

Light at the
end of the tunnel



Final Lecture: Course Overview

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Course Logistics

Last assignment: HW3

- Posted on the class Web page
- Due at midnight Wed 4/21

Final exam

- Cumulative, primary emphasis on the second half of the class
- Friday, April 27th 1:30-3:30pm
- Location: EECS 1200 (unique names: 'a'-'m') and EECS 1005 ('n'-'z').
- Sample exam and solution available online at course Web site

Office hours

- Instructor and GSI at the regular times this week
- All of us by appointment
- No discussion this Friday

Also, ask questions on the Phorum

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Goals of Today's Class

What are the key concepts in networking?

- Hierarchy, indirection, caching, randomization
- Soft state, layering, (de)multiplexing, e2e argument

Why was there no math in this course?

- Is theory even useful in data networking?
- Control theory, graph theory, game theory, optimization theory, queuing theory, scheduling theory, ...

What's going to happen to the Internet?

- Can we have our cake and eat it, too?

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Key Concepts in Networking

(Exam preparation idea: look for other examples)

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Networking Has Some Key Concepts

Course was organized around protocols

- But a small set of concepts recur in many protocols

Many of these are general CS concepts

- Hierarchy
- Indirection
- Caching
- Randomization

Others are somewhat networking-specific

- Soft state
- Layering
- (De)multiplexing
- End-to-end argument

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Hierarchy

Scalability of large systems

- Cannot store all information everywhere
- Cannot centrally coordinate each component

Hierarchy as a way to manage scale

- Divide large system into smaller pieces
- And manage the pieces separately

Hierarchy as a way to divide control

- Decentralized management of common infrastructure

Examples of hierarchy in the Internet

- Example #1: IP address blocks
- Example #2: routing protocols
- Example #3: Domain Name System (DNS)
- Example #4: super-peers in P2P systems

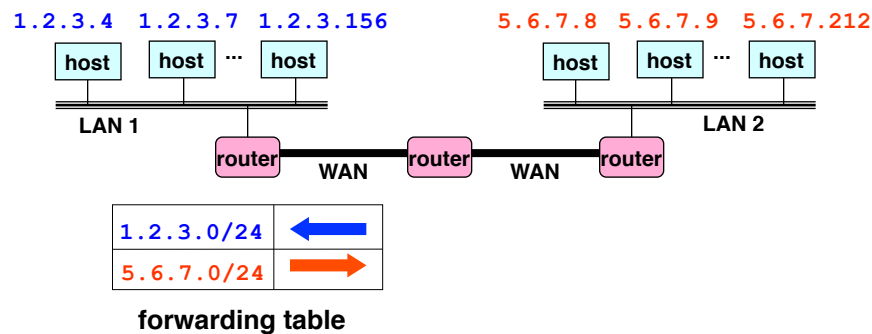


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Hierarchy: IP Address Blocks

Number related hosts from a common subnet

- 1.2.3.0/24 on the left LAN
- 5.6.7.0/24 on the right LAN



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Hierarchy: IP Address Blocks

Separation of control

- Prefix: assigned to an institution
- Addresses: assigned by the institution to their nodes

Who assigns prefixes?

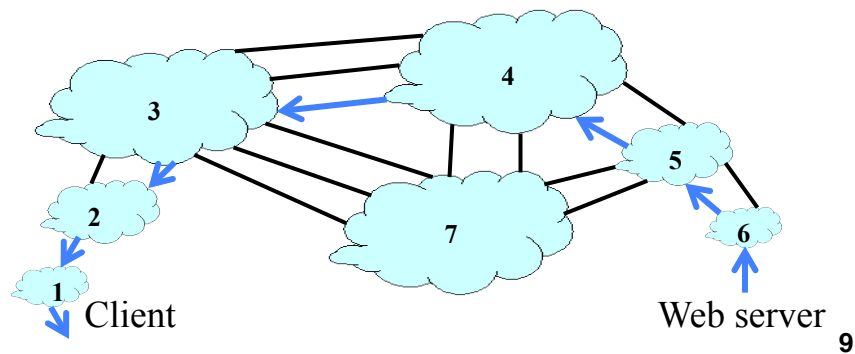
- Internet Corporation for Assigned Names and Numbers
 - Allocates large address blocks to Regional Internet Registries
- Regional Internet Registries (RIRs)
 - E.g., ARIN (American Registry for Internet Numbers)
 - Allocates address blocks within their regions
 - Allocated to Internet Service Providers and large institutions
- Internet Service Providers (ISPs)
 - Allocate address blocks to their customers
 - Who may, in turn, allocate to their customers...

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Hierarchy: Routing Protocols

AS-level topology

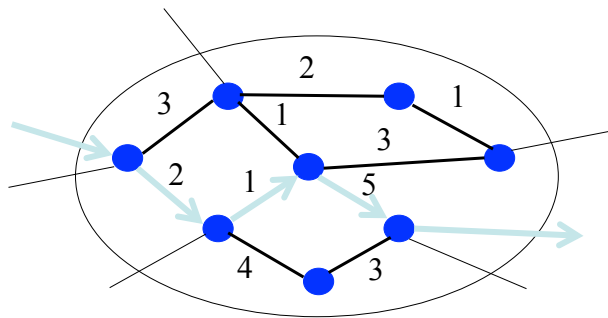
- Nodes are Autonomous Systems (ASes)
- Edges are links and business relationships
- Hides the detail within each AS's network



Hierarchy: Routing Protocols

Interdomain routing ignores details within an AS

- Routers flood information to learn the topology
- Routers determine “next hop” to reach other routers...
- By computing shortest paths based on the link weights



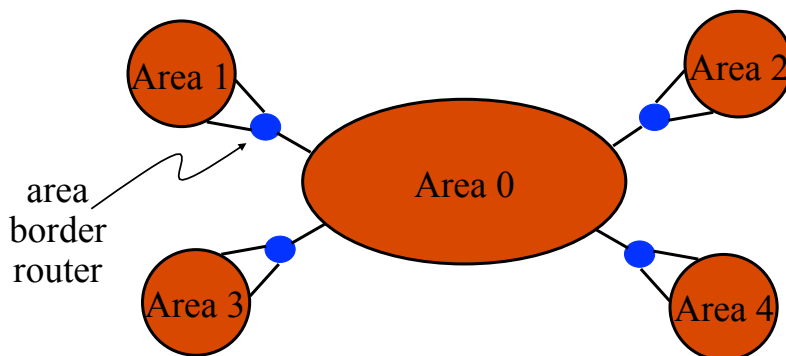
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Hierarchy: Routing Protocols

Scaling challenges within an AS

- Flooding link-state packets throughout the network
- Running Dijkstra's shortest-path algorithm

Introduce hierarchy through "areas"

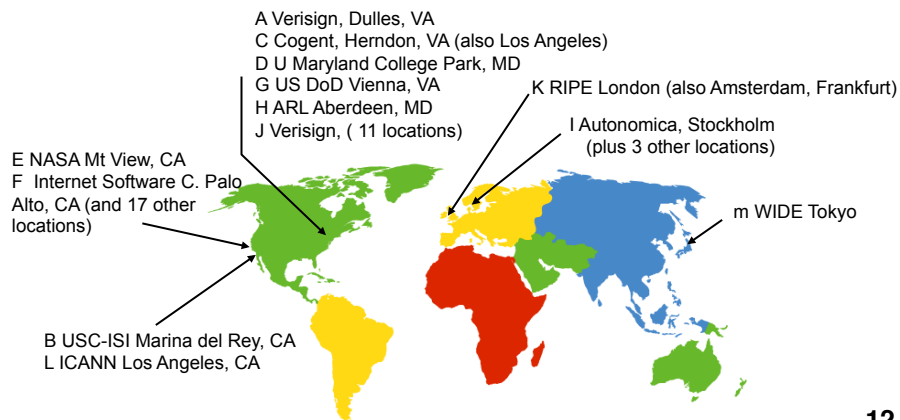


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Hierarchy: Domain Name System

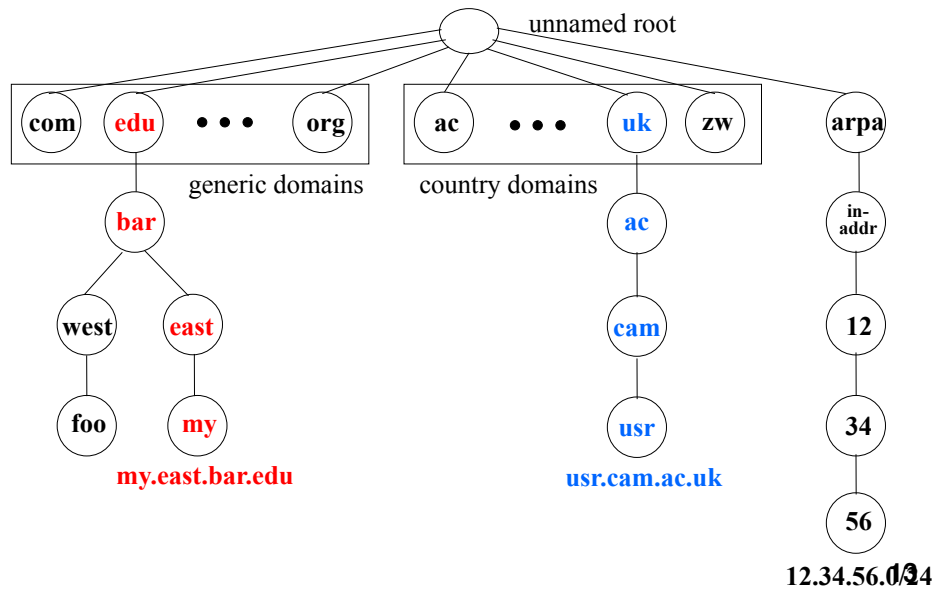
13 root servers (see <http://www.root-servers.org/>)

Labeled A through M



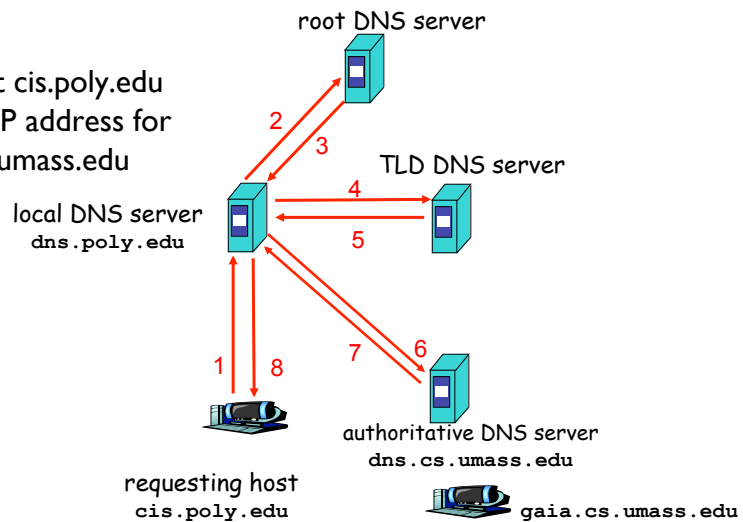
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Hierarchy: Domain Name System



Hierarchy: Domain Name System

Host at cis.poly.edu
wants IP address for
gaia.cs.umass.edu

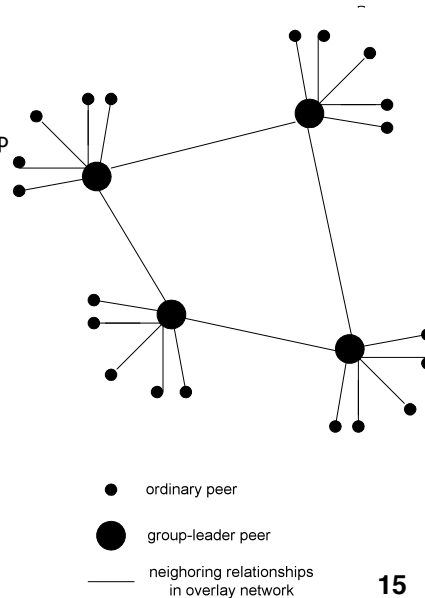


Hierarchy: Super Peers in KaZaA

Each peer is either a group leader or assigned to a group leader

- TCP connection between peer and its group leader
- TCP connections between some pairs of group leaders

Group leader tracks the content in all its children



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Indirection

Referencing by name

- Rather than the value itself
- E.g., manipulating a variable through a pointer

Benefits of indirection

- Human convenience
- Reducing overhead when things change

Examples of indirection in the Internet

- Example #1: host names instead of IP addresses
- Example #2: mobile IP

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Indirection: Host Names vs. Addresses

Host names

- Mnemonic name appreciated by humans
- Variable length, alpha-numeric characters
- Provide little (if any) information about location
- Examples: `www.cnn.com` and `ftp.eurocom.fr`

IP addresses

- Numerical address appreciated by routers
- Fixed length, binary number
- Hierarchical, related to host location
- Examples: `64.236.16.20` and `193.30.227.161`

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Indirection: Host Names vs. Addresses

Names are easier to remember

- `www.cnn.com` vs. `64.236.16.20`

Addresses can change underneath

- Move `www.cnn.com` to `173.15.201.39`
- E.g., renumbering when changing providers

Name could map to multiple IP addresses

- `www.cnn.com` to multiple replicas of the Web site

Map to different addresses in different places

- Address of a nearby copy of the Web site
- E.g., to reduce latency, or return different content

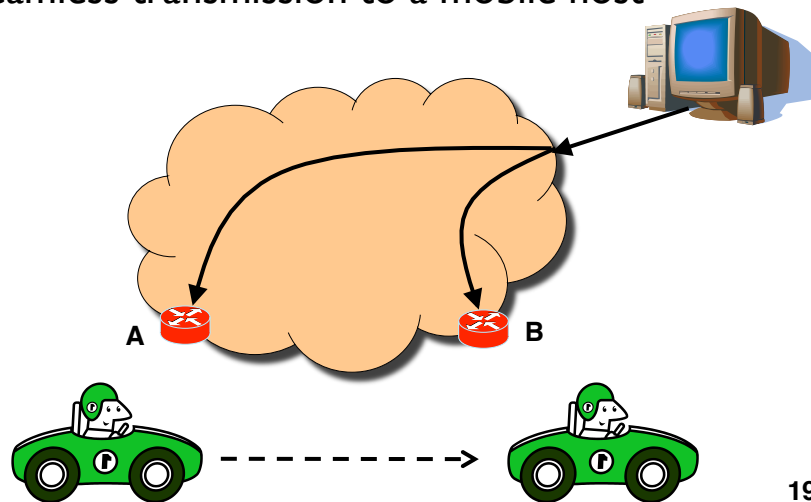
Multiple names for the same address

- E.g., aliases like `ee.mit.edu` and `cs.mit.edu`

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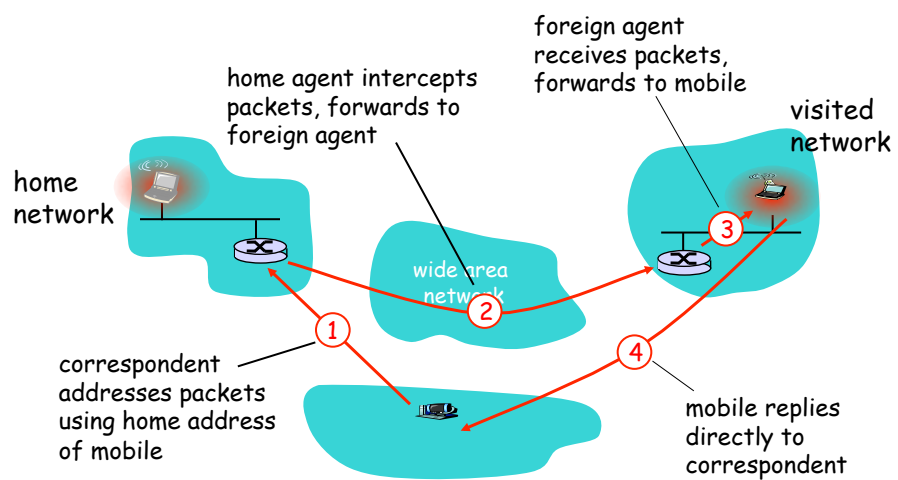
Indirection: Mobile IP

Seamless transmission to a mobile host



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Indirection: Mobile IP



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Caching

Duplicating data stored elsewhere

- To reduce latency for accessing the data
- To reduce resources consumed

Caching is often quite effective

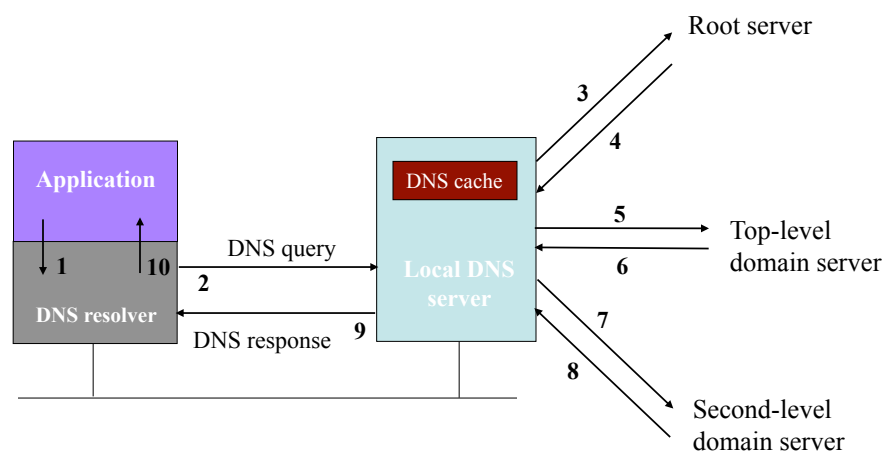
- Speed difference between cache and primary copy
- Locality of reference, and small set of popular data

Examples from the Internet

- Example #1: DNS caching
- Example #2: Web caching

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Caching: DNS Caching



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Caching: DNS Caching

What is cached?

- Mapping of names to IP addresses
- IP addresses for DNS servers (e.g., for .com)
- DNS queries that failed (e.g., www.cnn.com)

Why it reduces latency?

- DNS queries can take a long time (e.g., 1 second)
- Local DNS server is typically very close to the users

Why is the cache hit rate is very high?

- Cached information remains valid for awhile
- Popular sites (e.g., www.cnn.com) are visited often
- The cache is shared among a group of users

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Caching: Web Caching

What is cached?

- Web object, like an HTML file or embedded image

Where is it cached?

- Browser cache, proxy cache, main-memory on server

Why it reduces latency?

- Avoids fetching across the network (or the disk)
- Reduces load on the network and the server

What helps increase the hit rate?

- Cacheable content (not dynamically generated)
- Sharing of the cache among multiple users
- Small amount of very popular content

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Randomization

Distributed adaptive algorithms

- Multiple distributed parties
- Adapting to network conditions independently

Risk of synchronization

- Many parties reacting at the same time
- Leading to bad aggregate behavior

Randomization can desynchronize

- Example #1: Ethernet back-off mechanism
- Example #2: Random Early Detection

Rather than imposing centralized control

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Randomization: Ways to Share Media

Channel partitioning MAC protocols:

- Share channel efficiently and fairly at high load
- Inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

“Taking turns” protocols

- Eliminates empty slots without causing collisions
- Vulnerable to failures (e.g., failed node or lost token)

Random access MAC protocols

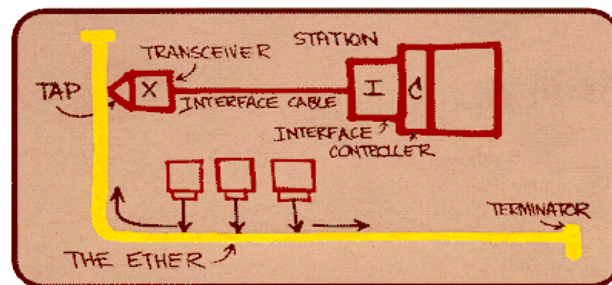
- Efficient at low load: single node can fully utilize channel
- High load: collision overhead

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Randomization: Ethernet Back-off

Random access: exponential back-off

- After collision, wait random time before retrying
- After m^{th} , choose K randomly from $\{0, \dots, 2^m - 1\}$
- Wait for $K \cdot 512$ bit times before trying again



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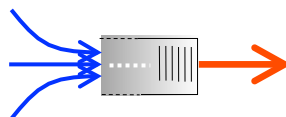
Randomization: Dropping Packets Early

Congestion on a link

- Eventually the queue becomes full
- And new packets must be dropped

Drop-tail queuing leads to *bursty* loss

- Many packets encounter a full queue
- Many TCP senders reduce their sending rates



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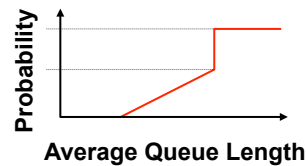
Randomization: Dropping Packets Early

Better to give early feedback

- Get a few connections to slow down
- ... before it is too late

Random Early Detection (RED)

- Randomly drop packets when queue (near) full
- Drop rate increases as function of queue length



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Soft State

State: stored in nodes by network protocols

- Installed by receiver of a set-up message
- Updated when network conditions change

Hard state: valid unless told otherwise

- Removed by receiver of a tear-down message
- Requires error handling to deal with sender failure

Soft state: invalid if not told to refresh

- Removed by receiver via a timeout
- Periodically refreshed as needed

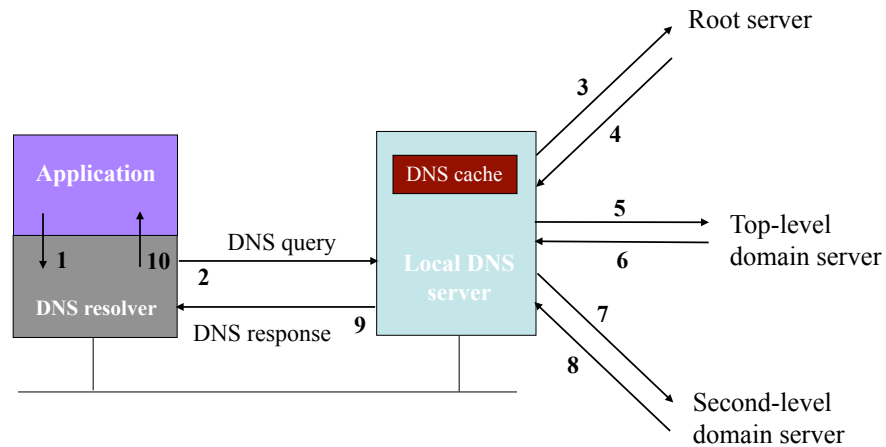
Soft state reduces complexity

- Example #1: DNS caching
- Example #2: DHCP leases



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Soft State: DNS Caching



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Soft State: DNS Caching

Cache consistency is a hard problem

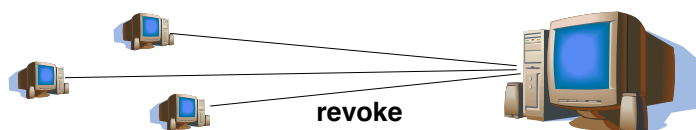
- Ensuring the cached copy is not out of date

Strawman: explicit revocation or updates

- Keep track of everyone who has cached information
- If name-to-host mapping changes, update the caches
- If you fail to reach a cache, keep trying till success

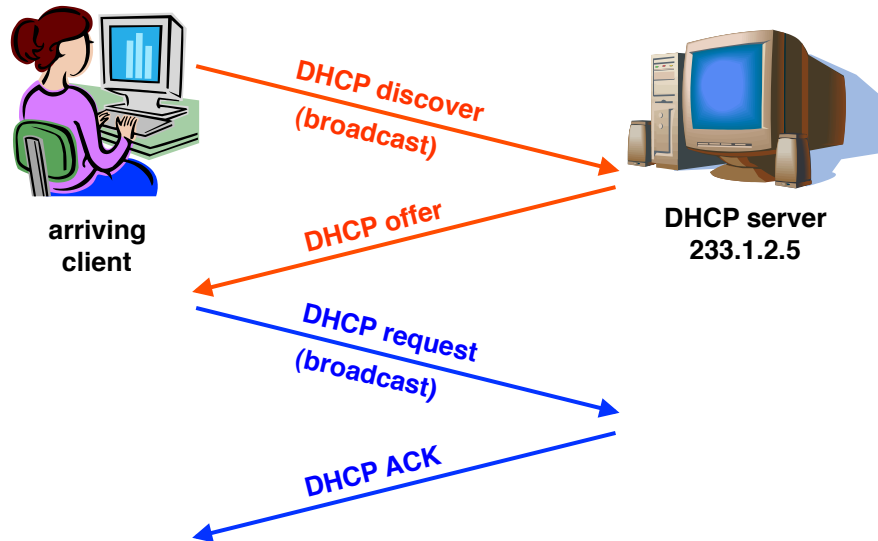
Soft state solution

- DNS responses include a "time to live" (TTL) field
- Cached entry is deleted after TTL expires



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Soft State: DHCP Bootstrapping



Dynamic Host Configuration Protocol 33

Soft State: DHCP Leases

DHCP “offer message” from the server

- Configuration parameters (proposed IP address, mask, gateway router, DNS server, ...)
- Lease time (the time information remains valid)

Why is a lease time necessary?

- Client can release address (DHCP RELEASE)
 - E.g., “ipconfig /release” at the DOS prompt
 - E.g., clean shutdown of the computer
- But, the host might *not* release the address
 - E.g., the host crashes (blue screen of death!)
 - E.g., buggy client software
- You don’t want address to be allocated forever

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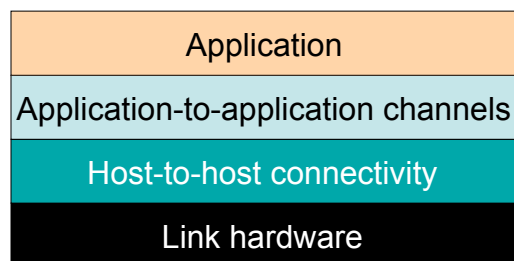
Layering: A Modular Approach

Sub-divide the problem

- Each layer relies on services from layer below
- Each layer exports services to layer above

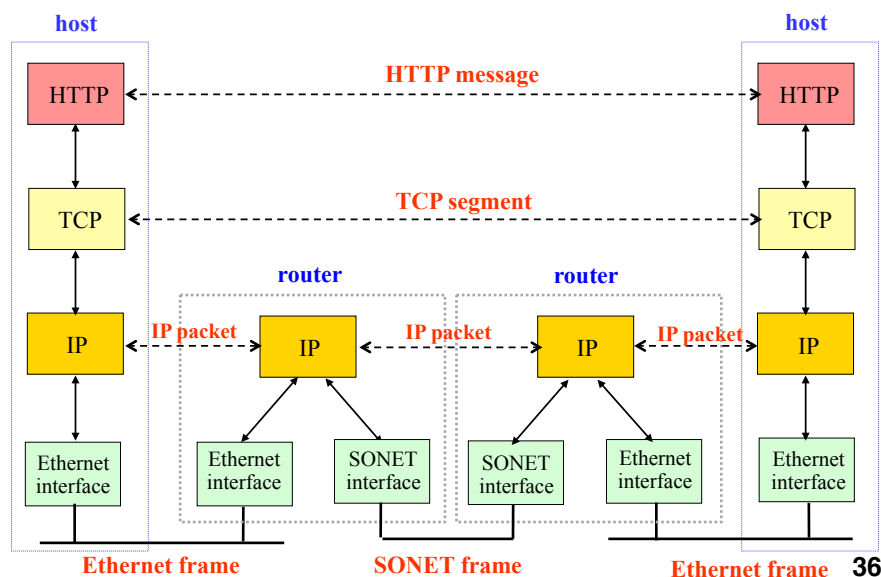
Interface between layers defines interaction

- Hides implementation details
- Layers can change without disturbing other layers



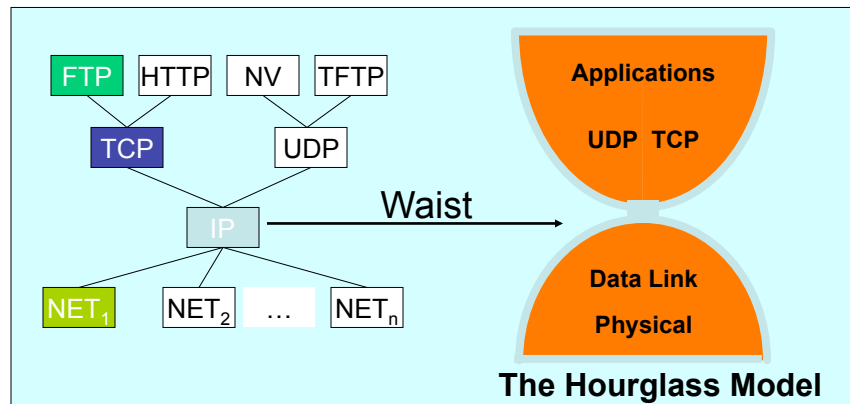
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Layering: Standing on Shoulders



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Layering: Internet Protocol Suite



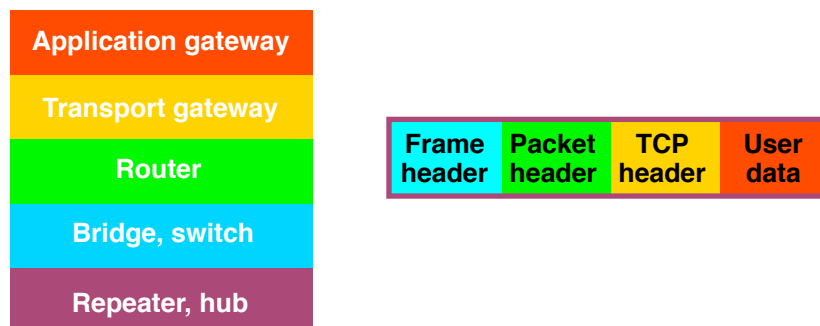
The waist facilitates interoperability

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Layering: Encapsulation of Data

Different devices switch different things

- Physical layer: electrical signals (repeaters and hubs)
- Link layer: frames (bridges and switches)
- Network layer: packets (routers)



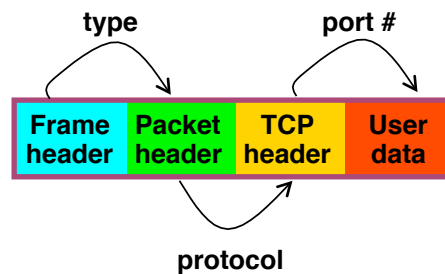
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Demultiplexing

Separating multiple streams out of one

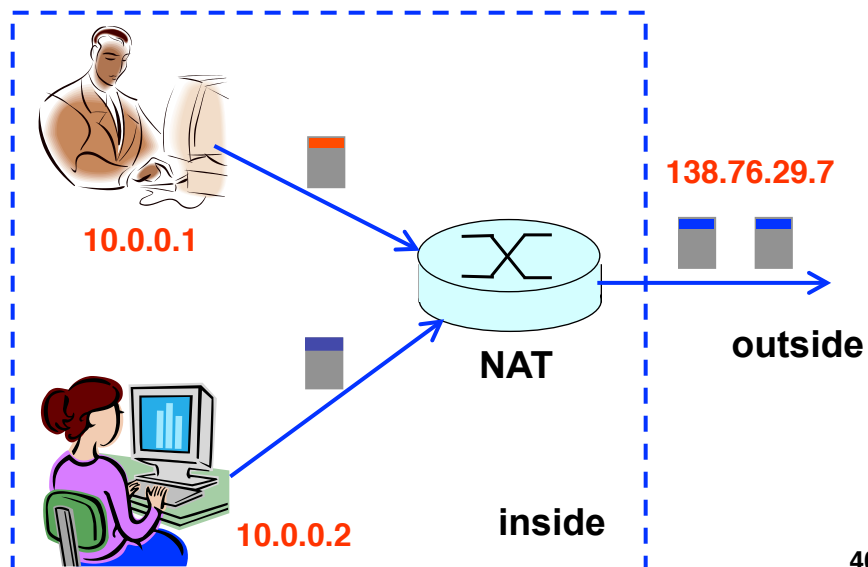
- Recognizing the separate streams
- Treating the separate streams accordingly

Examples in the Internet



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(De)multiplexing: With a NAT



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Power at the End Host

End-to-End Principle

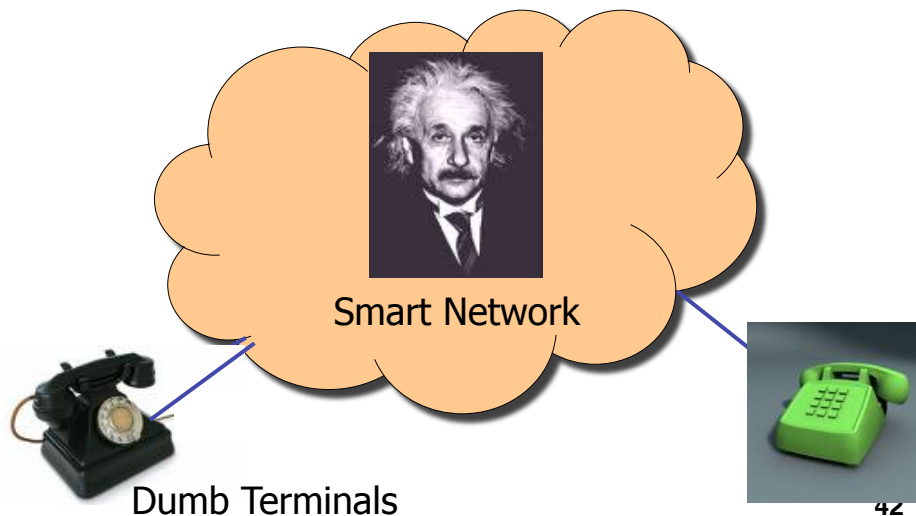
Whenever possible, communications protocol operations should be defined to occur at the **end-points** of a communications system.

Programmability

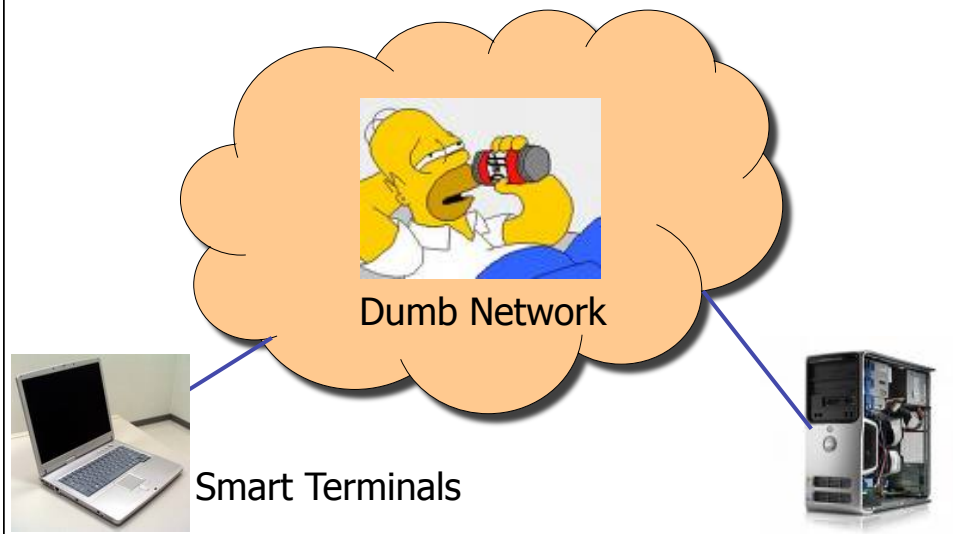
With programmable end hosts, new network services can be added at **any time, by anyone**.

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Telephone Network



Internet



Why No Math in This Course?

Hypothesis #1: theory not relevant to the Internet

- Body of mathematics created for telephone networks
- Teletraffic modeling, computing call blocking statistics
- Many of these models don't work in data networks

Hypothesis #2: too many kinds of math to cover

- Queuing theory: statistical multiplexing works
- Control theory: TCP congestion control works
- Optimization theory: TCP maximizes aggregate utility
- Game theory: reasoning about competing ASes
- We still need to build a much stronger foundation...

A question: is networking a domain or a discipline?

- A set of problems, or a set of solution techniques?

What Will Happen to the Internet

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No Strict Notions of Identity



"On the Internet, nobody knows you're a dog."

Leads to

- Spam
- Spoofing
- Denial-of-service
- Route hijacking

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Protocols Designed Based on Trust

That you don't spoof your addresses

- MAC spoofing, IP address spoofing, spam, ...

That port numbers correspond to applications

- Rather than being arbitrary, meaningless numbers

That you adhere to the protocol

- Ethernet exponential back-off after a collision
- TCP additive increase, multiplicative decrease

That protocol specifications are public

- So others can build interoperable implementations

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Nobody in Charge

Traffic traverses many Autonomous Systems

- Who's fault is it when things go wrong?
- How do you upgrade functionality?

Implicit trust in the end host

- What if some hosts violate congestion control?

Anyone can add any application

- Whether or not it is legal, moral, good, etc.

Nobody knows how big the Internet is

- No global registry of the topology

Spans many countries

- So no government can be in charge

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Challenging New Requirements

Disseminating data

- Rather than communicating between two machines

Mobile hosts

- Rather than machines at a fixed location

Sometimes-connected hosts

- Developing regions with intermittent connectivity

Large number of hosts

- Billions of small networked devices (e.g., sensors)

Real-time applications

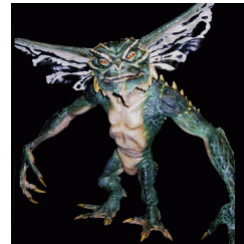
- Voice over IP, gaming, and IPTV

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The Internet of the Future

Can we fix what ails the Internet

- Security
- Performance
- Upgradability
- Managability
- <your favorite gripe here>



Without throwing out baby with bathwater

- Ease of adding new hosts
- Ease of adding new services
- Ease of adding new link technologies

An open technical and policy question...

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