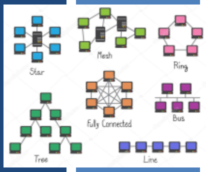
TCSS 558:
APPLIED DISTRIBUTED COMPUTING

Ch. 3 - Processes:
Servers

Ch. 4 - Communication

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



1

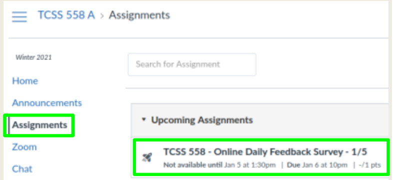
OBJECTIVES – 2/14

- Questions from 2/7
- Midterm Grading In Progress - Targeting Review Thursday
- Assignment 1: Key/Value Store
  - Java Maven project template files posted
- Chapter 3: Processes
  - Chapter 3.4: Servers
  - Chapter 3.5: Resource (Code) Migration (*light-review*)
- Chapter 4: Communication
  - Chapter 4.1: Foundations
  - Chapter 4.2: RPC (light-review)
  - Chapter 4.3: Message Oriented Communication

2

ONLINE DAILY FEEDBACK SURVEY

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



TCSS 558 A › Assignments

Winter 2021

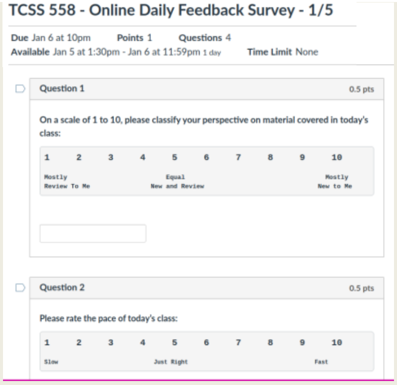
Search for Assignment

Home
Announcements
Assignments
Zoom
Chat

▾ Upcoming Assignments

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

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                  Equal                         Mostly
Review To Me            New and Review                New to Me
```

Question 2   0.5 pts

Please rate the pace of today's class:

```
1    2    3    4    5         6    7    8    9    10
Slow                Just Right                   Fast
```

4

MATERIAL / PACE

- Please classify your perspective on material covered in today's class (32 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.14** (↓ - *previous 6.66*)

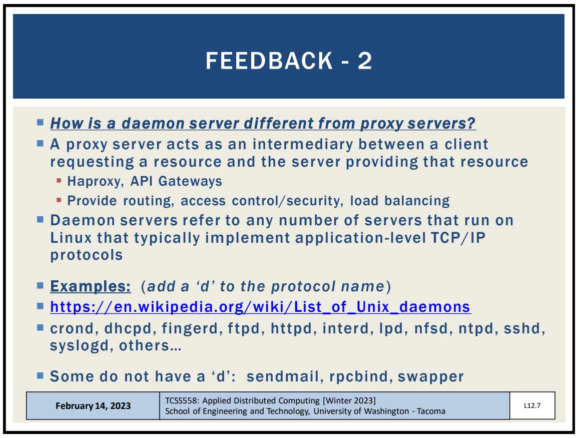
- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.84** (↓ - *previous 5.85*)

5

FEEDBACK FROM 2/7

- ***Does an EJB hold any major advantages over a more universal Object Server? Are they one and the same?***
- EJB server goes beyond object server
- Support is provided for many common and desired distributed systems features:
  - 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

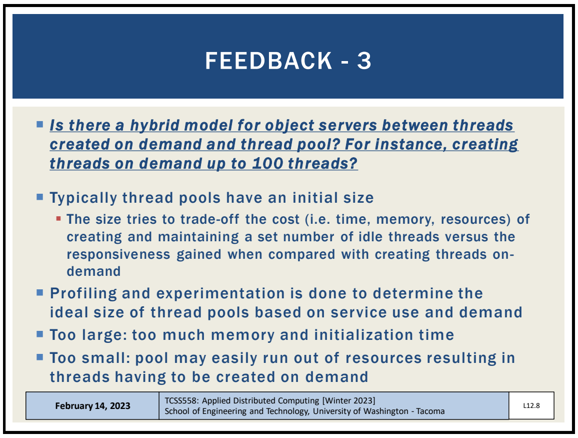
6



FEEDBACK - 2

- ***How is a daemon server different from proxy servers?***
- A proxy server acts as an intermediary between a client requesting a resource and the server providing that resource
  - Haproxy, API Gateways
  - Provide routing, access control/security, load balancing
- Daemon servers refer to any number of servers that run on Linux that typically implement application-level TCP/IP protocols
- **Examples:** (*add a 'd' to the protocol name*)
- https://en.wikipedia.org/wiki/List_of_Unix_daemons
- crond, dhcpd, fingerd, ftpd, httpd, interd, lpd, nfsd, ntpd, sshd, syslogd, others…
- Some do not have a 'd': sendmail, rpcbind, swapper

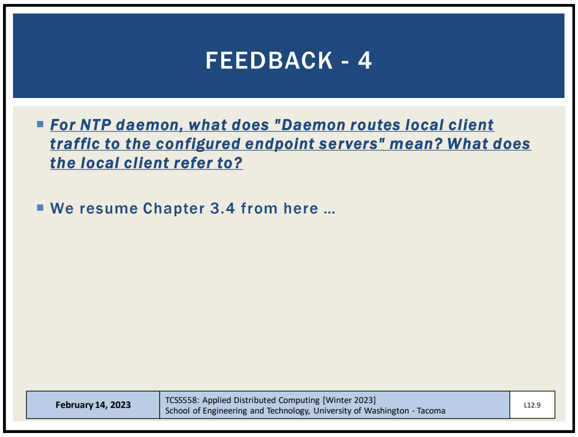
7



FEEDBACK - 3

- ***Is there a hybrid model for object servers between threads created on demand and thread pool? For instance, creating threads on demand up to 100 threads?***
- Typically thread pools have an initial size
  - The size tries to trade-off the cost (i.e. time, memory, resources) of creating and maintaining a set number of idle threads versus the responsiveness gained when compared with creating threads on-demand
- Profiling and experimentation is done to determine the ideal size of thread pools based on service use and demand
- Too large: too much memory and initialization time
- Too small: pool may easily run out of resources resulting in threads having to be created on demand

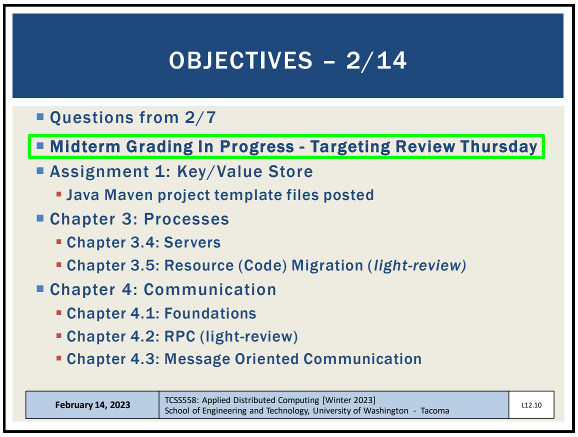
8



FEEDBACK - 4

- ***For NTP daemon, what does "Daemon routes local client traffic to the configured endpoint servers" mean? What does the local client refer to?***
- We resume Chapter 3.4 from here …

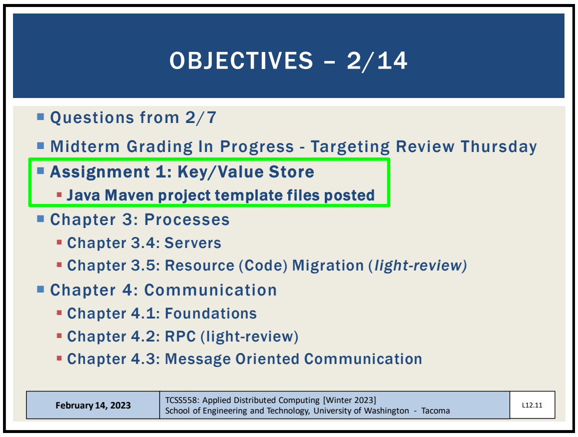
9



OBJECTIVES – 2/14

- Questions from 2/7
- **Midterm Grading In Progress - Targeting Review Thursday**
- Assignment 1: Key/Value Store
  - Java Maven project template files posted
- Chapter 3: Processes
  - Chapter 3.4: Servers
  - Chapter 3.5: Resource (Code) Migration (*light-review*)
- Chapter 4: Communication
  - Chapter 4.1: Foundations
  - Chapter 4.2: RPC (light-review)
  - Chapter 4.3: Message Oriented Communication

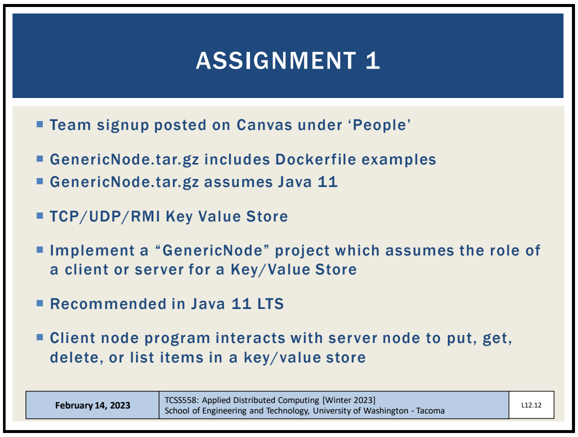
10



OBJECTIVES – 2/14

- Questions from 2/7
- Midterm Grading In Progress - Targeting Review Thursday
- **Assignment 1: Key/Value Store**
  - **Java Maven project template files posted**
- Chapter 3: Processes
  - Chapter 3.4: Servers
  - Chapter 3.5: Resource (Code) Migration (*light-review*)
- Chapter 4: Communication
  - Chapter 4.1: Foundations
  - Chapter 4.2: RPC (light-review)
  - Chapter 4.3: Message Oriented Communication

11



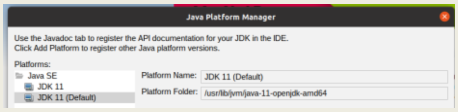
ASSIGNMENT 1

- Team signup posted on Canvas under 'People'
- GenericNode.tar.gz includes Dockerfile examples
- GenericNode.tar.gz assumes Java 11
- TCP/UDP/RMI Key Value Store
- Implement a "GenericNode" project which assumes the role of a client or server for a Key/Value Store
- Recommended in Java 11 LTS
- Client node program interacts with server node to put, get, delete, or list items in a key/value store

12

USING JAVA 11 IN NETBEANS

- In Netbeans IDE, under Tools menu, 'Java Platforms', be sure to install and select JDK 11


Java Platform Manager

Use the Javadoc tab to register the API documentation for your JDK in the IDE.
Click Add Platform to register other Java platform versions.

Platforms:
- Java SE
  - JDK 11
  - JDK 11 (Default)

Platform Name: JDK 11 (Default)
Platform Folder: /usr/lib/jvm/java-11-openjdk-amd64

- On left-hand Project menu, right-click on '**GenericNode**' project
- Select Properties
- Under Build | Compile, be sure Java Platform is JDK 11
- Under Sources, be sure Source/Binary Format is 11

OBJECTIVES – 2/14

- Questions from 2/7
- Midterm Grading In Progress - Targeting Review Thursday
- Assignment 1: Key/Value Store
  - Java Maven project template files posted
- **Chapter 3: Processes**
  - **Chapter 3.4: Servers**
  - Chapter 3.5: Resource (Code) Migration (*light-review*)
- Chapter 4: Communication
  - Chapter 4.1: Foundations
  - Chapter 4.2: RPC (light-review)
  - Chapter 4.3: Message Oriented Communication

CH. 3.4: SERVERS

WIDE AREA CLUSTERS

- Deployed across the internet
- Leverage resource/infrastructure from Internet Service Providers (ISPs)
- Cloud computing simplifies building WAN clusters
- Resources 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

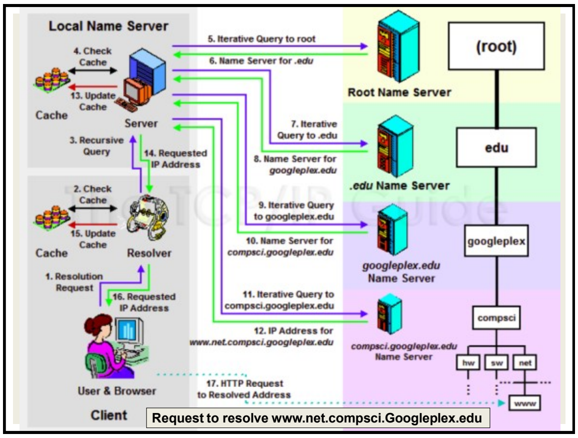
- Request dispatcher: routes requests to nearby server
- Example: Domain Name System
  - Hierarchical decentralized naming system

- Linux: find your DNS servers:

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

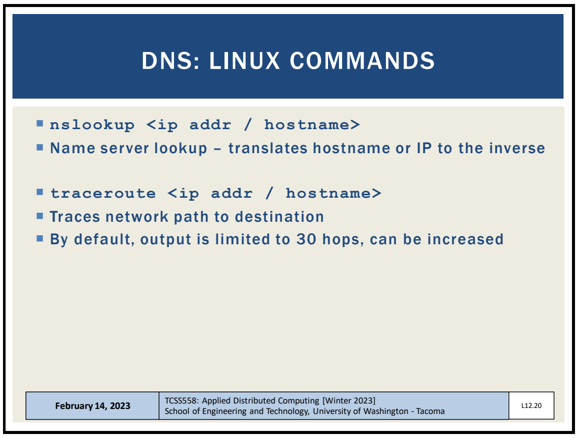
DNS LOOKUP

- 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*


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
TCP/IP Guide

Request to resolve www.net.compsci.Googleplex.edu

19

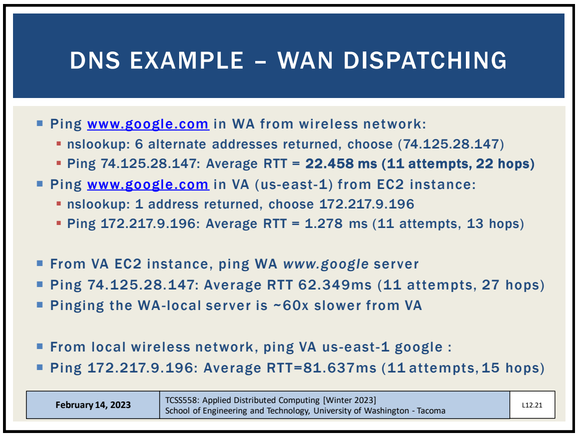


DNS: LINUX COMMANDS

- `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

20



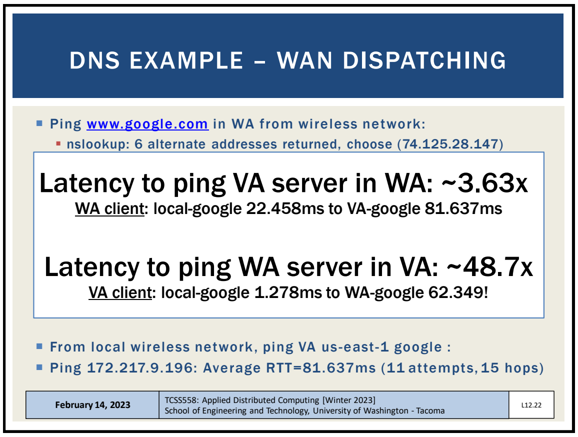
DNS EXAMPLE – WAN DISPATCHING

- 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)

21



DNS EXAMPLE – WAN DISPATCHING

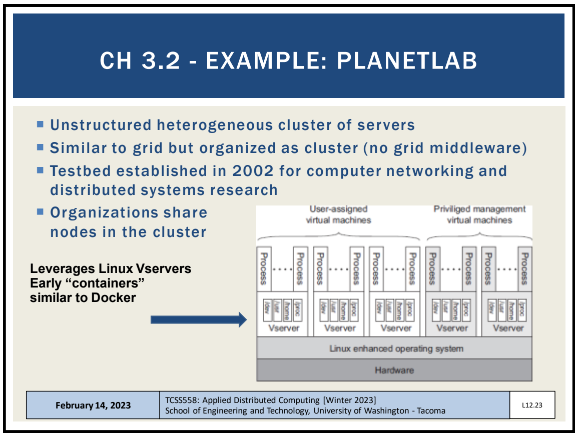
- Ping www.google.com in WA from wireless network:
  - nslookup: 6 alternate addresses returned, choose (74.125.28.147)

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)

22



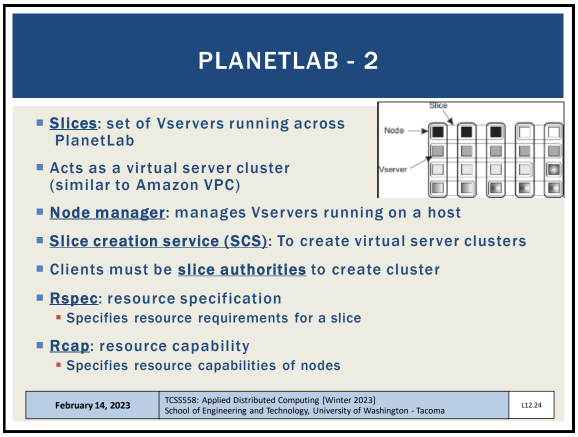
CH 3.2 - EXAMPLE: PLANETLAB

- Unstructured heterogeneous cluster of servers
- Similar to grid but organized as cluster (no grid middleware)
- Testbed established in 2002 for computer networking and distributed systems research
- Organizations share nodes in the cluster

Leverages Linux Vservers Early "containers" similar to Docker

User-assigned virtual machines
Priviliged management virtual machines
Process
Process
/dev
/usr
/home
/proc
Vserver
Linux enhanced operating system
Hardware

23



PLANETLAB - 2

- **Slices**: set of Vservers running across PlanetLab
- Acts as a virtual server cluster (similar to Amazon VPC)
- **Node manager**: manages Vservers running on a host
- **Slice creation service (SCS)**: To create virtual server clusters
- Clients must be **slice authorities** to create cluster
- **Rspec**: resource specification
  - Specifies resource requirements for a slice
- **Rcap**: resource capability
  - Specifies resource capabilities of nodes

24

VSERVERS

- Provided early “container-like” tool
- Vservers share a single operating system kernel
- Primary task is to support a group of processes
- Provides separation of name spaces
- Linux kernel maps process IDs: host OS → Vservers
- Each Vserver has its own set of libraries and file system
- Similar name separation as the “`chroot`” command
- Additional isolation provided to prevent unauthorized access among Vservers directory trees

25

VSERVERS - 2

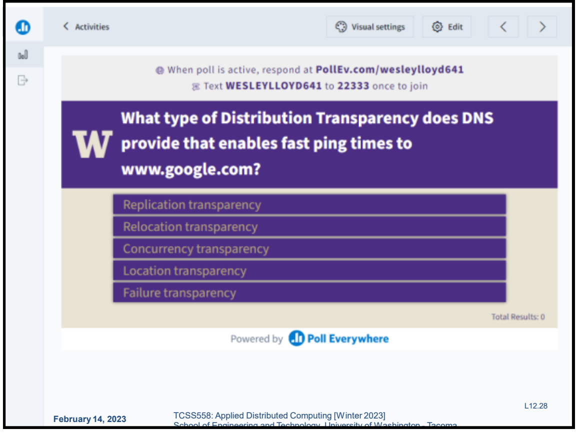
- **Advantages of Vservers (containers) vs. VMs:**
- Simpler resource allocation
- Possible to overbook resources by leveraging dynamic resource allocation - **Example: CPU or RAM** *(assignment 0, config 2)*
- VMs reserve a block of memory
- Containers can oversubscribe memory
  - Memory not formally reserved
  - Linux kernel shares memory among processes
  - Swap filesystem can use disk as extended RAM
- Memory sharing important for PlanetLab
  - Early nodes had limited memory (e.g. 4 GB)
- Vserver hogging most memory reset when out of swap space

26

OBJECTIVES – 2/14

- Questions from 2/7
- Midterm Grading In Progress - Targeting Review Thursday
- Assignment 1: Key/Value Store
  - Java Maven project template files posted
- Chapter 3: Processes
  - Chapter 3.4: Servers
  - **Chapter 3.5: Resource (Code) Migration (*light-review*)**
- Chapter 4: Communication
  - Chapter 4.1: Foundations
  - Chapter 4.2: RPC (light-review)
  - Chapter 4.3: Message Oriented Communication

27



When poll is active, respond at **PollEv.com/wesleylloyd641**
Text **WESLEYLLOYD641** to **22333** once to join

What type of Distribution Transparency does DNS provide that enables fast ping times to www.google.com?

- Replication transparency
- Relocation transparency
- Concurrency transparency
- Location transparency
- Failure transparency

Total Results: 0

Powered by Poll Everywhere

28

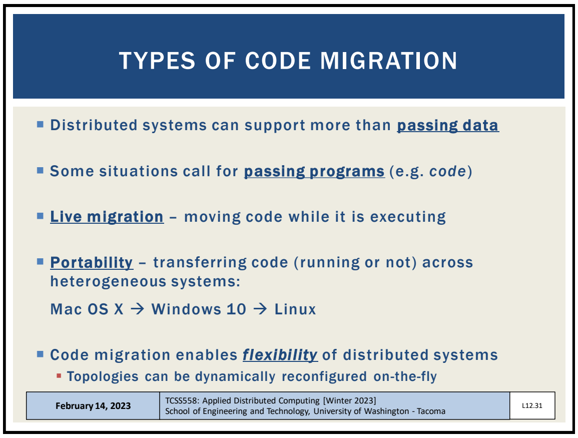
CH. 3.5: RESOURCE (CODE) MIGRATION

29

RESOURCE MIGRATION

- To support on-the-fly reorganization of distributed systems, at times there is interest in resource migration
- Can consider various types of resource migration
  - Code migration: source code, libraries
  - Process migration: a running job/task
  - VM migration: an entire virtual server!

30

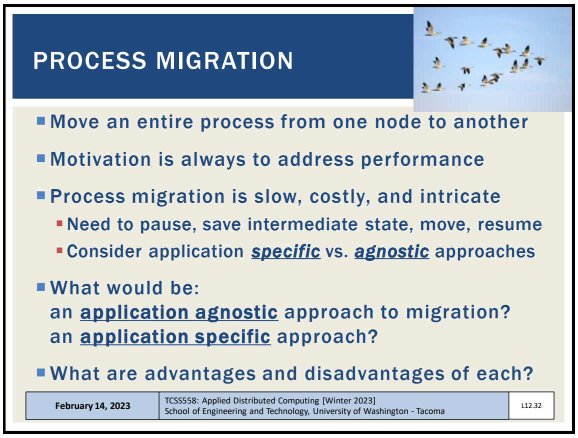


TYPES OF CODE MIGRATION

- Distributed systems can support more than **passing data**
- Some situations call for **passing programs** (e.g. *code*)
- **Live migration** – moving code while it is executing
- **Portability** – transferring code (running or not) across heterogeneous systems:

  Mac OS X → Windows 10 → Linux
- Code migration enables ***flexibility*** of distributed systems
  - Topologies can be dynamically reconfigured on-the-fly

31



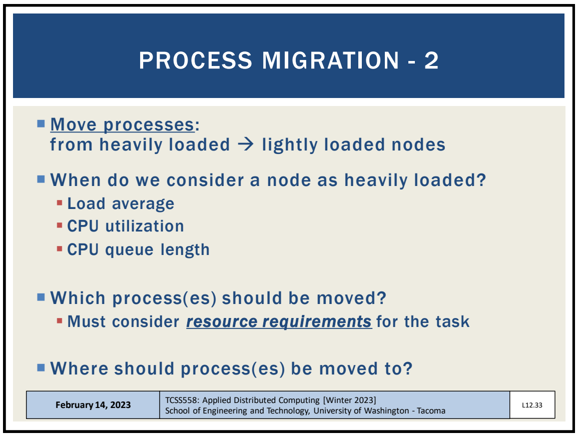
PROCESS MIGRATION

- Move an entire process from one node to another
- Motivation is always to address performance
- Process migration is slow, costly, and intricate
  - Need to pause, save intermediate state, move, resume
  - Consider application ***specific*** vs. ***agnostic*** approaches
- What would be:

  an **application agnostic** approach to migration?

  an **application specific** approach?
- What are advantages and disadvantages of each?

32

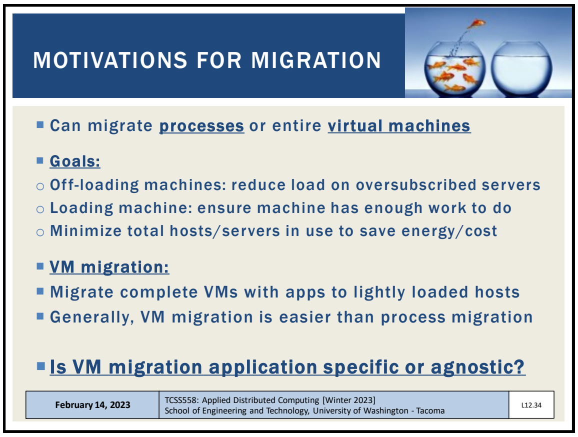


PROCESS MIGRATION - 2

- Move processes:

  from heavily loaded → lightly loaded nodes
- When do we consider a node as heavily loaded?
  - Load average
  - CPU utilization
  - CPU queue length
- Which process(es) should be moved?
  - Must consider ***resource requirements*** for the task
- Where should process(es) be moved to?

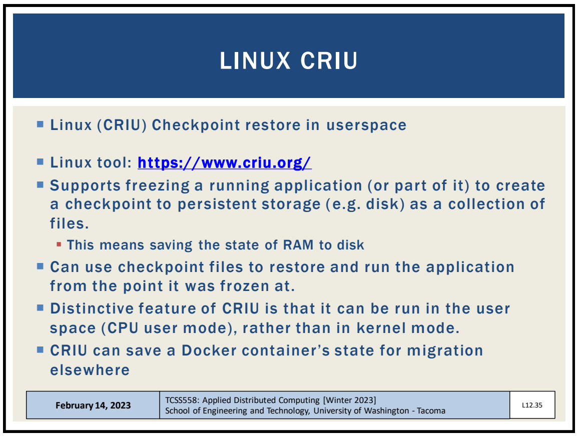
33



MOTIVATIONS FOR MIGRATION

- Can migrate **processes** or entire **virtual machines**
- **Goals:**
- ○ Off-loading machines: reduce load on oversubscribed servers
- ○ Loading machine: ensure machine has enough work to do
- ○ Minimize total hosts/servers in use to save energy/cost
- **VM migration:**
- Migrate complete VMs with apps to lightly loaded hosts
- Generally, VM migration is easier than process migration
- **Is VM migration application specific or agnostic?**

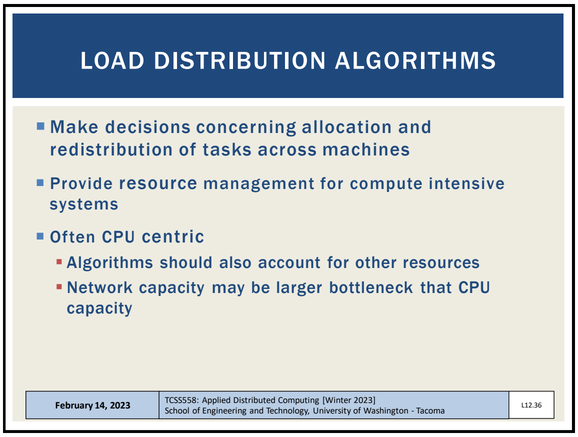
34



LINUX CRIU

- Linux (CRIU) Checkpoint restore in userspace
- Linux tool: https://www.criu.org/
- Supports freezing a running application (or part of it) to create a checkpoint to persistent storage (e.g. disk) as a collection of files.
  - This means saving the state of RAM to disk
- Can use checkpoint files to restore and run the application from the point it was frozen at.
- Distinctive feature of CRIU is that it can be run in the user space (CPU user mode), rather than in kernel mode.
- CRIU can save a Docker container's state for migration elsewhere

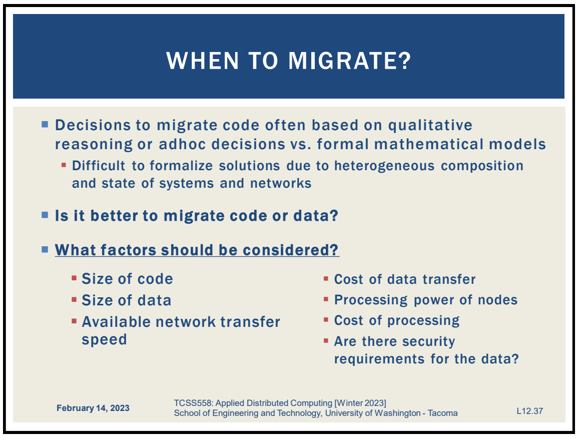
35



LOAD DISTRIBUTION ALGORITHMS

- Make decisions concerning allocation and redistribution of tasks across machines
- Provide resource management for compute intensive systems
- Often CPU centric
  - Algorithms should also account for other resources
  - Network capacity may be larger bottleneck that CPU capacity

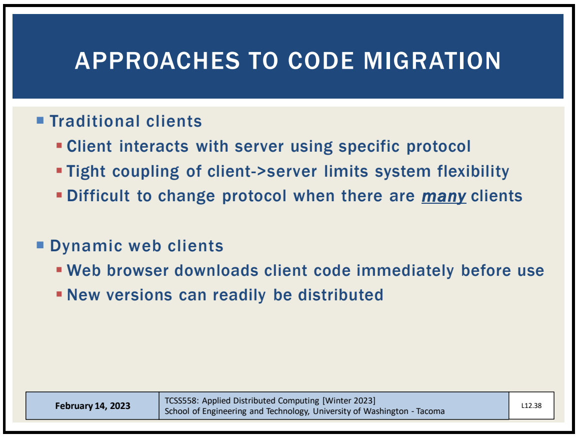
36



WHEN TO MIGRATE?

- Decisions to migrate code often based on qualitative reasoning or adhoc decisions vs. formal mathematical models
  - Difficult to formalize solutions due to heterogeneous composition and state of systems and networks
- **Is it better to migrate code or data?**
- **What factors should be considered?**
  - Size of code
  - Size of data
  - Available network transfer speed
  - Cost of data transfer
  - Processing power of nodes
  - Cost of processing
  - Are there security requirements for the data?

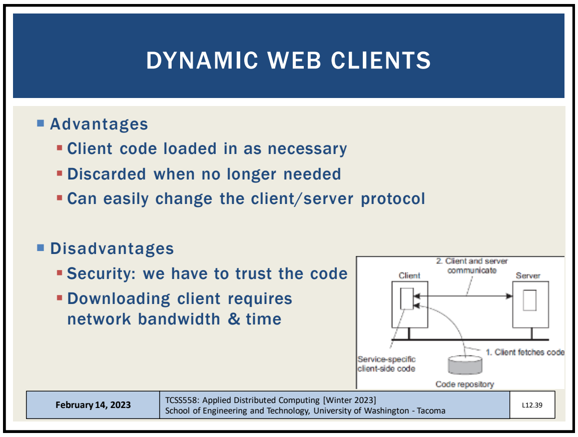
37



APPROACHES TO CODE MIGRATION

- Traditional clients
  - Client interacts with server using specific protocol
  - Tight coupling of client->server limits system flexibility
  - Difficult to change protocol when there are ***many*** clients
- Dynamic web clients
  - Web browser downloads client code immediately before use
  - New versions can readily be distributed

38

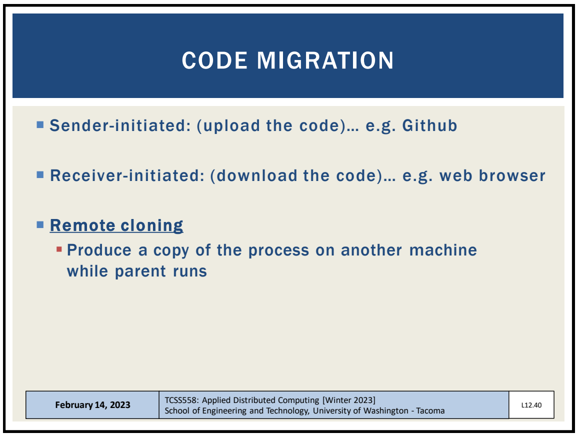


DYNAMIC WEB CLIENTS

- Advantages
  - Client code loaded in as necessary
  - Discarded when no longer needed
  - Can easily change the client/server protocol
- Disadvantages
  - Security: we have to trust the code
  - Downloading client requires network bandwidth & time

2. Client and server communicate
Client
Server
1. Client fetches code
Service-specific client-side code
Code repository

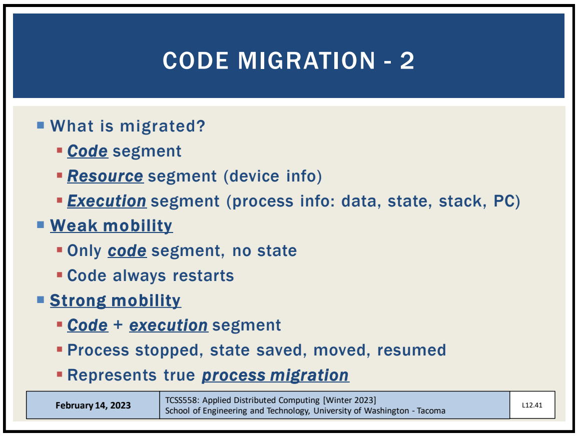
39



CODE MIGRATION

- Sender-initiated: (upload the code)… e.g. Github
- Receiver-initiated: (download the code)… e.g. web browser
- **Remote cloning**
  - Produce a copy of the process on another machine while parent runs

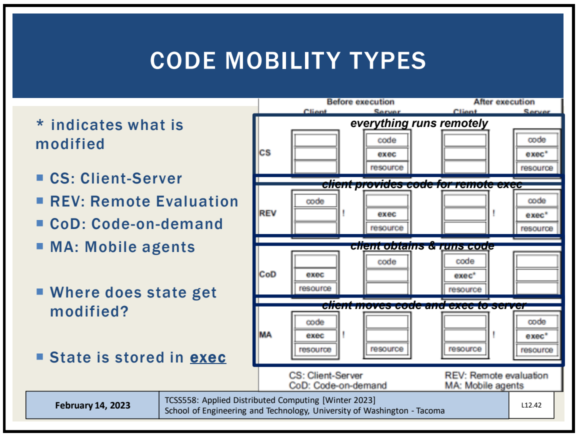
40



CODE MIGRATION - 2

- What is migrated?
  - ***Code*** segment
  - ***Resource*** segment (device info)
  - ***Execution*** segment (process info: data, state, stack, PC)
- **Weak mobility**
  - Only ***code*** segment, no state
  - Code always restarts
- **Strong mobility**
  - ***Code*** + ***execution*** segment
  - Process stopped, state saved, moved, resumed
  - Represents true ***process migration***

41



CODE MOBILITY TYPES

- * indicates what is modified
- CS: Client-Server
- REV: Remote Evaluation
- CoD: Code-on-demand
- MA: Mobile agents
- Where does state get modified?
- State is stored in **exec**

	Before execution			After execution	
	Client	Server		Client	Server
CS		code exec resource			code exec* resource
REV	code	exec resource	!		code exec* resource
CoD	exec resource	code		code exec* resource	
MA	code exec resource	resource	!	resource	code exec* resource

everything runs remotely (CS)

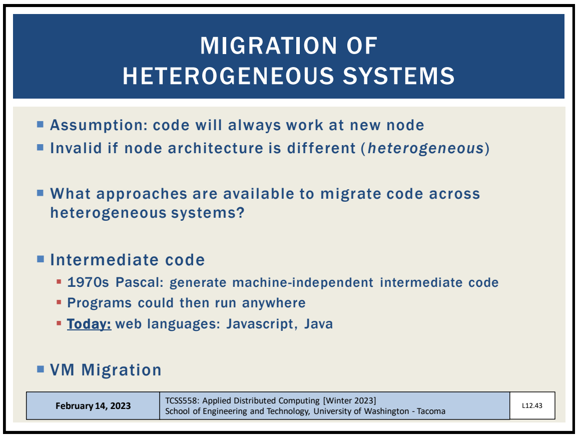
client provides code for remote exec (REV)

client obtains & runs code (CoD)

client moves code and exec to server (MA)

CS: Client-Server
CoD: Code-on-demand
REV: Remote evaluation
MA: Mobile agents

42



MIGRATION OF HETEROGENEOUS SYSTEMS

- Assumption: code will always work at new node
- Invalid if node architecture is different (*heterogeneous*)

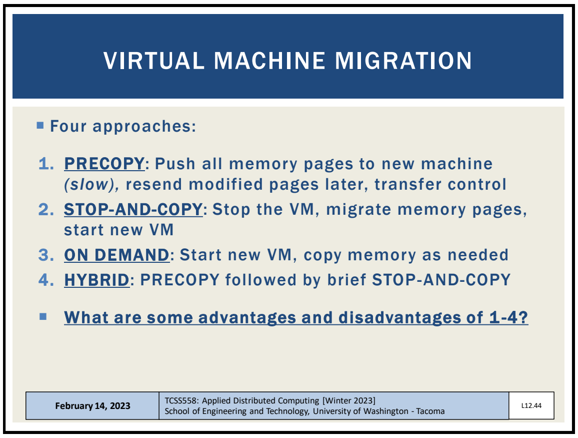
- What approaches are available to migrate code across heterogeneous systems?

- Intermediate code
  - 1970s Pascal: generate machine-independent intermediate code
  - Programs could then run anywhere
  - **Today:** web languages: Javascript, Java

- VM Migration

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.43

43



VIRTUAL MACHINE MIGRATION

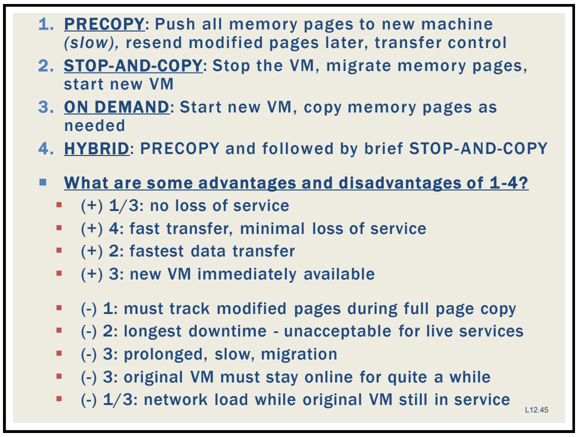
- Four approaches:

1. **PRECOPY**: Push all memory pages to new machine (*slow*), resend modified pages later, transfer control
2. **STOP-AND-COPY**: Stop the VM, migrate memory pages, start new VM
3. **ON DEMAND**: Start new VM, copy memory as needed
4. **HYBRID**: PRECOPY followed by brief STOP-AND-COPY

- **What are some advantages and disadvantages of 1-4?**

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.44

44



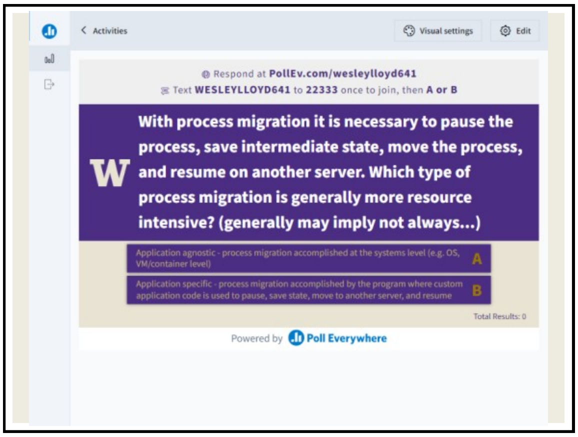
1. **PRECOPY**: Push all memory pages to new machine (*slow*), resend modified pages later, transfer control
2. **STOP-AND-COPY**: Stop the VM, migrate memory pages, start new VM
3. **ON DEMAND**: Start new VM, copy memory pages as needed
4. **HYBRID**: PRECOPY and followed by brief STOP-AND-COPY

- **What are some advantages and disadvantages of 1-4?**
  - (+) 1/3: no loss of service
  - (+) 4: fast transfer, minimal loss of service
  - (+) 2: fastest data transfer
  - (+) 3: new VM immediately available

  - (-) 1: must track modified pages during full page copy
  - (-) 2: longest downtime - unacceptable for live services
  - (-) 3: prolonged, slow, migration
  - (-) 3: original VM must stay online for quite a while
  - (-) 1/3: network load while original VM still in service

L12.45

45



Respond at PollEv.com/wesleylloyd641

Text WESLEYLLOYD641 to 22333 once to join, then A or B

With process migration it is necessary to pause the process, save intermediate state, move the process, and resume on another server. Which type of process migration is generally more resource intensive? (generally may imply not always...)

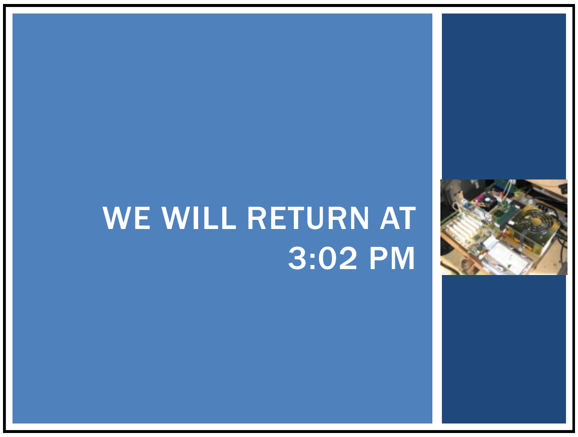
Application agnostic - process migration accomplished at the systems level (e.g. OS, VM/container level) A

Application specific - process migration accomplished by the program where custom application code is used to pause, save state, move to another server, and resume B

Total Results: 0

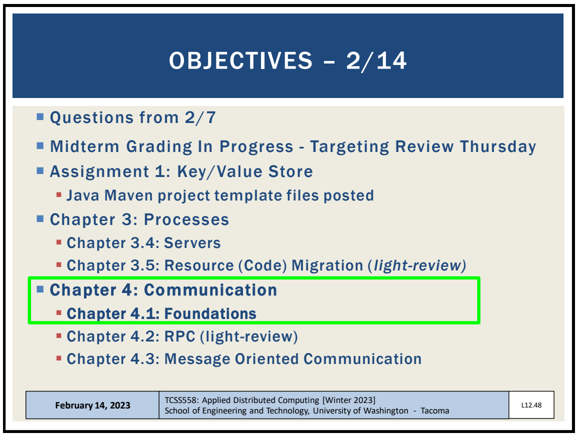
Powered by Poll Everywhere

46



WE WILL RETURN AT 3:02 PM

47

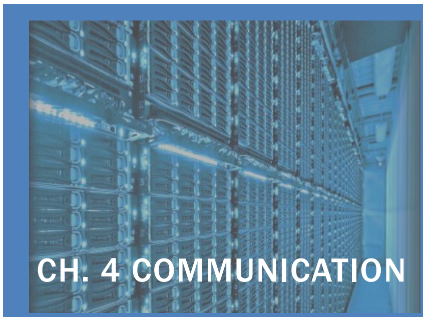


OBJECTIVES – 2/14

- Questions from 2/7
- Midterm Grading In Progress - Targeting Review Thursday
- Assignment 1: Key/Value Store
  - Java Maven project template files posted
- Chapter 3: Processes
  - Chapter 3.4: Servers
  - Chapter 3.5: Resource (Code) Migration (*light-review*)
- **Chapter 4: Communication**
  - **Chapter 4.1: Foundations**
  - Chapter 4.2: RPC (light-review)
  - Chapter 4.3: Message Oriented Communication

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.48

48



CH. 4 COMMUNICATION

CHAPTER 4

- 4.1 Foundations
  - Protocols
  - Types of communication
- 4.2 Remote procedure call
- 4.3 Message-oriented communication
  - Socket communication
  - Messaging libraries
  - Message-Passing Interface (MPI)
  - Message-queueing systems
  - Examples
- 4.4 Multicast communication
  - Flooding-based multicasting
  - Gossip-based data dissemination

Reviews and builds on content from Ch. 2/3

CH. 4.1: FOUNDATIONS

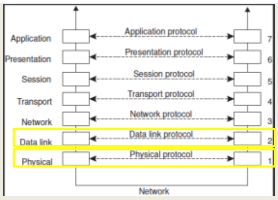
LAYERED PROTOCOLS

- Distributed systems lack shared memory
- All distributed system communication is based on sending and receiving low-level messages
  - P → Q
- <u>O</u>pen <u>S</u>ystems <u>I</u>nterconnection Reference Model (OSI Model)
  - Open systems communicate with any other open system
  - Standards govern format, contents, meaning of messages
  - Formalization of rules forms a **<u>communication protocol</u>**

LAYERED PROTOCOLS - 2

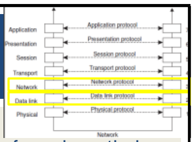
- Protocols provide a **<u>communication service</u>**
- **<u>Two service types:</u>**
  - **<u>Connection-oriented</u>**: sender/receiver establish connection, negotiate parameters of the protocol, close connection when done
  - Physical example: telephone
  - **<u>Connectionless</u>**: No setup. Sender sends. Receiver receives.
  - Physical example: Mailing a letter

OSI MODEL REVISITED



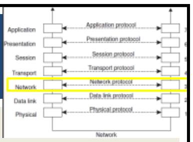
- Physical layer: just sends bits → … 0 0 0 1 0 1 1 0 1 1 …
- Data link layer: Groups bits into frames
  - Provides error correction via ***<u>checksum</u>***
  - Special bit pattern at start/end of frame

OSI MODEL - 2



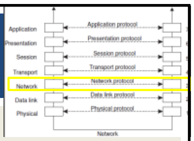
- Data link layer:
  - **Checksum**: computed by adding all bytes in frame in particular way
  - Added to message
  - Receiver removes checksum, recomputes checksum, and compares
  - If receiver and sender agree, frame is considered correct
  - Receiver can request failed frames to be resent
  - Frames assigned sequence numbers ***in the header***
- Network layer:
  - Sometimes referred to as the *Internet layer*
  - On WANs sending msgs between client/server requires routing
  - Provides addressing using IPV4 (32-bit), IPV6 (64-bit)

OSI MODEL - 3

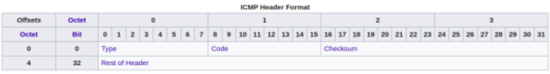


- Network layer:
  - Helps with routing network traffic
  - Shortest route (# of hops) may not be the best route
  - Minimizing delay (latency) is paramount
  - Routing algorithms: use long-term average network conditions, or try to adapt to changing conditions
  - ICMP Protocol: Internet Control Message Protocol
  - Not typically for sending data, used for diagnostic/control purposes
  - ICMP Examples: (*ping*, *traceroute*)

OSI MODEL - 4



- Internet Control Message Protocol (ICMP)
  - 8 bytes header: 4 fixed, 4 variable

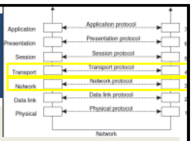


ICMP Header Format

Offsets	Octet	0								1								2								3							
Octet	Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	Type								Code								Checksum															
4	32	Rest of Header																															

  - Example message types:
  - 0- echo reply (**PING**), 3- destination unreachable, 4- source quench (congestion control), 5- redirect message, 8- echo request (**PING**), 9- router advertisement
  - Others: 10 (router solicitation), 11 (time exceeded), 12 (parameter problem), 13 (timestamp), 15 (info request), 16 (info reply), 17 (address mask request), 18 (address mask reply), 30-39 (**traceroute**), 40 (security failures), 42 (ext echo request)…255

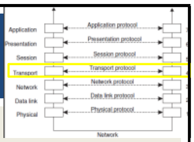
OSI MODEL - 5



- Transport layer:
  - Provides reliable connections
  - Reorganizes packets arriving out of sequence
  - Requests delivery of missing packets

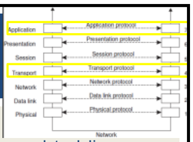
1. Breaks application layer protocol messages into pieces to transmit
2. Assigns messages sequence numbers
3. Sends all messages

OSI MODEL - 6



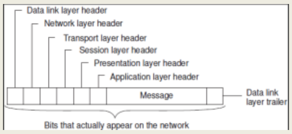
- Transport layer provides an infallible “message pipe”
  - Put messages in
  - Always come out undamaged, in correct order
- Transport layer protocols:
  - TCP: Transmission Control Protocol (connection-oriented)
  - UDP: Universal Datagram Protocol (connectionless)

OSI MODEL - 7



- Other transport protocols
  - Real-time transport protocol (RTP): real-time data, no data delivery guarantee
  - Streaming Control Transmission Protocol (SCTP): alternative to TCP
- Higher-level protocols:
- **Session layer**: mechanisms for opening, closing, managing session between communicating processes
- **Presentation layer**: deals with syntactical meaning of messages
  - Presentation services convert data among formats, for example:
  - from extended binary coded decimal interchange code (EBCDIC) to ASCII
- **Application layer**: protocols that don’t fit into other layers
  - Many protocols: FTP, SFTP, HTTP, etc. etc.

OSI MODEL - 8

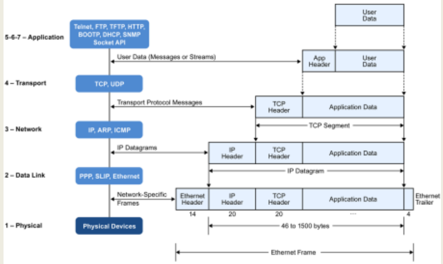


- Each OSI layer contributes overhead bits to the message
- Layers append data to front (and maybe end) of the message
- Receiver strips off headers as the message goes up the OSI model stack:

  physical → data-link → network → transport → application

PROTOCOL STACK

- Collection of layers used for communication from OSI model



MIDDLEWARE PROTOCOLS

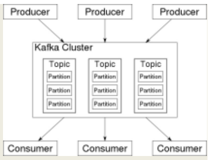
- Middleware is reused by many applications
- Provide needed functions applications are built and depend upon
  - For example: communication frameworks/libraries
- Middleware offer many general-purpose protocols
- Middleware protocol examples:
  - **Authentication protocols**: supports granting users and processes access to authorized resources
  - Doesn't fit as an "application specific" protocol
  - Considered a "Middleware protocol"

MIDDLEWARE PROTOCOLS - 2

- **Distributed commit protocols**
  - Coordinate a group of processes (nodes)
  - Facilitate all nodes carrying out a particular operation
  - Or abort transaction
  - Provides distributed atomicity (all-or-nothing) operations
- **Distributed locking protocols**
  - Protect a resource from simultaneous access from multiple nodes
- **Remote procedure call**
  - One of the oldest middleware protocols

MIDDLEWARE PROTOCOLS - 3

- **Message queueing services**
  - Support synchronization of data streams
  - Transfer real-time data
  - Distributed and scalable implementation



- **Multicast services**
  - Scale communication to thousands of receivers spread across the Internet

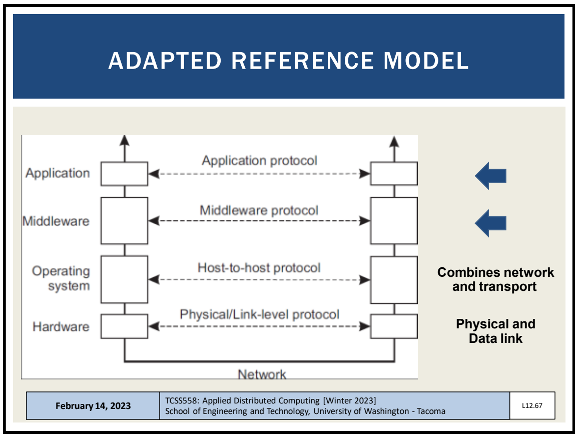
MIDDLEWARE PROTOCOLS - 3

- **Message queueing services**

KEY: middleware protocols offer functionality to satisfy the software requirements of ***many*** applications

Middleware functions are general, application-independent in nature

Functions are so commonly needed they are offered in reusable frameworks / libraries

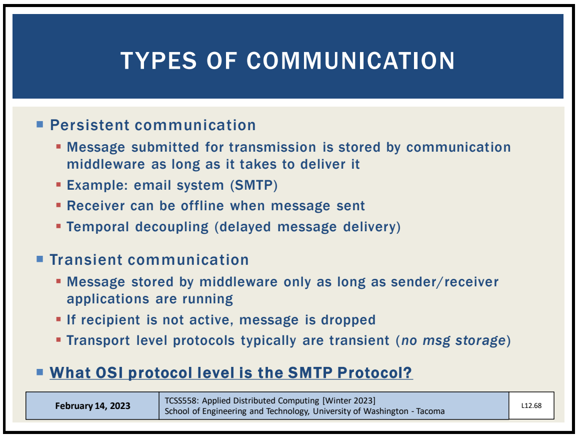


ADAPTED REFERENCE MODEL

Combines network and transport

Physical and Data link

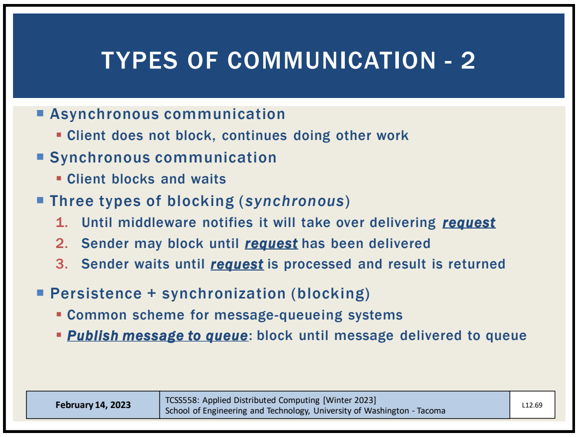
67



TYPES OF COMMUNICATION

- Persistent communication
  - Message submitted for transmission is stored by communication middleware as long as it takes to deliver it
  - Example: email system (SMTP)
  - Receiver can be offline when message sent
  - Temporal decoupling (delayed message delivery)
- Transient communication
  - Message stored by middleware only as long as sender/receiver applications are running
  - If recipient is not active, message is dropped
  - Transport level protocols typically are transient (*no msg storage*)
- **What OSI protocol level is the SMTP Protocol?**

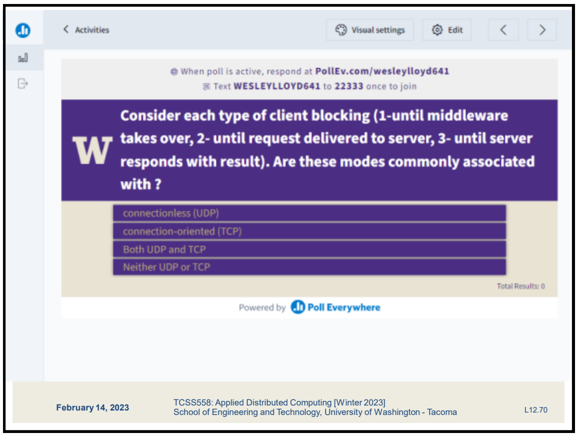
68



TYPES OF COMMUNICATION - 2

- Asynchronous communication
  - Client does not block, continues doing other work
- Synchronous communication
  - Client blocks and waits
- Three types of blocking (*synchronous*)
  1. Until middleware notifies it will take over delivering ***request***
  2. Sender may block until ***request*** has been delivered
  3. Sender waits until ***request*** is processed and result is returned
- Persistence + synchronization (blocking)
  - Common scheme for message-queueing systems
  - ***Publish message to queue***: block until message delivered to queue

69



When poll is active, respond at **PollEv.com/wesleylloyd641**
Text **WESLEYLLOYD641** to **22333** once to join

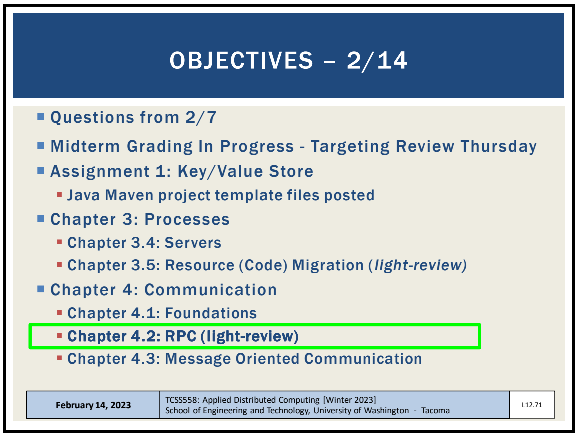
Consider each type of client blocking (1-until middleware takes over, 2- until request delivered to server, 3- until server responds with result). Are these modes commonly associated with ?

- connectionless (UDP)
- connection-oriented (TCP)
- Both UDP and TCP
- Neither UDP or TCP

Total Results: 0

Powered by Poll Everywhere

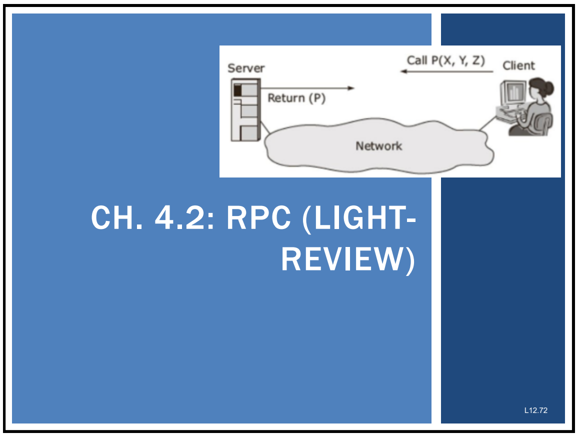
70



OBJECTIVES – 2/14

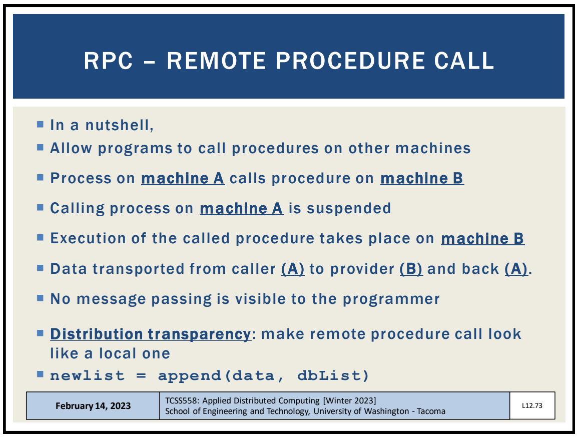
- Questions from 2/7
- Midterm Grading In Progress - Targeting Review Thursday
- Assignment 1: Key/Value Store
  - Java Maven project template files posted
- Chapter 3: Processes
  - Chapter 3.4: Servers
  - Chapter 3.5: Resource (Code) Migration (*light-review*)
- Chapter 4: Communication
  - Chapter 4.1: Foundations
  - **Chapter 4.2: RPC (light-review)**
  - Chapter 4.3: Message Oriented Communication

71



CH. 4.2: RPC (LIGHT-REVIEW)

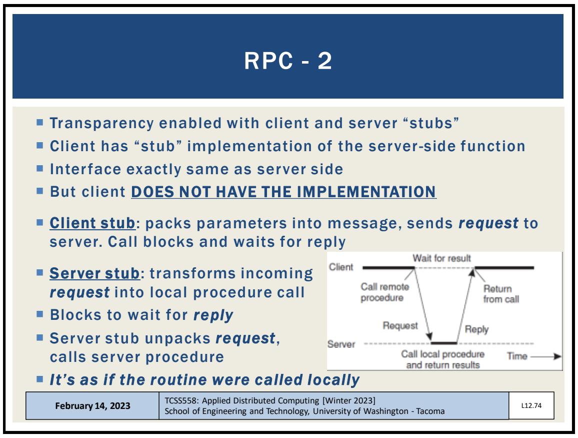
72



RPC – REMOTE PROCEDURE CALL

- In a nutshell,
- Allow programs to call procedures on other machines
- Process on **machine A** calls procedure on **machine B**
- Calling process on **machine A** is suspended
- Execution of the called procedure takes place on **machine B**
- Data transported from caller **(A)** to provider **(B)** and back **(A)**.
- No message passing is visible to the programmer
- **Distribution transparency**: make remote procedure call look like a local one
- `newlist = append(data, dbList)`

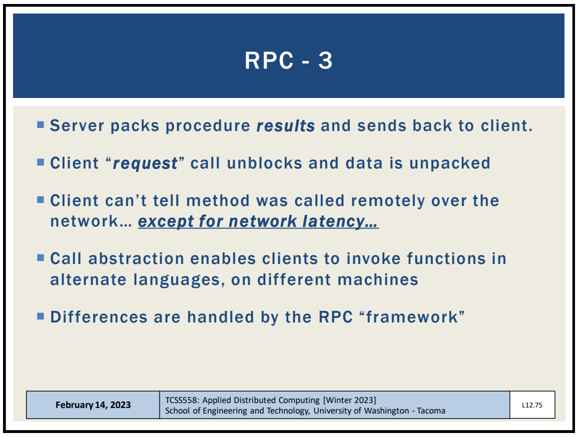
73



RPC - 2

- Transparency enabled with client and server "stubs"
- Client has "stub" implementation of the server-side function
- Interface exactly same as server side
- But client **DOES NOT HAVE THE IMPLEMENTATION**
- **Client stub**: packs parameters into message, sends ***request*** to server. Call blocks and waits for reply
- **Server stub**: transforms incoming ***request*** into local procedure call
- Blocks to wait for ***reply***
- Server stub unpacks ***request***, calls server procedure
- ***It's as if the routine were called locally***

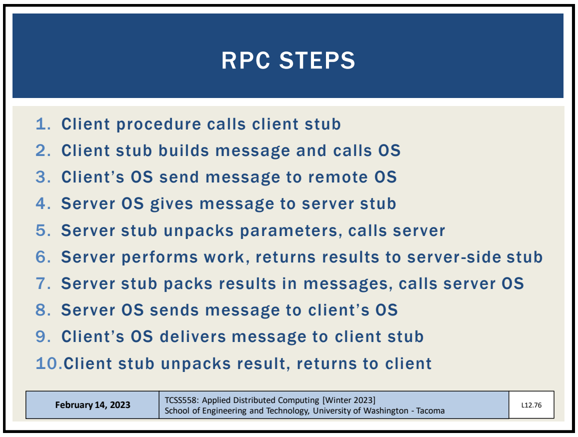
74



RPC - 3

- Server packs procedure ***results*** and sends back to client.
- Client "***request***" call unblocks and data is unpacked
- Client can't tell method was called remotely over the network… ***except for network latency…***
- Call abstraction enables clients to invoke functions in alternate languages, on different machines
- Differences are handled by the RPC "framework"

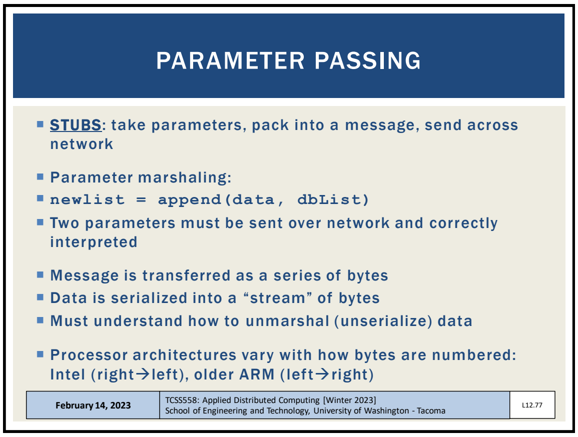
75



RPC STEPS

1. Client procedure calls client stub
2. Client stub builds message and calls OS
3. Client's OS send message to remote OS
4. Server OS gives message to server stub
5. Server stub unpacks parameters, calls server
6. Server performs work, returns results to server-side stub
7. Server stub packs results in messages, calls server OS
8. Server OS sends message to client's OS
9. Client's OS delivers message to client stub
10. Client stub unpacks result, returns to client

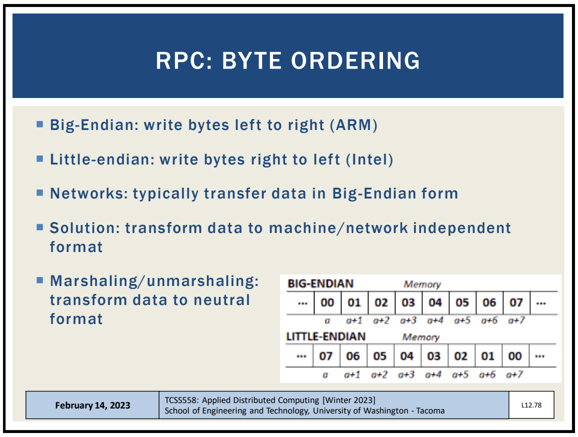
76



PARAMETER PASSING

- **STUBS**: take parameters, pack into a message, send across network
- Parameter marshaling:
- `newlist = append(data, dbList)`
- Two parameters must be sent over network and correctly interpreted
- Message is transferred as a series of bytes
- Data is serialized into a "stream" of bytes
- Must understand how to unmarshal (unserialize) data
- Processor architectures vary with how bytes are numbered: Intel (right→left), older ARM (left→right)

77



RPC: BYTE ORDERING

- Big-Endian: write bytes left to right (ARM)
- Little-endian: write bytes right to left (Intel)
- Networks: typically transfer data in Big-Endian form
- Solution: transform data to machine/network independent format
- Marshaling/unmarshaling: transform data to neutral format

BIG-ENDIAN *Memory*

…	00	01	02	03	04	05	06	07	…
	a	*a+1*	*a+2*	*a+3*	*a+4*	*a+5*	*a+6*	*a+7*	

LITTLE-ENDIAN *Memory*

…	07	06	05	04	03	02	01	00	…
	a	*a+1*	*a+2*	*a+3*	*a+4*	*a+5*	*a+6*	*a+7*	

78

RPC: PASS-BY-REFERENCE

- Passing by value is straightforward
- Passing by reference is challenging
- Pointers only make sense on local machine owning the data
- Memory space of client and server are different

- Solutions to **RPC pass-by-reference**:

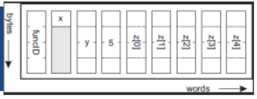
1. Forbid pointers altogether
2. Replace pass-by-reference with pass-by-value
   - Requires transferring entire object/array data over network
   - **Read-only optimization**: don't return data if unchanged on server
3. Passing global references
   - Example: file handle to file accessible by client and server via shared file system

RPC: DEVELOPMENT SUPPORT

- Let developer specify which routines will be called remotely
  - Automate client/server side stub generation for these routines

- Embed remote procedure call mechanism into the programming language
  - E.g. Java RMI

STUB GENERATION



- `void func(char x; float y; int z[5])`
- 1-byte character transmits with 3-padded bytes
- Float sent as whole word (4-bytes)
  - Array as group of words, proceed by word describing length
  - Client stub must package data in specific format
  - Server stub must receive and unpackage in specific format

- Client and server must agree on representation of simple data structures: int, char, floats w/ little endian
- RPC clients/servers: must agree on protocol
  - TCP? UDP?

STUB GENERATION - 2

- Interfaces are specified using an Interface Definition Language (IDL)

- Interface specifications in IDL are used to generate language specific stubs

- IDL is compiled into client and server-side stubs

- Much of the plumbing for RPC involves maintaining boilerplate-code

LANGUAGE BASED SUPPORT

- Leads to simpler application development

- Helps with providing access transparency
  - Differences in data representation, and how object is accessed
  - Inter-language parameter passing issues resolved: → ***just 1 language***

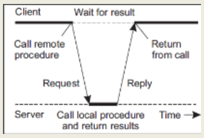
- Well known example: ***Java Remote Method Invocation*** RPC equivalent embedded in Java

RPC VARIATIONS

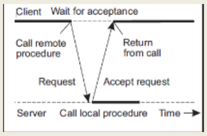
- RPC: client typically blocks until reply is returned
- Strict blocking ***unnecessary*** when there is no result

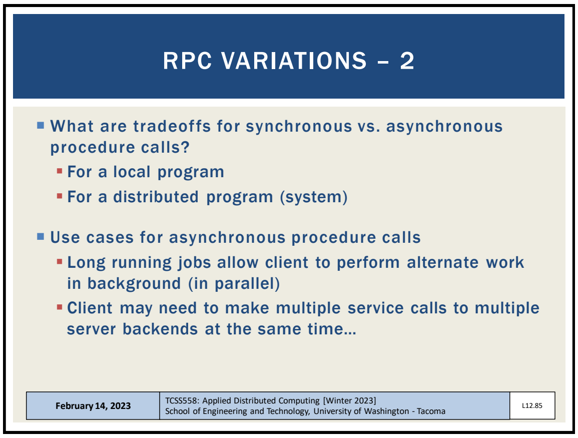
- **Asynchronous RPCs**
  - When no result, server can immediately send reply

Client/server synchronous RPC



Client/server asynchronous RPC



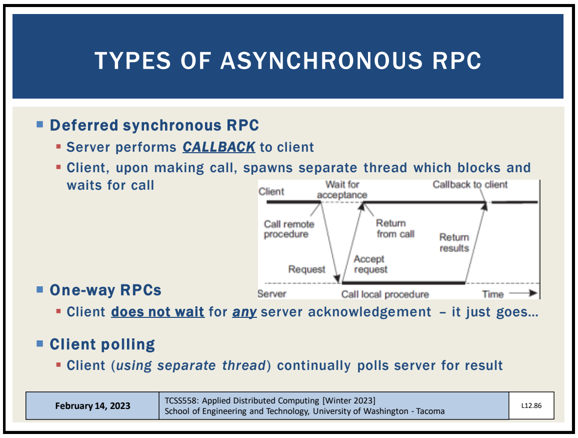


RPC VARIATIONS – 2

- What are tradeoffs for synchronous vs. asynchronous procedure calls?
  - For a local program
  - For a distributed program (system)
- Use cases for asynchronous procedure calls
  - Long running jobs allow client to perform alternate work in background (in parallel)
  - Client may need to make multiple service calls to multiple server backends at the same time…

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.85

85



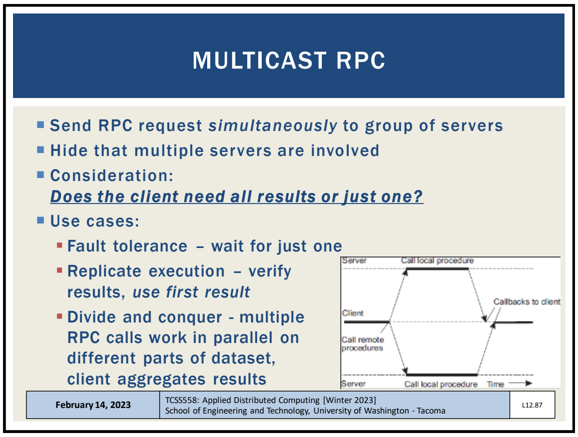
TYPES OF ASYNCHRONOUS RPC

- **Deferred synchronous RPC**
  - Server performs ***CALLBACK*** to client
  - Client, upon making call, spawns separate thread which blocks and waits for call
- **One-way RPCs**
  - Client **does not wait** for ***any*** server acknowledgement – it just goes…
- **Client polling**
  - Client (*using separate thread*) continually polls server for result

Client
Wait for acceptance
Callback to client
Call remote procedure
Return from call
Return results
Accept request
Request
Server
Call local procedure
Time

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.86

86

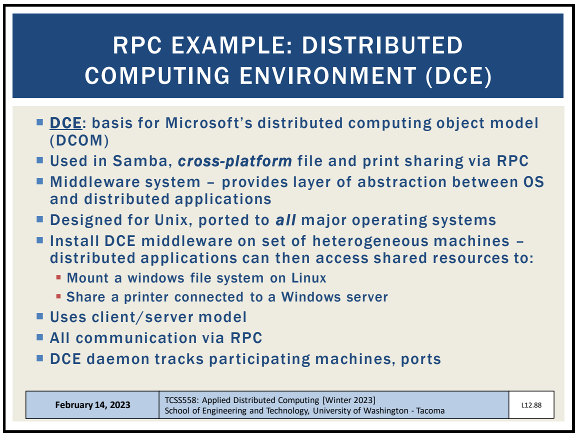


MULTICAST RPC

- Send RPC request *simultaneously* to group of servers
- Hide that multiple servers are involved
- Consideration:
  Does the client need all results or just one?
- Use cases:
  - Fault tolerance – wait for just one
  - Replicate execution – verify results, *use first result*
  - Divide and conquer - multiple RPC calls work in parallel on different parts of dataset, client aggregates results

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.87

87

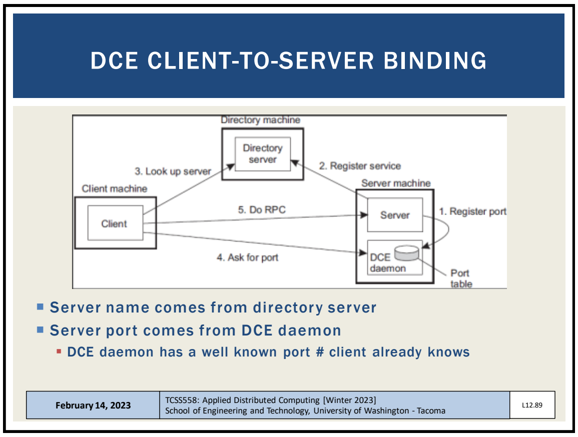


RPC EXAMPLE: DISTRIBUTED COMPUTING ENVIRONMENT (DCE)

- **DCE**: basis for Microsoft's distributed computing object model (DCOM)
- Used in Samba, ***cross-platform*** file and print sharing via RPC
- Middleware system – provides layer of abstraction between OS and distributed applications
- Designed for Unix, ported to ***all*** major operating systems
- Install DCE middleware on set of heterogeneous machines – distributed applications can then access shared resources to:
  - Mount a windows file system on Linux
  - Share a printer connected to a Windows server
- Uses client/server model
- All communication via RPC
- DCE daemon tracks participating machines, ports

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.88

88



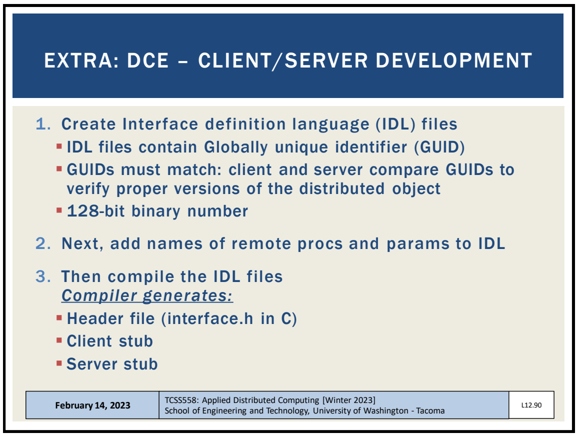
DCE CLIENT-TO-SERVER BINDING

Directory machine
Directory server
3. Look up server
2. Register service
Client machine
Server machine
5. Do RPC
Client
Server
1. Register port
4. Ask for port
DCE daemon
Port table

- Server name comes from directory server
- Server port comes from DCE daemon
  - DCE daemon has a well known port # client already knows

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.89

89

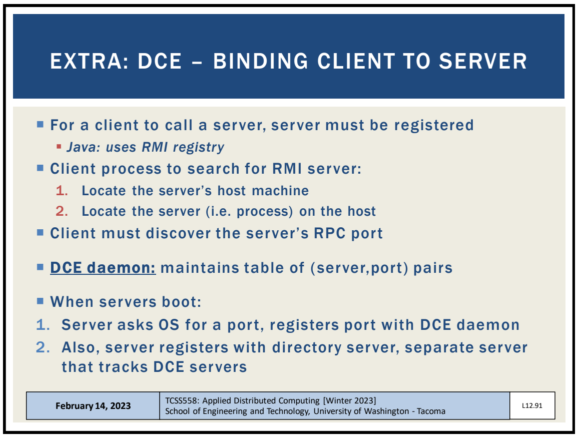


EXTRA: DCE – CLIENT/SERVER DEVELOPMENT

1. Create Interface definition language (IDL) files
   - IDL files contain Globally unique identifier (GUID)
   - GUIDs must match: client and server compare GUIDs to verify proper versions of the distributed object
   - 128-bit binary number
2. Next, add names of remote procs and params to IDL
3. Then compile the IDL files
   Compiler generates:
   - Header file (interface.h in C)
   - Client stub
   - Server stub

February 14, 2023 | TCSS558: Applied Distributed Computing [Winter 2023] School of Engineering and Technology, University of Washington - Tacoma | L12.90

90

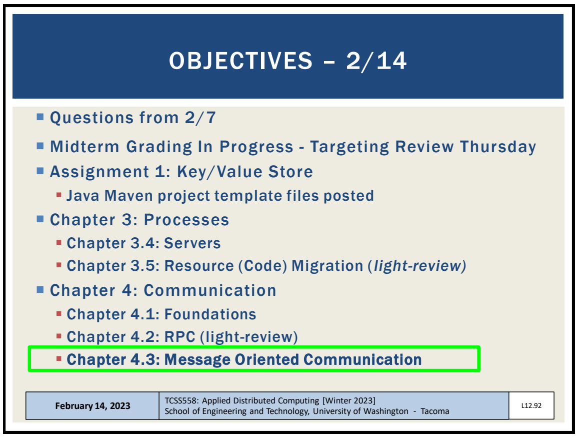


EXTRA: DCE – BINDING CLIENT TO SERVER

- For a client to call a server, server must be registered
  - *Java: uses RMI registry*
- Client process to search for RMI server:
  1. Locate the server's host machine
  2. Locate the server (i.e. process) on the host
- Client must discover the server's RPC port
- **DCE daemon:** maintains table of (server,port) pairs
- When servers boot:

1. Server asks OS for a port, registers port with DCE daemon
2. Also, server registers with directory server, separate server that tracks DCE servers

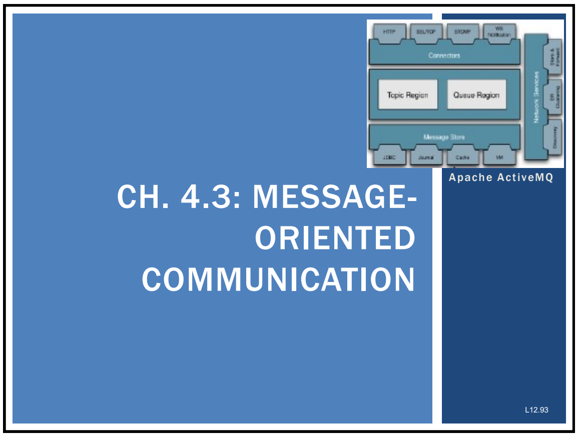
91



OBJECTIVES – 2/14

- Questions from 2/7
- Midterm Grading In Progress - Targeting Review Thursday
- Assignment 1: Key/Value Store
  - Java Maven project template files posted
- Chapter 3: Processes
  - Chapter 3.4: Servers
  - Chapter 3.5: Resource (Code) Migration (*light-review*)
- Chapter 4: Communication
  - Chapter 4.1: Foundations
  - Chapter 4.2: RPC (light-review)
  - **Chapter 4.3: Message Oriented Communication**

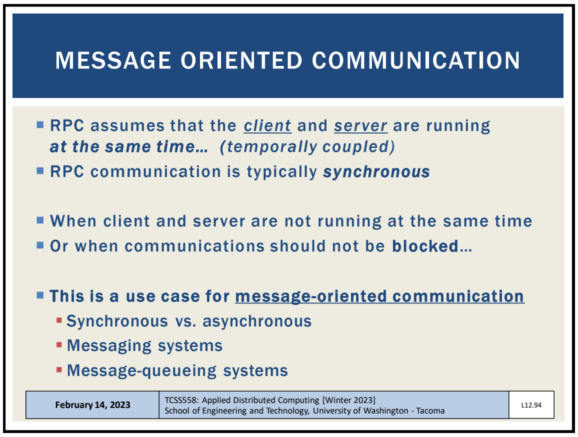
92



Apache ActiveMQ

CH. 4.3: MESSAGE-ORIENTED COMMUNICATION

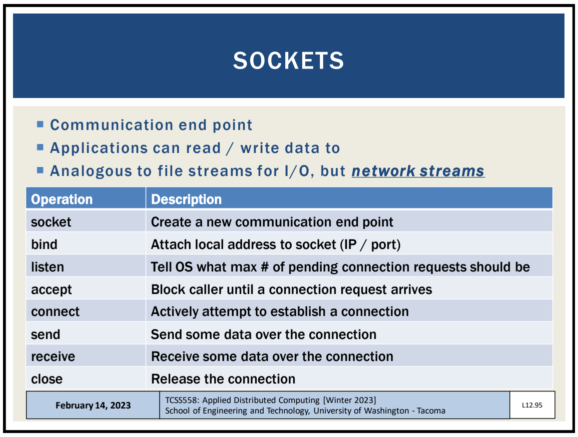
93



MESSAGE ORIENTED COMMUNICATION

- RPC assumes that the *client* and *server* are running ***at the same time…*** *(temporally coupled)*
- RPC communication is typically ***synchronous***
- When client and server are not running at the same time
- Or when communications should not be **blocked…**
- **This is a use case for message-oriented communication**
  - Synchronous vs. asynchronous
  - Messaging systems
  - Message-queueing systems

94

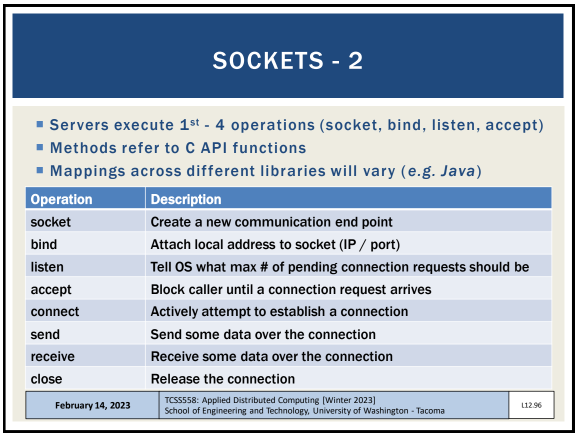


SOCKETS

- Communication end point
- Applications can read / write data to
- Analogous to file streams for I/O, but ***network streams***

Operation	Description
socket	Create a new communication end point
bind	Attach local address to socket (IP / port)
listen	Tell OS what max # of pending connection requests should be
accept	Block caller until a connection request arrives
connect	Actively attempt to establish a connection
send	Send some data over the connection
receive	Receive some data over the connection
close	Release the connection

95

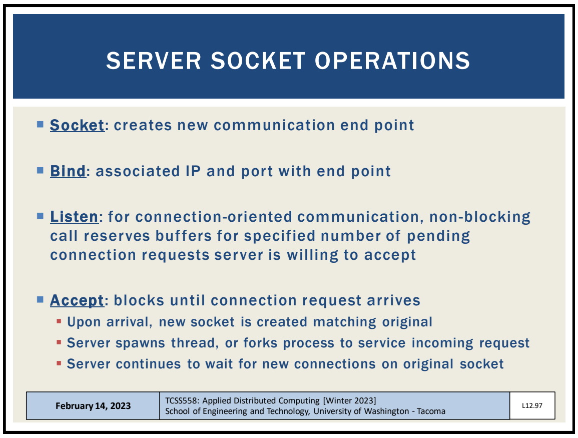


SOCKETS - 2

- Servers execute 1st - 4 operations (socket, bind, listen, accept)
- Methods refer to C API functions
- Mappings across different libraries will vary (*e.g. Java*)

Operation	Description
socket	Create a new communication end point
bind	Attach local address to socket (IP / port)
listen	Tell OS what max # of pending connection requests should be
accept	Block caller until a connection request arrives
connect	Actively attempt to establish a connection
send	Send some data over the connection
receive	Receive some data over the connection
close	Release the connection

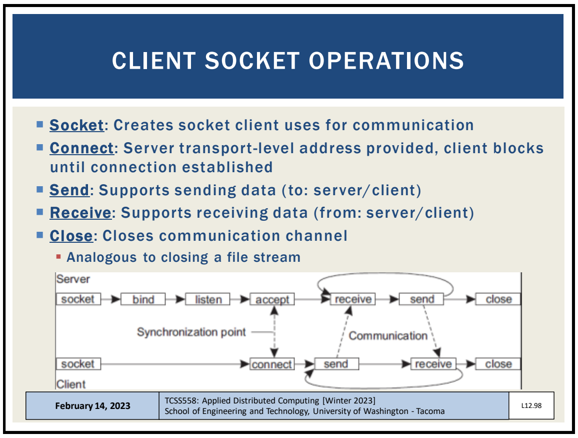
96



SERVER SOCKET OPERATIONS

- **Socket**: creates new communication end point
- **Bind**: associated IP and port with end point
- **Listen**: for connection-oriented communication, non-blocking call reserves buffers for specified number of pending connection requests server is willing to accept
- **Accept**: blocks until connection request arrives
  - Upon arrival, new socket is created matching original
  - Server spawns thread, or forks process to service incoming request
  - Server continues to wait for new connections on original socket

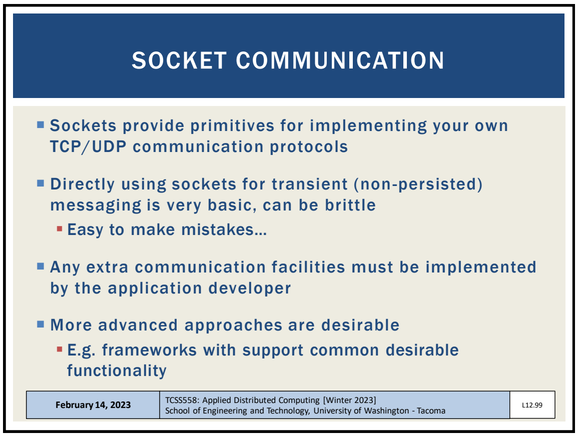
97



CLIENT SOCKET OPERATIONS

- **Socket**: Creates socket client uses for communication
- **Connect**: Server transport-level address provided, client blocks until connection established
- **Send**: Supports sending data (to: server/client)
- **Receive**: Supports receiving data (from: server/client)
- **Close**: Closes communication channel
  - Analogous to closing a file stream

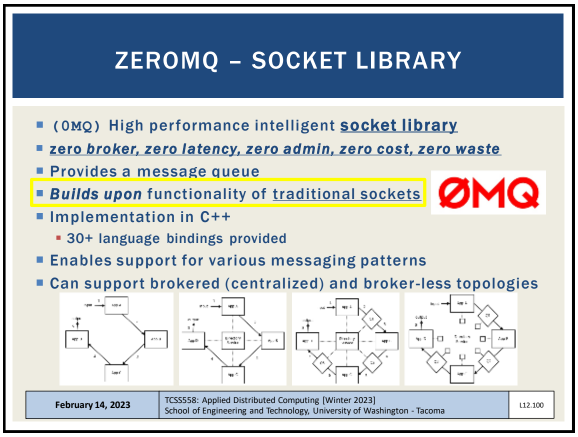
98



SOCKET COMMUNICATION

- Sockets provide primitives for implementing your own TCP/UDP communication protocols
- Directly using sockets for transient (non-persisted) messaging is very basic, can be brittle
  - Easy to make mistakes…
- Any extra communication facilities must be implemented by the application developer
- More advanced approaches are desirable
  - E.g. frameworks with support common desirable functionality

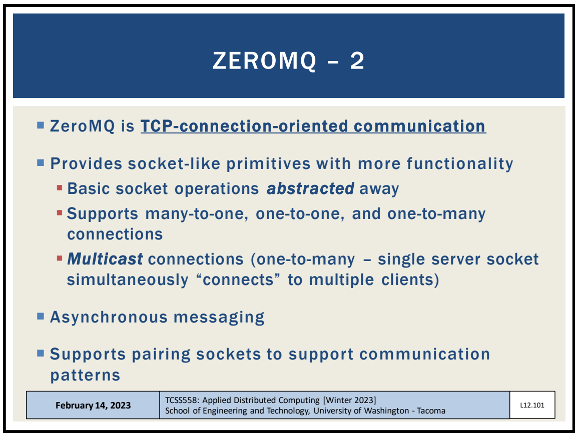
99



ZEROMQ – SOCKET LIBRARY

- (0MQ) High performance intelligent **socket library**
- ***zero broker, zero latency, zero admin, zero cost, zero waste***
- Provides a message queue
- ***Builds upon*** functionality of traditional sockets
- Implementation in C++
  - 30+ language bindings provided
- Enables support for various messaging patterns
- Can support brokered (centralized) and broker-less topologies

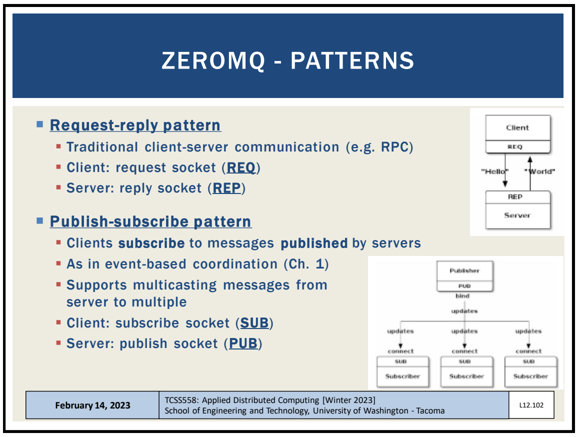
100



ZEROMQ – 2

- ZeroMQ is **TCP-connection-oriented communication**
- Provides socket-like primitives with more functionality
  - Basic socket operations ***abstracted*** away
  - Supports many-to-one, one-to-one, and one-to-many connections
  - ***Multicast*** connections (one-to-many – single server socket simultaneously "connects" to multiple clients)
- Asynchronous messaging
- Supports pairing sockets to support communication patterns

101



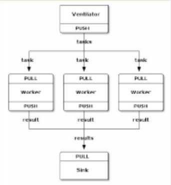
ZEROMQ - PATTERNS

- **Request-reply pattern**
  - Traditional client-server communication (e.g. RPC)
  - Client: request socket (**REQ**)
  - Server: reply socket (**REP**)
- **Publish-subscribe pattern**
  - Clients **subscribe** to messages **published** by servers
  - As in event-based coordination (Ch. 1)
  - Supports multicasting messages from server to multiple
  - Client: subscribe socket (**SUB**)
  - Server: publish socket (**PUB**)

102

ZEROMQ – PATTERNS - 2

- **Pipeline pattern (FIFO-queue)**
  - Analogous to a producer/consumer bounded buffer
  - Producing processes generate results, push to pipe
  - Consuming processes consume results, pull from pipe
  - Producers: push socket (**PUSH** socket)
  - Consumers: pull socket (**PULL** socket)
  - Push- distributes messages to all pull clients evenly
  - Consumers pull results from pipe and push results downstream



103

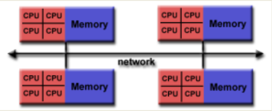
QUEUEING ALTERNATIVES

- Cloud services
  - Amazon Simple Queueing Service (SQS)
  - Azure service bus
- Open source frameworks
  - Nanomsg
  - ZeroMQ

104

MESSAGE PASSING INTERFACE (MPI)

- MPI introduced – version 1.0 March 1994
- Message passing API for parallel programming: ***supercomputers***
- Communication protocol for parallel programming for: Supercomputers, High Performance Computing (HPC) clusters
- Point-to-point and collective communication
- Goals: high performance, scalability, portability
- Most implementations in C, C++, Fortran



105

MOTIVATIONS FOR MPI

- Motivation: sockets insufficient for interprocess communication on large scale HPC compute clusters and super computers
  - Sockets at the wrong level of abstraction
  - Sockets designed to communicate over the network using general purpose TCP/IP stacks
  - Not designed for proprietary protocols
  - Not designed for high-speed interconnection networks used by supercomputers, HPC-clusters, etc.
  - Better buffering and synchronization needed

106

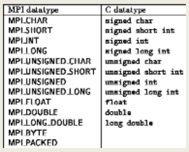
MOTIVATIONS FOR MPI - 2

- Supercomputers had proprietary communication libraries
  - Offer a wealth of efficient communication operations
- All libraries mutually incompatible
- Led to significant portability problems developing parallel code that could migrate across supercomputers
- Led to development of MPI
  - To support transient (non-persistent) communication for parallel programming

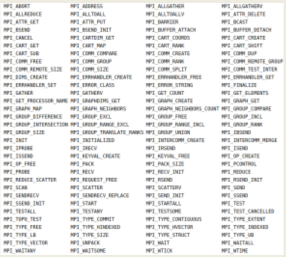
107

MPI FUNCTIONS / DATATYPES

- Very large library, v1.0 (1994) 128 functions
- Version 3 (2015) 440+
- MPI data types:
- Provide common mappings



MPI datatype	C datatype
MPI_CHAR	signed char
MPI_SHORT	signed short int
MPI_INT	signed int
MPI_LONG	signed long int
MPI_UNSIGNED_CHAR	unsigned char
MPI_UNSIGNED_SHORT	unsigned short int
MPI_UNSIGNED	unsigned int
MPI_UNSIGNED_LONG	unsigned long int
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double
MPI_BYTE	
MPI_PACKED	



MPI_ABORT	MPI_ADDRESS	MPI_ALLGATHER	MPI_ALLGATHERV
MPI_ALLREDUCE	MPI_ALLTOALL	MPI_ALLTOALLV	MPI_ATTR_DELETE
MPI_ATTR_GET	MPI_ATTR_PUT	MPI_BARRIER	MPI_BCAST
MPI_BSEND	MPI_BSEND_INIT	MPI_BUFFER_ATTACH	MPI_BUFFER_DETACH
MPI_CANCEL	MPI_CARTDIM_GET	MPI_CART_COORDS	MPI_CART_CREATE
MPI_CART_GET	MPI_CART_MAP	MPI_CART_RANK	MPI_CART_SHIFT
MPI_CART_SUB	MPI_COMM_COMPARE	MPI_COMM_CREATE	MPI_COMM_DUP
MPI_COMM_FREE	MPI_COMM_GROUP	MPI_COMM_RANK	MPI_COMM_REMOTE_GROUP
MPI_COMM_REMOTE_SIZE	MPI_COMM_SIZE	MPI_COMM_SPLIT	MPI_COMM_TEST_INTER
MPI_DIMS_CREATE	MPI_ERRHANDLER_CREATE	MPI_ERRHANDLER_FREE	MPI_ERRHANDLER_GET
MPI_ERRHANDLER_SET	MPI_ERROR_CLASS	MPI_ERROR_STRING	MPI_FINALIZE
MPI_GATHER	MPI_GATHERV	MPI_GET_COUNT	MPI_GET_ELEMENTS
MPI_GET_PROCESSOR_NAME	MPI_GRAPHDIMS_GET	MPI_GRAPH_CREATE	MPI_GRAPH_GET
MPI_GRAPH_MAP	MPI_GRAPH_NEIGHBORS	MPI_GRAPH_NEIGHBORS_COUNT	MPI_GROUP_COMPARE
MPI_GROUP_DIFFERENCE	MPI_GROUP_EXCL	MPI_GROUP_FREE	MPI_GROUP_INCL
MPI_GROUP_INTERSECTION	MPI_GROUP_RANGE_EXCL	MPI_GROUP_RANGE_INCL	MPI_GROUP_RANK
MPI_GROUP_SIZE	MPI_GROUP_TRANSLATE_RANKS	MPI_GROUP_UNION	MPI_IBSEND
MPI_INIT	MPI_INITIALIZED	MPI_INTERCOMM_CREATE	MPI_INTERCOMM_MERGE
MPI_IPROBE	MPI_IRECV	MPI_IRSEND	MPI_ISEND
MPI_ISSEND	MPI_KEYVAL_CREATE	MPI_KEYVAL_FREE	MPI_OP_CREATE
MPI_OP_FREE	MPI_PACK	MPI_PACK_SIZE	MPI_PCONTROL
MPI_PROBE	MPI_RECV	MPI_RECV_INIT	MPI_REDUCE
MPI_REDUCE_SCATTER	MPI_REQUEST_FREE	MPI_RSEND	MPI_RSEND_INIT
MPI_SCAN	MPI_SCATTER	MPI_SCATTERV	MPI_SEND
MPI_SENDRECV	MPI_SENDRECV_REPLACE	MPI_SEND_INIT	MPI_SSEND
MPI_SSEND_INIT	MPI_START	MPI_STARTALL	MPI_TEST
MPI_TESTALL	MPI_TESTANY	MPI_TESTSOME	MPI_TEST_CANCELLED
MPI_TOPO_TEST	MPI_TYPE_COMMIT	MPI_TYPE_CONTIGUOUS	MPI_TYPE_EXTENT
MPI_TYPE_FREE	MPI_TYPE_HINDEXED	MPI_TYPE_HVECTOR	MPI_TYPE_INDEXED
MPI_TYPE_LB	MPI_TYPE_SIZE	MPI_TYPE_STRUCT	MPI_TYPE_UB
MPI_TYPE_VECTOR	MPI_UNPACK	MPI_WAIT	MPI_WAITALL
MPI_WAITANY	MPI_WAITSOME	MPI_WTICK	MPI_WTIME

108

COMMON MPI FUNCTIONS

- MPI - no recovery for process crashes, network partitions
- Communication among grouped processes:`(groupID, processID)`
- IDs used to route messages in place of IP addresses

Operation	Description
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send message, wait until copied to local/remote buffer
MPI_ssend	Send message, wat until transmission starts
MPI_sendrecv	Send message, wait for reply
MPI_isend	Pass reference to outgoing message and continue
MPI_issend	Pass reference to outgoing messages, wait until receipt start
MPI_recv	Receive a message, block if there is none
MPI_irecv	Check for incoming message, **do not block!**

MESSAGE-ORIENTED-MIDDLEWARE

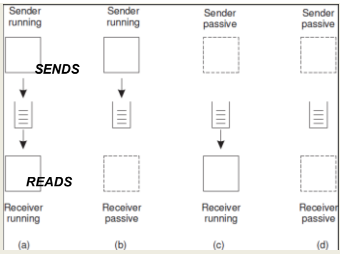
- **Message-queueing systems**
  - Provide extensive support for ***persistent*** asynchronous communication
  - In contrast to transient systems
  - Temporally decoupled: messages are eventually delivered to recipient queues
- Message transfers may take minutes vs. sec or ms
- Each application has its own private queue to which other applications can send messages

MESSAGE QUEUEING SYSTEMS: USE CASES

- Enables communication between applications, or sets of processes
  - User applications
  - App-to-database
  - To support distributed real-time computations
- Use cases
  - Batch processing, Email, workflow, groupware, routing subqueries

MESSAGE QUEUEING SYSTEMS

- Scenarios:
  (a) Sender/receiver both running
  (b) Sender running, receiver offline
  (c) Sender offline, receiver running
  (d) Sender/receiver both offline



- Queue persists msgs, and attempts to send them but no one may be available to receive them…

MESSAGE QUEUEING SYSTEMS - 2

- **Key:** Truly persistent messaging
- Message queueing systems can persist messages for awhile and senders and receivers can be offline
- **Messages**
- Contain *any* data, may have size limit
- Are properly addressed, to a destination queue
- **Basic Inteface**
- PUT: called by sender to append msg to specified queue
- GET: blocking call to remove oldest msg from specified queue
  - Blocked if queue is empty
- POLL: Non-blocking, gets msg from specified queue

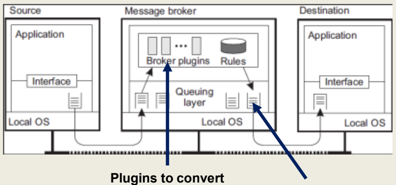
MESSAGE QUEUEING SYSTEMS ARCHITECTURE

- **Basic interface cont'd**
- NOTIFY: install a callback function, for when msg is placed into a queue. Notifies receivers
- **Queue managers**: manage individual message queues as a separate process/library
- Applications get/put messages only from ***local*** queues
- Queue manager and apps share local network
- **ISSUES:**
- How should we reference the destination queue?
- How should names be resolved (looked-up)?
  - Contact address (host, port) pairs
  - Local look-up tables can be stored at each queue manager

MESSAGE QUEUEING SYSTEMS ARCHITECTURE - 2

- **ISSUES**:
- How do we route traffic between queue managers?
  - How are name-to-address mappings efficiently kept?
  - Each queue manager should be known to all others
- **Message brokers**
- Handle message conversion among different users/formats
- Addresses cases when senders and receivers don't speak the same protocol (language)
- Need arises for message protocol converters
  - "Reformatter" of messages
- Act as application-level gateway

MESSAGE BROKER ORGANIZATION



Plugins to convert messages between APPs

Application-level Queues

AMQP PROTOCOL

- Message-queueing systems initially developed to enable legacy applications to interoperate
- Decouple inter-application communication to "open" messaging-middleware
- Many are proprietary solutions, ***so not very open***
- e.g. Microsoft Message Queueing service, Windows NT 1997
- **Advanced message queueing protocol (AMQP)**, 2006
- Address openness/interoperability of proprietary solutions
- Open wire protocol for messaging with powerful routing capabilities
- Help *abstract* messaging and application interoperability by means of a generic open protocol
- Suffer from incompatibility among protocol versions
- pre-1.0, 1.0+

AMQP - 2

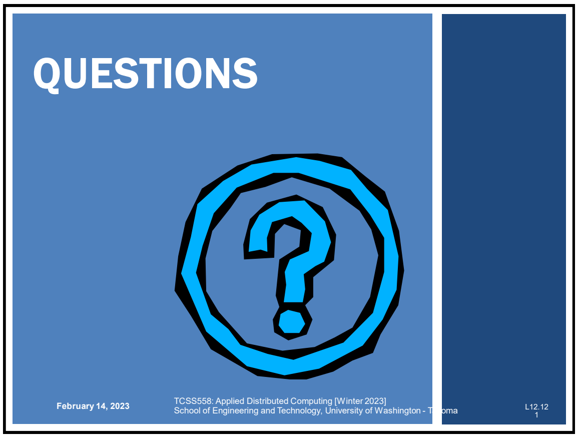
- Consists of: Applications, Queue managers, Queues
- **Connections:** set up to a queue manager, TCP, with potentially many channels, stable, reused by many channels, long-lived
- **Channels:** support short-lived one-way communication
- **Sessions:** bi-directional communication across two channels
- **Link:** provide fine-grained flow-control of message transfer/status between applications and queue manager

AMQP MESSAGING

- AMQP nodes: producer, consumer, queue
- Producer/consumer: represent regular applications
- Queues: store/forward messages
- Persistent messaging:
- **Messages** can be marked ***durable***
- These messages can only be delivered by nodes able to recover in case of failure
- Non-failure resistant nodes must reject durable messages
- **Source/target** nodes can be marked ***durable***
- Track what is durable (node state, node+msgs)

MESSAGE-ORIENTED-MIDDLEWARE EXAMPLES:

- **Some examples:**
- RabbitMQ, Apache QPid
  - Implement Advanced Message Queueing Protocol (AMQP)
- Apache Kafka
  - **Dumb broker** (message store), similar to a distributed log file
  - **Smart consumers** – intelligence pushed off to the clients
  - Stores stream of records in categories called topics
  - Supports voluminous data, many consumers, with minimal O/H
  - Kafka **does not track** which messages were read by each consumer
  - Messages are removed after timeout
  - Clients must track their own consumption (*Kafka doesn't help*)
  - Messages have key, value, timestamp
  - Supports high volume pub/sub messaging and streams



QUESTIONS

February 14, 2023

TCSS558: Applied Distributed Computing [Winter 2023]
School of Engineering and Technology, University of Washington - Tacoma

L12.12
1

121