# TCSS 558: APPLIED DISTRIBUTED COMPUTING

**Processes: Threads & Virtualization, Clients & Servers**

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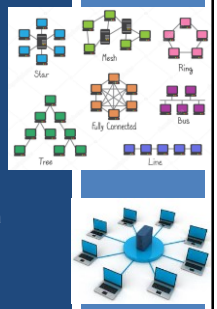




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## OBJECTIVES – 1/31

- **Questions from 1/26**
- Assignment 1: Key/Value Store
  - Coming Soon
- Midterm Thursday February 9
  - 2nd hour - Tuesday February 9 – practice midterm questions
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - Chapter 3.4: Servers



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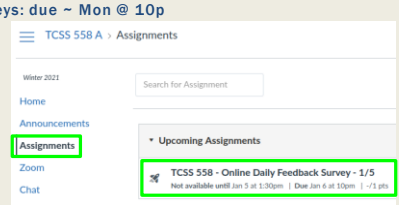
## ONLINE DAILY FEEDBACK SURVEY

- 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



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## SURVEY QUESTIONS

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



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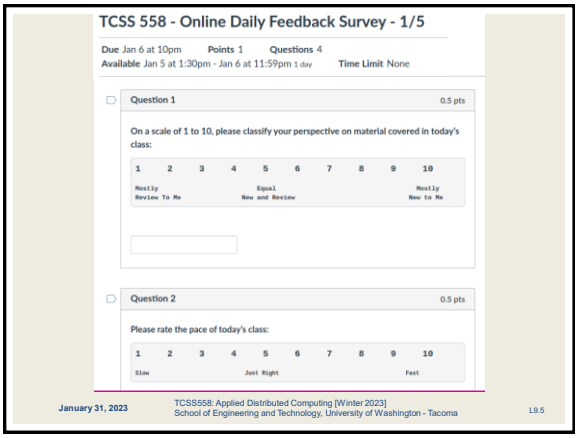


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## MATERIAL / PACE

- Please classify your perspective on material covered in today's class (30 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.25 (↓ - *previous 6.60*)**
- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.62 (↑ - *previous 5.58*)**



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## FEEDBACK FROM 1/26

- ***The concept of kernel threads was a bit anomalous***
- Helpful links on Linux processes and threads:
- https://www.baeldung.com/linux/process-vs-thread
- https://www.baeldung.com/linux/monitor-process-thread-count
- https://medium.com/@boutnaru/the-linux-process-journey-kworker-f947634da73



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## FEEDBACK - 2

- ***What the difference between single process OS and system before memory mapping implementation?***
- By memory mapping implementation, do you mean OSes before virtual memory where each process's memory was managed with different virtual segments (code, stack, heap, data) and pages ?
- Modern single process OS for cloud computing feature threads that share the same memory space
- Threads may not have been a feature of very early systems



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## FEEDBACK - 3

- ***What are code segments and code pages?***
- Linux manages memory in 4KB pages
- Each process has a memory segment called the *code segment*
- The code segment consists of 1+ code pages (4KB each)



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## FEEDBACK - 4

- ***How many context switches will there be on example from slide L9.33? Two? Three?***
- **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

- Just three context switches ?
- When will the program context switch?
- On a single core computer?
- On a multi-core computer?



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## FEEDBACK - 5

- Not possible to know the number of context switches precisely
  - The process may have other threads
  - A context switch occurs every time quantum (~10ms) to ensure other threads have a chance to execute
  - Context switches also occur as a result of system interrupts
  - Not all system interrupts are expected/predictable
- Single core CPU computer may have more context switches for running this program
  - Multiple threads must share a single CPU and increase load



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## ASSIGNMENT 0

- ***Preparing for Assignment 0:***
  - Establish AWS Account
    - Standard account
      - Complete AWS Cloud Credits Survey and provide AWS account ID
      - Credits will be automatically loaded by Amazon into accounts
- Tasks:
  - Task 1 - Establish local Linux/Ubuntu environment
  - Task 2 –AWS account setup, obtain user credentials
  - Task 3 – Intro to: Amazon EC2 & Docker: create Dockerfile for Apache Tomcat
  - Task 4 – Create Dockerfile for haproxy
  - Task 5 – Working with Docker-Machine
  - Task 6 - Config 3 multiple server configs to load balance requests for RESTful Fibonacci web service
  - Task 7 – Test configs and submit results



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## TESTING CONNECTIVITY TO SERVER

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



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## CH. 3: PROCESSES
## CH. 3.1: THREADS

L9.17

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## 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



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## MULTIPLE THREADS

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

- Identify parent process explicitly:

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

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



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## 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

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## 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 . . .



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## 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**



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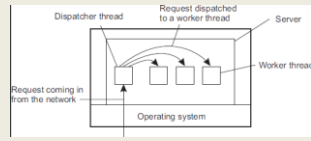
## MULTITHREADED SERVERS

- 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



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## SINGLE THREAD & FSM SERVERS

- Single thread server
  - A single thread handles all client requests
  - BLOCKS for I/O
  - All waiting requests are queued until thread is available
- Finite state machine
  - Server has a single thread of execution
  - I/O 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



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## SERVER DESIGN ALTERNATIVES

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

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



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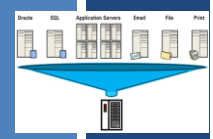

## CH. 3.2: VIRTUALIZATION



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## VIRTUALIZATION

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



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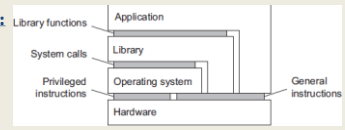
## TYPES OF VIRTUALIZATION

- **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



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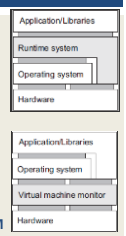
## TYPES OF VIRTUALIZATION - 2

- **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



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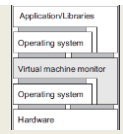
## TYPES OF VIRTUALIZATION - 3

- **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



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## EVOLUTION OF AWS VIRTUALIZATION

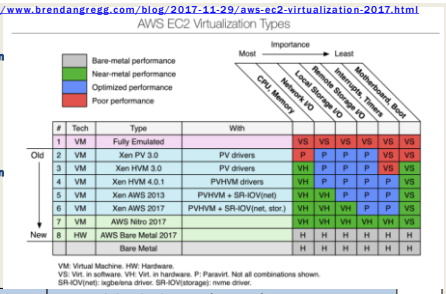
From http://www.brendangregg.com/blog/2017-11-29/aws-ec2-virtualization-2017.html

**VS: Virtualization in software**

**P: Paravirtual**

**VH: Virtualization in Hardware**

**H: Hardware**




| # | Tech | Type | With | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | VM | Fully Emulated | | VS | VS | VS | VS | VS | VS |
| 2 | VM | Xen PV 3.0 | PV drivers | P | P | P | P | VS | VS |
| 3 | VM | Xen HVM 3.0 | PV drivers | VH | P | P | P | VS | VS |
| 4 | VM | Xen HVM 4.0.1 | PVHVM drivers | VH | P | P | P | P | VS |
| 5 | VM | Xen AWS 2013 | PVHVM + SR-IOV(net) | VH | VH | P | P | P | VS |
| 6 | VM | Xen AWS 2017 | PVHVM + SR-IOV(net, stor.) | VH | VH | VH | P | P | VS |
| 7 | VM | AWS Nitro 2017 | | VH | VH | VH | VH | VH | VS |
| 8 | HW | AWS Bare Metal 2017 | | H | H | H | H | H | H |
| | | Bare Metal | | H | H | H | H | H | H |

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



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## 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



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## 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)



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## 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%



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## WE WILL RETURN AT 2:40PM

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## CH. 3.3: CLIENTS



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## TYPES OF CLIENTS

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



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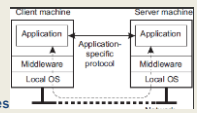
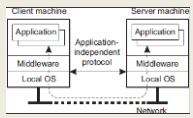
## CLIENTS

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



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## 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



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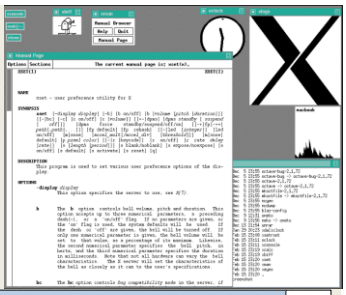
## X WINDOWS - 2

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





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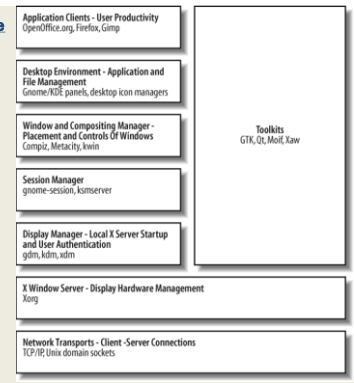
## Layered architecture

- 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



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## EXAMPLE: VNC SERVER

- How to Install VNC server on Ubuntu EC2 Instance VM:
- `sudo apt-get update`
- `# ubuntu 16.04`
- `sudo apt-get install ubuntu-desktop`
- `sudo apt-get install gnome-panel gnome-settings-daemon metacity nautilus gnome-terminal`
- `# on ubuntu 18.04`
- `sudo apt install xfce4 xfce4-goodies`
- `sudo apt-get install tightvncserver  # both`
- Start VNC server to create initial config file
- `vncserver :1`



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## EXAMPLE: VNC SERVER – UBUNTU 16.04

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

```
#!/bin/sh

export XKL_XMODMAP_DISABLE=1
unset SESSION_MANAGER
unset DBUS_SESSION_BUS_ADDRESS

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

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



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## EXAMPLE: VNC SERVER – UBUNTU 18.04

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

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



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## VNC SERVER - UBUNTU 20.04 - GNOME

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

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

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



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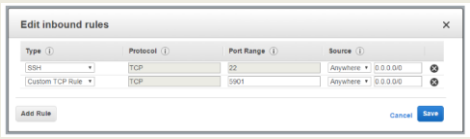
## EXAMPLE: VNC SERVER - 3

- On the VM: reload config by restarting server
- `vncserver -kill :1`
- `vncserver :1`

- Open port 22 & 5901 in EC2 security group:



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## 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
```



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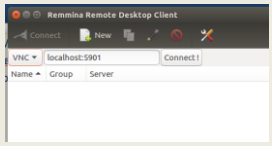
## EXAMPLE: VNC CLIENT - 2

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



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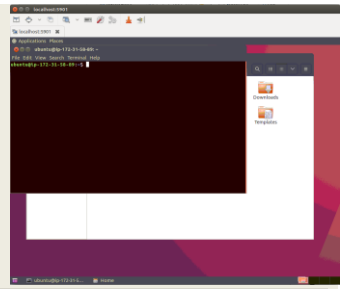
## REMOTE COMPUTER IN THE CLOUD

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





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## 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



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## THIN CLIENTS - 2

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

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



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## THIN CLIENTS - 3

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

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



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## TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols

Pixel-level VNC ⟷ Graphics IIb X11



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## TRADEOFFS: ABSTRACTION OF REMOTE DISPLAY PROTOCOLS

- Tradeoff space: abstraction level of remote display protocols

Pixel-level VNC ⟷ Graphics IIb X11

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

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



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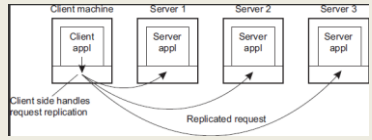
## CLIENT ROLES IN PROVIDING DISTRIBUTION TRANSPARENCY

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



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## 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



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## OBJECTIVES – 1/31

- Questions from 1/26
- Assignment 1: Key/Value Store
  - Coming Soon
- Midterm Thursday February 9
  - 2nd hour - Tuesday February 9 – practice midterm questions
- Chapter 3: Processes
  - Chapter 3.1: Threads
    - Threading Models
    - Multithreaded clients/servers
  - Chapter 3.2: Virtualization
  - Chapter 3.3: Clients
  - **Chapter 3.4: Servers**



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## SERVERS

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



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## SERVERS - 2

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

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

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

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



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## END POINTS

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



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## COMMON PORTS

packetlife.net

TCP/UDP Port Numbers

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

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## TYPES OF SERVERS

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



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## NTP EXAMPLE

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



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## SUPERSERVER

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



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## INTERRUPTING A SERVER

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



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## STATELESS SERVERS

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



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## STATEFUL SERVERS

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



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## STATEFUL SERVERS - 2

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



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## OBJECT SERVERS

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



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## OBJECT SERVERS - 2

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



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## EJB – ENTERPRISE JAVA BEANS

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



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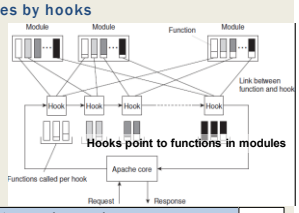
## APACHE WEB SERVER

- 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



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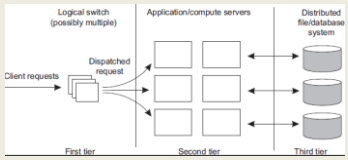
## SERVER CLUSTERS

- 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



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## 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



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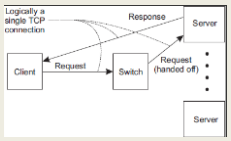
## LAN REQUEST DISPATCHING - 2

- 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



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## 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?



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## WAN REQUEST DISPATCHING

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

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



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## DNS LOOKUP

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



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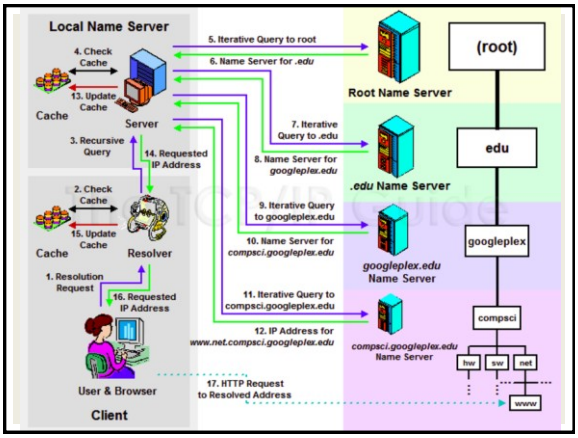


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## DNS: LINUX COMMANDS

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



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## DNS EXAMPLE – WAN DISPATCHING

- Ping www.google.com in WA from wireless network:
  - nslookup: 6 alternate addresses returned, choose (74.125.28.147)
  - Ping 74.125.28.147: Average RTT = **22.458 ms (11 attempts, 22 hops)**
- Ping www.google.com in VA (us-east-1) from EC2 instance:
  - nslookup: 1 address returned, choose 172.217.9.196
  - Ping 172.217.9.196: Average RTT = 1.278 ms (11 attempts, 13 hops)
- From VA EC2 instance, ping WA *www.google* server
- Ping 74.125.28.147: Average RTT 62.349ms (11 attempts, 27 hops)
- Pinging the WA-local server is ~60x slower from VA
- From local wireless network, ping VA us-east-1 google :
- Ping 172.217.9.196: Average RTT=81.637ms (11 attempts, 15 hops)



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## DNS EXAMPLE – WAN DISPATCHING

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

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

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

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



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## QUESTIONS



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