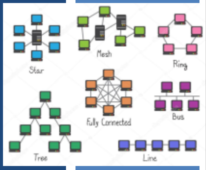
TCSS 558: APPLIED DISTRIBUTED COMPUTING

Processes:
Threads & Virtualization, Clients & Servers

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



1

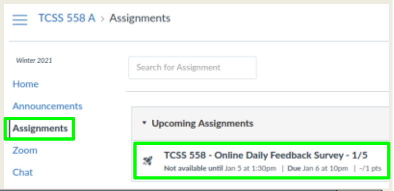
OBJECTIVES – 1/30

- Questions from 1/25
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

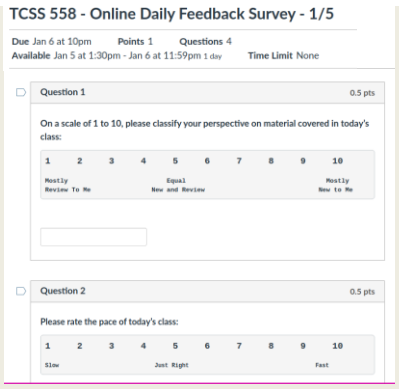
2

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



3



TCSS 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

4

MATERIAL / PACE

- Please classify your perspective on material covered in today's class (26 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- <u>Average – 6.77 (↑ - *previous 5.95*)</u>

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- <u>Average – 5.73 (↑ - *previous 5.45*)</u>

5

FEEDBACK FROM 1/25

- ***When conducting a random walk in an unstructured peer-to-peer system, is any logic employed to ensure you do not run a cycle?***
  - As with flooding, with random walk, if a node has previously received the data it is trying to propagate to a neighbor, from the neighbor, then it will not forward the data to the neighbor
  - Nodes only send the data to neighbors that are assumed to not have the data
- ***Do we keep track of the neighbors we have asked, and always randomly select a new neighbor from a list of unasked neighbors if the neighbor we ask cannot find the data?***
  - Yes, there would be no purpose to forward the data twice to the same node

6

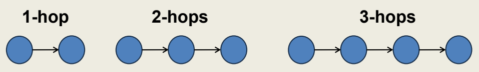
FEEDBACK - 2

- ***In the chord system, when a node recieves a query for a key k which it doesn't store, then in the text book it's mentioned that it forwards the query to the smallest id greater than or equal to k which is nothing but the successor of k.]***
- ***But in the slides its mentioned, it will be forwarded to node with m-bit id closest to but not greater than k.***
  - The finger table format from Chapter 5 has a slightly different format
  - The id(s) on page 248 (3rd edition), are just indexes (from 1 to 5), they do not correspond to node numbers in the chord.
  - In the example for lecture 7, the finger table has node numbers paired with subsequent forwarding IDs, not just generic indexes
  - For the textbook, forward to node q, where $q = FT_p[j] \le FT_p[j+1]$
  - The book does not make the following clear:
    - when you run out of table entries, forward to last one
    - when the first entry in the table is greater than k, forward it there
  - The format used on the slides is preferred over the book in this case

7

FEEDBACK - 3

- ***The concept of hop in structured systems seemed slightly confusing. Could you please reiterate it?***
- We are referring to the number of links used to exchange data between two nodes



8

FEEDBACK - 4

- ***I still don't understand what is m-bound and d-bound.***
  - The webservices application has two variants
  - Variant #1: the resource-bound component is "M"- the application server
    - The letter M stands for "Model". The web service is a **model** that estimates soil erosion due to water run-off.
  - Variant #2: the resource-bound component is "D" – the relational database
    - The application was modified to have a nested SQL query
    - "select * from (select * from …);
    - For sequential search of a single table, nesting forces n^2 evaluations as opposed to only n for the standard query. This makes the database more resource constrained than the web application server and is a bad SQL bug !
- ***Can you provide ppt file? Because images are blocked in pdf files.***
  - Some slides have old animations. Ppt is available by email request

9

OBJECTIVES – 1/30

- Questions from 1/25
- **Assignment 1: Cloud Computing Infrastructure Tutorial**
  - **New testFibService.sh script**
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

10

AWS CLOUD CREDITS UPDATE

- We have been approved to receive AWS CLOUD CREDITS for TCSS 558 – Winter 2024
- Credits will be provided by email request
  - Please include: 12-digit AWS account ID, and AWS account email
- Credits will first be provided for students not in F'23 TCSS562
- 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
- Credit codes are carefully exchanged, and not shared by IM
- For students ***unable*** to create a standard AWS account: Please contact instructor by email - *Instructor will work to create hosted IAM user account*

11

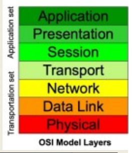
ASSIGNMENT 1

- ***Preparing for Assignment 1: Intro to Cloud Computing Infrastructure and Load Balancing***
  - Establish AWS Account - Standard account
- Now posted:
  - Task 0 - Establish local Linux/Ubuntu environment
  - Task 1 –AWS account setup, obtain user credentials
  - Task 2 – Intro to: Amazon EC2 & Docker: create Dockerfile for Apache Tomcat
  - Task 3 – Create Dockerfile for haproxy (software load balancer)
  - Task 4 – Working with Docker-Machine
  - Task 5 – Submit Results of testing alternate server configs

12

TESTING CONNECTIVITY TO SERVER (PG 16-18)

- testFibPar.sh script is a parallel test script
- Orchestrates multiple threads on client to invoke server multiple times in parallel
- To simplify coordination of parallel service calls in BASH, testFibPar.sh script ignores errors !!!
- To help test client-to-server connectivity, there is also a testFibService.sh script that supports 3 tests
- TEST 1: Network layer test
  - Ping (ICMP)
- TEST 2: Transport layer test
  - TCP: telnet (TCP Port 8080) – security group (fw) test
- TEST 3: Application layer test
  - HTTP REST – web service test

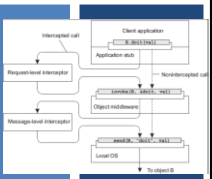


13

OBJECTIVES – 1/30

- Questions from 1/25
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

14



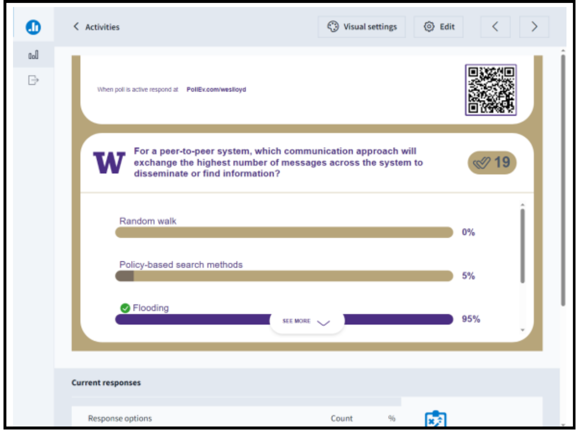
CH 2.3: SYSTEM ARCHITECTURES

15

REVIEW QUESTIONS

- What is difference in finding/disseminating data in unstructured vs. structured peer-to-peer networks?
  - Structured: can grasp the number of messages required based on the organization and structure of the system
  - Fixed hypercube
  - Chord system
  - Unstructured: requires broadcast like message schemes that gossip to find/disseminate data: Flooding, Random walk

16



When poll is active respond at PollEv.com/weslloyd

For a peer-to-peer system, which communication approach will exchange the highest number of messages across the system to disseminate or find information? 19

Random walk 0%

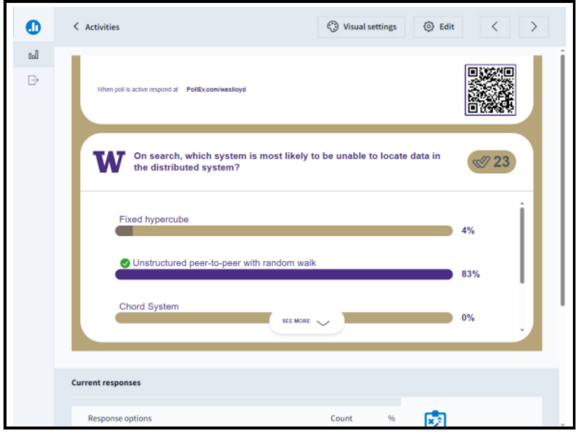
Policy-based search methods 5%

Flooding 95%

Current responses

Response options Count %

17



When poll is active respond at PollEv.com/weslloyd

On search, which system is most likely to be unable to locate data in the distributed system? 23

Fixed hypercube 4%

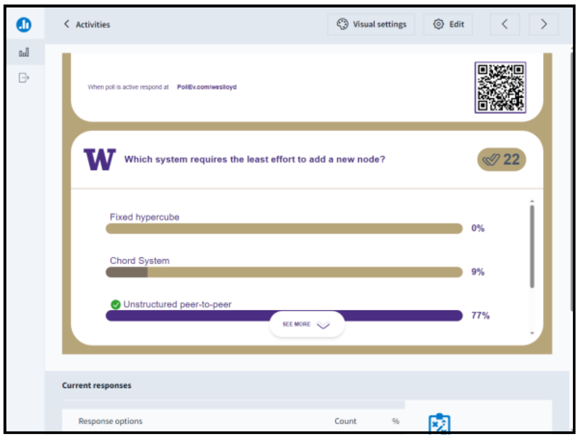
Unstructured peer-to-peer with random walk 83%

Chord System 0%

Current responses

Response options Count %

18



When poll is active respond at PollEv.com/weslloyd

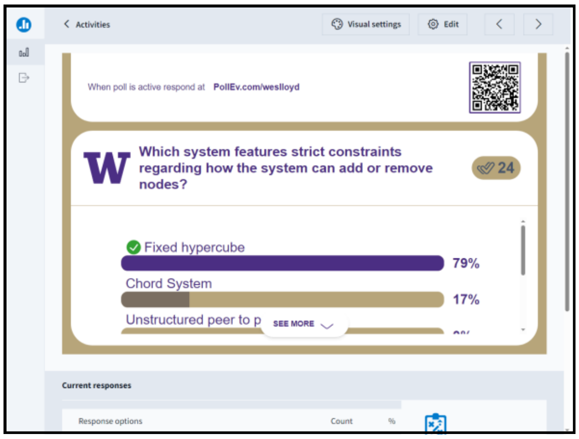
Which system requires the least effort to add a new node? 22

Fixed hypercube 0%
Chord System 9%
✓ Unstructured peer-to-peer 77%

Current responses

Response options Count %

19



When poll is active respond at PollEv.com/weslloyd

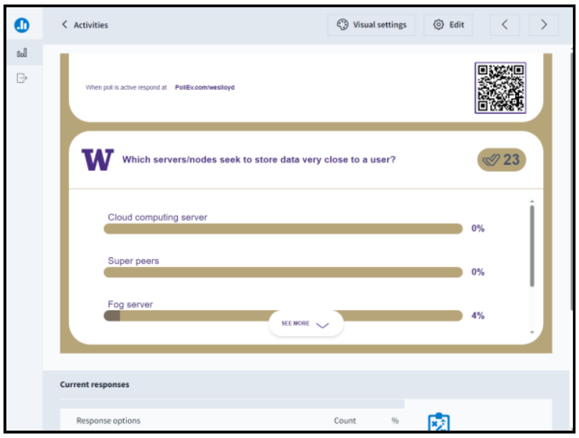
Which system features strict constraints regarding how the system can add or remove nodes? 24

✓ Fixed hypercube 79%
Chord System 17%
Unstructured peer to p

Current responses

Response options Count %

20



When poll is active respond at PollEv.com/weslloyd

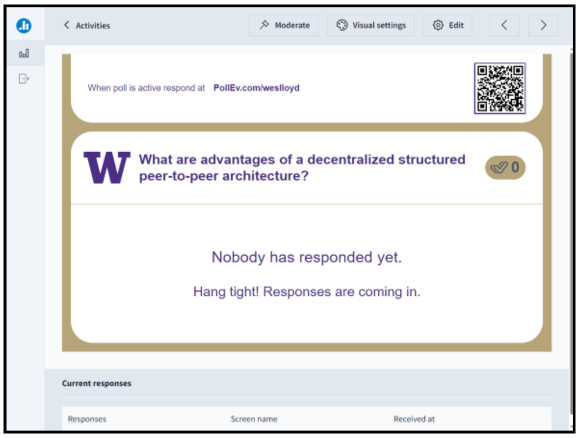
Which servers/nodes seek to store data very close to a user? 23

Cloud computing server 0%
Super peers 0%
Fog server 4%

Current responses

Response options Count %

21



When poll is active respond at PollEv.com/weslloyd

What are advantages of a decentralized structured peer-to-peer architecture? 0

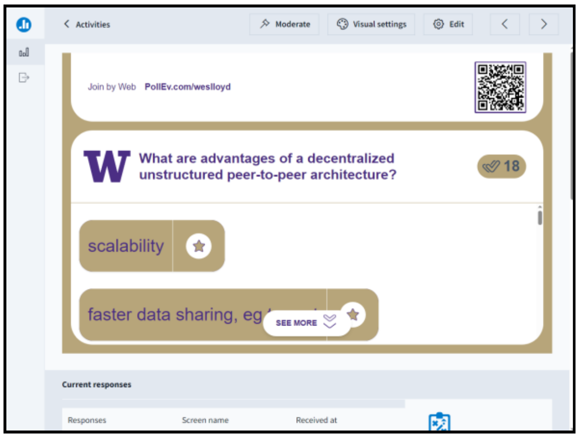
Nobody has responded yet.

Hang tight! Responses are coming in.

Current responses

Responses Screen name Received at

22



Join by Web PollEv.com/weslloyd

What are advantages of a decentralized unstructured peer-to-peer architecture? 18

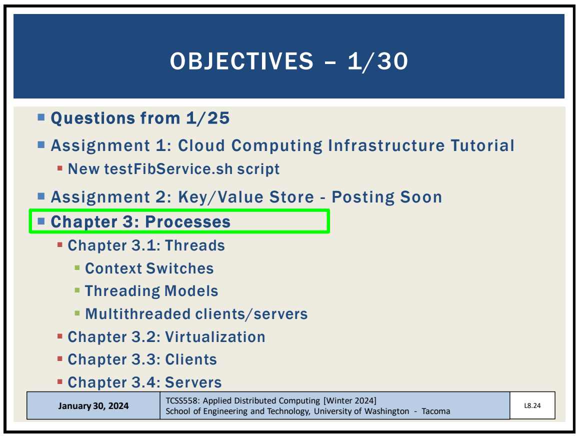
scalability

faster data sharing, eg

Current responses

Responses Screen name Received at

23

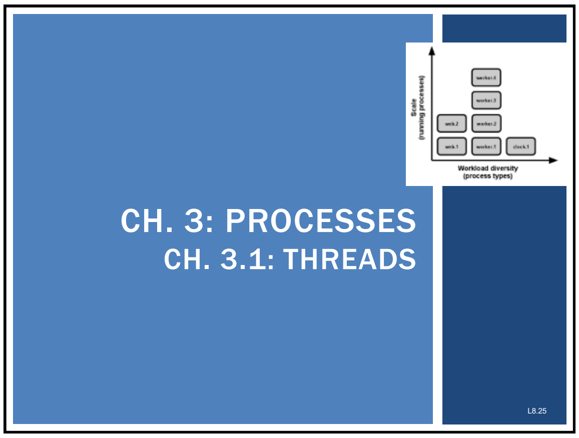


OBJECTIVES – 1/30

- Questions from 1/25
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.24

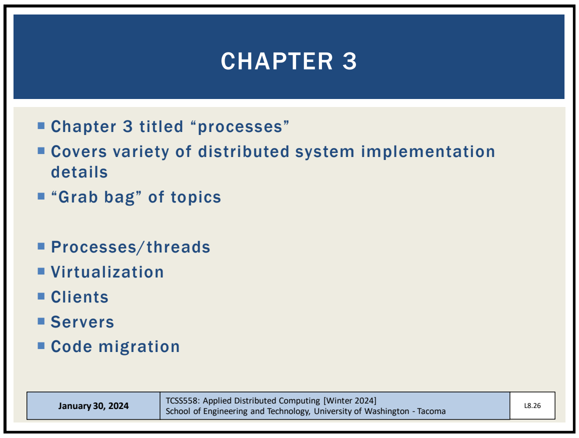
24


Scale (running processes)
Workload diversity (process types)
worker.4
worker.3
web.2
worker.2
web.1
worker.1
clock.1

CH. 3: PROCESSES
CH. 3.1: THREADS

L8.25

25



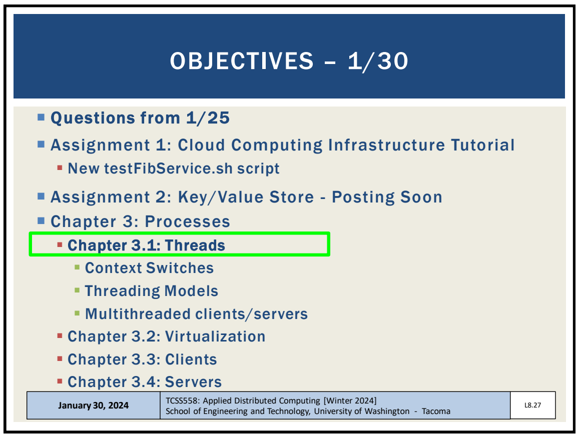
CHAPTER 3

- Chapter 3 titled "processes"
- Covers variety of distributed system implementation details
- "Grab bag" of topics

- Processes/threads
- Virtualization
- Clients
- Servers
- Code migration

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.26

26

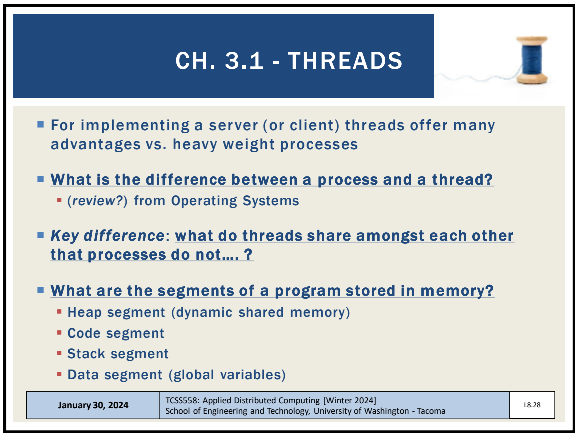


OBJECTIVES – 1/30

- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - **Chapter 3.1: Threads**
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.27

27

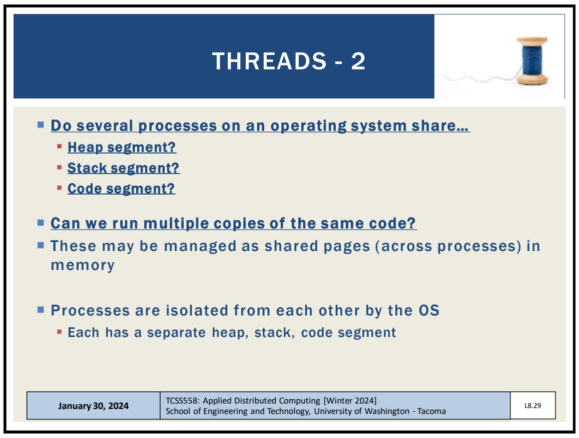


CH. 3.1 - THREADS

- For implementing a server (or client) threads offer many advantages vs. heavy weight processes
- **What is the difference between a process and a thread?**
  - *(review?)* from Operating Systems
- ***Key difference*: what do threads share amongst each other that processes do not…. ?**
- **What are the segments of a program stored in memory?**
  - Heap segment (dynamic shared memory)
  - Code segment
  - Stack segment
  - Data segment (global variables)

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.28

28



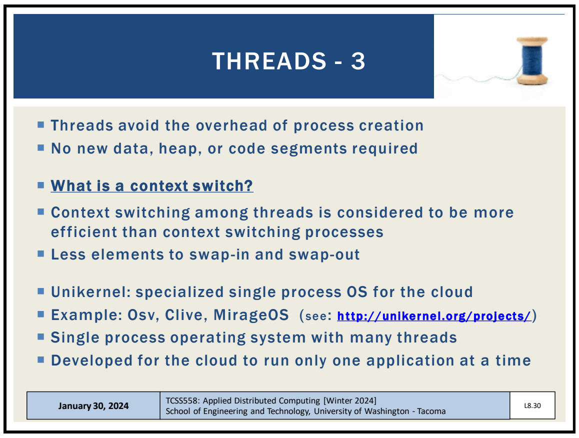
THREADS - 2

- **Do several processes on an operating system share…**
  - **Heap segment?**
  - **Stack segment?**
  - **Code segment?**
- **Can we run multiple copies of the same code?**
- These may be managed as shared pages (across processes) in memory

- Processes are isolated from each other by the OS
  - Each has a separate heap, stack, code segment

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.29

29



THREADS - 3

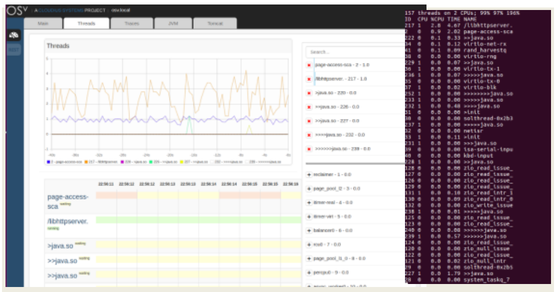
- Threads avoid the overhead of process creation
- No new data, heap, or code segments required
- **What is a context switch?**
- Context switching among threads is considered to be more efficient than context switching processes
- Less elements to swap-in and swap-out

- Unikernel: specialized single process OS for the cloud
- Example: Osv, Clive, MirageOS (see: **http://unikernel.org/projects/**)
- Single process operating system with many threads
- Developed for the cloud to run only one application at a time

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.30

30

OSV: ONE PROCESS, MANY THREADS



```
157 threads on 2 CPUs; 99% 97% 196%
ID  CPU %CPU TIME NAME
217 1   2.8  4.67 /libhttpserver.
2   0   0.9  2.02 page-access-sca
222 0   0.1  0.33 >>java.so
34  0   0.1  0.12 virtio-net-rx
41  0   0.1  0.09 rand_harvestq
38  0   0.0  0.00 virtio-rng
229 1   0.0  0.07 >>java.so
36  1   0.0  0.00 virtio-tx-1
236 1   0.0  0.07 >>>>>java.so
35  0   0.0  0.00 virtio-tx-0
37  1   0.0  0.02 virtio-blk
252 1   0.0  0.00 >>>>>>>>>java.so
233 1   0.0  0.00 >>>>>java.so
232 1   0.0  0.48 >>>>java.so
31  0   0.0  0.00 >init
30  0   0.0  0.00 solthread-0x2b3
237 1   0.0  0.00 >>>>>>java.so
32  0   0.0  0.00 netisr
33  1   0.0  0.11 >init
231 1   0.0  0.00 >>>java.so
39  0   0.0  0.00 isa-serial-inpu
40  0   0.0  0.00 kbd-input
228 1   0.0  0.00 >>java.so
128 0   0.0  0.00 zio_read_issue_
127 0   0.0  0.00 zio_read_issue_
126 0   0.0  0.00 zio_read_issue_
129 0   0.0  0.00 zio_read_issue_
131 1   0.0  0.10 zio_read_intr_1
130 0   0.0  0.09 zio_read_intr_0
132 0   0.0  0.00 zio_write_issue
238 1   0.0  0.01 >>>>>>java.so
125 0   0.0  0.00 zio_read_issue_
123 0   0.0  0.00 zio_read_issue_
240 0   0.0  0.00 >>>>>>java.so
239 1   0.0  0.57 >>>>>>java.so
124 0   0.0  0.00 zio_read_issue_
120 0   0.0  0.00 zio_null_issue
122 0   0.0  0.00 zio_read_issue_
121 0   0.0  0.02 zio_null_intr
29  0   0.0  0.00 solthread-0x2b5
227 1   0.0  1.79 >>java.so
28  0   0.0  0.00 system_taskq_7
```

31

THREADS - 4

- Important implications with threads:
- (1) multi-threading should lead to performance gains
- (2) thread programming requires additional effort when threads share memory
  - Known as thread **synchronization**, or enabling **concurrency**
- Access to **critical sections** of code which modify shared variables must be **mutually exclusive**
  - No more than one thread can execute at any given time
  - Critical sections must run **atomically** on the CPU

32

WE WILL RETURN AT 2:40PM

33

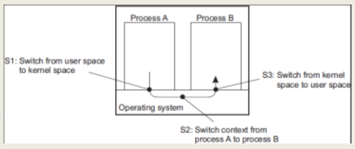
BLOCKING THREADS

- Example: spreadsheet with formula to compute sum of column
- User modifies values in column
- Multiple threads:
1. Supports interaction (UI) activity with user
2. Updates spreadsheet calculations in parallel
3. Continually backs up spreadsheet changes to disk
- Single core CPU
  - Tasks appear as if they are performed simultaneously
- Multi core CPU
  - Tasks ***execute*** simultaneously

34

INTERPROCESS COMMUNICATION

- IPC – mechanism using pipes, message queues, and shared memory segments
- IPC mechanisms incur context switching
  - Process I/O must execute in kernel mode
- **How many context switches are required for process A to send a message to process B using IPC?**
- **#1 C/S:** Proc A→kernel thread
- **#2 C/S:** Kernel thread→Proc B

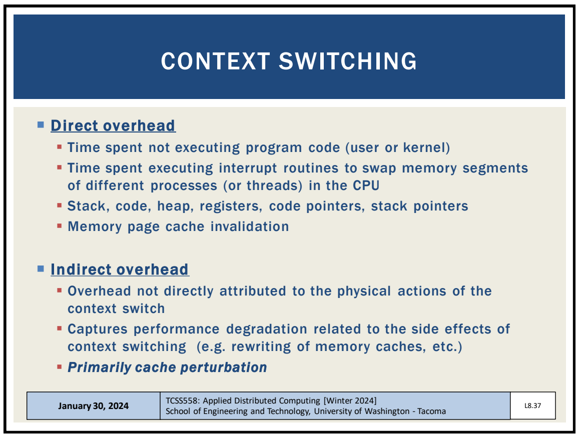

Process A
Process B
S1: Switch from user space to kernel space
S3: Switch from kernel space to user space
Operating system
S2: Switch context from process A to process B

35

OBJECTIVES – 1/30

- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - **Context Switches**
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

36

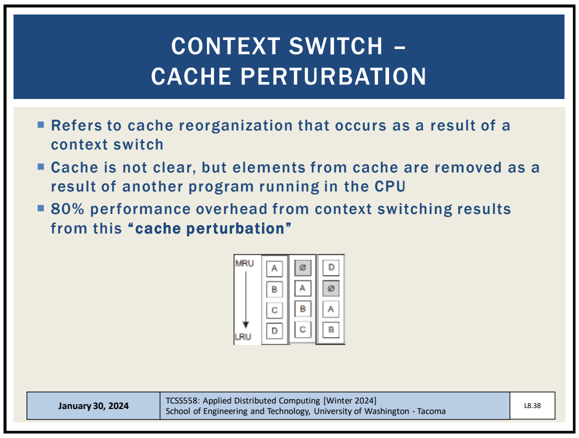


CONTEXT SWITCHING

- **Direct overhead**
  - Time spent not executing program code (user or kernel)
  - Time spent executing interrupt routines to swap memory segments of different processes (or threads) in the CPU
  - Stack, code, heap, registers, code pointers, stack pointers
  - Memory page cache invalidation
- **Indirect overhead**
  - Overhead not directly attributed to the physical actions of the context switch
  - Captures performance degradation related to the side effects of context switching (e.g. rewriting of memory caches, etc.)
  - ***Primarily cache perturbation***

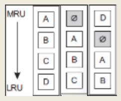
January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.37

37



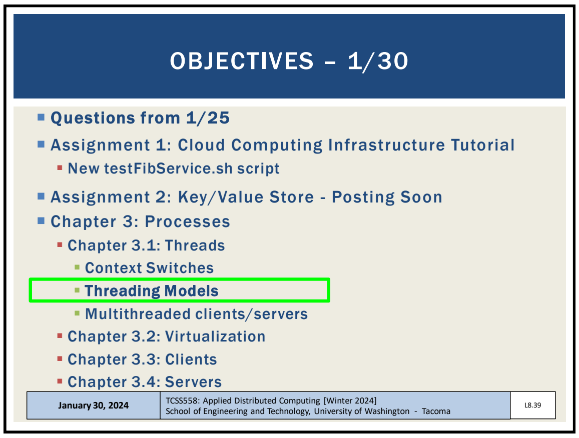
CONTEXT SWITCH – CACHE PERTURBATION

- Refers to cache reorganization that occurs as a result of a context switch
- Cache is not clear, but elements from cache are removed as a result of another program running in the CPU
- 80% performance overhead from context switching results from this **"cache perturbation"**



January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.38

38

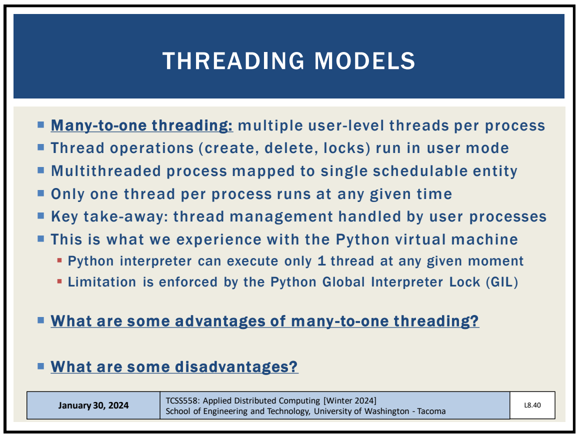


OBJECTIVES – 1/30

- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - **Threading Models**
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.39

39

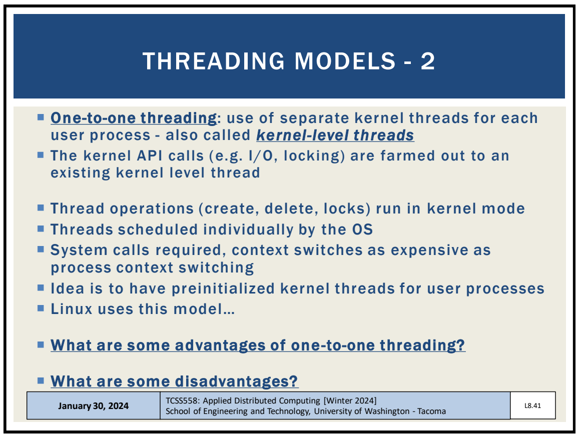


THREADING MODELS

- **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 one thread per process runs at any given time
- Key take-away: thread management handled by user processes
- This is what we experience with the Python virtual machine
  - Python interpreter can execute only 1 thread at any given moment
  - Limitation is enforced by the Python Global Interpreter Lock (GIL)
- **What are some advantages of many-to-one threading?**
- **What are some disadvantages?**

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.40

40

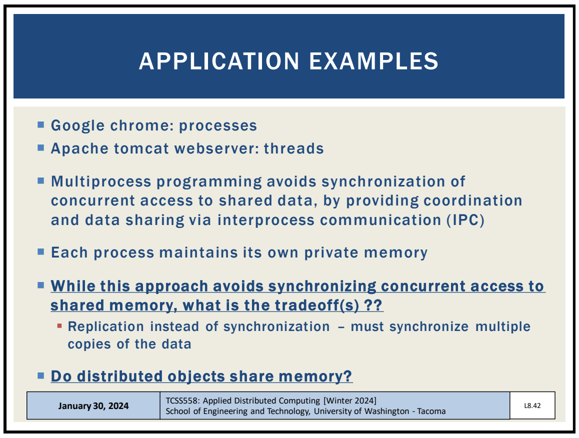


THREADING MODELS - 2

- **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?**

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.41

41

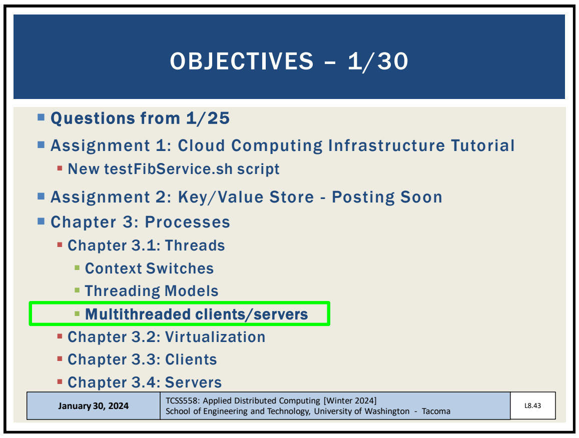


APPLICATION EXAMPLES

- 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?**

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.42

42

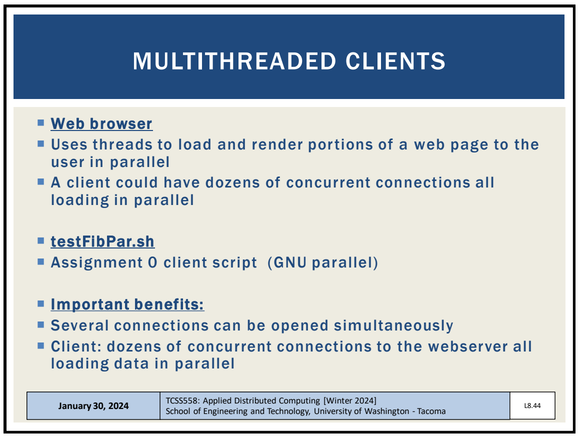


OBJECTIVES – 1/30

- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - **Multithreaded clients/servers**
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.43

43



MULTITHREADED CLIENTS

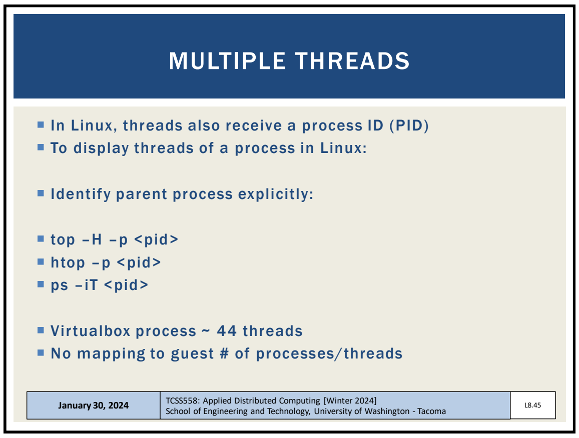
- **Web browser**
- Uses threads to load and render portions of a web page to the user in parallel
- A client could have dozens of concurrent connections all loading in parallel

- **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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.44

44



MULTIPLE THREADS

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

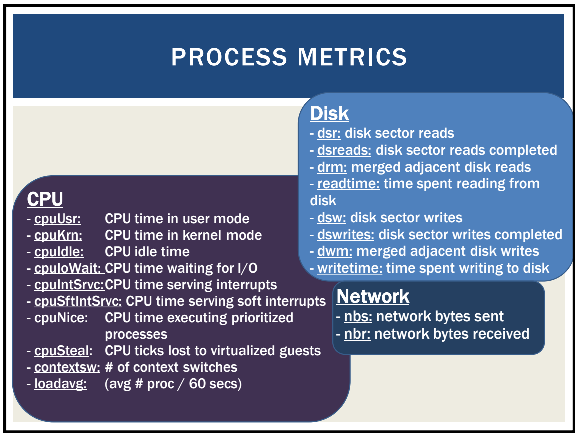
- Identify parent process explicitly:

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

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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.45

45



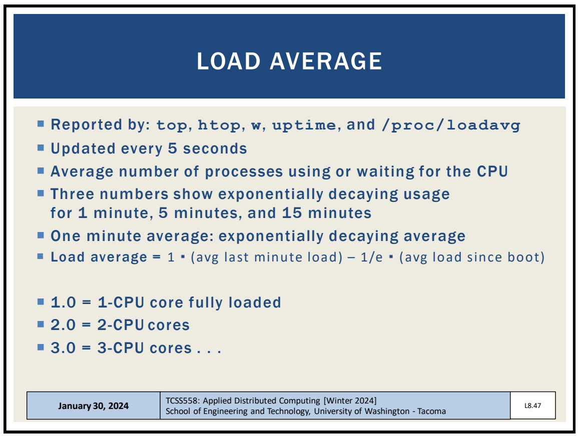
PROCESS METRICS

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

46



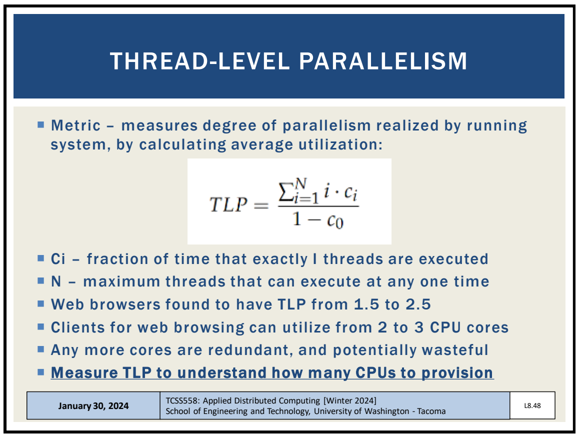
LOAD AVERAGE

- 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 • (avg last minute load) – 1/e • (avg load since boot)

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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.47

47



THREAD-LEVEL PARALLELISM

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

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

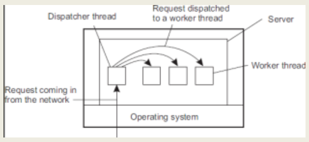
- Ci – fraction of time that exactly I threads are executed
- N – maximum threads that can execute at any one time
- Web browsers found to have TLP from 1.5 to 2.5
- Clients for web browsing can utilize from 2 to 3 CPU cores
- Any more cores are redundant, and potentially wasteful
- **Measure TLP to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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.48

48

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


Dispatcher thread
Request dispatched to a worker thread
Server
Worker thread
Request coming in from the network
Operating system

49

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

50

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. . .

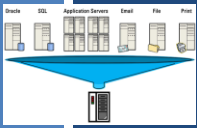
Model	Characteristics
Multithreading	Parallelism, blocking I/O
Single-thread	No parallelism, blocking I/O
Finite-state machine	Parallelism, non-blocking I/O

51

OBJECTIVES – 1/30

- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - **Chapter 3.2: Virtualization**
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers

52



CH. 3.2: VIRTUALIZATION

53

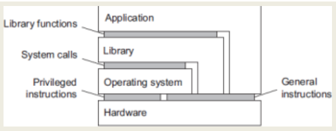
VIRTUALIZATION

- 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)

54

TYPES OF VIRTUALIZATION

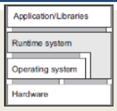
- **Levels of instructions:**
- **Hardware**: CPU
  - Privileged instructions
    KERNEL MODE
  - General instructions
    USER MODE
- **Operating system**: system calls
- **Library**: programming APIs: e.g. C/C++,C#, Java libraries
- **Application**:
- **Goal of virtualization:**
  mimic these interface to provide a virtual computer

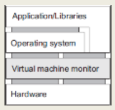


55

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

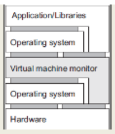




56

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



57

EVOLUTION OF AWS VIRTUALIZATION

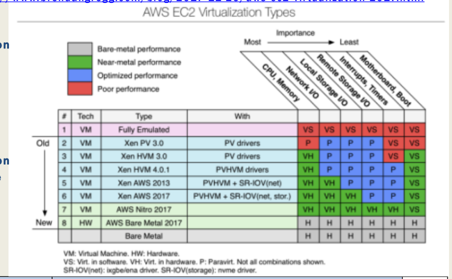
From http://www.brendangregg.com/blog/2017-11-29/aws-ec2-virtualization-2017.html

VS:
Virtualization in software

P:
Paravirtual

VH:
Virtualization in Hardware

H:
Hardware


AWS EC2 Virtualization Types

Importance
Most → Least
Old
New

▨	Bare-metal performance
🟩	Near-metal performance
🟦	Optimized performance
🟥	Poor performance

#	Tech	Type	With	CPU, Memory	Network I/O	Local Storage I/O	Remote Storage I/O	Interrupts, Timers	Motherboard, Boot
1	VM	Fully Emulated		VS	VS	VS	VS	VS	VS
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.

58

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

59

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)

60

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%

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.61

61

OBJECTIVES – 1/30

- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - **Chapter 3.3: Clients**
  - Chapter 3.4: Servers

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.62

62

CH. 3.3: CLIENTS

L8.63

63

TYPES OF CLIENTS

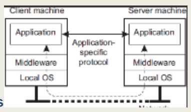
- Thick clients
  - Web browsers
    - Client-side scripting
  - Mobile apps
  - Multi-tier MVC apps
- Thin clients
  - Remote desktops/GUIs (very thin)

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.64

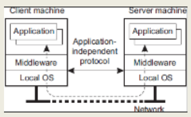
64

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



January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.65

65

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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.66

66

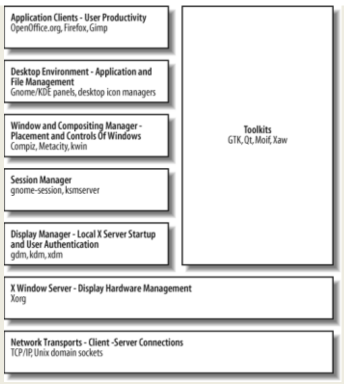
X WINDOWS - 2

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

67

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
Toolkits
GTK, Qt, Moif, Xaw
X Window Server - Display Hardware Management
Xorg
Network Transports - Client -Server Connections
TCP/IP, Unix domain sockets

68

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`

69

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 &
```

70

EXAMPLE: VNC SERVER – UBUNTU 18.04

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

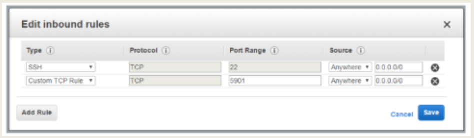
```
#!/bin/bash
xrdb $HOME/.Xresources
startxfce4 &
```

71

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:



Edit inbound rules

Type	Protocol	Port Range	Source	
SSH	TCP	22	Anywhere	0.0.0.0/0
Custom TCP Rule	TCP	5901	Anywhere	0.0.0.0/0

72

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>
```

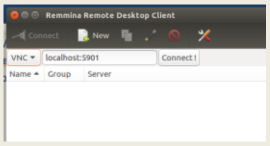
- For example:

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

73

EXAMPLE: VNC CLIENT - 2

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

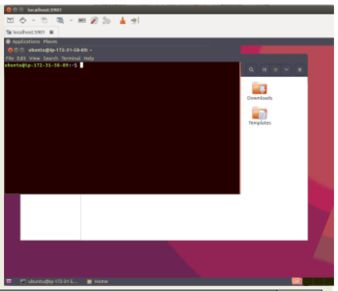

Remmina Remote Desktop Client

VNC ▾ | localhost:5901 | Connect !

74

REMOTE COMPUTER IN THE CLOUD

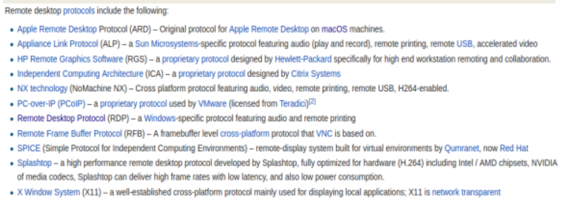
- EC2 instance with a GUI. . .!!!



75

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

76

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 adverselt 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

77

THIN CLIENTS - 3

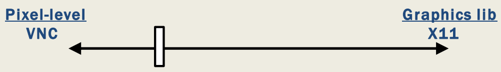
- Virtual network computing (VNC)
- Send display over the network at the pixel level (instead of X lib events)
- Reduce pixel encodings to save bandwidth – fewer colors
- Pixel-based approaches loose application semantics
- Can transport any GUI this way

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

78

TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

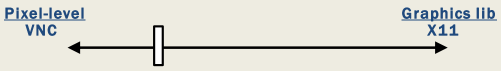
- Tradeoff space: abstraction level of remote display protocols



79

TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols



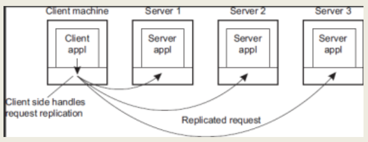
- Generic – no app context
- Graphics data
- Higher network bandwidth
- Fewer colors
- Utilize graphics compression
- More network traffic

- Application context is available
- UI data/operations
- Lower network bandwidth
- More colors

80

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



81

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

82

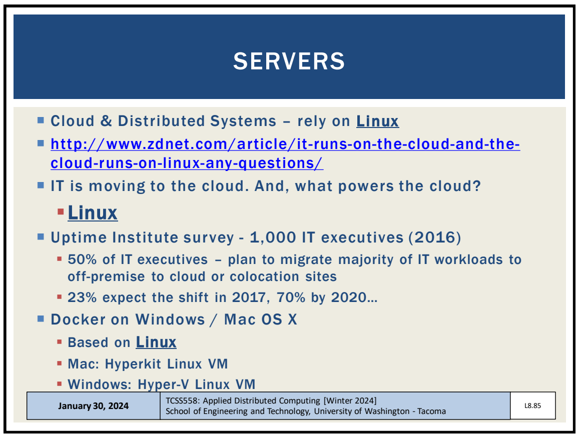
OBJECTIVES – 1/30

- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - **Chapter 3.4: Servers**

83

CH. 3.4: SERVERS

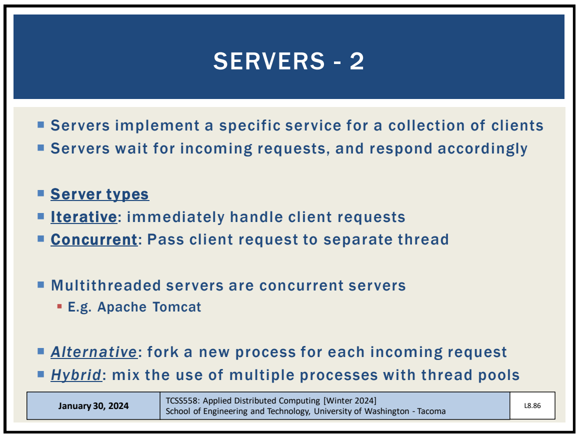
84



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

85



SERVERS - 2

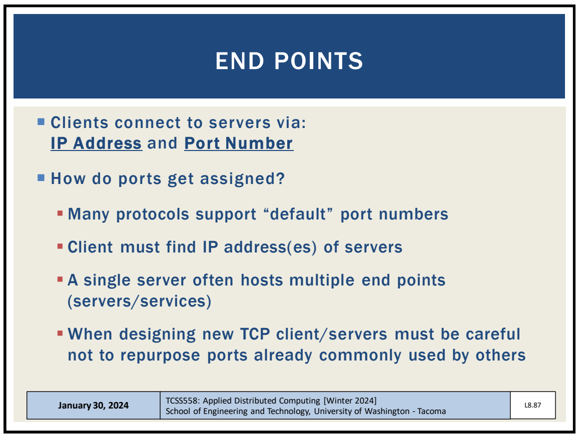
- Servers implement a specific service for a collection of clients
- Servers wait for incoming requests, and respond accordingly

- **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

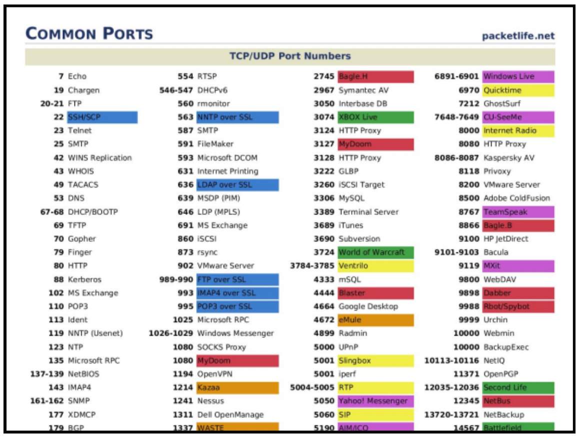
86



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

87



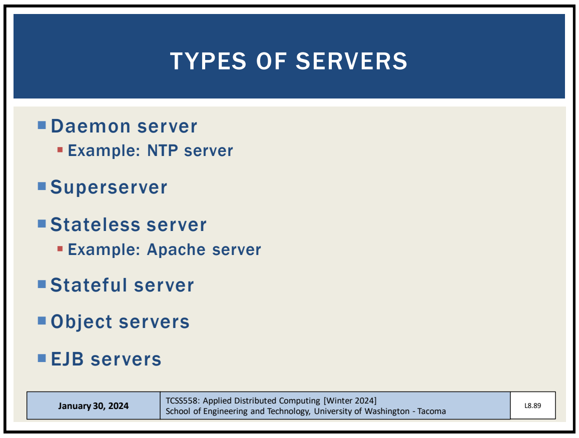
COMMON PORTS

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/ICQ	14567	Battlefield

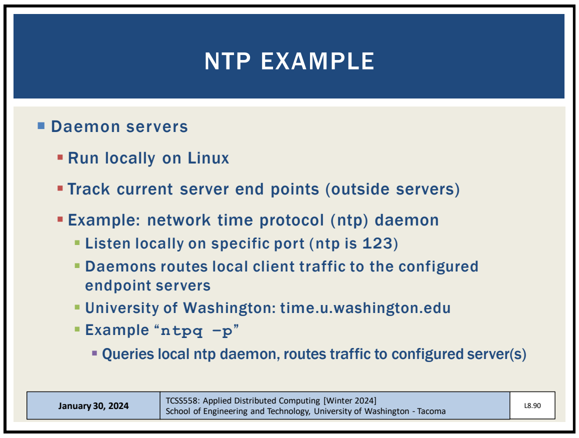
88



TYPES OF SERVERS

- Daemon server
  - Example: NTP server
- Superserver
- Stateless server
  - Example: Apache server
- Stateful server
- Object servers
- EJB servers

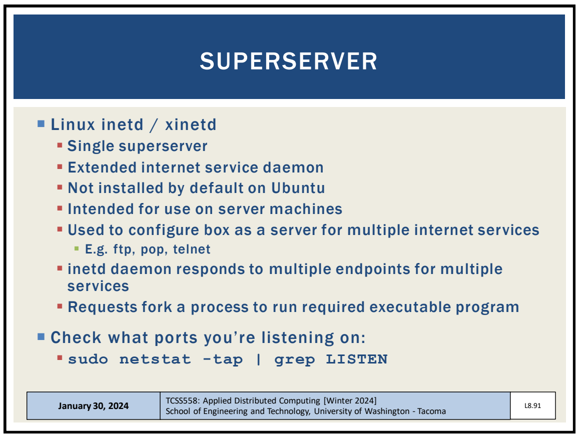
89



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)

90

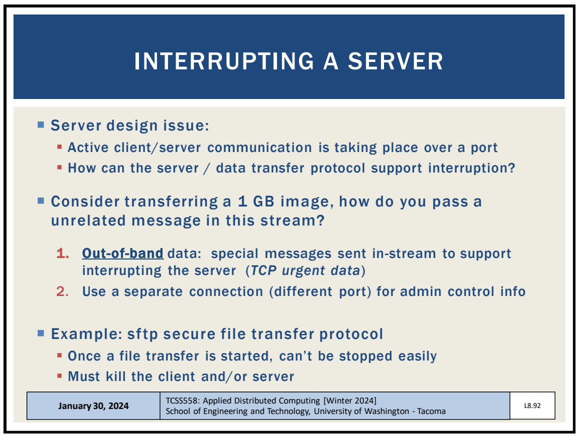


SUPERSERVER

- 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`

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.91

91

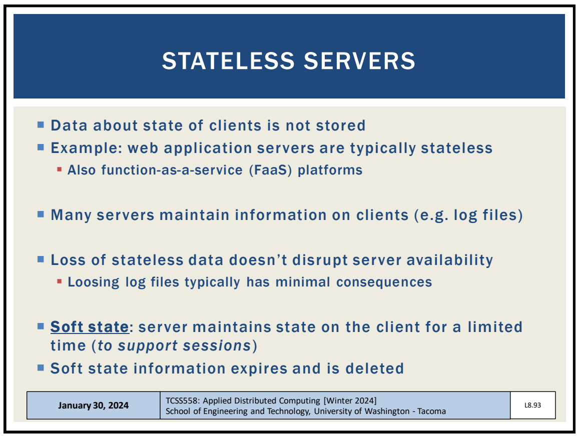


INTERRUPTING A SERVER

- 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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.92

92

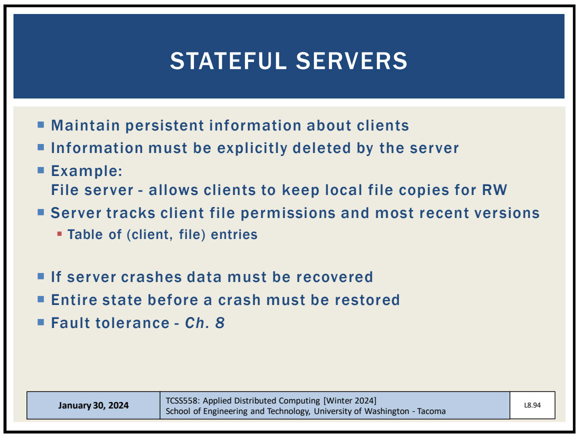


STATELESS SERVERS

- 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
  - Loosing 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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.93

93

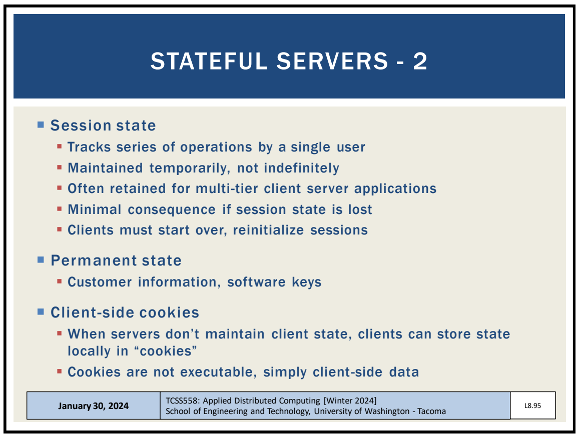


STATEFUL SERVERS

- 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*

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.94

94

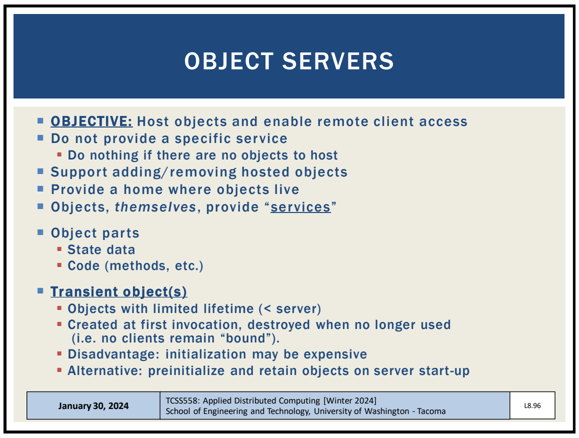


STATEFUL SERVERS - 2

- 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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.95

95



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

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.96

96

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?**

97

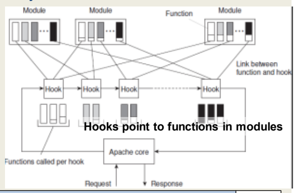
EJB – ENTERPRISE JAVA BEANS

- 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

98

APACHE WEB SERVER

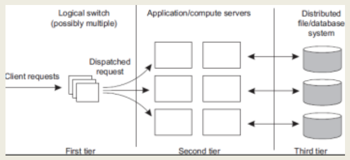
- Highly configurable, extensible, platform independent
- Supports TCP HTTP protocol communication
- Uses hooks – placeholders for group of functions
- Requests processed in phases by hooks
- Many hooks:
  - Translate a URL
  - Write info to log
  - Check client ID
  - Check access rights
- Hooks processed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


Module
Module
Function
Module
Link between function and hook
Hook
Hook
Hook
Hook
Hooks point to functions in modules
Apache core
Functions called per hook
Request
Response

99

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


Logical switch (possibly multiple)
Application/compute servers
Distributed file/database system
Dispatched request
Client requests
First tier
Second tier
Third tier

100

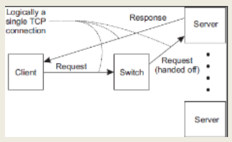
LAN REQUEST DISPATCHING

- 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

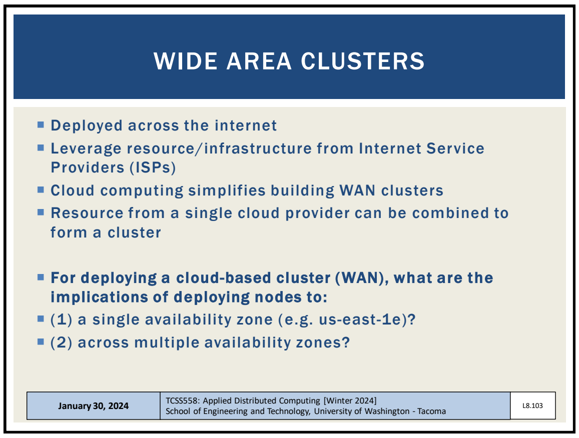
101

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



102

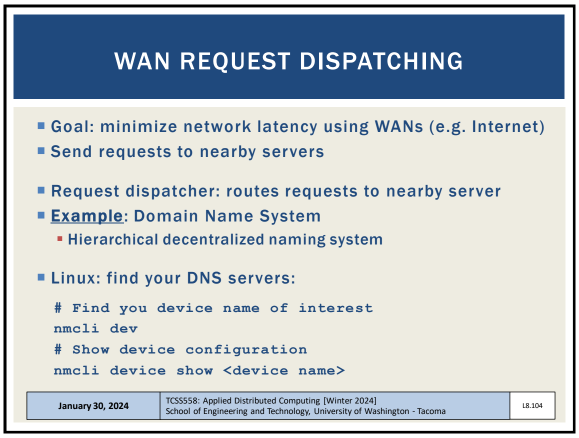


WIDE AREA CLUSTERS

- 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?

103



WAN REQUEST DISPATCHING

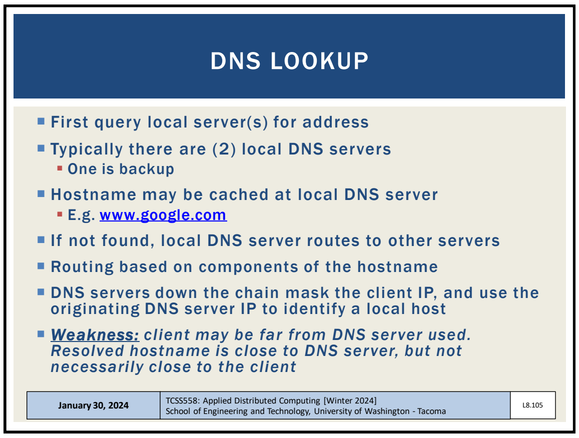
- Goal: minimize network latency using WANs (e.g. Internet)
- Send requests to nearby servers

- 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>
```

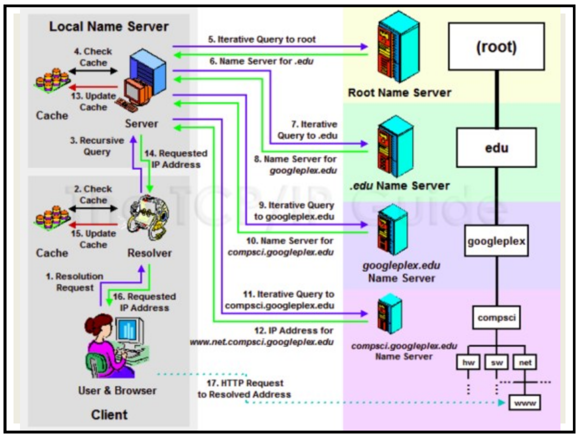
104



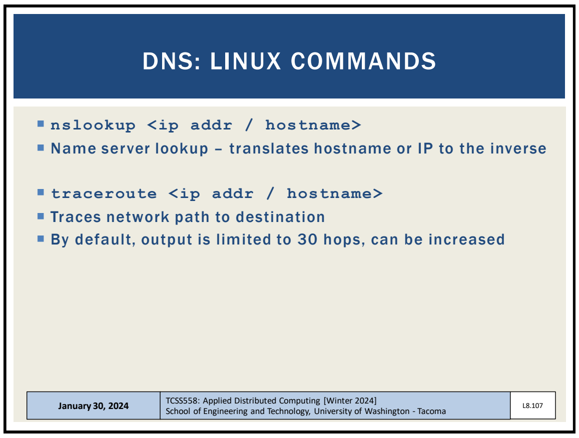
DNS LOOKUP

- 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*

105


Local Name Server
4. Check Cache
13. Update Cache
Cache
Server
3. Recursive Query
14. Requested IP Address
2. Check Cache
15. Update Cache
Cache
Resolver
1. Resolution Request
16. Requested IP Address
User & Browser
Client
5. Iterative Query to root
6. Name Server for .edu
7. Iterative Query to .edu
8. Name Server for googleplex.edu
9. Iterative Query to googleplex.edu
10. Name Server for compsci.googleplex.edu
11. Iterative Query to compsci.googleplex.edu
12. IP Address for www.net.compsci.googleplex.edu
17. HTTP Request to Resolved Address
Root Name Server
.edu Name Server
googleplex.edu Name Server
compsci.googleplex.edu Name Server
(root)
edu
googleplex
compsci
hw
sw
net
www

106

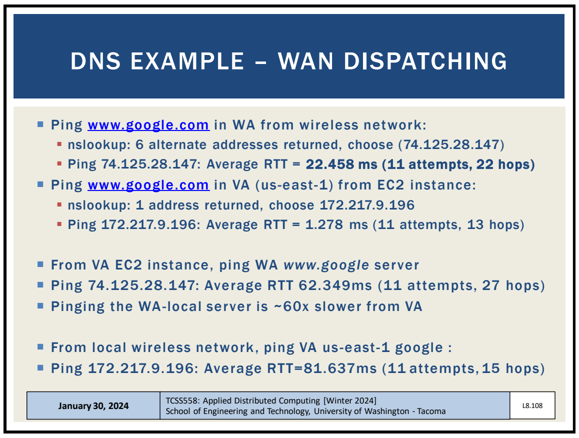


DNS: LINUX COMMANDS

- `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

107



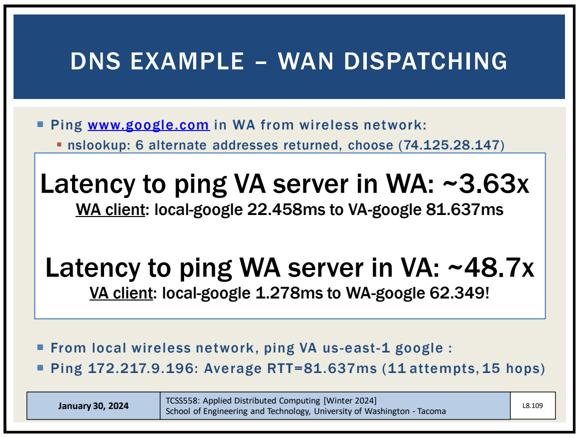
DNS EXAMPLE – WAN DISPATCHING

- 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)

108



DNS EXAMPLE – WAN DISPATCHING

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

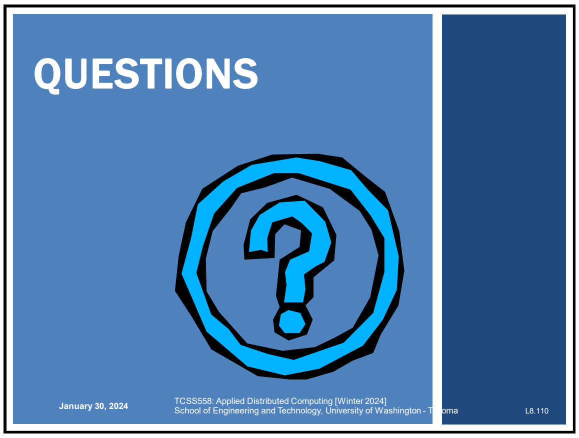
Latency to ping VA server in WA: ~3.63x
WA client: local-google 22.458ms to VA-google 81.637ms

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)

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.109

109



QUESTIONS

January 30, 2024 | TCSS558: Applied Distributed Computing [Winter 2024] School of Engineering and Technology, University of Washington - Tacoma | L8.110

110