

# CS 352

# The Application Layer

Lecture 3.1, Spring 2020

<http://www.cs.rutgers.edu/~sn624/352>

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# Application-layer Protocol

- Types of messages exchanged,
  - e.g., request, response
- **Message format:**
  - Syntax: what fields in messages & how fields are delineated
  - Semantics: meaning of information in fields
- **Actions:** when and how processes send & respond to messages

## Public-domain protocols:

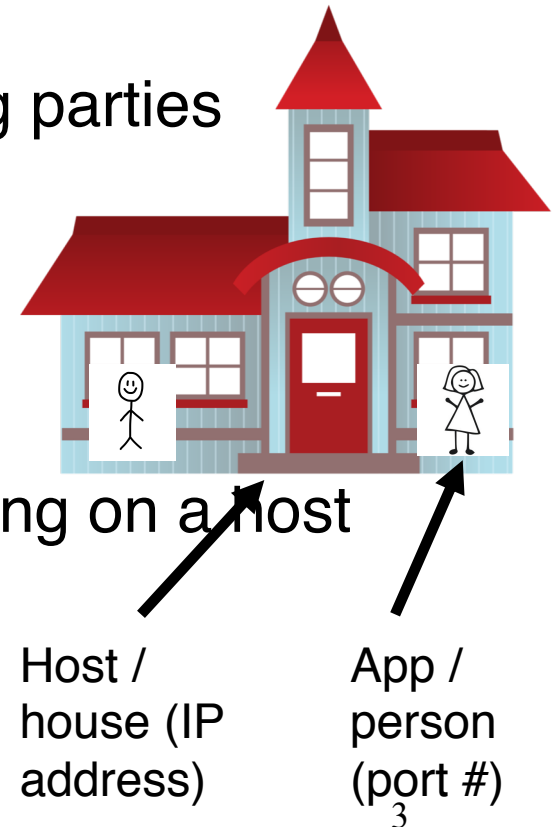
- defined in RFCs
- allows for interoperability
- e.g., HTTP, SMTP

## Proprietary protocols:

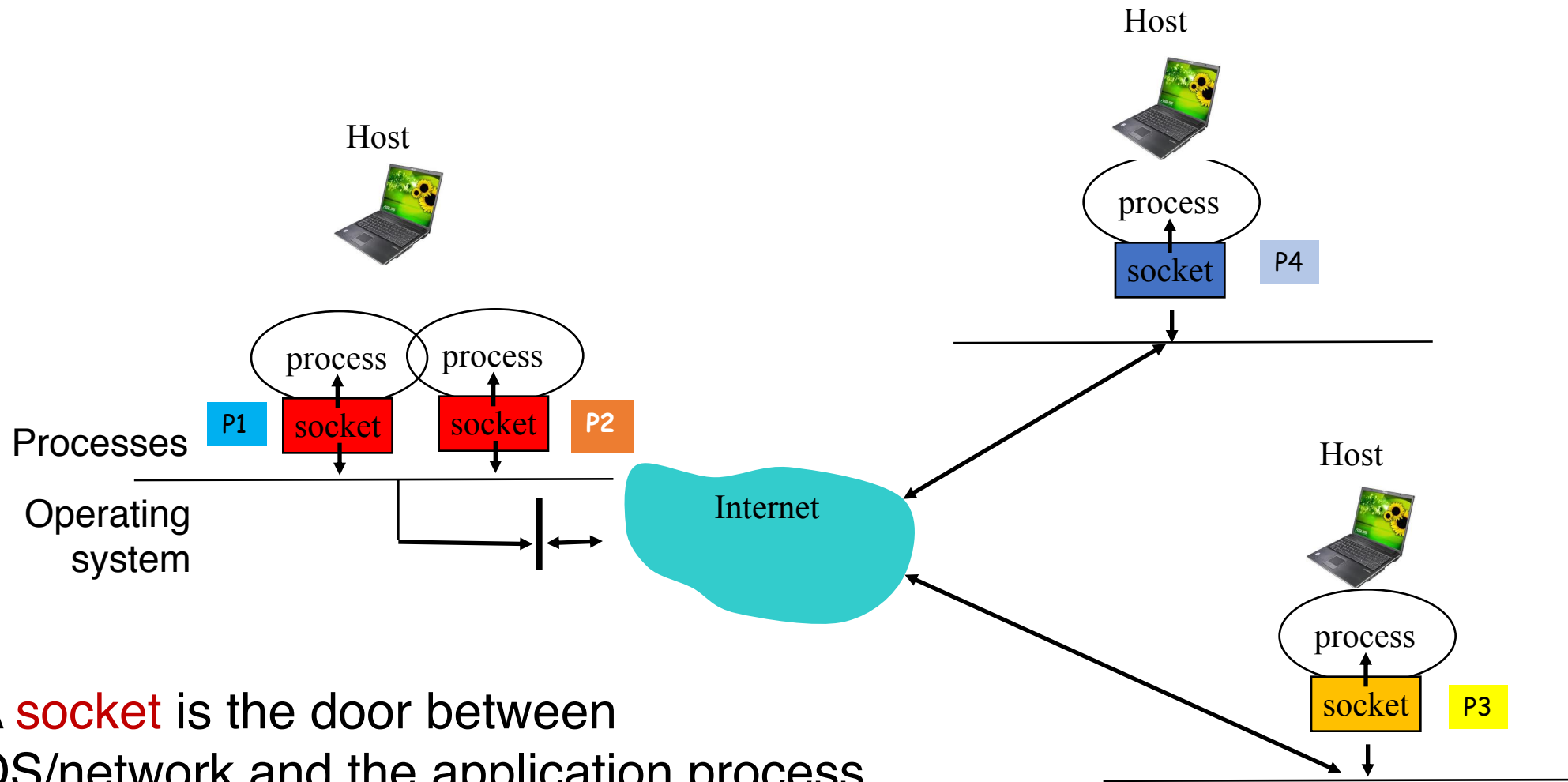
- e.g., Skype

# Application Addresses

- We usually think of an application executing on a single endpoint
- However, applications can reside on, say, 2 different endpoints connected by a network
- In order to communicate, need to identify the communicating parties
  - Telephone network: phone number (10 digits)
- Computer network: **IP address**
  - IPv4 (32 bits) 128.6.24.78
  - IPv6 (128 bits) 2001:4000:A000:C000:6000:B001:412A:8000
- Suppose there is more than one networked program executing on a host
  - In addition to host address, we need one more address
    - “Which Program to talk to?”
- The identity for an application: **port number (+ IP addr)**



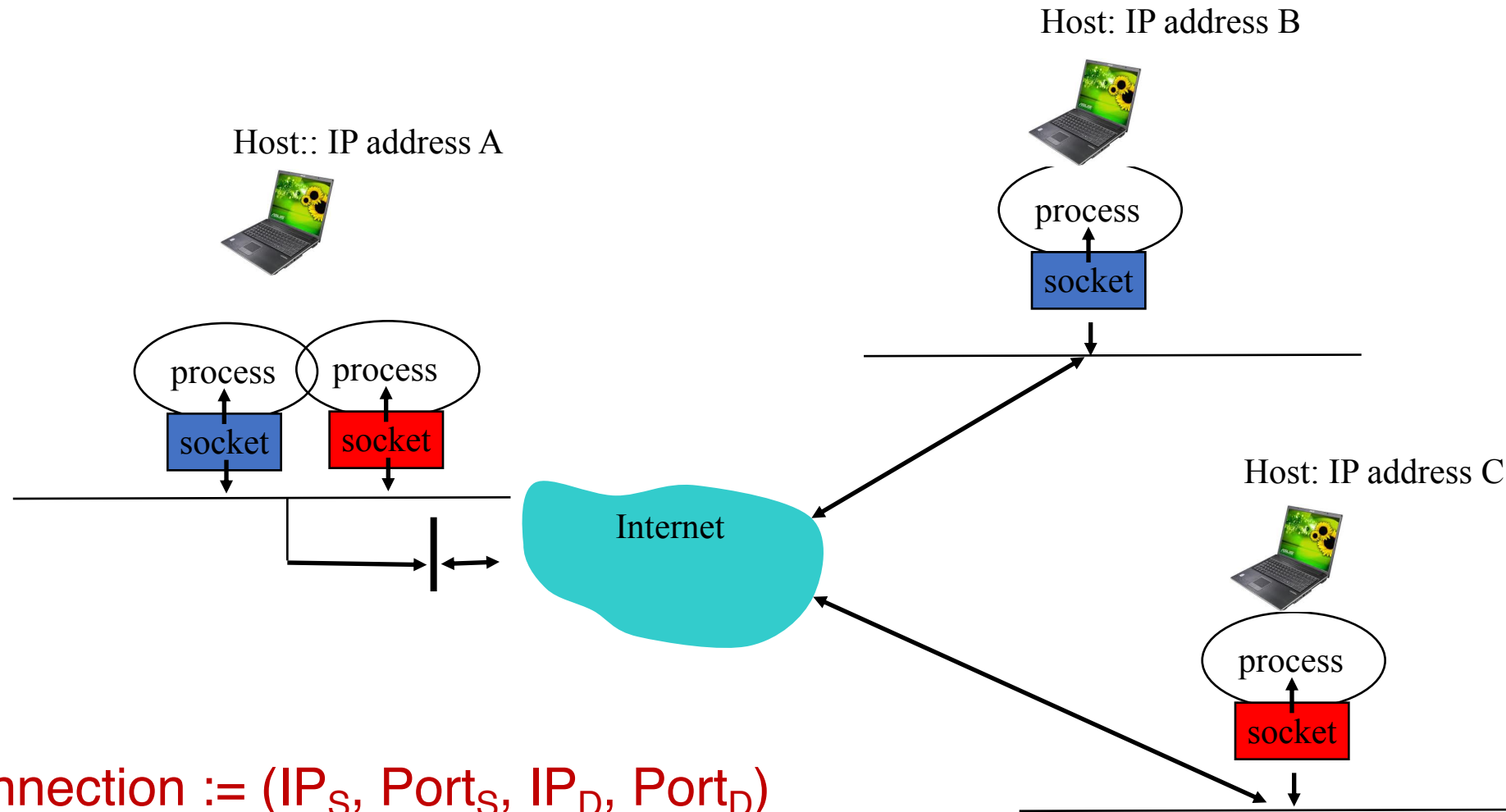
# IP address & port number



A **socket** is the door between  
OS/network and the application process

The **application's programming interface** to the network

# An app-layer connection is a 4-tuple

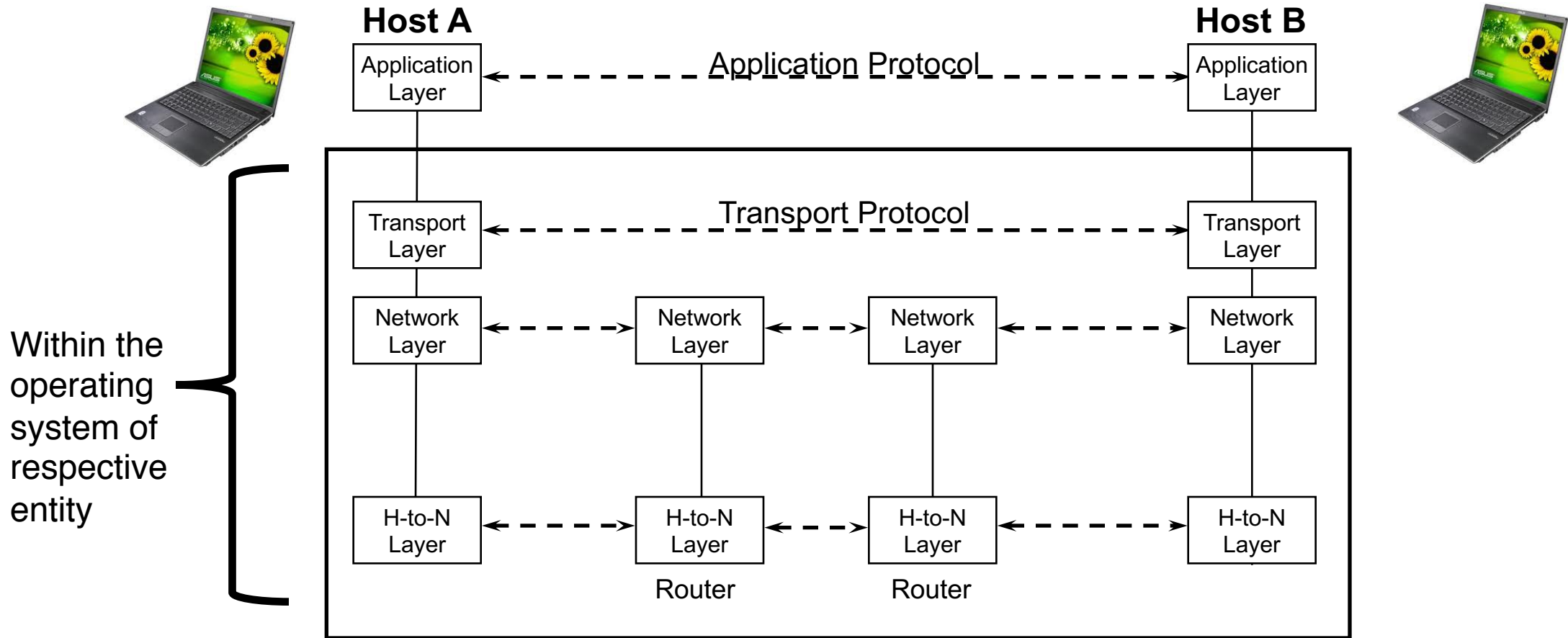


**Connection := (IP<sub>S</sub>, Port<sub>S</sub>, IP<sub>D</sub>, Port<sub>D</sub>)**  
(S = source, D = destination)

# App-layer connections

- A small demo

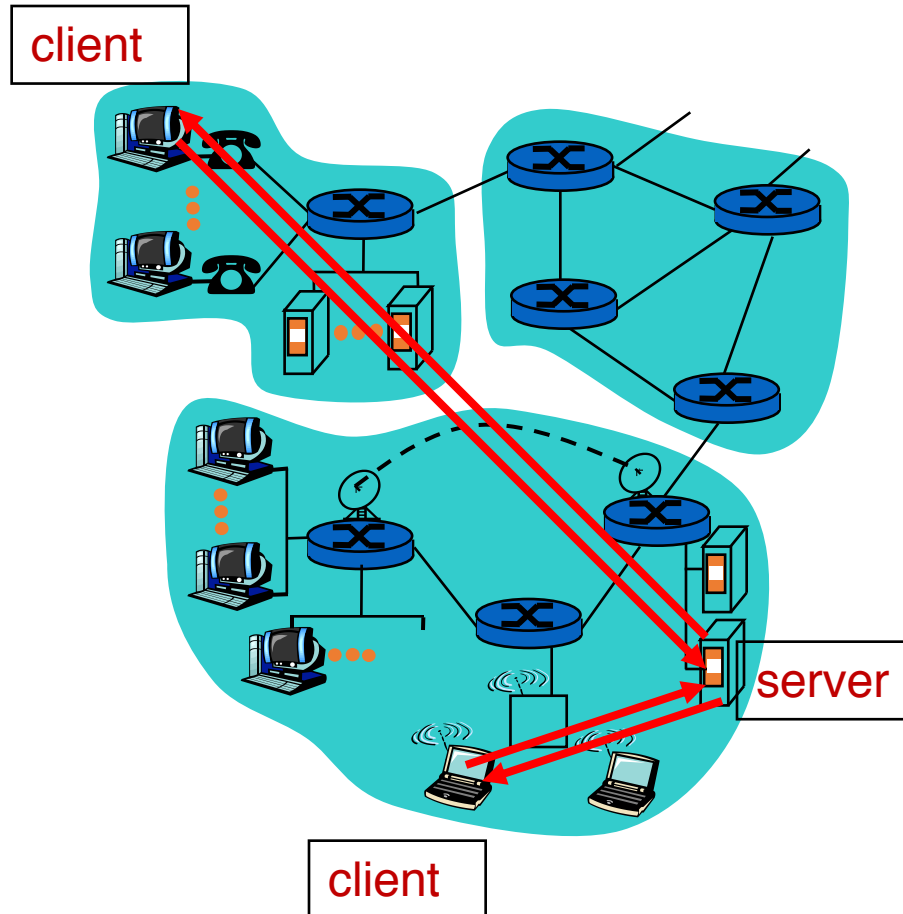
# Recall: Apps rely on services by lower layers



# Common Architectures of Applications



# Client-server architecture



## Server:

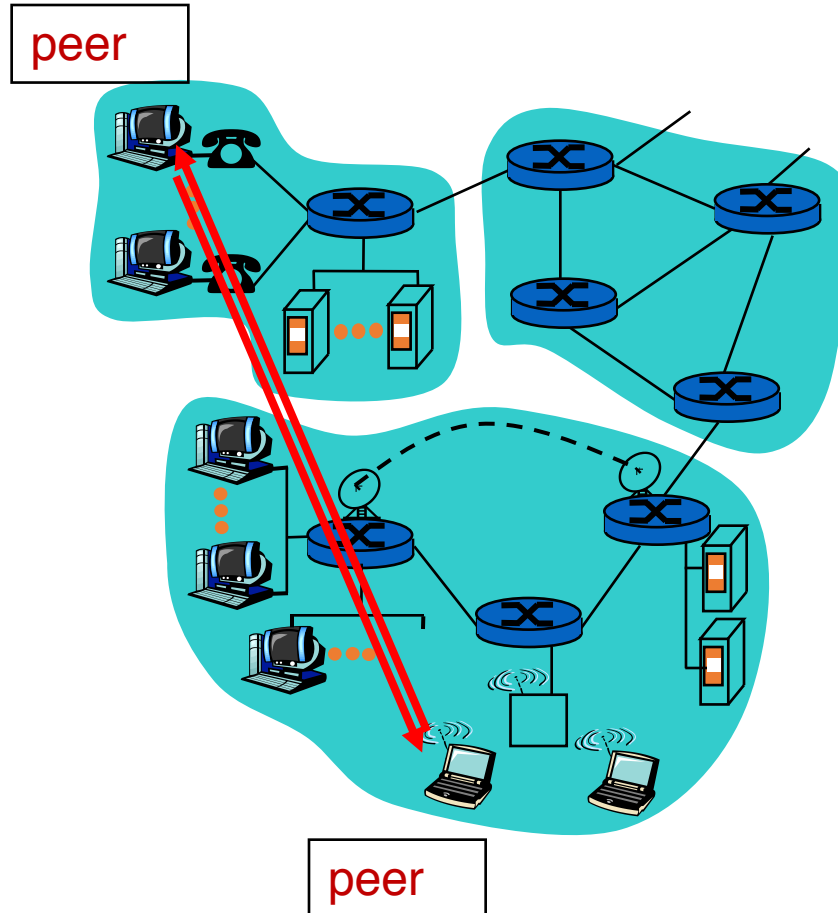
- always-on endpoint
- “permanent” IP address
- server farms (“data centers”) for scaling

## Clients:

- communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do not communicate directly with each other

- The web (HTTP) works this way.
- Many mobile apps work this way (e.g., Instagram)

# Peer-to-peer (P2P) architecture



- **Peers:**
  - Intermittently connected hosts
  - Directly talking to each other
- Little to no reliance on always-up servers
  - Examples: BitTorrent, Skype
- Today, many applications use a **hybrid** model
  - Example: Skype “supernodes”

# Going forward: A few applications

- Domain Name System
- The web: HTTP
- Mail
- File transfer



# CS 352

# Domain Name System

Lecture 3.2, Spring 2020

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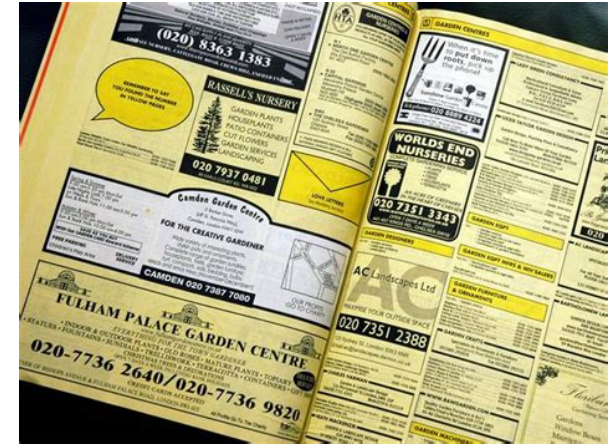
“You have my name. Can you  
lookup my address?”

# Domain Name System (DNS)

- Problem statement:
  - Average brain can easily remember 7 digits for a few names
  - On average, IP addresses have 12 digits
  - We need an easier way to remember IP addresses
- Solution:
  - Use alphanumeric names to refer to hosts. Called **host names** or **domain names**
  - We need a **directory**: add a service to map between alphanumeric host names and binary IP addresses
  - We call this process **Address Resolution**

# Types of Directories

- Directories map a *name* to an *address*
- Simplistic designs
  - Central directory
  - Ask everyone (e.g., flooding)
  - Tell everyone (e.g., push to a file like /etc/hosts)
- Scalable distributed designs
  - Hierarchical namespace (e.g., Domain Name System (DNS))
  - Flat name space (e.g., Distributed Hash Table)





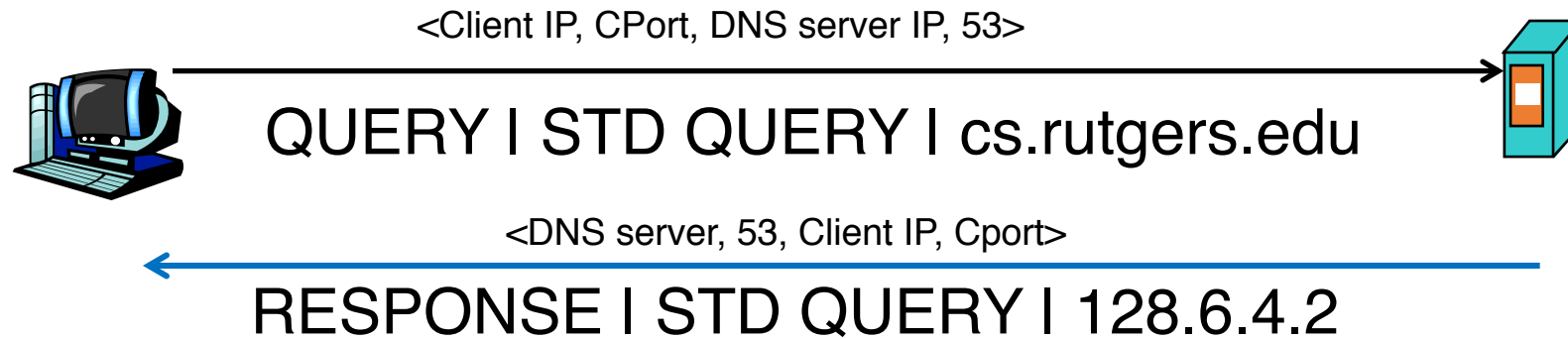
# Simple DNS

- What if every host has a local directory?
- /etc/hosts.txt
  - How things worked in the early days of the Internet!
- What if hosts moved around? How do you keep this up to date?

<b>nowski Maciej</b> Gerny Kryst. tr 11 610 41 <b>nowski Mieczysław</b> Lehens- mittel Hopfenstr 91 522 47 <b>nowski Mieczysław R.</b> Snausteyer 28 415 65 <b>nowski Stanisław</b> Mechan- iker Bahnhofstr 2 596 78 <b>nowski Stanisław</b> Desin- kt. Hausrenung, Siemestr 45 599 82 <b>nowski Stanisław</b> Dr. med. nowskastr 13 826 08 <b>nowski, Szymon</b> Verteilungs- stelle Sosna Pomska Erdo-Mech- schistr 673 03 <b>nowski Tadeusz</b> Lastreiw- n Pusz-M-Str 13 936 45 <b>nowski W.</b> Eisenwarenverk. nowastr 8 614 03 <b>nowski W.</b> Eisenw.-Verk. Hahernallee 12a 436 86 <b>nowski Wacław</b> + Nordind- ice 130 509 47 <b>nowski Zdzisław</b> + Co. arschauer Müllabfuhr Ks. Mac- wica-Str 3/5 10 30 53 <b>nowski Zygmunt</b> Ing. Miko- wasastr 41 832 44 <b>onko H. u. Wojciechowski</b> r. Baug. GmbH Krucast 8 881 84 <b>onko Henryk</b> Ing. Boernero- Parkwastr 7 11 17 14 <b>onko Adam</b> Dr. med. I. innere nkt. Radomer Str 43 979 69 <b>onko Stanisław</b> Kinderkon- d. Bldg. I Markthalle 157 <b>onka Eugenia</b> Widolstr 25 643 98 <b>onki Alfons</b> Feldtherm- re 117a 436 62 <b>onki Jan</b> Seilenn. Brower- str 12 636 65 <b>onki Jannus</b> Klenopier- Str. Hoonstr 28 826 04 <b>owicz Adam</b> Ing.-Mech. Ba- reckastr 45 431 48 <b>owicz S.</b> Marschallstr 15 925 80	<b>Zahrad Uterp.</b> Spółecnych u. Hauptanstalt I. Sozialversiche- rung <b>Sozialversicherungskasse</b> in Warschau Weichselufer 33 Zentrale * 558 00 Deutscher Kommissar 240 66 Stellvertr. d. Deutsches Kommis- sars 348 48 Deutscher Chefart 628 95 Hausverwaltung 686 99 Zentrale Analit. Laborat. Sonn. u. Feiertage 11-12 558 04 Wirtschaftslager Dorfstr 20 805 13 Schreibmat-Lager Polnast 34 992 62 Druckerei Litmannstadtstr 32 627 56 Landgut Grotz 510 86 Nachtverbindungen (nach 19 Uhr) Weichselufer 35 Rote Flötens 558 01 Intendant 558 02 Garage 558 03 I. Bezirk Smulikowskistr 1/3 Zentrale * 558 00 Röntgenanstalt Zielast 11 675 78 II. Bezirk Polnast 34 Oberarzt 932 84 Vertrauensärzte 746 47 Büroleiter u. Sekretariat 830 71 Meldebüro u. Intendant 856 57 Referat d. Krankenhauses Oberschwester 822 06 Naturheilkunst 744 14 Chemisches Laboratorium 681 66 820 36 III. Bezirk Litmannstadt Str 52 Oberarzt 542 82 Vertrauensärzte 231 16 Büroleiter u. Ref. d. Facharzt- Büro 217 34 Referat d. Hausärzte 345 88 Meldebüro u. Ref. d. Barlei-	<b>Spallinski Mieczysław</b> Snaust- kuchstr 1 740 59 <b>Spaltenstein Franciszek</b> Lud- nast 9 927 27 <b>Sparkasse</b> s. unter Kassel <b>Spartaria Holzindustrie</b> GmbH Blumenstr 4 323 02 <b>Spartaria Holzindustrie</b> GmbH Madalinskistr 87 422 02 <b>Spasinska Jadwiga</b> Rakowiec- kast 5 425 35 <b>Spasowicz Eugeniusz</b> 6 Sier- pienskr 24 944 47 <b>Spasowiczowa Aniela</b> + Be- amin Redarskast 26 238 95 <b>Spaw</b> Stahlkonstruktionswerke Kwiecinski Wl. Pradyskistr 17 321 49 <b>Specht Elzbieta</b> Kurstr 108 10 23 49 <b>Specht Willi</b> Ingenieur- kast 6 900 89 <b>Speck Paula</b> Wele. u. Spiritus- sechldg Neue Welt 3 805 72 Ordemtr 19 633 14 <b>Spedillo</b> Transportbüro Postpl 9 358 00 <b>Speditionhaus Adolf u. Ed- ard Holler</b> Zweigniederlaschldg Dlugastr 29 11 19 70 <b>Spedo</b> Sped.-Büro Marschallstr 10 692 59 <b>Speich Walter</b> + Ing. Kfm. Marstr 8 739 24 <b>Speldel Max</b> Beauftragte d. Kom- missar. Verwaltung sichergestellt. Grundstücke I. Warschau Grotz- gost 2 426 35 <b>Spel</b> + elekt. Anl. u. Materialien- lager Bartoszewicza M. Gasowski B. Wapolskistr 9 734 57 <b>Sperling J. &amp; Co.</b> Wagen u. Mo- tallwarenbr. GmbH Mlynarska- str 30 253 59 <b>Sperling Juliusz</b> Kfm. Wap- olskistr 30 253 59	<b>Spiet</b> Spil.-Ing. Erben aus Zytniast 20 Direktion 636 39 Verkaufsst. 321 02 <b>Spiritus Monopol Staatl.</b> Zah- kowskast 27-38 Werkleiter Büro Sekretärin 10 17 15 10 17 15 Stellvertreter d. Werkleiter Leiter u. Büro 10 60 22 Wohnung 10 60 22 Hauptplortier Auskunt 10 07 06 Personalbüro Leiter 10 14 69 Technische Abt. Leiter 10 42 32 Büro d. Techn. Abt. 10 02 77 Mechanische Werkstätte 10 43 49 Abt. Haushaltung Leiter Büro 10 14 81 Wohnung 10 14 81 Einkaufsst. 10 31 89 Verkaufsst. u. Großhandlung 10 26 25 Abt. Brantweinreinigung 10 16 77 Leiter 10 04 05 Rechnungsabteilung u. Buchführung 10 16 77 10 04 05 <b>Spiro Gertrud</b> Verk. v. Spirit. u. Zigaretten Nowinskistr 2 Büro 11 00 21 <b>Spiro Gertrud</b> Geschäftsbh. Zytniast 18 224 04 <b>Spiro Walerian</b> Ing. Arch. Pietekastr 9 12 50 15 <b>Spitzbarth-Benda Karol</b> + Schauspieler Neue Welt 30 248 76 <b>Spiz</b> Arbeitsgenossenschaftl. Un- tern. I. Tief- u. Hochbauark. Kro- czast 14 960 62 <b>Spizowski Jan</b> Zahnarzt Javo- rinskistr 7 723 12 <b>Spilawa-Neyman Helena</b> Neue Burgstr 10 998 49 <b>Spilawa-Neyman Jan</b> Ing.-Arch. Radomer Str 43 946 28	<b>Grasynastr 15</b> * 401 40 verbindet mit sämtlichen Abteilungen u. Referaten. Zucker-, Kunstionig-, Narmelade- Konserven- u. Petroleum-Ref- erale 448 05 Baureferat Grasynastr 22 418 39 Genossenschaftl. Korrespondenz- kurse Wiktorskast 16 434 45 Zweigstelle Warschau 427 24 Leiter u. Büro 427 14 Verkaufsst. Verk. v. Sacha- rin u. Kontingentart. I. d. Kreis Warschau 427 14 Ref. Kontingentart. I. d. Stadt Warschau 407 54 Lager Grasynastr 19 439 68 Litmannstadt Str 81 291 88 302 30 302 31 Kolejowastr 5 334 44 Wlochy 11 Listopadast 24 684 34 Zweigstelle I. Schreibwarenhan- del Rosanast 8/10 413 97 Osterezeug. u. Fischkons. Fabr. Halestr 196 900 15 Büro Halestr 264 717 25 Tulow. u. Briefumschlagfabr. Dlu- gast 48 Büro 11 06 82 Expedition 11 09 79 Schachtelbr. Marionstadtstr 23 232 14 Hosigstr 14 614 00 Le Exaktbr. Mokolowskast 9 Verpackungsabtl. 941 49 Auto-Werkstätte Barokwastr 4 11 09 88 Genossenschaftl. Schule Drei- kreuzpl 8/10 914 19 Ordnungsabtl. m. Anteilb. Vorstand 245 16 Direktor 247 13 + Warenhaus Leiter 697 63 + Einkaufsbüro 242 27 Einkaufsbüro 640 70 Verkaufsbüro 500 25 Auftragbüro 252 53 + Auftragbüro 234 19 Gaststätte 593 29 Magazin 255 54	<b>Spychalski Wit</b> solim. Skakast 1 <b>Spyra Jan</b> Nap- Inh. techn. Hand- skast 1 <b>Srebrny Kazimi</b> lusz 16 <b>Srednicka Wlad</b> Korsettmacherin F <b>Srednicki Br. M</b> we Kolost 10 <b>Srednicki Broni</b> Loki Wroclawstr 1 <b>Srednicki Stani</b> Kindergarten Targow <b>Srednicki Stanis</b> str 52 <b>Srednicki Leon</b> str 31 <b>Srocki Stefan</b> Pl <b>Sroczyńska Apol</b> str 20 <b>Sroczyńska Iren</b> <b>Sroczyńska Kar</b> bldg. Inbstrat 26 <b>Sroczyński u. He</b> bld. Nienlager u schallstr 91 <b>Sroczyński E. S</b> Metallw. Abt. eler nigskberger Str 4/4 <b>Sroczyński J. &amp;</b> med. Laborat. E <b>Sroczyński Jan H</b> ria-Kosmiera-Str <b>Sroczyński Kar</b> Leczkast 4 <b>Sroczyński Karo</b> + Grybowkasta <b>Sroczyński Kazi</b> Kinderarzt Sporta <b>Sroczyński Wito</b> str 2a
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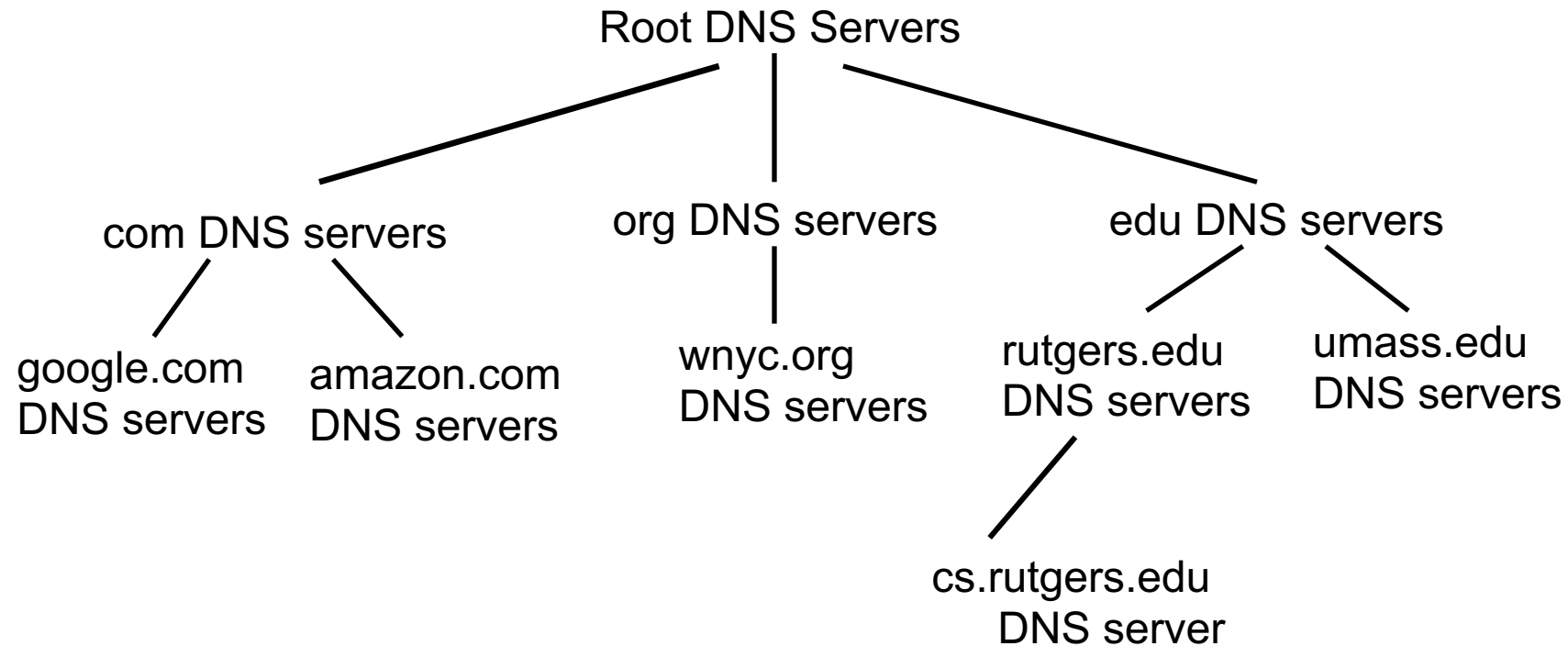
# Simple DNS

DOMAIN NAME	IP ADDRESS
www.yahoo.com	98.138.253.109
cs.rutgers.edu	128.6.4.2
www.google.com	74.125.225.243
www.princeton.edu	128.112.132.86



- Key idea: Implement a server that looks up a table.
- Will this scale?
  - Every new host needs to be entered in this table
  - Performance: can the server serve billions of Internet users
  - Failure: what if the server or the database crashes?
  - How to secure this server?

# Distributed and hierarchical database



RFC 1034: **Distribution through hierarchy enables scaling**

# DNS Protocol

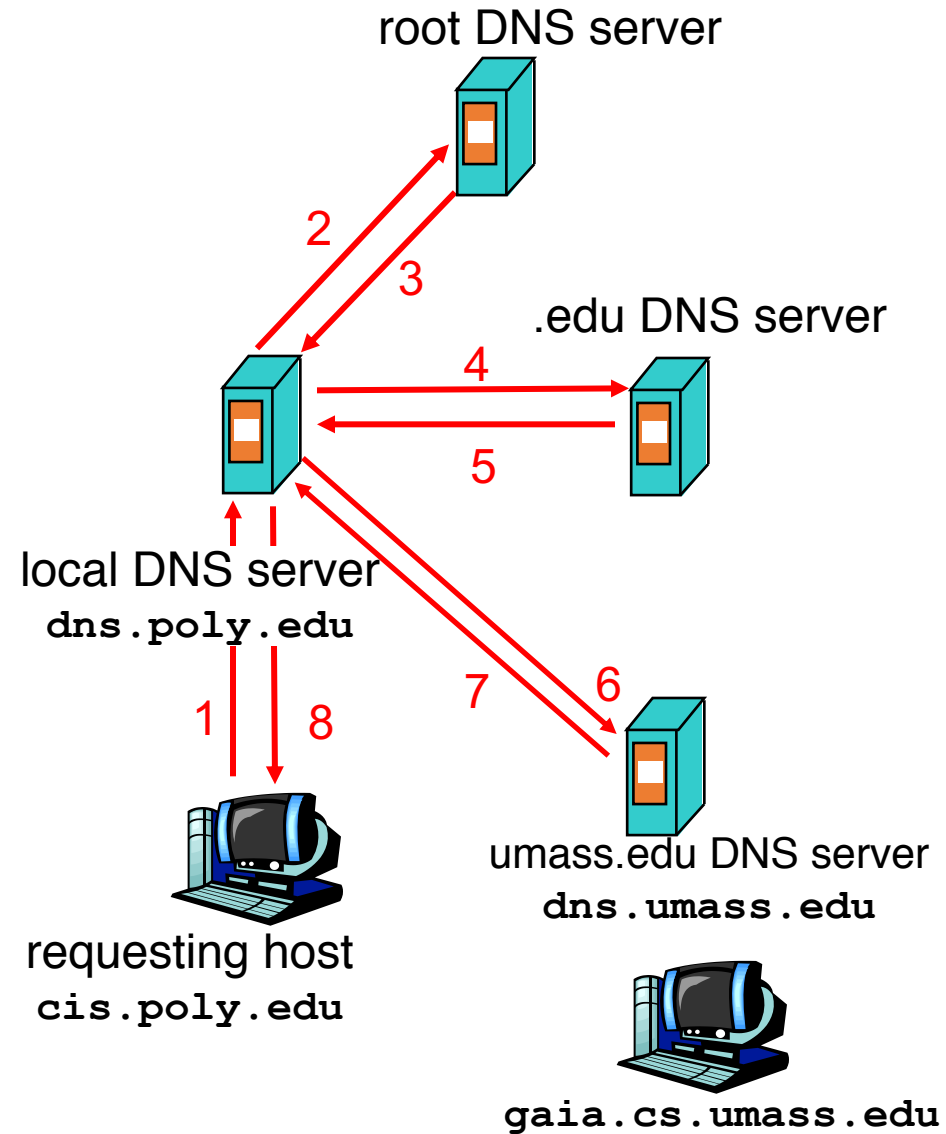
- Client and Server
- Client connects to Port 53 on server
- Assume DNS server IP known
- Two types of messages
  - Queries
  - Responses
- Type of Query (OPCODE) methods
  - Standard query (0x0)
    - Request domain name for a given IP address
  - Updates (0x5)
    - Provide a binding of IP address to domain name
- Each type has a common message format that follows the header

# DNS Protocol

- When client wants to know an IP address for a host name
  - Client sends a DNS query to the “local” name server in its network
  - If name server contains the mapping, it returns the IP address to the client
  - Otherwise, the name server forwards the request to the root name server
  - The request works its way down the tree toward the host until it reaches a name server with the correct mapping

# Example

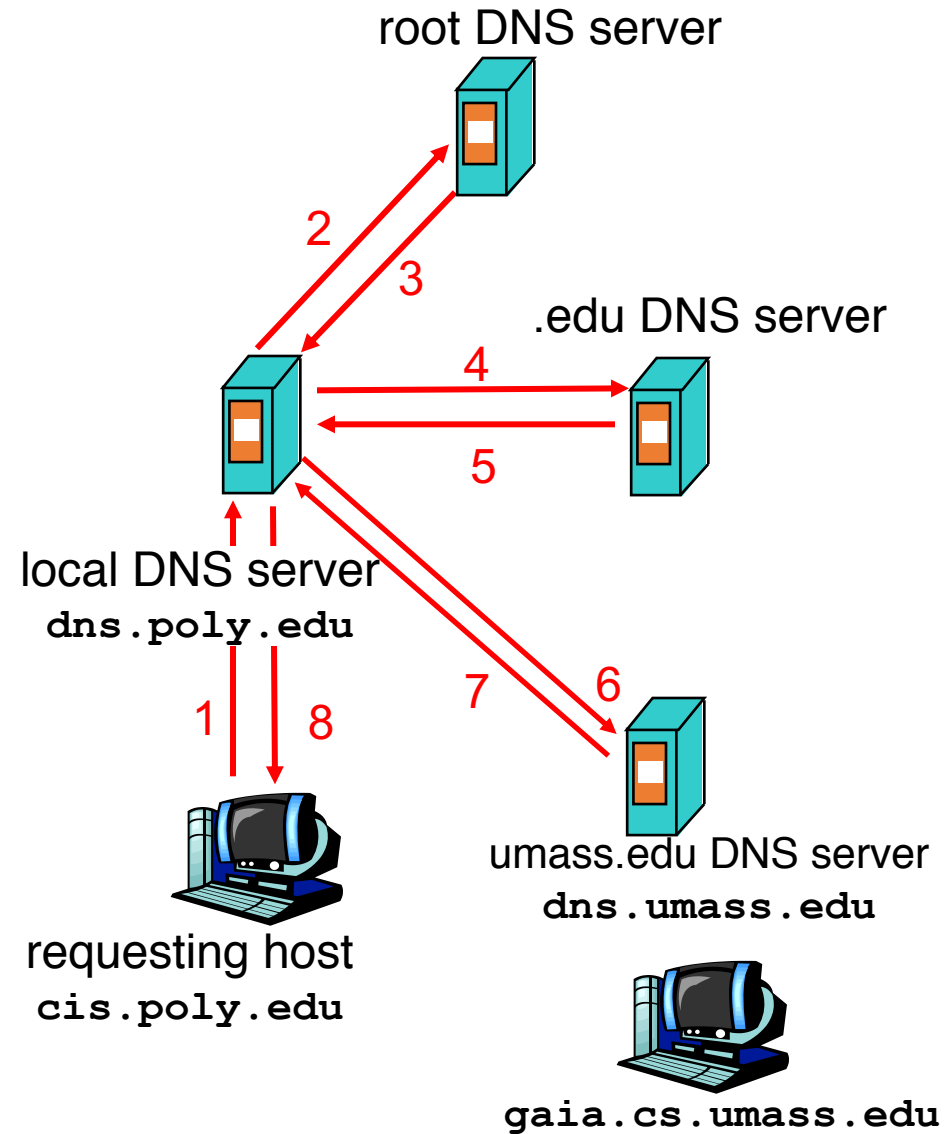
- Host at cis.poly.edu wants IP address for gaia.cs.umass.edu
- Local DNS server
- Root DNS server
- TLD DNS server
- **Authoritative** DNS server



# Query type

## Iterative query:

- Contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”
- Queries are iterative for the local DNS server



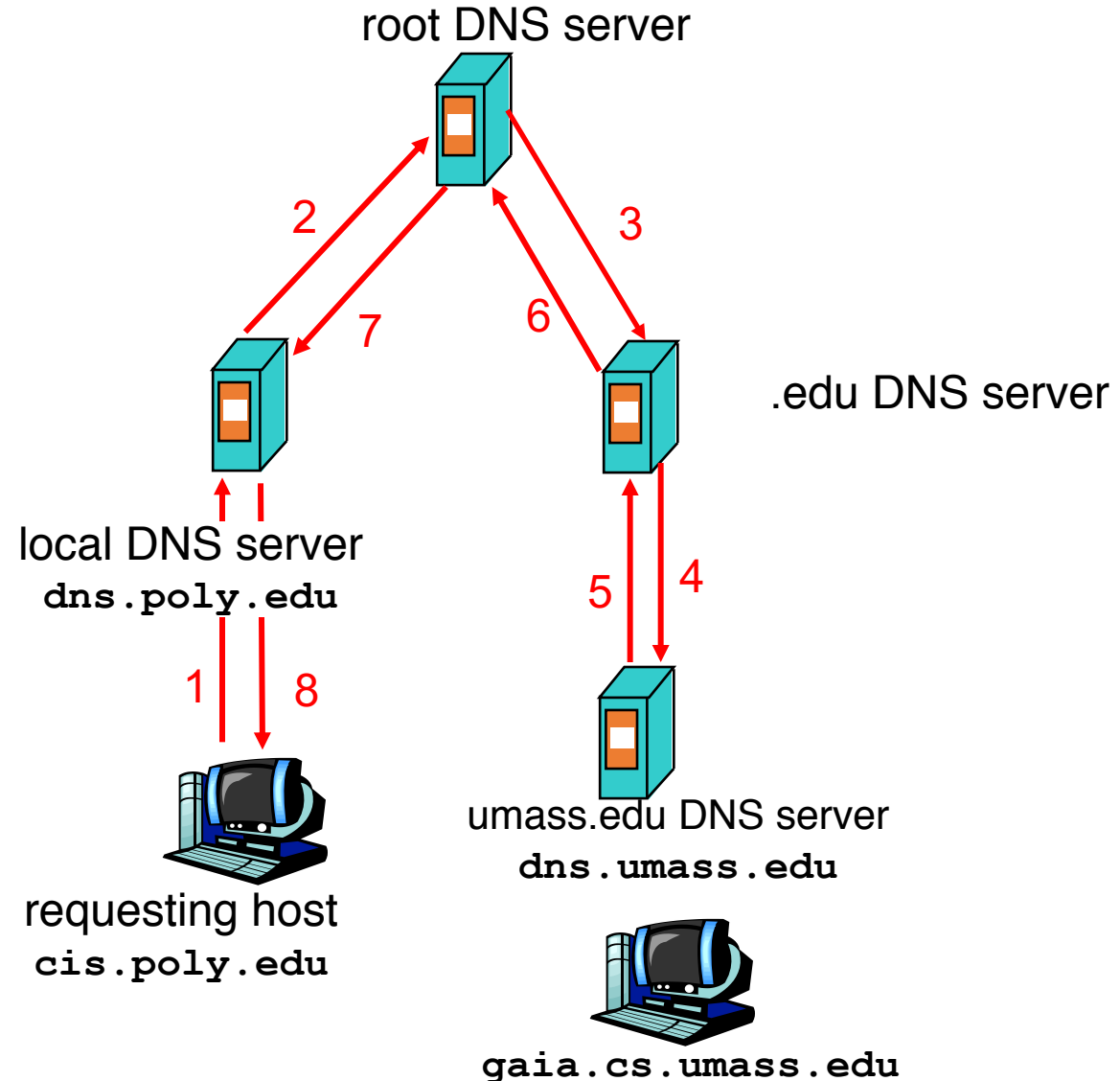
# Query type

## Recursive query:

- Puts burden of name resolution on the contacted name server

Problem: think about the root DNS server.

- Must it answer every DNS query?





# DNS in action

- A small demo



# CS 352

# DNS Records

Lecture 3.3, Spring 2020

<http://www.cs.rutgers.edu/~sn624/352>

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# DNS records

DNS: distributed database storing resource records (RR)

RR format: (name, type, class, ttl, addr)

Type=A

- ❖ **name** is hostname
- ❖ **value** is IP address

Type=AAAA

- ❖ **name** is hostname
- ❖ **value** is IPv6 address

• Type=NS

- **name** is domain (e.g. foo.com)
- **value** is hostname of authoritative name server for this domain

Type=CNAME

- ❖ **name** is alias name for some “canonical” (the real) name  
www.ibm.com is really  
servereast.backup2.ibm.com
- ❖ **value** is canonical name

Type=MX

- ❖ **value** is name of mailserver associated with **name**

# DNS Record example

RRs in response  
to query

NAME	Design.cs.rutgers.edu
TYPE	A
CLASS	IN
TTL	1 day(86400)
ADDRESS	192.26.92.30

records for  
authoritative  
servers  
Information about  
nameserver

NAME	Cs.rutgers.edu
TYPE	NS
CLASS	IN
TTL	1 day(86400)
NSDNAME	Ns-lcsr.rutgers.edu

DNS serves as a general repository of information on the Internet...

# DNS record types

- A small demo

# DNS caching and updating records

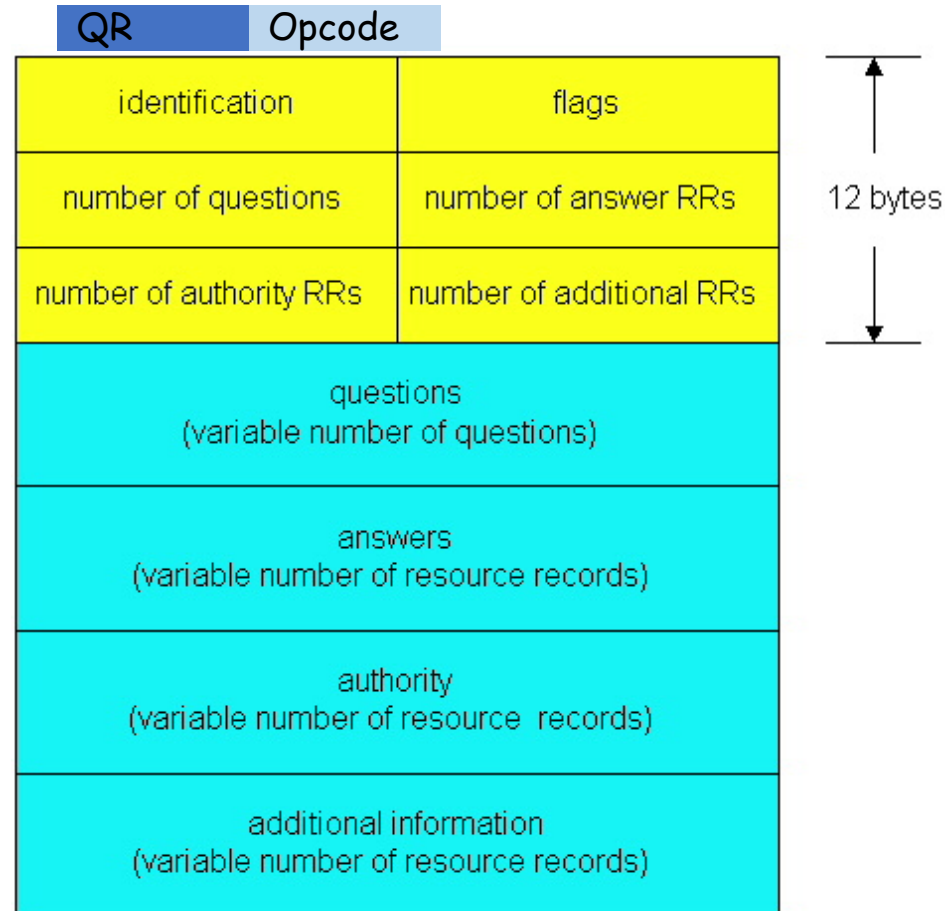
- Once (any) name server learns a name to IP address mapping, it *caches* the mapping
  - Cache entries timeout (disappear) after some time
  - TLD servers typically cached in local name servers
  - In practice, root name servers aren't visited often

# DNS protocol messages

DNS protocol : *query* and *reply* messages, both with same *message format*

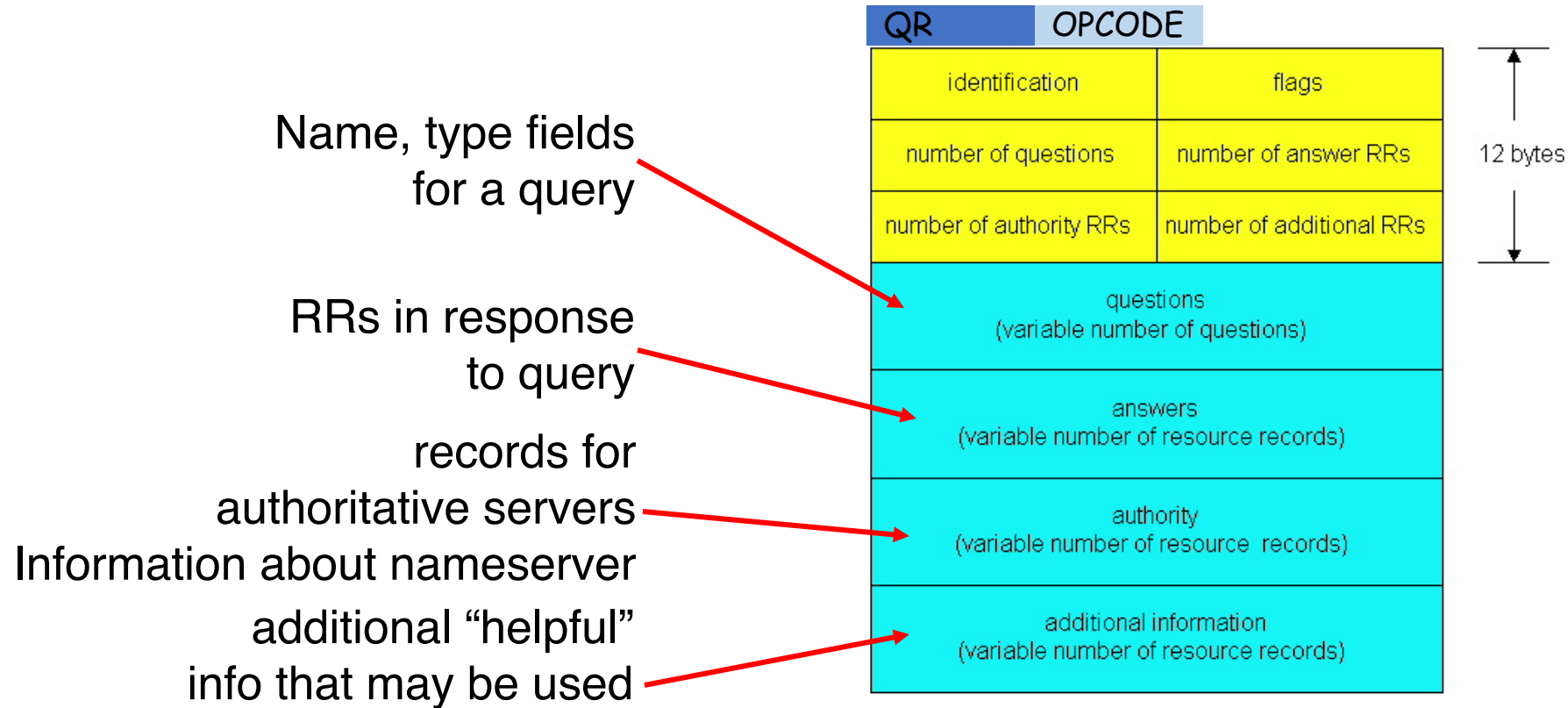
## Message header

- QR = 0 for Query, 1 for response
- Opcode= 0 standard
- **identification**: 16 bit # for query, reply to query uses same #
- **flags**:
  - Authoritative answer
  - recursion desired
  - recursion available
  - reply is authoritative





# DNS protocol, messages



# Bootstrapping DNS

- How does a host contact the name server if all it has is the domain name and no (name server) IP address?
- IP address of at least 1 nameserver (usually, a local resolver) must be known a priori
- The name server may be bootstrapped “statically”, e.g.,
  - File `/etc/resolv.conf` in unix
  - Start -> settings-> control panel-> network ->TCP/IP -> properties in windows
- ... or with another protocol!
  - **DHCP**: Dynamic Host Configuration Protocol (more on this later)

# Summary of DNS

- Hostname to IP address translation via a global network of servers
- Use Multiple layers of indirection
  - Hierarchically scale
  - Good performance (load distribution)
  - Resilient to local transient failure
- Additional load distribution can happen at each level (e.g., TLD server)
- Uses **caching** all over for better performance
- DNS can be used to implement useful primitives atop domain names:
- Example: Replicated Web services
- Domain-authoritative server will return an address from a pool of IP addresses. Example: Google server farm

# Some themes and observations on DNS

- Request/response nature of the protocol
- How messages are structured: simple, text-based protocol
  - Similarly in HTTP, SMTP, FTP
- Caching

