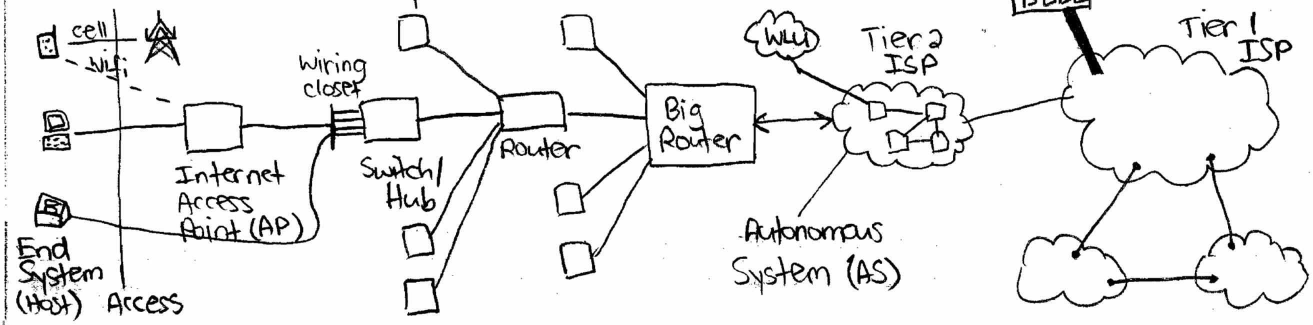
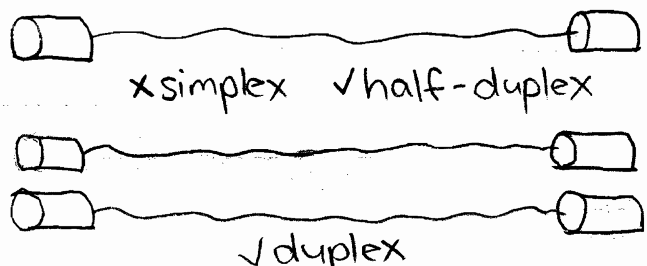
CS 436

03 Jan 2012

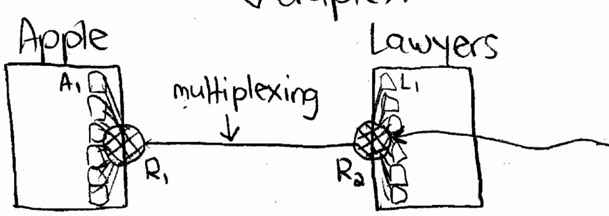
Internet
~ service view: delivers bits from one place to another
~ formal definition: set of all reachable IP addresses
~ topology view
Protocol
~ formal relationship and interaction



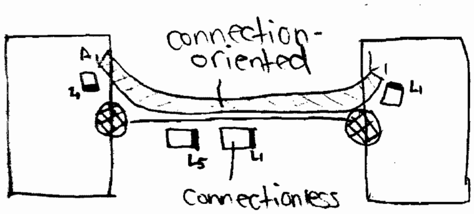
05 Jan 2012



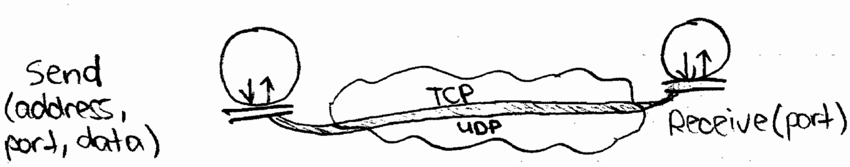
simplex: ⟶
half-duplex: ⟶ or ⟵
duplex: ⇄



~ addresses
~ port numbers
demultiplexing



datagram
connection-oriented: cell network
connectionless: internet

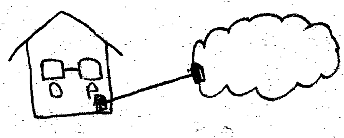


IP Address
a.b.c.d
0-255

IP

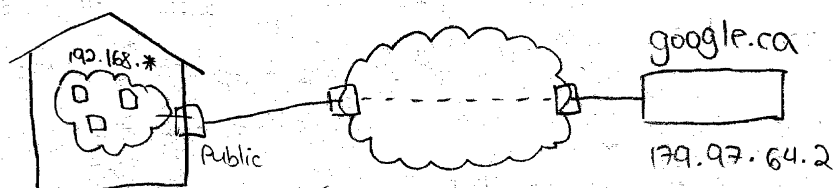
~ Public : reachable

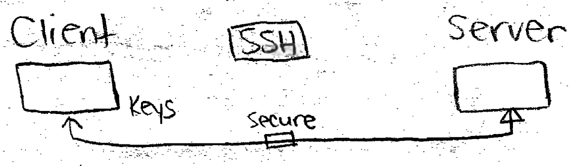
~ Private : 10.*.*.* , 192.168.*.*



D = desktop
P = printer (private)

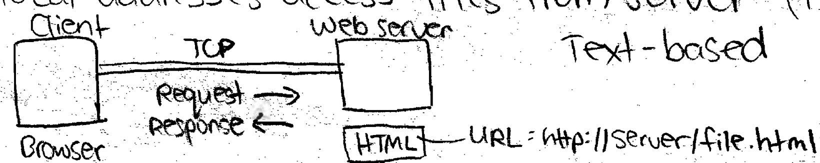
Network Address Translation (NAT)





NFS : local addresses access files from server (remote)

WWW :



Text-based

$\underbrace{\text{GET}}_{\text{method}}$ $\underbrace{\text{/somedir/somefile.html}}_{\text{location}}$ $\underbrace{\text{HTTP/1.1}}_{\text{version}}$

Host : URL

User-Agent : Mozilla

Accept-Language : en

~ cookie : string file (like an ID)

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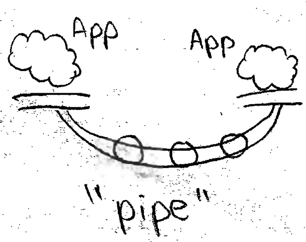


1. Reliability
   ~ Error rate
   - bit error rate
   - packet loss rate

e.g. send "1111" using redundancy : (1111)(1111)(1111)

e.g. require confirmation for each packet

2. Throughput ("bandwidth" - incorrect use of word)

~ bits/sec

3. Delay
   ~ speed of light propogation delay
   ~ queueing
   ~ link throughput

~ speed of light takes about 1/4 of a second to travel around the world, 4-80 min for mars

~ link throughput:

10^6 bits

10^3 bits/sec

10^3 sec $\approx$ 20 min

limited by file size

4. Security/Privacy
5. Cost
   ~ money
   ~ energy

~ how do these things interact?

Cookies

Client ———— Server

→ Request

Response ←

~ Stateless: no memory of any clients

~ Apache: "a patchy" server, stateless

Client ———— Server

→ Request (ID)

← Response (cookie)

Storage

db (cookie, URL)

Amazon

Doubleclick

→ Request (cookie)

← Customized response

Third Party Cookies

Google (Doubleclick)

~ knows what you bought on Amazon and watched on CNN

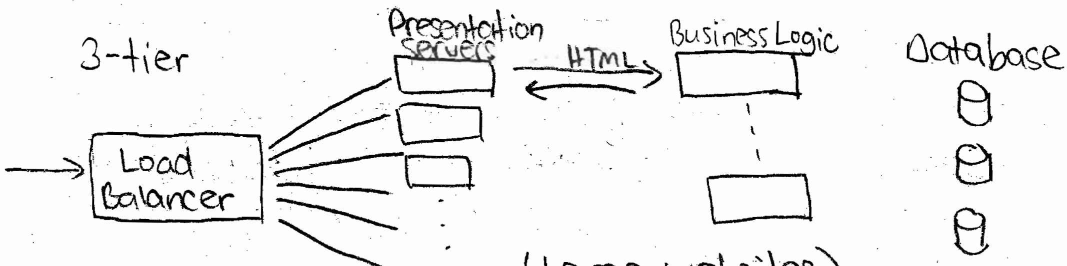
CNN.com

~ Another method: use ads to track your behaviour

Web

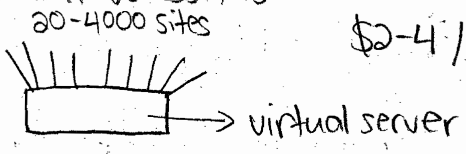
~99% of all hits for top 1000 websites

~ 3-tier



(Large websites)

~ Small websites:



\$2-4 /month/page = \$thousands profit
e.g. 1&1 (Germany)

DNS

~ giving a baby a name based on coordinates and time
~ or, ... grandparent . parent . baby

Registrar
serverlol. cs. uwat. ca (tree)
unique
top level domain
Domain Name Space (DNS)

~ hierarchy
~ delegation
~ namespace
DNS Name ⟶ IP Address

1. Easier to remember names
2. Load Balancing
3. Aliasing (name to name)

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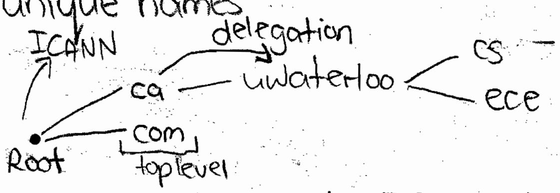
Domain name service:

1. unique names

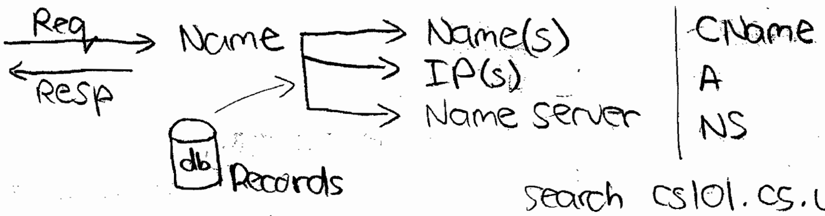


2. Mapping names to IP addresses
3. Aliasing: Names ⟶ Names
eg. uwaterloo.ca ⟶ www1.uwaterloo.ca ⟶ IP, IP, IP

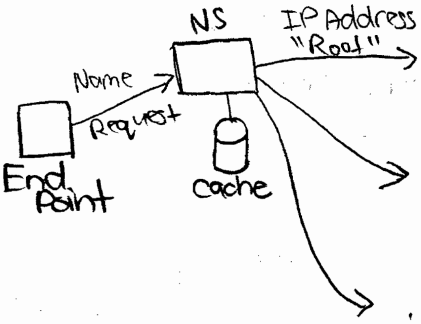
officemax.com → staples.com

uwaterloo.ca → { www1.uwaterloo.ca, www2.uwaterloo.ca, ⋮ www9.uwaterloo.ca }

Name Server:



search cs101.cs.uwaterloo.ca



Root
NS CA NS1.ca
A NS1.ca 128.32.6.4

NS1.ca
NS uwaterloo.ca NS1.uwaterloo.ca
A ns1.uwaterloo.ca 129.97.128.2

...

(Application layer)

"resolution" name → IP, iterative or recursive

Iterative: Your local NS keeps requesting to other servers

Recursive: Each request goes deeper into the servers

NSLookup and Dig

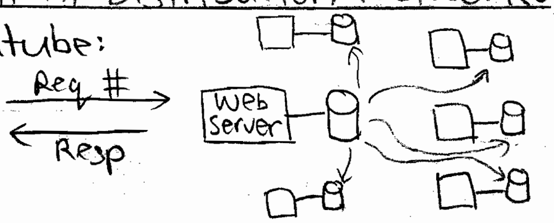
Better than having one centralized server:
- if an owner changes their IP, difficult/hassle
- speed of light limit
- very heavy load on one server

TTL: Time to Live (86400 seconds = 1 day)

Story: Who is the Donkey?

Content Distribution Networks (CDN)

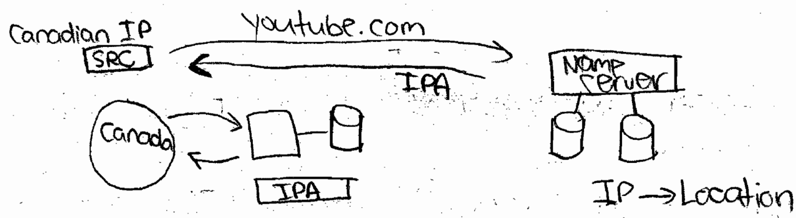
Youtube:



Push and pull content distribution

each "copy" server has a cache which stores the most recently requested videos

Request routing: detects your location and sends you video from geographically nearby server



~ Akamai : how to route requests – "akamization"

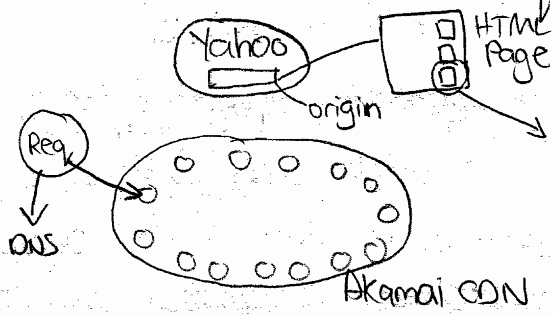


Image tag
URL → Akamai's name
Yahoo.com/img/img1.jpg to
yahoo.akamai.com/img/img1.jpg

~ Akamaization : change the image tag
~ CName aliasing : images.yahoo.com yahoo.akamai.com

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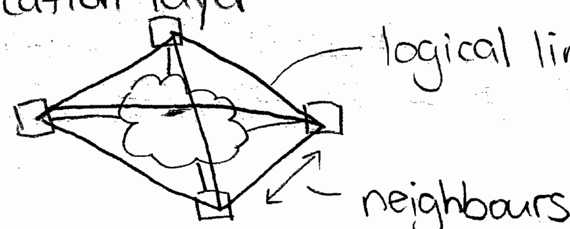
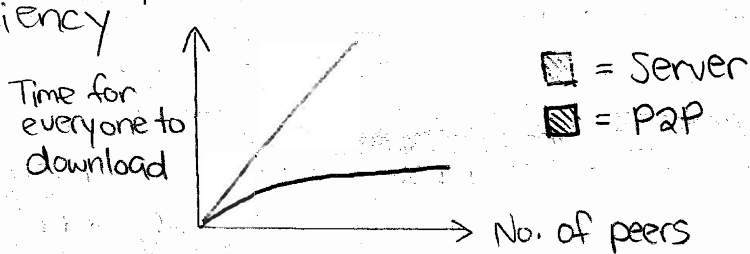
<u>Peer-to-Peer</u>
~ Goal of P2P : efficient use of resources
~ application layer

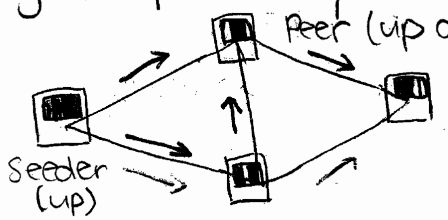


~ multiple copies of content
~ anonyminity
~ efficiency



<u>BitTorrent</u> (2001)
~ Torrent :
- key to overlay network
- description of file

~ Trackers:
- keep track of peers in overlay: IP Address, sharing stats
- e.g. thepiratebay

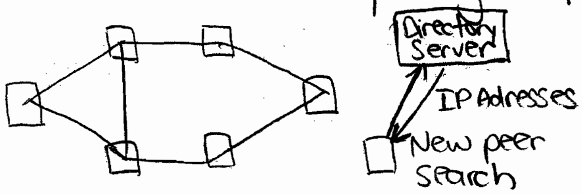


Chunks: ~256 KB

~ if leecher isn't sharing with a peer, that peer will drop the connection

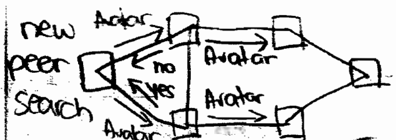
~ freeriding: connecting to new peers when being dropped

~ Search:
- torrent search engine
- centralized directory (e.g. Napster)



Advantage: No 3rd party search, easier to implement
Disadv: 1 point of failure, hard to scale

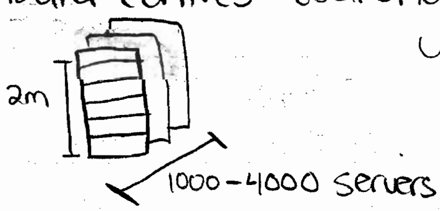
- decentralized search



e.g. Skype
~ in data centres (e.g. facebook bittorrent)

The Cloud

~ a datacentre
~ centralized content
~ online apps.
~ renting computing power
~ Physical view:
- Data centres: warehouse full of servers



usually >10 000 servers
Microsoft: 200 000
Cooling: ~ major cost
~ in cool regions

~ Service view:
- e.g. gmail, dropbox, youtube

Applications
Platforms
Infrastructure
Virtualization
Servers + Hard Disks

Platforms (PaaS)
e.g. Windows Azure
~auto scaling ~reliability ~data backup
Infrastructure (IaaS)
e.g. Amazon Web Services
~rent a server ~more flexible

Virtualization: Allows you to "slice" a server

~ Advantage of Cloud:
- users can access data from anywhere
- stable, "unlimited" power
- flexibility
- much cheaper cost (e.g. on demand, per use)

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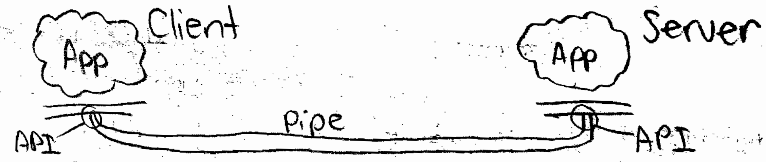


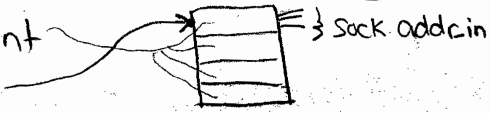
~ Prof K's Tattoo Parlor

<u>Client</u> | <u>Server</u>

Establish "store front" socket()
Listen bind()

Determine server location
Connect ⟶
Accept
R/W (Socket) ⟵⟶ (Socket) R/W
Close | Close

~ Socket FD = int
Socket Table



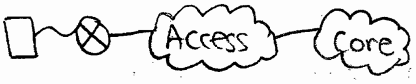
Sock Addr_in
- Address family: AF_INet/(AF_Uni
- IP Address: IP of server or "any"
- Port number: Server's Port

Host Ent - what is returned by DNS

~ Story: Eye of the bird
~ refer to printed program

24 Jan 2012

Application	Email, HTTP, SSH, P2P, DNS
Transport	Goal: <u>Logical</u> communication between apps. Apps think they're ~~directly~~ connected.
Network	Routing datagrams between networks
Link	Communication between nodes on same link
Physical	Air, copper, fiber

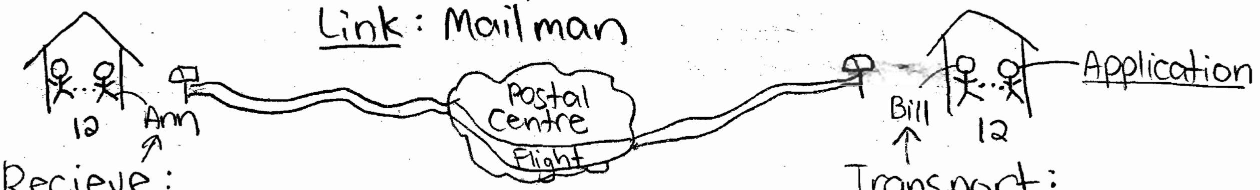


Vancouver

<u>Network Layer</u>: Canada Post

<u>Link</u>: Mailman

KW



Recieve:

1. Collect from mailbox
2. Hand letters out.

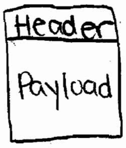
<u>Physical</u>:

Trucks, Planes

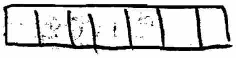
<u>Transport</u>:

1. Collect
2. Take to mailbox

Header: Info attached to a packet to indicate destination, src (e.g. envelope)



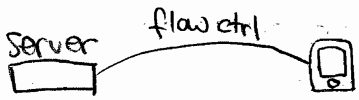
Segment: Transport-layer piece of the msg

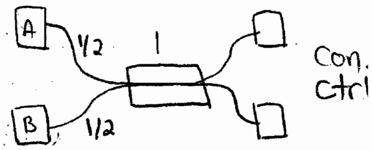


Network provides <u>best</u> <u>effort</u> service

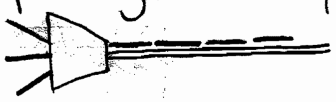
Transport can provide services

- reliable delivery
- flow control
- Congestion control



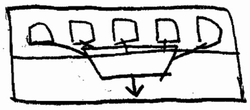


Multiplexing / Demultiplexing



→ Multiplexing: Many signals to 1 medium

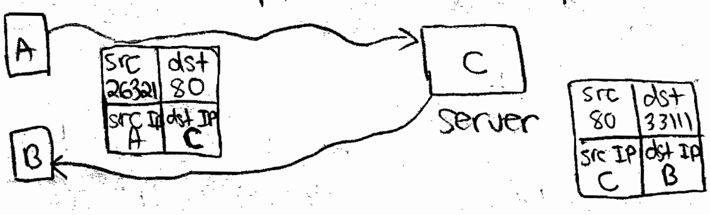
← Demultiplexing: Multiple signals sharing channel, separates



Applications

Transport

~ Ports
- unique identifier of applications on end-host
- 16 bits, 2^{16}
- 0 – 1023 reserved for well-known services
- Port 80: http, Port 21: ftp



UDP

~ User Datagram Protocol
~ Goal: As simple transport as possible
~ Connectionless: as soon as there's data to send, send it
~ UDP header: 16 bits

src port (optional)	dst port (required)
Length (of data)	CheckSum (optional)
Data ⋮	

header

Error detection if some no. of bits are corrupt, then transport protocol (UDP) detects this

~ UDP lacks:
- reliability
- in order delivery
- flow control
- congestion control

TCP (1974)
- complicated protocol

Why UDP?
- faster, fine-grained control, real-time apps, no connection stat
- no connection establishment, small packet header, VOIP, video chatting, some video games

~ What protocols are used:

	App	Transfer
Email	SMTP	TCP
Web	HTTP	TCP
File transfer	FTP	TCP
Remote file servers	NFS	UDP (typically)
Streaming	proprietary	UDP
VOIP	proprietary	UDP
Network Management	SNMP	UDP

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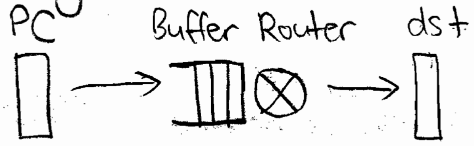
Buffer:

~ Bucket that holds packets until a system is ready for them.

Reliability

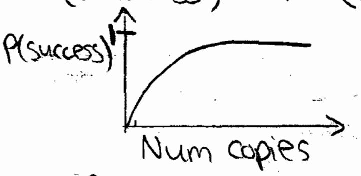
~ Messages sent will be delivered

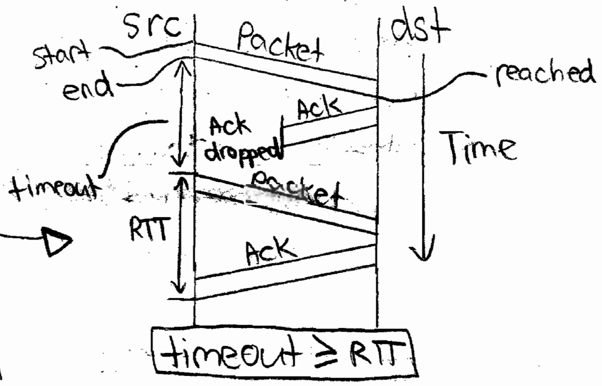


If buffer is full, packet is thrown away.

~ Multiple copies

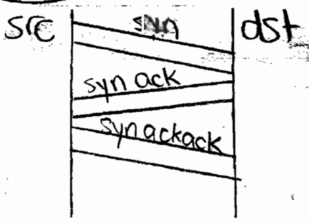
$P(\text{success}) = 1 - (\text{error rate})^{\text{Num of copies}}$

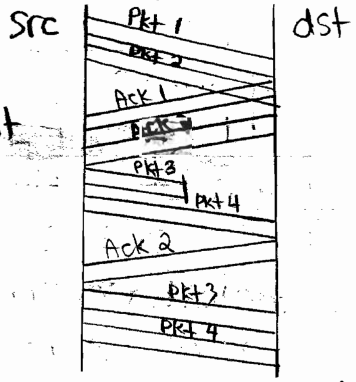




~ Ask for acknowledgement

- Timeout = some amount of time, after which we assume packet was dropped
- Round trip time = time for a packet to be sent to dst and for dst to acknowledge
- Cumulative ack
- 3-way handshake:

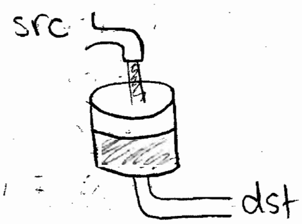




Flow Control

~ Techniques to match a src's sending rate to the service rate of the dst and network devices between src and dst

~ Objectives:

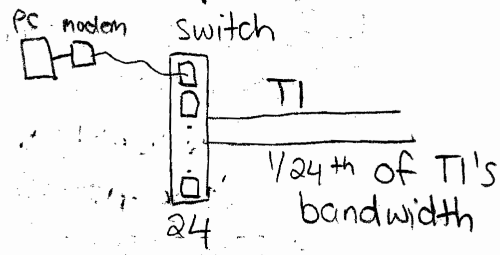


- simplicity
- efficiency (minimal overheads)
- fairness (bandwidth share)
- stability (converge to an equilibrium)

Open Loop Flow Control

~ No feedback between sender and dst

~ Admission control
- user asks for certain requirements (descriptor) like bandwidth, latency
- dst admits / rejects request
- eg. dial-up:

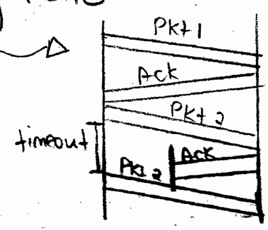


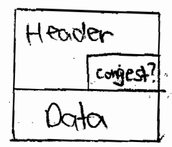
<u>Closed Loop Flow Control</u>

~ Sender and dst dynamically decide on a sending rate

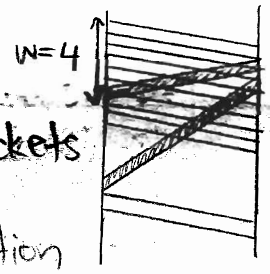
~ Devices do <u>not</u> reserve enough bandwidth for communication (statistical multiplexing)

~ Explicit: Network devices use explicit control messages to negotiate the sending rate
- e.g. Stop and wait

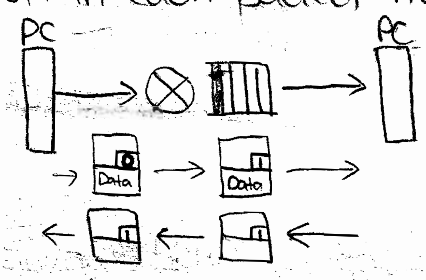




~ Static window:
Send w packets before waiting,
w = transmission window = # un-acked packets



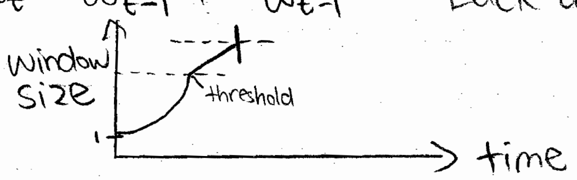
~ <u>Explicit</u> congestion notification
- bit in each packet header indicates congestion



0 : no congestion
1 : congested

~ Implicit flow control: Dynamically adjust transmission window, in response to undelivered packets

~ Dynamic w:
- start at 1
- Each ack, double the window size until w reaches a threshold (slow start)
- $w_t = w_{t-1} + \frac{}{w_{t-1}}$ Each ack, increase window



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~ Flow control : match sending and receiving rate
~ Segment : part of a message
~ Buffer : bucket that holds segments until sys is ready
~ Open-loop flow control : no feedback
~ Admission control : only allow access from connections we know we can support
~ Closed-loop flow control : feedback, statistical multiplexing
~ Ack : acknowledgement that packet was recieved
~ Timeout : after this amount of time, we assume pkt lost
~ Sequence numbers : No. assigned to each pkt

<u>TCP</u>

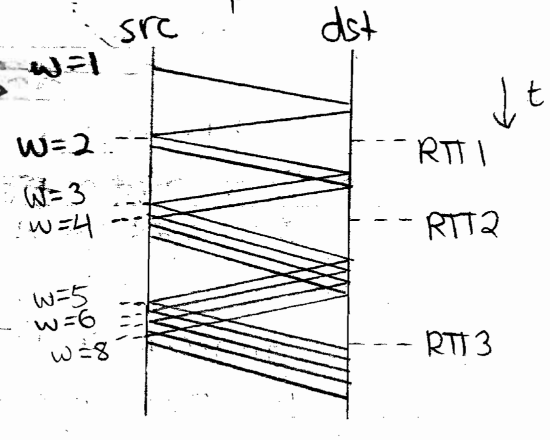
~ Reliability
~ Flow control
~ Congestion control

} Same mechanism

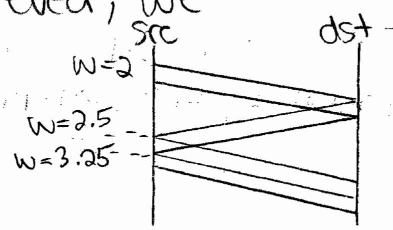
Only info is : Did the packet reach dst?

~ Transmission window W : No. of un-ack'd packets we're allowed to send

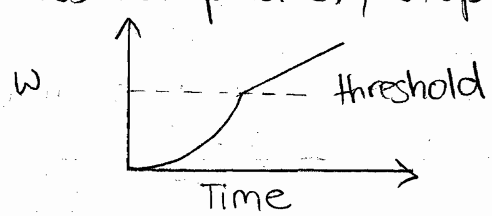
~ **Dynamic window : init w=1**
Slow start : each time recieve ack, increase w by 1



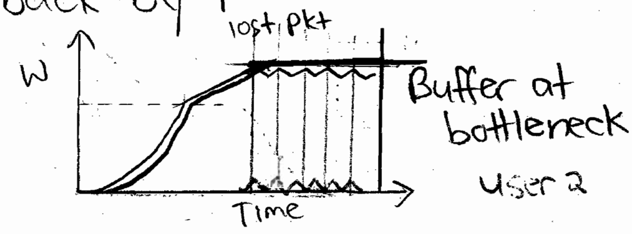
~ Congestion avoidance :
When ack receieved, we set $w = w + \frac{1}{w}$



When there is a loss of packet, step w back by 1



Normal

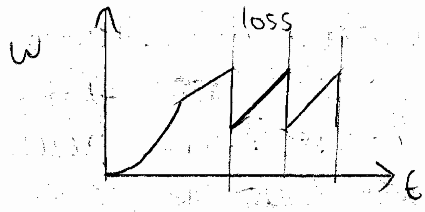


Packet loss

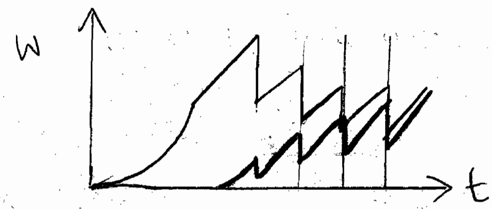
Unfair

Fairness: n senders, $\frac{1}{n}$ transmission bandwidth

~ Additive increase, Multiplicative decrease (AIMD): when loss detected, cut w in half



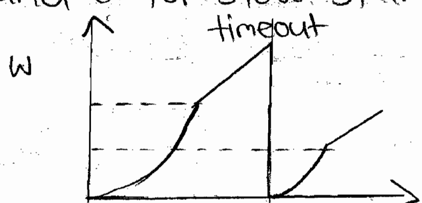
1 sender



2 senders

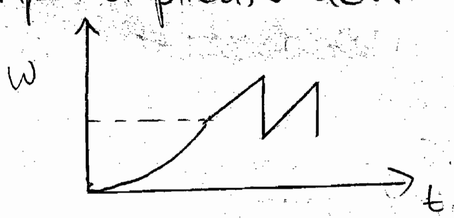
~ Timeout: Go back to pkt with sequence no. that was not ack'd, resend this packet, and following pkts. Set w=1 and enter slow start

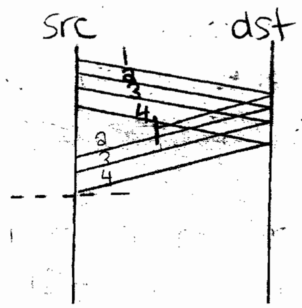
W=1



Threshold is cut in half

~ Triple duplicate ack





w is cut in half. Threshold = new w, stay in congestion avoid

TCP Details:

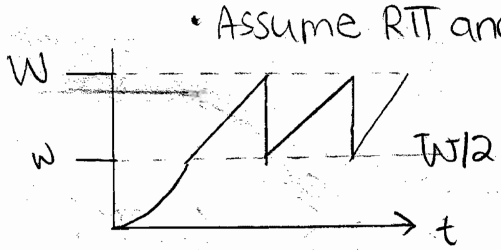
~ Close connection: End-host A sends FIN. End-host B ACK and sends FIN. A ACK's the FIN.

~ How to set timeout for packet loss? Measure the RTT timeout $\geq$ RTT + something to account for variance

~ Average throughput: (throughput = transmission rate)

$\frac{w}{RTT}$ W = w when packet loss occurs,

- Assume loss always detected by triple dup. ack.
- Assume RTT and W are const for the duration



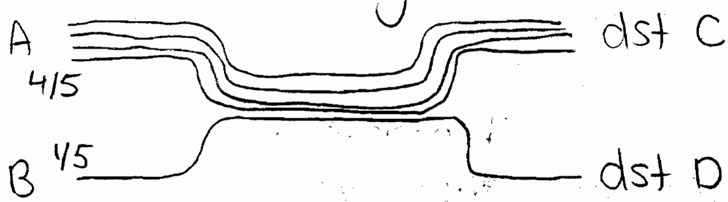
Average throughput $= \frac{3/4\ W}{RTT}$

02 Feb 2012

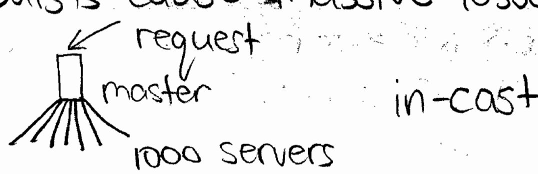
- Flow control: Regulate the sending rate to match the receiving rate vs. Congestion Control: Control the entry of traffic into the network to prevent congestion collapse
- Timeout: Time until we declare a packet lost
- Throughput $= \frac{W}{RTT}$

<u>Drawbacks of TCP</u>

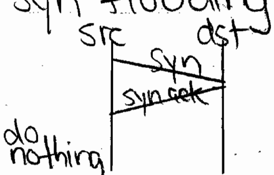
- Fairness can be gamed



- Assumes that packet losses mean congestion
  e.g. 10 Gbps link, 1500 byte packets. In order to send at 10 Gbps: $W = 83\,333$. 1 packet loss every 5 billion packets. Unrealistic!
- Detects congestion using loss
  - TCP has to fill the bottleneck buffer
  - Bursts cause massive losses



- Sensitive to threshold
  e.g. If $W=1$, 3 RTT's to get a webpage, but if you start with $W=10$, only 1 RTT needed
- Syn flooding

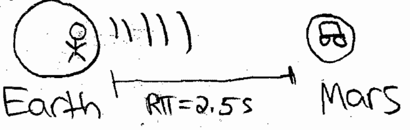


  - a form of Denial of Service Attack (DoS)
- Only info TCP has is packet loss
  - have to overflow buffers to find amount of available bandwidth

~ Explicit congestion notification
- when buffer nearly full, we mark congestion field
- drawback: all network devices have to support it
- Implicit: Changing protocol only involves changing end-hosts

<u>What is an Ideal Transport Protocol?</u>

~ Depends on the network



100 Mbps

100 Mbps · 2.5s = 256Mb = <u>32 MB</u>

before receiving an ack

~ Datacentre Networks:
- high bandwidth, low RTT
- Microsoft: TCP + explicit congestion notification (ECN)
- single owner of datacentre
- buy switches with ECN support
- ECN: Additive decrease in window size

~ Wireless Networks
- High loss rates
- Solution: Use link layer to help TCP
- ∴ Links themselves help TCP by quickly retransmitting lost segments

~ TCP works very well on wide range of networks
- Wide Area Networks (the Internet)
- works well for wide range of RTT's
- widely tested
- best we have

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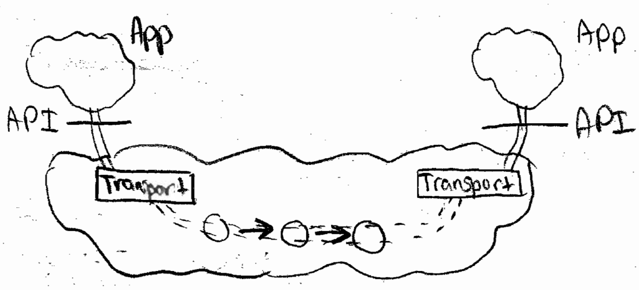


~ addresses

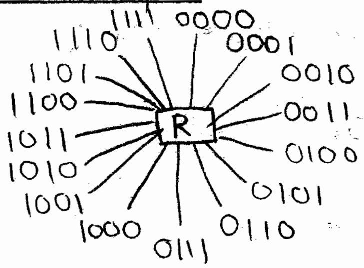
~ forwarding

~ routing

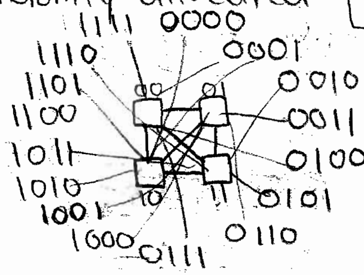
~ geo. addressing

~ hierarchy

Network Layer



Randomly allocated:

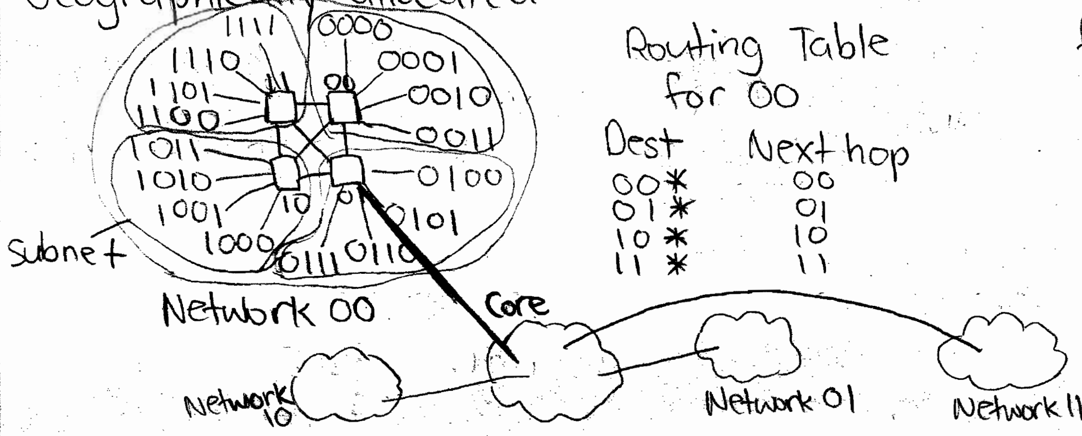


Routing Table for 00

Dest	Next hop
0011	01
0111	10
⋮	⋮

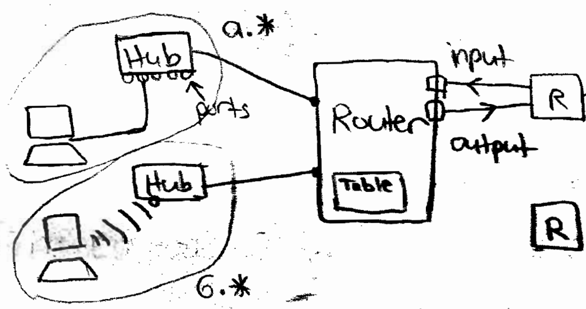
12 entries for each table

Geographically allocated:

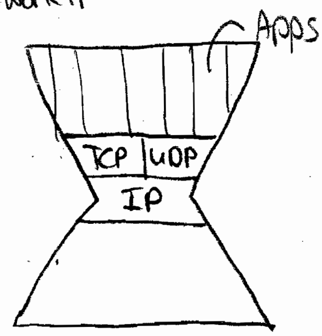


Routing Table for 00

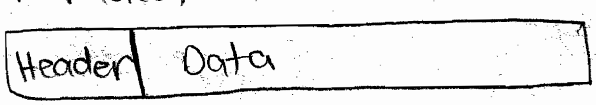
Dest	Next hop
00*	00
01*	01
10*	10
11*	11



IP
Internet
Protocol



- IP Addresses: IPv4 - 32 bits, a.b.c.d., $a,b,c,d \in [0,255]$
- e.g. 129.97.|24.|2   129.97.0.0/16
  Netmask   First 16 bits relevant
- ARIN allocates netmasks
- 3 layers: core, network, subnet
- IP Packet



↳ version, src addr, dst addr

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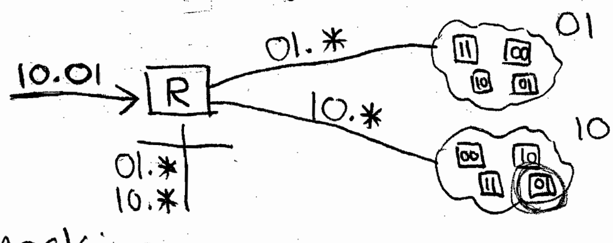
- 32 bit IP Addresses, $2^{32} \approx 4$ billion IP's

~ Aggregation

$\underbrace{a.b.c.0}$ $\underbrace{/30}_{\text{mask}}$ ignore 32-30 = last 2



~ Masking

$$\begin{array}{lll} & 1011\,0111 & /4 \\ \text{AND} & 1111\,0000 & \leftarrow \text{mask} \\ \hline & 1011\,0000 & \end{array}$$

select top 4 bits

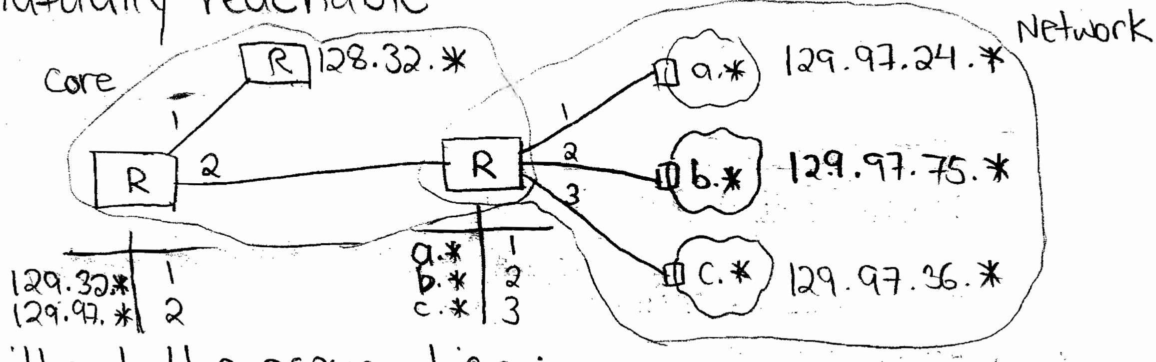
e.g. 129.97.24.* is a /24 network

~

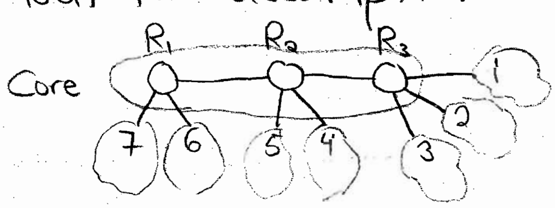
129.97.75.0	129.97.75.4
129.97.75.1	129.97.75.5
129.97.75.2	129.97.75.6
129.97.75.3	129.97.75.7
129.97.75.0 /30	129.97.75.4 /30

~ Assumption: All addresses within a subnet are mutually reachable

~



~ Without the assumption:



R_1:

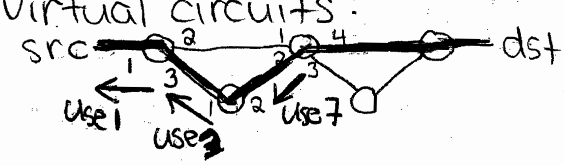
Dst	Next
4	R_2
5	R_2
1	R_2
2	R_2
3	R_2

R_2:

Dst	Next
1	R_3
2	R_3
3	R_3
6	R_1
7	R_1

~ Datagrams = Postcards

~ Virtual circuits:



- pin paths
- use short addresses

Step 1: Send datagram

Dst	Port	Next label
1	3	3 (from "use 3")

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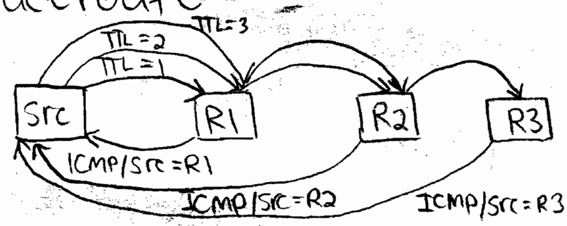
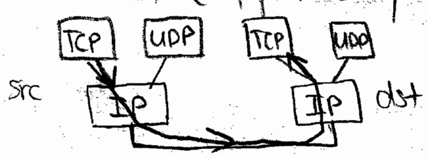
IP Header

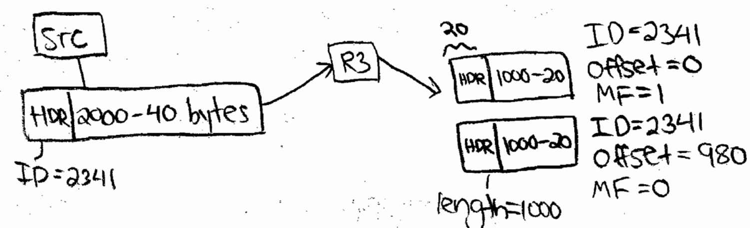
1. Version < 4 - 32 bit, most used; 6 - bit, "the future"
2. Header length (in "words" - 4 bytes) ~ 20 bytes (5 words)
3. Options
4. Type of Service < Delay-sensitive (e.g. Skype); Delay-insensitive (e.g. bitTorrent)
   - Not used because can't be enforced
   - ATM service, but was dropped
5. Length (header + Data) in bytes : 16 bit (65536 bytes)
6. TTL : Time to Live : set to 0-255 by source. Decremented by every router. if field == 0 → drop. Source is sent an error message - Internet Control Message Protocol (ICMP) - Packet expired

~ Traceroute



7. Protocol (Upper Layer)





8. ID
9. Fragment Offset
10. Fragment Flags < DF: Don't frag; MF: More frag

- Grouped together
- spoof by setting all MF=1

11. Header checksum (sum = 65536)

~ Parity bit:

- Even parity: 1011 011 $\boxed{1}$ 0111 100 $\boxed{0}$
- chosen so sum always adds to particular number (65536

12. Src address

13. Dst address

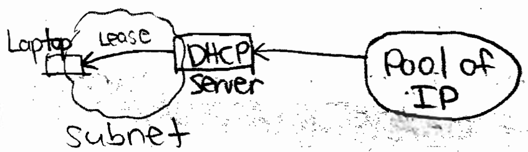
<u>Address Allocation</u>

~ IP Address

- For an interface

~ 2 steps to get an address:

1. Allocation: Organizations get a block of addresses
   - Internet Assigned Numbers Authority (IANA). Registrars, e.g. ARIN (North America), RIPE (Europe)
2. Hand it out (DHCP): Dynamic Host Config Protocol



Lan or subnet:

Media ~~Access Address~~ (MAC)

special address - broadcast, subnet number 111111

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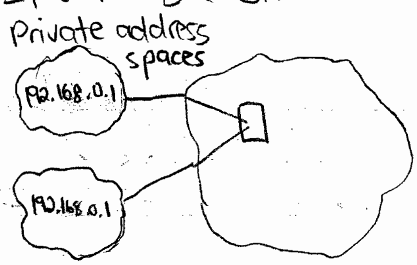
~ IPv4: 32 bit

Private address spaces



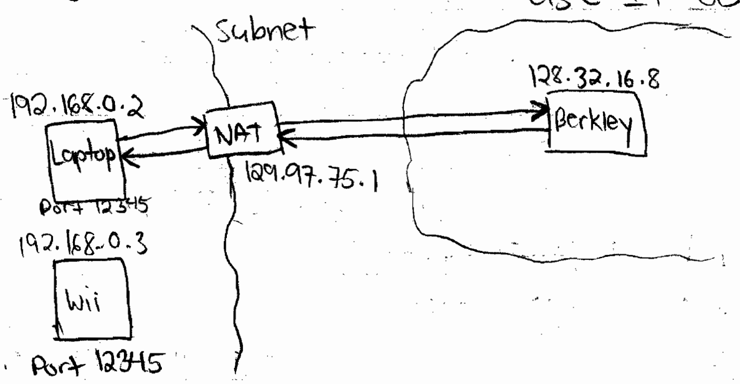
"net ten"

10.* /8 - first network (ARPANET)

192.168.0.0/16

- need NAT to translate (Network Address Translation)
- use IP as you wish

~



GNAT (TCP/IP) Orig Port#

Src	Port #	dst	Orig Port
192.168.0.2	12001	128.32.16.8	12345
192.168.0.3	12002	128.32.16.8	12345

~ timeout for NAT table ≈ 30 min

~ (funny network story)

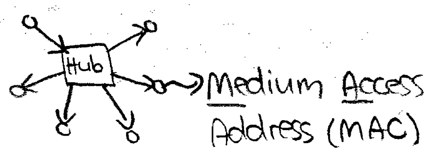
~ App Layer
Transport – TCP/UDP
Network – IP
Link Layer – Ethernet
Physical

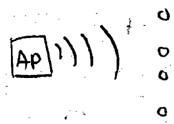
↔ Duplex

→ or ← Simplex

o——o point-to-point

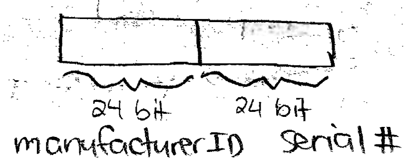
~ Broadcast medium





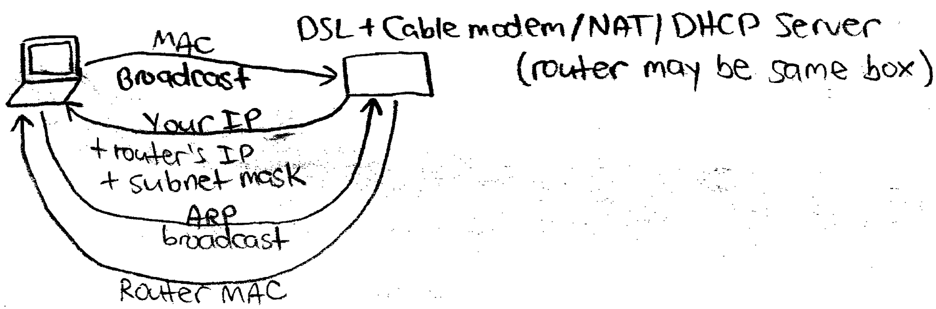
1. How do interfaces get a unique MAC address?
2. How can a source learn the destination address?

~ Ethernet MAC – wired and wireless (wifi)

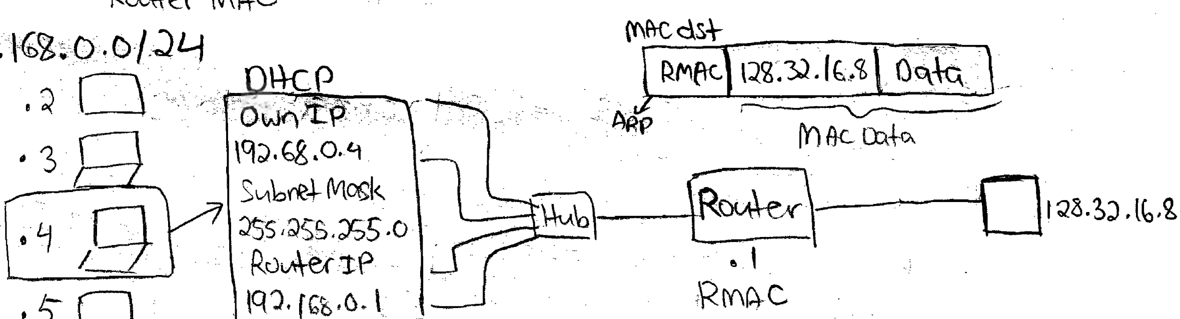


- get from IEEE
  $1000 per manufacturer ID

~ ARP: Address Resolution Protocol



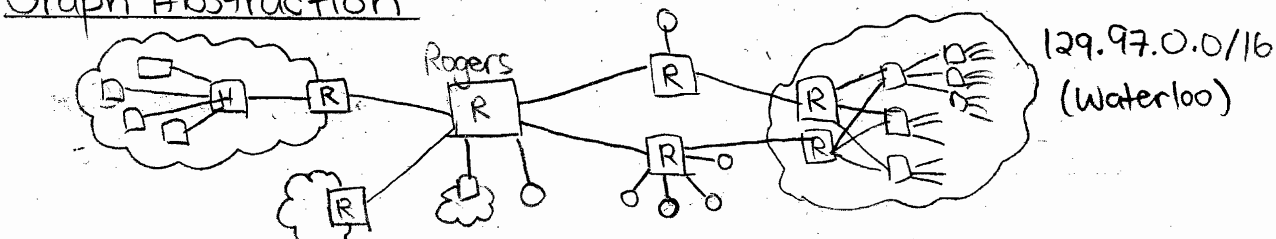
~ 192.168.0.0/24

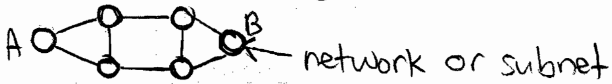


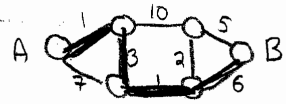
If ((dst IP And Subnet Mask) == (My IP And Subnet Mask))
Then Local → get dst MAC from ARP
Else Remote → dst MAC = RMAC

~ 255.255.255.0 means the same as 192.168.0.0/24

<u>Graph Abstraction</u>







weight represents "goodness of link"
low weights are better

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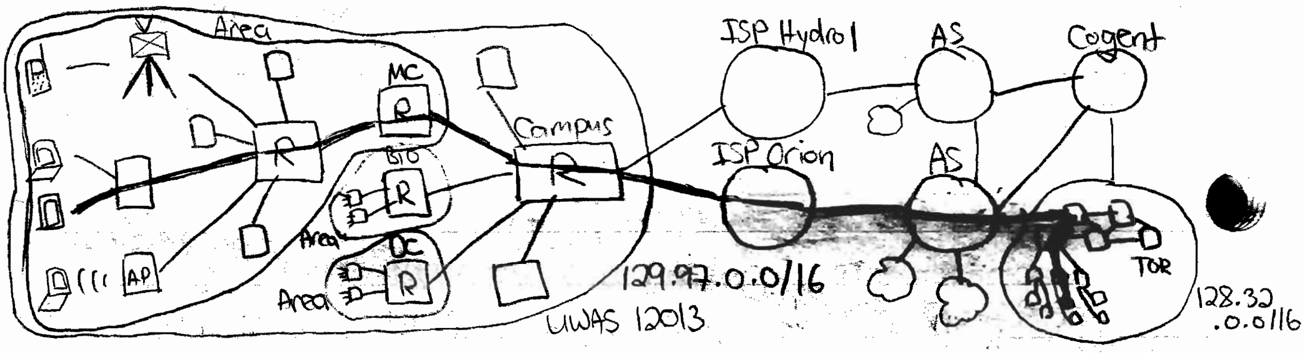
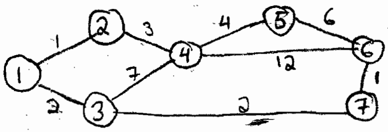
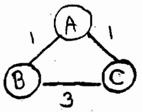




Higher weight is worse



Two algorithms:
- Link state
- Distance vector

Link state - Assume:

1. Each node knows its attached edges and the nodes at the other ends
2. Links are bi-directional
3. Link weights are shared in common
4. All node names are global

A: | A | B | 1 |

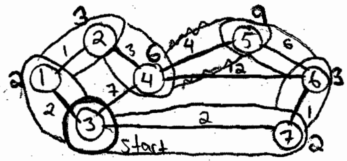
| A | C | 1 |

C: | C | A | 1 |

| C | B | 3 |

B: (own, nbr, wt) | B | A | 1 | , | B | C | 3 |

Link state packets
- flooded, rarely
- everyone gets packet
- travels each edge once



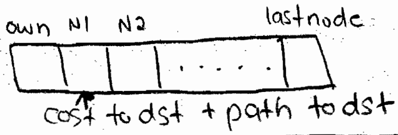
"growing blob"
Dijkstra's algorithm

Node	time	path
3	0	self
1	2	3-1
7	2	3-7
6	3	3-7-6
2	3	3-1-2
4	6	3-1-2-4
5	9	3-7-6-5

OSPF
Open Shortest Path First

~ Happiness = Have − Want

~ Distance Vector



| A | B 1 | C 1 |

| B | A 1 | C 3 |

| C | A 1 | B 3 |

• sent only to neighbours

What B Knows

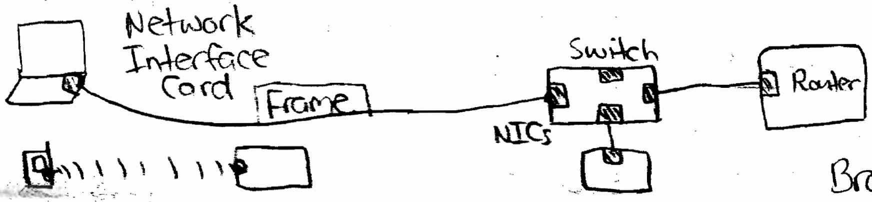
Time	Node	Cost
0	A	1
0	C	3
Receives packet from A		
1	C	2 through A

BGP - Border Gateway Protocol

01 Mar 2012

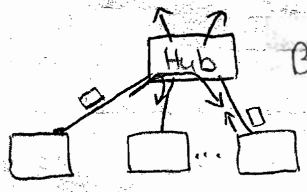
Link Layer

~

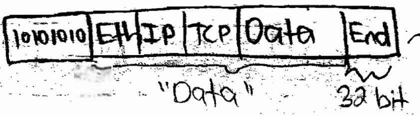


Point to Point

Broadcast < wireless, Hubs



Broadcast
• collisions



~ Cyclic Redundancy Checksum (group theory)

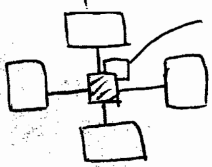
~ Services
• Framing
• Error control:

Integer + x % 7 = 0

Checksum
3,4
14,0
23,5

~ App: x, Trans: segment, Net: packet, Link: frame, Physical: bits
• Flow control: say "stop" if buffer full

~ Multiple Access



controller < msg, time

• frequency division multiplexing (muxing) → allocate freq
• time division multiplexing → time base
• code division multiplexing → allocate codes

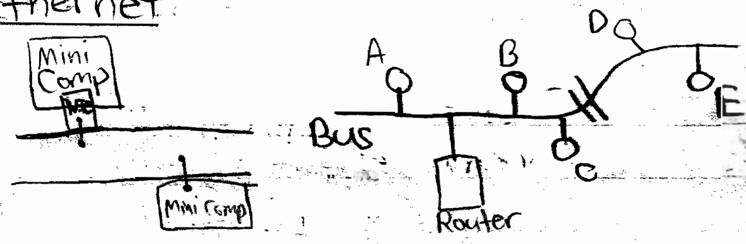
• polling
• token ring
• aloha

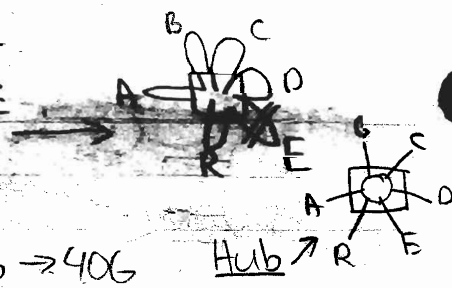
- CSMA – carrier sense multiple access
- CSMA/CD – CSMA + collision detect + random backoff
  Used by Ethernet
  If collision
      choose backoff_value
          random (1, backoff)
          backoff = 2 * backoff
      count down backoff value
  Try again

~ Freq + Time : cell phones (Rogers)
~ Code : cell phones (Bell)
~ Aloha : cable
~ Story : Metcalf (Ethernet)

Ethernet

~





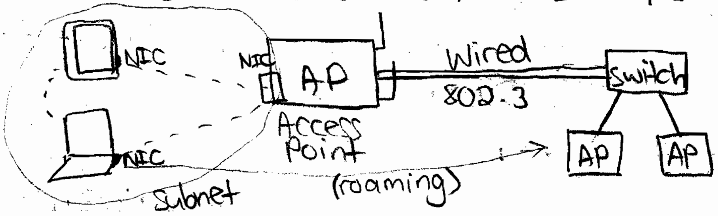
- 1 Mbps → 10 → 100 → 1G → 10G → 40G
- copper wire → fiber
- hub → Ethernet switch (no CSMA needed)

~

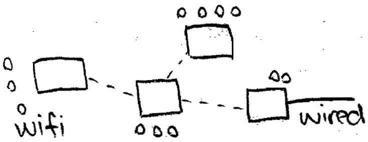
Preamble	Start of Frame	MAC Dest	MAC SRC	Type	IP TCP Payload	Data load	CRC
7 * 10101010 64 bits	10101011	6 bytes	6 bytes	what kind of eth upper layer			32 bit
		3 manufacturer, 3 serial #					

06 Mar 2012

~ Ethernet : 802.3
Wifi : 802.11 (b, a, g, n, ac)
~ Standard distribution : IEEE/IETF/ITU

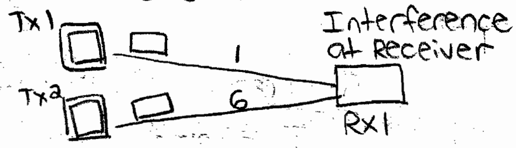


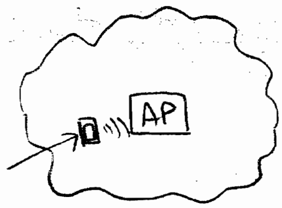
- infrastructure mode
- ad hoc mode

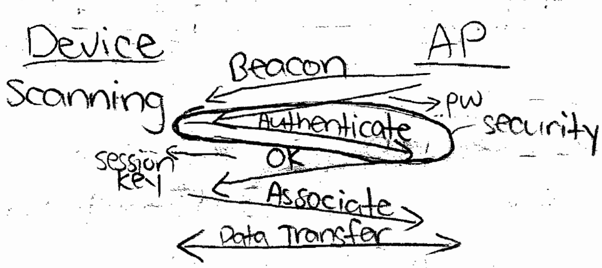
~ 

wireless mesh
- messy
- doesn't work

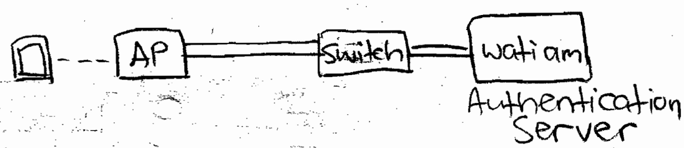
~ Wireless "Link"
- noisy
- channels
- interference at receiver due to collision

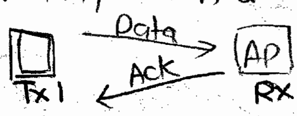


~ 802.11 b : 1, 2, 11 Mbps, 3 channels (1, 6, 11), 2.4 GHz
~ 802.11 a : up to 54 Mbps, 12 channels, 5GHz
~ 2.4 GHz covers more/better than 5GHz
~ 5 GHz is absorbed by water/people, 700 MHz is better but used by television
~ 802.11 g : up to 54Mbps, 3 channels, 2.4 GHz
~ 802.11 n : up to 108 Mbps, 1 channel, 2.4 GHz
~ 802.11 ac (coming)
~ 



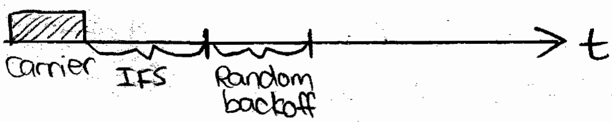
~ (cash register story)
~ Security
- over-the-air
- authentication
- Wired Equivalent Privacy (WEP) : easy to break
- WPA, WPA 2



~ 

~ Wired vs Wireless (802.3 vs 802.11)
1. Ack
2. Random backoff <u>before</u> Tx
3. Double backoff on collision

] CSMA/CA (collision avoidance)



IFS : Interframe spacing

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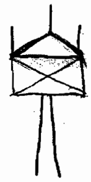
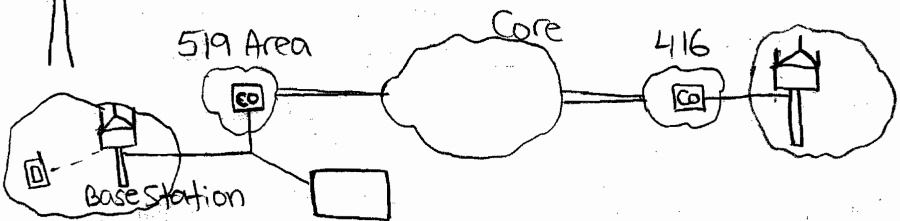
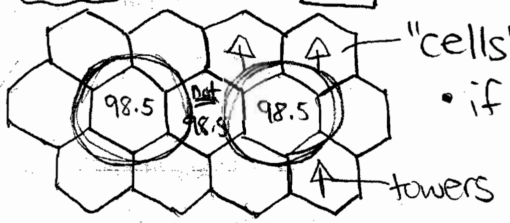
~  cell phone tower

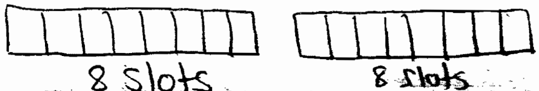


~ 

- if driving fast, handover

~ 1G - analog

~ 2G - FDM + TDM (GSM) - digital



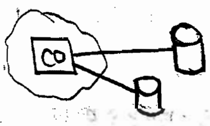
- time division
- frequency division

~ 3G - data-oriented - peak ~200 kbps

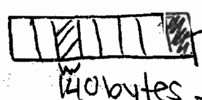
~ 4G - all IP (IPv6) - peak 1Gbps ↓ 500 Mbps ↑

~ LTE-Advanced, IMT-Advanced (4G)

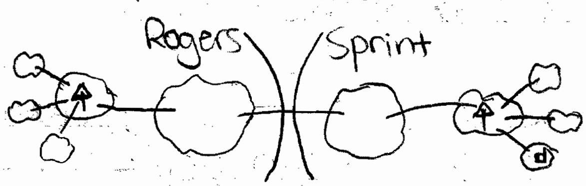
~  IMSI
(Sim Subscriber ID Module)



Home Location Register (#, credit card)
Visitor Location Register (#, cell tower)

~  signalling channel : when to ring, etc

SMS - Small Messaging Service

~ 

Roaming

~ OFDM

~ MIMO -
multiple in
multple out

4 paths
8 kbps → 1 Gbps

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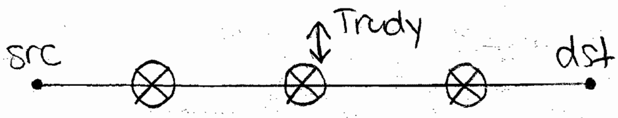
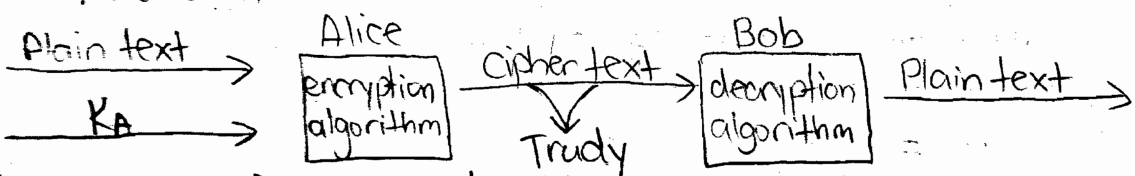
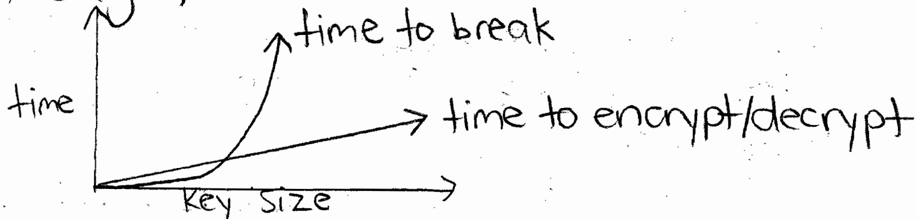


- Types of Attacks
  - copy
  - injection
  - replace / modify
  - spoofed
  - inferred
  - preventing delivery (DoS)
- Western Digital hack story
- Ken Thompson
  - put a backdoor in any UNIX system
  - no evidence in code
- Pentagon Tiger team
  - server in locked room
  - DEC letter forged work request
- House Keys
  - forging by taking a photo
- Despite the presence of malicious parties:
  - Privacy: Messages can't be eavsdropped or inferred
  - Authentication: Messages sent to right party
  - Integrity: Can't be tampered with
  - Denial of service: Ensure delivery
- Encryption
  - Encode a message so that only intended receiver can read it



- How secure is encryption?
  - attacker could try all keys
  - strength of encryption depends on number of keys

• breaking encryption : should be exponential in key strength



~ How practical?
• Usually depends on efficient encrypt / decrypt
• Security depends on long keys (and hard to guess)

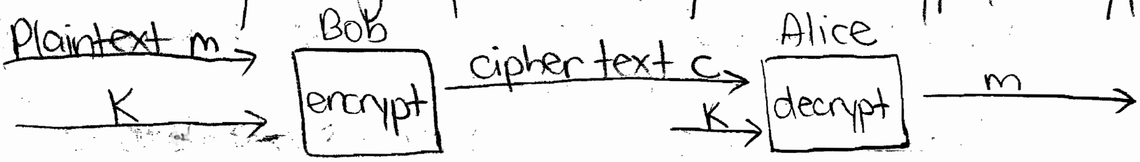
~ Time to check all 5-letter passwords (lower case)
• $26^5 \sim 10$ million
• In 1975 : 1 day, 1992 : 10 sec, 2008 : 0.001 sec

~ 6 letter password : upper, lower, numerical, control
• $70^6 \sim 600$ Billion
• In 1992 : 6 days, 2008 : < 1 sec using 1000 PC's

Cryptography

~ Two types : secret key (symmetric), public key (asymmetric)

~ Secret Key : single private key for encrypt / decrypt



~ First scheme : $a \rightarrow e$, $b \rightarrow f$, $c \rightarrow g$
• only 25 combinations (N-1)

~ Second attempt (random) :
$a \rightarrow d$; $b \rightarrow b$, $c \rightarrow a$, $d \rightarrow e$, $e \rightarrow d$, $f \rightarrow c$
• N! combinations (6! or 26!)

~ Both parties have to know key

~ One-time Pad :
• random sequence of bits that's the same length as m
• m = 01000110 XOR $\oplus$
p = 11011001
c = 10011111
• secure because m and p are same size (bits)
• 2^m combinations : too large! (size of msg)

~ DES (data encryption standard)

- key is 56 bits
- $m = \boxed{c_1 | c_2 | c_3 | c_4 | c_5 | c_6}$ Cipher block Chaining

$$\boxed{C_3 | C_1 | C_2 | C_5 | C_6 | C_4}$$

~ Public Key Crypto : keys for encryption are public (K_A^+, K_B^+), keys for decryption are private (K_A^-, K_B^-)

- Alice wants to send m to Bob
  $c = K_B^+(m)$
- Bob decrypts by
  $m = K_B^-(K_B^+(m))$
- Relies on the existance of one-way functions

~ RSA (Rivest, Shamir, Adleman, 1978)

- Choice of public/private keys
- encrypt/decrypt algorithms

~ Bob needs to choose K_B^+, K_B^-

1. Choose two large primes, p and q
2. Compute $n = pq$ and $z = (p-1)(q-1)$
3. Choose a number e, ($e < n$) and e and z are relatively prime (no common factors)
4. Find d such that $ed - 1$ is divisible by z
5. $K_B^+ = (n, e)$, $K_B^- = (n, d)$

~ Alice wants to send m to Bob ($m < n$)

- To encrypt she computes m^e and the remainder when m^e is divided by n: $c = m^e \bmod n$
- To decrypt, Bob computes $m = c^d \bmod n$

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$$\left.\begin{array}{l} 1.\ p, q \text{ primes} \\ 2.\ n = pq \text{ and } z = (p-1)(q-1) \\ 3.\ e \text{ st } e < n \text{ and } \gcd(e, z) = 1 \\ 4.\ d \text{ st } ed - 1 \equiv 0 \bmod z \\ 5.\ c = m^e \bmod n \text{ and } m = c^d \bmod n \end{array}\right\} \text{RSA}$$

~ e.g. Bob chooses $p=5$ and $q=7$. Then, $n=35$ and $z=24$.
Choose $e=5$, $d=29$. $a=1, b=2, c=3, \ldots$
Message = "L". $m=12$. $c = m^5 = 248832 \bmod 35 = 17$.
Decrypt: $m = 17^{29} \bmod 35 = 4819\ldots \bmod 35 = 12$. M = "L".

~ Why does RSA work?
$K_B^-(K_B^+(m)) = (m^e)^d \bmod n$.

~ Theorem: If p, q are prime and $n=pq$, then $x^y \bmod n = x^{(y \bmod (p-1)(q-1))}$, so:

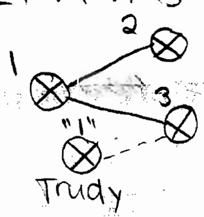
$$K_B^-(K_B^+(m)) = m^{(ed \bmod (p-1)(q-1))} \bmod n$$
$$= m^1 \bmod n \quad (\text{b/c } \bmod (p-1)(q-1) = 1)$$
$$= m \quad (\text{since } m < n)$$

~ Breaking RSA is as hard as factoring
~ Quantum computers: poly-time factoring
~ RSA is compute expensive
~ DES is much faster
~ Use RSA to exchange private keys then switch to DES.

Message Integrity

~ To authenticate a message, Bob must verify:
- Message originated from Alice
- m was not tampered with in transit.

If m has these properties, it has integrity.



← Routers. Trudy poses as Router 1.

Cryptographic hash function:
- computationally infeasible to find two messages x and y st. $H(x) = H(y)$.
- e.g. MD5 (Rivest), SHA-1

~ First attempt at message integrity:
1. Alice has m, computes $H(m)$
2. Sends $(m, H(m))$ to Bob.
3. Bob computes $H(m)$. If $H(m) = h$, everything is OK.

Attack: Trudy creates m', sends Bob $(m', H(m'))$

~ We need a secret!
~ Let authentication key = s

~ Integrity protocol:

1. Alice computes $\boxed{H(m+s)}$ – Message authentication code
2. Send $(m, H(m+s))$ to Bob.
3. Bob checks if $H(m+s) = h$. If so, everything is OK.

<u>Digital Signature</u>

~ Attests that an entity owns something or agrees to its contents.

~ Needs to be: verifiable, non-forgeable

~ Bob's signature must be unique.

~ Public key crypto has unique private and public keys.

~ Bob's signature is $K_B^-(m)$. Why?

- If his public key is known, then anyone can check his signature.

~ Attack: Trudy announces K_B^+ as her public signature.

~ Public Key Certification: Certifies that a public key belongs to a specific entity.

~ Certification Authority (CA):

1. Verifies that an entity is who it says it is.
2. Issues certificate that binds the public key to entity.
   - 36 commercial CA's

<u>End-Point Authentication</u>

~ Process of proving your identity.

~ Authentication Protocol 1.0 (ap1.0)

- Says "I'm Alice"
- Attack: Trudy says "I'm Alice"

~ ap2.0:

- Alice says ("I'm Alice", IP address).
- Attack: Trudy spoofs Alice's IP

~ ap3.0

- key = ("I'm Alice", password)
- Attack: sniff network traffic for password

~ ap 3.1

- key = ("I'm Alice", encrypted password)
- Attack: Playback attack (resend encrypted password)

~ ap4.0: Need to verify password is fresh.

1. Alice says "I'm Alice" to Bob.
2. Chooses a one-time-use number R, sends R to Alice.
3. Alice encrypts R using $K_{AB}(R)$, sends to Bob.
4. Bob decrypts. If equals R, then it's Alice.

Security in Practice

~ No way to prove secureness
- Can show known attacks don't work
- If no known attacks (long time), it should be secure

~ Black hat and white hat hackers
~ Vulnerability scanning
~ Password cracking
~ Packet sniffing
~ Spoofing
~ Root kit
~ Social Engineering *
~ Trojan horses, viruses, worms, keyloggers

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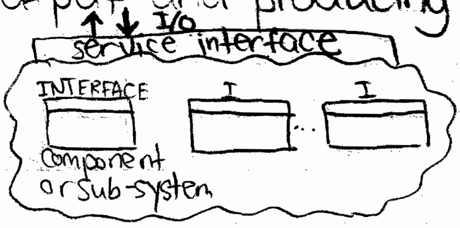
Distributed systems

~ System: Set of interacting components with specific input/output and producing functionality (service)

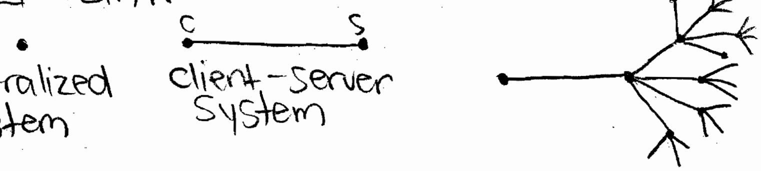


- computation
- storage
- communication

"resources"

~ SECURITY
Application → Distributed System (networked application)
Transport
Network
Link

~

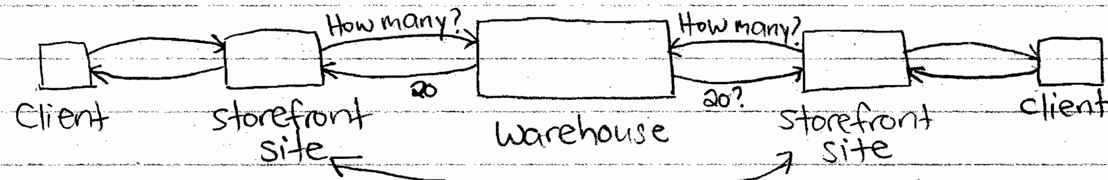


centralized System

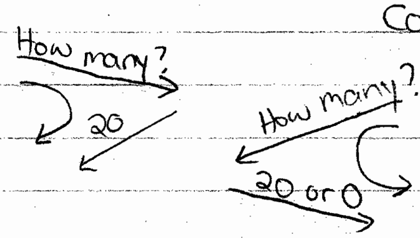
client-server System

Distributed System

CS 436 (cont'd)



Concurrency → inconsistensy



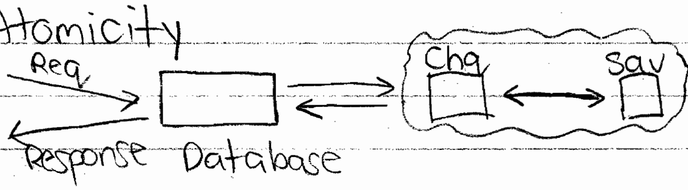
Desireable Properties
- atomicity
- consistency
- isolation
- durability

} ACID

- fault tolerance
- scalability
- synchrony
- transparency
- performance
- heterogeneity

~ Motivation:
- scalability
- fault tolerance
- delegation: local control
- localization

~ Atomicity



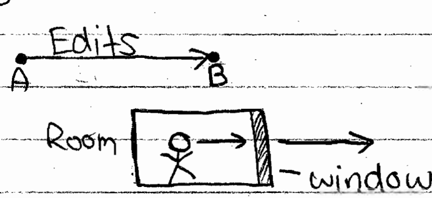
Transfer $200 from chequing to savings.

Read chq
Write sav
Write chq

} Transaction

~ Consistency: after transaction, chq amt + sav amt is the same.
~ Isolation: as if you're the only user on the system.
~ Durability: nothing gets undone after completed.
~ Fault tolerance: define faults
- Link failure, computer failure, disk failure
- Packet corruption, incorrect computation, disk corruption
- Combination of failures causes huge problems

~ Scalability: e.g. Wikipedia, google, cell phones
~ Performance: need a metric
~ Synchrony: "happens before"



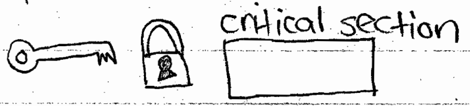
~ Transparency: services are independent of implementation

~ Heterogeneity: Different brands can be used

~ Locking (for Atomicity):

- concurrency + sharing

  processes   # of tic-tac-toe players



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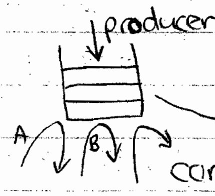
- concurrent processes servicing the queue



~ if queue length > 0 then   (read)

  do work:

  - remove job from queue
  - decrement queue length   (write)
  - process job

  else wait for queue

- mutual exclusion
- need lock manager
- granularity < space / time

~ get_lock (ql, ID);

if (ql > 0) {   (read)

  remove job;

  ql--;   (write)

  release_lock (ql, ID); ← release as soon as possibly can

  process job;

} else release_lock (ql, ID);

~ Read Lock, Write Lock

- Many readers
- 1 writer + many readers

~ If program crashes before releasing lock, lock manager can check if it died - difficult to know what to do

~ Solution to dead lock: two-phase locking

~ Deadlock:

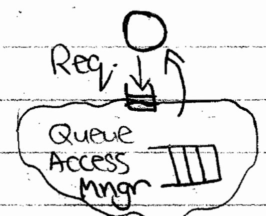
Process A	Process B
get_lock (ql1, ID)	get_lock (q2, ID)
get_lock (ql2, ID)	get_lock (q1, ID)

~ $A \rightleftarrows B$ $\quad$ $A \to B$, $B \to C$, $C \to A$

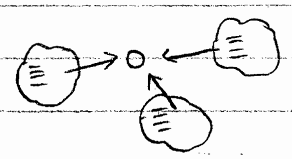
~ Solution : Lock ordering

~ Implementation :

1. Object-Synchronized : Java, C#, ...
2. Lock manager (pthreads) : C
3. Message passing



dequeue-queue



~ Design Principles

- No Global State
- No Central Control
- No Global Clock (?)
  GPS and Time server are solutions to this
- Separate Policy and Mechanism (customizability)
- Explicit Interfaces

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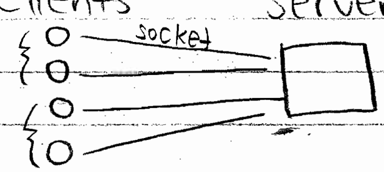
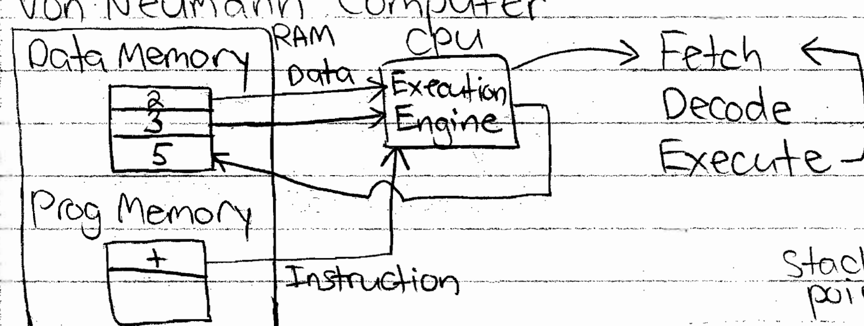
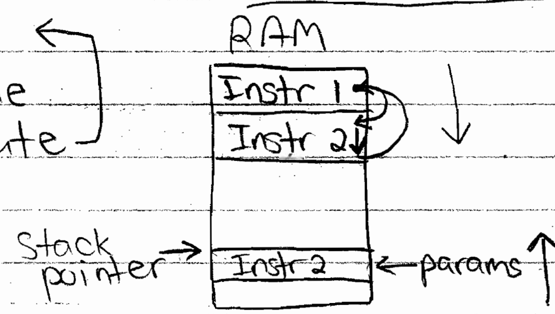
~ Client-server



~ von Neumann Computer



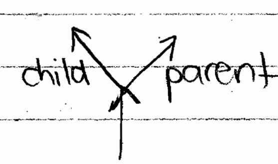
Procedure Call



~ Process :

- Instruction counter (PC)
- Register set (+SP)
- Memory state

fork()



~ Forking :

```
x = fork()
if (x == 0)        /* child */
   { do child stuff }
else
   { do parent stuff }
```

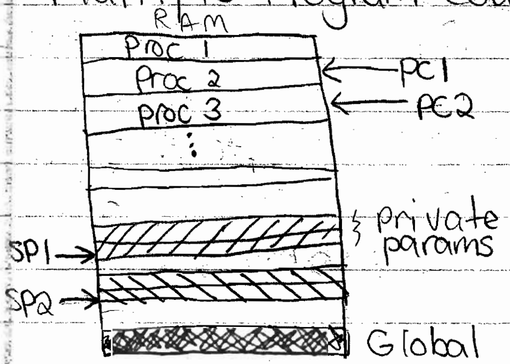
```
Parent

listen();
s = accept();
  x = fork();
  if (x == 0)
    {game} -> read/write (s)
else
```

~ Shared Memory needed for global variables

~ Threads

- multiple Program Counters and Stack Pointers



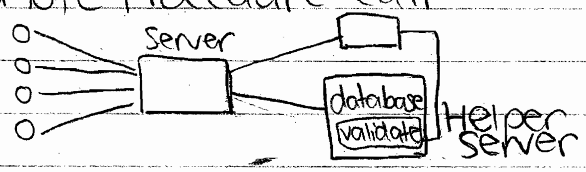
pthreads

- create thread (dummy)

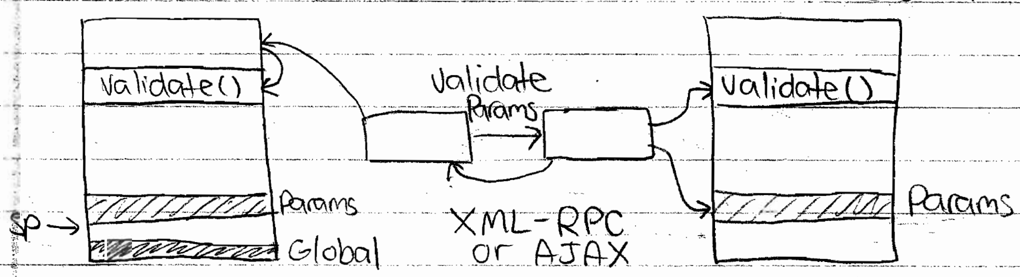
```
listen();
s1 = accept();    (np ++)
listen();
s2 = accept();    (np ++)
num_players += 2;
pthread_create(game, s1, s2)
```

- game() { ... np -= 2 }

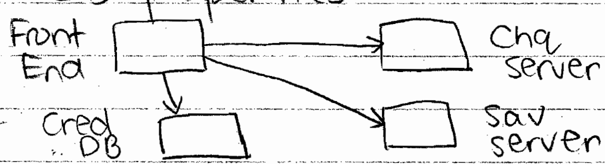
~ Remote Procedure Call




```
if (validate(login, pw))
   then ok
   else try again
```

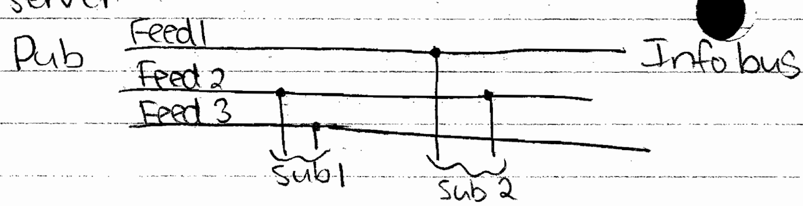


~ Transaction : Set of operations that satisfy the ACID properties



~ Publish subscribe

- Twitter feed
- RSS

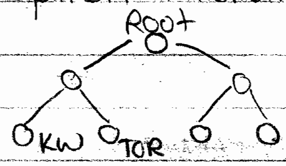


29 Mar 2012

Design Techniques

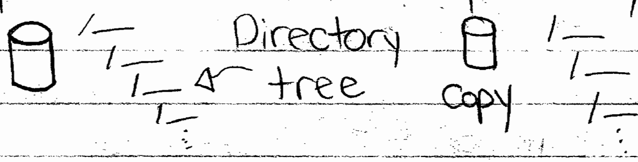
~ Hierarchy — Delegation

- DNS : server101.cs.uwaterloo.ca ⟶ IP Address
- Implicit Hierarchy : e.g. Yahoo Homepage



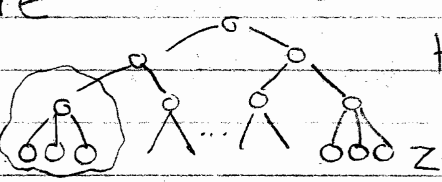
Delegation :
"Look for the name space"

~ Replication → Failover - primary / backup



Read-only is easy,
Read-write is very difficult

- Advantages : more capacity, scaling
- Disadvantages : cost, maintaining consistency, dealing with failure
- Google search :
  1 server
  x3 copies

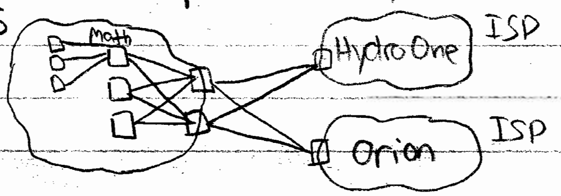


HDFS

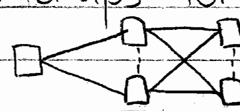
~ Story : "complience port" - Parnassus

- hot backup vs cold backup

UW AS



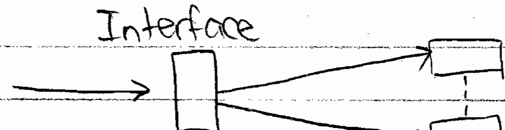
- both main routers are backups for each other



~ Indirection : "Go there"

Root Server :
IP addresses ⟶ .com
of TCP Name ⟶ .info
Servers ⟶ .net

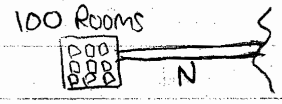
Interface



Front End
Load Balancing

- e.g. calling 1-800 #
- page tables

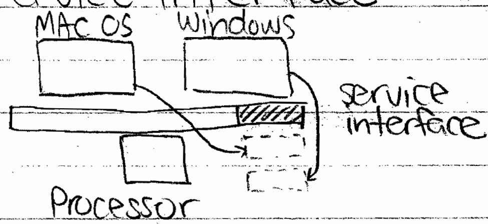
~ Multiplexing : "sharing"
- saves cost
- Demultiplexing : need ID
- performance can suffer

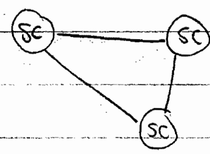


- N = ? Pick a number and adjust as it goes

~ 12 Phrases :
- Wake up
- Relax
- Breathe
- Feel the Earth
- Be grateful
- Be effortless
- Trust yourself
- Control your mind
- Do no harm
- Life is good
- Be happy now
- Let it go

~ Virtualization
- e.g. Santa Clause in a mall
- Service interface

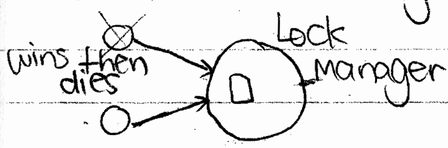




communicate to all santa clauses

- "private servers"

~ Soft State : "Forget it"



- have expiry time
- lock must be renewed
- DHCP lease

Some Exam Notes

Multiple Access
~ Frequency division: allocate frequency, "muxing"
~ Time division: time base
~ Code division: allocate codes
~ Polling: ask clients
~ Token ring: pass token
~ Aloha: send anytime, random backoff
~ CSMA: check before transmission, random backoff
~ CSMA/CD: CSMA with collision detect
~ CSMA/CA: require ack, random backoff before transmission, double backoff upon collision