Multiple Processor Systems

Today

- Basic hardware and OS issues in
- Multi-processors
- Multi-computers
- Distributed systems

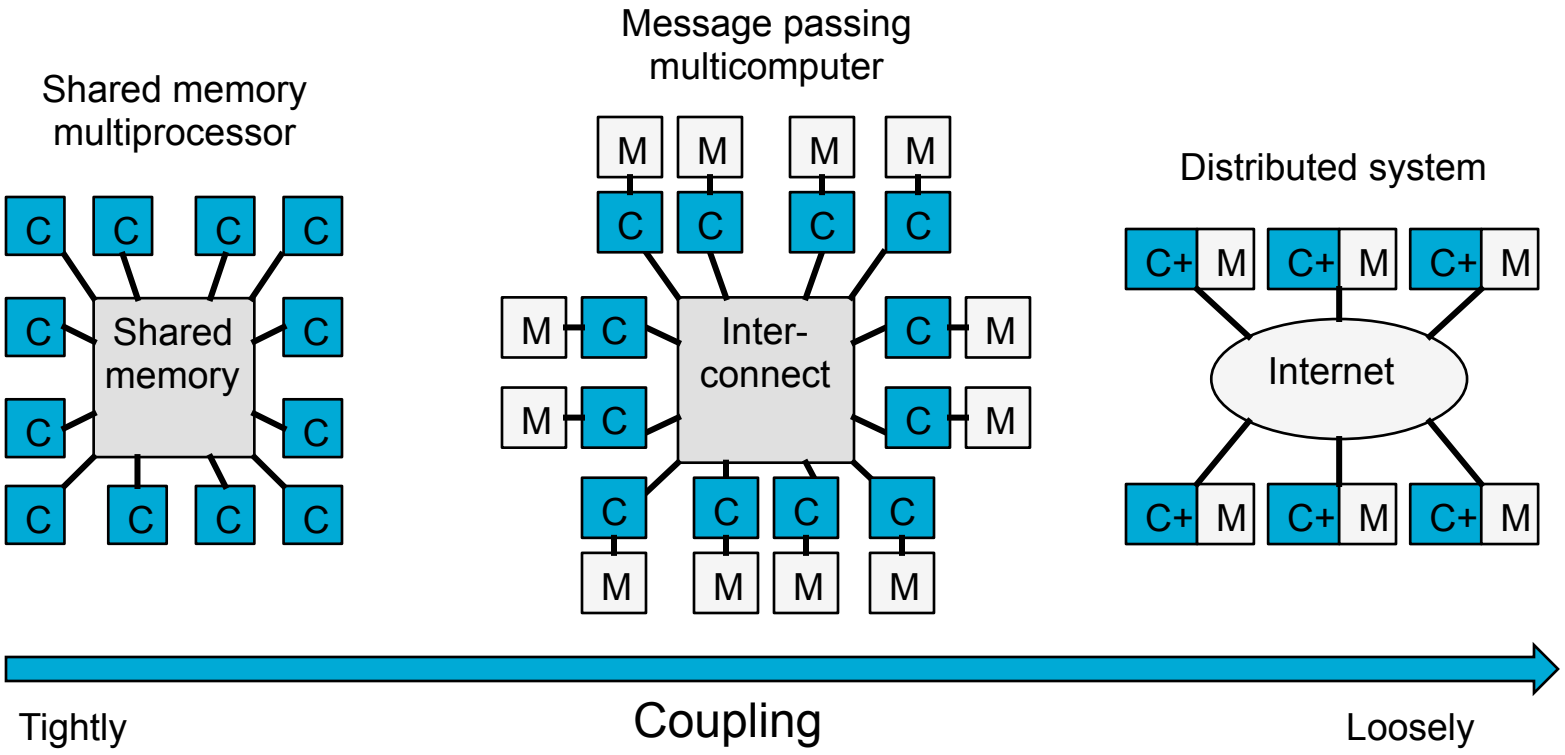
Multiple processor systems

- We always need more computation power
- Making clocks run faster won't do it for long
  - Special theory of relativity limits signals' speed to ~20cm/nsec on wire
    - 1GHz computer – signals cannot travel more than 20cm within one cycle (10^9 cycles/second, 10^9 nanoseconds/sec)
    - 10GHz – 2cm, 100GHz – 2mm, … to let the signal do a roundtrip within one cycle
  - Even if we can make them that small, temperature/heat dissipation is another issue

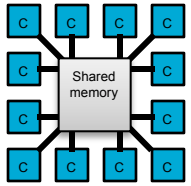
- Alternative – Pile machines together, as
  - Massively parallel machines
  - Over the Internet

Multiple processor systems

- Challenge – Let them talk to each other to tackle a common problem
  - All communication between as message exchange
  - Differences in the time, distance and logical organization



Shared-memory systems



- Shared-memory – Nodes have equal access to memory, typically managed as paged virtual address space
- Uniform & Nonuniformed Memory Access (N/UMA)
  - In UMA all memory words can be read as fast as every other
- Interconnecting nodes
  - UMA – Bus-based (a few 10s), cross-bar or multistage switching (still need quite a few switches)
  - NUMA – Add local memory, forget uniform access time!
    - With/without caching to hide differences; which must be somehow kept consistent
  - Multicore chips – aka chip-level multiprocessors (CMPs)

Multiprocessor OS types

- Each CPU with its own OS
  - Shared OS code, separate OS data structures
  - Simplest, but poor performance
    - E.g. Disk blocks? Each OS has its own cache – inconsistency; No caches – good for consistency, bad for performance
- Master-slave
  - A master holds the one copy of OS and tables, and distributes tasks among slaves
  - No synchronization issues, but master becomes a bottleneck
- Symmetric multiprocessing (SMP)
  - One copy of the OS, but any CPU can run it
    - On a sys call, the CPU where it was made traps to the kernel and processes it
  - Problem – need to synchronize access to shared OS state

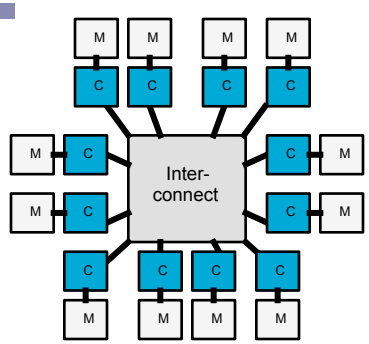
Multiprocessor OS issues – Synchronization

- CPUs in MPs frequently need to synchronize
  - E.g. when accessing kernel critical regions
- Disabling interrupts won't do
- TSL – Need to lock the bus to implement it
  - But spin-lock blocks everybody trying to use the bus
  - And cache invalidation generates a lot of traffic between holder and requesters of the lock (caches work with 32-64B blocks)
  - Test (read) before TSL? Read only poll is cheaper, only invalidated when lock owners frees the lock/writes
- Spinning or switching
  - Testing repeatedly is not productive and CPU switching wastes cycles – can you learn from past behavior (how long did you spin last)?

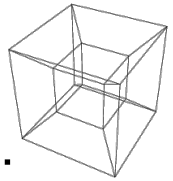
Multiprocessor OS issues – Scheduling

- Now bi-dimensional – which thread *and* where?
  - Timesharing – Simplest, a single ready queue
    - Contention for shared data structure, affinity to preserve state
  - Space sharing
    - Split CPUs dynamically to run related threads at the same time in different slices
- Gang scheduling – Time and space
  - Group of related threads in gangs, scheduled as a unit
    - Gang members start and end their time slices together
  - All members of a gang run simultaneously, on different timeshared CPUs
    - So, communicating members can request/reply almost immediately

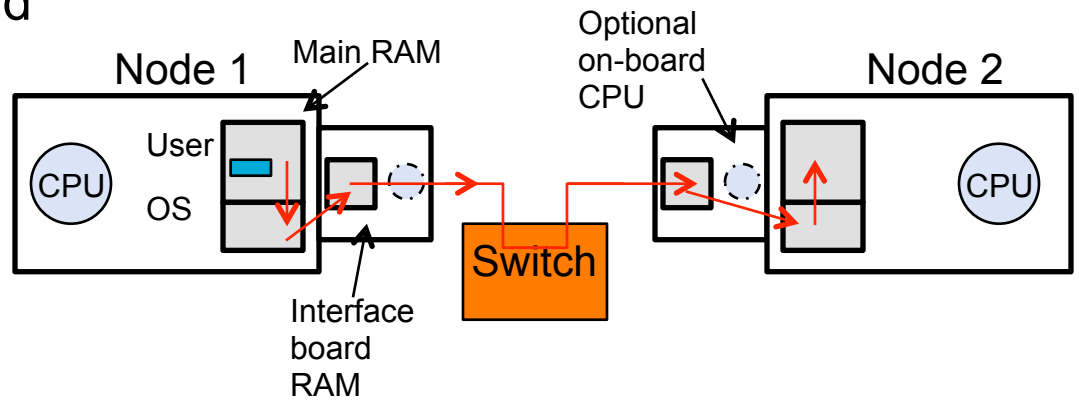
Message passing multicomputer



- CPU-Mem pairs connected by a high-speed network (clusters, COWS)
  - Easier to build/cheaper than MP
    - A stripped down PC (no keyword, mouse, or monitor)
  - Cloud computing services are build on them

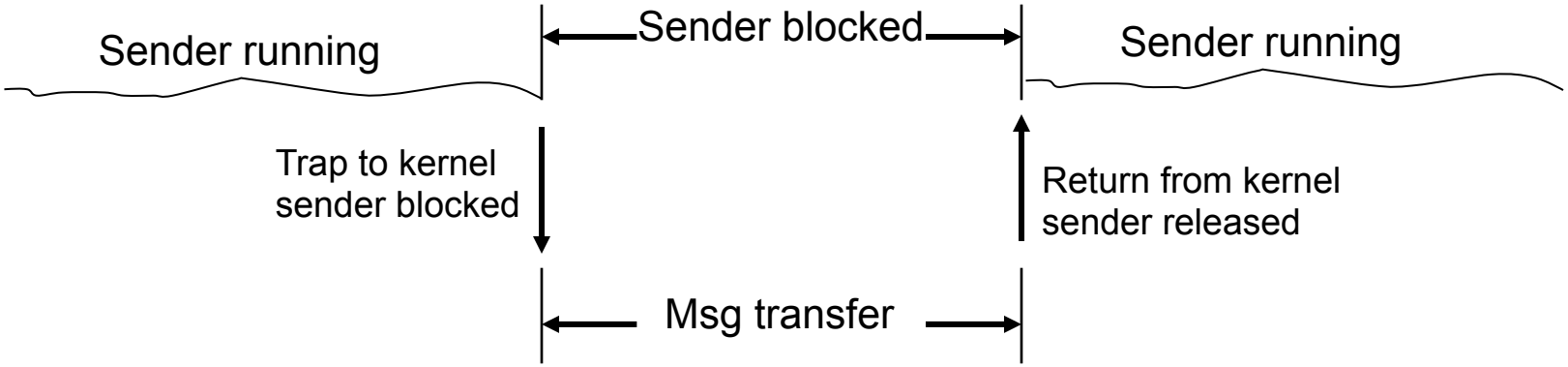


- Between CPUs, a high-speed interconnect
  - Organizations – Single switch, ring, mesh, hypercube …
  - Switching – Store-and-forward or circuit switching
  - Network interfaces – RAM, DMA, network processors, …
  - Key issue – avoid unnecessary copying of messages



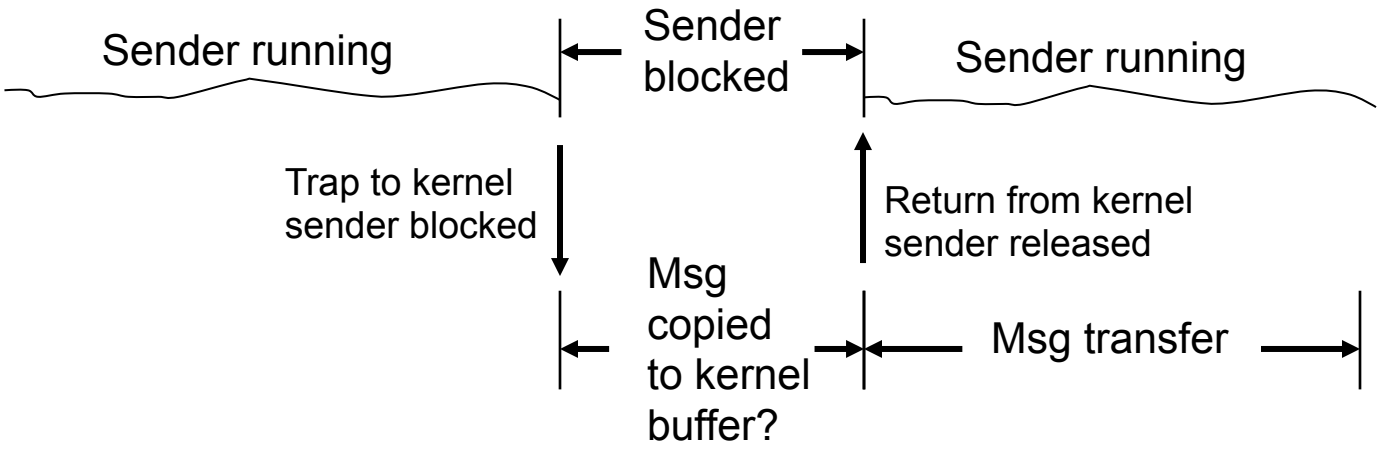
Multicomputer OS issues – Communication

- No shared memory, communication via msg passing
  - Easier to build, harder to program
- Send & receive, at the barest minimum
  - How to address a target node? cpu# and port# ?
  - Send/receive blocks thread until msg is sent/received



Multicomputer OS issues – Communication

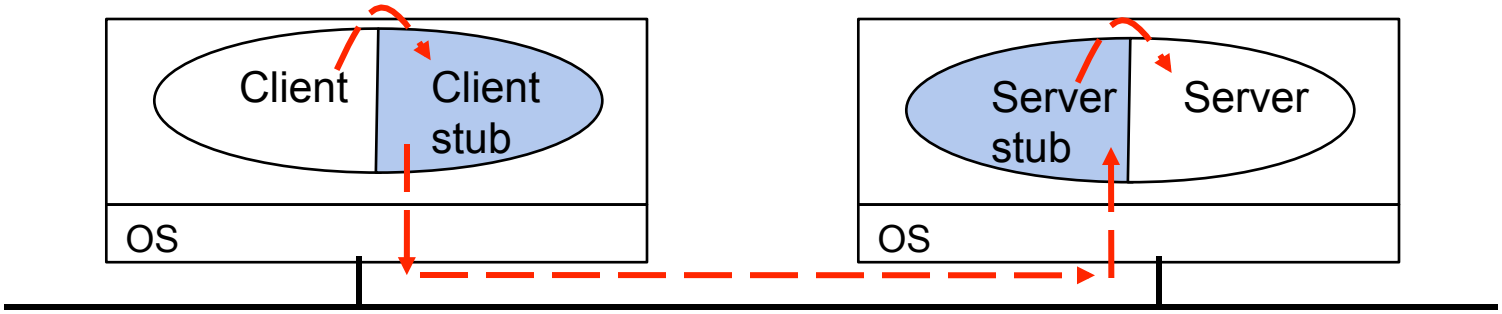
- Send & receive, at the barest minimum
  - Non-blocking sender – send returns control to sender immediately, before msg is sent



    - Sender can go on with its work, but what about the unsent msg? Copy to kernel space? $$, COW?
  - Non-blocking receive
    - Interrupts – costly, slow and complicated
    - Poll for arrived messages – how often?
    - Pop-up threads and active messages

Multicomputer OS issues – Communication

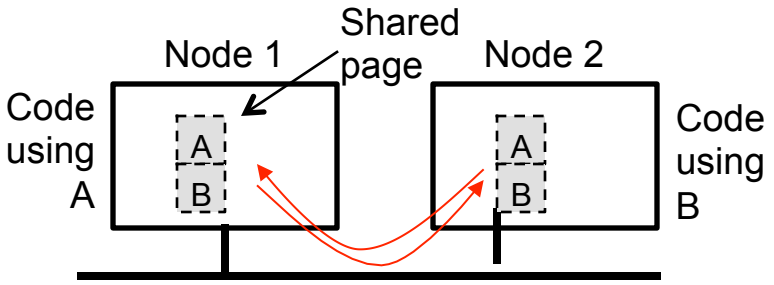
- Remote Procedure Calls
  - Msg passing is I/O, for many, the wrong programming model
  - RPC (Birrell, Nelson ‘84) – simple idea, subtle implications
    - Allow a process to call procedures in another machine
  - To make it look like a procedure call - client and server stubs that pack and unpack the parameters and deal w/ the call



  - Some problems
    - Pointers, weakly typed languages (array length?), …
    - Global variables (now not longer shared)

Multicomputer OS issues – Memory

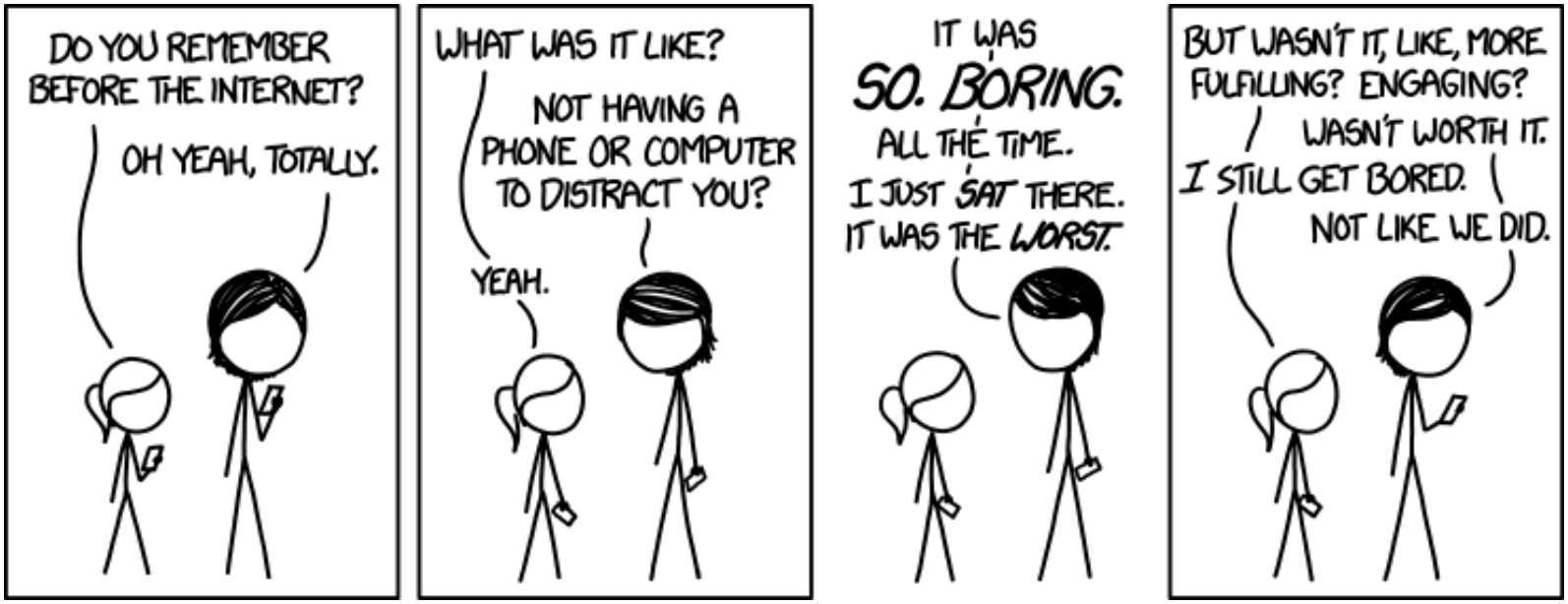
- Many programmers still prefer shared memory
  - Distributed shared memory without physically sharing it
- Basic idea
  - Each page is located in one of the memories
  - Each machine has its own virtual mem and page tables
  - When a page fault occurs, OS locates the page and requests it from the CPU holding it (remote memory, rather than disk)
- Improving performance
  - Replication of read only pages – easy
  - Replicating read/write pages – special handling to ensure consistency when pages are modified
  - False sharing
  - Failing machines …



Multicomputer OS issues – Scheduling

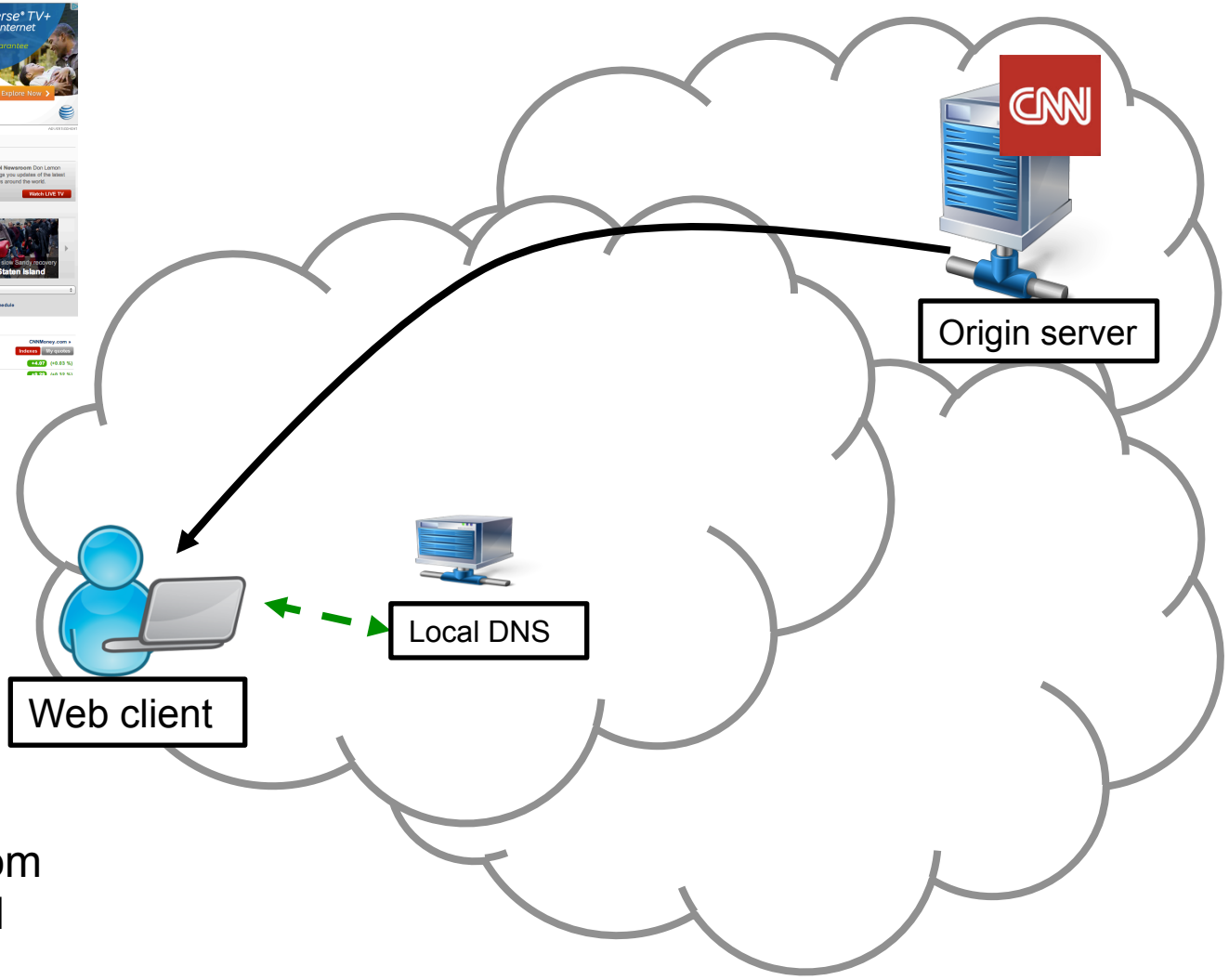
- Scheduling done per node, each has its own set of processes – easier
  - But allocation of processes to nodes is key
- Allocation can be done in a number of ways
  - A graph-theoretic approach
    - Split graph (of processes/traffic xchng) as tightly coupled clusters
    - Schedule them to nodes
  - More distributed models
    - Sender-initiated – at process creation, if origin node is overloaded, pick a random node, if load is bellow threshold, move it there
    - Receiver-initiated – if a node loads is too low, pick another one at random and ask for extra work
    - At runtime – load balancing can be done at run-time if you expect a process to last for long enough to justify migration

And now a short break …



xkcd

A “simple” visit to cnn.com



cnn.com?

% nslookup cnn.com
Server 192.168.1.1

A “simple” visit to cnn.com

Chartbeat

ScorecardResearch

insightexpress
discover tomorrow, today

TRUSTe
CERTIFIED PRIVACY

atlas

DoubleVerify
Trust in Advertising

CNN

quigo
Deep Web Technologies

TURNER
BROADCASTING SYSTEM, INC.

nielsen

AOL

facebook

amazon web services™

Akamai

AudienceScience

Level (3) COMMUNICATIONS

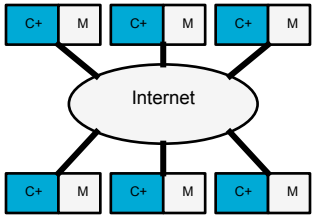
Google

34 DNS lookups

204 HTTP requests

520 KB of data downloaded

Distributed systems



- Very broad definition
  - Collection of independent, interconnected processors that communicate and coordinate through msg exchanges
  - … appears to its users as a single coherent system
- Loosely-coupled - each system is completely autonomous
  - Each host runs an independent autonomous OS
  - Computers don't really trust each other
  - Some resources are shared, but most are not
  - The system may look differently from different hosts
  - Typically, communication times are long

Distributed systems – what for?

- Resource sharing – both, physical resources and information
- Computation speedup – to solve large problems, we will need many cooperating machines
- Reliability – machines fail frequently
- Communication – people collaborating remotely
- Many applications are by their nature distributed (ATMs, airline ticket reservation, etc)

Distributed systems challenges

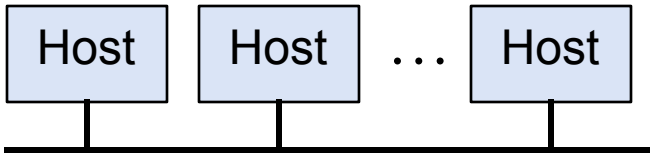
- Making resources available
  - A key goal of DS – making convenient to share resources
- Scalability
  - In numbers (users, resources), geographic span and administration complexity
- Providing transparency
  - Hide the fact that the system **is** distributed
  - Some types of transparency
    - Location – Where's the resource located?
    - Replication – Are there multiple copies?
    - Concurrency – Is there anybody else accessing the resource now?
    - Failure – Has it been working all along?
  - How *much* transparency?

Distributed systems challenges

- Openness
  - Services should follow agreed-upon rules on component syntax & semantics
- Security
  - Sharing, as always, introduces security issues
- Adding to this, common false assumptions
  - The network is reliable / secure / homogenous
  - The topology does not change
  - Latency is zero / Bandwidth is infinite /Transport cost is zero
  - There is one administrator

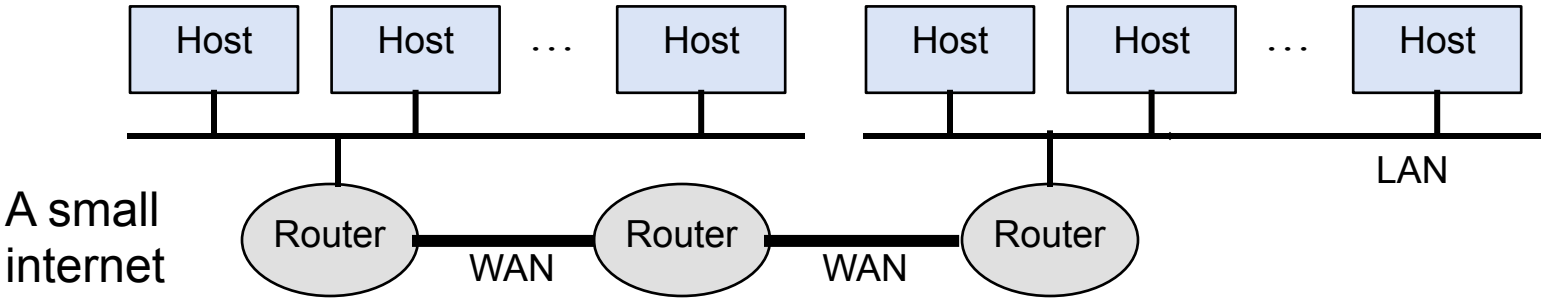
The network underneath

- Connecting hosts in a distributed system – a network
  - A hierarchical system (once) organized by geo proximity
- Lowest level – Local Area Network (LAN)
  - Most popular LAN technology – Ethernet
    - Ethernet segment – hosts connected through adapters and wires to a hub; segments can be bridge

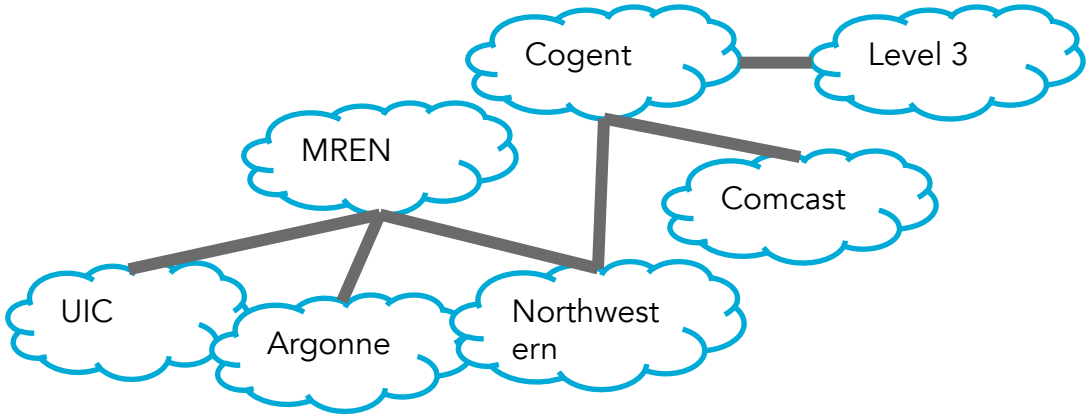


  - Packetized – fixed packets (frames) include header + payload
  - Each adapters has a globally unique address (MAC)
  - Broadcast network – Carrier Sense Multiple Access with Collision Detection (CSMA-CD)

The network underneath

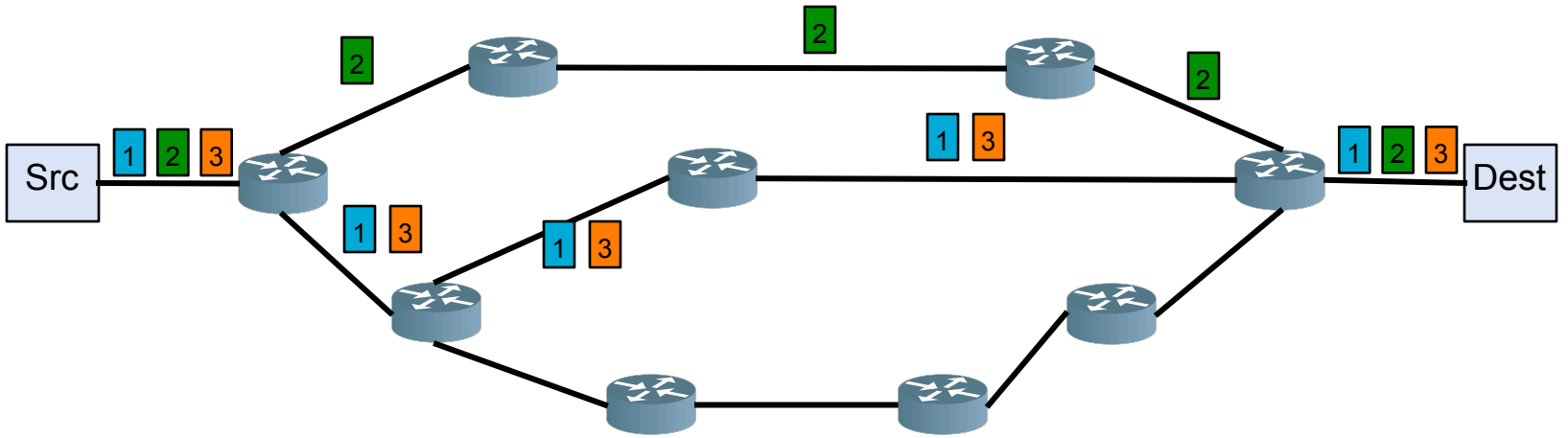


- Higher in the hierarchy, LANs connected through specialized computers *routers* to form an internet
- Internet is made of collections of independently managed internets/networks – aka autonomous systems (AS)



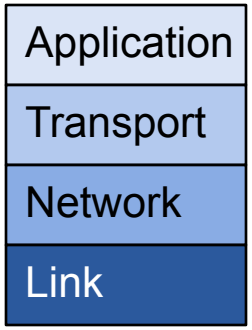
A packet switched network

- Data is broken into packets, each packet is routed separately from src to dest
- Contrast with circuit switching – a physical circuit is reserved from src to dest (e.g., buffer space)
- Links and routers
  - Links physically move packets from place to place
  - Routers receive packets from incoming links and put them on outgoing ones toward the dest



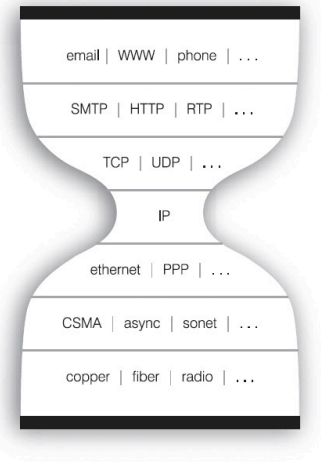
From source to destination

- Using packet switching networks to provide reliable, efficient communication is complex …
- Layering protocols
  - Link – physically interfacing with communication medium to move a packet over a link; Ethernet, WiFi 802.11
  - Network – moving packets over multiple links, from src to destination; IP (Internet Protocol)
  - Transport – provides a msg service to apps; apps don't need to care that communication is in packets; TCP, UDP
  - Application – implementing app need; Web, DNS, P2P, email … and protocols like HTTP, DNS, SMTP …



Network layer – Internet protocol

- An unreliable, best-effort service
  - "Sorry, buffer's full so I got to drop your packet"
- Each connection between a node and a network, an *interface*, every interface a unique address (IP)
  - A 32bit for IPv4 NU webserver 129.105.215.254
  - Often group by their prefixes 129.105.0.0/16
- The IP hourglass, a design principle
  - Overarching goal of Internet tech development – connectivity
  - "IP over everything"



The network is unreliable

- Packets get lost or corrupted on the way
  - Flipped bits, links down, buffers overflow, …
- One approach, ignore it – the application can handle it
  - UDP/IP (User Datagram Protocol)
- For reliability
  - How does the sender knows the receiver got it? ACK
  - What if the ACK gets lost? Timeout
  - What if the ACK just gets delayed? Counters
  - …

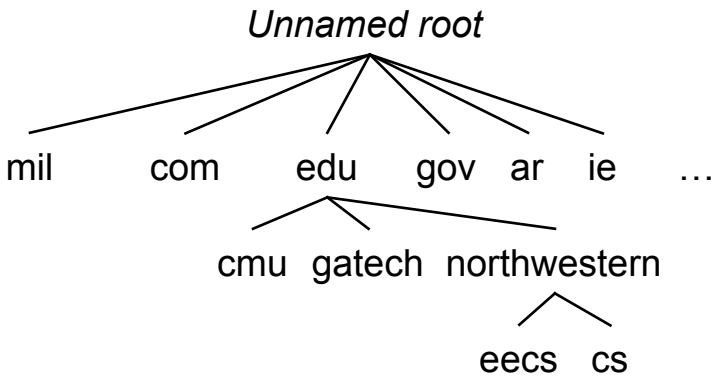
Reliable transport on an unreliable network

- Transmission Control Protocol (TCP)
  - Reliable multi-packet messages from unreliable single-packet datagrams
- With TCP/IP and lower layers we get
  - Reliable delivered of …
  - multi-packet messages between ..
  - two address spaces in two different machines over heterogeneous networks;
  - all without caring for the details
- Higher protocol layers facilitate specific services
  - SMTP for email, HTTP for Web, FTP for file transfer, …

From names to IP addresses

- Large strings of integers (IP) are hard to remember
- To make it easier, use human friendly domain names

  zappa.cs.northwestern.edu (165.124.180.8)
- Originally mapping was kept in a text file (HOSTS.TXT)
- Since 1998 through a distributed DB – Domain Name System (DNS)



A subset of the Internet domain hierarchy

Now that you can communicate …

- How do you order events happening in different machines without a common clock?
  - Keeping all clocks somewhat synchronized
  - Ignore real-time clocks, just logical ordering could be enough
- How do you ensure mutual exclusion?
  - E.g., Token passing, voting, …
- Replication for fault tolerance or performance
  - How do you read the NYT when you are in Europe?
  - Where do you place replicas?
  - How do you keep multiple replicas consistent?
- …
- A whole class just to get you started …

More? Take EECS 340, 345 or 3/495s

- 340 – Introduction to networking
  - The nitty-gritty details on how machines talk to each other
- 3/495 – Internet-scale experimentation
  - Designing, building and measuring Internet-scale distributed systems and their underlying network
- 345 – Distributed systems
  - Naming things, communicating, ordering of events, some reliability, self-destructing data for increased privacy …
- 3/495 – DS in challenging environments
  - Hot and crazy ideas pushing distributed systems to uncomfortable spaces (outer-space, under-water, downtown, volcanoes, …)