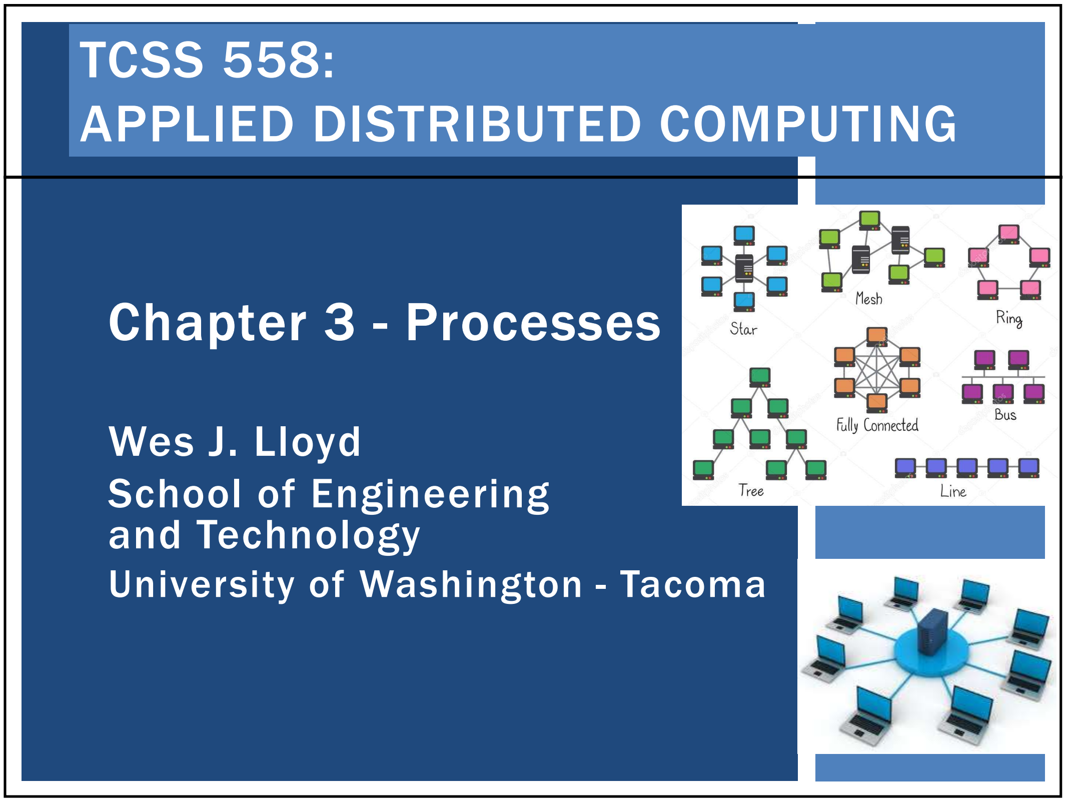

TCSS 558:
APPLIED DISTRIBUTED COMPUTING

Chapter 3 - Processes

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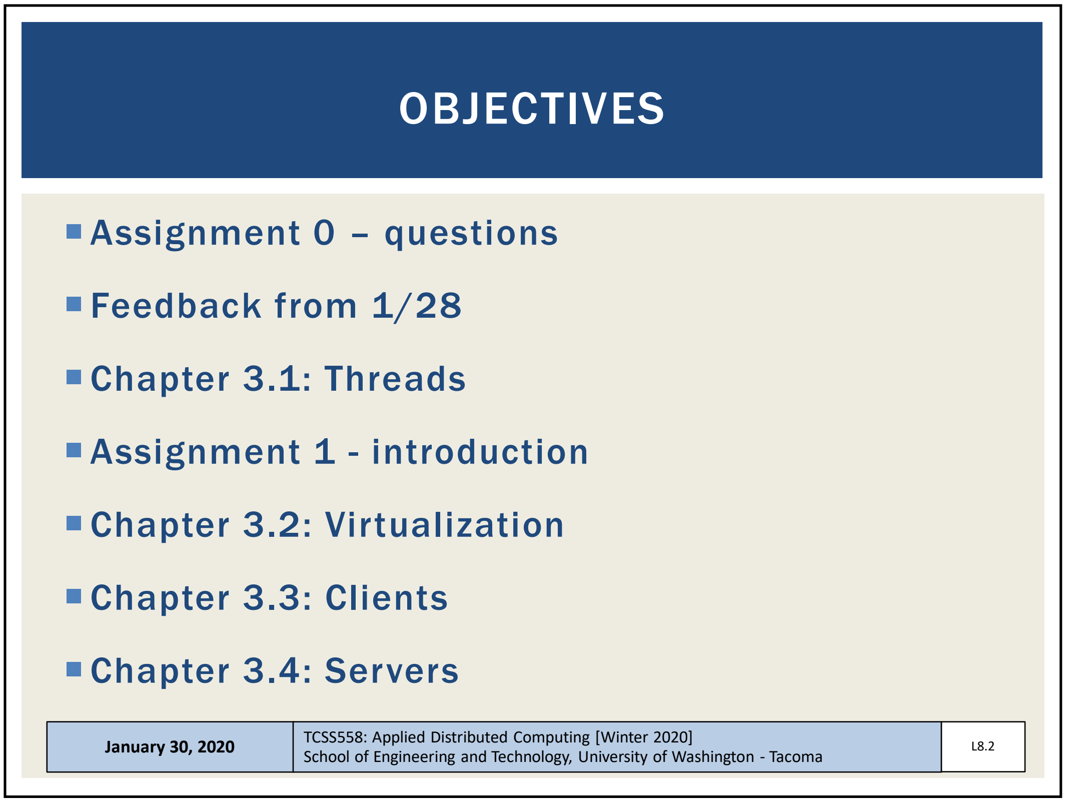

OBJECTIVES

- Assignment 0 – questions
- Feedback from 1/28
- Chapter 3.1: Threads
- Assignment 1 - introduction
- Chapter 3.2: Virtualization
- Chapter 3.3: Clients
- Chapter 3.4: Servers

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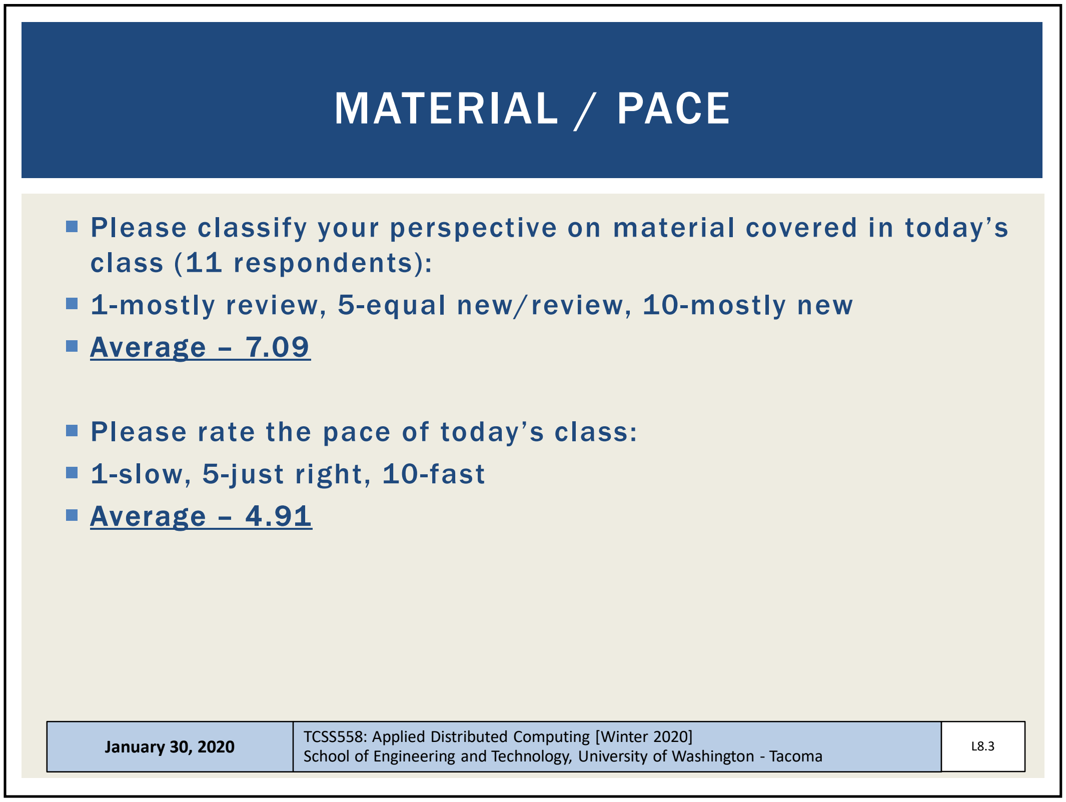
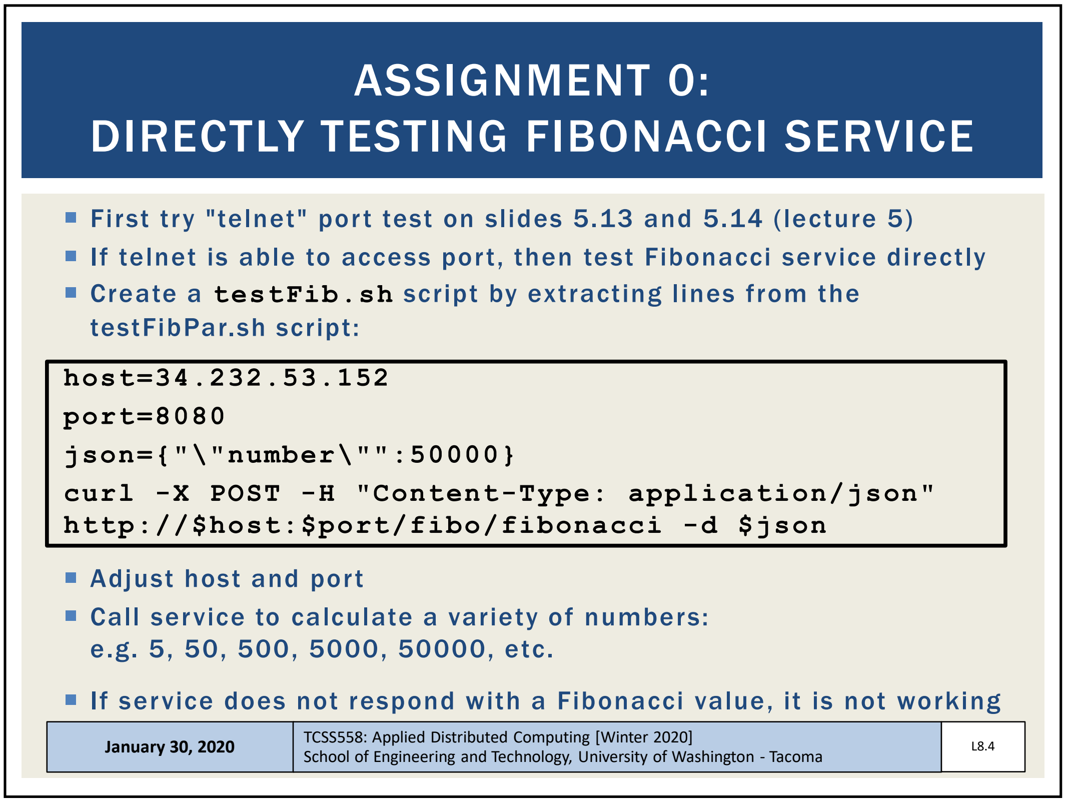


MATERIAL / PACE

- Please classify your perspective on material covered in today's class (11 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- Average – 7.09

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- Average – 4.91

3



ASSIGNMENT 0: DIRECTLY TESTING FIBONACCI SERVICE

- First try "telnet" port test on slides 5.13 and 5.14 (lecture 5)
- If telnet is able to access port, then test Fibonacci service directly
- Create a **testFib.sh** script by extracting lines from the testFibPar.sh script:

```
host=34.232.53.152
port=8080
json={"\"number\"":50000}
curl -X POST -H "Content-Type: application/json"
http://$host:$port/fibo/fibonacci -d $json
```

- Adjust host and port
- Call service to calculate a variety of numbers: e.g. 5, 50, 500, 5000, 50000, etc.

- If service does not respond with a Fibonacci value, it is not working

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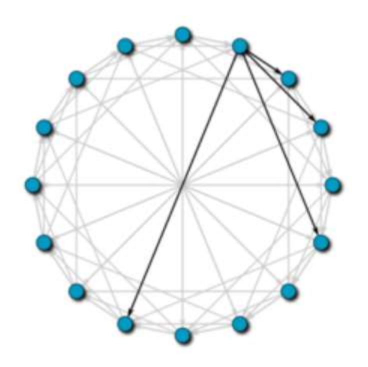
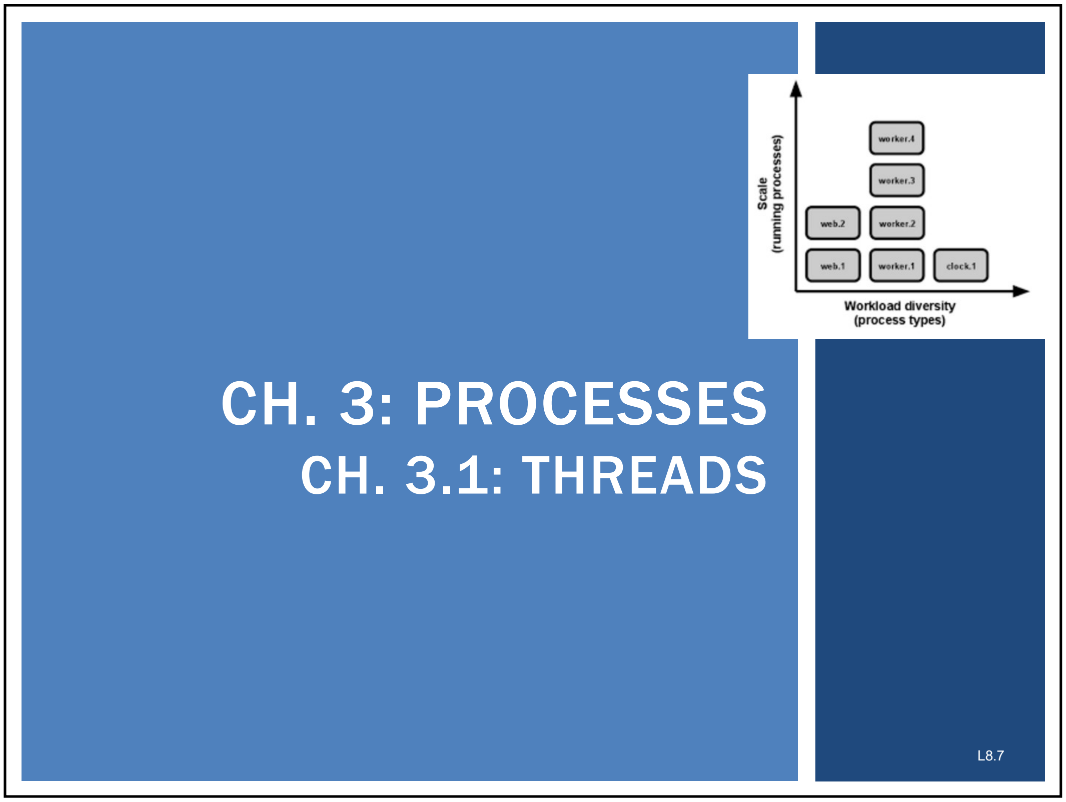
FEEDBACK FROM 1/28

- ***How does a system get implemented as structure vs. unstructured?***
- Developers or designers may intentionally select the distributed system architecture
- - OR - there may be no choice.
  A given architecture is **required** by the constraints of the devices involved in the communication
- **Example**: Ad hoc wireless sensor network
  - Structured peer-to-peer not option as nodes rapidly join & leave
  - Centralized client/server or multitier not possible as system has only peer nodes and no central servers

FEEDBACK - 2

- What is the difference between adhoc lists that nodes in an **Unstructured Peer-to-Peer System** maintain, and the finger table stored by nodes of a **Chord System**?
- Key similarity:
  - Both lists consist of nodes that the nodes can directly communicate with
  - There is a 1-hop network link
- Key difference:
  - Finger tables in Chord System are used to route messages to implement a distributed hash table
  - Each node has table that describes how to route queries
  - *(more in Ch. 5)*




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

CH. 3: PROCESSES

CH. 3.1: THREADS

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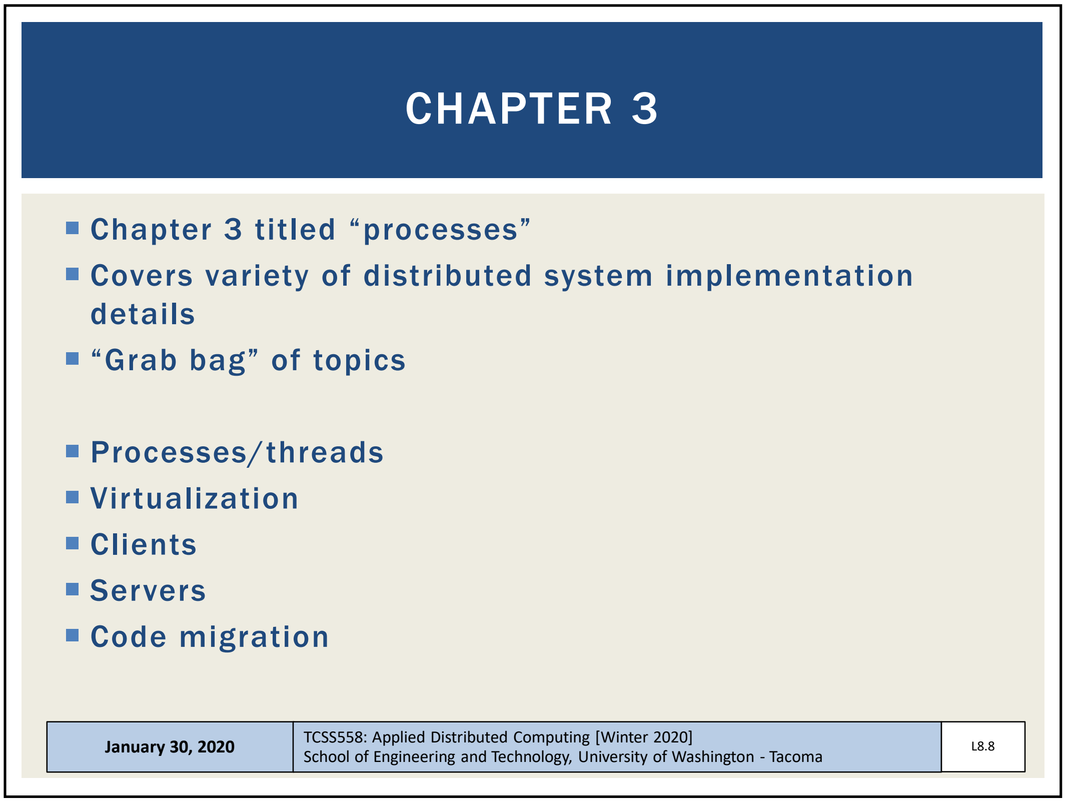

CHAPTER 3

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

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

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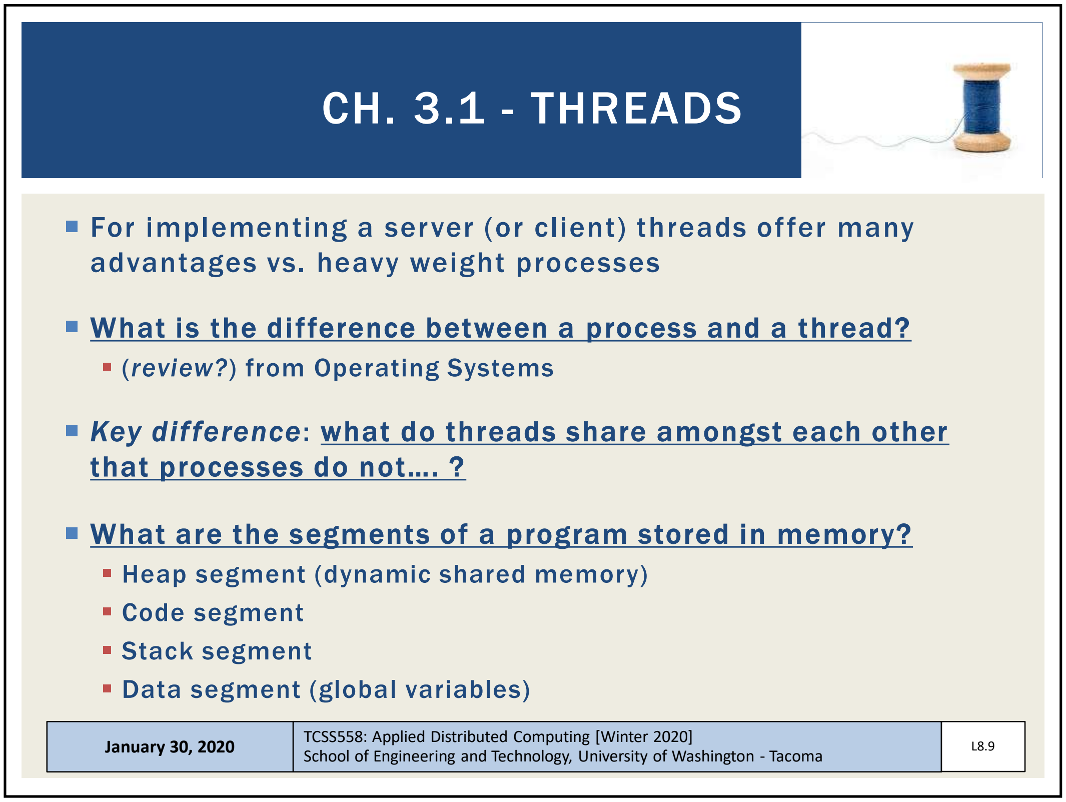

CH. 3.1 - THREADS

- 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)

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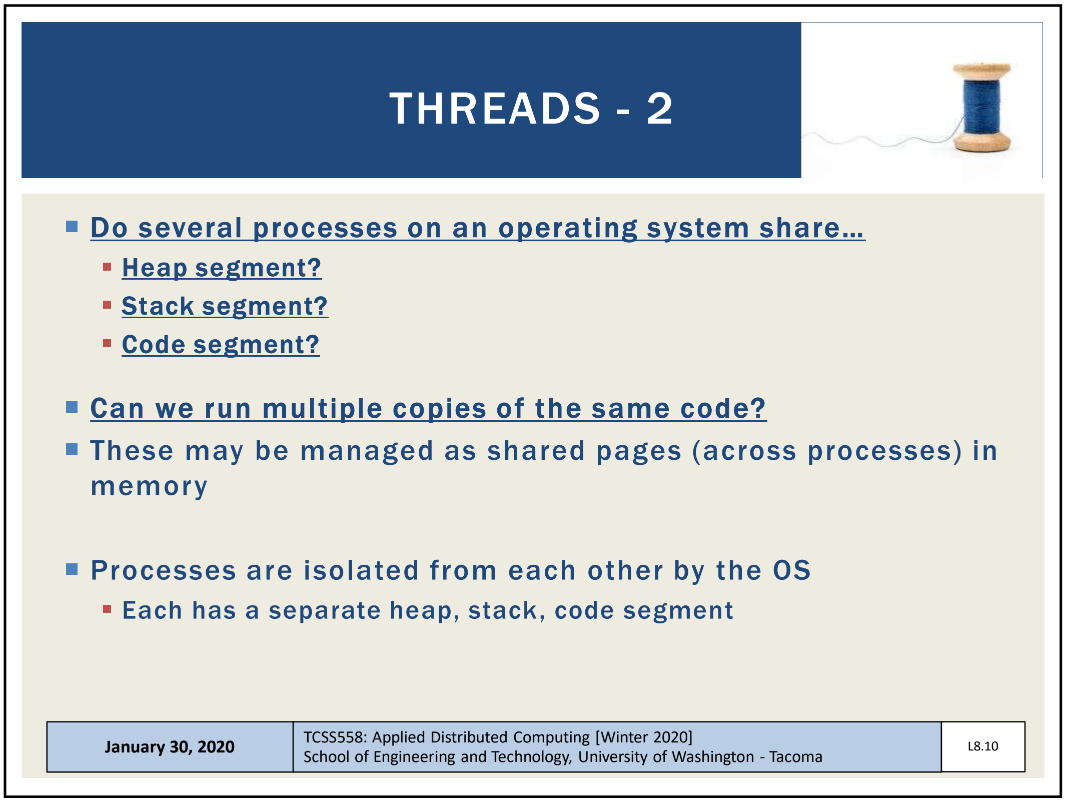

THREADS - 2

- 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

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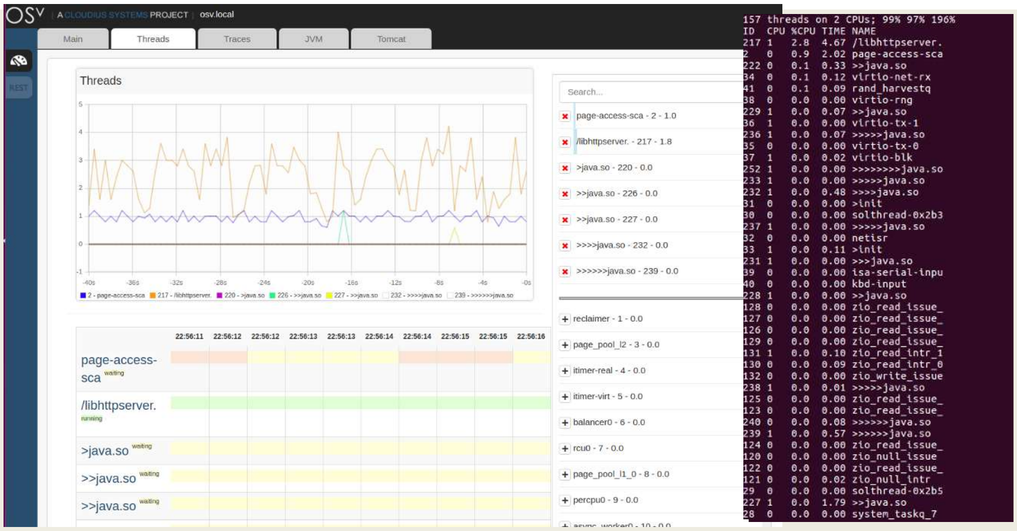
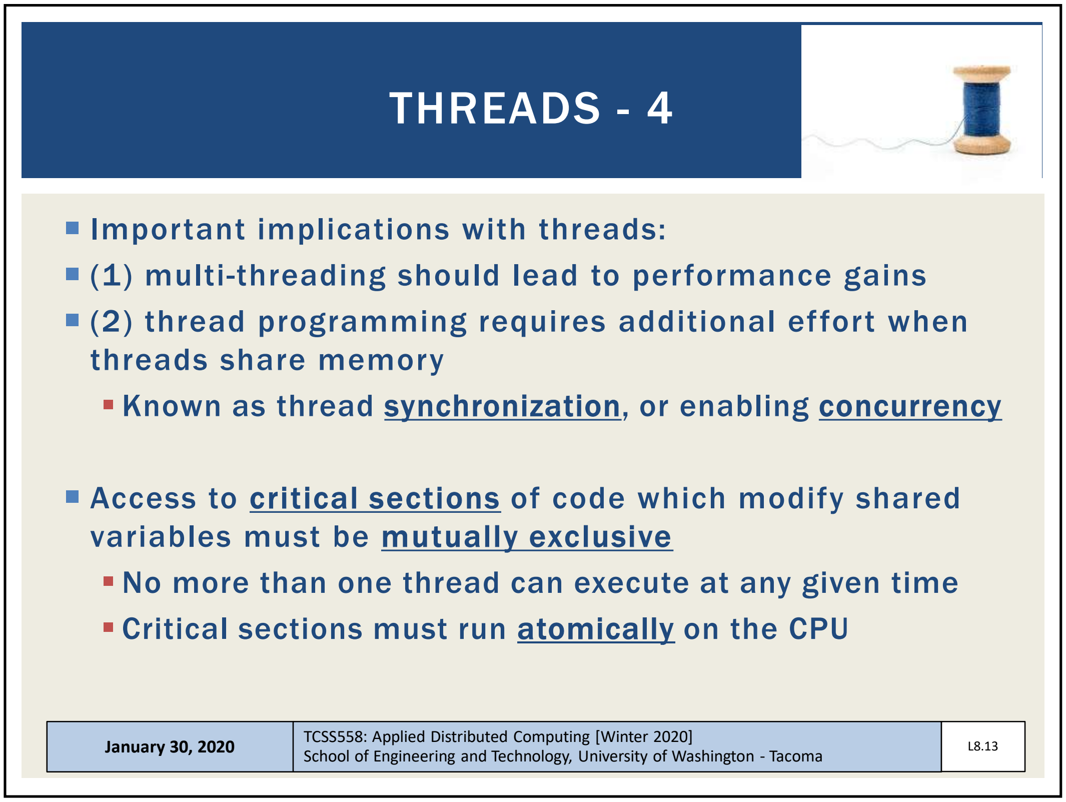
THREADS - 3

- Threads avoid the overhead of process creation
- No new 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

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  0.08 >>>>>>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
```



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

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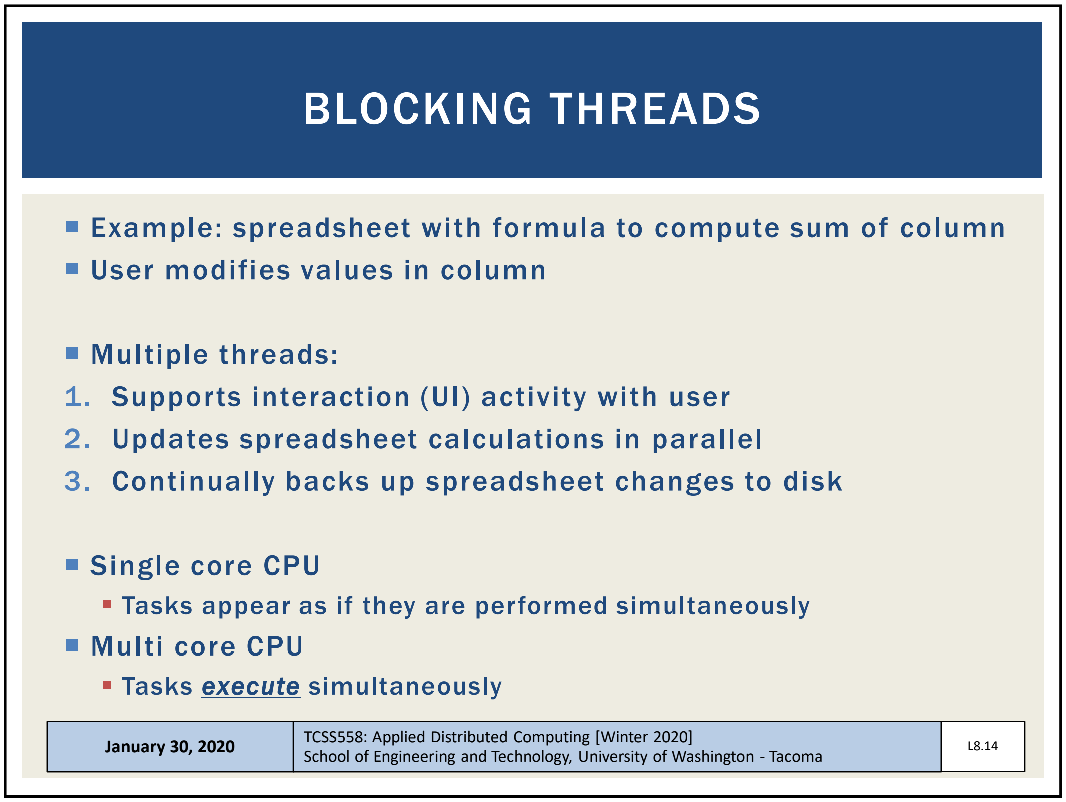

BLOCKING THREADS

- 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

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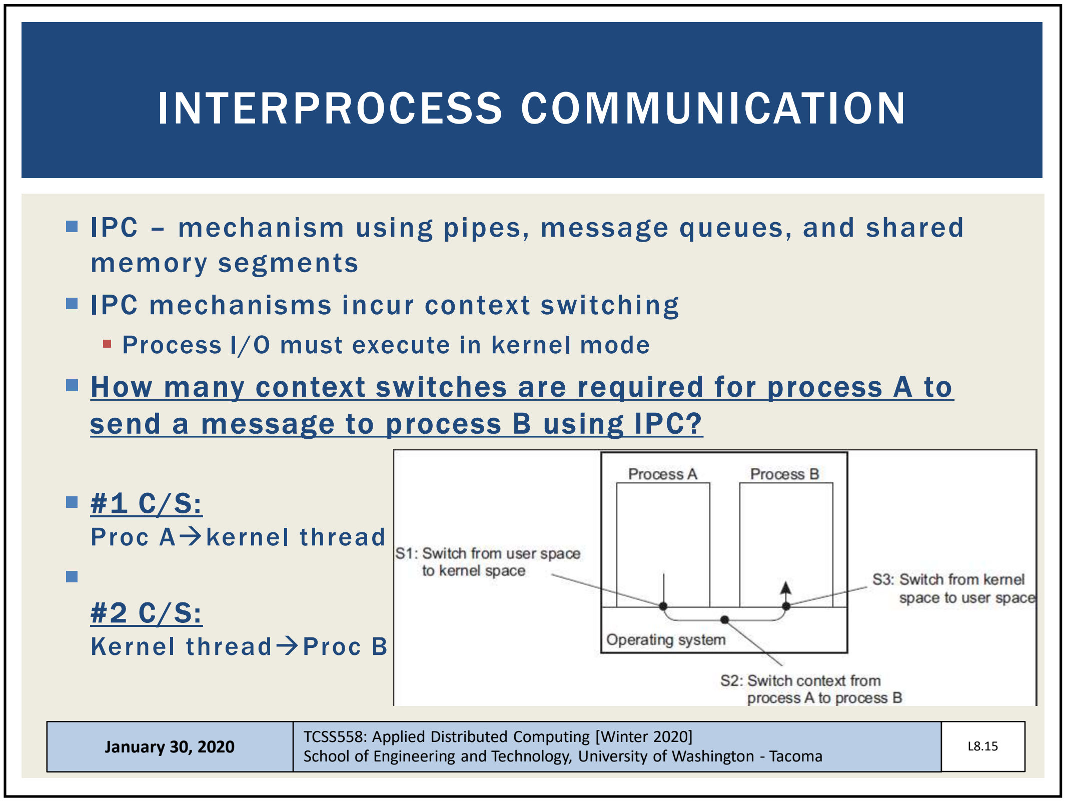

INTERPROCESS COMMUNICATION

- 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

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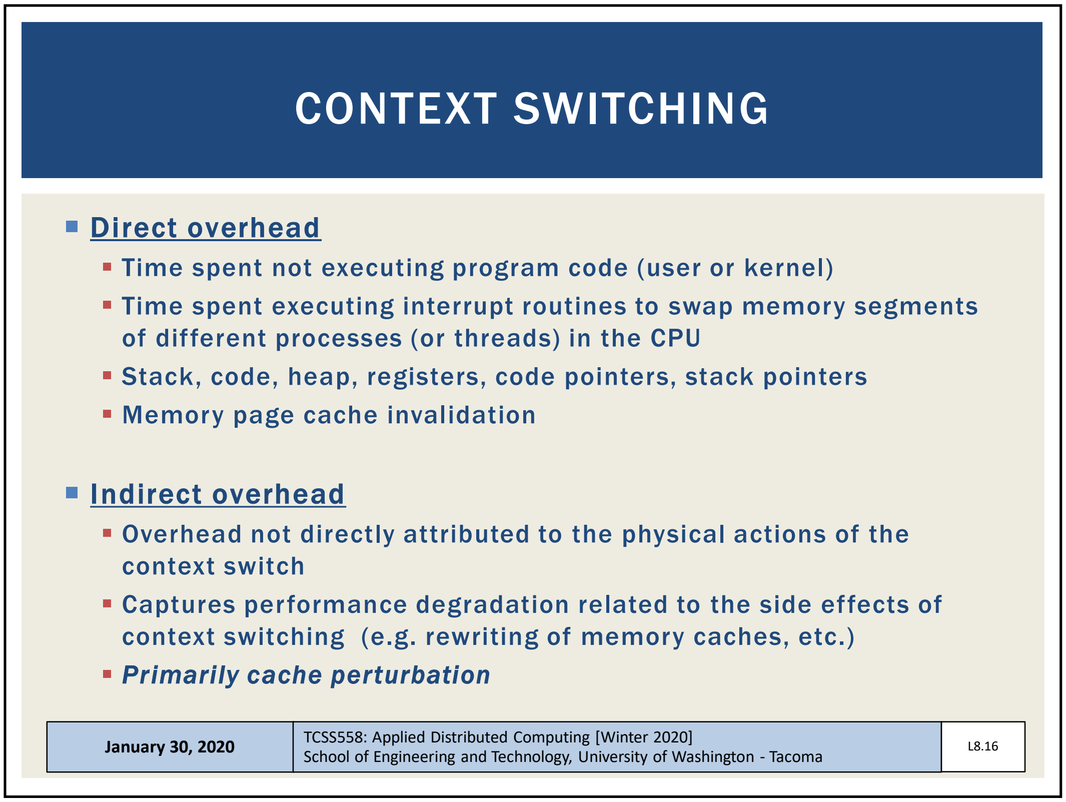

CONTEXT SWITCHING

- **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***

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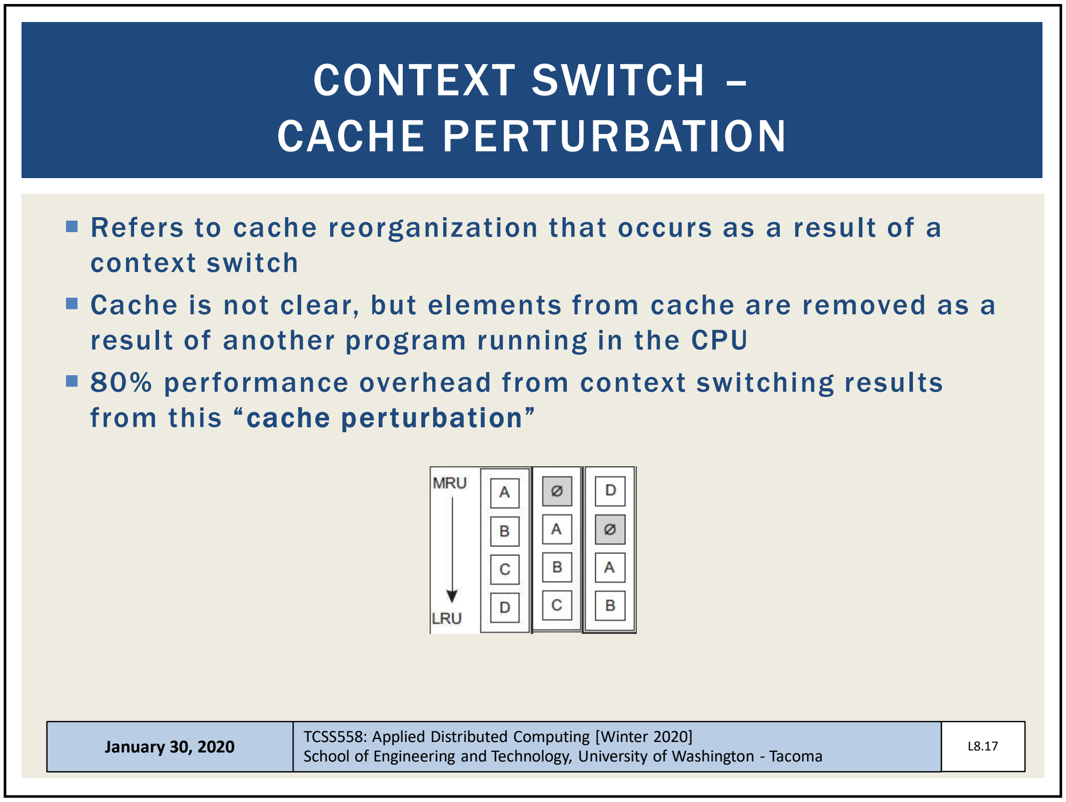
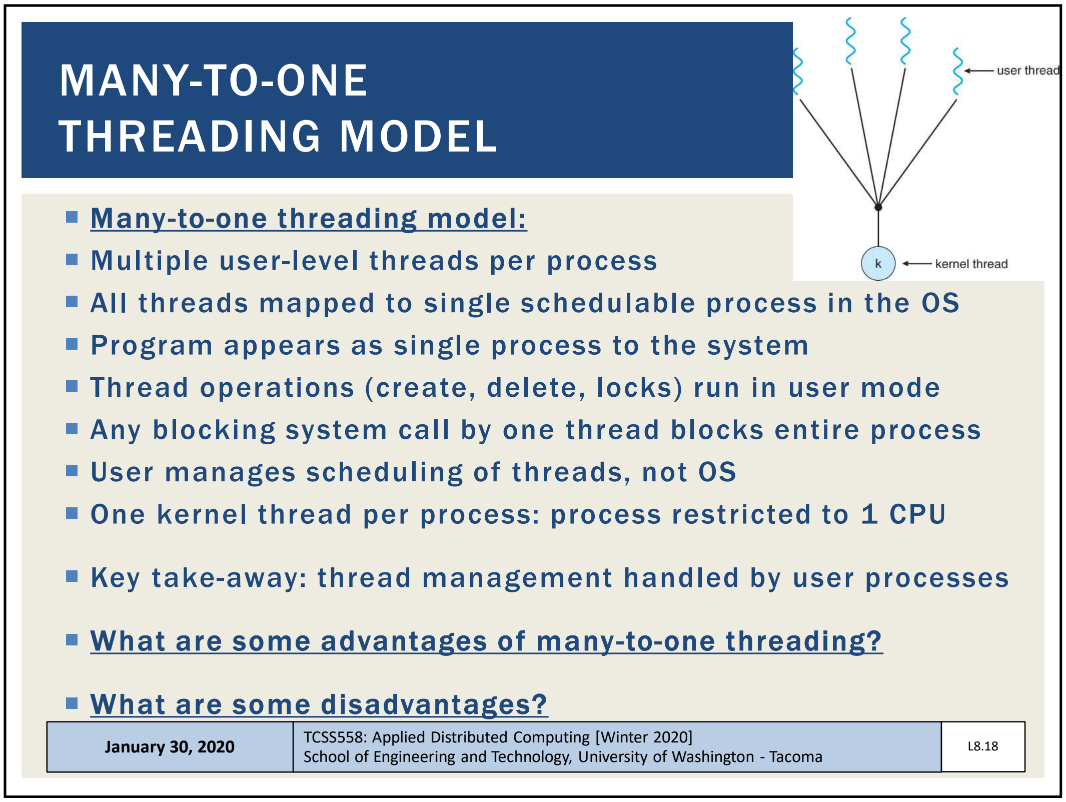


CONTEXT SWITCH – CACHE PERTURBATION

- 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**"

MRU
LRU
A
B
C
D
∅
A
B
C
D
∅
A
B

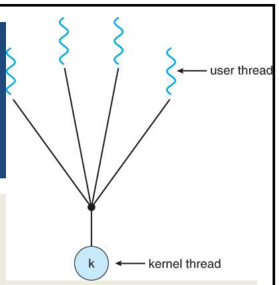


MANY-TO-ONE THREADING MODEL

user thread
k
kernel thread

- <u>**Many-to-one threading model:**</u>
- Multiple user-level threads per process
- All threads mapped to single schedulable process in the OS
- Program appears as single process to the system
- Thread operations (create, delete, locks) run in user mode
- Any blocking system call by one thread blocks entire process
- User manages scheduling of threads, not OS
- One kernel thread per process: process restricted to 1 CPU
- Key take-away: thread management handled by user processes
- <u>**What are some advantages of many-to-one threading?**</u>
- <u>**What are some disadvantages?**</u>

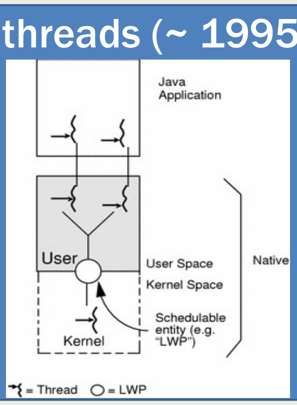
MANY-TO-ONE THREADING MODEL



- **Many-to-one threading model:**
- Multiple user-level threads per process

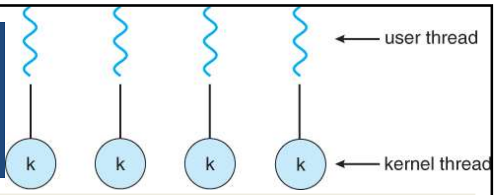
Initial implementation of Java threads (~ 1995?) used many-to-one threading model

This threading model is now seldomly used

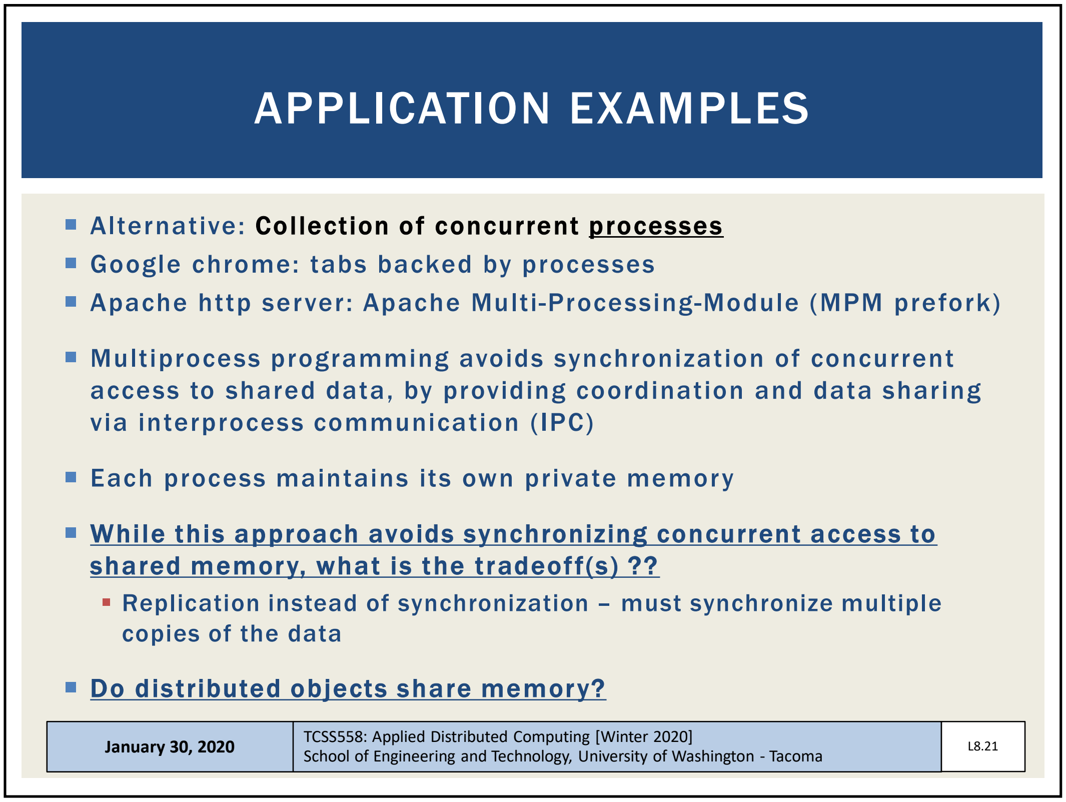


- **What are some disadvantages?**

ONE-TO-ONE THREADING MODEL



- Threads operations managed by the OS (create, delete, lock)
- Thread ops run in kernel mode using separate kernel threads
  - Kernel API calls farmed out to preinitialized kernel level theads
  - Requires system calls and context switch from user to kernel thread
- One user thread to one kernel thread
- User process can use many kernel threads
- Also called ***kernel-level threads***
- All threads scheduled individually by the OS
- Enables running single process across multiple CPUs
- Now commonly used… (used in Linux)
- **What are some advantages of one-to-one threading?**
- **What are some disadvantages?**



APPLICATION EXAMPLES

- Alternative: **Collection of concurrent <u>processes</u>**
- Google chrome: tabs backed by processes
- Apache http server: Apache Multi-Processing-Module (MPM prefork)
- 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
- **<u>While this approach avoids synchronizing concurrent access to shared memory, what is the tradeoff(s) ??</u>**
  - Replication instead of synchronization – must synchronize multiple copies of the data
- **<u>Do distributed objects share memory?</u>**

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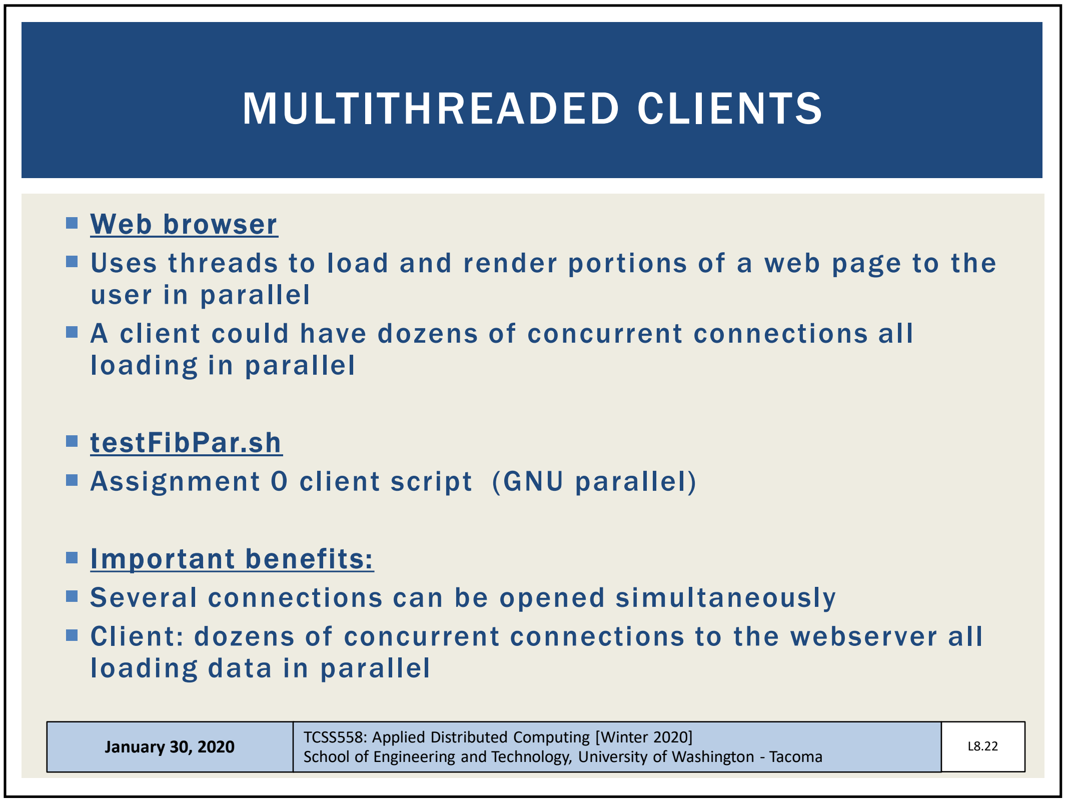

MULTITHREADED CLIENTS

- **<u>Web browser</u>**
- 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
- **<u>testFibPar.sh</u>**
- Assignment 0 client script (GNU parallel)
- **<u>Important benefits:</u>**
- Several connections can be opened simultaneously
- Client: dozens of concurrent connections to the webserver all loading data in parallel

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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

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

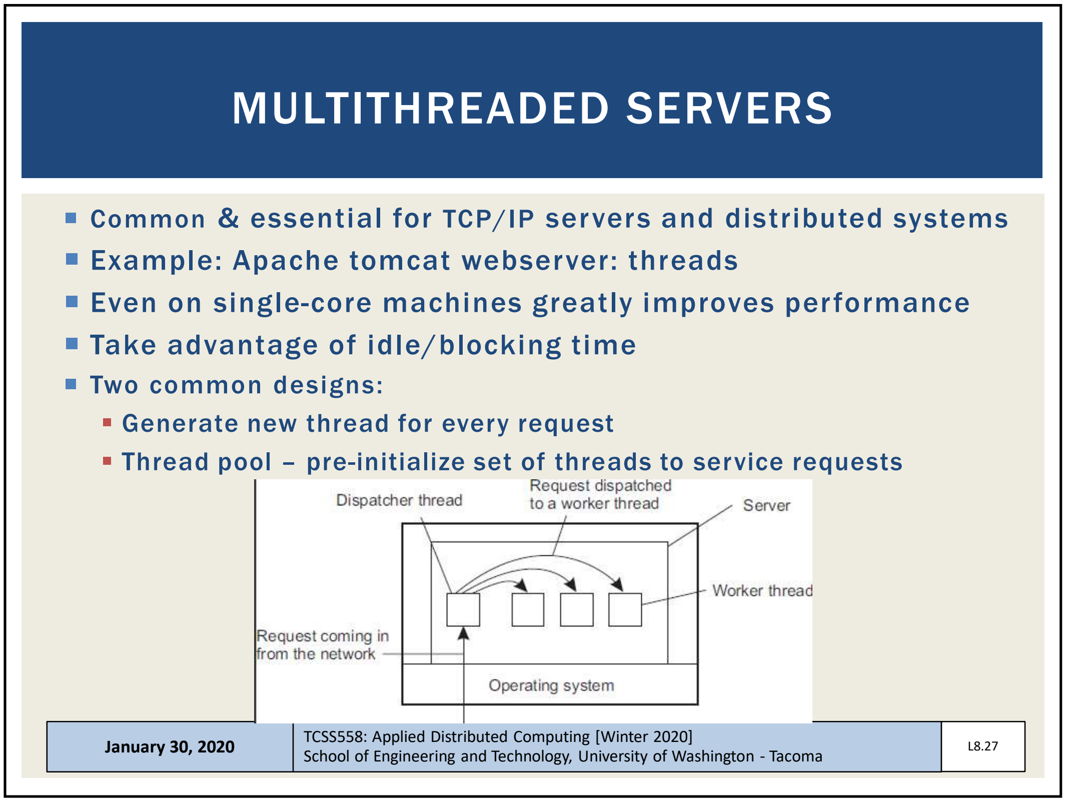
- 1.0 = 1-CPU core fully loaded
- 2.0 = 2-CPU cores
- 3.0 = 3-CPU cores . . .

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
- <u>Measure TLP to understand how many CPUs to provision</u>



MULTITHREADED SERVERS

- Common & essential for TCP/IP servers and distributed systems
- Example: Apache tomcat webserver: threads
- Even on single-core machines greatly improves performance
- Take advantage of idle/blocking time
- Two common 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

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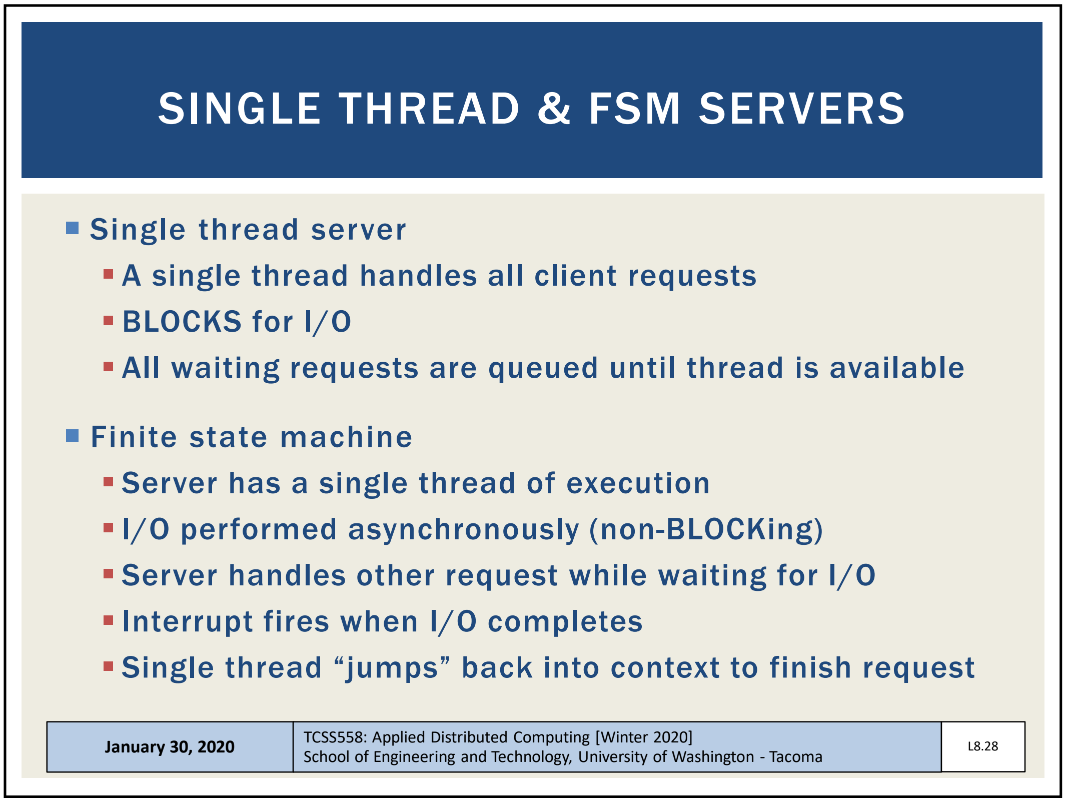

SINGLE THREAD & FSM SERVERS

- 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 performed asynchronously (non-BLOCKing)
  - Server handles other request while waiting for I/O
  - Interrupt fires when I/O completes
  - Single thread "jumps" back into context to finish request

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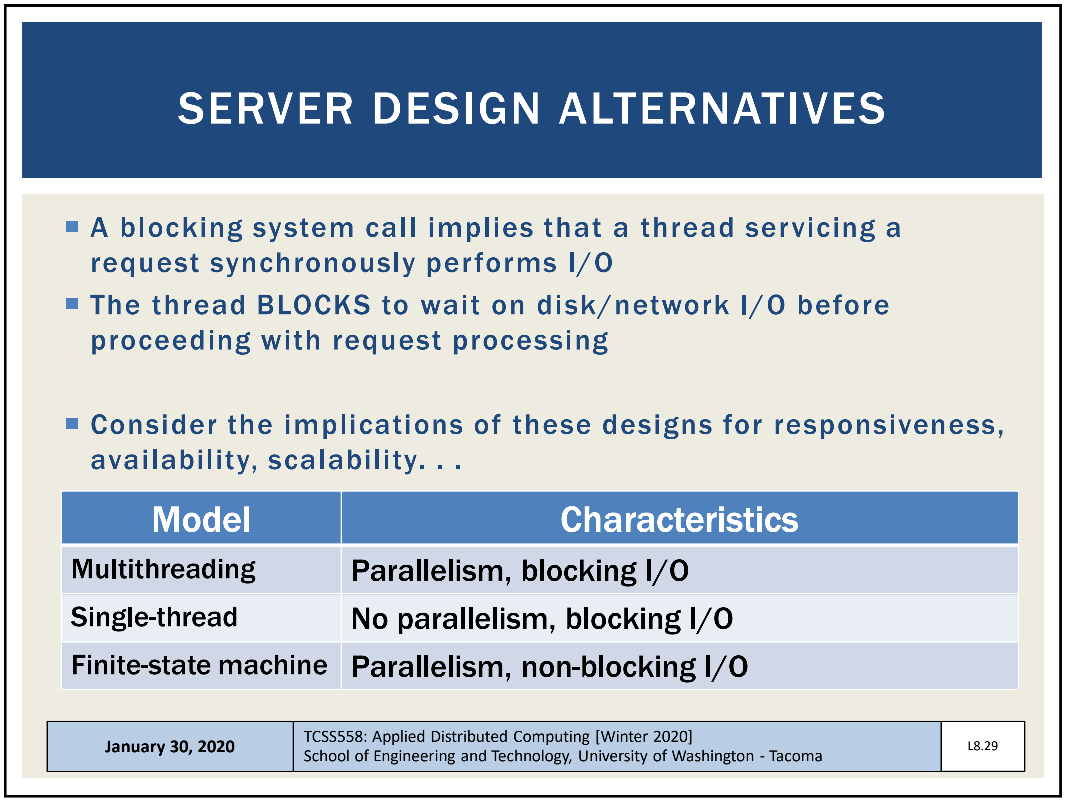

SERVER DESIGN ALTERNATIVES

- 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

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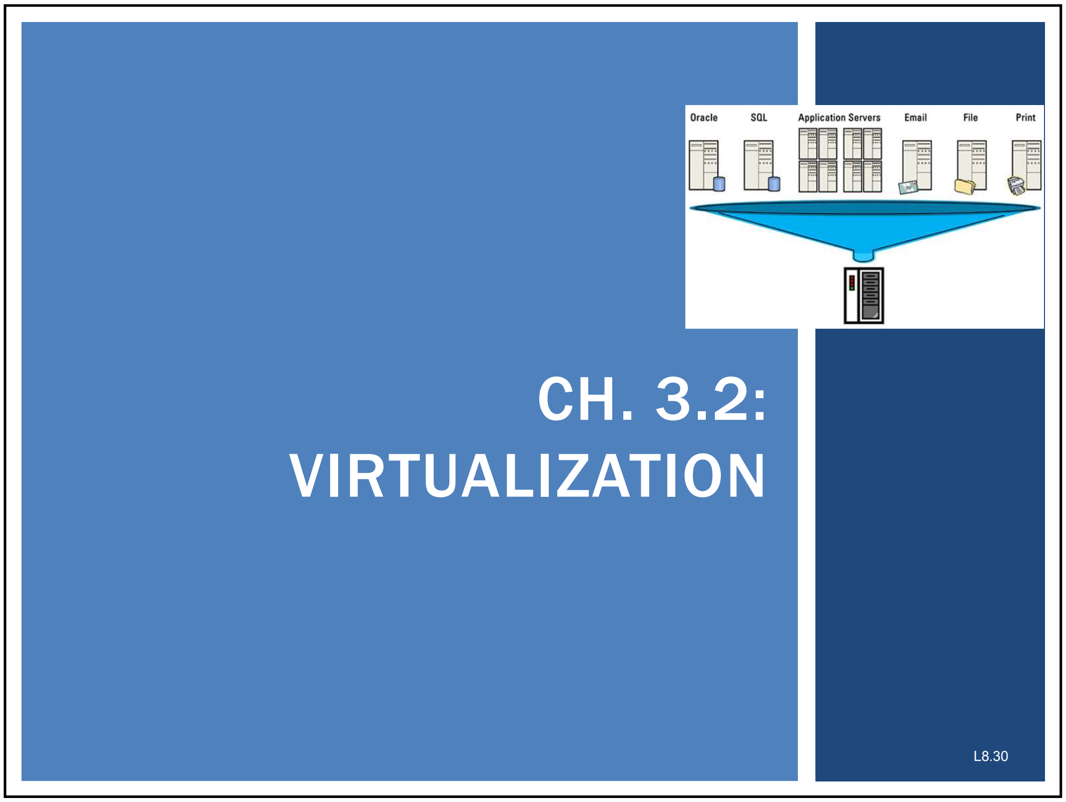

CH. 3.2: VIRTUALIZATION

L8.30

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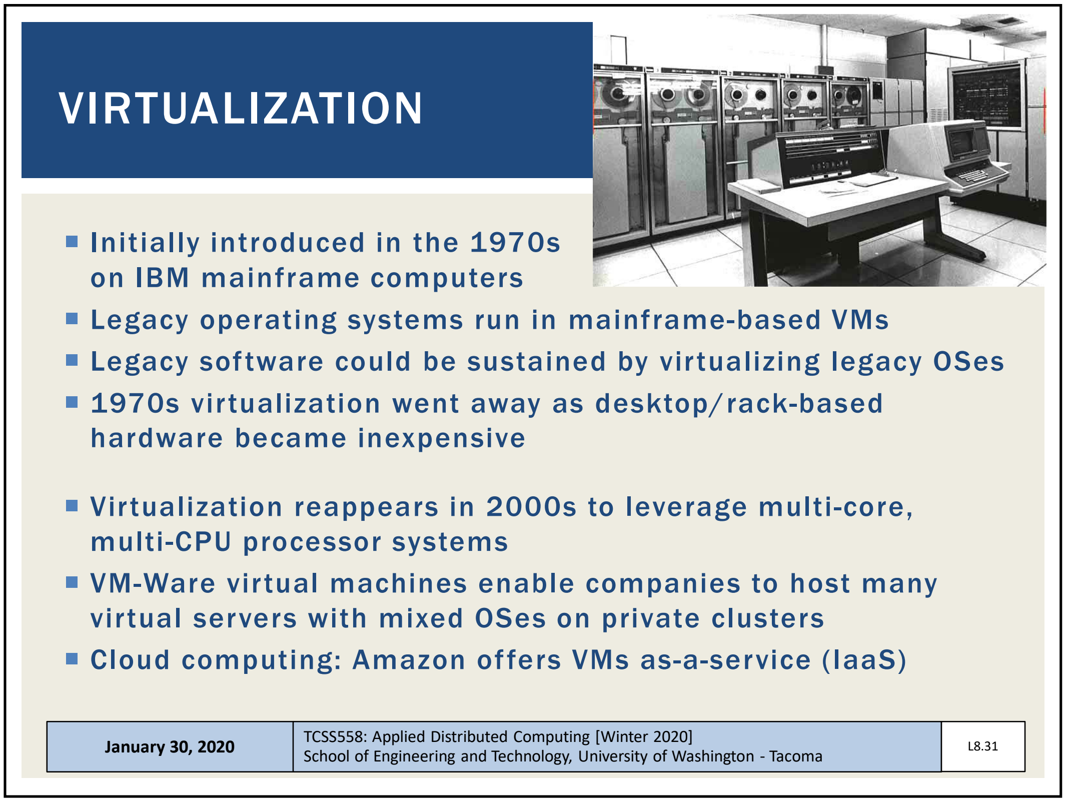
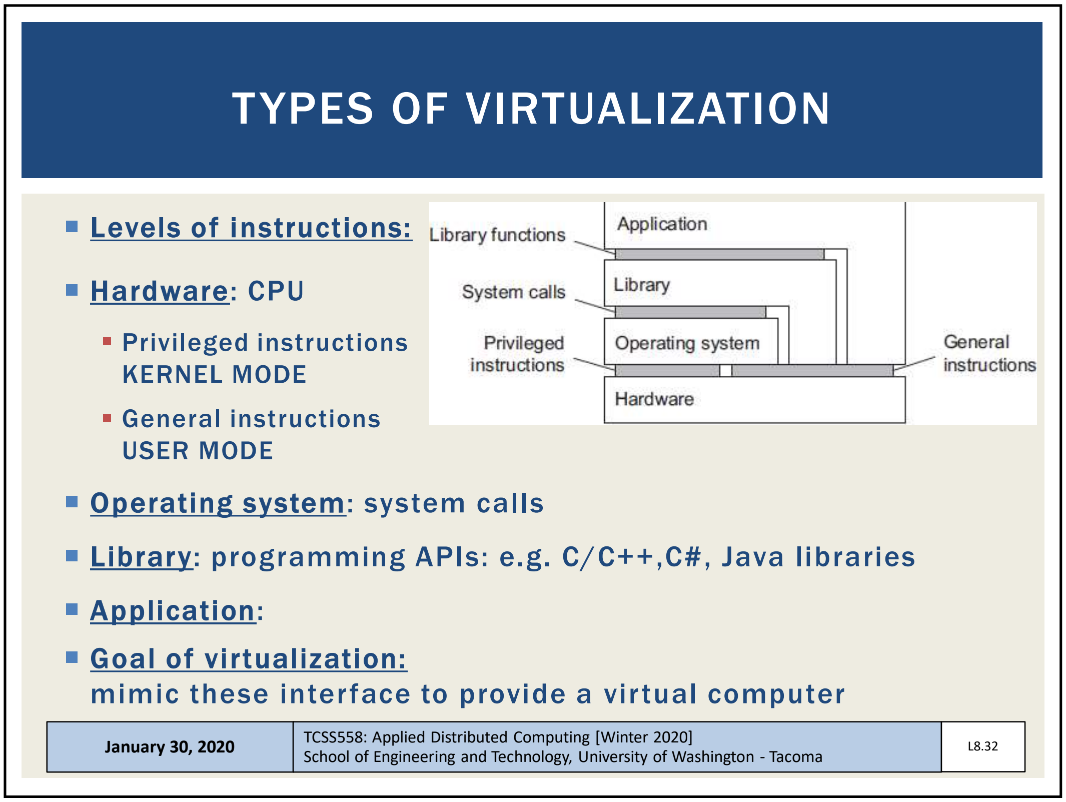


VIRTUALIZATION

- 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

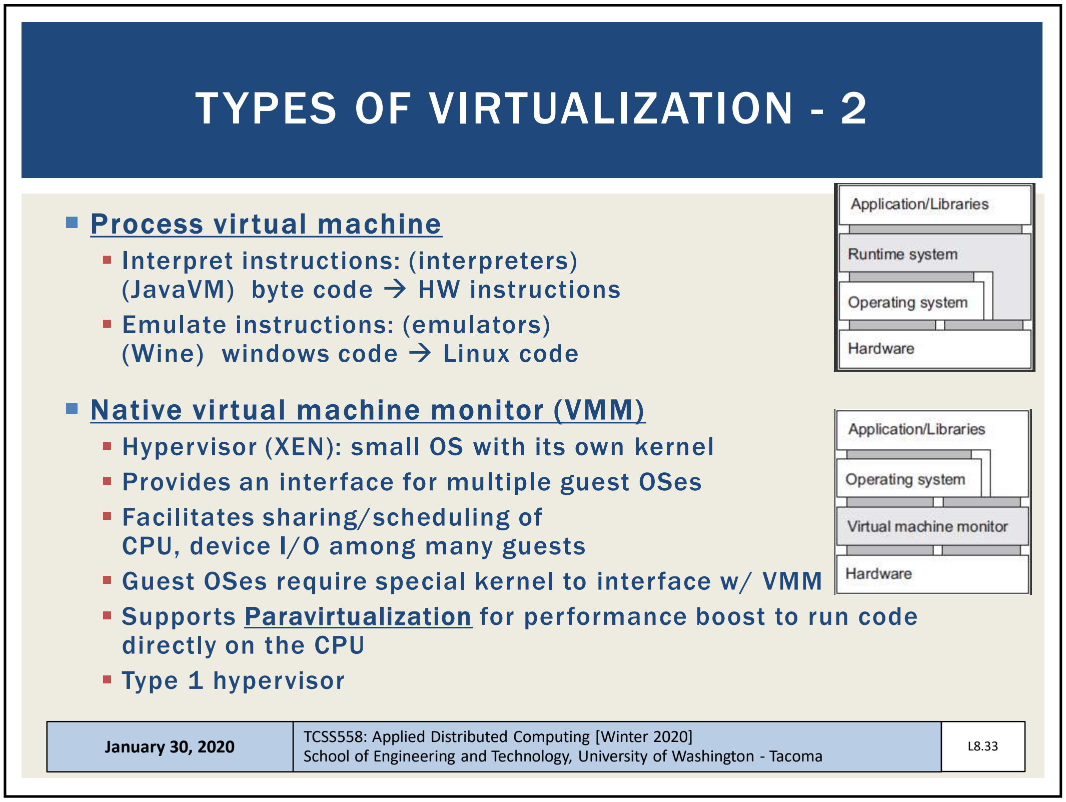
- Virtualization reappears in 2000s to leverage multi-core, multi-CPU processor systems
- VM-Ware virtual machines enable companies to host many virtual servers with mixed OSes on private clusters
- Cloud computing: Amazon offers VMs as-a-service (IaaS)



TYPES OF VIRTUALIZATION

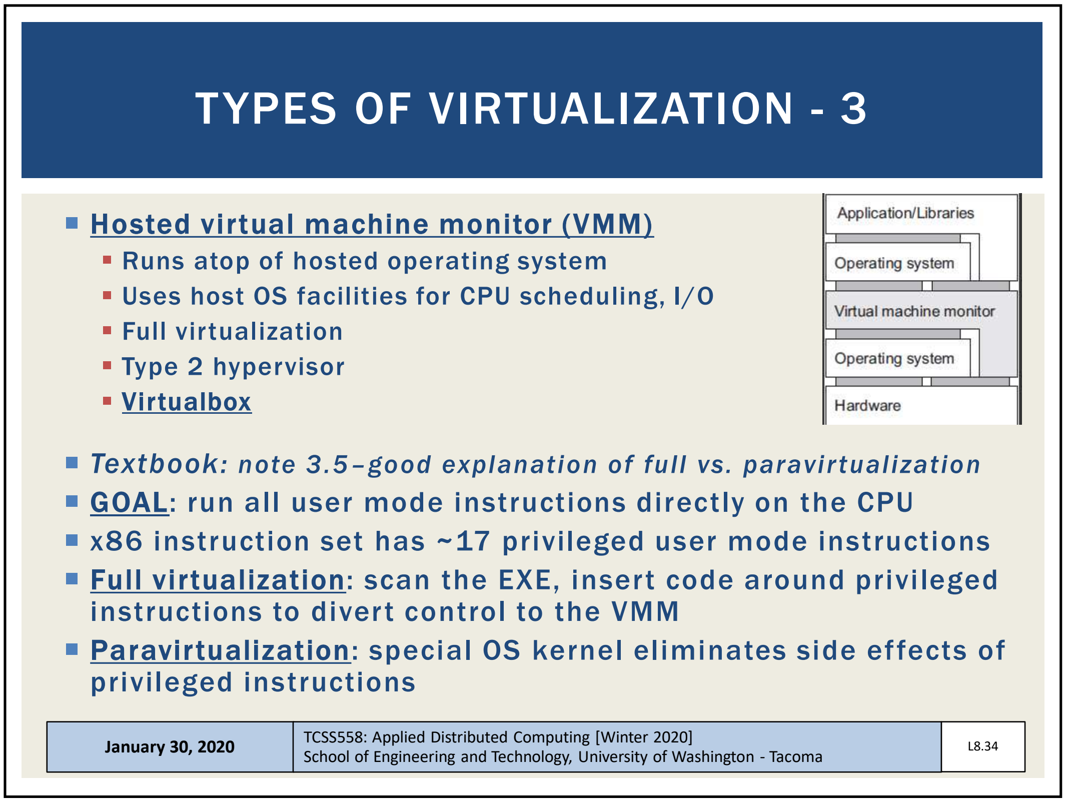
- **Levels of instructions:**
- **Hardware**: CPU
  - Privileged instructions KERNEL MODE
  - General instructions USER MODE
- **Operating system**: system calls
- **Library**: programming APIs: e.g. C/C++,C#, Java libraries
- **Application**:
- **Goal of virtualization:** mimic these interface to provide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

Library functions
Application
System calls
Library
Privileged instructions
Operating system
General instructions
Hardware



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



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**

Application/Libraries
Operating system
Virtual machine monitor
Operating system
Hardware

- *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

EVOLUTION OF AWS VIRTUALIZATION

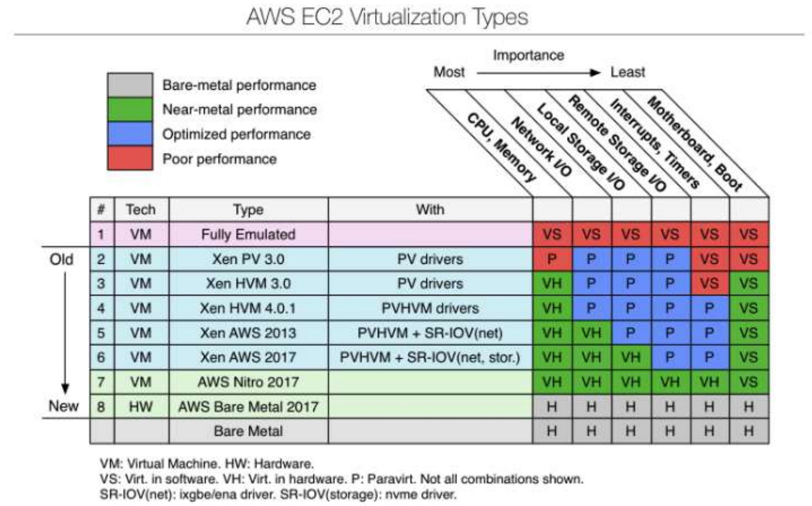
From http://www.brendangregg.com/blog/2017-11-29/aws-ec2-virtualization-2017.html

VS: Virtualization In software

P: Paravirtual

VH: Virtualization In Hardware

H: Hardware



AWS EC2 Virtualization Types

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

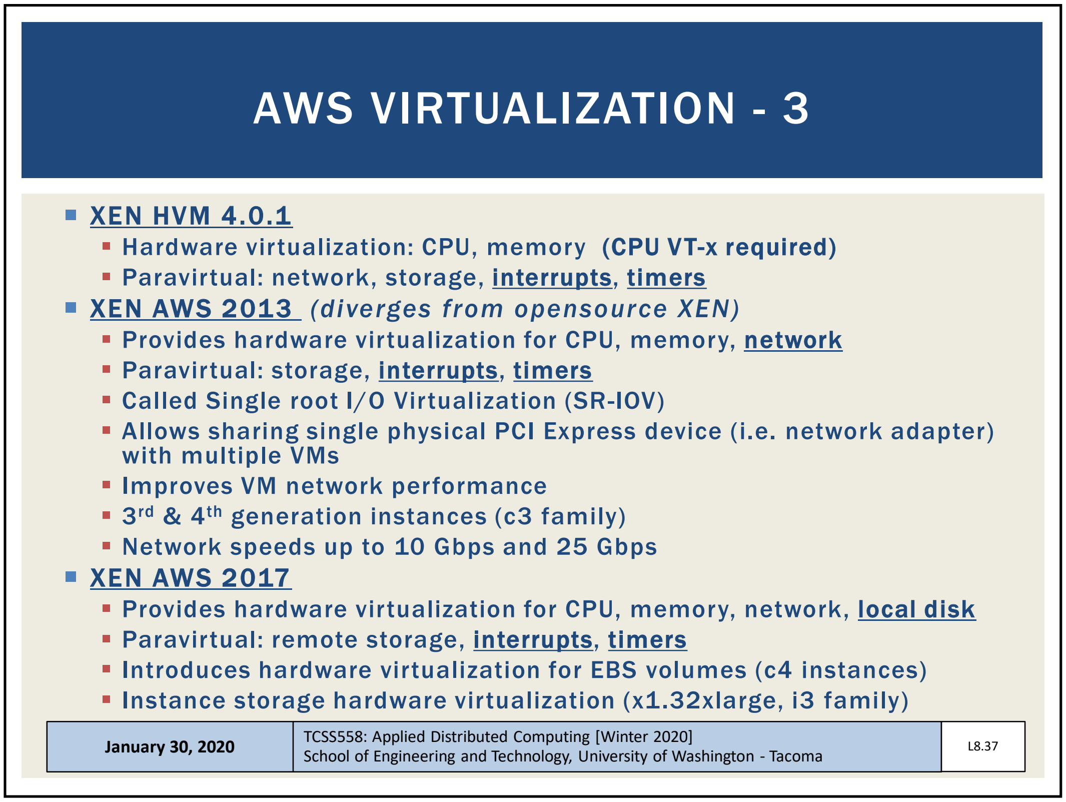
Importance: Most → Least

	#	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
Old	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
New	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.

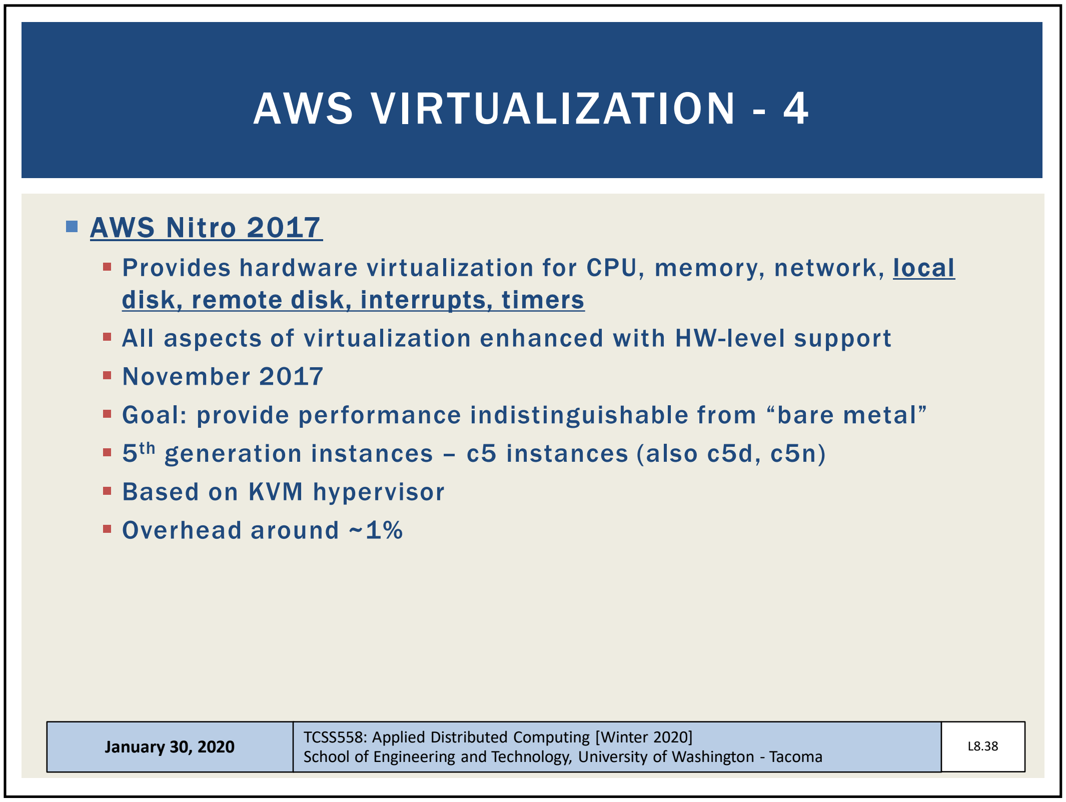
AWS VIRTUALIZATION - 2

- **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



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)



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%

CH. 3.3: CLIENTS

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TYPES OF CLIENTS

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

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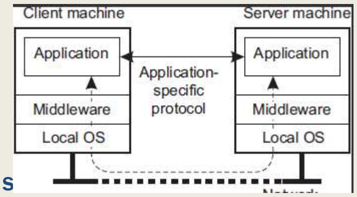
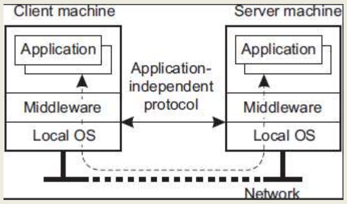
CLIENTS

- 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

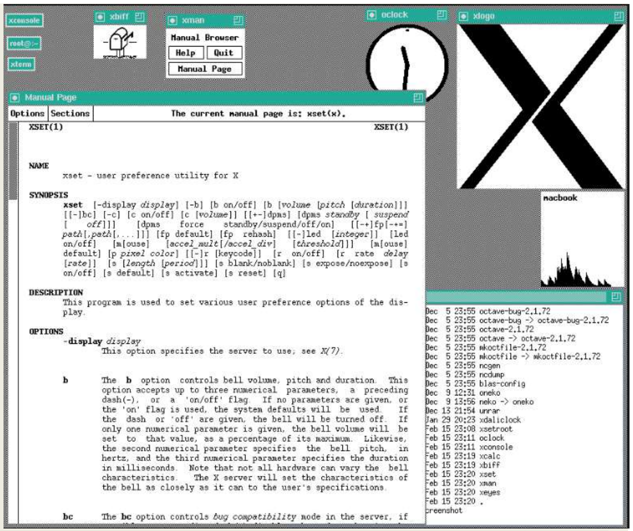


X WINDOWS

- 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

X WINDOWS - 2

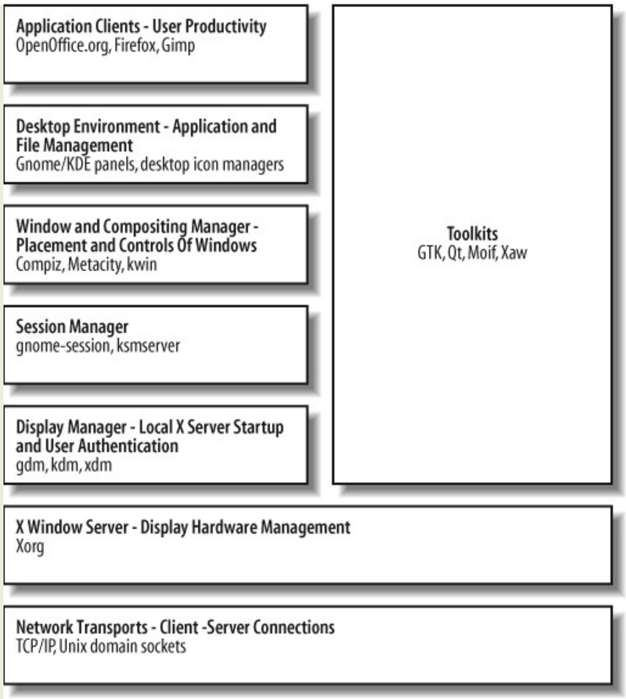
- Window manager:
  - Application running atop of X-windows which provides flair
  - Many variants
  - Without X windows is quite bland



```
XSET(1)                                                    XSET(1)

NAME
       xset - user preference utility for X

SYNOPSIS
       xset  [-display display] [-b] [b on/off] [b [volume [pitch [duration]]]
       [[-]bc] [-c] [c on/off] [c [volume]] [[+-]dpms] [dpms standby [ suspend
       [   off]]]    [dpms    force    standby/suspend/off/on]    [[-+]fp[-+=]
       path[,path[,...]]] [fp default] [fp  rehash]  [[-]led  [integer]]  [led
       on/off]   [m[ouse]   [accel_mult[/accel_div]   [threshold]]]   [m[ouse]
       default] [p pixel color] [[-]r [keycode]]  [r  on/off]  [r  rate  delay
       [rate]]  [s [length [period]]] [s blank/noblank] [s expose/noexpose] [s
       on/off] [s default] [s activate] [s reset] [q]

DESCRIPTION
       This program is used to set various user preference options of the dis-
       play.

OPTIONS
       -display display
               This option specifies the server to use; see X(7).

       b       The  b  option  controls bell volume, pitch and duration.  This
               option accepts up to three numerical  parameters,  a  preceding
               dash(-),  or  a  'on/off' flag.  If no parameters are given, or
               the 'on' flag is used, the system defaults will  be  used.   If
               the  dash  or 'off' are given, the bell will be turned off.  If
               only one numerical parameter is given, the bell volume will  be
               set  to  that value, as a percentage of its maximum.  Likewise,
               the second numerical parameter specifies  the  bell  pitch,  in
               hertz, and the third numerical parameter specifies the duration
               in milliseconds.  Note that not all hardware can vary the  bell
               characteristics.   The X server will set the characteristics of
               the bell as closely as it can to the user's specifications.

       bc      The bc option controls bug compatibility mode in the server, if
```

```
Dec  5 23:55 octave-bug-2.1.72
Dec  5 23:55 octave-bug -> octave-bug-2.1.72
Dec  5 23:55 octave-2.1.72
Dec  5 23:55 octave -> octave-2.1.72
Dec  5 23:55 mkoctfile-2.1.72
Dec  5 23:55 mkoctfile -> mkoctfile-2.1.72
Dec  5 23:55 ncgen
Dec  5 23:55 ncdump
Dec  5 23:55 blas-config
Dec  9 12:31 oneko
Dec  9 13:56 neko -> oneko
Dec 13 21:54 unrar
Jan 29 20:23 xdaliclock
Feb 15 23:08 xsetroot
Feb 15 23:11 oclock
Feb 15 23:11 xconsole
Feb 15 23:19 xcalc
Feb 15 23:19 xbiff
Feb 15 23:20 xset
Feb 15 23:20 xman
Feb 15 23:20 xeyes
Feb 15 23:20 .
creenshot
```

- 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

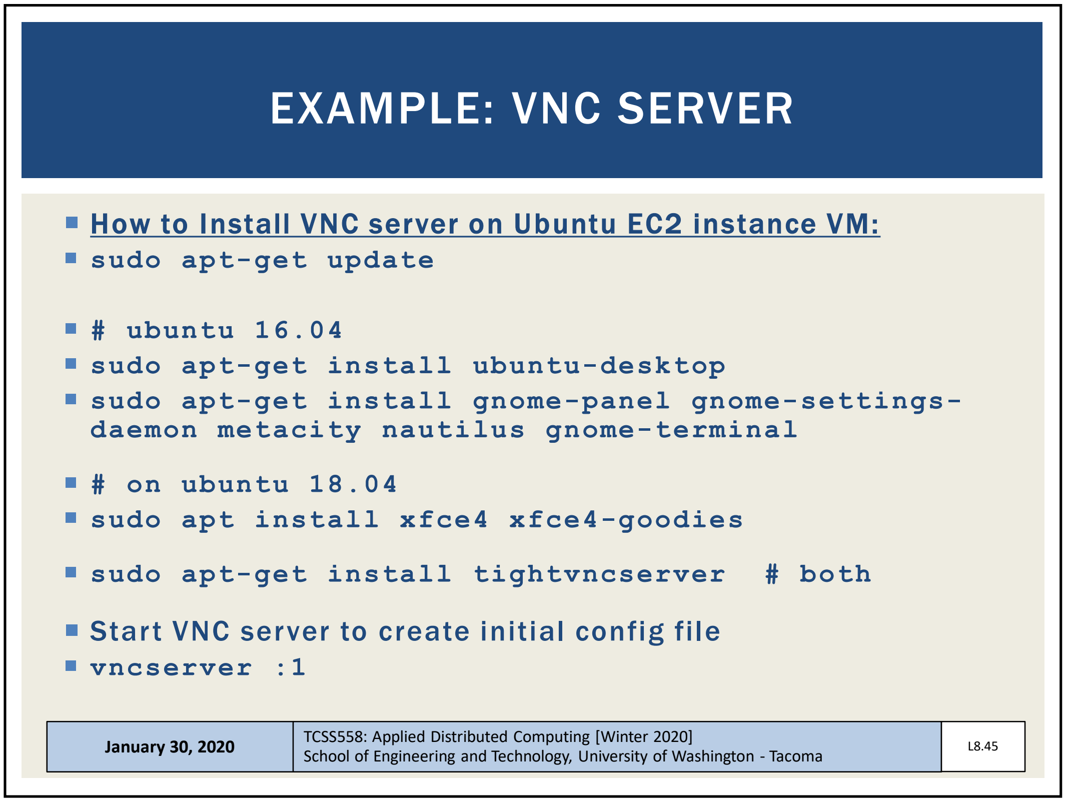
Session Manager
gnome-session, ksmserver

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



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`

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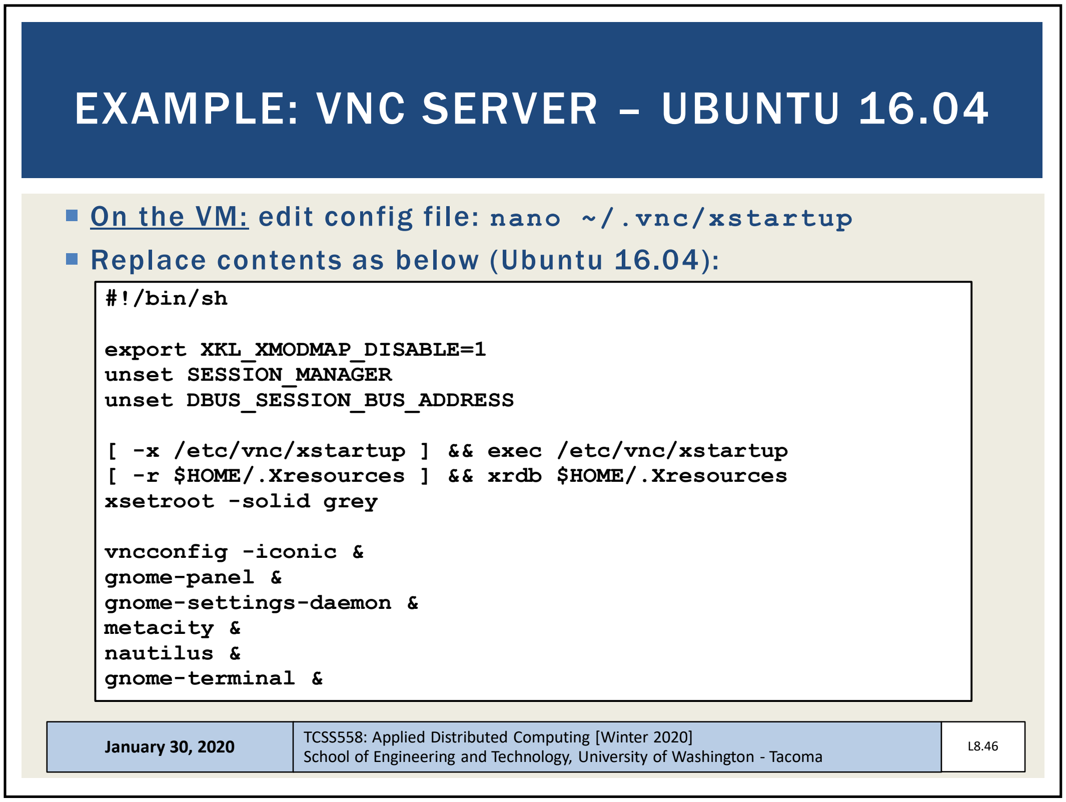

EXAMPLE: VNC SERVER – UBUNTU 16.04

- 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 &
```

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EXAMPLE: VNC SERVER – UBUNTU 18.04

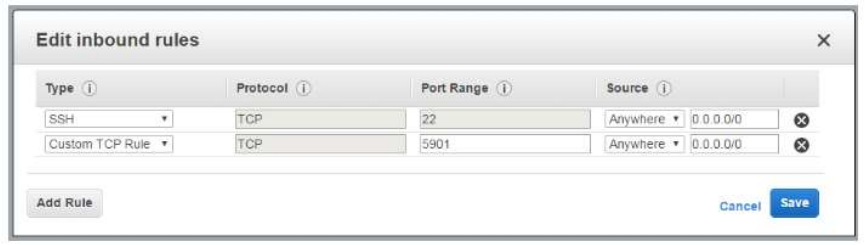
- On the VM:
- Edit config file: `nano ~/.vnc/xstartup`
- Replace contents as below (Ubuntu 18.04):

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

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	0.0.0.0/0
Custom TCP Rule	TCP	5901	Anywhere	0.0.0.0/0

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

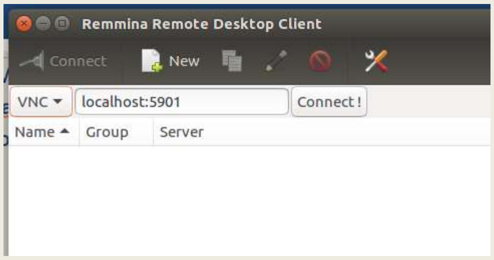
```
ssh -i <ssh-keyfile> -L 5901:127.0.0.1:5901 -N
-f -l <username> <EC2-instance ip_address>
```

- For example:

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

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"

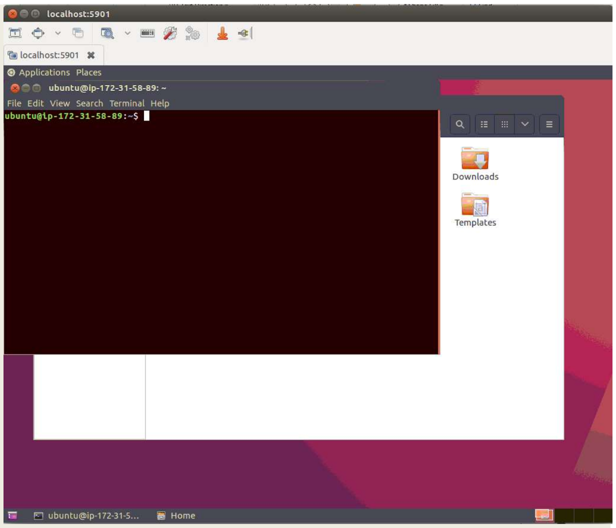


Remmina Remote Desktop Client

VNC ▾ localhost:5901 Connect !

REMOTE COMPUTER IN THE CLOUD

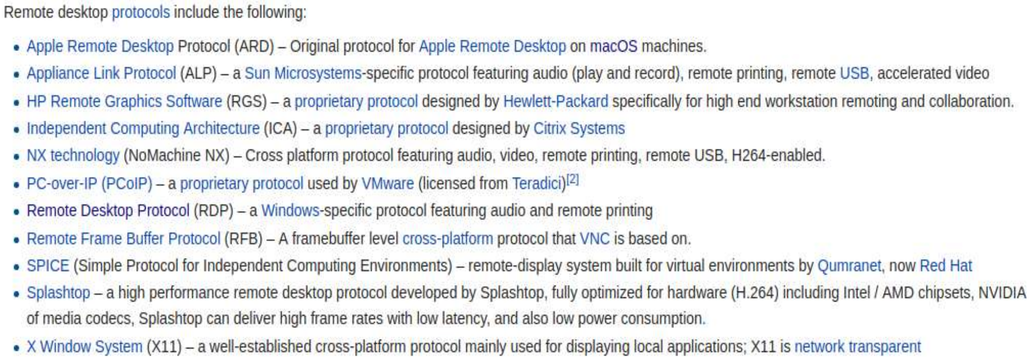
- EC2 instance with a GUI. . .!!!



```
ubuntu@ip-172-31-58-89:~$
```

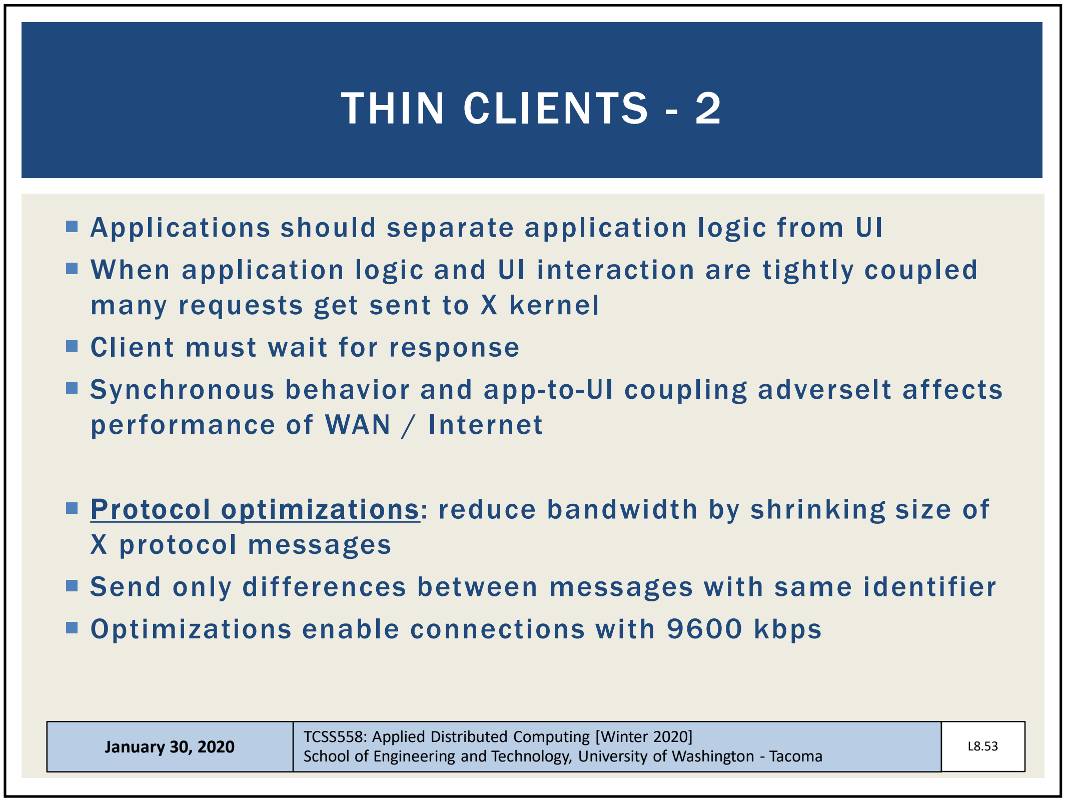
THIN CLIENTS

- 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



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

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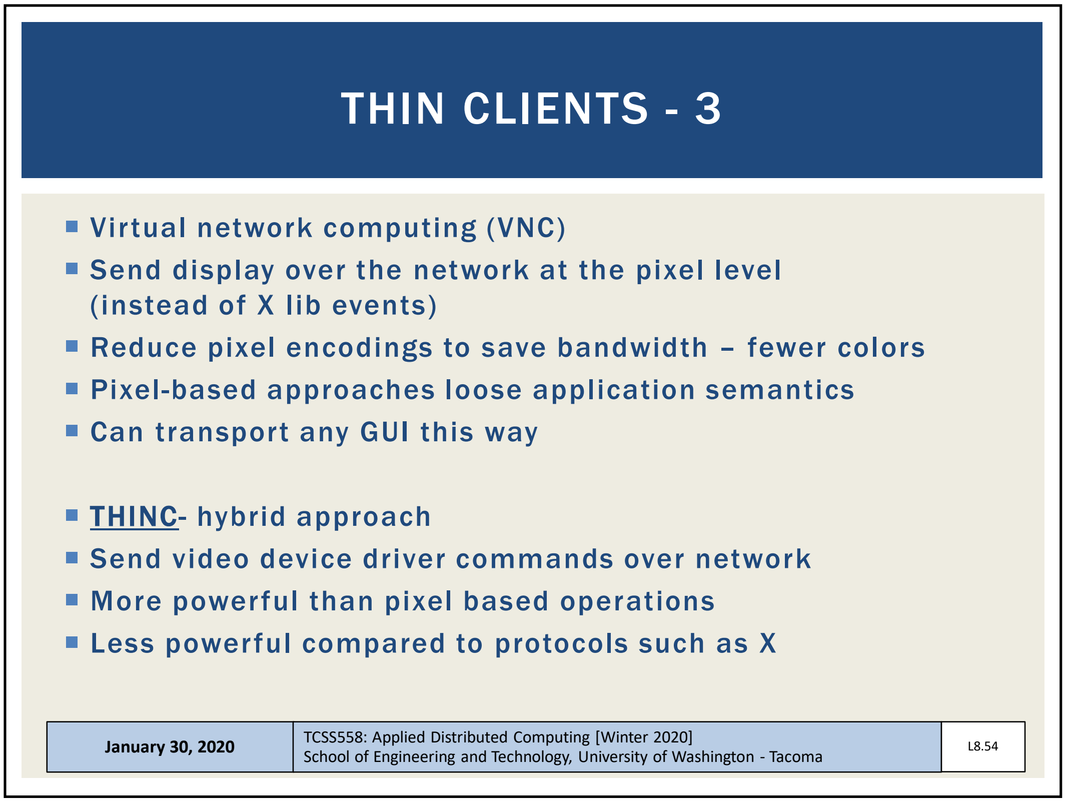

THIN CLIENTS - 3

- 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

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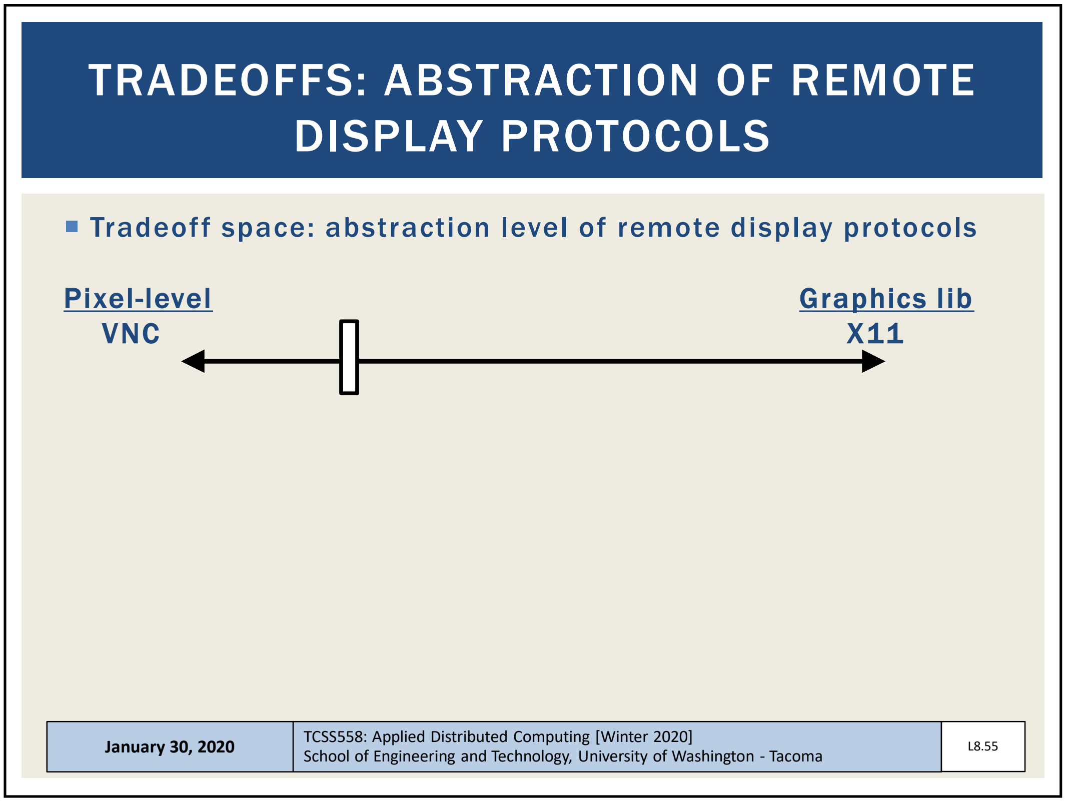


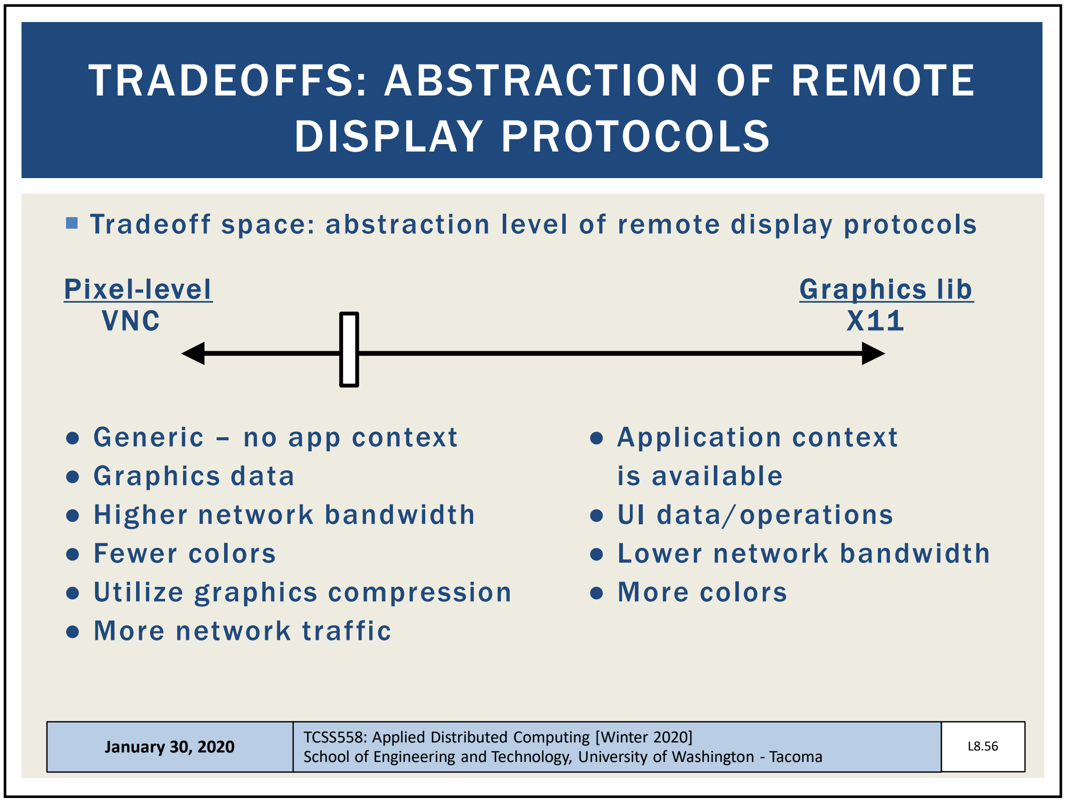
TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols

Pixel-level
VNC

Graphics lib
X11

55



TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols

Pixel-level
VNC

Graphics lib
X11

- 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

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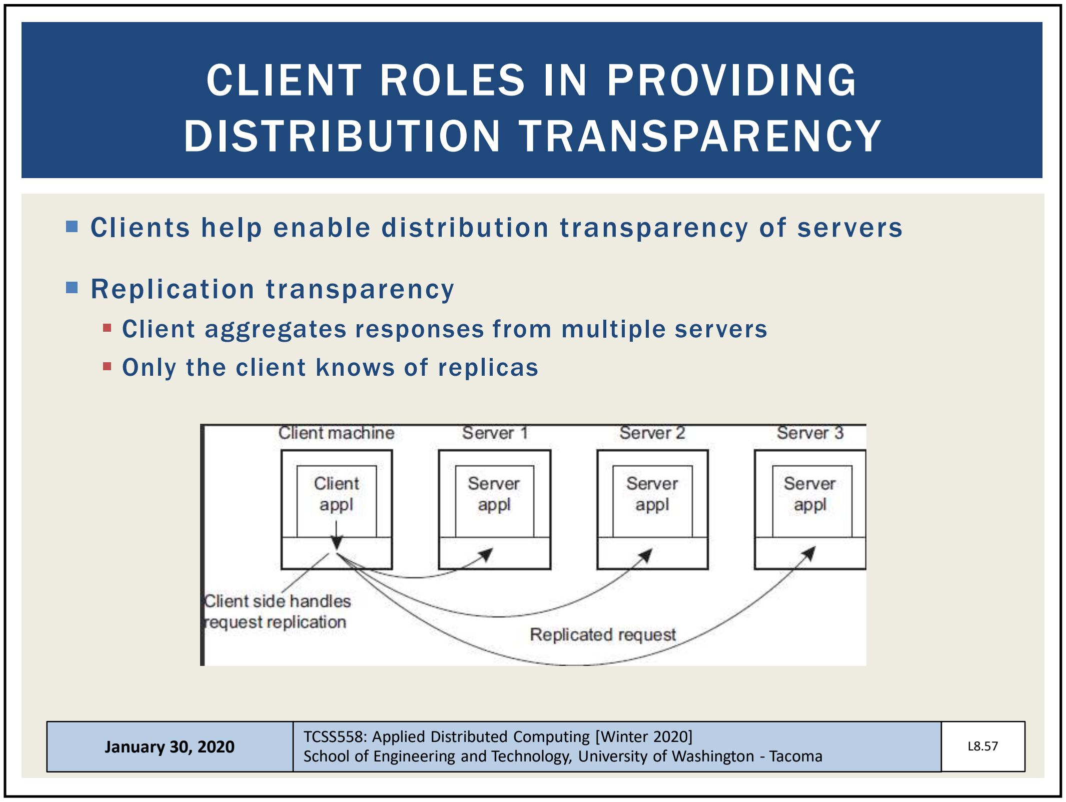
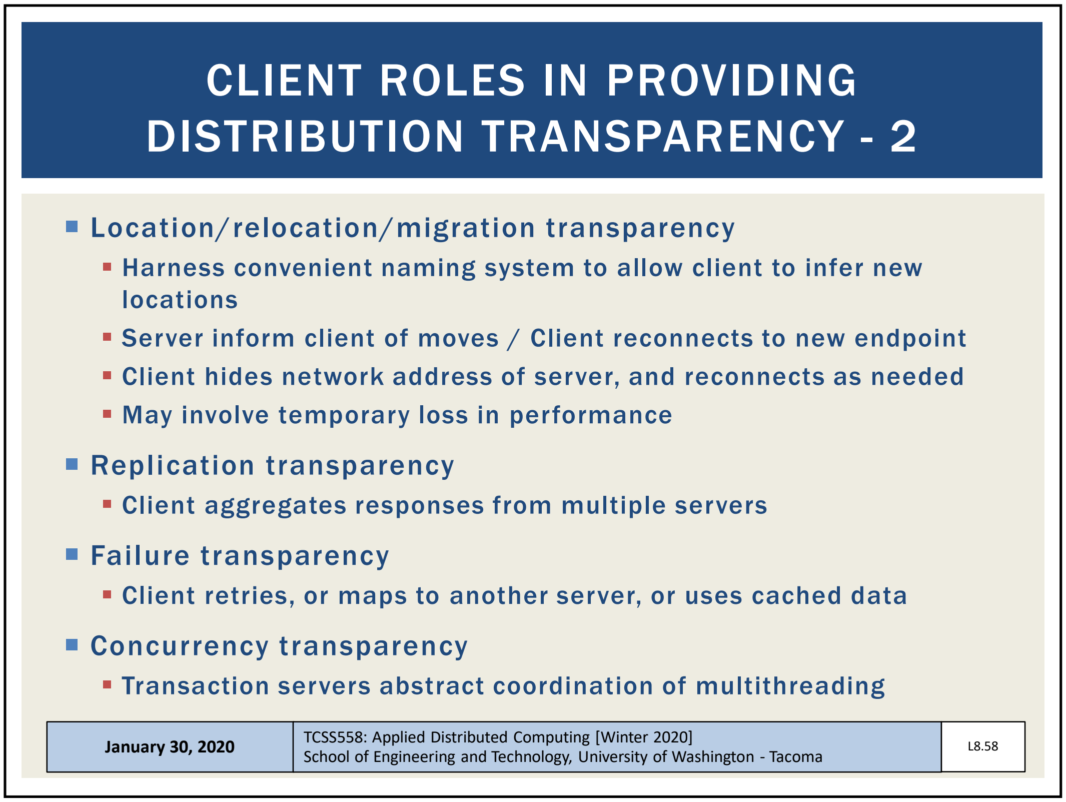


CLIENT ROLES IN PROVIDING DISTRIBUTION TRANSPARENCY

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



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

CH. 3.4: SERVERS

L8.59

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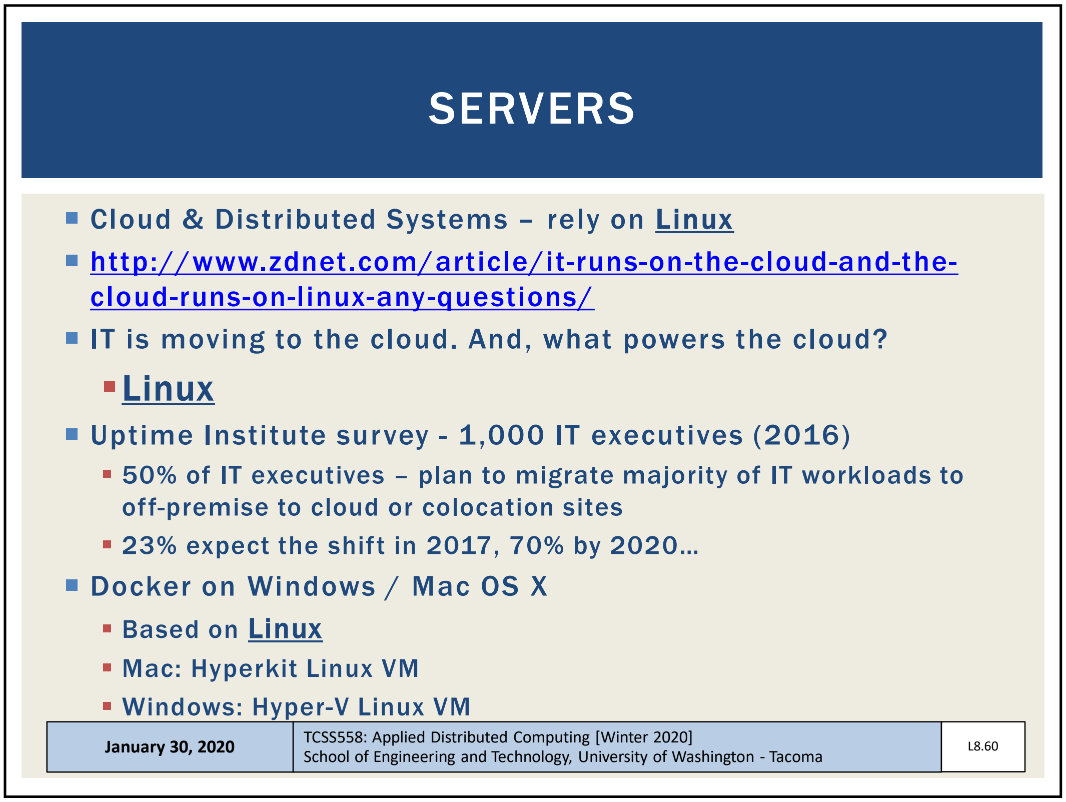

SERVERS

- 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

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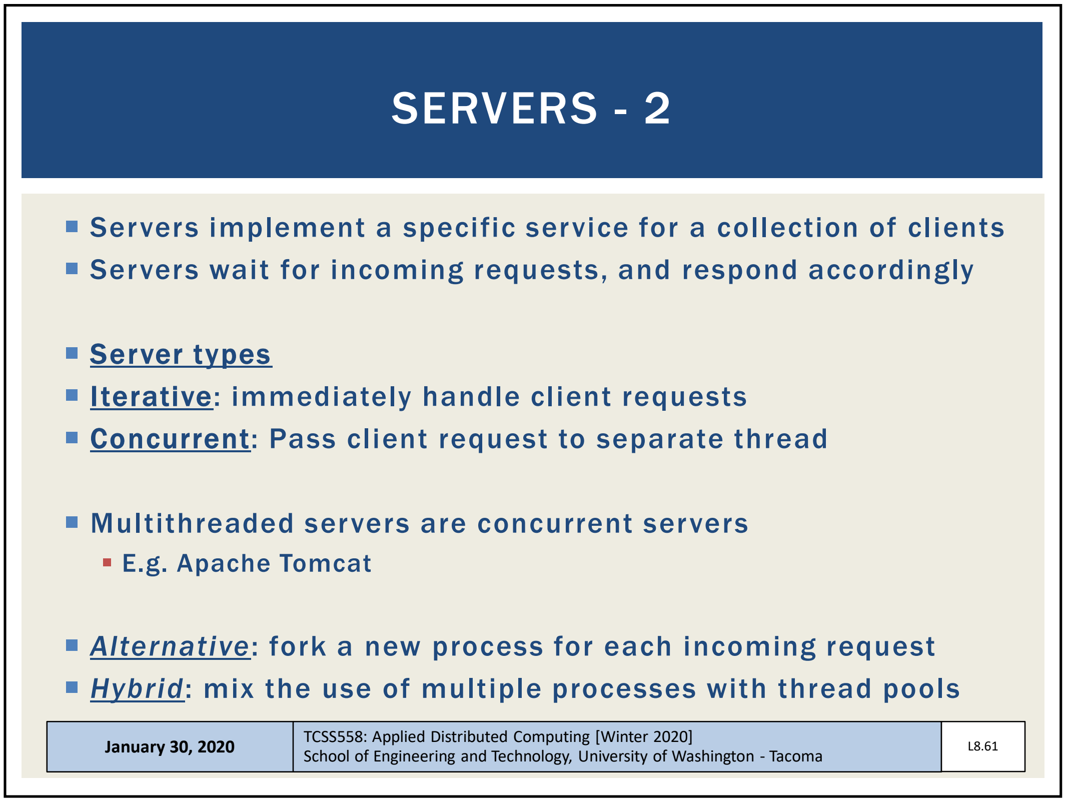

SERVERS - 2

- 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

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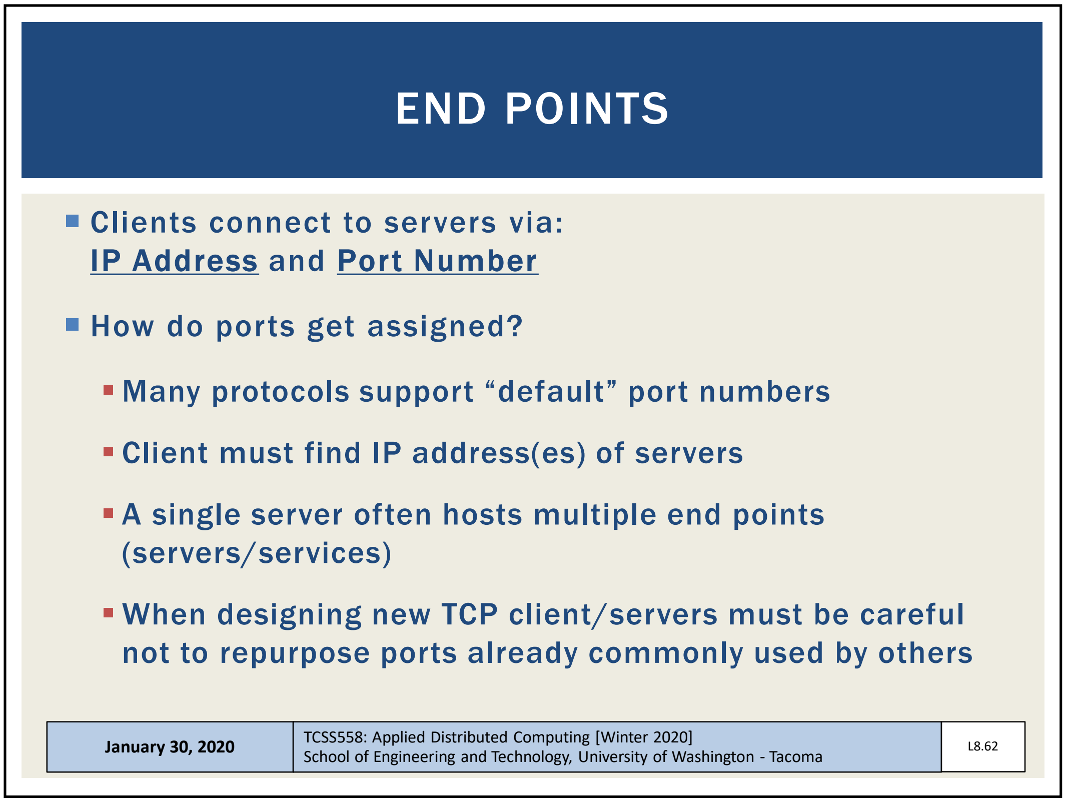

END POINTS

- 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

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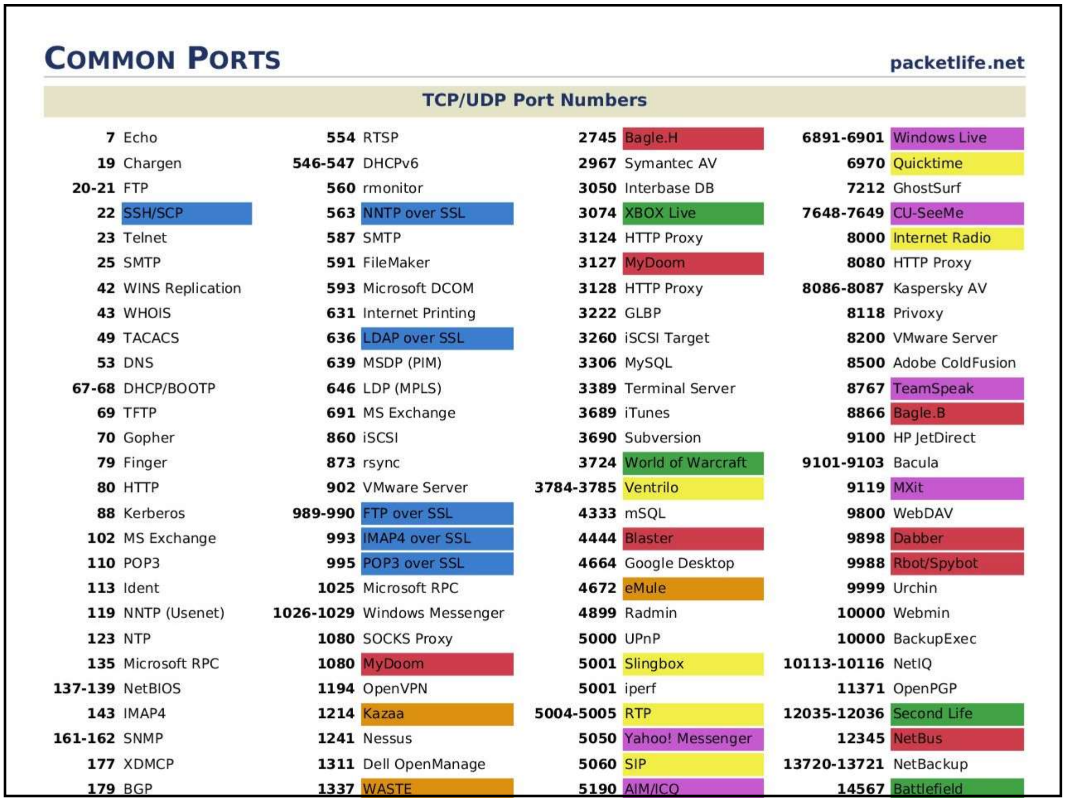

COMMON PORTS

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

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TYPES OF SERVERS

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

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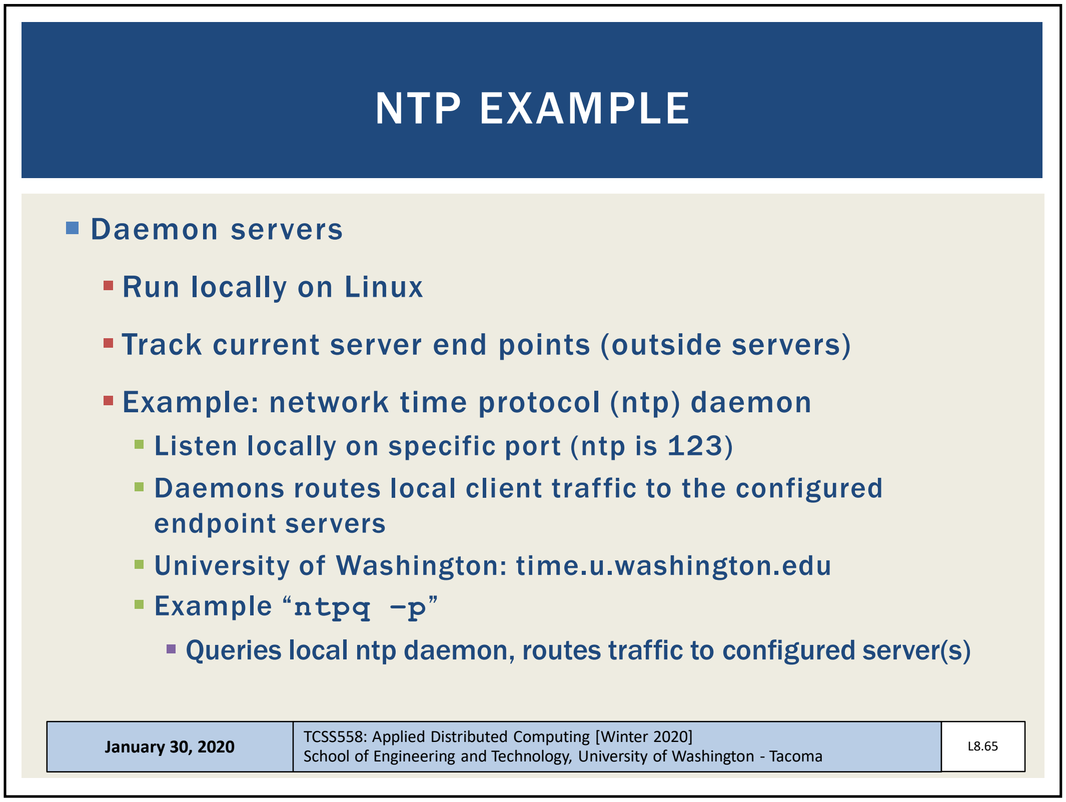

NTP EXAMPLE

- 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)

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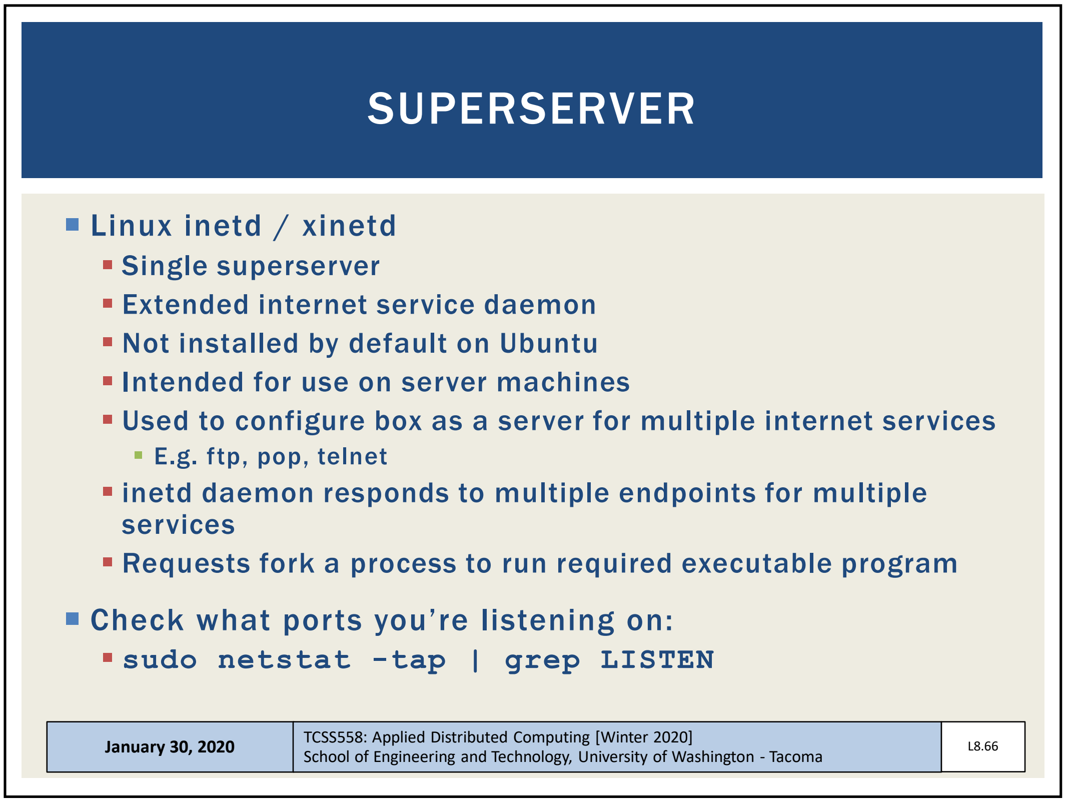

SUPERSERVER

- 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`

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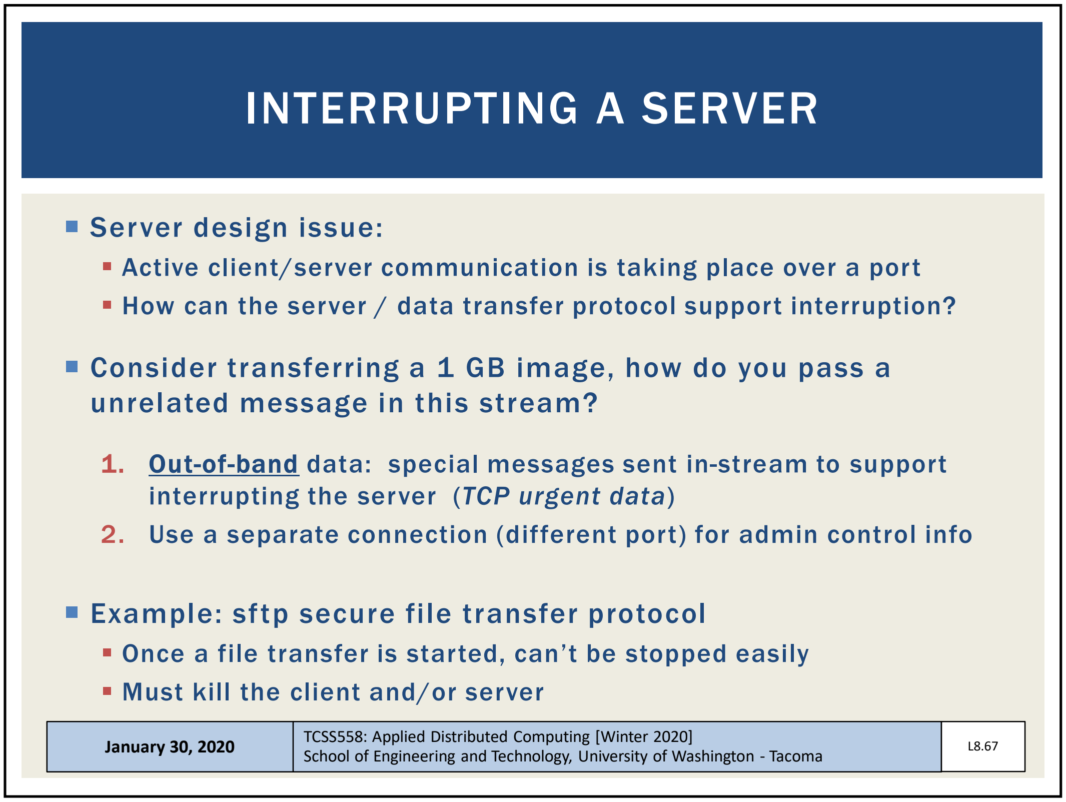

INTERRUPTING A SERVER

- 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

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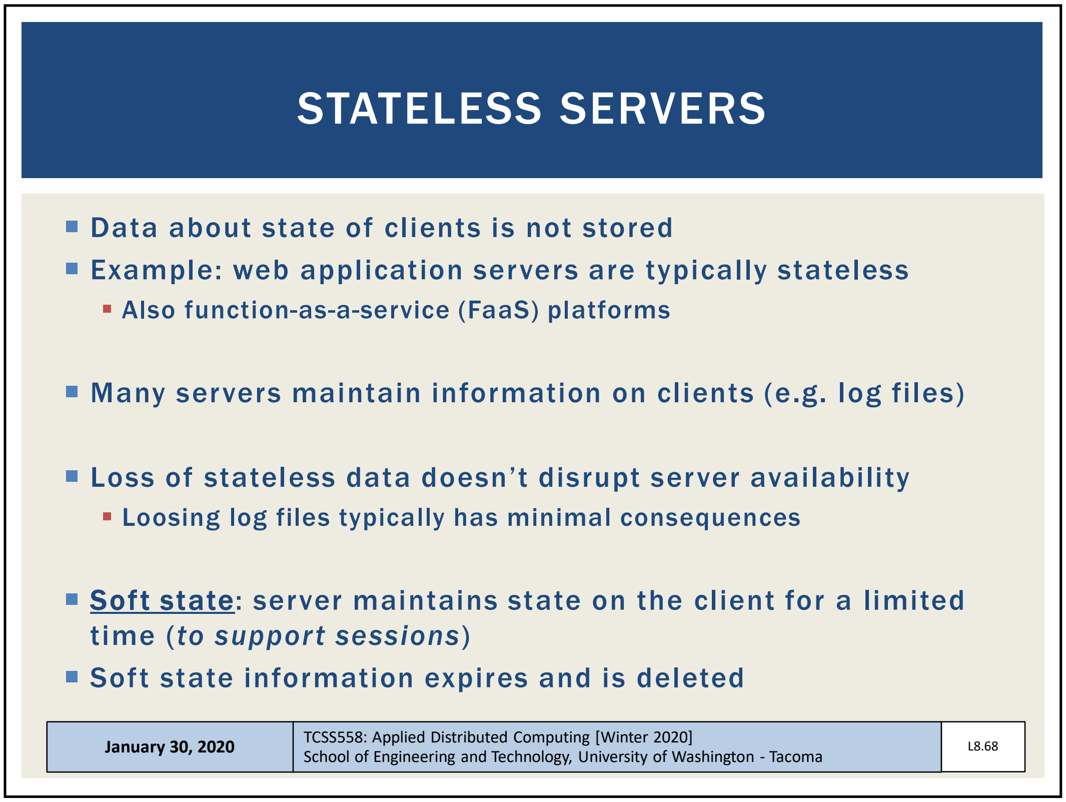

STATELESS SERVERS

- 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

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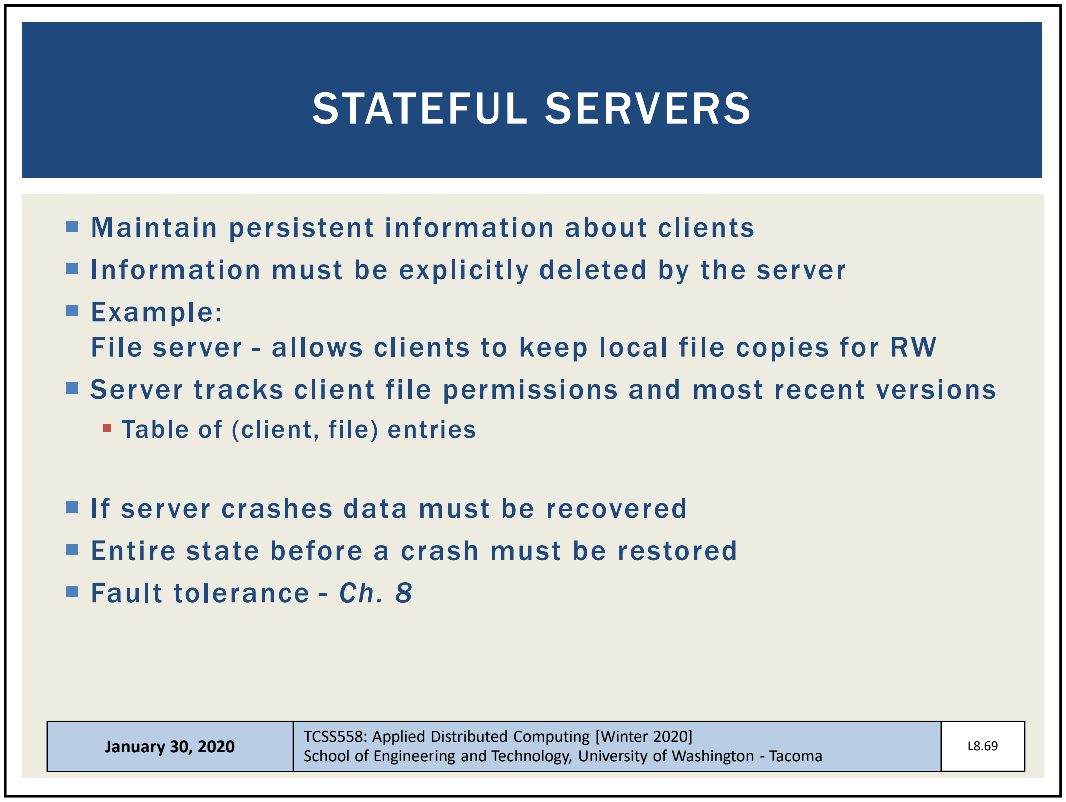

STATEFUL SERVERS

- 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*

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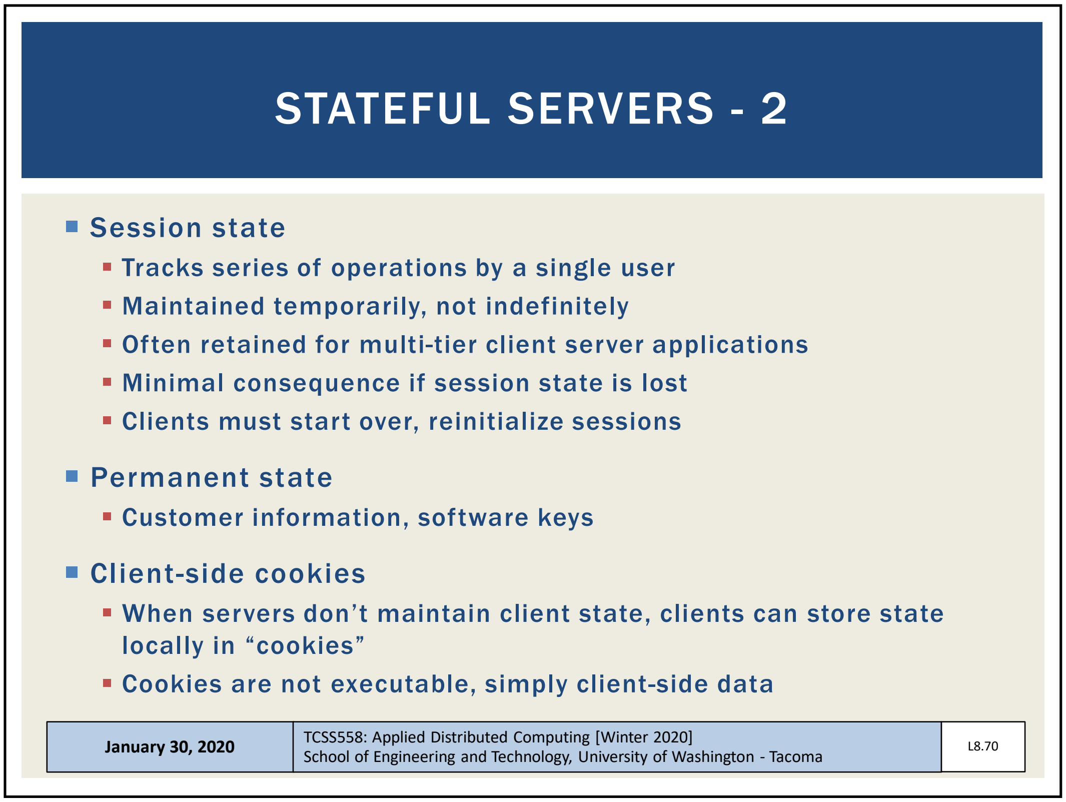

STATEFUL SERVERS - 2

- 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

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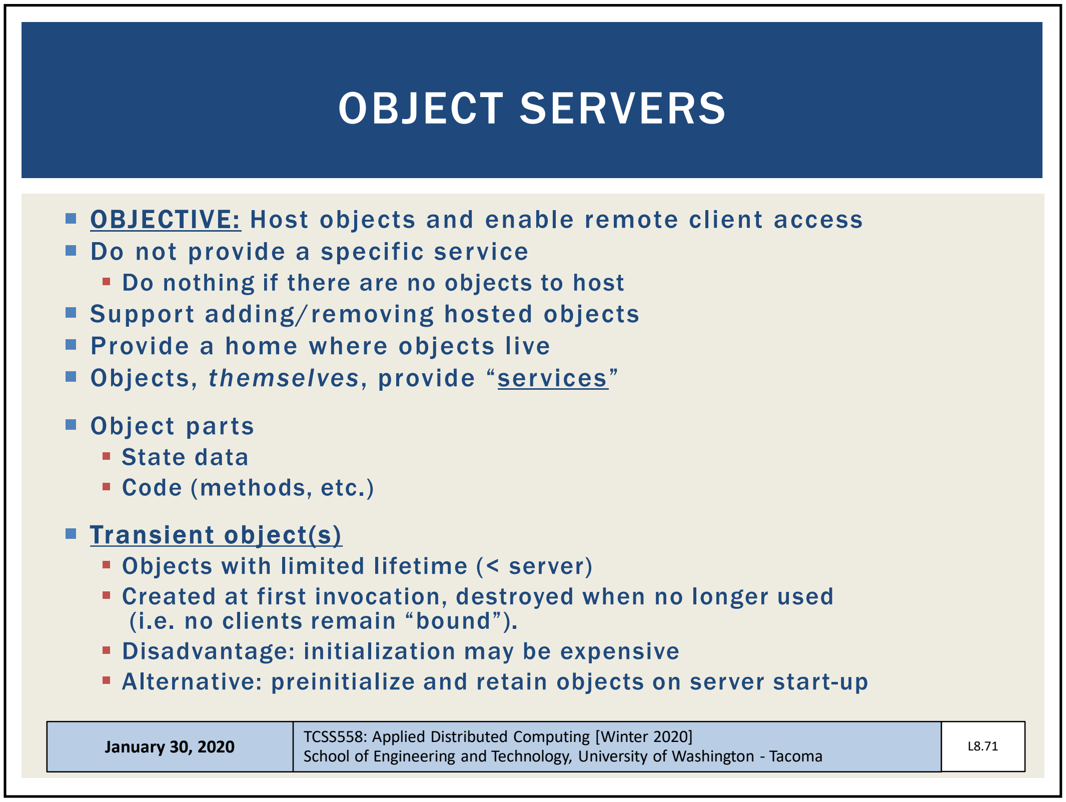

OBJECT SERVERS

- **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

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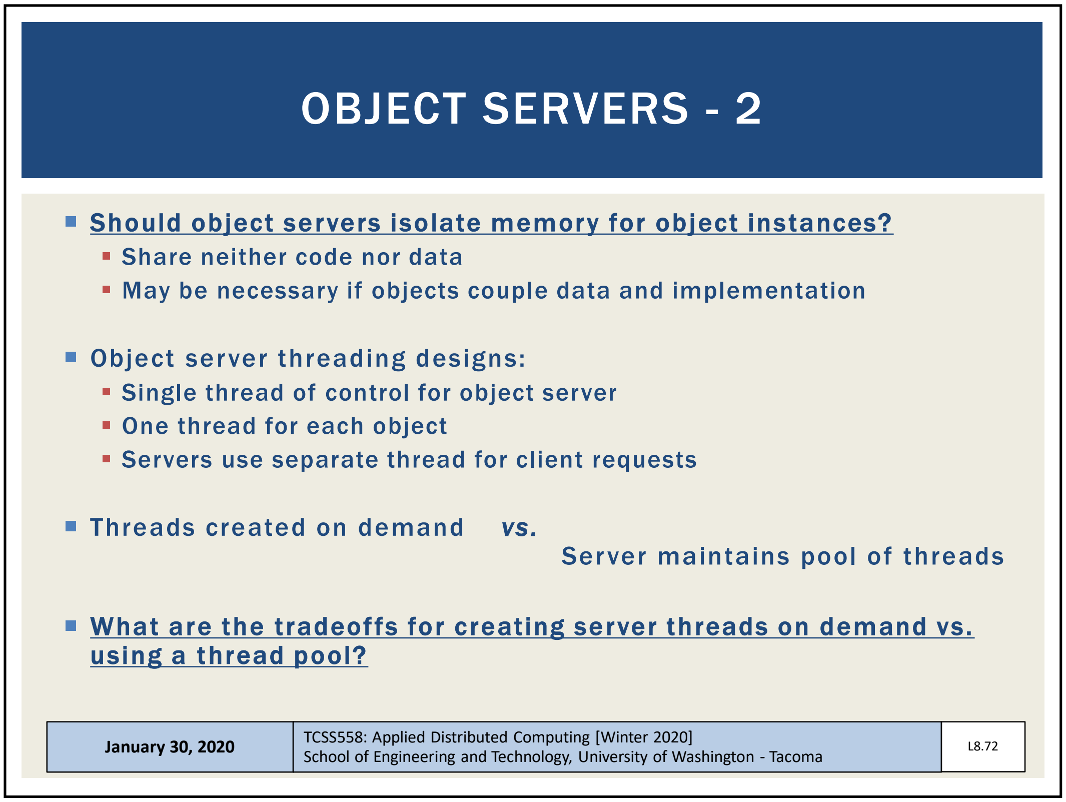

OBJECT SERVERS - 2

- **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?**

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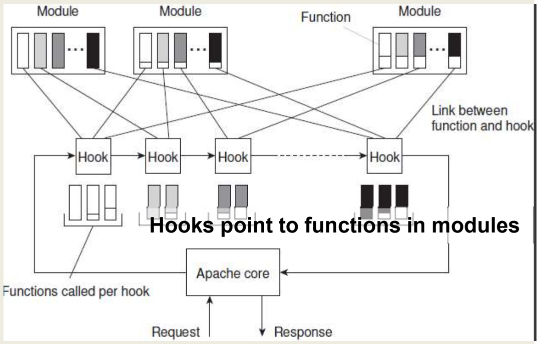
EJB – ENTERPRISE JAVA BEANS

- 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

APACHE WEB SERVER

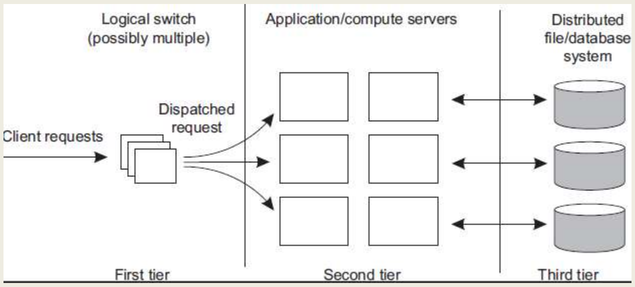
- Highly configurable, extensible, platform independent
- Supports TCP HTTP protocol communication
- Uses hooks – placeholders for group of functions
- Requests processed in phases by hooks
- Many hooks:
  - Translate a URL
  - Write info to log
  - Check client ID
  - Check access rights
- Hooks processed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



Hooks point to functions in modules

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



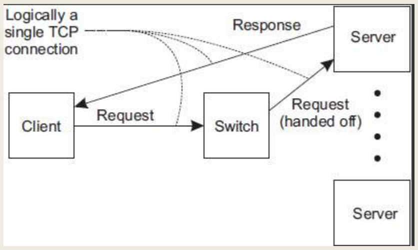
LAN REQUEST DISPATCHING

- 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

LAN REQUEST DISPATCHING - 2

- Who is the best server to handle the request?

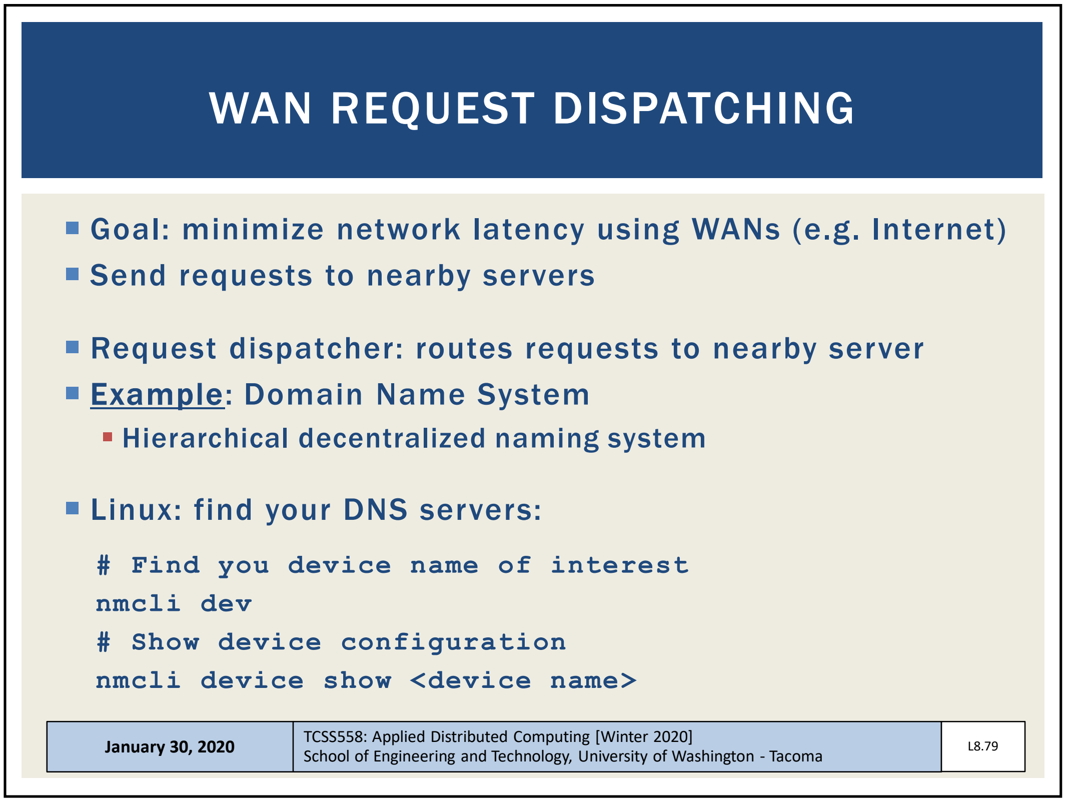
- Switch plays important role in distributing requests
- Implements load balancing
- **Round-robin** – routes client requests to servers in a looping fashion
- **Transport-level** – route client requests based on TCP port number
- **Content-aware request distribution** – route requests based on inspecting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



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?



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>
```

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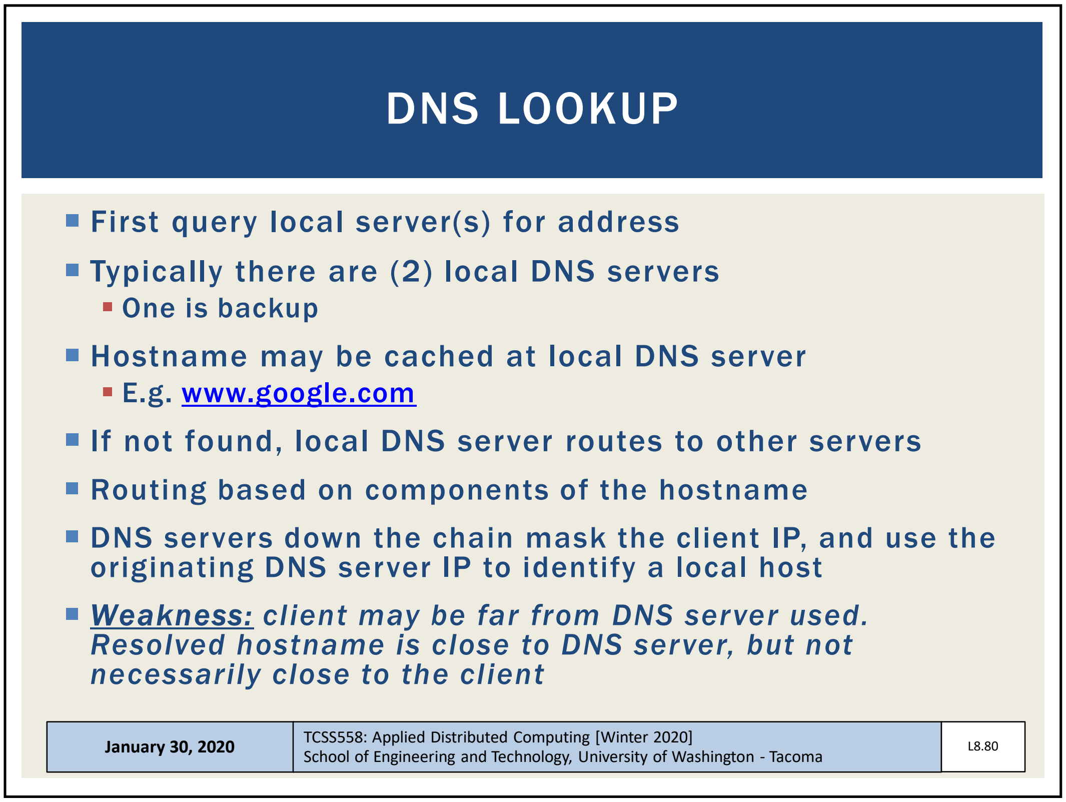

DNS LOOKUP

- 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*

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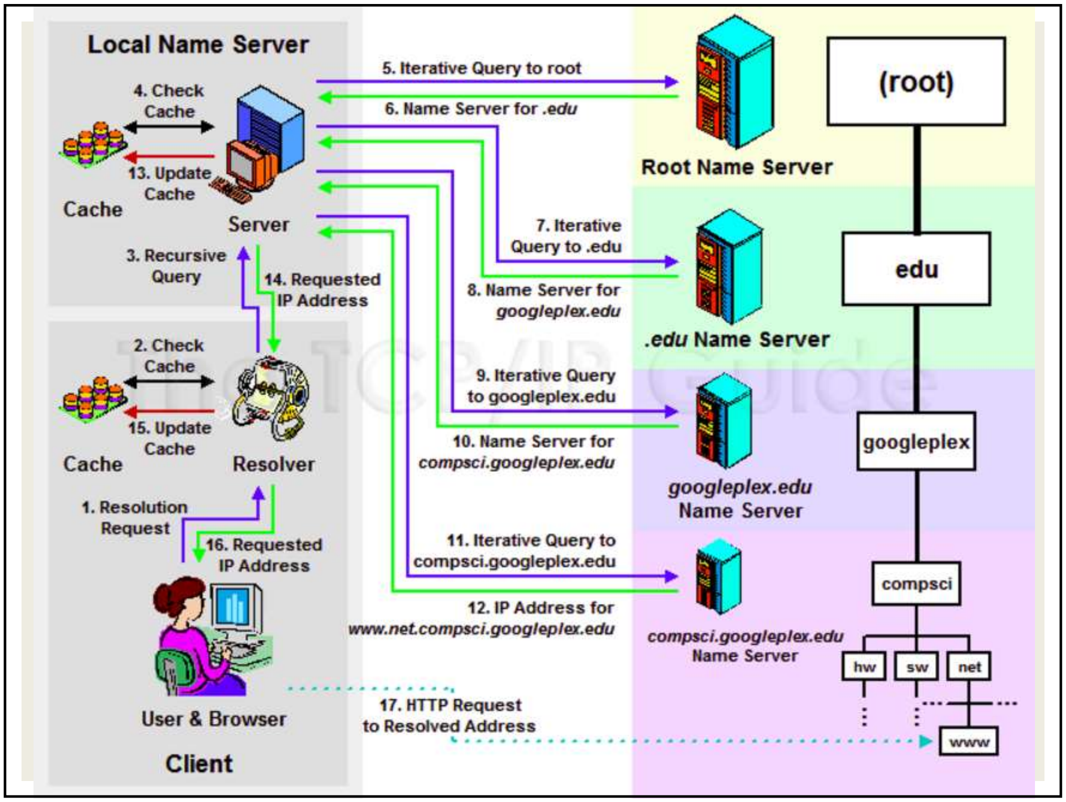
Local Name Server
4. Check Cache
13. Update Cache
Cache
Server
3. Recursive Query
14. Requested IP Address
2. Check Cache
15. Update Cache
Cache
Resolver
1. Resolution Request
16. Requested IP Address
User & Browser
Client
5. Iterative Query to root
6. Name Server for .edu
7. Iterative Query to .edu
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
The TCP/IP Guide

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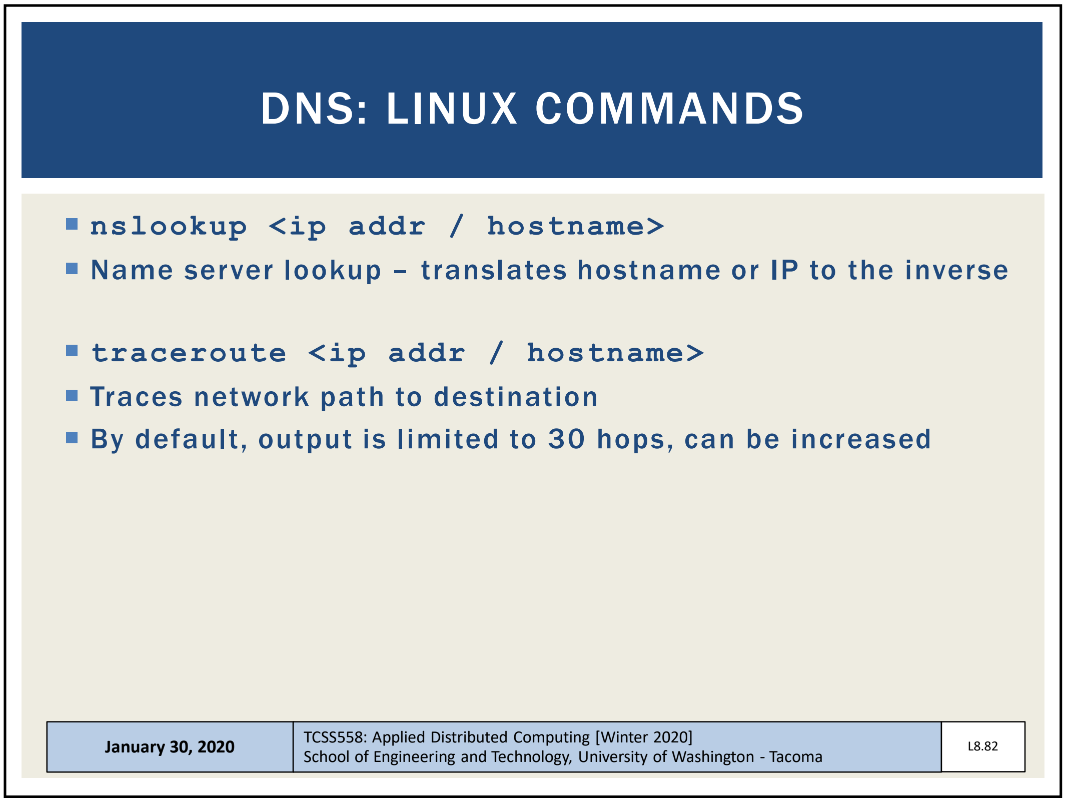

DNS: LINUX COMMANDS

- `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

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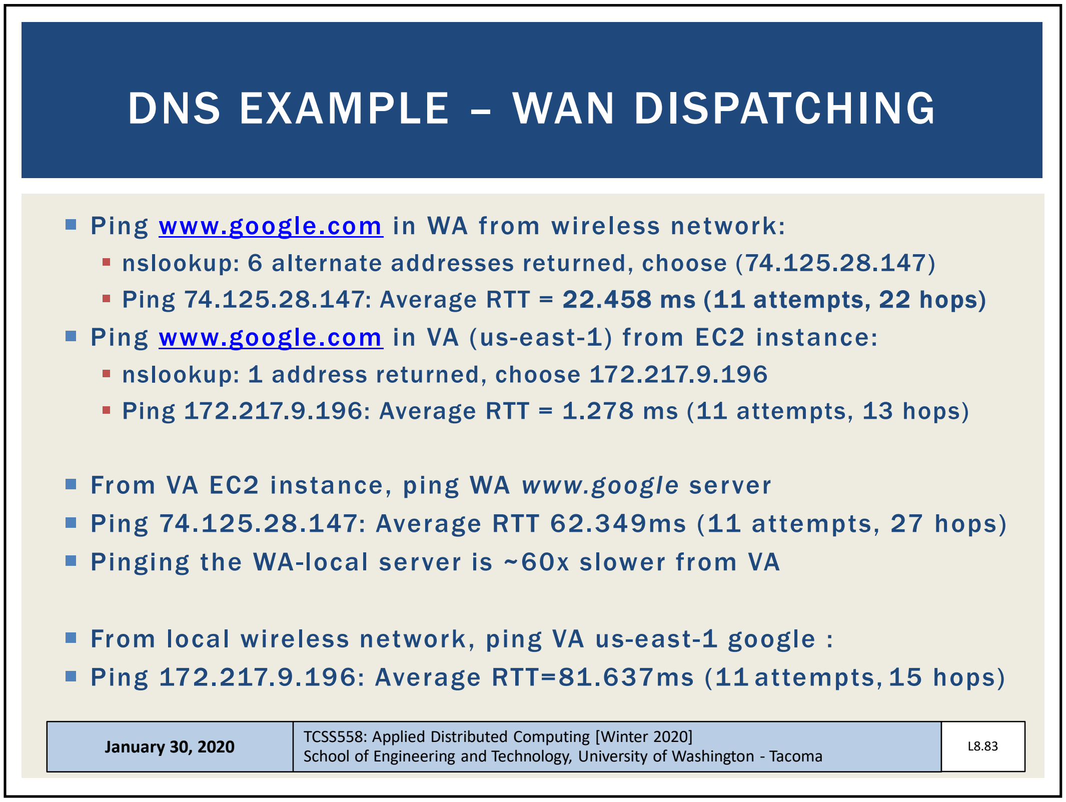

DNS EXAMPLE – WAN DISPATCHING

- 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)

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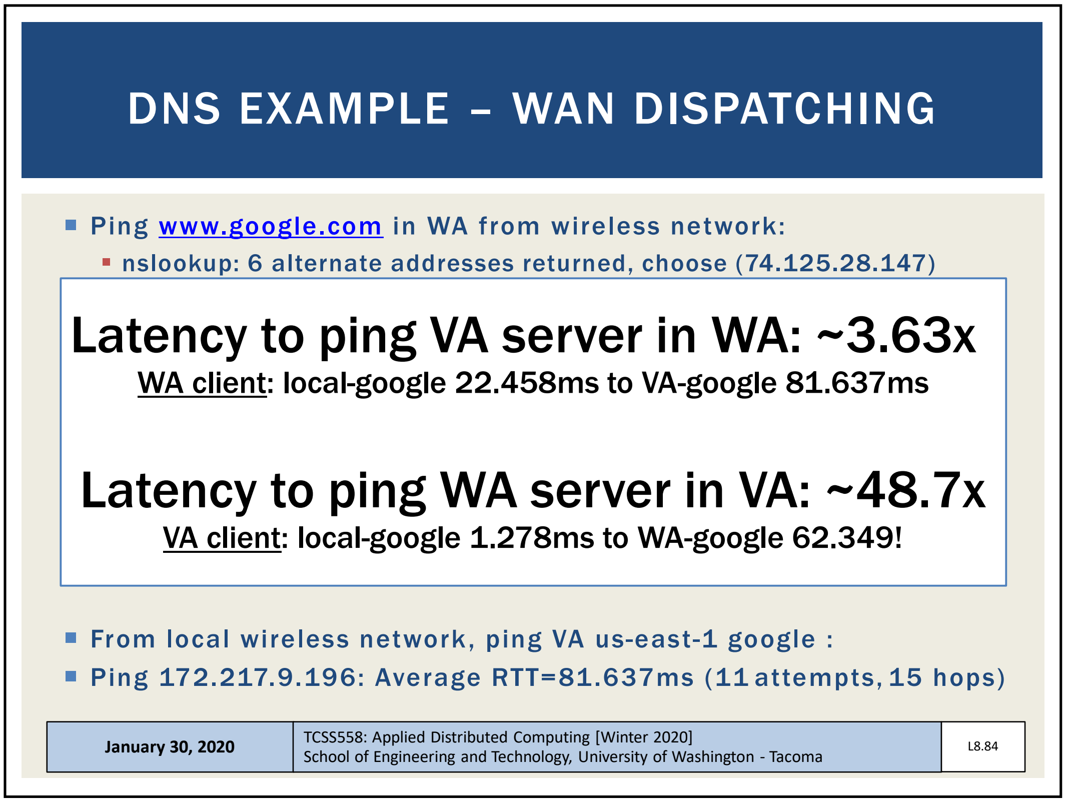

DNS EXAMPLE – WAN DISPATCHING

- 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)

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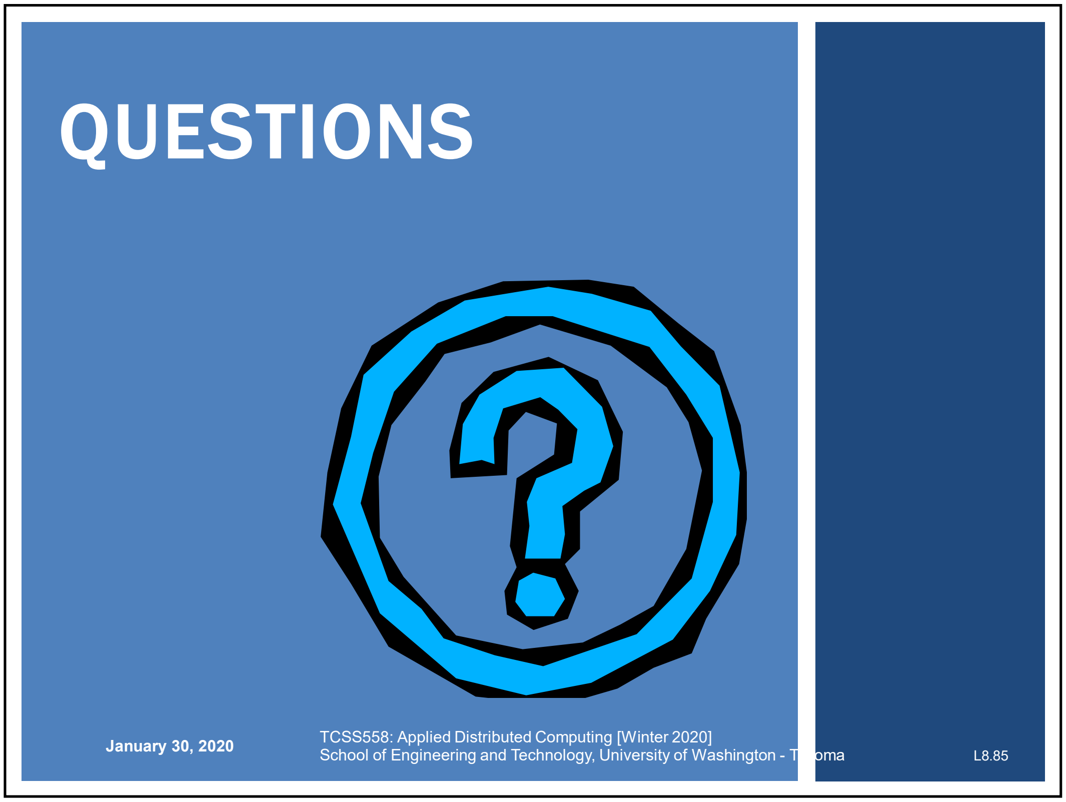

QUESTIONS

January 30, 2020

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RESEARCH DIRECTIONS

October 5, 2017

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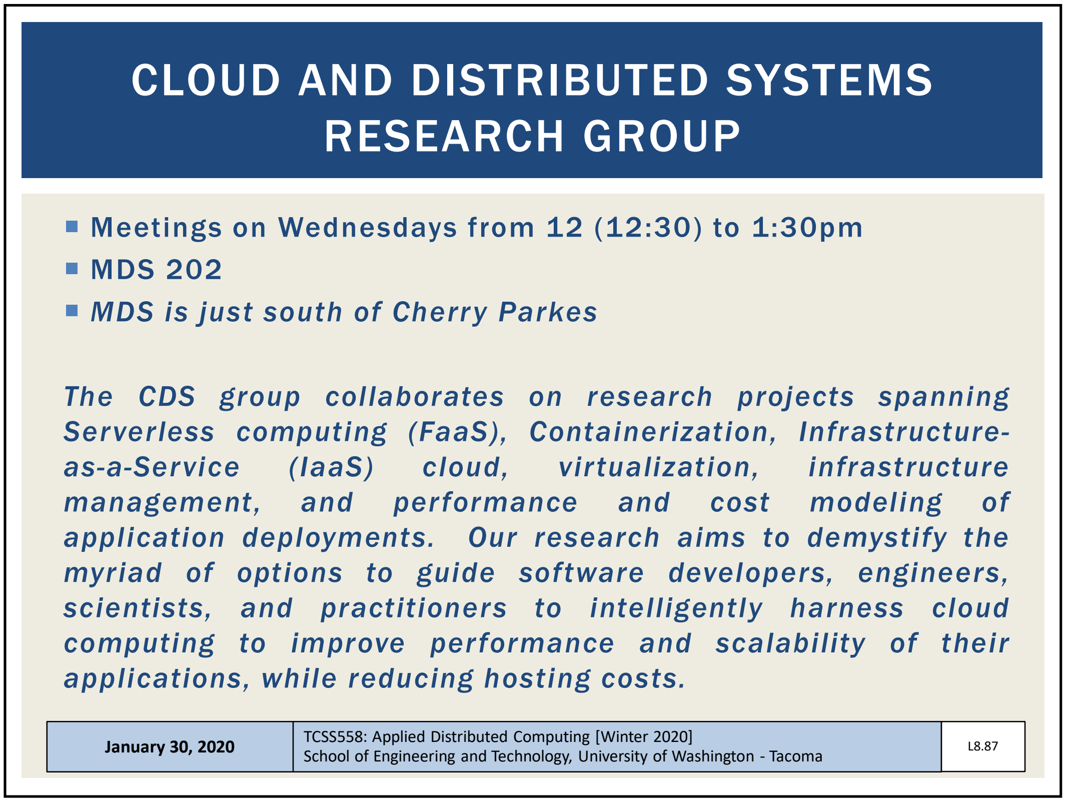
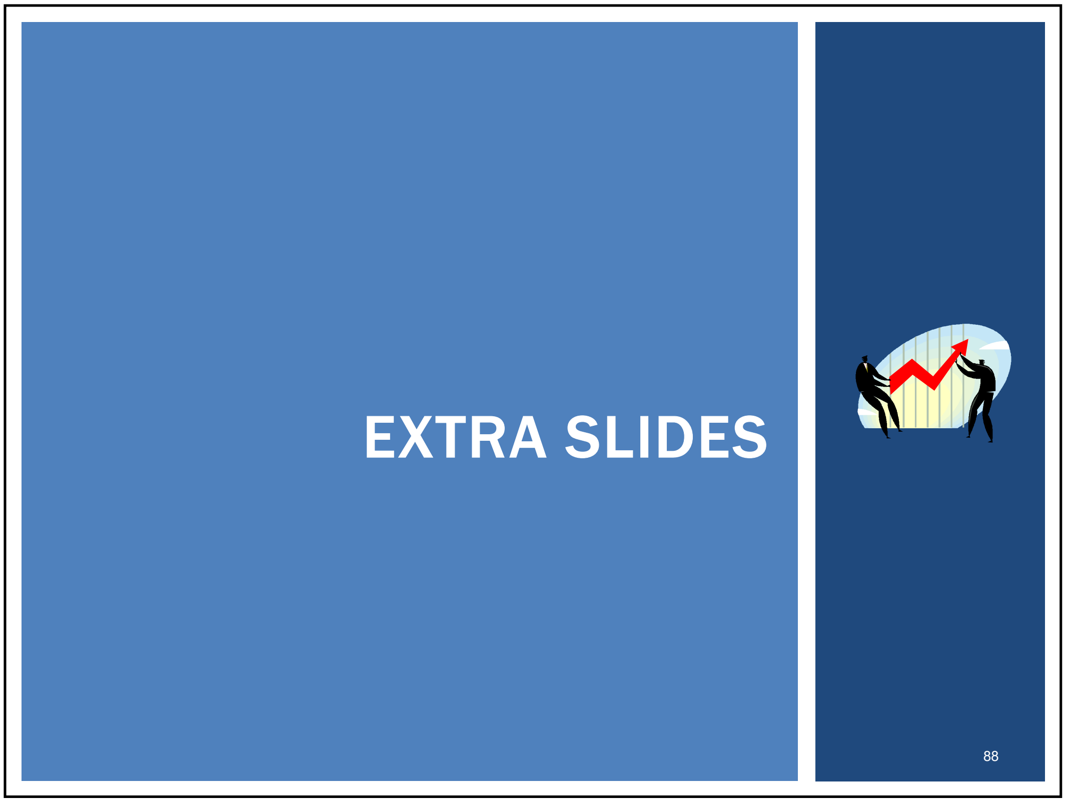


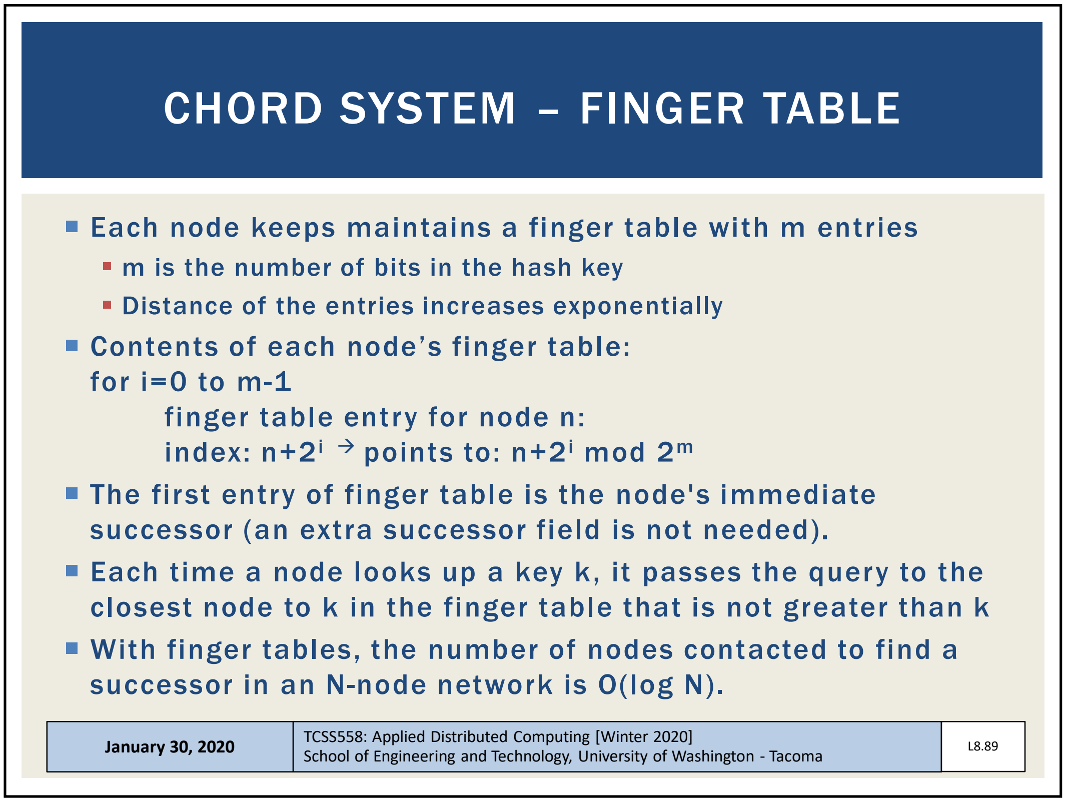
CLOUD AND DISTRIBUTED SYSTEMS RESEARCH GROUP

- Meetings on Wednesdays from 12 (12:30) to 1:30pm
- MDS 202
- *MDS is just south of Cherry Parkes*

The CDS group collaborates on research projects spanning Serverless computing (FaaS), Containerization, Infrastructure-as-a-Service (IaaS) cloud, virtualization, infrastructure management, and performance and cost modeling of application deployments. Our research aims to demystify the myriad of options to guide software developers, engineers, scientists, and practitioners to intelligently harness cloud computing to improve performance and scalability of their applications, while reducing hosting costs.

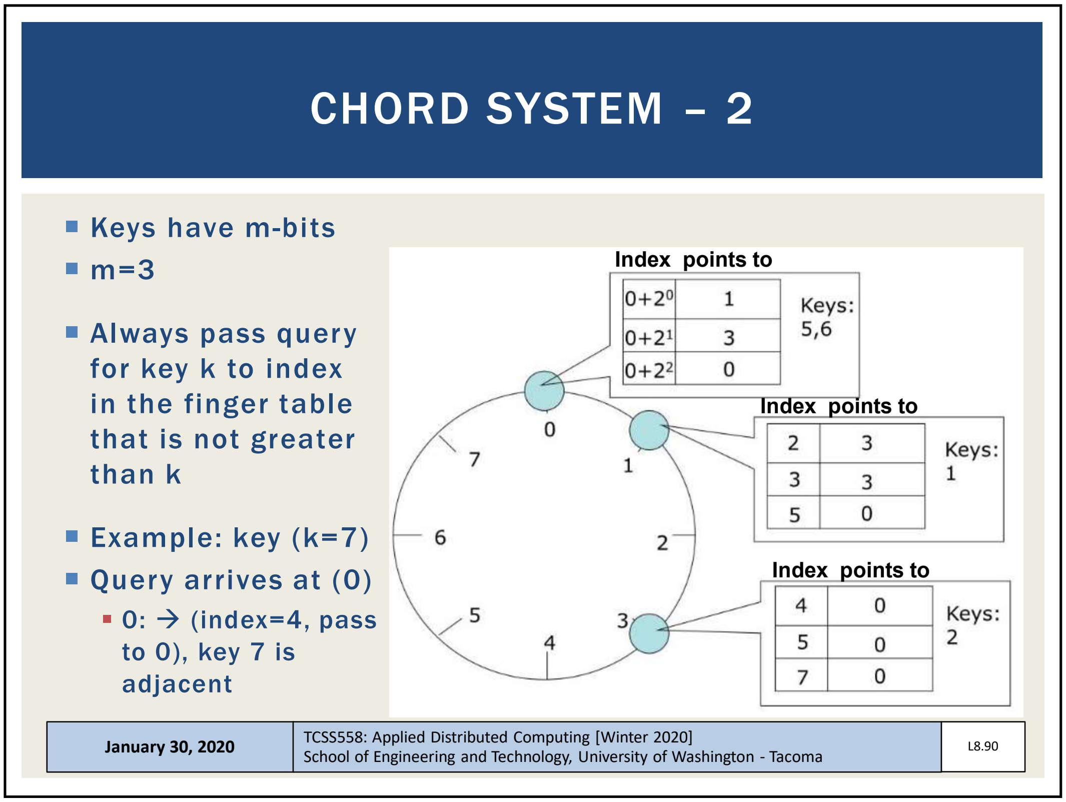


EXTRA SLIDES



CHORD SYSTEM – FINGER TABLE

- Each node keeps maintains a finger table with m entries
  - m is the number of bits in the hash key
  - Distance of the entries increases exponentially
- Contents of each node's finger table:
  for i=0 to m-1
  finger table entry for node n:
  index: $n+2^i$ → points to: $n+2^i \bmod 2^m$
- The first entry of finger table is the node's immediate successor (an extra successor field is not needed).
- Each time a node looks up a key k, it passes the query to the closest node to k in the finger table that is not greater than k
- With finger tables, the number of nodes contacted to find a successor in an N-node network is O(log N).



CHORD SYSTEM – 2

- Keys have m-bits
- m=3
- Always pass query for key k to index in the finger table that is not greater than k
- Example: key (k=7)
- Query arrives at (0)
  - 0: → (index=4, pass to 0), key 7 is adjacent

Index	points to
$0+2^0$	1
$0+2^1$	3
$0+2^2$	0

Keys: 5,6

Index	points to
2	3
3	3
5	0

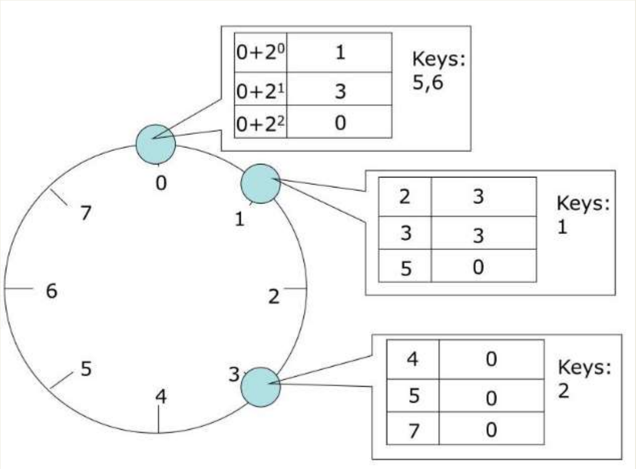
Keys: 1

Index	points to
4	0
5	0
7	0

Keys: 2

CHORD SYSTEM – 2

- Example (k=7)
- Query arrives at (1)
  - 1: → (index=5, pass to 0), key 7 is adjacent
- Query arrives at (3)
  - 1: → (index=7, pass to 0), key 7 is adjacent
- Example (k=6)



$0+2^0$	1
$0+2^1$	3
$0+2^2$	0

Keys: 5,6

2	3
3	3
5	0

Keys: 1

4	0
5	0
7	0

Keys: 2