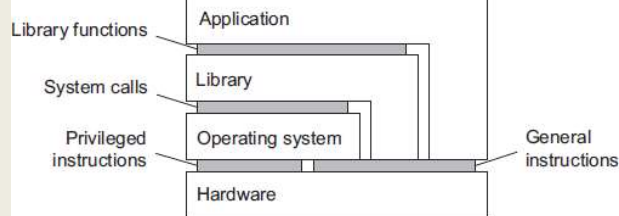
L9.35

TYPES OF VIRTUALIZATION

▪ Levels of Instructions:

▪ Hardware: CPU

- Privileged instructions
KERNEL MODE
- General instructions
USER MODE



▪ Operating system: system calls

▪ Library: programming APIs: e.g. C/C++, C#, Java libraries

▪ Application:

▪ Goal of virtualization:

mimic these interface to provide a virtual computer

February 4, 2021

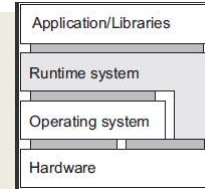
TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.36

TYPES OF VIRTUALIZATION - 2

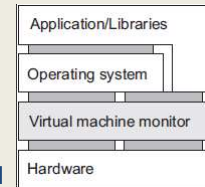
■ Process virtual machine

- Interpret instructions: (interpreters)
(JavaVM) byte code → HW instructions
- Emulate instructions: (emulators)
(Wine) windows code → Linux code



■ Native virtual machine monitor (VMM)

- Hypervisor (XEN): small OS with its own kernel
- Provides an interface for multiple guest OSES
- Facilitates sharing/scheduling of CPU, device I/O among many guests
- Guest OSES require special kernel to interface w/ VMM
- Supports Paravirtualization for performance boost to run code directly on the CPU
- Type 1 hypervisor



February 4, 2021

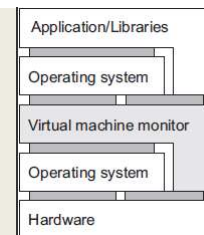
TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.37

TYPES OF VIRTUALIZATION - 3

■ Hosted virtual machine monitor (VMM)

- Runs atop of hosted operating system
- Uses host OS facilities for CPU scheduling, I/O
- Full virtualization
- Type 2 hypervisor
- Virtualbox



- *Textbook: note 3.5 – good explanation of full vs. paravirtualization*
- **GOAL:** run all user mode instructions directly on the CPU
- x86 instruction set has ~17 privileged user mode instructions
- **Full virtualization:** scan the EXE, insert code around privileged instructions to divert control to the VMM
- **Paravirtualization:** special OS kernel eliminates side effects of privileged instructions

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.38

EVOLUTION OF AWS VIRTUALIZATION

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

AWS EC2 Virtualization Types

VS:
Virtualization
In software

P:
Paravirtual

VH:
Virtualization
In Hardware

H:
Hardware

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

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

February 4, 2021

TCS558: Applied Distributed Computing [Winter 2021]
 School of Engineering and Technology, University of Washington - Tacoma

L9.39

AWS VIRTUALIZATION - 2

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

February 4, 2021

TCS558: Applied Distributed Computing [Winter 2021]
 School of Engineering and Technology, University of Washington - Tacoma

L9.40

AWS VIRTUALIZATION - 3

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

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.41

AWS VIRTUALIZATION - 4

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

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.42


**WE WILL RETURN AT
2:50PM**



OBJECTIVES – 2/4

- Questions from 1/28
- Assignment 1: Key/Value Store
 - Java Maven project template files posted
- Midterm Thursday February 11
 - 2nd hour - Tuesday February 9 – practice midterm questions
- Chapter 3: Processes
 - Chapter 3.1: Threads
 - Threading Models
 - Multithreaded clients/servers
 - Chapter 3.2: Virtualization
 - Chapter 3.3: Clients
 - Chapter 3.4: Servers

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.44
------------------	---	-------



CH. 3.3: CLIENTS

L9.45

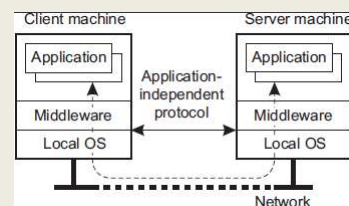
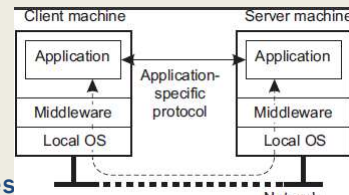
TYPES OF CLIENTS

- **Thick clients**
 - **Web browsers**
 - Client-side scripting
 - **Mobile apps**
 - **Multi-tier MVC apps**
- **Thin clients**
 - **Remote desktops/GUIs (very thin)**

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.46
------------------	---	-------

CLIENTS

- **Application specific protocol**
 - Thick clients
 - Clients maintain local data
 - Middleware (APIs)
 - Clients synchronize data with remote nodes
 - Example: shared calendar application
- **Application independent**
 - Thin clients
 - Client acts as a remote terminal
 - Provides interface to user (GUI / UI)
 - Server houses entire application stack



February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.47

X WINDOWS

- Layered architecture to transport UI over network
- Remote desktop functionality for Linux/Unix systems
- X kernel acts as a server
 - Provides the **X protocol**: application level protocol
 - Xlib instances (client applications) exchange data and events with X kernels (servers)
 - Clients and servers on single machine → Linux GUI
 - Client and server communication transported over the network → remote Linux GUI

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.48

X WINDOWS - 2

- **Window manager:**
 - Application running atop of X-windows which provides flair
 - Many variants
 - Without X windows is quite bland

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
 School of Engineering and Technology, University of Washington - Tacoma

L9.49

- **Layered architecture**
- **X-kernel: low level interface/APIs for controlling screen, capturing keyboard and mouse events (X window Server)**
- **Provided on Linux as Xlib**
- **Provides network enabled GUI**
- **Layering allows for use for custom window managers**

Application Clients - User Productivity
 OpenOffice.org, Firefox, Gimp

Desktop Environment - Application and File Management
 Gnome/KDE panels, desktop icon managers

Window and Compositing Manager - Placement and Controls Of Windows
 Compiz, Metacity, kwin

Session Manager
 gnome-session, ksmserver

Display Manager - Local X Server Startup and User Authentication
 gdm, kdm, xdm

X Window Server - Display Hardware Management
 Xorg

Network Transports - Client -Server Connections
 TCP/IP, Unix domain sockets

Toolkits
 GTK, Qt, Motif, Xaw

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
 School of Engineering and Technology, University of Washington - Tacoma

L9.50

EXAMPLE: VNC SERVER

- [How to Install VNC server on Ubuntu EC2 instance VM:](#)
- `sudo apt-get update`

- `# ubuntu 16.04`
- `sudo apt-get install ubuntu-desktop`
- `sudo apt-get install gnome-panel gnome-settings-daemon metacity nautilus gnome-terminal`

- `# on ubuntu 18.04`
- `sudo apt install xfce4 xfce4-goodies`

- `sudo apt-get install tightvncserver # both`

- **Start VNC server to create initial config file**
- `vncserver :1`

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.51

EXAMPLE: VNC SERVER – UBUNTU 16.04

- [On the VM:](#) edit config file: `nano ~/.vnc/xstartup`
- **Replace contents as below (Ubuntu 16.04):**

```
#!/bin/sh

export XKL_XMODMAP_DISABLE=1
unset SESSION_MANAGER
unset DBUS_SESSION_BUS_ADDRESS

[ -x /etc/vnc/xstartup ] && exec /etc/vnc/xstartup
[ -r $HOME/.Xresources ] && xrdb $HOME/.Xresources
xsetroot -solid grey

vncconfig -iconic &
gnome-panel &
gnome-settings-daemon &
metacity &
nautilus &
gnome-terminal &
```

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.52

EXAMPLE: VNC SERVER - UBUNTU 18.04

- On the VM:
- Edit config file: `nano ~/.vnc/xstartup`
- Replace contents as below (Ubuntu 18.04):

```
#!/bin/bash
xrdb $HOME/.Xresources
startxfce4 &
```

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.53

VNC SERVER - UBUNTU 20.04 - GNOME

```
# install vnc server
sudo apt install tigervnc-standalone-server
Sudo apt install ubuntu-gnome-desktop
vncserver :1          # creates a config file
vncserver -kill :1   # stop server
vi ~/.vnc/xstartup   # edit config file

#!/bin/sh
# Start Gnome 3 Desktop
[ -x /etc/vnc/xstartup ] && exec /etc/vnc/xstartup
[ -r $HOME/.Xresources ] && xrdb $HOME/.Xresources
vncconfig -iconic &
dbus-launch --exit-with-session gnome-session &

sudo systemctl start gdm          # start gnome desktop
sudo systemctl enable gdm
vncserver :1                       # restart vnc server
```

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.54

EXAMPLE: VNC SERVER - 3

- On the VM: reload config by restarting server
 - `vncserver -kill :1`
 - `vncserver :1`
-
- Open port 22 & 5901 in EC2 security group:

Type	Protocol	Port Range	Source
SSH	TCP	22	Anywhere 0.0.0.0
Custom TCP Rule	TCP	5901	Anywhere 0.0.0.0

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.55

EXAMPLE: VNC CLIENT

- On the client (e.g. laptop):
- Create SSH connection to securely forward port 5901 on the EC2 instance to your localhost port 5901
- This way your VNC client doesn't need an SSH key

```
ssh -i <ssh-keyfile> -L 5901:127.0.0.1:5901 -N  
-f -l <username> <EC2-instance ip_address>
```

- For example:

```
ssh -i mykey.pem -L 5901:127.0.0.1:5901 -N -f -  
l ubuntu 52.111.202.44
```

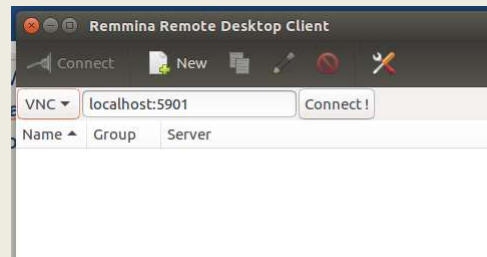
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.56

EXAMPLE: VNC CLIENT - 2

- On the client (e.g. laptop):
- Use a VNC Client to connect
- Remmina is provided by default on Ubuntu 16.04
- Can “google” for many others
- Remmina login:
- Chose “VNC” protocol
- Log into “localhost:5901”



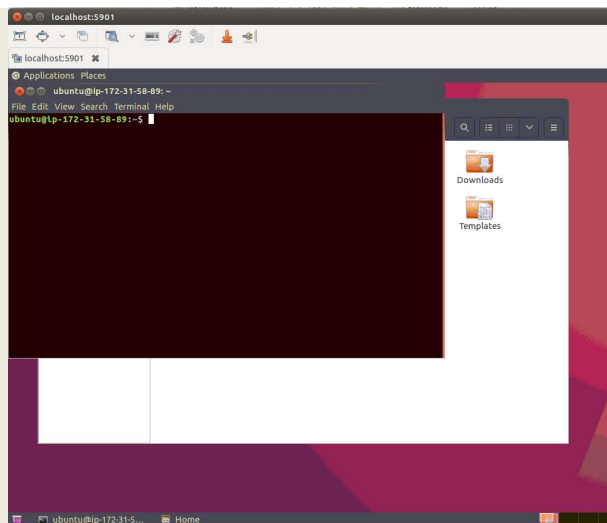
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.57

REMOTE COMPUTER IN THE CLOUD

- EC2 instance
with a GUI. . .!!!



February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.58

THIN CLIENTS

- **Thin clients**
 - **X windows protocol**
 - **A variety of other remote desktop protocols exist:**

Remote desktop protocols include the following:

- Apple Remote Desktop Protocol (ARD) – Original protocol for Apple Remote Desktop on macOS machines.
- Appliance Link Protocol (ALP) – a Sun Microsystems-specific protocol featuring audio (play and record), remote printing, remote USB, accelerated video
- HP Remote Graphics Software (RGS) – a proprietary protocol designed by Hewlett-Packard specifically for high end workstation remoting and collaboration.
- Independent Computing Architecture (ICA) – a proprietary protocol designed by Citrix Systems
- NX technology (NoMachine NX) – Cross platform protocol featuring audio, video, remote printing, remote USB, H264-enabled.
- PC-over-IP (PCoIP) – a proprietary protocol used by VMware (licensed from Teradici)^[2]
- Remote Desktop Protocol (RDP) – a Windows-specific protocol featuring audio and remote printing
- Remote Frame Buffer Protocol (RFB) – A framebuffer level cross-platform protocol that VNC is based on.
- SPICE (Simple Protocol for Independent Computing Environments) – remote-display system built for virtual environments by Qumranet, now Red Hat
- Splashtop – a high performance remote desktop protocol developed by Splashtop, fully optimized for hardware (H.264) including Intel / AMD chipsets, NVIDIA of media codecs, Splashtop can deliver high frame rates with low latency, and also low power consumption.
- X Window System (X11) – a well-established cross-platform protocol mainly used for displaying local applications; X11 is network transparent

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.59
------------------	---	-------

THIN CLIENTS - 2

- **Applications should separate application logic from UI**
- **When application logic and UI interaction are tightly coupled many requests get sent to X kernel**
- **Client must wait for response**
- **Synchronous behavior and app-to-UI coupling adversely affects performance of WAN / Internet**

- **Protocol optimizations:** reduce bandwidth by shrinking size of X protocol messages
- **Send only differences between messages with same identifier**
- **Optimizations enable connections with 9600 kbps**

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.59
------------------	---	-------

THIN CLIENTS - 3

- Virtual network computing (VNC)
- Send display over the network at the pixel level (instead of X lib events)
- Reduce pixel encodings to save bandwidth – fewer colors
- Pixel-based approaches lose application semantics
- Can transport any GUI this way

- **THINC**- hybrid approach
- Send video device driver commands over network
- More powerful than pixel based operations
- Less powerful compared to protocols such as X

February 4, 2021

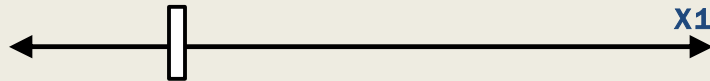
TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.61

TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols

Pixel-level
VNC



Graphics lib
X11

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

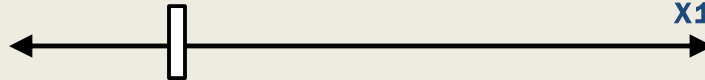
L9.62

TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols

Pixel-level
VNC

Graphics lib
X11



- | | |
|--|---|
| <ul style="list-style-type: none">Generic – no app contextGraphics dataHigher network bandwidthFewer colorsUtilize graphics compressionMore network traffic | <ul style="list-style-type: none">Application context is availableUI data/operationsLower network bandwidthMore colors |
|--|---|

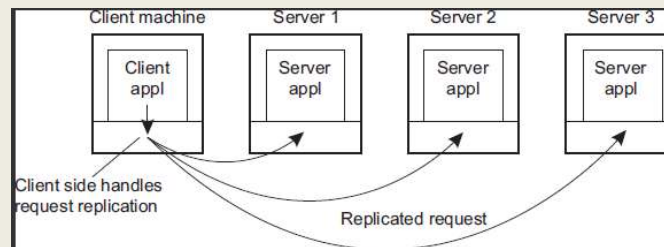
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.63

CLIENT ROLES IN PROVIDING DISTRIBUTION TRANSPARENCY

- Clients help enable distribution transparency of servers
- Replication transparency
 - Client aggregates responses from multiple servers
 - Only the client knows of replicas



February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.64

CLIENT ROLES IN PROVIDING DISTRIBUTION TRANSPARENCY - 2

- **Location/relocation/migration transparency**
 - Harness convenient naming system to allow client to infer new locations
 - Server inform client of moves / Client reconnects to new endpoint
 - Client hides network address of server, and reconnects as needed
 - May involve temporary loss in performance
- **Replication transparency**
 - Client aggregates responses from multiple servers
- **Failure transparency**
 - Client retries, or maps to another server, or uses cached data
- **Concurrency transparency**
 - Transaction servers abstract coordination of multithreading

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.65

OBJECTIVES - 2/4

- Questions from 1/28
- **Assignment 1: Key/Value Store**
 - Java Maven project template files posted
- **Midterm Thursday February 11**
 - 2nd hour - Tuesday February 9 - practice midterm questions
- **Chapter 3: Processes**
 - Chapter 3.1: Threads
 - Threading Models
 - Multithreaded clients/servers
 - Chapter 3.2: Virtualization
 - Chapter 3.3: Clients
 - **Chapter 3.4: Servers**

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.66



CH. 3.4: SERVERS

L9.67

SERVERS

- Cloud & Distributed Systems – rely on **Linux**
- <http://www.zdnet.com/article/it-runs-on-the-cloud-and-the-cloud-runs-on-linux-any-questions/>
- IT is moving to the cloud. And, what powers the cloud?
 - **Linux**
- Uptime Institute survey - 1,000 IT executives (2016)
 - 50% of IT executives – plan to migrate majority of IT workloads to off-premise to cloud or colocation sites
 - 23% expect the shift in 2017, 70% by 2020...
- Docker on Windows / Mac OS X
 - Based on **Linux**
 - Mac: Hyperkit Linux VM
 - Windows: Hyper-V Linux VM

February 4, 2021	TCSS558: Applied Distributed Computing [Winter 2021] School of Engineering and Technology, University of Washington - Tacoma	L9.68
------------------	---	-------

SERVERS - 2

- Servers implement a specific service for a collection of clients
- Servers wait for incoming requests, and respond accordingly

- **Server types**
- **Iterative:** immediately handle client requests
- **Concurrent:** Pass client request to separate thread

- Multithreaded servers are concurrent servers
 - E.g. Apache Tomcat

- **Alternative:** fork a new process for each incoming request
- **Hybrid:** mix the use of multiple processes with thread pools

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.69

END POINTS

- Clients connect to servers via:
IP Address and Port Number

- How do ports get assigned?
 - Many protocols support “default” port numbers
 - Client must find IP address(es) of servers
 - A single server often hosts multiple end points (servers/services)
 - When designing new TCP client/servers must be careful not to repurpose ports already commonly used by others

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.70

COMMON PORTS				packetlife.net
TCP/UDP Port Numbers				
7 Echo	554 RTSP	2745 Bagle.H	6891-6901 Windows Live	
19 Chargen	546-547 DHCPv6	2967 Symantec AV	6970 Quicktime	
20-21 FTP	560 rmonitor	3050 Interbase DB	7212 GhostSurf	
22 SSH/SCP	563 NNTP over SSL	3074 XBOX Live	7648-7649 CU-SeeMe	
23 Telnet	587 SMTP	3124 HTTP Proxy	8000 Internet Radio	
25 SMTP	591 FileMaker	3127 MyDoom	8080 HTTP Proxy	
42 WINS Replication	593 Microsoft DCOM	3128 HTTP Proxy	8086-8087 Kaspersky AV	
43 WHOIS	631 Internet Printing	3222 GLBP	8118 Privoxy	
49 TACACS	636 LDAP over SSL	3260 iSCSI Target	8200 VMware Server	
53 DNS	639 MSDP (PIM)	3306 MySQL	8500 Adobe ColdFusion	
67-68 DHCP/BOOTP	646 LDP (MPLS)	3389 Terminal Server	8767 TeamSpeak	
69 TFTP	691 MS Exchange	3689 iTunes	8866 Bagle.B	
70 Gopher	860 iSCSI	3690 Subversion	9100 HP JetDirect	
79 Finger	873 rsync	3724 World of Warcraft	9101-9103 Bacula	
80 HTTP	902 VMware Server	3784-3785 Ventrilo	9119 MXit	
88 Kerberos	989-990 FTP over SSL	4333 mSQL	9800 WebDAV	
102 MS Exchange	993 IMAP4 over SSL	4444 Blaster	9898 Dabber	
110 POP3	995 POP3 over SSL	4664 Google Desktop	9988 Rbot/Spybot	
113 Ident	1025 Microsoft RPC	4672 eMule	9999 Urchin	
119 NNTP (Usenet)	1026-1029 Windows Messenger	4899 Radmin	10000 Webmin	
123 NTP	1080 SOCKS Proxy	5000 UPnP	10000 BackupExec	
135 Microsoft RPC	1080 MyDoom	5001 Slingbox	10113-10116 NetIQ	
137-139 NetBIOS	1194 OpenVPN	5001 iperf	11371 OpenPGP	
143 IMAP4	1214 Kazaa	5004-5005 RTP	12035-12036 Second Life	
161-162 SNMP	1241 Nessus	5050 Yahoo! Messenger	12345 NetBus	
177 XDMCP	1311 Dell OpenManage	5060 SIP	13720-13721 NetBackup	
179 BGP	1337 WASTE	5190 AIM/ICO	14567 Battlefield	

TYPES OF SERVERS

- **Daemon server**
 - Example: NTP server

- **Superserver**

- **Stateless server**
 - Example: Apache server

- **Stateful server**

- **Object servers**

- **EJB servers**

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.72

NTP EXAMPLE

- **Daemon servers**
 - Run locally on Linux
 - Track current server end points (outside servers)
 - Example: network time protocol (ntp) daemon
 - Listen locally on specific port (ntp is 123)
 - Daemons routes local client traffic to the configured endpoint servers
 - University of Washington: time.u.washington.edu
 - Example “`ntpq -p`”
 - Queries local ntp daemon, routes traffic to configured server(s)

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.73

SUPERSERVER

- **Linux inetd / xinetd**
 - Single superserver
 - Extended internet service daemon
 - Not installed by default on Ubuntu
 - Intended for use on server machines
 - Used to configure box as a server for multiple internet services
 - E.g. ftp, pop, telnet
 - inetd daemon responds to multiple endpoints for multiple services
 - Requests fork a process to run required executable program
- **Check what ports you're listening on:**
 - `sudo netstat -tap | grep LISTEN`

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.74

INTERRUPTING A SERVER

- **Server design issue:**
 - Active client/server communication is taking place over a port
 - How can the server / data transfer protocol support interruption?
- Consider transferring a 1 GB image, how do you pass a unrelated message in this stream?
 1. **Out-of-band** data: special messages sent in-stream to support interrupting the server (*TCP urgent data*)
 2. Use a separate connection (different port) for admin control info
- **Example: sftp secure file transfer protocol**
 - Once a file transfer is started, can't be stopped easily
 - Must kill the client and/or server

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.75

STATELESS SERVERS

- Data about state of clients is not stored
- **Example: web application servers are typically stateless**
 - Also function-as-a-service (FaaS) platforms
- Many servers maintain information on clients (e.g. log files)
- Loss of stateless data doesn't disrupt server availability
 - Losing log files typically has minimal consequences
- **Soft state:** server maintains state on the client for a limited time (*to support sessions*)
- Soft state information expires and is deleted

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.76

STATEFUL SERVERS

- Maintain persistent information about clients
- Information must be explicitly deleted by the server
- Example:
 - File server - allows clients to keep local file copies for RW
- Server tracks client file permissions and most recent versions
 - Table of (client, file) entries
- If server crashes data must be recovered
- Entire state before a crash must be restored
- Fault tolerance - *Ch. 8*

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.77

STATEFUL SERVERS - 2

- Session state
 - Tracks series of operations by a single user
 - Maintained temporarily, not indefinitely
 - Often retained for multi-tier client server applications
 - Minimal consequence if session state is lost
 - Clients must start over, reinitialize sessions
- Permanent state
 - Customer information, software keys
- Client-side cookies
 - When servers don't maintain client state, clients can store state locally in "cookies"
 - Cookies are not executable, simply client-side data

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.78

OBJECT SERVERS

- **OBJECTIVE:** Host objects and enable remote client access
- Do not provide a specific service
 - Do nothing if there are no objects to host
- Support adding/removing hosted objects
- Provide a home where objects live
- Objects, *themselves*, provide “services”
- Object parts
 - State data
 - Code (methods, etc.)
- **Transient object(s)**
 - Objects with limited lifetime (< server)
 - Created at first invocation, destroyed when no longer used (i.e. no clients remain “bound”).
 - Disadvantage: initialization may be expensive
 - Alternative: preinitialize and retain objects on server start-up

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.79

OBJECT SERVERS - 2

- **Should object servers isolate memory for object instances?**
 - Share neither code nor data
 - May be necessary if objects couple data and implementation
- Object server threading designs:
 - Single thread of control for object server
 - One thread for each object
 - Servers use separate thread for client requests
- Threads created on demand vs. Server maintains pool of threads
- **What are the tradeoffs for creating server threads on demand vs. using a thread pool?**

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.80

EJB – ENTERPRISE JAVA BEANS

- EJB- specialized Java object hosted by a EJB web container
- 4 types: stateless, stateful, entity, and message-driven beans
- Provides “middleware” standard (framework) for implementing back-ends of enterprise applications
- EJB web application containers integrate support for:
 - Transaction processing
 - Persistence
 - Concurrency
 - Event-driven programming
 - Asynchronous method invocation
 - Job scheduling
 - Naming and discovery services (JNDI)
 - Interprocess communication
 - Security
 - Software component deployment to an application server

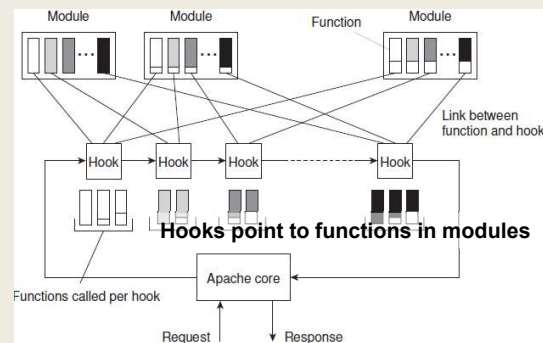
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.81

APACHE WEB SERVER

- Highly configurable, extensible, platform independent
- Supports TCP HTTP protocol communication
- Uses hooks – placeholders for group of functions
- Requests processed in phases by hooks
- Many hooks:
 - Translate a URL
 - Write info to log
 - Check client ID
 - Check access rights
- Hooks processed in order enforcing flow-of-control
- Functions in replaceable modules



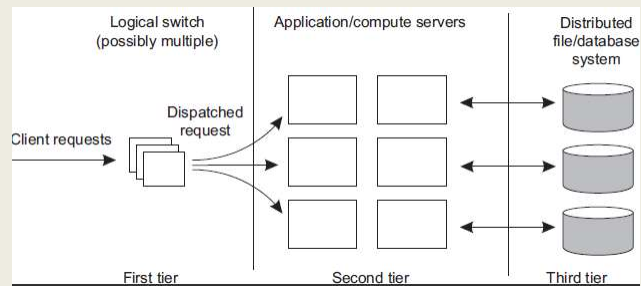
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.82

SERVER CLUSTERS

- Hosted across an LAN or WAN
- Collection of interconnected machines
- Can be organized in tiers:
 - Web server → app server → DB server
 - App and DB server sometimes integrated



February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.83

LAN REQUEST DISPATCHING

- Front end of three tier architecture (logical switch) provides distribution transparency – hides multiple servers
- Transport-layer switches: switch accepts TCP connection requests, hands off to a server
 - Example: hardware load balancer (F5 networks – Seattle)
 - HW Load balancer - OSI layers 4-7
- Network-address-translation (NAT) approach:
 - All requests pass through switch
 - Switch sits in the middle of the client/server TCP connection
 - Maps (rewrites) source and destination addresses
- Connection hand-off approach:
 - **TCP Handoff**: switch hands of connection to a selected server

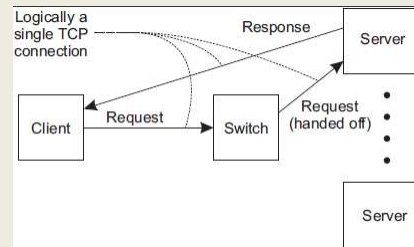
February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.84

LAN REQUEST DISPATCHING - 2

- Who is the best server to handle the request?
- Switch plays important role in distributing requests
- Implements load balancing
- **Round-robin** – routes client requests to servers in a looping fashion
- **Transport-level** – route client requests based on TCP port number
- **Content-aware request distribution** – route requests based on inspecting data payload and determining which server node should process the request



February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.85

WIDE AREA CLUSTERS

- Deployed across the internet
- Leverage resource/infrastructure from Internet Service Providers (ISPs)
- Cloud computing simplifies building WAN clusters
- Resource from a single cloud provider can be combined to form a cluster
- For deploying a cloud-based cluster (WAN), what are the implications of deploying nodes to:
 - (1) a single availability zone (e.g. us-east-1e)?
 - (2) across multiple availability zones?

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.86

WAN REQUEST DISPATCHING

- Goal: minimize network latency using WANs (e.g. Internet)
- Send requests to nearby servers
- Request dispatcher: routes requests to nearby server
- **Example:** Domain Name System
 - Hierarchical decentralized naming system
- Linux: find your DNS servers:

```
# Find you device name of interest
nmcli dev
# Show device configuration
nmcli device show <device name>
```

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.87

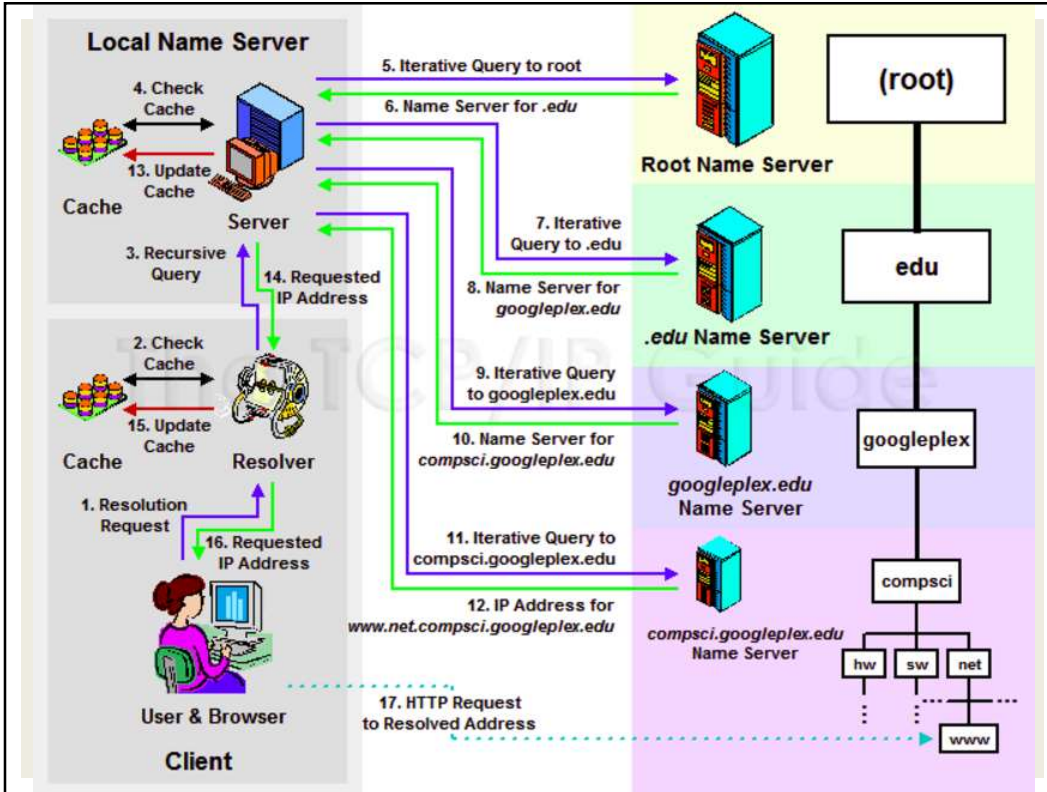
DNS LOOKUP

- First query local server(s) for address
- Typically there are (2) local DNS servers
 - One is backup
- Hostname may be cached at local DNS server
 - E.g. www.google.com
- If not found, local DNS server routes to other servers
- Routing based on components of the hostname
- DNS servers down the chain mask the client IP, and use the originating DNS server IP to identify a local host
- **Weakness:** *client may be far from DNS server used. Resolved hostname is close to DNS server, but not necessarily close to the client*

February 4, 2021

TCCS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.88



DNS: LINUX COMMANDS

- `nslookup <ip addr / hostname>`
- Name server lookup - translates hostname or IP to the inverse
- `traceroute <ip addr / hostname>`
- Traces network path to destination
- By default, output is limited to 30 hops, can be increased

DNS EXAMPLE – WAN DISPATCHING

- Ping www.google.com in WA from wireless network:
 - nslookup: 6 alternate addresses returned, choose (74.125.28.147)
 - Ping 74.125.28.147: Average RTT = **22.458 ms (11 attempts, 22 hops)**
- Ping www.google.com in VA (us-east-1) from EC2 instance:
 - nslookup: 1 address returned, choose 172.217.9.196
 - Ping 172.217.9.196: Average RTT = 1.278 ms (11 attempts, 13 hops)

- From VA EC2 instance, ping WA *www.google* server
- Ping 74.125.28.147: Average RTT 62.349ms (11 attempts, 27 hops)
- Pinging the WA-local server is ~60x slower from VA

- From local wireless network, ping VA us-east-1 google :
- Ping 172.217.9.196: Average RTT=81.637ms (11 attempts, 15 hops)

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.91

DNS EXAMPLE – WAN DISPATCHING

- Ping www.google.com in WA from wireless network:
 - nslookup: 6 alternate addresses returned, choose (74.125.28.147)

Latency to ping VA server in WA: ~3.63x
WA client: local-google 22.458ms to VA-google 81.637ms

Latency to ping WA server in VA: ~48.7x
VA client: local-google 1.278ms to WA-google 62.349!

- From local wireless network, ping VA us-east-1 google :
- Ping 172.217.9.196: Average RTT=81.637ms (11 attempts, 15 hops)

February 4, 2021

TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma

L9.92

QUESTIONS

February 4, 2021 TCSS558: Applied Distributed Computing [Winter 2021]
School of Engineering and Technology, University of Washington - Tacoma L9.93