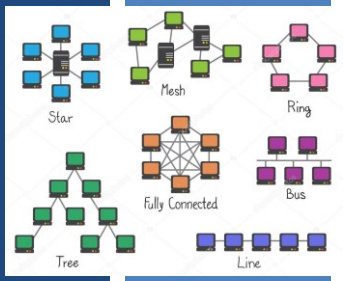
# TCSS 558: APPLIED DISTRIBUTED COMPUTING

## Processes: Threads & Virtualization, Clients & Servers

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& Technology (SET)
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1

## OBJECTIVES – 1/30

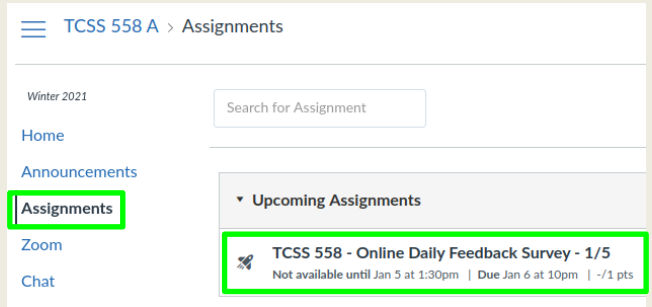
- **Questions from 1/25**
- Assignment 1: Cloud Computing Infrastructure Tutorial
  - New testFibService.sh script
- Assignment 2: Key/Value Store - Posting Soon
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Context Switches
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 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
- **Average – 6.77 (↑ - *previous 5.95*)**

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



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

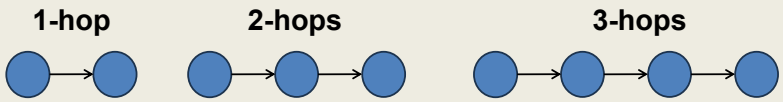
- ***In the chord system, when a node recieves a query for a key k which it doesn't store, then in the text book it's mentioned that it forwards the query to the smallest id greater than or equal to k which is nothing but the successor of k. ]***
- ***But in the slides its mentioned, it will be forwarded 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 $q = FT_p[j] \leq FT_p[j+1]$
  - 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

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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*

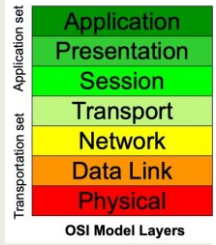


## ASSIGNMENT 1

- ***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

## 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

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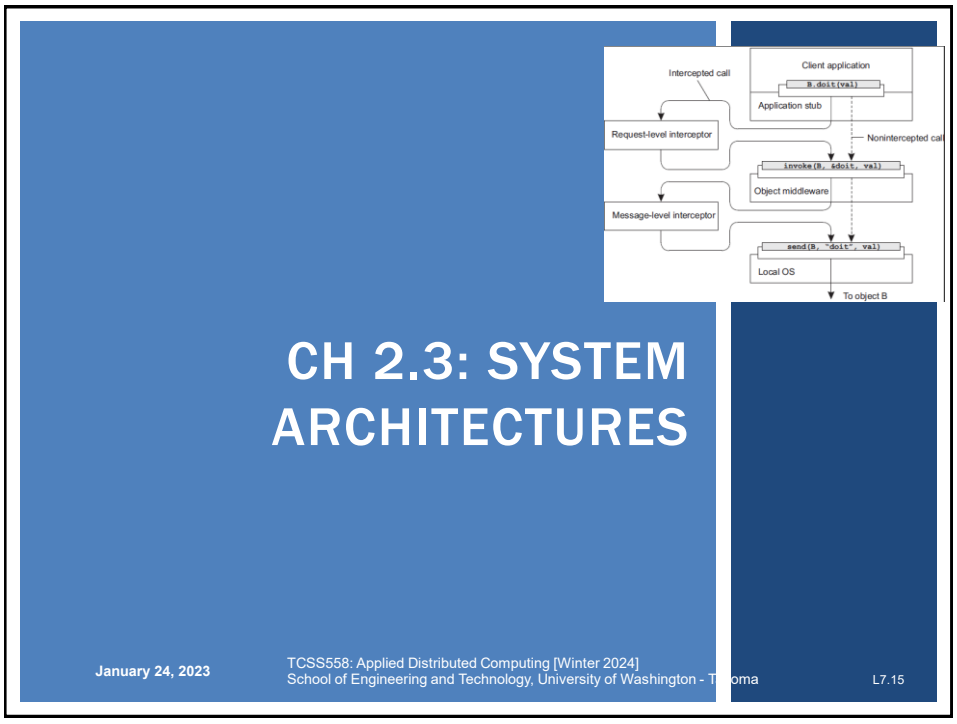
14



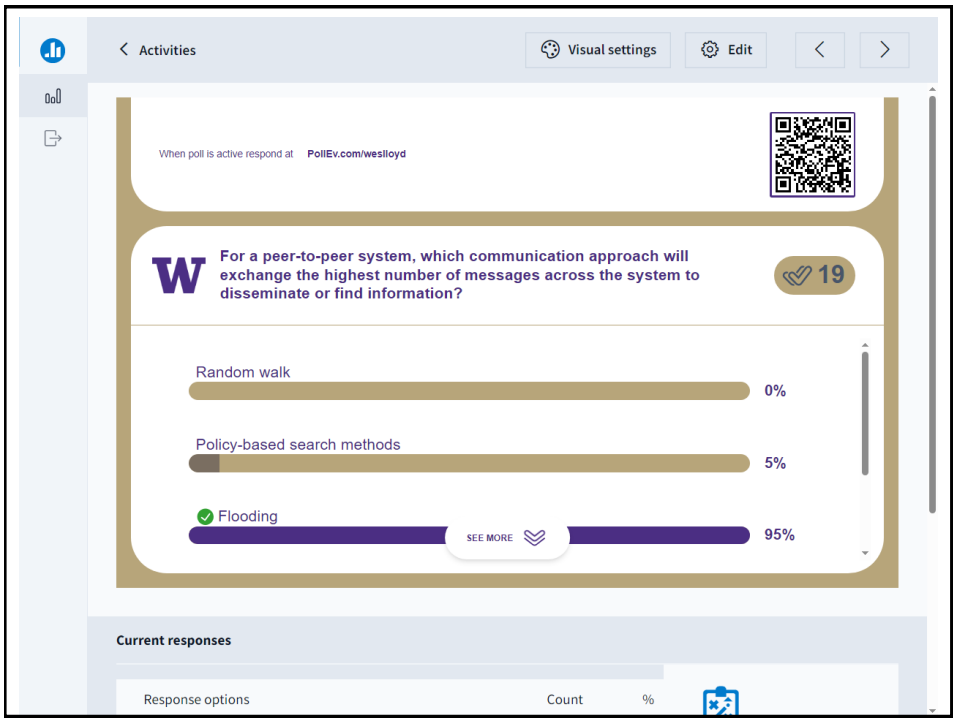

15

## REVIEW QUESTIONS

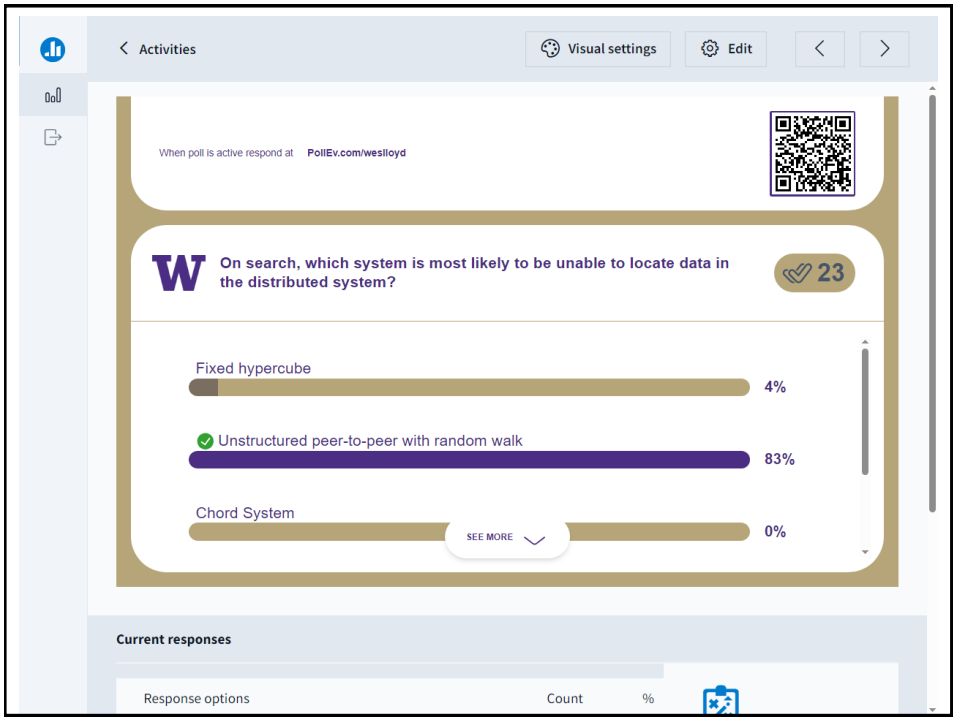
- What is difference in finding/disseminating data in unstructured vs. structured peer-to-peer networks?
  - Structured: can grasp the number of messages required based on the organization and structure of the system
  - Fixed hypercube
  - Chord system
  - Unstructured: requires broadcast like message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

| January 24, 2023 | TCSS558: Applied Distributed Computing [Winter 2024]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.16 |
|---|---|---|

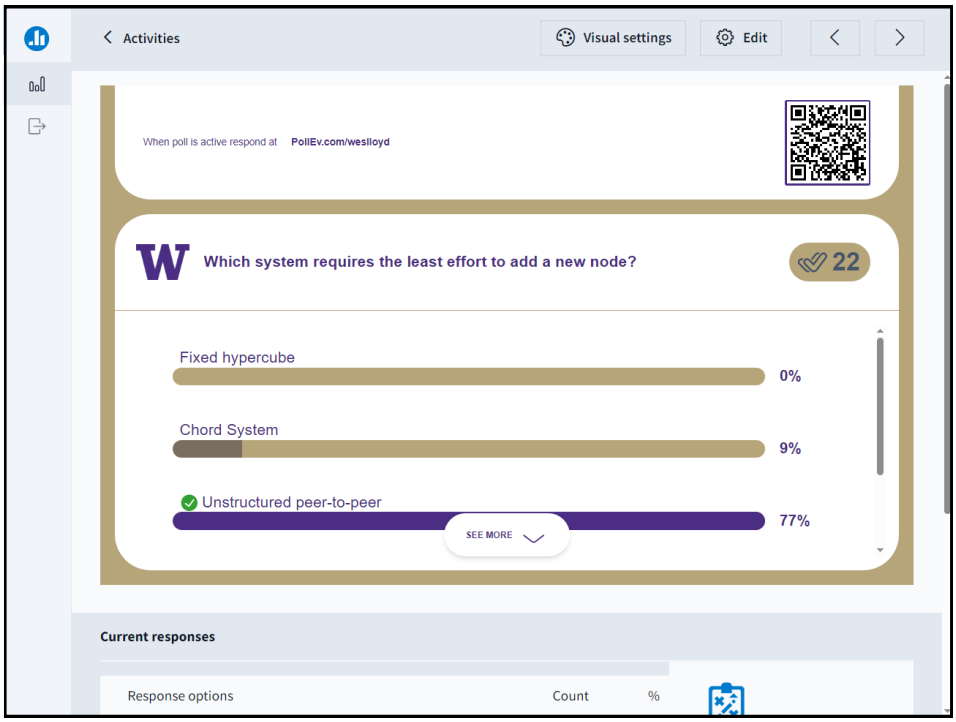
16


Activities
Visual settings
Edit
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%
SEE MORE
Current responses
Response options
Count
%

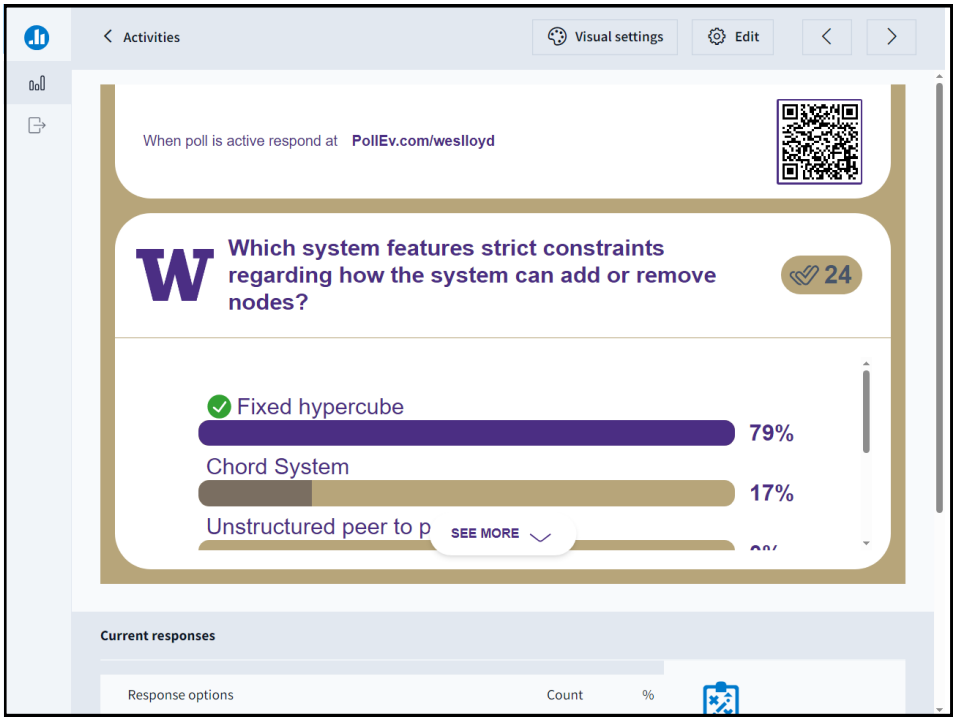
17


Activities
Visual settings
Edit
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%
SEE MORE
Current responses
Response options
Count
%

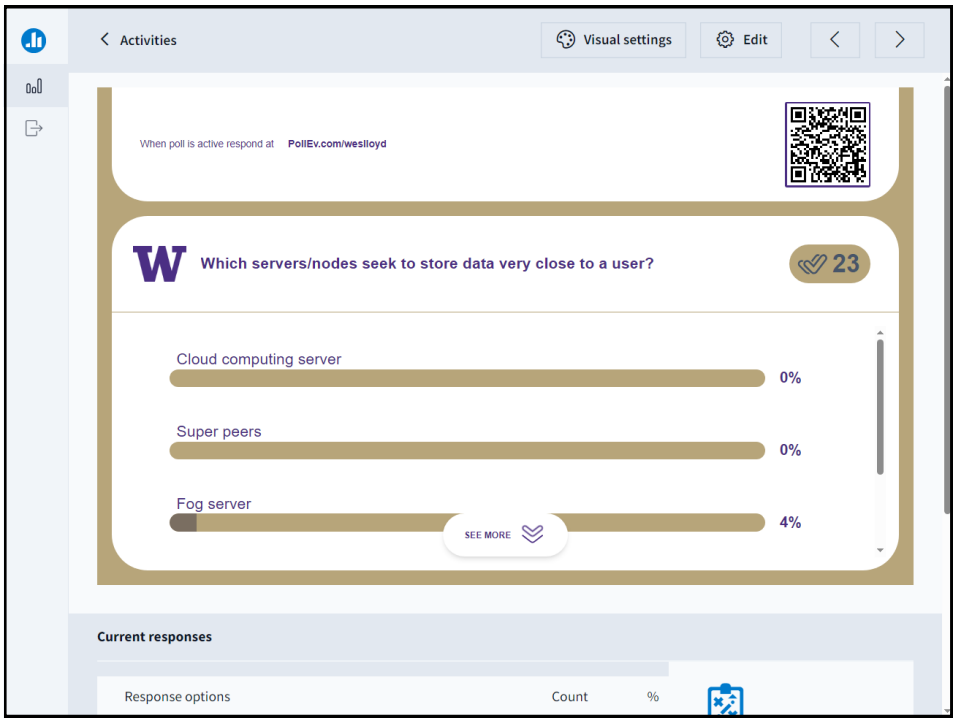
18


Activities
Visual settings
Edit
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%
SEE MORE
Current responses
Response options
Count
%

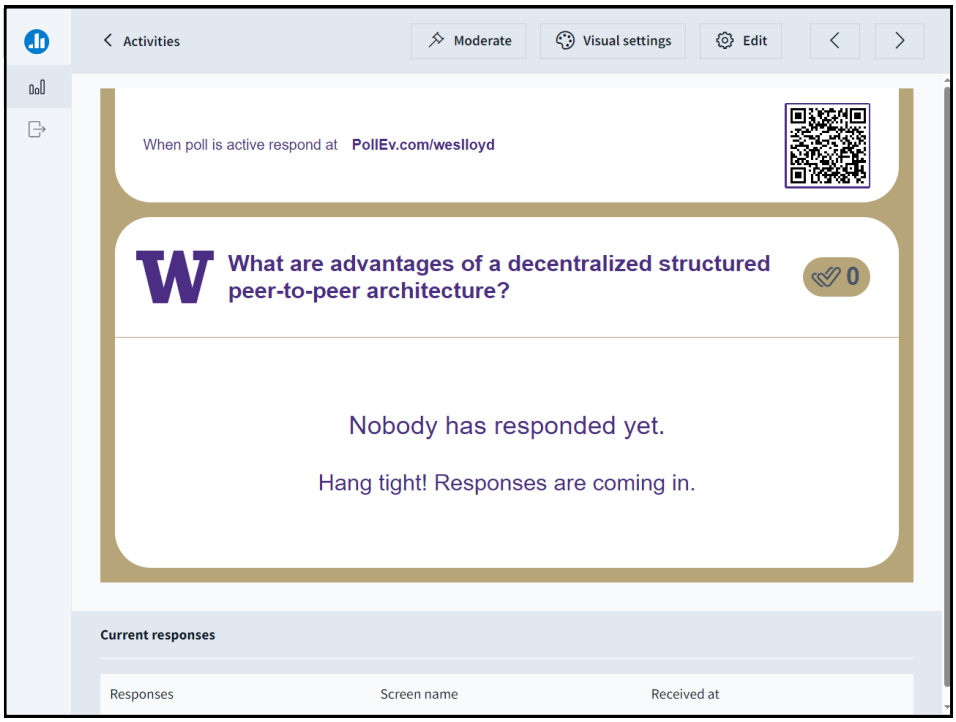
19


Activities
Visual settings
Edit
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
SEE MORE
Current responses
Response options
Count
%

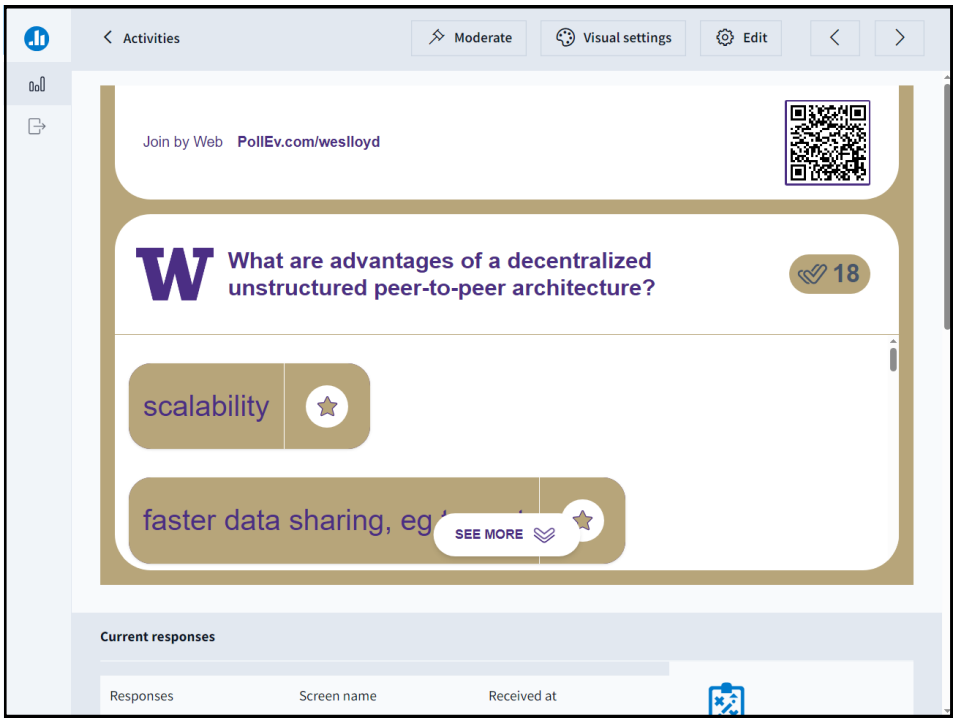
20


Activities
Visual settings
Edit
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%
SEE MORE
Current responses
Response options
Count
%

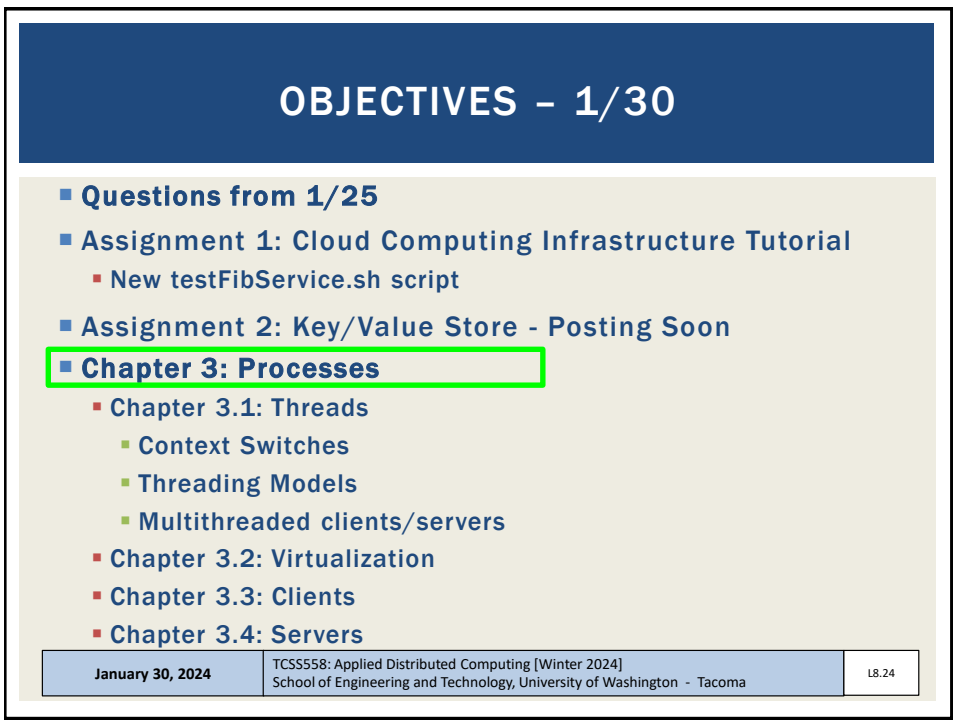
21


Activities
Moderate
Visual settings
Edit
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


Activities
Moderate
Visual settings
Edit
Join by Web PollEv.com/weslloyd
What are advantages of a decentralized unstructured peer-to-peer architecture?
18
scalability
faster data sharing, eg
SEE MORE
Current responses
Responses
Screen name
Received at

23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January 30, 2024
TCSS558: Applied Distributed Computing [Winter 2024]
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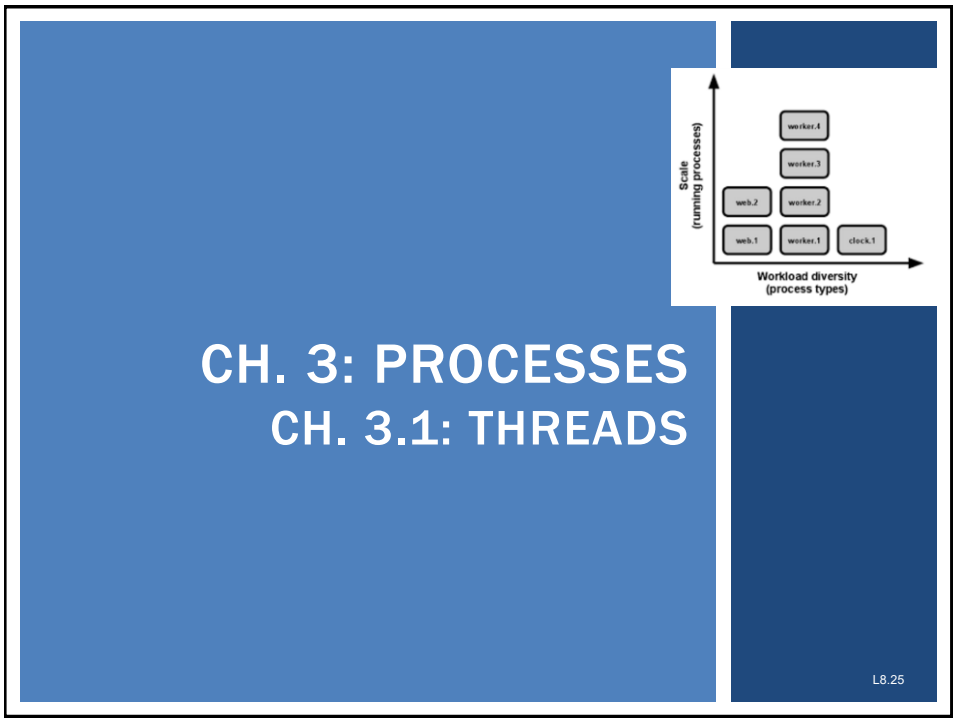
24




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



26

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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)



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



29

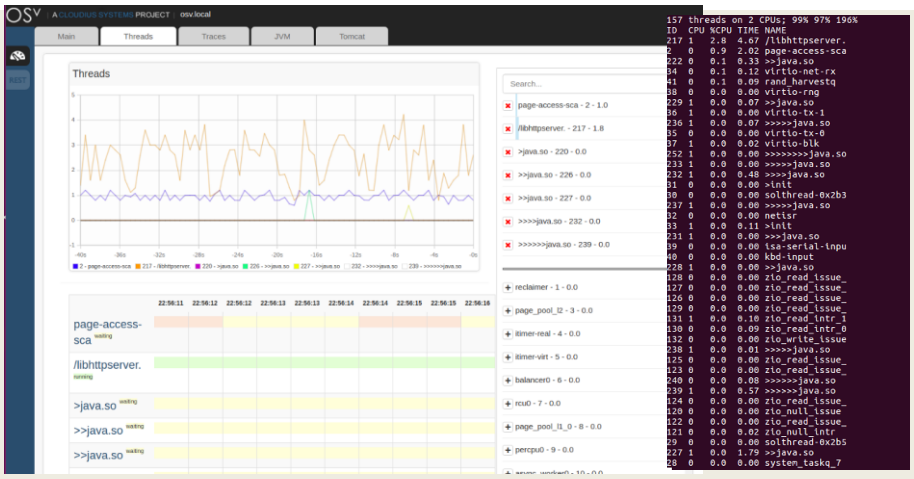
## THREADS - 3

- 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



30

## OSV: ONE PROCESS, MANY THREADS






31

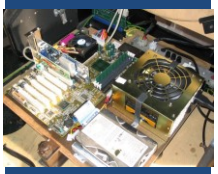
## THREADS - 4

- 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

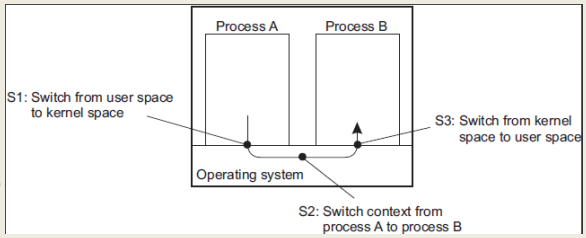
- Single core CPU
  - Tasks appear as if they are performed simultaneously
- Multi core CPU
  - Tasks ***execute*** simultaneously



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






35

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36

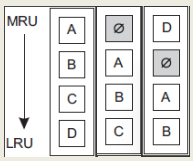
## CONTEXT SWITCHING

- **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***



## 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"**



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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?**



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?**



## 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?**

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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



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



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 . . .



47

## THREAD-LEVEL PARALLELISM

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

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

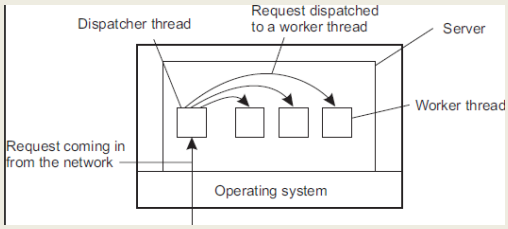
- Ci – fraction of time that exactly I threads are executed
- N – maximum threads that can execute at any one time
- Web browsers found to have TLP from 1.5 to 2.5
- Clients for web browsing can utilize from 2 to 3 CPU cores
- Any more cores are redundant, and potentially wasteful
- **Measure TLP to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



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






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 |



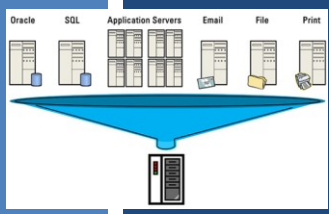
51

## 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

L8.53

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

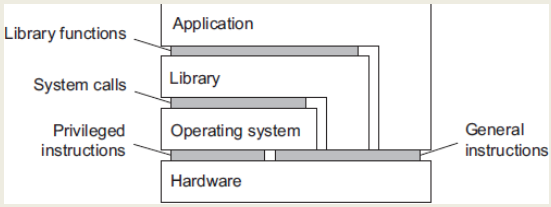
- Virtualization reappears in 2000s to leverage multi-core, multi-CPU processor systems
- VM-Ware virtual machines enable companies to host many virtual servers with mixed OSes on private clusters
- Cloud computing: Amazon offers VMs as-a-service (IaaS)



54

## TYPES OF VIRTUALIZATION

- **Levels of Instructions:**
- **Hardware**: CPU
  - Privileged instructions
    KERNEL MODE
  - General instructions
    USER MODE



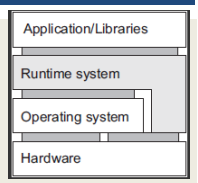

- **Operating system**: system calls
- **Library**: programming APIs: e.g. C/C++,C#, Java libraries
- **Application**:
- **Goal of virtualization:**
  mimic these interface to provide a virtual computer



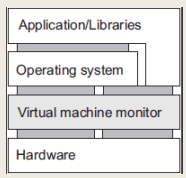
55

## 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

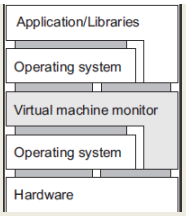





56

## 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

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.



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%



61

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  - Chapter 3.4: Servers



62


63

## TYPES OF CLIENTS

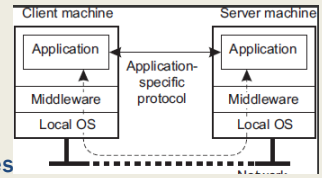
- Thick clients
  - Web browsers
    - Client-side scripting
  - Mobile apps
  - Multi-tier MVC apps
- Thin clients
  - Remote desktops/GUIs (very thin)



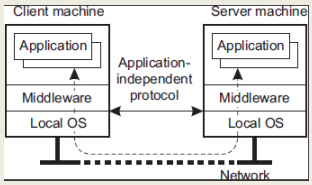
64

# 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






65

# X WINDOWS

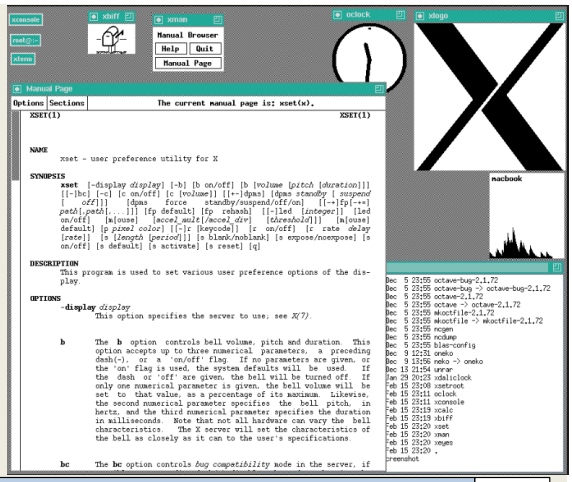
- Layered architecture to transport UI over network
- Remote desktop functionality for Linux/Unix systems
- X kernel acts as a server
  - Provides the **X protocol**: application level protocol
  - Xlib instances (client applications) exchange data and events with X kernels (servers)
  - Clients and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



66

# X WINDOWS - 2

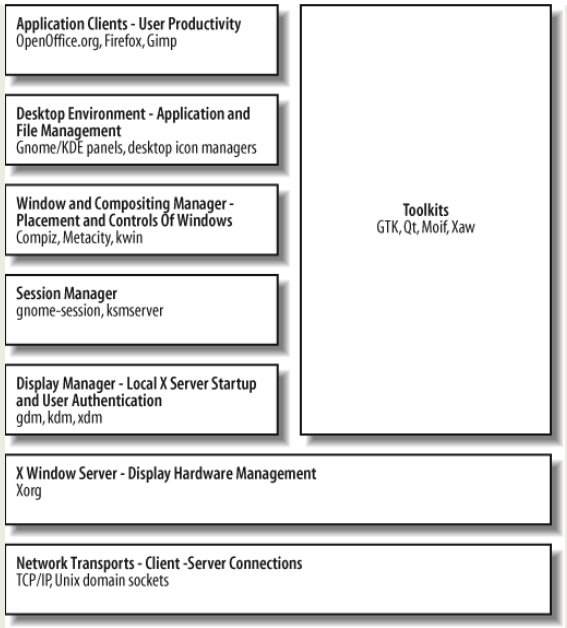
- Window manager:
  - Application running atop of X-windows which provides flair
  - Many variants
  - Without X windows is quite bland






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






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 &
```

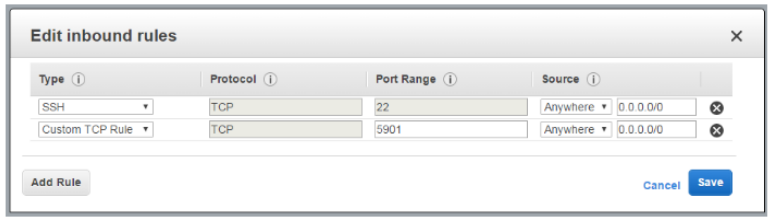


71

## 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:






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:

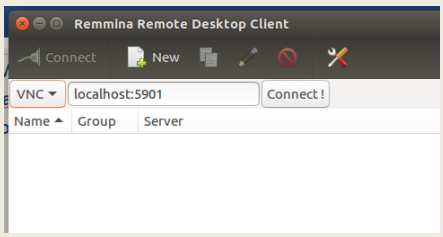
```
ssh -i mykey.pem -L 5901:127.0.0.1:5901 -N -f -
l ubuntu 52.111.202.44
```



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"

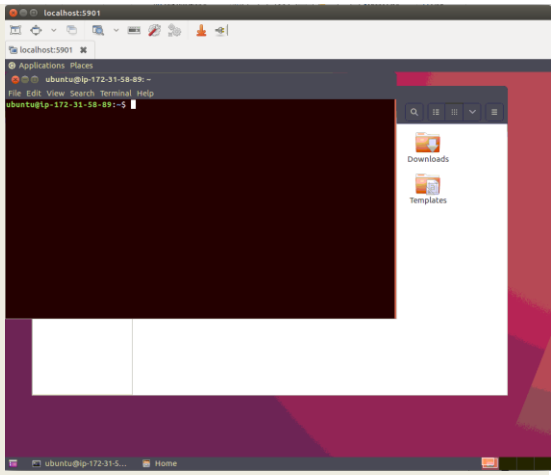





74

## 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



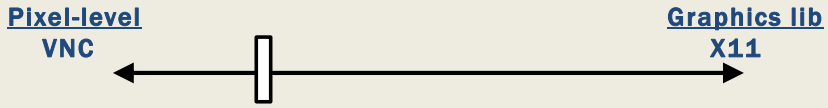
## THIN CLIENTS - 3

- 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

## TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols

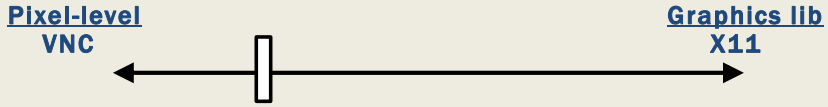





79

## 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

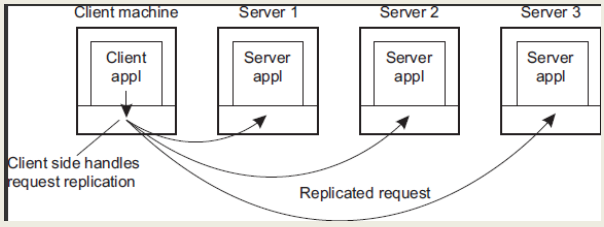
- Application context is available
- UI data/operations
- Lower network bandwidth
- More colors



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

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83




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`



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



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



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*



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



## 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

## 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?**

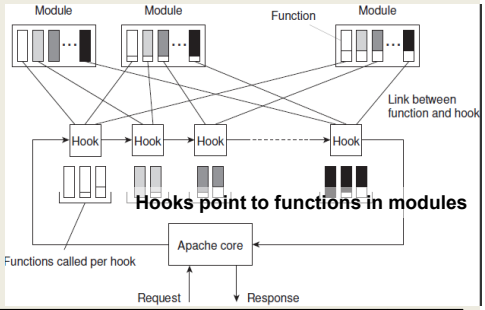


## EJB – ENTERPRISE JAVA BEANS

- 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

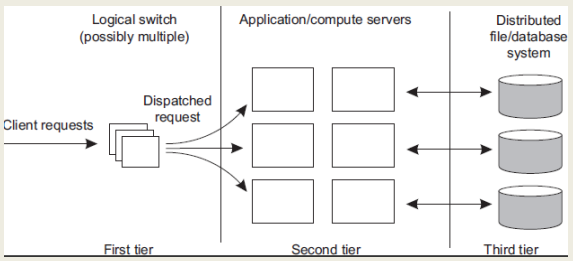





99

## 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






100

## LAN REQUEST DISPATCHING

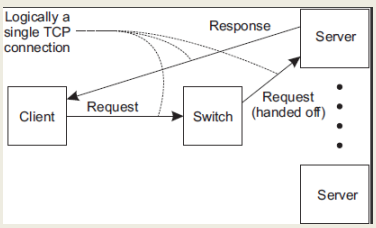
- Front end of three tier architecture (logical switch) provides distribution transparency – hides multiple servers
- Transport-layer switches: switch accepts TCP connection requests, hands off to a server
  - Example: hardware load balancer (F5 networks – Seattle)
  - HW Load balancer - OSI layers 4-7
- 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>
```



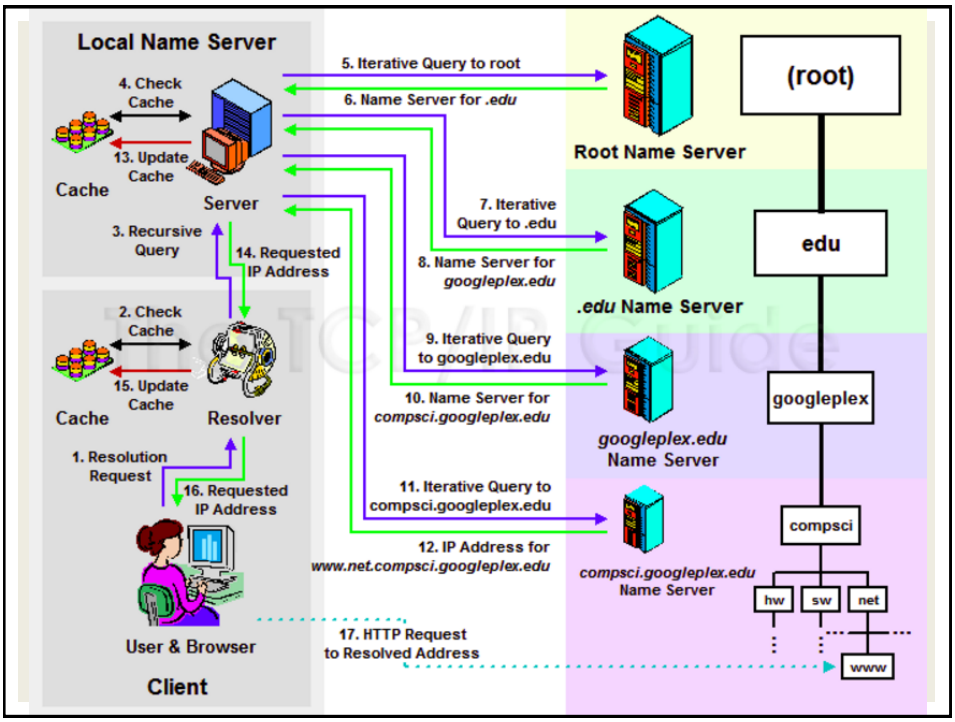
104

# 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




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)



109

## QUESTIONS



110