CS 88: Security and Privacy

19: DNS and UDP

04-11-2024

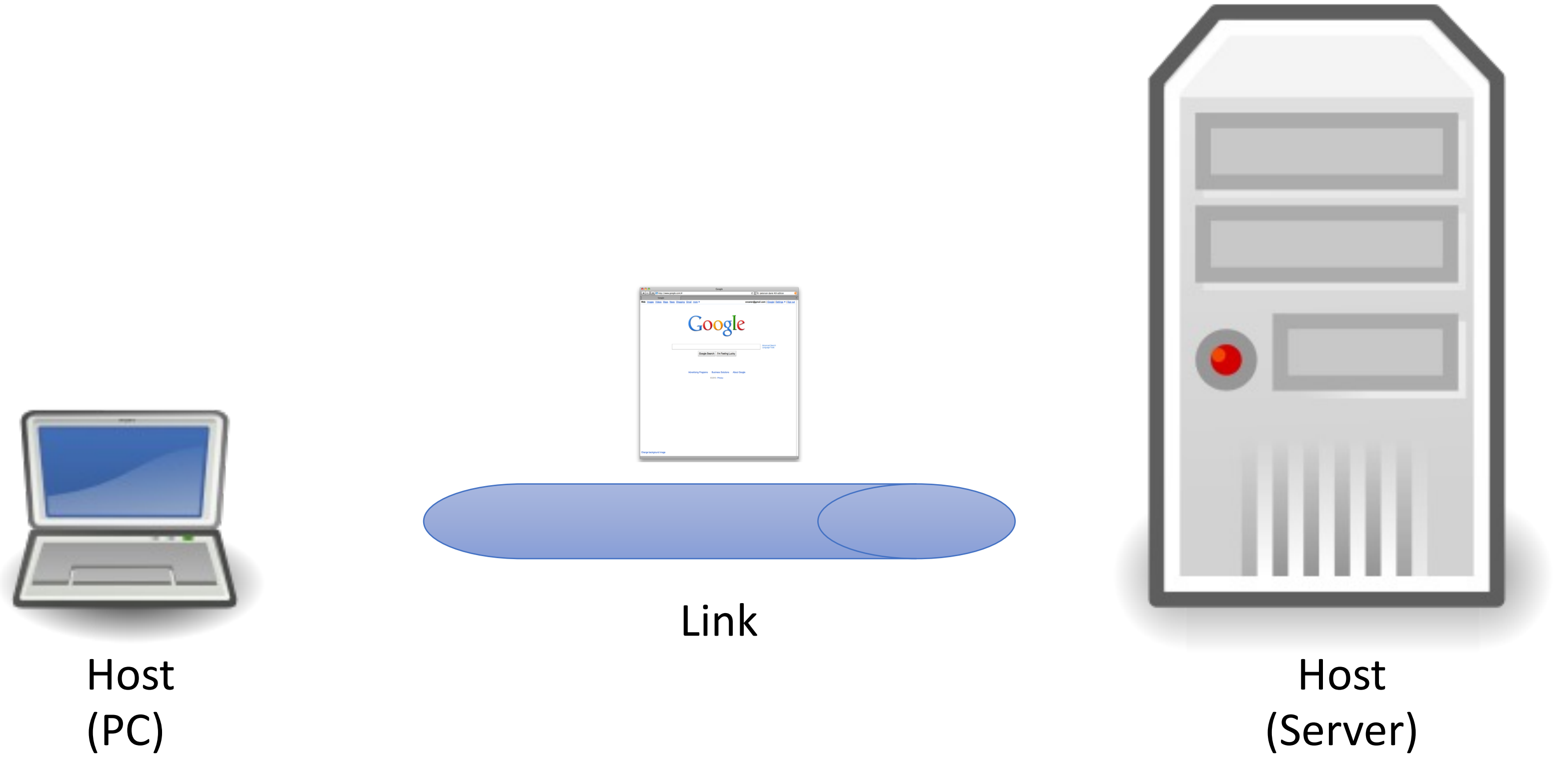
slides adapted from Dave Levine, Jim Kurose

SWARTHMORE COLLEGE

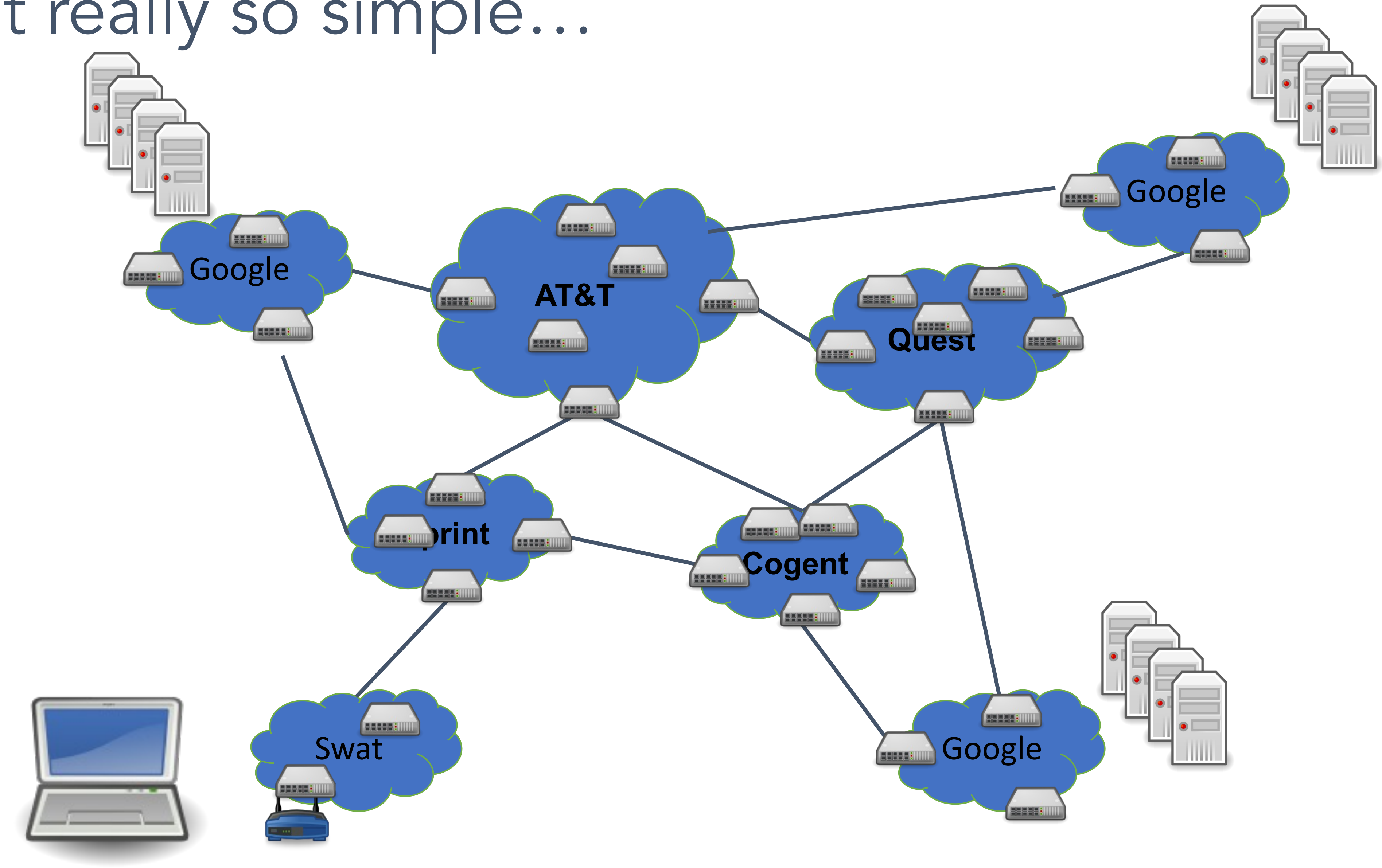
Reading Quiz

A "Simple" Task

<u>Send information from one computer to another</u>



Not really so simple…



We only need…

- Manage complexity and scale up
- Naming and addressing
- Moving data to the destination
- Reliability and fault tolerance
- Resource allocation, Security, Privacy..

Five-Layer Internet Model

Application: the application (e.g., the Web, Email)
Transport: end-to-end connections, reliability
Network: routing
Link (data-link): framing, error detection
Physical: 1's and 0's/bits across a medium (copper, the air, fiber)

OSI 5 Layer Model

Network

Responsible for packet forwarding. How to get a packet to the final destination when there are many hops along the way.

Data Link

How to get packet to the next hop. Transmission of data frames between two nodes connected by a physical link.

Physical

How do bits get translated into electrical, optical, or radio signals

OSI 5 Layer Model

Transport	Allows a client to establish a connection to specific services (e.g., web server on port 80). Provides reliable communication.
Network	Responsible for packet forwarding. How to get a packet to the final destination when there are many hops along the way.
Data Link	How to get packet to the next hop. Transmission of data frames between two nodes connected by a physical link.
Physical	How do bits get translated into electrical, optical, or radio signals

OSI 5 Layer Model

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Defines how individual applications communicate. For example, **HTTP** defines how browsers send requests to web servers.

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Allows a client to establish a connection to specific services (e.g., web server on port 80). Provides reliable communication.

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OSI 5 Layer Model

Layer	Description
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Transport	Allows a client to establish a connection to specific services (e.g., web server on port 80). Provides reliable communication.
Network	Responsible for packet forwarding. How to get a packet to the final destination when there are many hops along the way.
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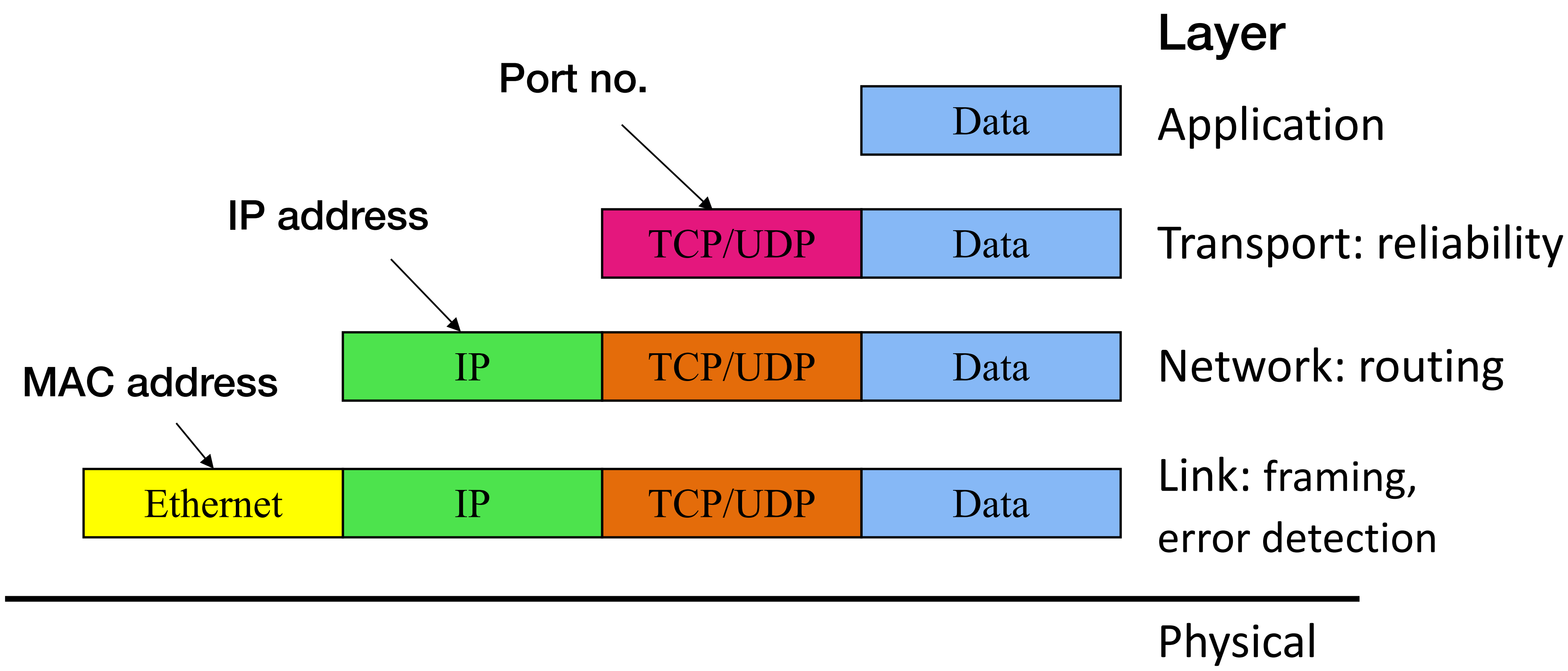
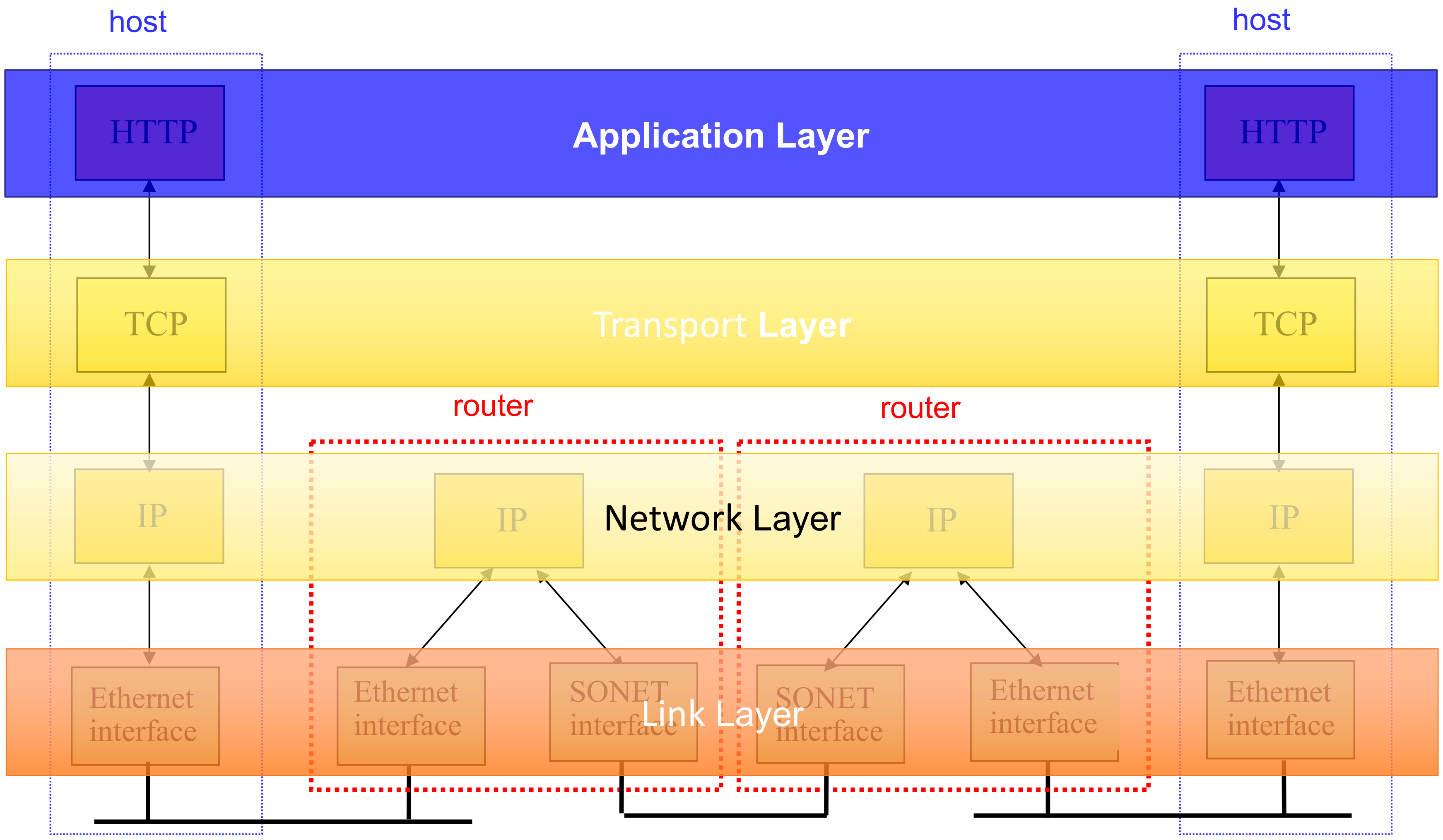
Layering and encapsulation



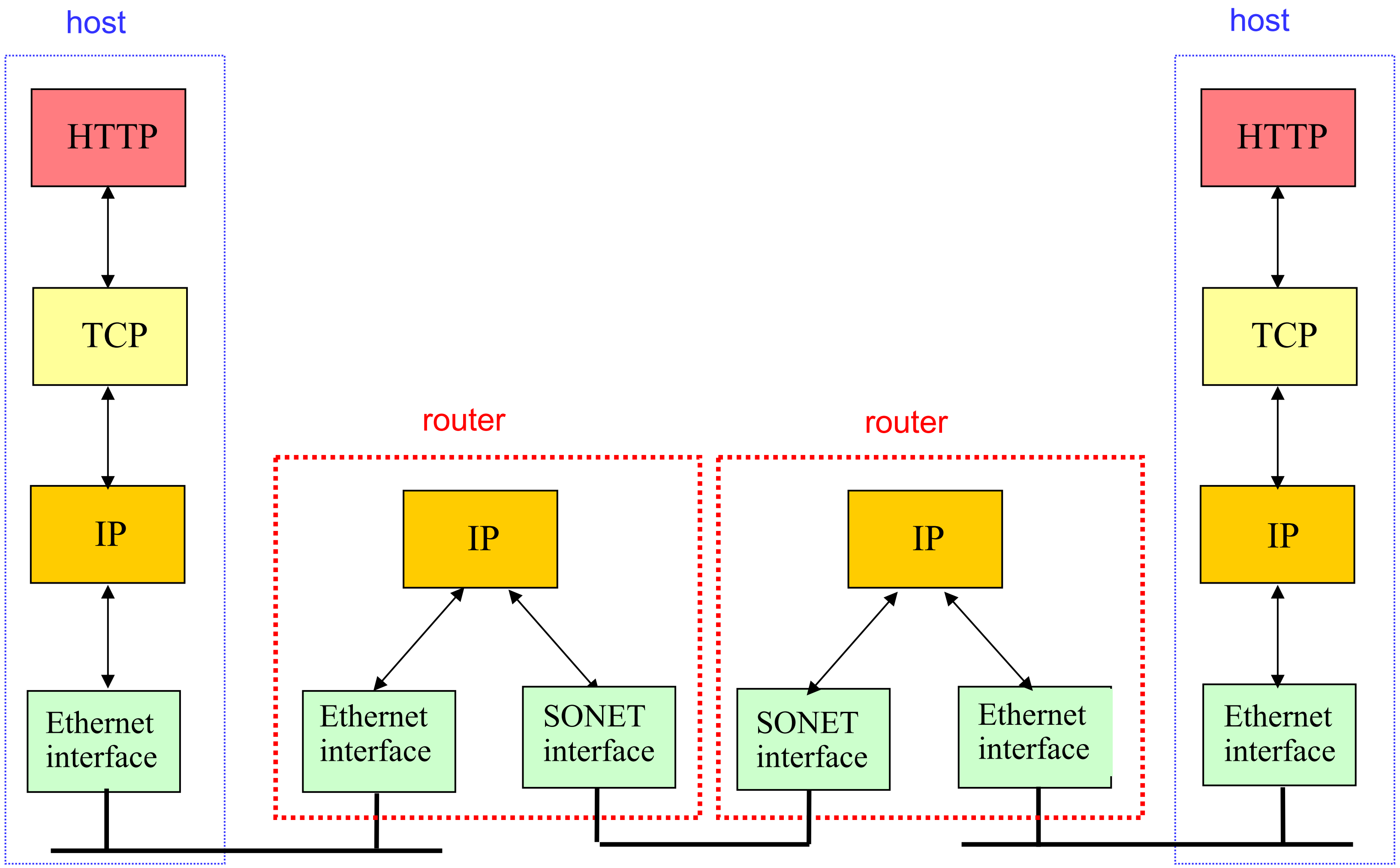
Abstraction!

- Hides the complex details of a process
- Use abstract representation of relevant properties make reasoning simpler
- Ex: Alice and Bob’s knowledge of postal system:
  - Letters with addresses go in, come out other side

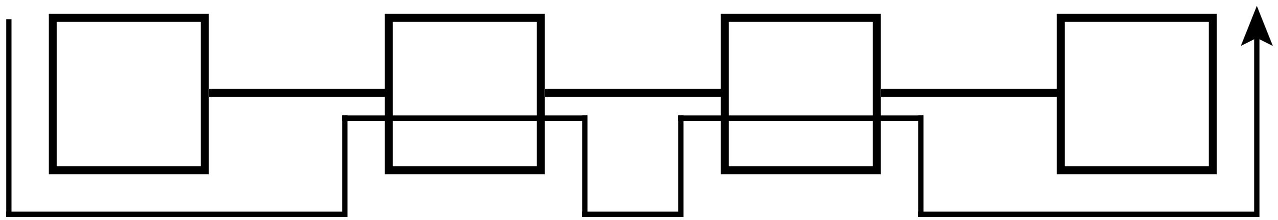
TCP/IP Protocol Stack



TCP/IP Protocol Stack



The "End-to-End" Argument



Don't provide a function at lower layer if you have to do it at higher layer anyway ...

... unless there is a very good performance reason to do so.

Examples: error control, quality of service

Reference: Saltzer, Reed, Clark, "End-To-End Arguments in System Design," ACM Transactions on Computer Systems, Vol. 2 (4), pp. 277-288, 1984.

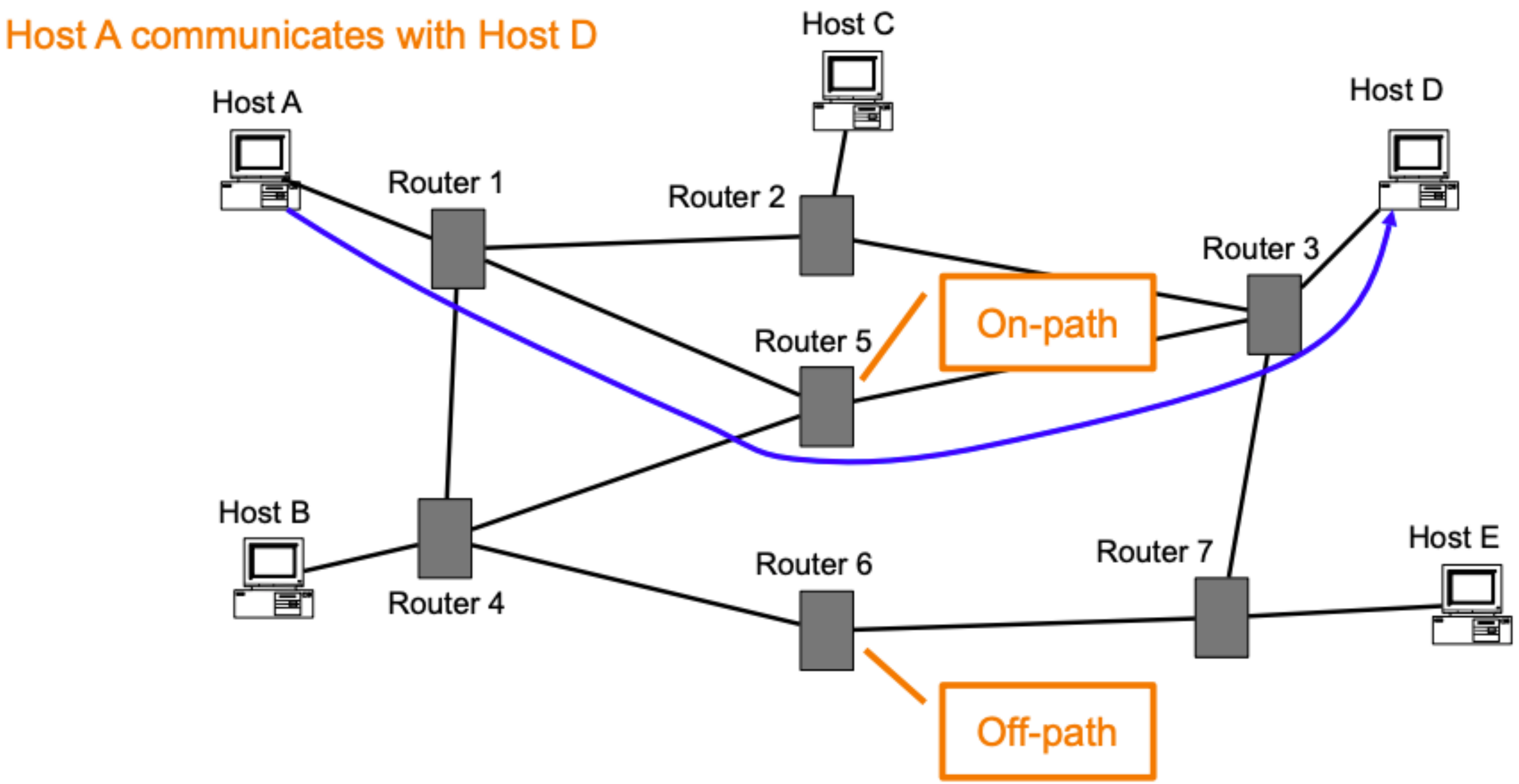
Threat modeling for network attacks

Basic security goals:

- **Confidentiality:** No one should be able to read our data/communications unless we want them to.
- **Integrity:** No one can manipulate our data/communications unless we want them to.
- **Availability:** We can access our data/communication capabilities when we want to.

Network Attacks: Classes of Attackers

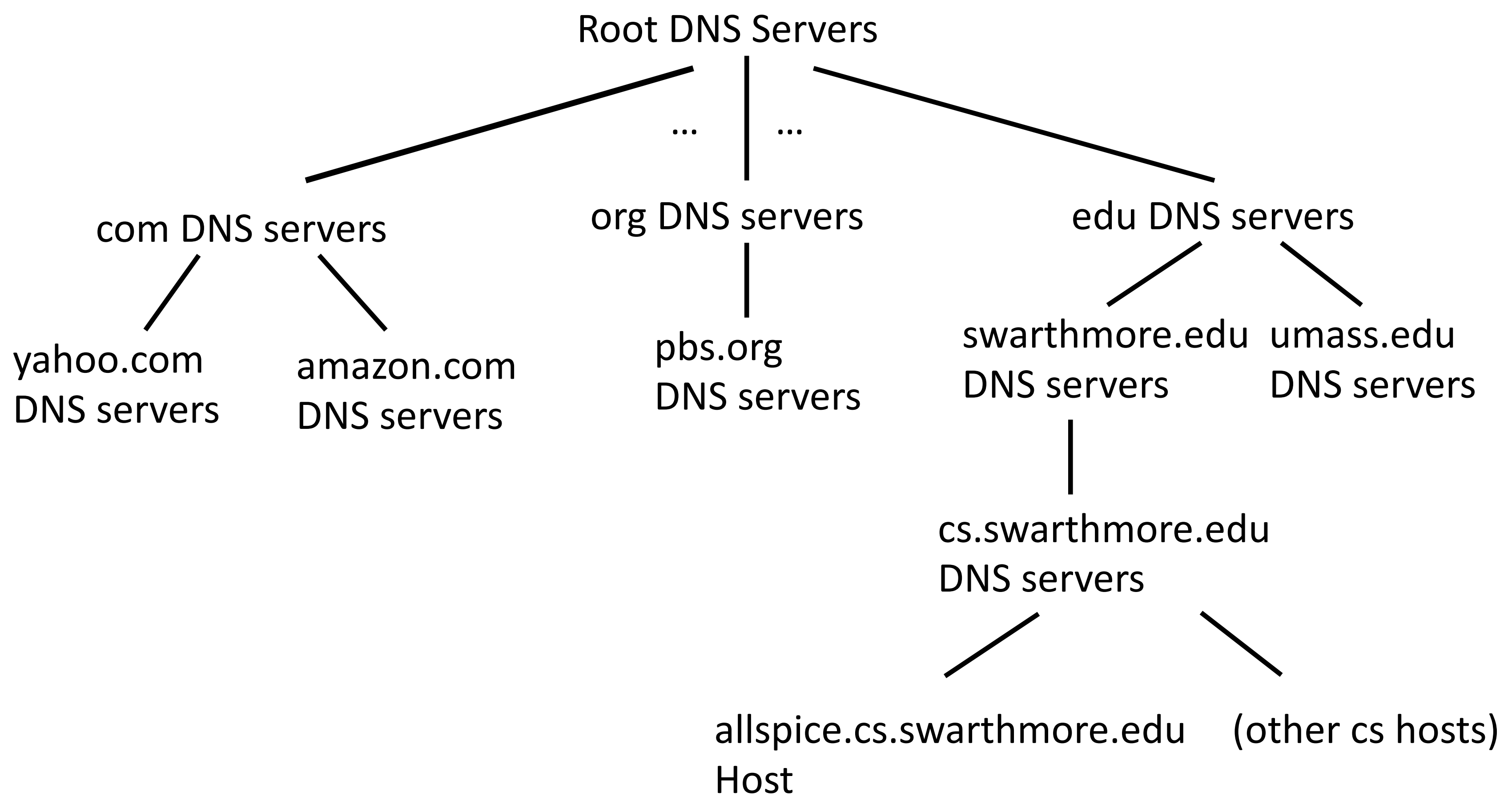
- MiTM: Can see packets, and can modify and drop packets
- On-path: Can see packets, but can't modify or drop packets
- Off-path: Can't see, modify, or drop packets



Which type of attacker is more powerful?

A. on-path
B. off-path
C. neither is strictly stronger than the other

DNS: a distributed, hierarchical database



- allspice.cs.swarthmore.edu.

Nameless root, Usually implied.

Goals of DNS

A wide-area distributed database

Possibly biggest such database in the world!

Goals

- Scalability; decentralized maintenance
- Robustness
- Global scope
- Names mean the same thing everywhere
- Distributed updates/queries
- Good performance

DNS: Application Layer Protocol

- distributed database
  - implemented in hierarchy of many name servers.
- application-layer protocol:
  - hosts communicate to name servers
  - resolve names → addresses
- *Core Internet function, implemented as application-layer protocol*

DNS: Domain Name System

People: many identifiers:

- name, swat ID, SSN, passport #

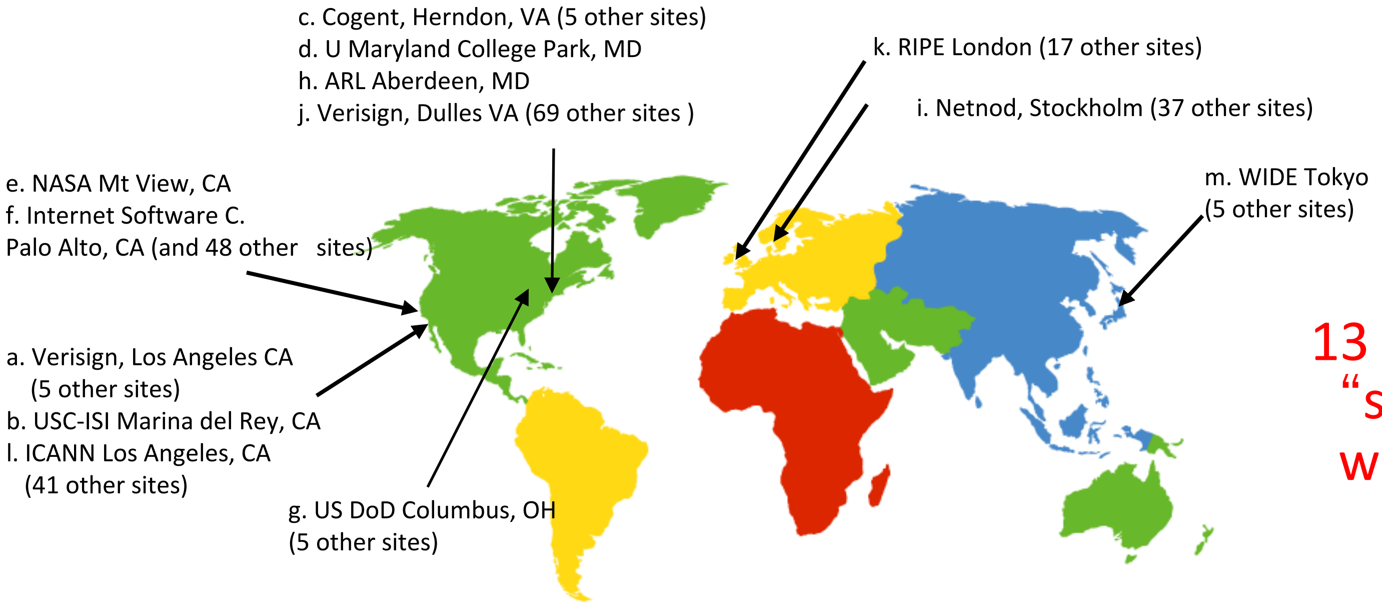
Internet hosts (endpoints), routers (devices inside a n/w):

- “name”, e.g., www.google.com - used by humans
- IP address (32 bit) - used for addressing packets

How do we map between IP address and name, and vice versa ?

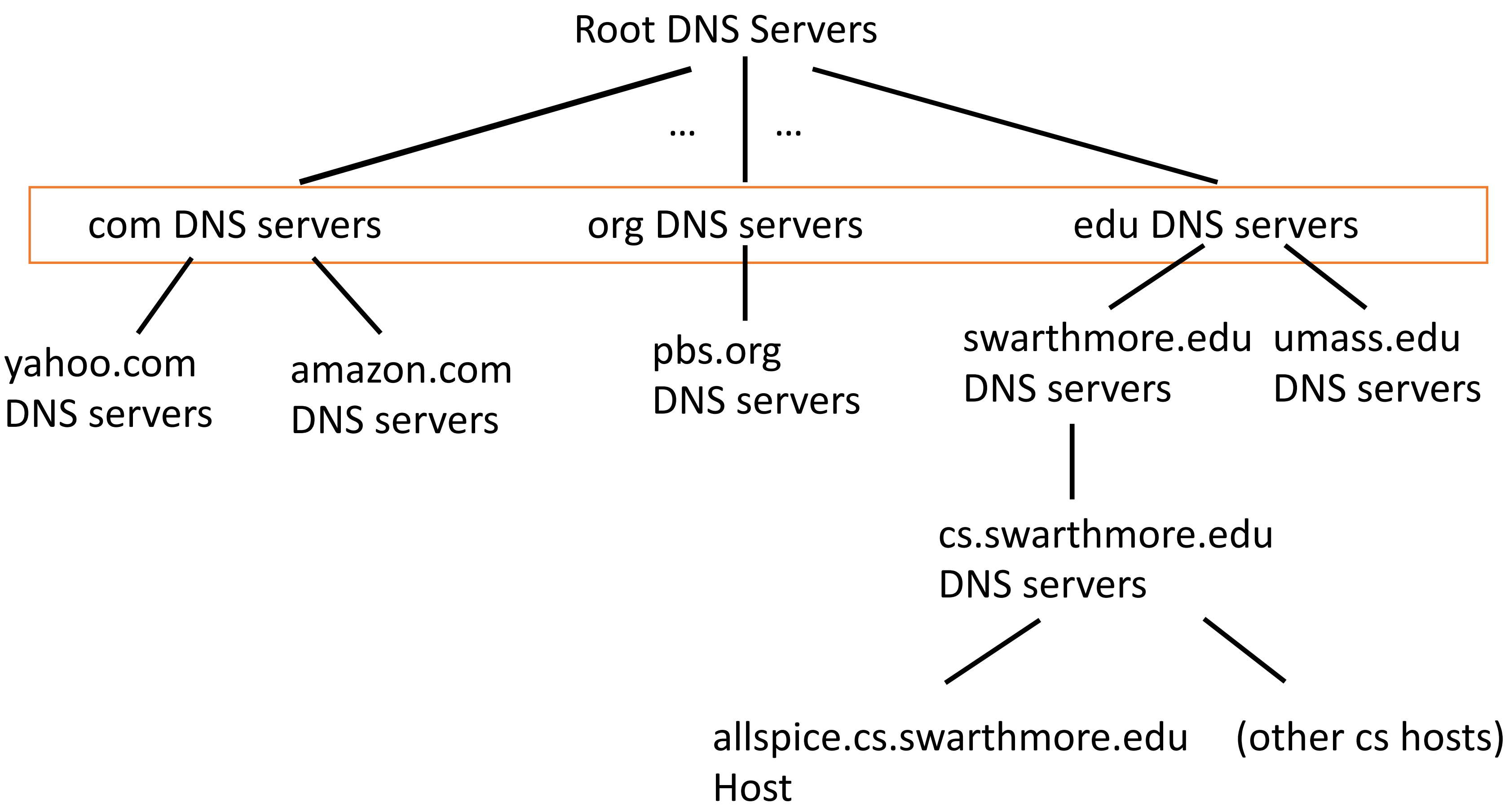
DNS: Root Name Servers

- Root name server:
  - Knows how to find top-level domains (.com, .edu, .gov, etc.)
  - How often does the location of a TLD change?
  - approx. 400 total root servers
  - Significant amount of traffic is not legitimate

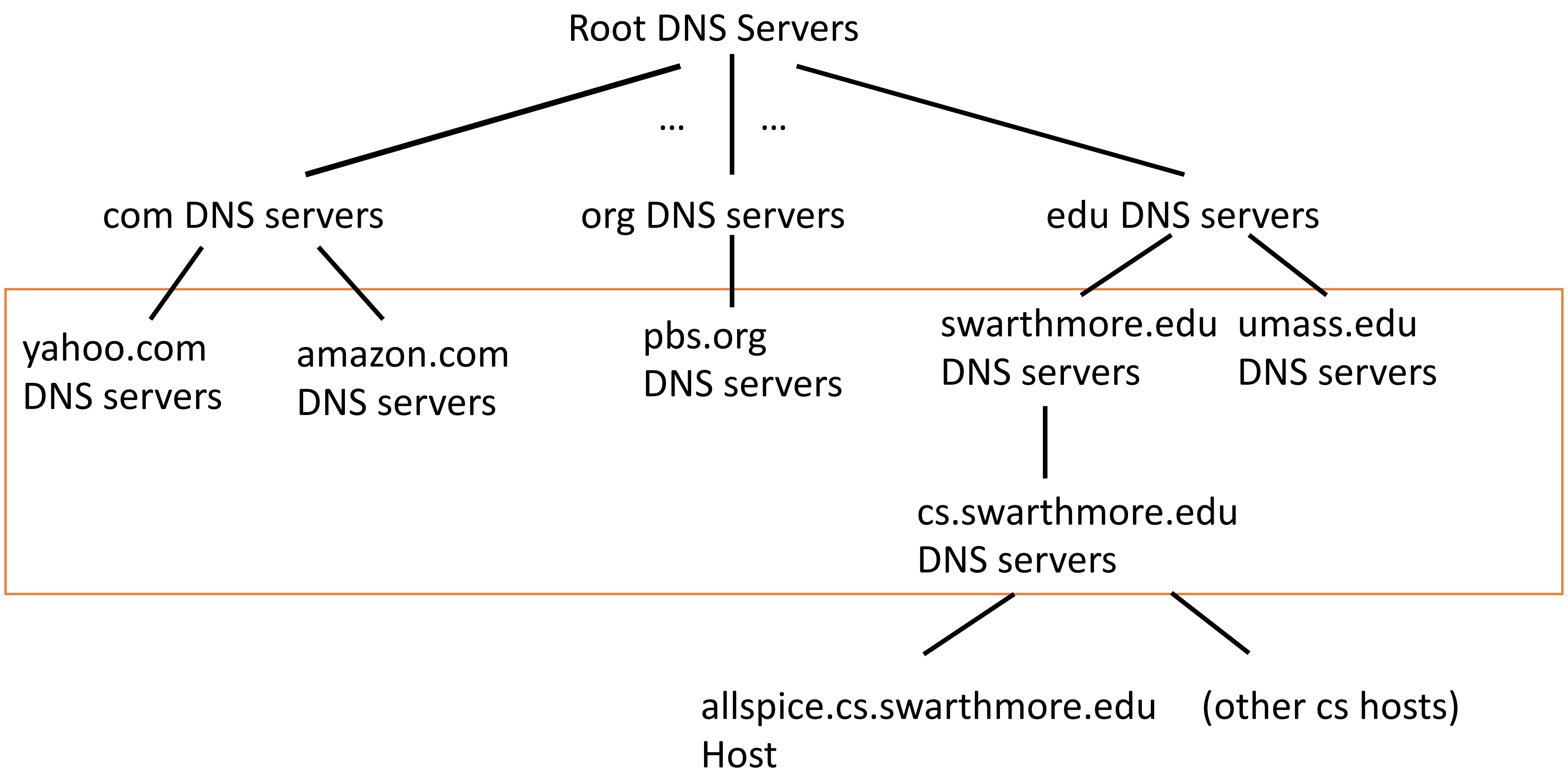


13 root name "servers" worldwide

DNS: a distributed, hierarchical database



DNS: a distributed, hierarchical database



Authoritative Servers

Authoritative DNS servers:

- Organization’s own DNS server(s), providing authoritative hostname to IP mappings for organization’s named hosts
- Can be maintained by organization or service provider, easily changing entries
- Often, but not always, acts as organization’s local name server (for responding to look-ups)

Local DNS Name Server

- Each ISP (residential ISP, company, university) has (at least) one
  - also called “default name server”
- When host makes DNS query, query is sent to its local DNS server
  - has local cache of recent name-to-address translation pairs (but may be out of date!)
  - acts as proxy, forwards query into hierarchy

Uses of DNS

Hostname to IP address translation

- Reverse lookup: IP address to hostname translation

Host name aliasing: other DNS names for a host

- Alias hostnames point to canonical hostname

Email: look up domain’s mail server by domain name

Different DNS Mappings

1-1 mapping between domain name and IP addr

- www.cs.cornell.edu maps to 132.236.207.20

Multiple domain names maps to the same IP addr

- eecs.mit.edu and cs.mit.edu both map to 18.62.1.6

Single domain name maps to multiple IP addrs

- aol.com and www.aol.com map to multiple IP addrs

Some valid domain names don’t map to any IP addr

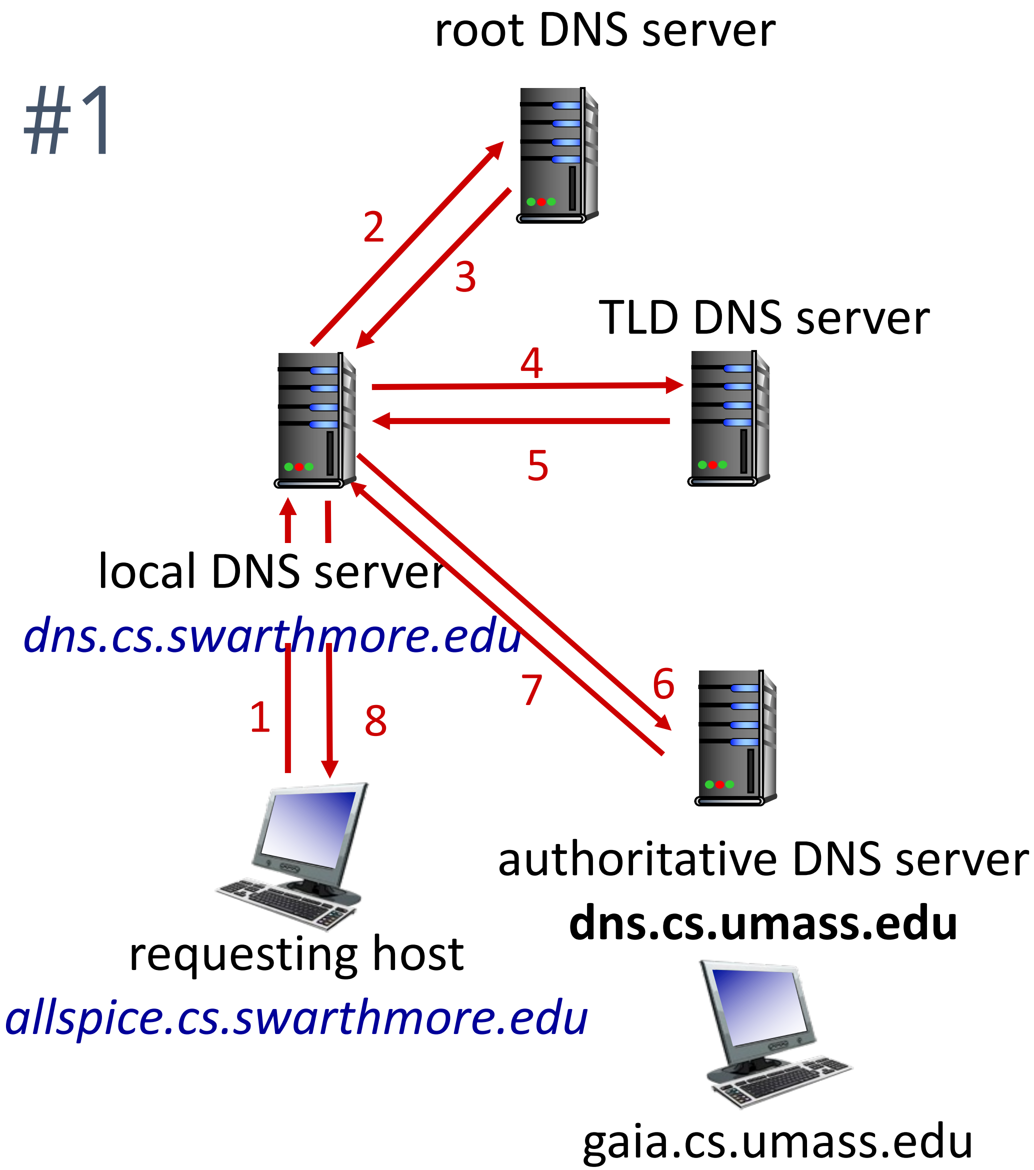
- cmcl.cs.cmu.edu

DNS name resolution example #1

- allspice wants IP address for gaia.cs.umass.edu

iterative query:

- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"

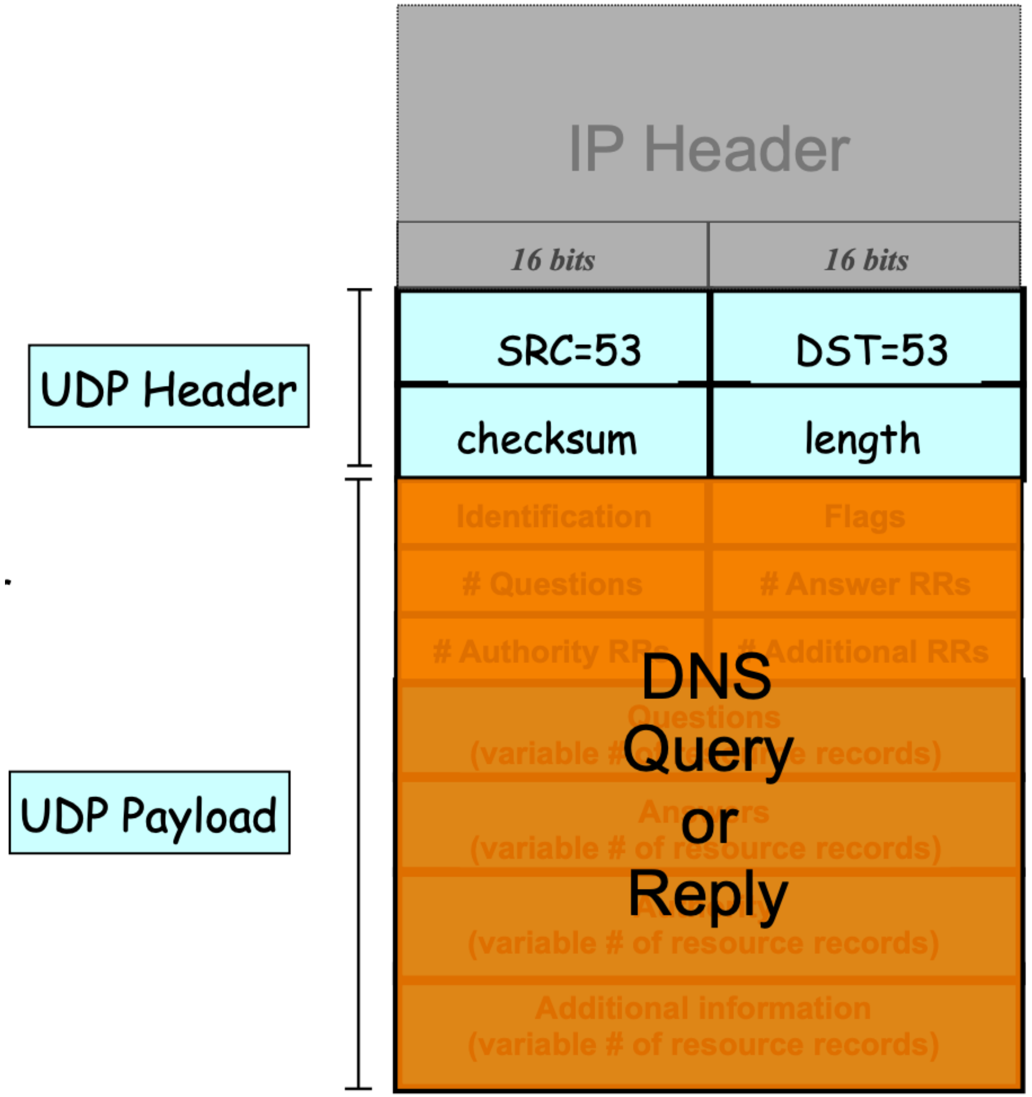


DNS Packet

Lightweight exchange of *query* and *reply* messages, both with same message format

Primarily uses UDP for its transport protocol, which is what we'll assume

Frequently, both clients and servers use port 53

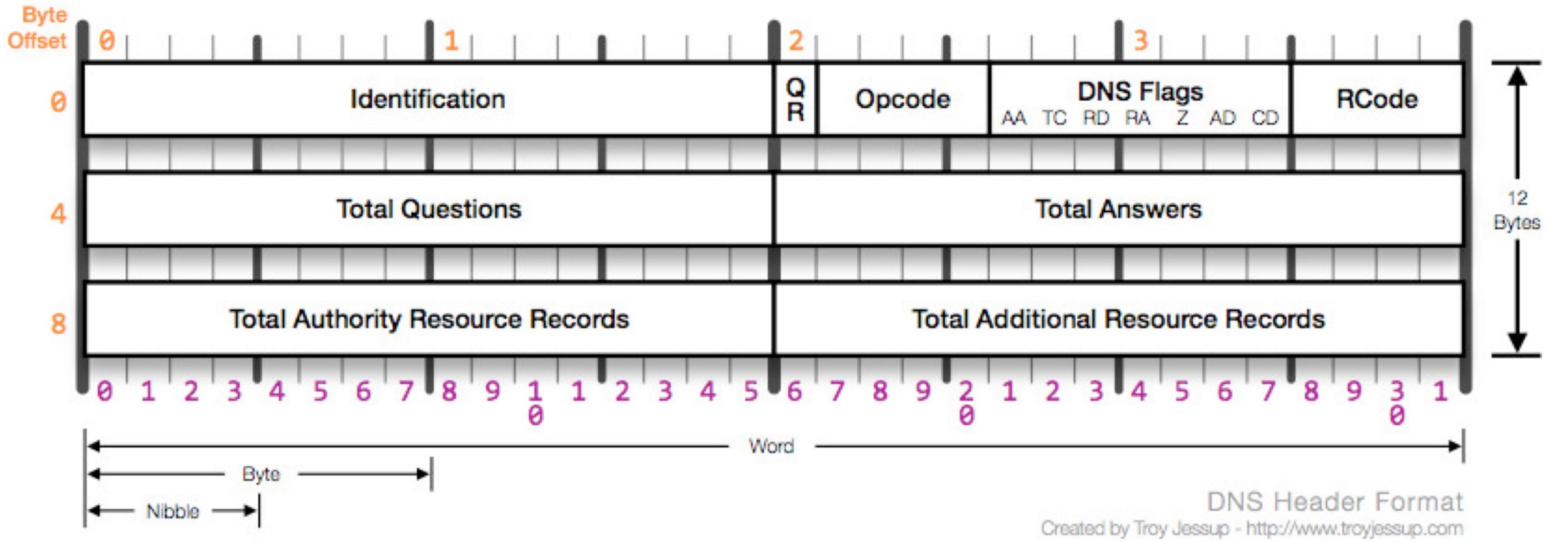


DNS Packet

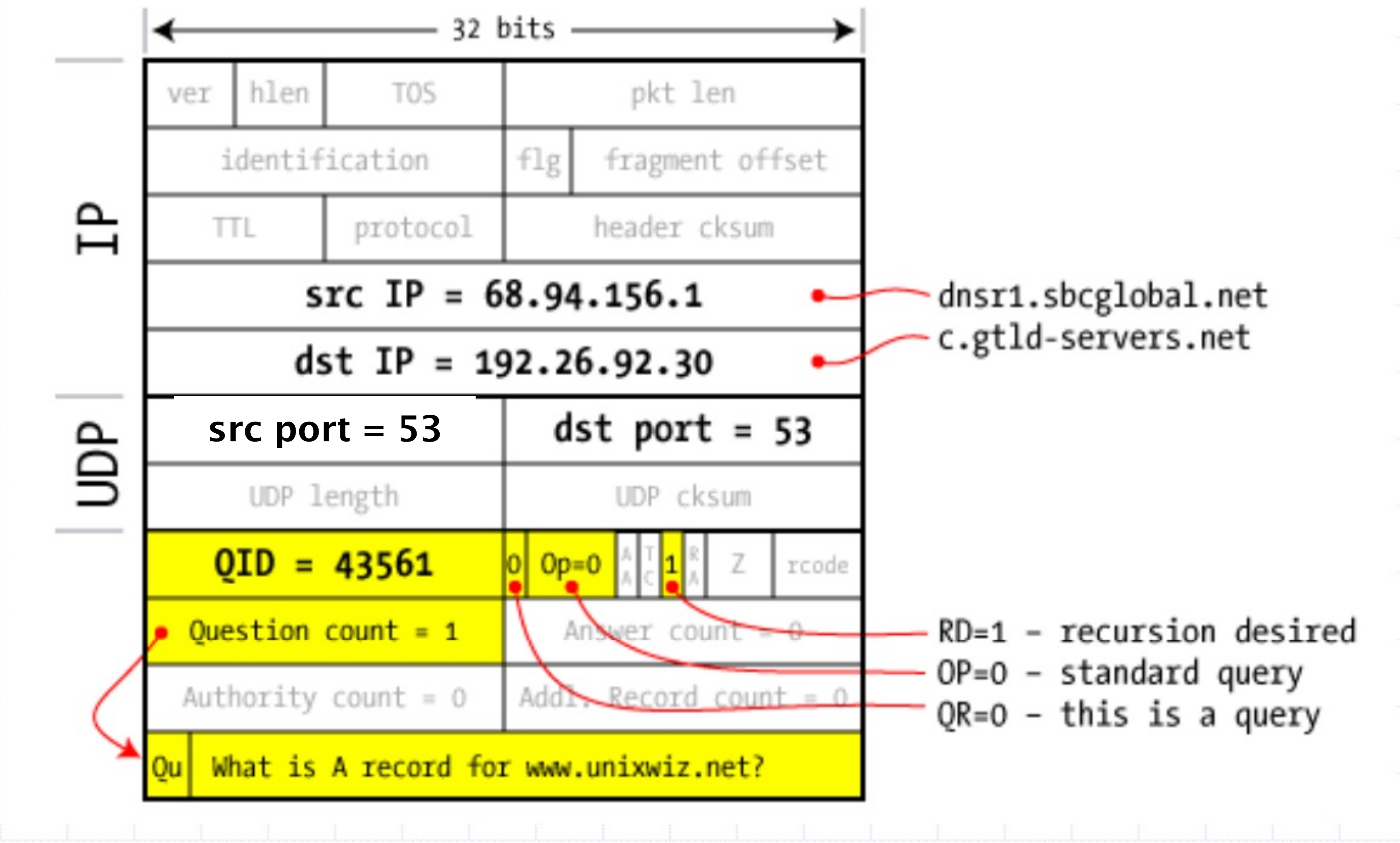
DNS requests sent over UDP

Four sections: questions, answers, authority, additional records

Query ID:
16 bit random value
Links response to query

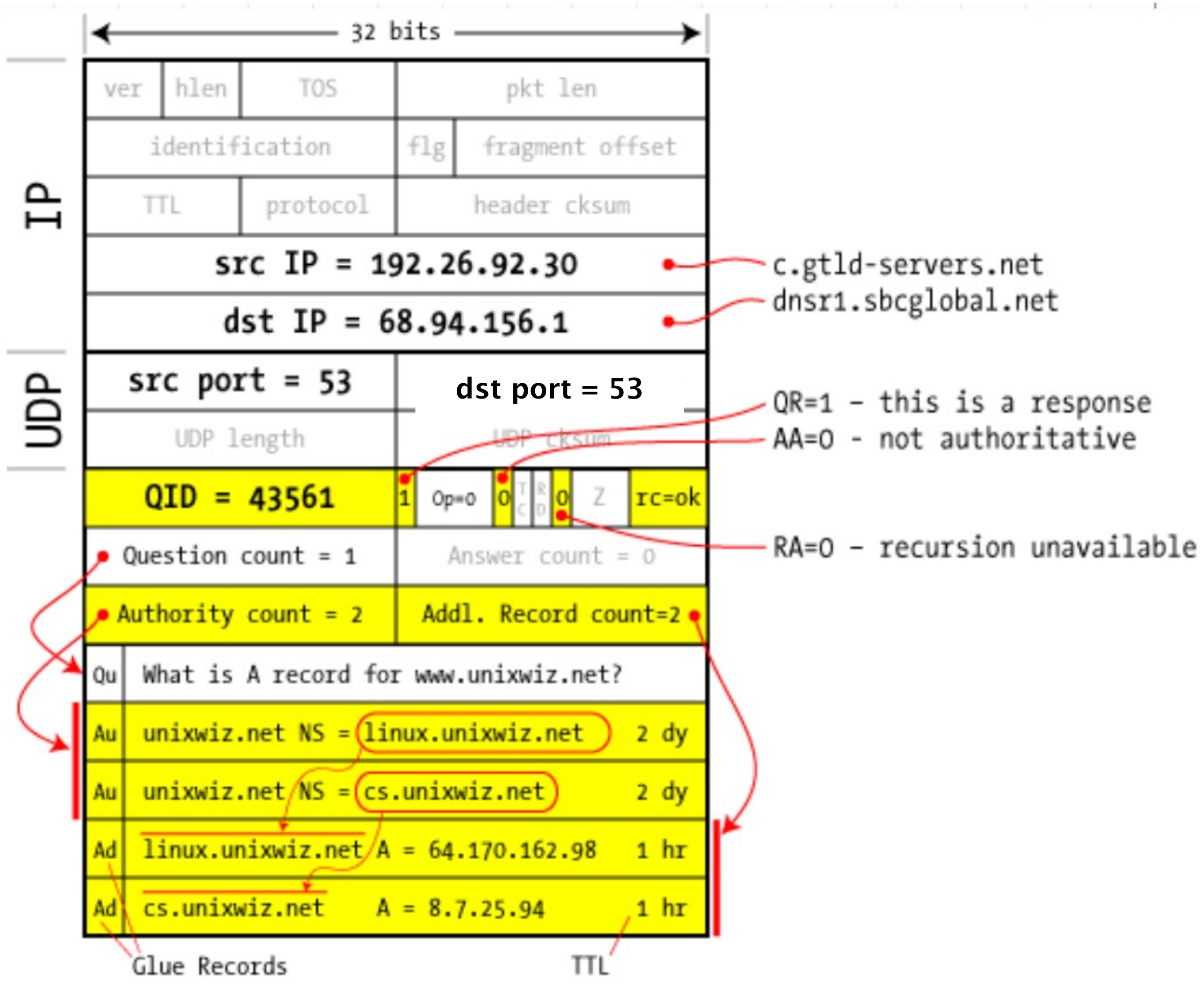


Request



32 bits
IP
UDP
ver
hlen
TOS
pkt len
identification
flg
fragment offset
TTL
protocol
header cksum
src IP = 68.94.156.1
dst IP = 192.26.92.30
dnsr1.sbcglobal.net
c.gtld-servers.net
src port = 53
dst port = 53
UDP length
UDP cksum
QID = 43561
0
Op=0
AA
TC
1
RA
Z
rcode
Question count = 1
Answer count = 0
Authority count = 0
Addl. Record count = 0
Qu
What is A record for www.unixwiz.net?
RD=1 - recursion desired
OP=0 - standard query
QR=0 - this is a query

Response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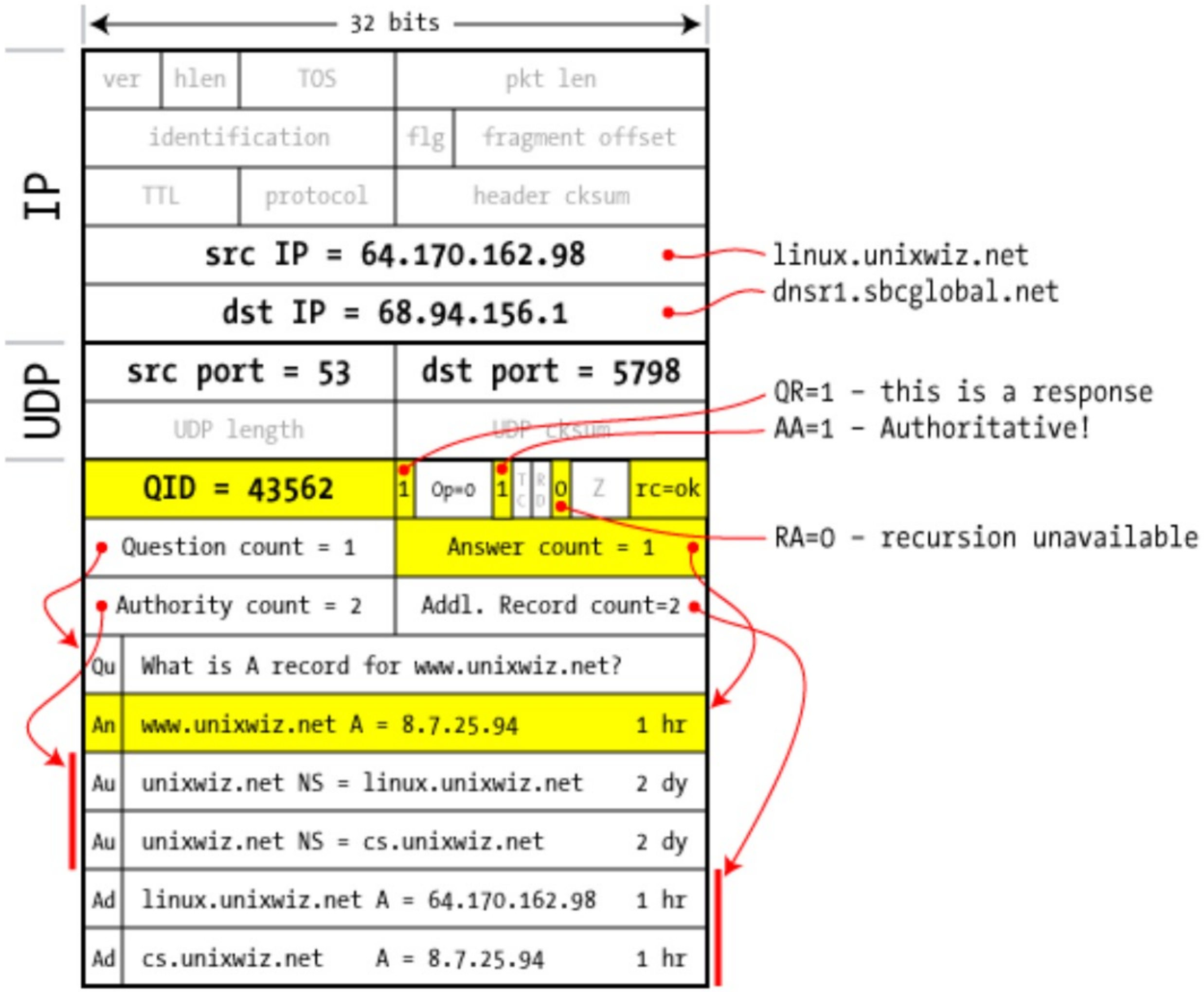
src IP = 192.26.92.30
dst IP = 68.94.156.1
c.gtld-servers.net
dnsr1.sbcglobal.net
src port = 53
dst port = 53
UDP length
UDP cksum
QR=1 - this is a response
AA=0 - not authoritative
QID = 43561
1
Op=0
0
0
Z
rc=ok
RA=0 - recursion unavailable
Question count = 1
Answer count = 0
Authority count = 2
Addl. Record count=2
Qu
What is A record for www.unixwiz.net?
Au
unixwiz.net NS = linux.unixwiz.net
2 dy
Au
unixwiz.net NS = cs.unixwiz.net
2 dy
Ad
linux.unixwiz.net A = 64.170.162.98
1 hr
Ad
cs.unixwiz.net A = 8.7.25.94
1 hr
Glue Records
TTL

Authoritative Response



Common Security Assumptions

- Attackers can interact with our systems without particular notice.
- *Probing* (poking at systems) may go unnoticed ...
  - even if highly repetitive, leading to crashes, and *easy to detect*
  - Attackers can obtain access to a copy of a given system to measure and/or determine how it works

- It's easy for attackers to know general information about their targets:
  - OS types, software versions, usernames, server ports, IP addresses, usual patterns of activity, administrative procedures

(Note, these tend to be pessimistic ... but prudent)

Common Security Assumptions

- Attackers can make use of automation – they can often find clever ways to automate
- Attackers can pull off complicated coordination across a bunch of different elements/systems
- Attackers can bring large resources to bear if needed – computation, network capacity
  - But they are *not* super-powerful (e.g., control entire Internet Service Providers)

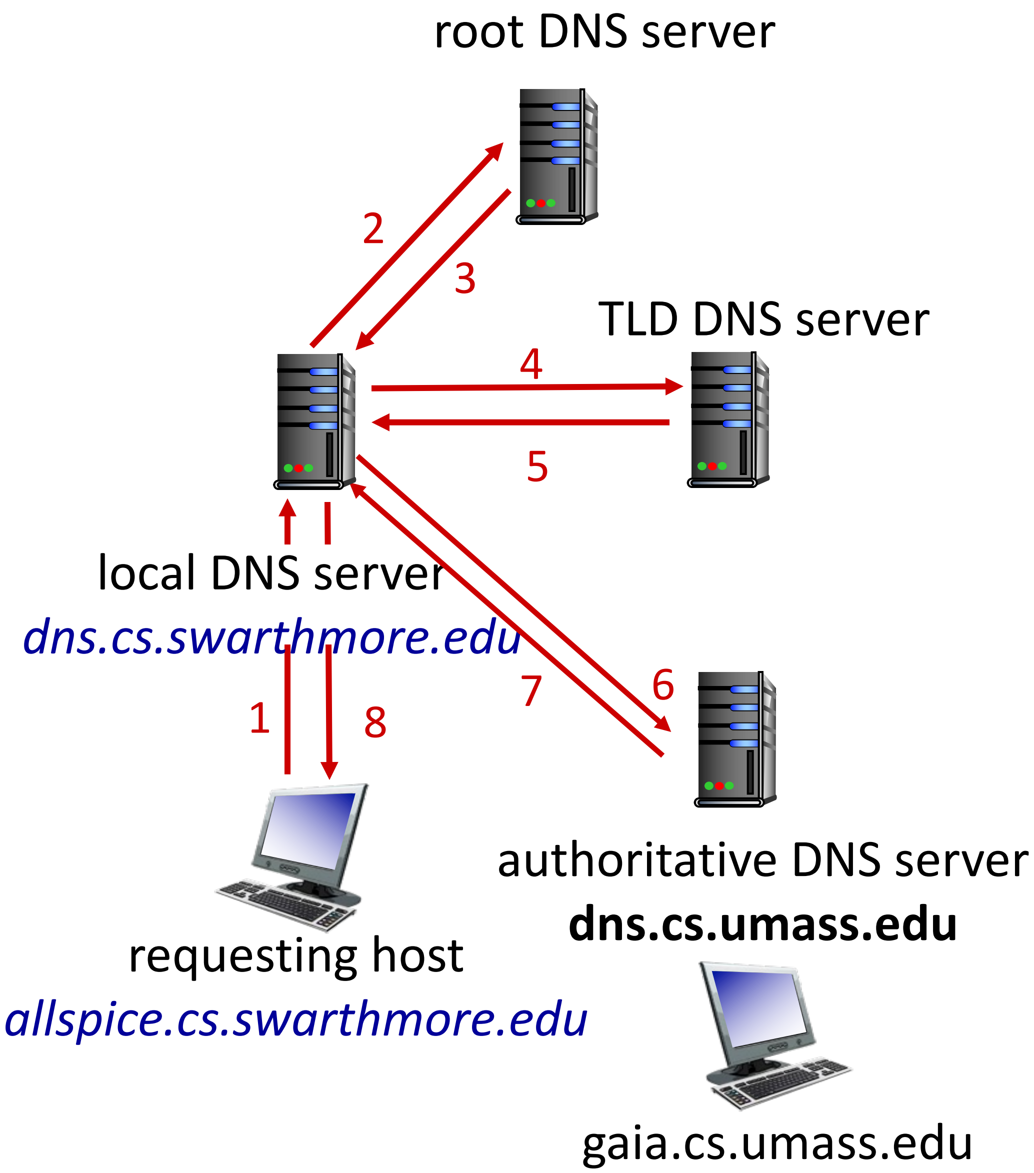
DNS security

DNS Vulnerabilities:

- No authentication
- Connectionless transport layer protocol (UDP)

DNS Attacks:

- Amplification Attack
- Cache Poisoning
- Man-in-the-middle
- DNS Redirection
- DDoS
- DNS Injection



Attacking DNS

DDoS attacks

- Bombard root servers with traffic
  - Not successful to date
  - Traffic Filtering
  - Local DNS servers cache IPs of TLD servers, bypassing root
- Bombard TLD servers
  - Potentially more dangerous

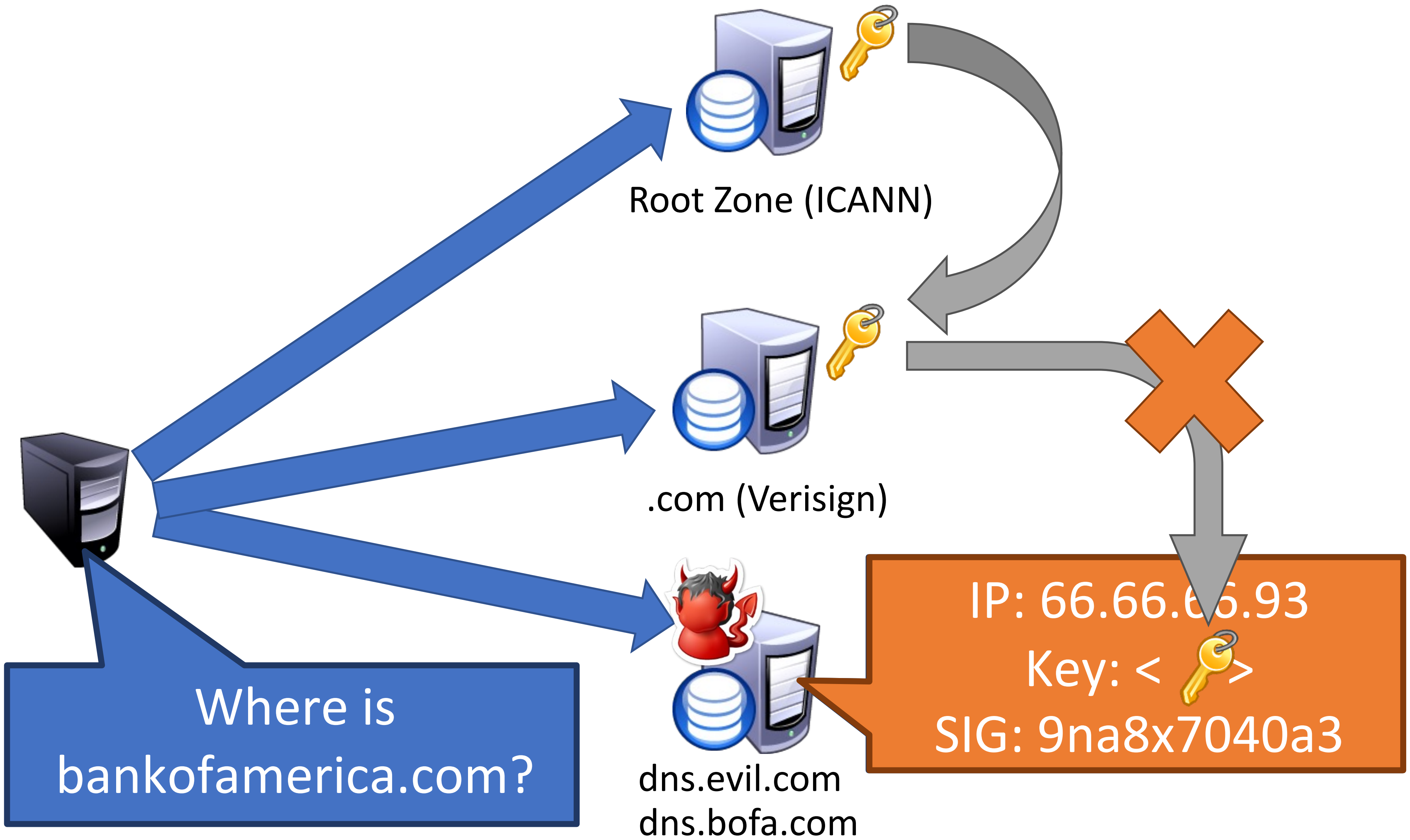
Redirect attacks

- Man-in-middle
  - Intercept queries
- DNS cache poisoning
  - Send bogus replies to DNS server that caches

Exploit DNS for DDoS

- Send queries with spoofed source address: target IP
- Requires amplification

DNSSEC Hierarchy of Trust



Solution: DNSSEC

- Cryptographically sign critical resource records
  - Resolver can verify the cryptographic signature
- Two new resource types
  - Type = DNSKEY
    - Name = Zone domain name
    - Value = Public key for the zone
  - Type = RRSIG
    - Name = (type, name) tuple, i.e. the query itself
    - Value = Cryptographic signature of the query results

Creates a hierarchy of trust within each zone

Prevents hijacking and spoofing

How many answers
Time to live in seconds
How many additional records?

```
$ dig @a.root-servers.net www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 57494
;; QUERY: 1, ANSWER: 0, AUTHORITY: 2, ADDITIONAL: 2

;; QUESTION SECTION:
;www.freebsd.org.         IN     A

;; AUTHORITY SECTION:
org.                172800 IN     NS     b0.org.afilias-nst.org.
org.                172800 IN     NS     d0.org.afilias-nst.org.

;; ADDITIONAL SECTION:
b0.org.afilias-nst.org.   172800 IN     A      199.19.54.1
d0.org.afilias-nst.org.   172800 IN     A      199.19.57.1
```

```
$ dig @a.root-servers.net www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 57494
;; QUERY: 1, ANSWER: 0, AUTHORITY: 2, ADDITIONAL: 2

;; QUESTION SECTION:
;www.freebsd.org.             IN      A

;; AUTHORITY SECTION:
org.                   172800 IN      NS      b0.org.afilias-nst.org.
org.                   172800 IN      NS      d0.org.afilias-nst.org.

;; ADDITIONAL SECTION:
b0.org.afilias-nst.org.   172800 IN      A       199.19.54.1
d0.org.afilias-nst.org.   172800 IN      A       199.19.57.1
```

How many answers

Time to live in seconds

How many additional records?

16-bit transaction identifier that enables the DNS client to match up the reply with it's original request.

the question we asked the server

type of response A = IP address, and NS = name server

Glue records

How many answers?
How many additional records?

(authoritative for org.)

```
$ dig @199.19.54.1 www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 39912
;; QUERY: 1, ANSWER: 0, AUTHORITY: 3, ADDITIONAL: 0

;; QUESTION SECTION:
;www.freebsd.org.         IN     A

;; AUTHORITY SECTION:
freebsd.org.       86400  IN     NS     ns1.isc-sns.net.
freebsd.org.       86400  IN     NS     ns2.isc-sns.com.
freebsd.org.       86400  IN     NS     ns3.isc-sns.info.
```

How many answers?
what does it mean if the answer s
How many additional records?

(authoritative for org.)

```
$ dig @199.19.54.1 www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 39912
;; QUERY: 1, ANSWER: 0, AUTHORITY: 3, ADDITIONAL: 0

;; QUESTION SECTION:
;www.freebsd.org.            IN     A

;; AUTHORITY SECTION:
freebsd.org.         86400  IN     NS     ns1.isc-sns.net.
freebsd.org.         86400  IN     NS     ns2.isc-sns.com.
freebsd.org.         86400  IN     NS     ns3.isc-sns.info.
```

(authoritative for freebsd.org.)

```
$ dig @ns1.isc-sns.net www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 17037
;; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;www.freebsd.org.          IN     A

;; ANSWER SECTION:
www.freebsd.org.    3600   IN     A      69.147.83.33

;; AUTHORITY SECTION:
freebsd.org.        3600   IN     NS     ns2.isc-sns.com.
freebsd.org.        3600   IN     NS     ns1.isc-sns.net.
freebsd.org.        3600   IN     NS     ns3.isc-sns.info.

;; ADDITIONAL SECTION:
ns1.isc-sns.net.    3600   IN     A      72.52.71.1
ns2.isc-sns.com.    3600   IN     A      38.103.2.1
ns3.isc-sns.info.   3600   IN     A      63.243.194.1
```

How many answers?
what does the answer tell us
How many authoritative records?
what does the authority tell us?
How many additional records?

(authoritative for freebsd.org.)

```
$ dig @ns1.isc-sns.net www.freebsd.org +norecurse
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 17037
;; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;www.freebsd.org.            IN      A

;; ANSWER SECTION:
www.freebsd.org.     3600    IN      A       69.147.83.33

;; AUTHORITY SECTION:
freebsd.org.         3600    IN      NS      ns2.isc-sns.com.
freebsd.org.         3600    IN      NS      ns1.isc-sns.net.
freebsd.org.         3600    IN      NS      ns3.isc-sns.info.

;; ADDITIONAL SECTION:
ns1.isc-sns.net.     3600    IN      A       72.52.71.1
ns2.isc-sns.com.     3600    IN      A       38.103.2.1
ns3.isc-sns.info.    3600    IN      A       63.243.194.1
```

How many answers?
How many authoritative records?
How many additional records?

Protocol Layering

Networks use a stack of protocol layers
- Each layer has different responsibilities.
- Layers define abstraction boundaries

Lower layers provide services to layers above
- Don’t care what higher layers do

Higher layers use services of layers below
- Don’t worry about how the layer below works

- Application Layer
- Transport: end-to-end connections, reliability
- Network: routing
- Link (data-link): framing, error detection
- Physical: 1’s and 0’s/bits across a medium (copper, the air, fiber)

Transport Layer perspective

Networks use a stack of protocol layers

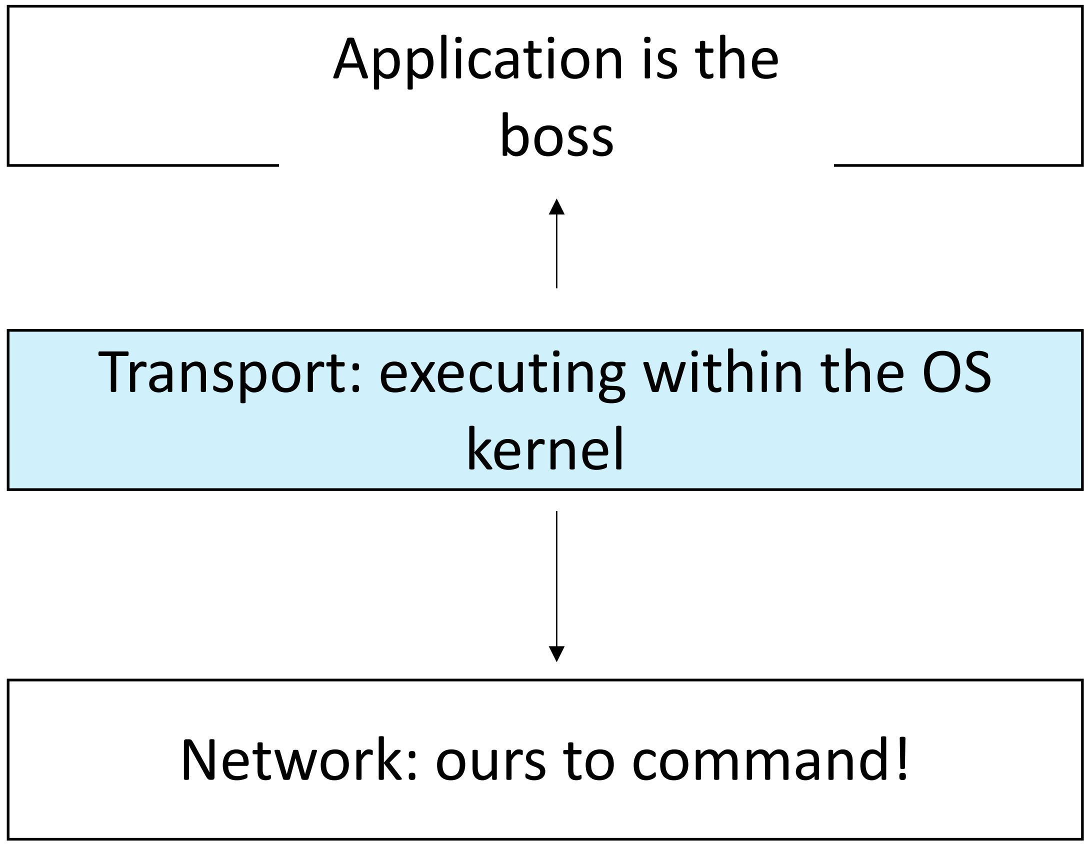
- Each layer has different responsibilities.
- Layers define abstraction boundaries

Lower layers provide services to layers above

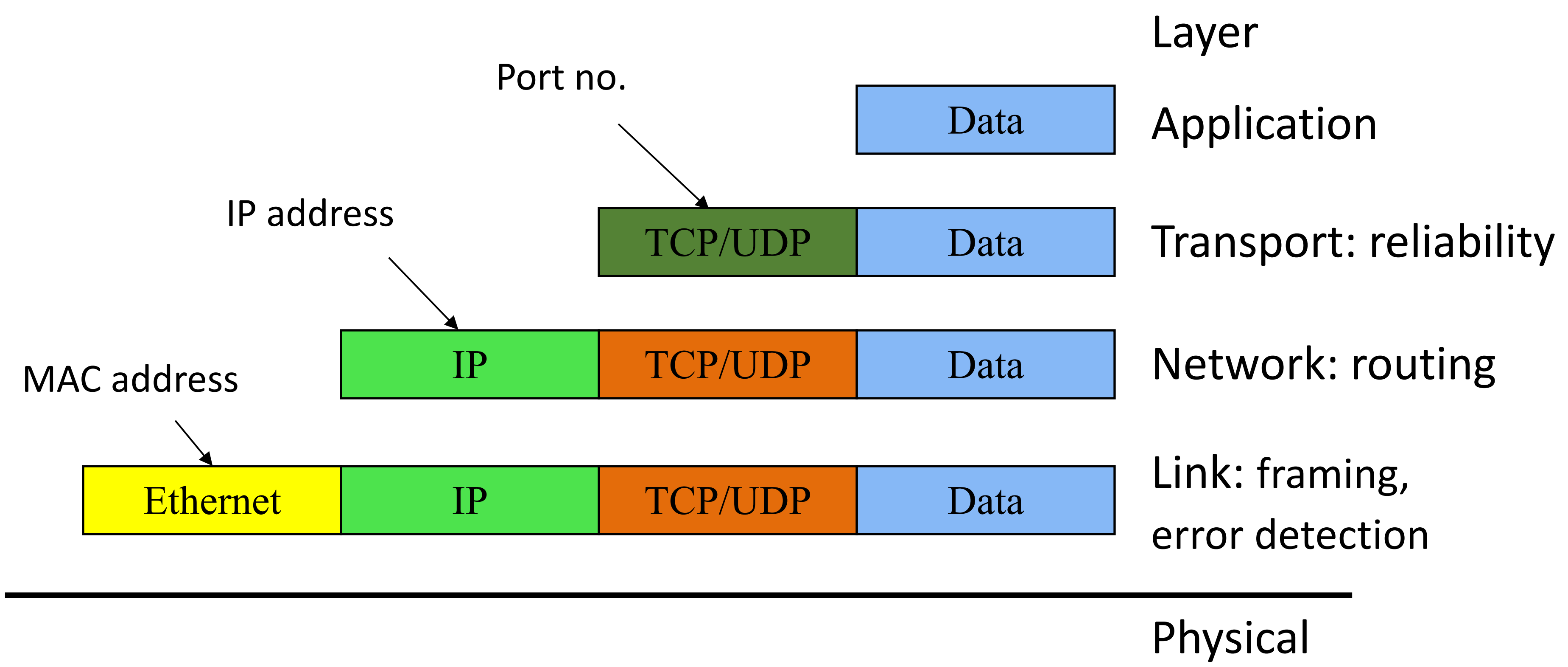
- Don’t care what higher layers do

Higher layers use services of layers below

- Don’t worry about how the layer below works



Layering and encapsulation



Ports: An Analogy

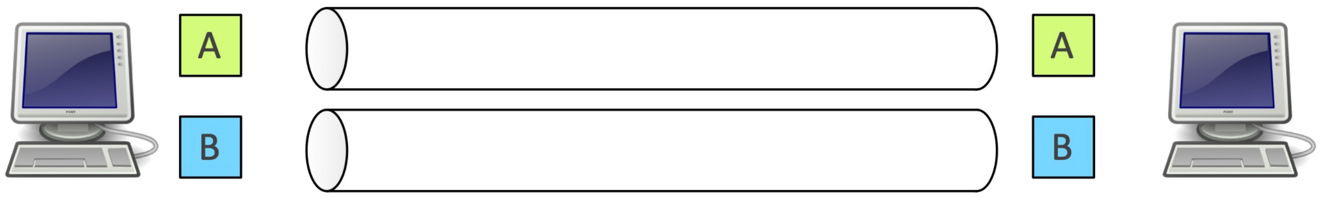
- Alice is pen pals with Bob. Alice’s roommate, Carol, is also pen pals with Bob
- Bob’s replies are addressed to the same global (IP) address
  - How can we tell which letters are for Alice and which are for Bob?
- Solution: Add a room number (port number) inside the letter
  - In private homes, usually a port number is meaningless
  - But, in public offices (servers), like Cory Hall, the port numbers are constant and known

Ports

Each application on a host is identified by a *port number*

TCP connection established between port *A* on host *X* to port *B* on host *Y* Ports are 1–65535 (16 bits)

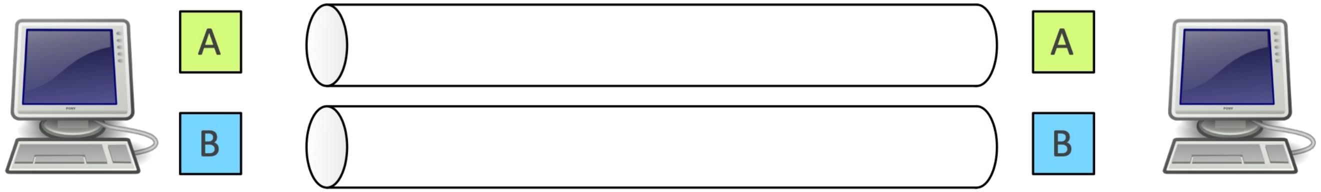
Some destination port numbers used for specific applications by convention



Ports

Ports help us distinguish between different applications on the same computer or server

- On private computers, port numbers can be random
- On public servers, port numbers should be constant and well-known (so users can access the right port)



IP Header: send to: 1.2.3.4

TCP Header: send to: port 80

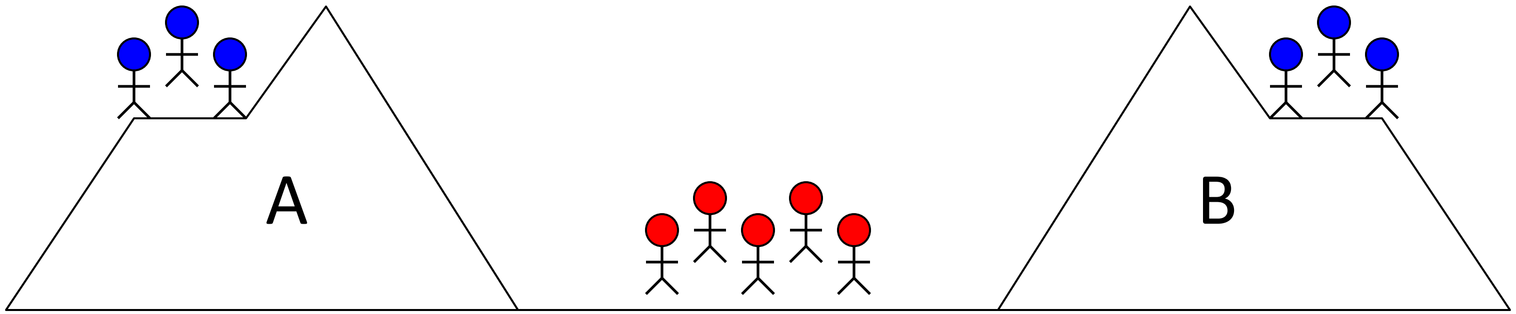
HTTP: GET “Remember the milk!”

Common Ports

Port	Application
80	HTTP (Web)
443	HTTPS (E2E encrypted Web)
25	SMTP
22	SSH
23	Telnet
53	DNS

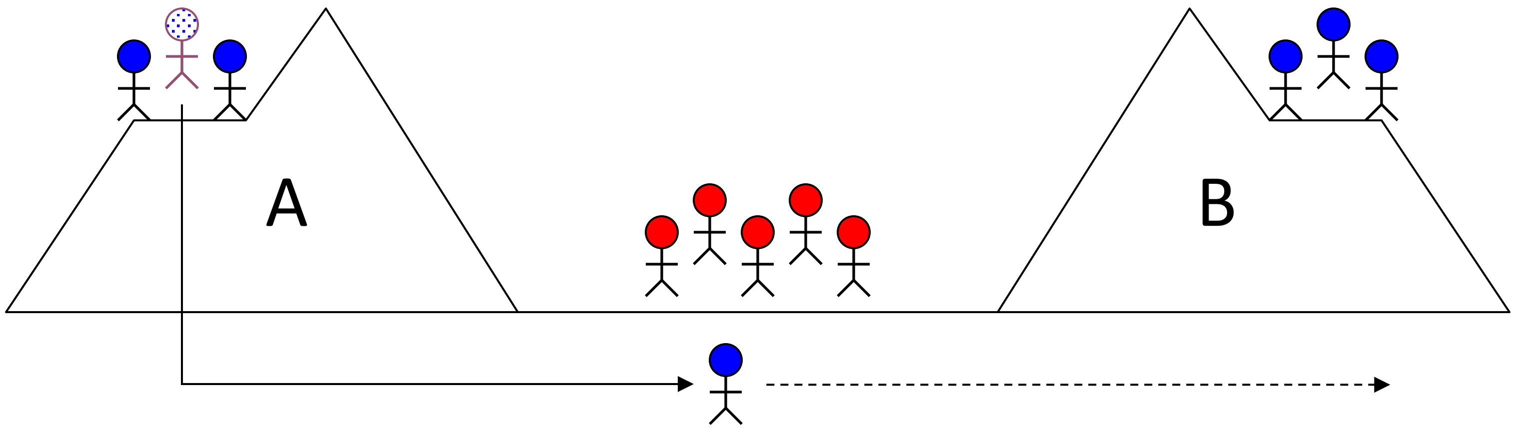
Transmission Control Protocol (TCP)

The Two Generals Problem



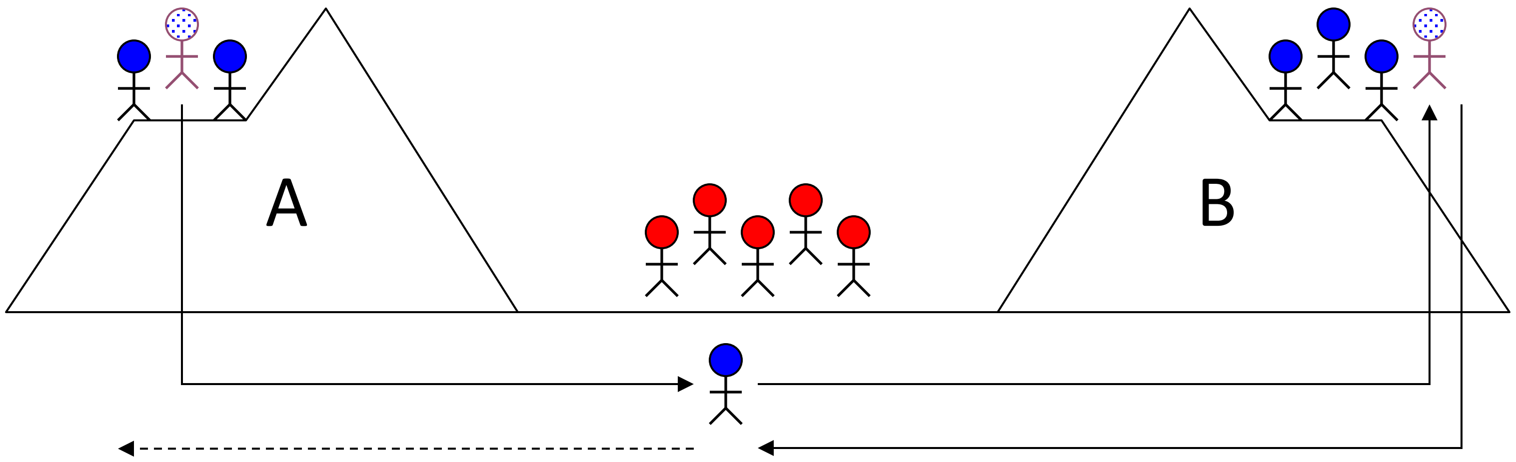
- Two army divisions (blue) surround enemy (red)
  - Each division led by a general
  - Both must agree when to simultaneously attack
  - If either side attacks alone, defeat
- Generals can only communicate via messengers
  - Messengers may get captured (unreliable channel)

The Two Generals Problem



- How to coordinate?
  - Send messenger: "Attack at dawn"
  - What if messenger doesn't make it?

The Two Generals Problem

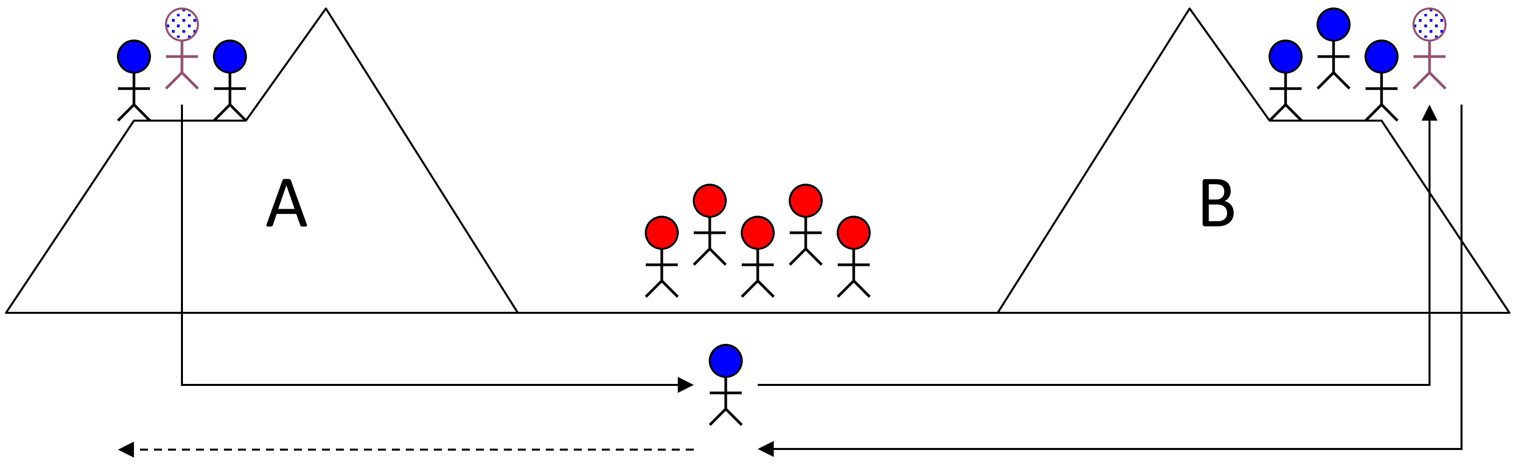


- How to be sure messenger made it?
  - Send acknowledgment: “I delivered message”

In the “two generals problem”, can the two armies reliably coordinate their attack? (using what we just discussed)

- A. Yes (explain how)
- B. No (explain why not)

The Two Generals Problem



- Result
  - Can't create perfect channel out of faulty one
  - <u>Can only increase probability of success</u>

Designing reliability over an unreliable link. What can go wrong?

A. Packets can be dropped
B. Packets can arrive out or order
C. Acknowledgements can arrive out of order
D. All of the above
E. There are more issues….

Designing reliability over an unreliable link. What can go wrong?

- Problem: IP packets have a limited size. To send longer messages, we have to manually break messages into packets
    - When sending packets: TCP will automatically split up messages
    - When receiving packets: TCP will automatically reassemble the packets
    - Now the user doesn’t need to manually split up messages!
- Problem: Packets can arrive out of order
    - When sending packets: TCP labels each byte of the message with increasing numbers
    - When receiving packets: TCP can use the numbers to rearrange bytes in the correct order
- Problem: Packets can be dropped
    - When receiving packets: TCP sends an extra message acknowledging that a packet has been received
    - When sending packets: If the acknowledgement doesn’t arrive, re-send the packet

Transmission Control Protocol (TCP)

- Provides a byte stream abstraction
  - Bytes go in one end of the stream at the source and come out at the other end at the destination
  - TCP automatically breaks streams into **segments**,
- Provides ordering
  - Segments contain sequence numbers, so the destination can reassemble the stream in order
- Provides reliability
  - The destination sends acknowledgements (ACKs) for each sequence number received
  - If the source doesn't receive the ACK, the source sends the packet again
- Provides ports
  - Multiple services can share the same IP address by using different ports