# Chapter 9
# Applications

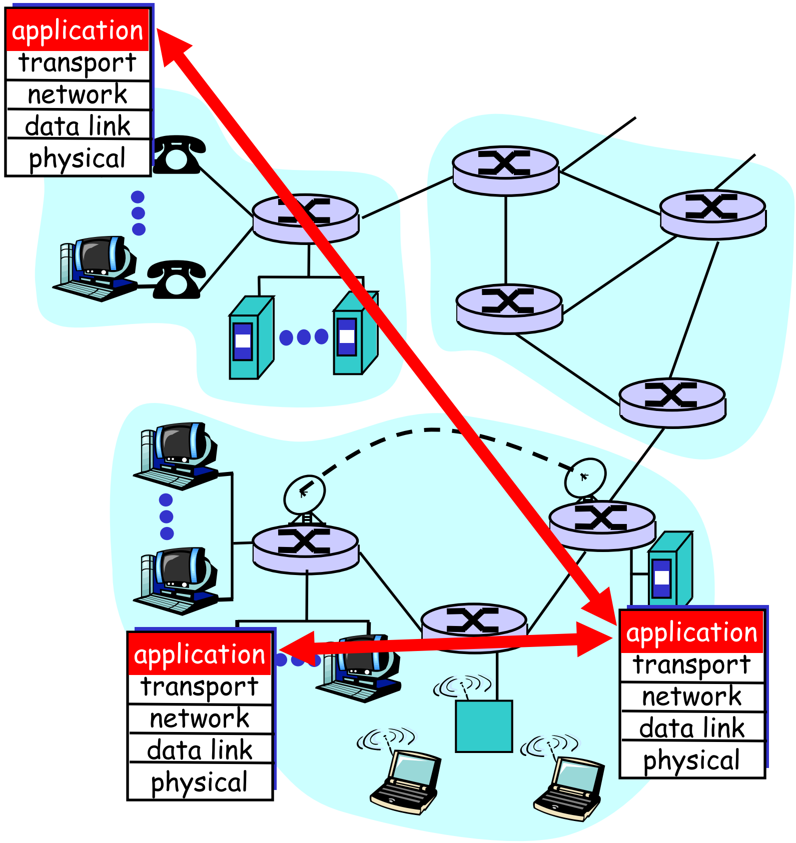
# Applications and application-layer protocols

Application: communicating, distributed processes

- running in network hosts in "user space"
- exchange messages to implement application
- e.g., email, ftp, Web

Application-layer protocols

- one "piece" of an app
- define messages exchanged by apps and actions taken
- use communication services provided by lower layer protocols (TCP, UDP)



# Network applications: some jargon

Process: program running within a host.

- within same host, two processes communicate using interprocess communication (defined by OS).
- processes running in different hosts communicate with an application-layer protocol

- user agent: software process, interfacing with user "above" and network "below".
  - implements application-level protocol
  - Web: browser
  - E-mail: mail reader
  - streaming audio/video: media player

# Client-server paradigm

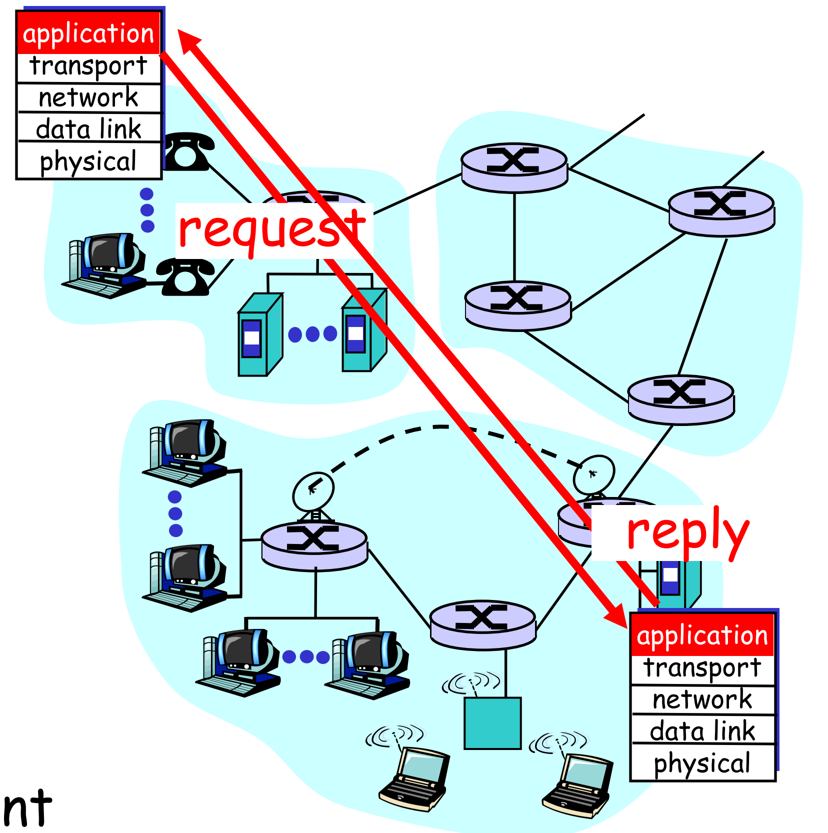
Typical network app has two pieces: *client* and *server*

**Client:**

- initiates contact with server ("speaks first")
- typically requests service from server,
- Web: client implemented in browser; e-mail: in mail reader

**Server:**

- provides requested service to client
- e.g., Web server sends requested Web page, mail server delivers e-mail



# Internet apps: application, transport protocols

| Application | Application layer protocol | Underlying transport protocol |
|---|---|---|
| e-mail | smtp [RFC 821] | TCP |
| remote terminal access | telnet [RFC 854] | TCP |
| Web | http [RFC 2068] | TCP |
| file transfer | ftp [RFC 959] | TCP |
| streaming multimedia | proprietary (e.g. RealNetworks) | TCP or UDP |
| remote file server | NSF | TCP or UDP |
| Internet telephony | proprietary (e.g., Vocaltec) | typically UDP |

# Traditional Applications

# Traditional Applications

- The traditional applications are directly invoked by users:
  - **World Wide Web**, **E-mail** and **Network Management**
- Focus on four application protocols:
  - **SMTP: Simple Mail Transfer Protocol**
    - Is used to exchange electronic mail
  - **HTTP: HyperText Transport Protocol**
    - Is used to communicate between Web browsers and Web servers
  - **DNS: Domain Name System Protocol**
    - Is used to query name servers and send the responses
  - **SNMP: Simple Network Management Protocol**
    - Is used to query or modify the state of remote network nodes

# Traditional Applications

- All of these application protocols follow the same **request/reply** communication mechanism
  - All are implemented on top of either **TCP or UDP**
- Each protocol (except DNS) has a companion protocol that specifies **the format of the data** that can be exchanged
  - **SMTP: RFC 822 and MIME (Multipurpose Internet Mail Extensions)** define the format of email messages
  - **HTTP: HTML (HyperText Markup Language)** is a specification that defines the form of those pages
  - **SNMP: MIB (Management Information Base)** defines the variables that can be queried

# Electronic Mail
# (SMTP, MIME, IMAP)

# Message Format (RFC 822)

- **RFC 822** defines messages to have two parts:
  - A **header** and a **body**
  - Both parts are represented in **ASCII text**
- The message header is a series of **<CRLF>**-terminated lines
  - <CRLF> stands for carriage-return + line-feed
    - Are a pair of ASCII control characters often used to indicate **the end of a line of text**
  - The header is separated from the message body by a **blank line**
  - Each header line contains a **type** and **value** separated by a colon (:)

# American Standard Code for Information Interchange (ASCII)

- 7 bit code
- Reserves the first 32 codes (numbers 0–31 decimal) for control characters
- Line feed 0A
- Carriage return 0D

**USASCII code chart**

| $b_7 b_6 b_5$ → Bits | | | | | 0 0 0 | 0 0 1 | 0 1 0 | 0 1 1 | 1 0 0 | 1 0 1 | 1 1 0 | 1 1 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $b_4$ | $b_3$ | $b_2$ | $b_1$ | Column / Row | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 0 | 0 | 0 | 0 | 0 | NUL | DLE | SP | 0 | @ | P | ` | p |
| 0 | 0 | 0 | 1 | 1 | SOH | DC1 | ! | 1 | A | Q | a | q |
| 0 | 0 | 1 | 0 | 2 | STX | DC2 | " | 2 | B | R | b | r |
| 0 | 0 | 1 | 1 | 3 | ETX | DC3 | # | 3 | C | S | c | s |
| 0 | 1 | 0 | 0 | 4 | EOT | DC4 | $ | 4 | D | T | d | t |
| 0 | 1 | 0 | 1 | 5 | ENQ | NAK | % | 5 | E | U | e | u |
| 0 | 1 | 1 | 0 | 6 | ACK | SYN | & | 6 | F | V | f | v |
| 0 | 1 | 1 | 1 | 7 | BEL | ETB | ' | 7 | G | W | g | w |
| 1 | 0 | 0 | 0 | 8 | BS | CAN | ( | 8 | H | X | h | x |
| 1 | 0 | 0 | 1 | 9 | HT | EM | ) | 9 | I | Y | i | y |
| 1 | 0 | 1 | 0 | 10 | LF | SUB | * | : | J | Z | j | z |
| 1 | 0 | 1 | 1 | 11 | VT | ESC | + | ; | K | [ | k | { |
| 1 | 1 | 0 | 0 | 12 | FF | FS | , | < | L | \ | l | \| |
| 1 | 1 | 0 | 1 | 13 | CR | GS | − | = | M | ] | m | } |
| 1 | 1 | 1 | 0 | 14 | SO | RS | . | > | N | ^ | n | ~ |
| 1 | 1 | 1 | 1 | 15 | SI | US | / | ? | O | _ | o | DEL |

# Message Format (RFC 822)

- The message header includes the following types:
  - **To:** identifies the message **recipient**
  - **Subject:** something about the **purpose** of the message
  - Other headers are filled in by the underlying **mail delivery system**
  - **Date:** when the message was transmitted
  - **From:** what user sent the message
  - **Received:** each mail server that handled this message
  - There are also many other header lines
- RFC 822 was extended in 1993 to allow email messages to carry many **different types of data**
  - Audio, video, images, Word documents, and so on

# Message Format (MIME, First Piece)

- **MIME (Multipurpose Internet Mail Extensions)** consists of **three** basic pieces
- The **first piece** is a collection of **header lines**
  - Expand the original set defined by RFC 822
- These **header lines** describe the data being carried in the message body
  - **MIME-Version:** the version of MIME being used
  - **Content-Description:** a human-readable description of what's in the message, analogous to the **Subject:** line
  - **Content-Type:** the type of data contained in the message
  - **Content-Transfer-Encoding:** how the data in the message body is encoded

# Message Format (MIME, Second Piece)

- The **second piece** is **definitions** for a set of **content types and subtypes**
  - MIME defines two different **still image types**: **image/gif** and **image/jpeg**
  - MIME also defines **text types**: **text/plain** (simple text) and **text/richtext** (a message that contains “marked up” text)
    - Marked up text: e.g., text using special fonts, italics, etc.
  - MIME defines an **application type**:
    - **Subtypes:** the output of different application programs (e.g., **application/postscript** and **application/msword**)
- MIME also defines a **multipart type** that says how a message carrying more than one data type is structured

# Message Format (MIME, Third Piece)

- The **third piece** is a way to **encode the various data types** so they can be shipped in an **ASCII email message**
  - Email messages contain only ASCII
- They might pass through a number of **intermediate systems** that assume the message is in ASCII
  - The messages would **corrupt** if it contained **non-ASCII characters**
- Some data types (e.g. a JPEG image):
  - Any given **8-bit byte** in the image might contain one of **256 different values**
  - Only a **subset** of these values are **valid ASCII characters**
    - Number of ASCII characters < 256

# Message Format (MIME, Third Piece)

- MIME uses a **straightforward** encoding of binary data into the ASCII character set
  - The encoding is called **base64**
    - Map every **three bytes** of the original binary data into **four ASCII characters**
  - Group the binary data into **24-bit** (3×8) units, and breaking each such unit into **four 6-bit** (4×6 = 24) **pieces**
  - Each **6-bit piece** maps onto one of **64 valid ASCII** characters (the first 64 values in the ASCII character set)
    - The **52** upper- and lower-case letters, the **10** digits 0 through 9, and the special characters **+ and /**
- "ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789+/"

# Message Format (MIME)

- A message that contains some plain text, a JPEG image and a PostScript file would look something like this:

```
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary="-------417CA6E2DE4ABCAFBC5"
From: Alice Smith <Alice@cisco.com>
To: Bob@cs.Princeton.edu
Subject: promised material
Date: Mon, 07 Sep 1998 19:45:19 -0400

---------417CA6E2DE4ABCAFBC5
Content-Type: text/plain; charset=us-ascii
Content-Transfer-Encoding: 7bit

Bob,
```

# Message Format (MIME)

```
Bob,

Here's the jpeg image and draft report I promised.

--Alice

---------417CA6E2DE4ABCAFBC5
Content-Type: image/jpeg
Content-Transfer-Encoding: base64
```

... *unreadable encoding of a jpeg figure*

```
---------417CA6E2DE4ABCAFBC5
Content-Type: application/postscript; name="draft.ps"
Content-Transfer-Encoding: 7bit
```

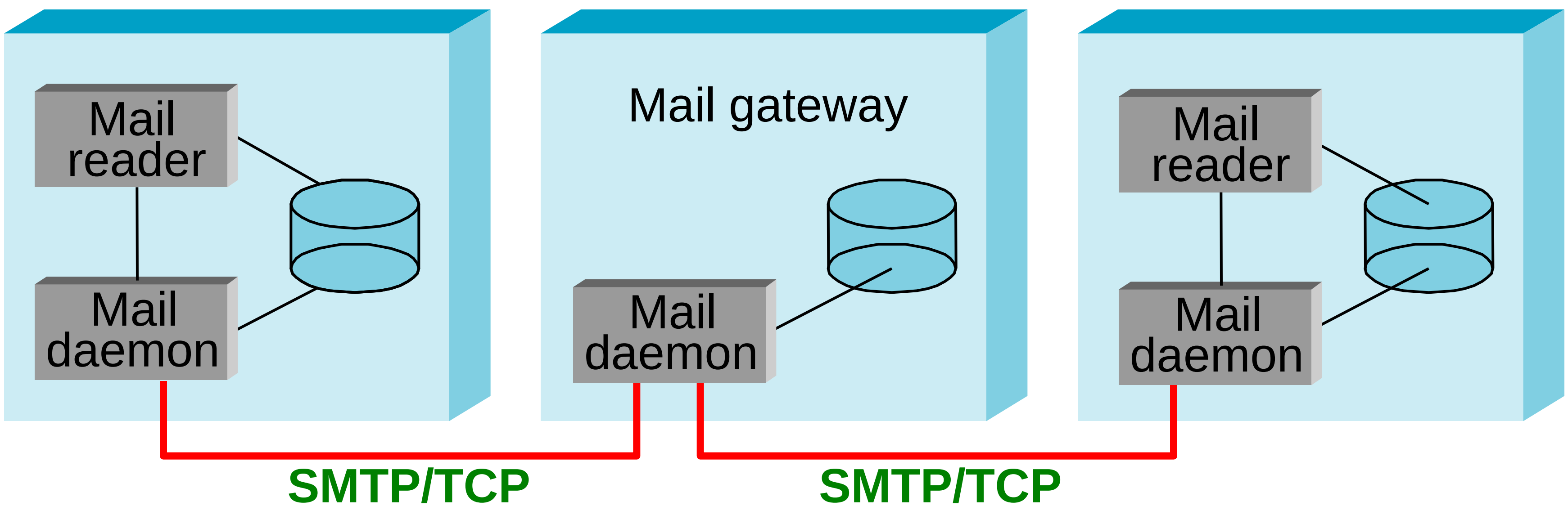
... *readable encoding of a PostScript document*

# Message Transfer (SMTP)

- **SMTP:** the protocol used to transfer messages from one host to another
  - Users interact with a **mail reader**
    - Use to compose, file, search, and read their email
  - There is a **mail daemon** (or process) running on each host
  - The daemon uses SMTP running **over TCP** to transmit the message to a daemon running on another machine
  - The daemon puts incoming messages into the user's **mailbox**
    - User's mail reader can later find it

# Message Transfer (SMTP)

- In many cases, the mail traverses one or more **mail gateways** on its route from the sender's host to the receiver's host
  - These gateways also run a **sendmail** process
- A mail gateway typically **buffers** messages on disk and is willing to **try retransmitting** them to the next machine for several days



# Message Transfer (SMTP)

- For example, mail delivered to **Bob@oz.nthu.edu.tw**
  - Is first sent to a **mail gateway** OZ at NTHU
  - Then is forwarded **(a second SMTP/TCP connection)** to the specific machine on which Bob is reading his email
- The forwarding gateway maintains a database that maps **users** into the **machine** on which they currently receive their mails
  - The sender **need not** be aware of this specific name
  - The recipient's machine may not always be up
- Each SMTP session involves a dialog between the two mail daemons
  - One acting as the **client** and the other acting as the **server**
  - SMTP is also **ASCII based**

# Message Transfer (SMTP)

- Bob at Princeton (cs.princeton.edu) is trying to send mail to users Alice and Tom at Cicso (cisco.com)
- HELO cs.princeton.edu ← **From cs.princeton.edu**
- 250 Hello daemon@mail.cs.princeton.edu [128.12.169.24] ← **From cisco.com**
- MAIL FROM:<Bob@cs.princeton.edu>
- 250 OK
- RCPT TO:<Alice@cisco.com>
- 250 OK
- RCPT TO:<Tom@cisco.com>
- 550 No such user here
- DATA
- 354 Start mail input; end with <CRLF>.<CRLF>
- ...etc. etc. etc.
- <CRLF>.<CRLF>
- 250 OK
- QUIT
- 221 Closing connection

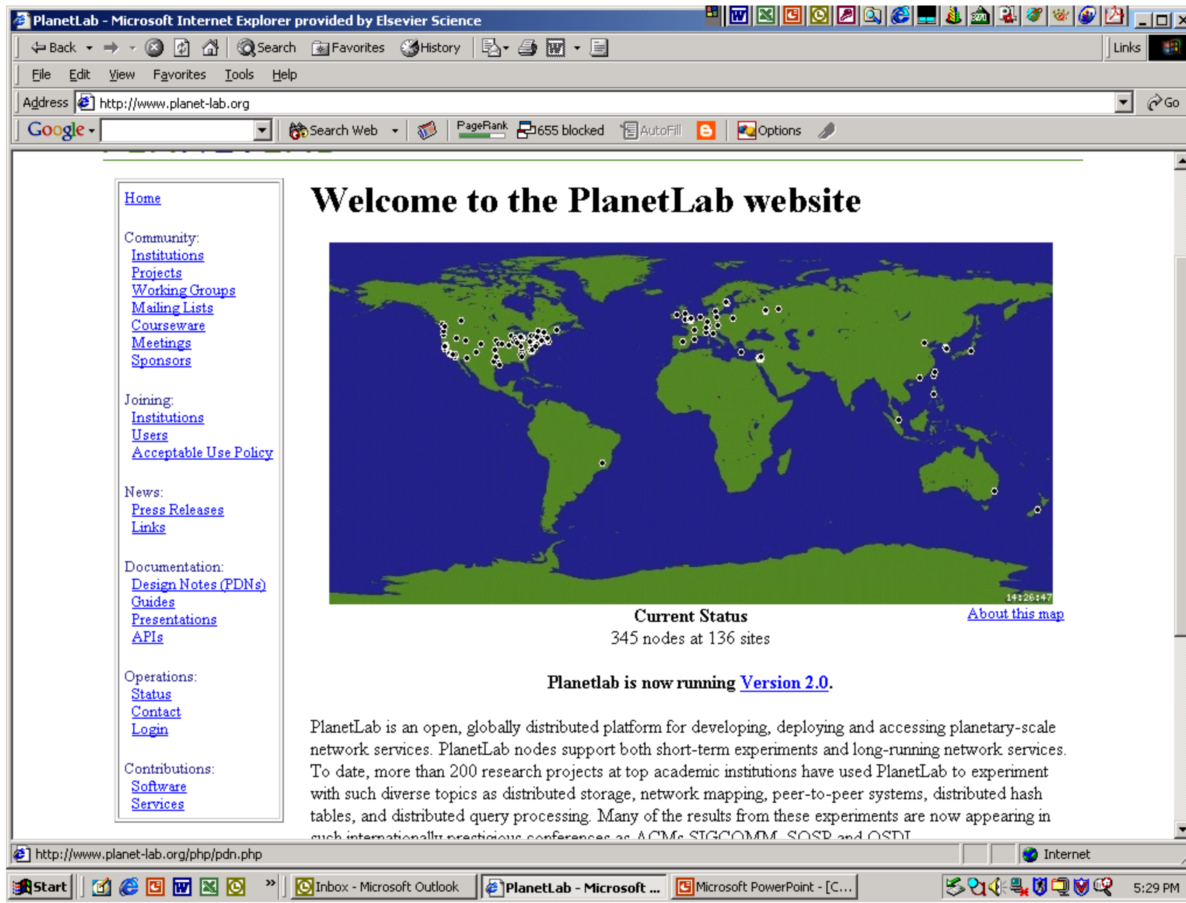
# Mail Reader

- The final step is for the user to actually **retrieve** his or her messages from the mailbox
  - Read them, reply to them, and possibly save a copy for future reference
  - The user performs all these actions by interacting with a **mail reader**
- In other cases, the user accesses his or her mailbox **from a remote machine** using yet another protocol
  - **Post Office Protocol (POP)**
  - **Internet Message Access Protocol (IMAP)**

# World Wide Web (HTTP)

# World Wide Web (HTTP)

- Web is viewed as a set of cooperating clients and servers
  - All of whom speak the same language: **HTTP**
- Web browser:
  - Netscape
  - Explorer



# World Wide Web (HTTP)

- Any Web browser has a function that allows the user to **"open a URL"**
  - **http://www.cs.princeton.edu/index.html**
  - It would open a **TCP connection** to the Web server at a machine called **www.cs.princeton.edu**
  - It would Retrieve and display the file called **index.html**
- Most files on the Web contain images and text, and some have audio and video clips
- They also include URLs that point to other files
  - These **embedded URLs** are called **hypertext links**

# World Wide Web (HTTP)

- When a page is selected, the browser (the client) acquires the page from the server using HTTP running over TCP
  - HTTP is a **text-oriented** protocol
- Each HTTP message has the general form:
  - **START_LINE <CRLF>**
  - **MESSAGE_HEADER <CRLF>**
  - **<CRLF>**
  - **MESSAGE_BODY <CRLF>**
- **START_LINE:** indicates whether this is a **request** message or a **response** message
- **MESSAGE_HEADER:** defines many possible header types
  - The set is terminated by a **blank line**
- **MESSAGE_BODY:** is the contents of the requested message

# Request Messages

- **START_LINE** of a **request message** specifies three things:
  - The operation to be performed
  - The Web page the operation should be performed on
  - The version of HTTP being used
- The two most common operations are
  - **GET:** used to retrieve and display a Web page
  - **HEAD:** used to **test the validity** of a hypertext link or to see if a particular page has been **modified** since the browser last fetched it
- **GET** http://www.cs.princeton.edu/index.html HTTP/1.1
  - The client wants the server on host www.cs.princeton.edu to return the page named index.html
  - Uses an **absolute** URL

# Request Messages

- It is also possible to use a **relative** identifier
  - Specify the host name in one of the **MESSAGE_HEADER**
  - **GET index.html HTTP/1.1**
  - **Host: www.cs.princeton.edu**

| Operation | Description |
|---|---|
| OPTIONS | Request information about available options |
| GET | Retrieve document identified in URL |
| HEAD | Retrieve meta-information about document identified in URL |
| POST | Give information (e.g., annotation) to server |
| PUT | Store document under specified URL |
| DELETE | Delete specified URL |
| TRACE | Loopback request message |
| CONNECT | For use by proxies |

# Response Messages

- **Response messages** begin with a single **START_LINE** with
  - The **version of HTTP** being used
  - A **three-digit code** indicating whether or not the request was successful, and
  - A text string giving the **reason**
  - **HTTP/1.1 202 Accepted   HTTP/1.1 404 Not Found**
- There are five general types of response codes

| Code | Type | Example Reasons |
|---|---|---|
| 1xx | Informational | Request received, continuing process |
| 2xx | Success | Action successfully received, understood, and accepted |
| 3xx | Redirection | Further action must be taken to complete the request |
| 4xx | Client Error | Request contains bad syntax or cannot be fulfilled |
| 5xx | Server Error | Server failed to fulfill an apparently valid request |

# Response Messages

- Response messages can also contain one or more **MESSAGE_HEADER** lines
  - Relay additional information back to the client
- For example, the **Location header** line specifies that the requested URL is available at another location
  - http://www.cs.princeton.edu/index.html had moved to http://www.princeton.edu/cs/index.html
- The server at the original address might respond with
  - **HTTP/1.1 301 Moved Permanently**
  - **Location: http://www.princeton.edu/cs/index.html**

# TCP Connections

- The original version of **HTTP (1.0)** established a **separate** TCP connection **for each data item** retrieved from the server
  - This was a very inefficient mechanism
  - Retrieving a page that included some text and a dozen icons
    - Would result in **13** separate TCP connections being established and closed
- The most important improvement in the latest version of **HTTP (1.1)** is to allow **persistent connections**
  - The client and server can exchange **multiple** request/response messages over **the same** TCP connection

# TCP Connections

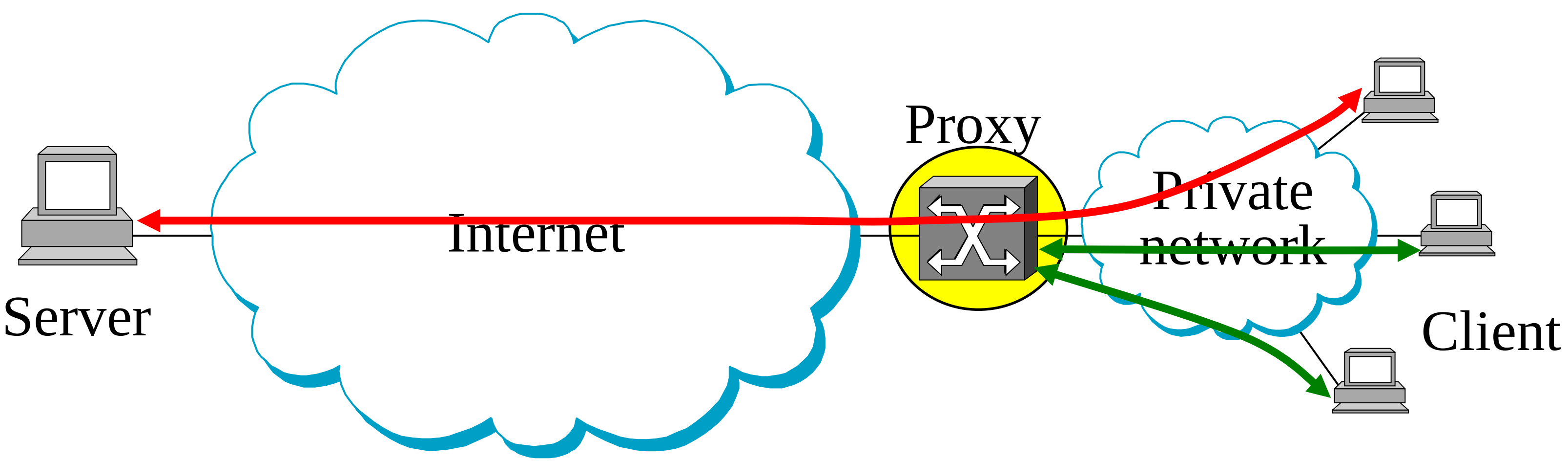
- Persistent connections have two advantages:
  - Eliminate the connection setup overhead
    - **Reduces** the **delay** and the **load** on the server, as well as on the network, caused by the additional TCP packets
  - TCP's congestion window mechanism is able to operate **more efficiently**
    - Does not go through the **slow start** phase for each page
- Neither the client nor server necessarily knows **how long** to keep a particular TCP connection open
  - The server must **time out** and **close** a connection if it has received no requests on the connection for a period of time

# Caching

- From the **client's** perspective, a page that can be retrieved from a nearby cache can be **displayed much more quickly**
- From the **server's** perspective, having a cache intercept and satisfy a request **reduces the load on the server**
- Caching can be implemented in many different places:
  - A **user's browser** can cache recently accessed pages
    - Display the cached copy if the user visits the same page again
  - A **site** can support a single sitewide cache
    - Allows users to take advantage of pages previously downloaded by **other users**
  - **ISPs** can cache pages

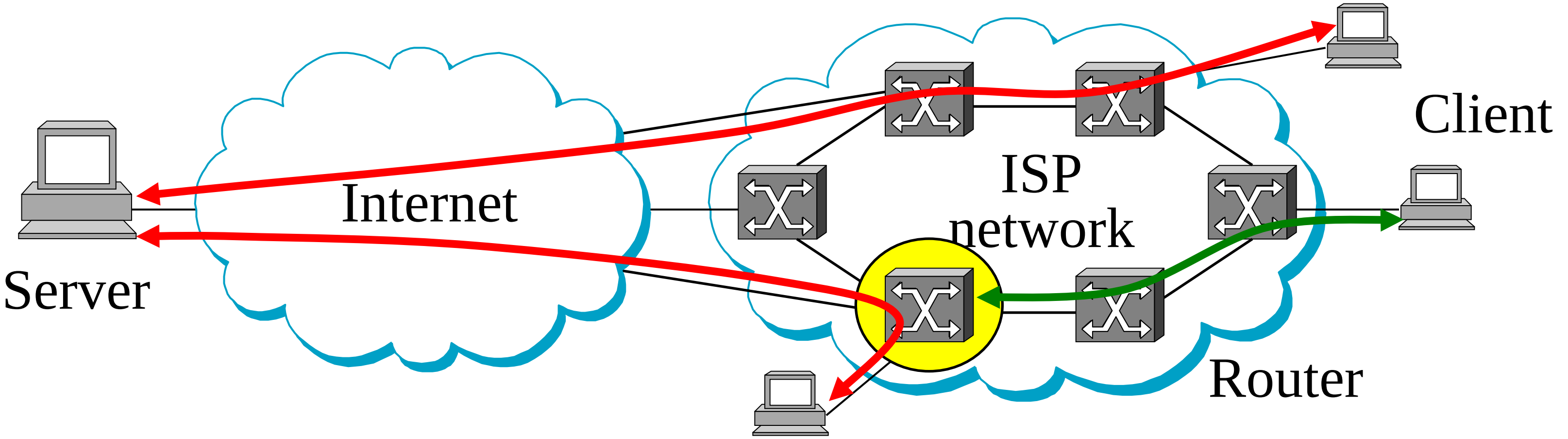
# Caching

- In the second case, the users within the site most likely know **what machine** is caching pages on behalf of the site
  - They configure their browsers to connect directly to the **caching host** (called a **proxy**)



# Caching

- In contrast, the sites that connect to the ISP are probably not aware that the **ISP is caching pages**
  - The HTTP requests coming out of the various sites pass through **a common ISP router**
  - This router **peeks inside the URL** for the requested page
    - If it has the page in its cache, it returns this page
    - If not, it forwards the request to the server



# Caching

- No matter where pages are cached, the cache needs to make sure it is not responding with an **out-of-date version** of the page
  - The **server** assigns an **expiration date** to each page it sends back to the client
    - In the Expires header field
  - The **cache** **remembers** this date
    - It need **not re-verify** the page each time it is requested until after that expiration date has passed

# Domain Name Service (DNS)

# Domain Name Service (DNS)

- We have been using **addresses** to identify hosts (192.12.69.5)
  - Addresses are perfectly suitable for processing by **routers**
  - Addresses are **not exactly user friendly**
- A **unique name** is also assigned to each host in a network
- **Host names** differ from host addresses in two important ways:
  - They are usually of **variable length** and containing letters
    - Easier for humans to remember
  - They typically contain **no information** that helps the network to locate the host
- A **naming server** must be developed to map **user-friendly** names into **router-friendly** addresses

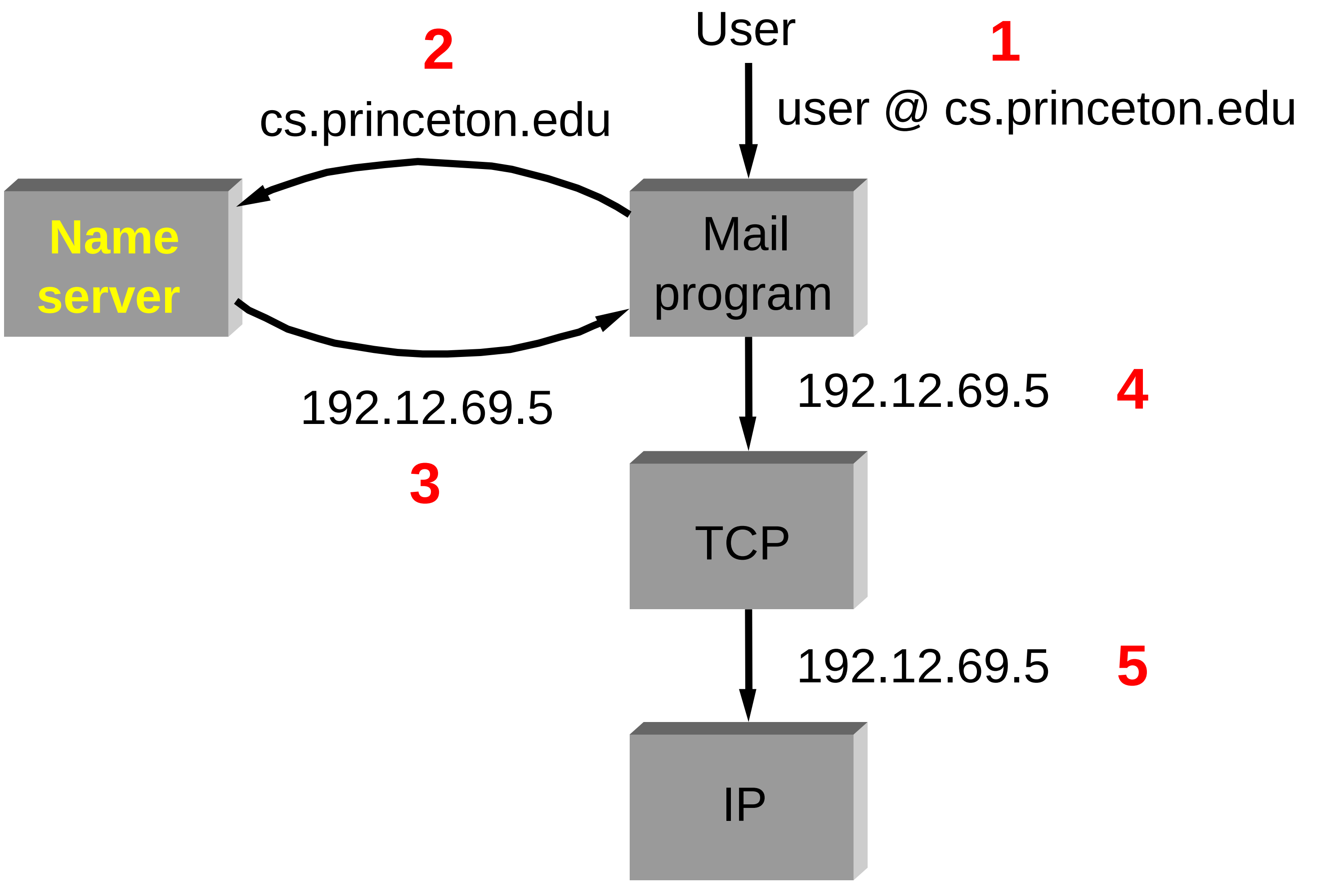
# Domain Name Service (DNS)

- **Name space:** defines the set of possible names
  - **Flat:** names are not divisible into components, or
  - **Hierarchical:** XXX.com, XXX.tw, XXX.nthu.edu.tw
- The naming system maintains a collection of bindings of **names to values**
  - The value is generally an **IP address**
- **Resolution mechanism** is a procedure that returns the corresponding value
- **Name server** is a specific implementation of a resolution mechanism that is available on a network
  - It can be queried by sending it a message

# Domain Name Service (DNS)

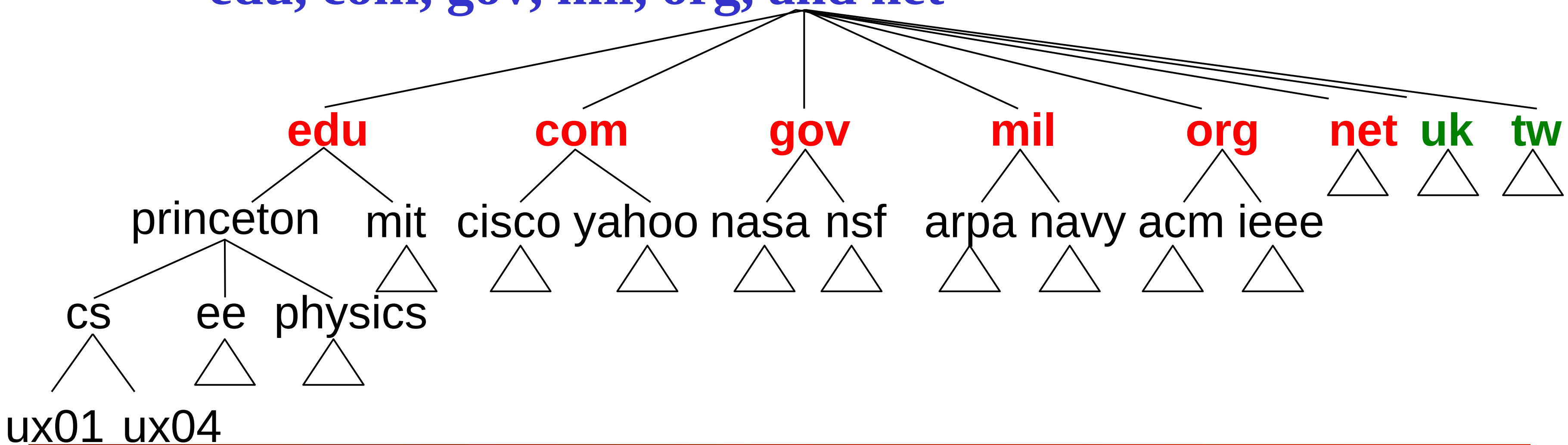
- The Internet has a particularly well-developed naming system — **Domain Name System (DNS)**
  - DNS employs a **hierarchical** name space
  - The name space is partitioned into **disjoint** pieces and distributed throughout the Internet
- A user presents a **host name** to an application program (such as the Web Browser)
  - This program engages the naming system to **translate** this name into a **host address**
  - According to the returned **host's IP address**, the application then **opens a connection** to this host

# Domain Name Service (DNS)



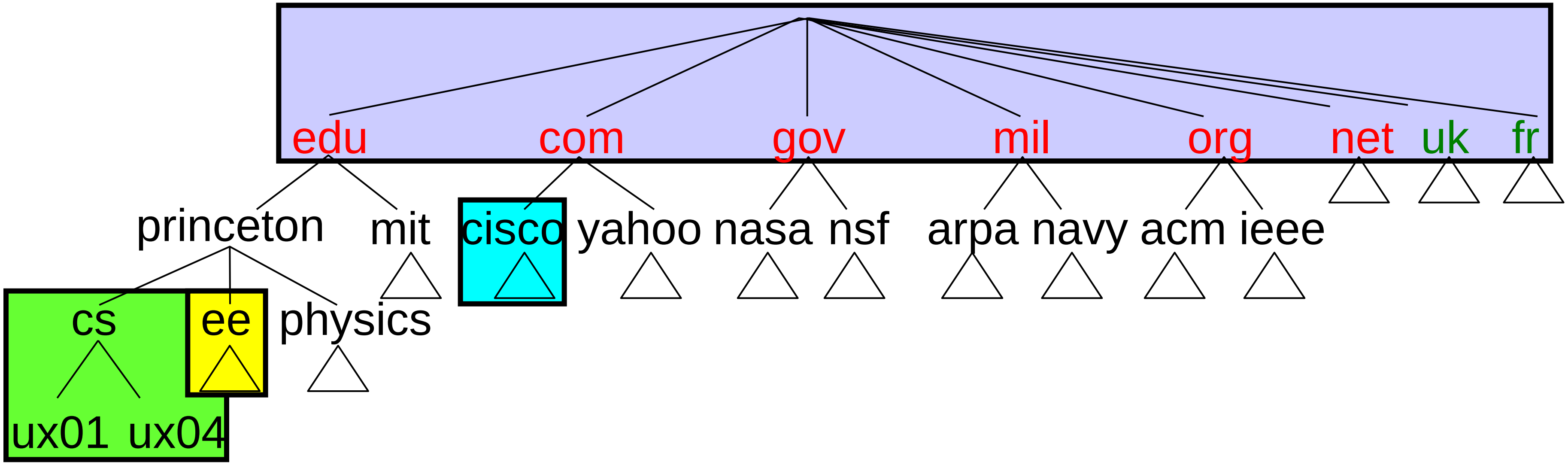
# Domain Hierarchy

- DNS names are processed from **right to left** (ee.nthu.edu.tw)
- DNS maps domain names into values
  - We assume that these values are **IP addresses**
- Each node in the tree corresponds to a **domain**
  - The leaves in the tree correspond to the **hosts** being named
- There are domains for **each country**, plus **“big six” domains**:
  - **edu, com, gov, mil, org, and net**



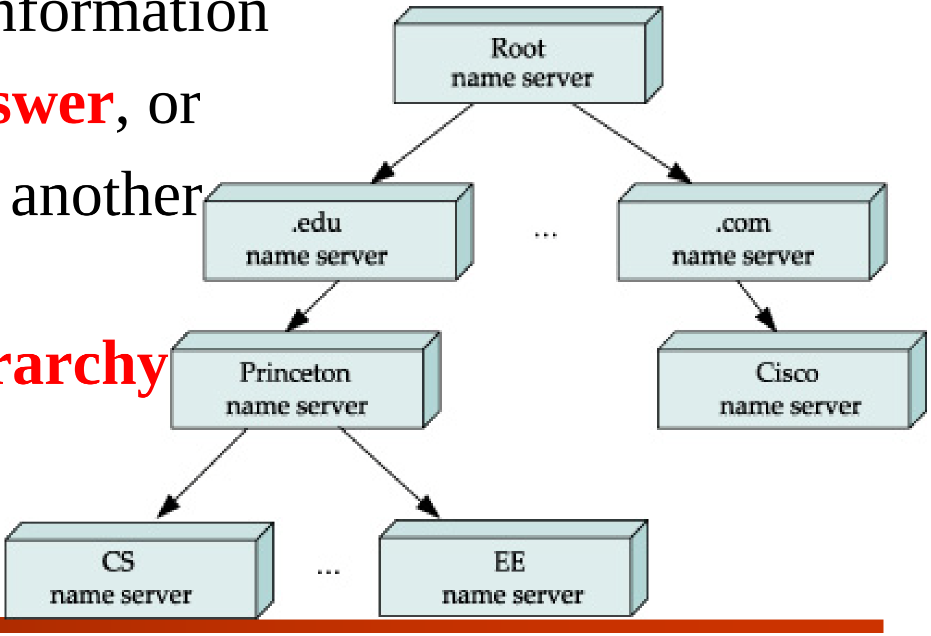
# Name Servers

- How this hierarchy is actually implemented?
  - The first step is to partition the hierarchy into subtrees called **zones**
- Each zone can be thought of as corresponding to some **administrative authority**
  - Which is responsible for that portion of the hierarchy



# Name Servers

- **Zone:** corresponds to the fundamental unit of implementation in DNS — the **name server**
- The information is implemented in **two or more** name servers
  - For the sake of **redundancy**
- Clients send queries to name servers, and name servers respond with the requested information
  - May contain the **final answer**, or
  - May contain a **pointer** to another server for next query
- DNS is represented by a **hierarchy of name servers** rather than by a hierarchy of domains



# Name Servers

- The zone information is implemented as resource records
  - A resource record is a **name-to-value** binding
  - A 5-tuple that contains the following fields:

**<Name, Value, Type, Class, TTL>**

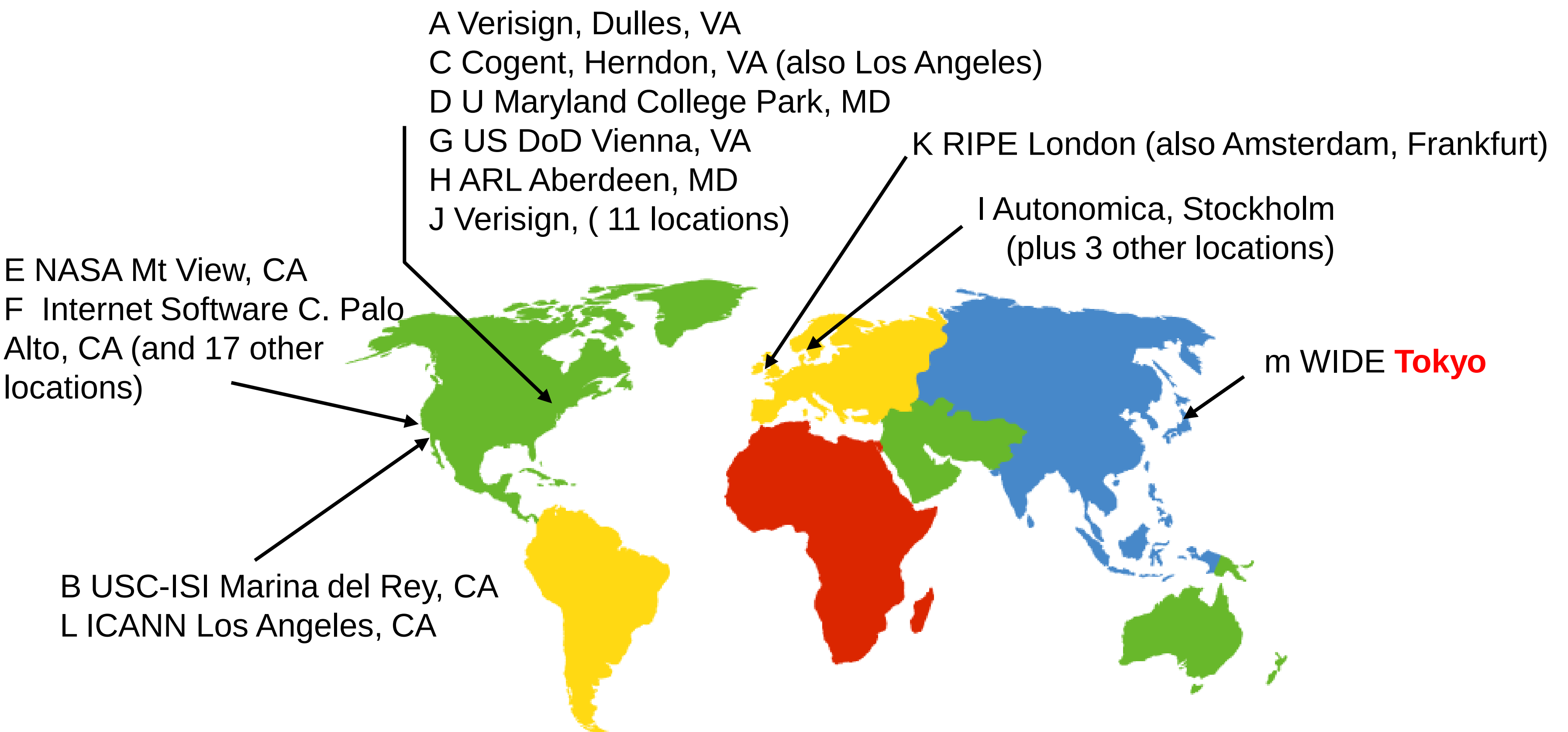
- **Type:** specifies how the **Value** should be interpreted
  - **A: Value** is an **IP address**
  - **NS: Value** gives **the domain name for a name server** that knows how to resolve names within the domain
  - **CNAME: Value** gives the **canonical name** for a particular host
  - **MX: Value** gives **the domain name for a mail server** that accepts messages for the specified domain

# Name Servers

- **Class:** allows entities to define useful record types
  - **IN:** the only widely used Class which is used by the Internet
- **TTL:** shows how long this resource record is valid
  - When the TTL expires, the server must erase the record from its cache

# Root Servers

- **13** root servers (see **http://www.root-servers.org/**)
  - Labeled **A** through **M**



# Name Servers **(Root Server)**

- First, the root name server contains an **NS record** for each **second-level server**
- It also has an **A record** that translates this name into the corresponding **IP address**
- These two records effectively implement a **pointer** from the root name server to each of the second-level servers

**< princeton.edu, cit.princeton.edu, NS, IN>**

**<cit.princeton.edu, 128.196.128.233, A, IN>**

**Second-level server**

**<cisco.com, ns.cisco.com, NS, IN>**

**<ns.cisco.com, 128.96.32.20, A, IN>**

**…**

# Name Servers **(Second-Level Server)**

- The domain **princeton.edu** has a name server available on host **cit.princeton.edu** that contains the following records
  - Some records give the **final answer (IP addresses)**
  - Others point to **third-level name servers**

**<cs.princeton.edu, gnat.cs.princeton.edu, NS, IN>**

**<gnat.cs.princeton.edu, 192.12.69.5, A, IN>**

**<ee.princeton.edu, helios.ee.princeton.edu, NS, IN>**

**<helios.ee.princeton.edu, 128.196.28.166, A, IN>**

**<jupiter.physics.princeton.edu, 128.196.4.1, A, IN>**

**<saturn.physics.princeton.edu, 128.196.4.2, A, IN>**

**<mars.physics.princeton.edu, 128.196.4.3, A, IN>**

**<venus.physics.princeton.edu, 128.196.4.4, A, IN>...**

# Name Servers **(Third-Level Server)**

- Finally, a third-level name server, such as the one managed by domain **cs.princeton.edu**, contains **A records** for **all** of its hosts
- It might also define **a set of aliases (CNAME records)** for each of those hosts
  - Aliases are sometimes just **convenient (e.g., shorter) names** for machines
  - For example, **www.cs.princeton.edu** is an alias for the host named **cicada.cs.princeton.edu**

# Name Servers **(Third-Level Server)**

**<cs.princeton.edu, gnat.cs.princeton.edu, MX, IN>**

**<cicada.cs.princeton.edu, 192.12.69.60, A, IN>**

**<cic.cs.princeton.edu, cicada.cs.princeton.edu, CNAME,IN>**

**<gnat.cs.princeton.edu, 192.12.69.5, A, IN>**

**<gna.cs.princeton.edu, gnat.cs.princeton.edu, CNAME, IN>**

**<www.cs.princeton.edu, 192.12.69.35, A, IN>**

**<cicada.cs.princeton.edu, roach.cs.princeton.edu, CNAME, IN>**

**…**

# Name Resolution **(Root Server)**

- Suppose the client wants to resolve **cicada.cs.princeton.edu**
- The client first sends a **query** containing this name to the **root server**
- The root server, unable to match the entire name,
  - Returns **the best match** it has — the **NS record** for **princeton.edu**
- The root server also returns **all** records that are related to this record
  - The **A record** for **cit.princeton.edu**

**< princeton.edu, cit.princeton.edu, NS, IN>**

**<cit.princeton.edu, 128.196.128.233, A, IN>**

# Name Resolution **(Second-Level Server)**

- The client next sends **the same query** to the name server at IP host **128.196.128.233**
- This server also **cannot match** the whole name
  - Returns the **NS** and corresponding **A records** for the **cs.princeton.edu** domain

**<cs.princeton.edu, gnat.cs.princeton.edu, NS, IN>**

**<gnat.cs.princeton.edu, 192.12.69.5, A, IN>**

# Name Resolution **(Third-Level Server)**

- Finally, the client sends **the same query** as before to the server at IP host **192.12.69.5**
- This time gets back the **A record** for **cicada.cs.princeton.edu**

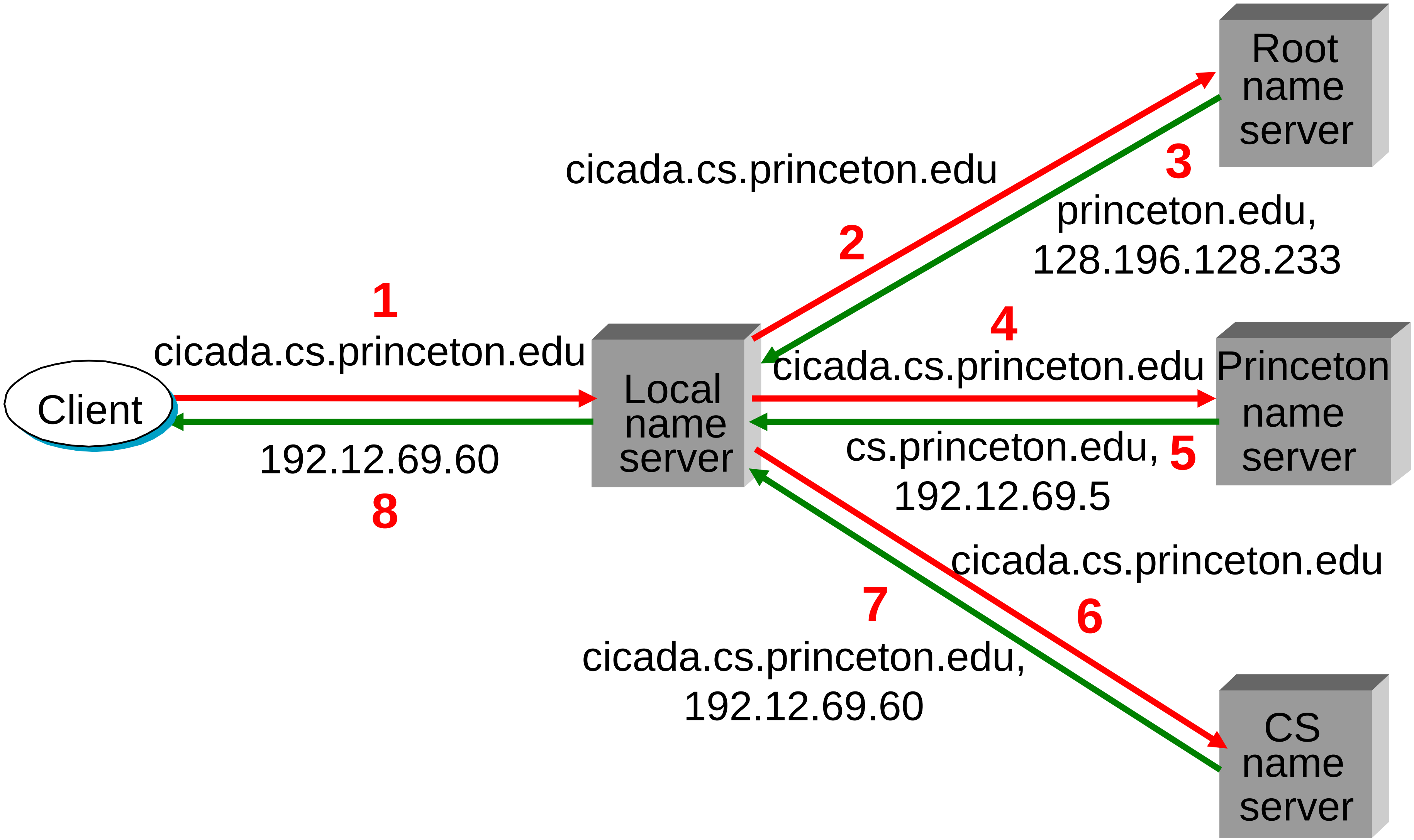
  **<cicada.cs.princeton.edu, 192.12.69.60, A, IN>**

- In practice, not all clients know about the root servers
  - The client program running on each Internet host is **initialized** with the address of a **local name server**
- For example, a local name server **gnat.cs.princeton.edu**

  **<'root', venera.isi.edu, NS, IN>**

  **<venera.isi.edu, 128.9.0.32, A, IN>**

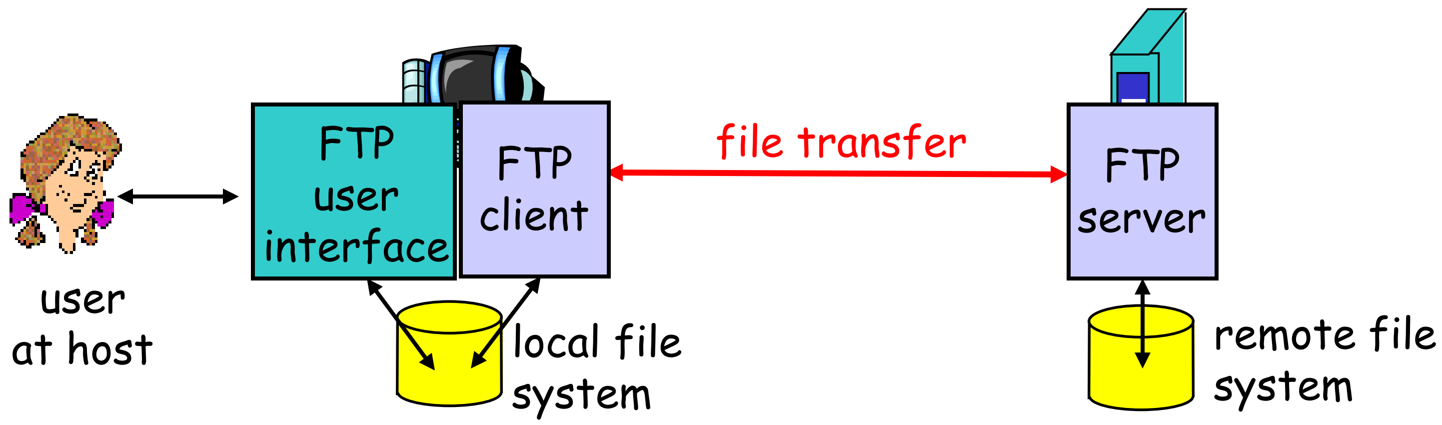
# Name Resolution



# Simple Network Management Protocol (SNMP)

- Allow us to read, write state information on different network nodes
- It is a request/reply protocol: GET and SET
- SNMP runs on top of UDP
- Management information base (MIB) -- A MIB is a collection of managed objects residing in a virtual information store.
  - 10 different groups in MIB-II
  - for example: System, Interfaces, Address Translation, IP. TCP, UDP
- Presentation format: ASN.1

# ftp: the file transfer protocol

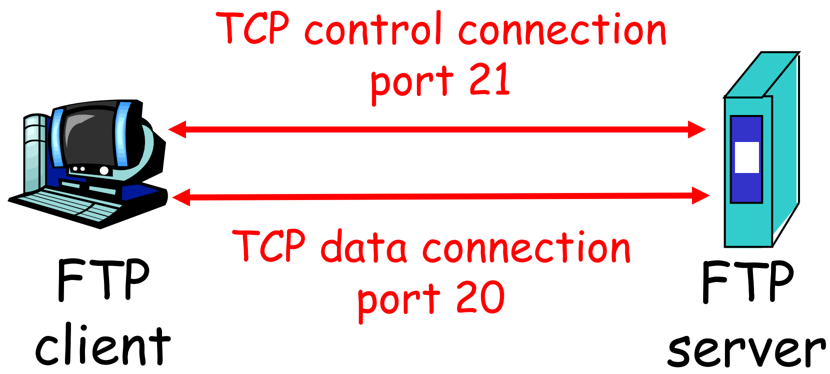



- transfer file to/from remote host
- client/server model
  - *client:* side that initiates transfer (either to/from remote)
  - *server:* remote host
- ftp: RFC 959
- ftp server: port 21

# ftp: separate control, data connections

- ftp client contacts ftp server at port 21, specifying TCP as transport protocol
- two parallel TCP connections opened:
  - control: exchange commands, responses between client, server.

    "out of band control"
  - data: file data to/from server
- ftp server maintains "state": current



# ftp commands, responses

## Sample commands:

- sent as ASCII text over control channel
- **USER *username***
- **PASS *password***
- **LIST** return list of file in current directory
- **RETR filename** retrieves (gets) file
- **STOR filename** stores (puts) file onto remote host

## Sample return codes

- status code and phrase (as in http)
- **331 Username OK, password required**
- **125 data connection already open; transfer starting**
- **425 Can't open data connection**
- **452 Error writing file**

# Web Services

- SOAP (Simple Object Access Protocol)
  - It relies on Extensible Markup Language (XML) as its message format
  - It relies on other Application Layer protocols (most notably Remote Procedure Call (RPC) and HTTP) for message negotiation and transmission
  - SOAP can form the foundation layer of a web services protocol stack, providing a basic messaging framework upon which web services can be built.
  - The SOAP architecture consists of several layers of specifications for message format, message exchange patterns (MEP), underlying transport protocol bindings, message processing models, and protocol extensibility.
  - Partial stardards(profiles): WS-I Basic Profile

# Web Services

- REpresentational State Transfer (REST)
- Individual web services are regarded as resources identified by URIs and accessed via HTTP
- Competition with SOAP
  – The most important HTTP methods are POST, GET, PUT and DELETE. These are often respectively associated with the CREATE, READ, UPDATE, DELETE operations associated with database technologies
  – SOAP may have an advantage in adapting or wrapping previously written legacy applications to conform to web services
- 80% of Amazon traffic uses REST interface

# Multimedia Applications

# Multimedia Applications

- We need to develop a number of general-purpose protocols for use by **multimedia applications**
  - **QoS signaling protocol:** To request the **allocation of resources** so that the desired QoS can be provided
    - **RSVP (Resource Reservation Protocol)**
  - **Transport protocol:** With rather different characteristics than TCP and with more functionality than UDP
    - **Real-time Transport Protocol (RTP)** (Chapter 5)
  - **Session control protocol:** For example, to make **IP-based telephone calls** across the Internet
    - **SIP (Session Initiation Protocol)**
    - **H.323**

# Session Control and Call Control

# Session Control and Call Control

- Suppose you want to hold a videoconference at a certain time and make it available to a wide number of participants
  - Use the **multicast IP address** for transmission
  - Send it using **RTP over UDP** port number 4000
- A working group (**Multiparty Multimedia Session Control group**) has defined protocols for this purpose
  - **SDP (Session Description Protocol)**
  - **SAP (Session Announcement Protocol)**
  - **SIP (Session Initiation Protocol)**
  - **SCCP (Simple Conference Control Protocol)**

# Session Description Protocol (SDP)

- The name and the purpose of the session
- Start and end time for the session
- The media type (e.g., audio, video) that comprise the session
- Detailed information needed to receive the session (e.g., the multicast address, the transport protocol, the port numbers, the encoding schemes)
- SDP provides the information formatted in ASCII
- SDP sends out the session information
- Still need SIP to locate the user and negotiate the encoding schemes.

# Session Control and Call Control (SIP)

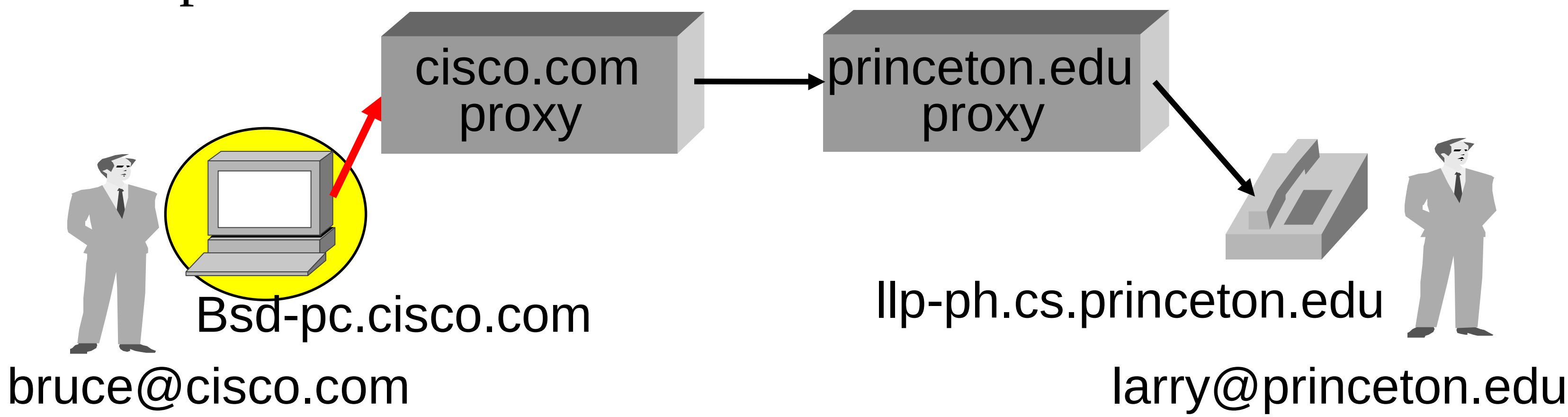
- **SIP** is an application-layer protocol based on a similar **request/response** model
- The SIP capabilities are grouped into five categories:
  - **User location:** determines the **correct device** with which to communicate to reach a particular user
  - **User availability:** determine if the user is **willing or able to** take part in a particular communication session
  - **User capabilities:** determine such items as the choice of **media** and **coding scheme** to use
  - **Session setup:** establish **session parameters** such as port numbers to be used by the communicating parties
  - **Session management:** has a range of functions including **transferring** sessions and **modifying** session parameters

# Session Control and Call Control (SIP)

- **SIP** is primarily used for **human-to-human** communication
  - Need to locate **individual users**, not just machines
  - Need to know **where the user is right now**
- This is further complicated by the fact that a user might choose to communicate using a range of **different devices**
- The user must be able to have **control** over when, where, and from whom he receives calls
- **SIP proxy:**
  - Enables a user to have control over his calls
  - Proxies also perform functions **on behalf of callers**

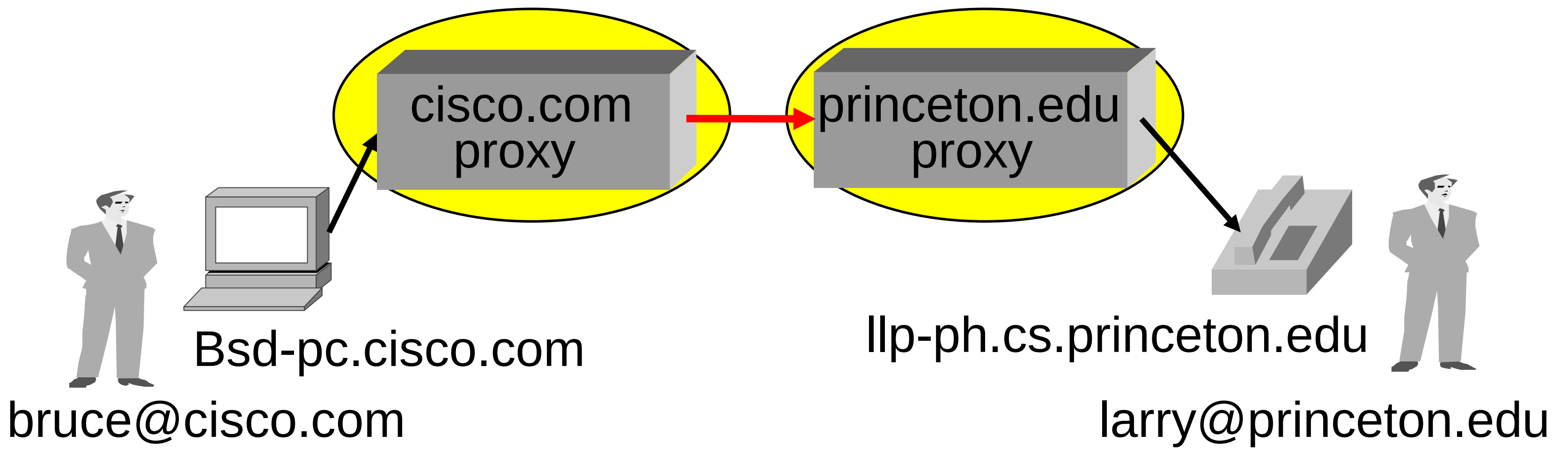
# Session Control and Call Control (SIP)

- Each user has a name in the format **user@domain**
- User Bruce wants to initiate a session with Larry
  - Sends his **initial SIP message** to the **local proxy** for his domain — cisco.com
  - This initial message contains a SIP URI (uniform resource identifier) ⇒ **SIP: larry@princeton.edu**
- SIP URI provides complete **identification** of a user, but **does not** provide his **location**



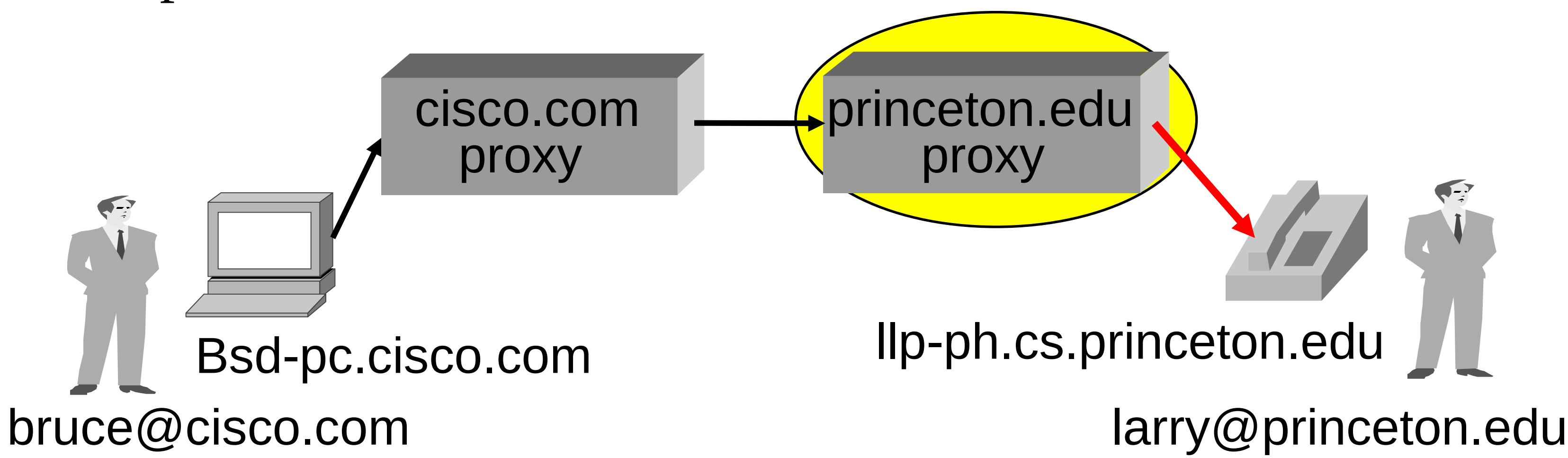
# Session Control and Call Control (SIP)

- The cisco.com proxy looks at the SIP URI and deduces that this message should be **sent to the princeton.edu proxy**
- Assume that the princeton.edu proxy has a mapping from the name larry@princeton.edu to the **IP address** of **one or more** devices at which Larry **currently** wishes to receive messages



# Session Control and Call Control (SIP)

- The proxy can therefore forward the message to Larry’s **chosen device(s)**
- (Forking) Sending the message to **more than one device** may be done either **in parallel** or **in series**
  – e.g., send it to his cellphone if he doesn’t answer the phone at his desk



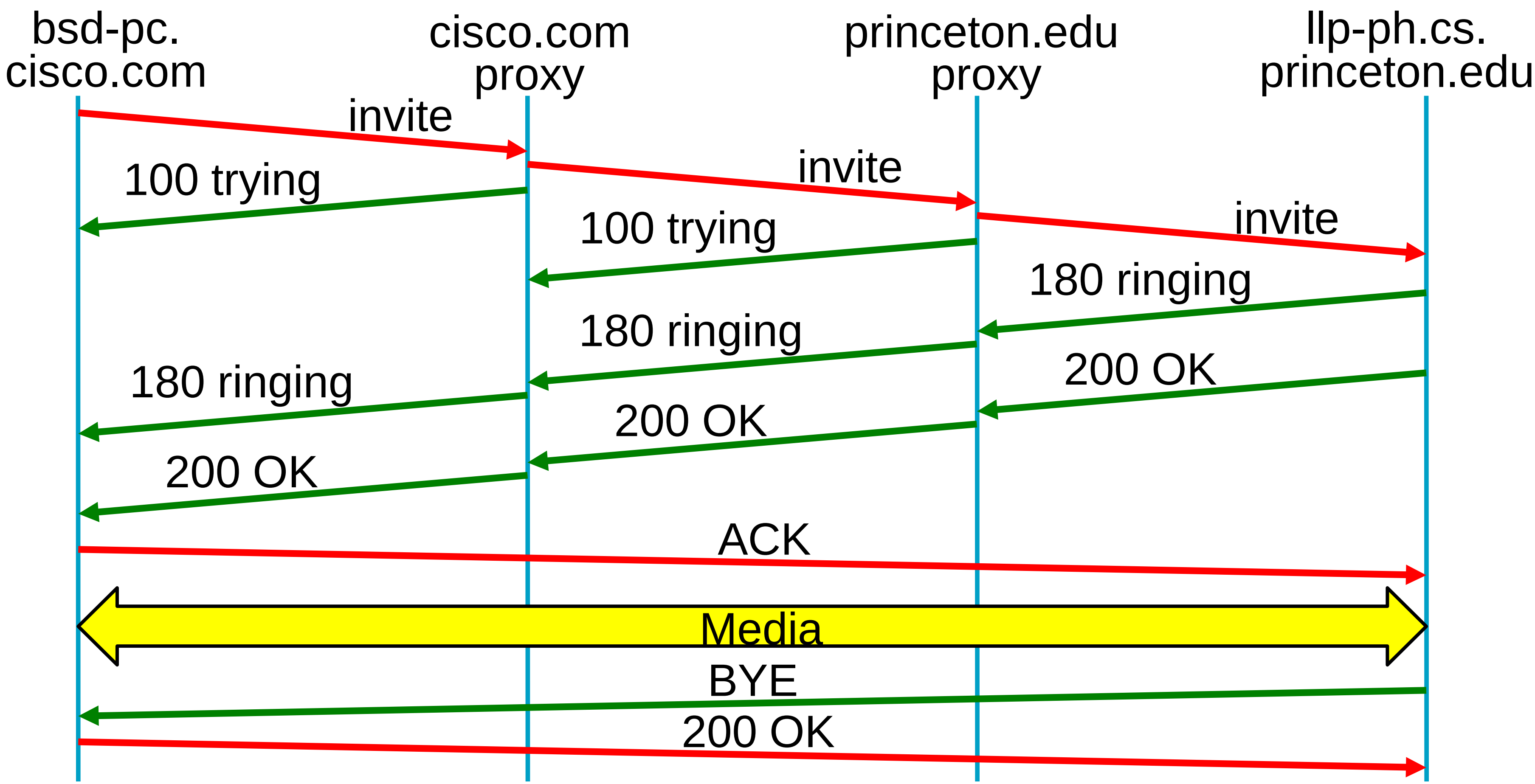
# Session Control and Call Control (SIP)

- The initial message from Bruce to Larry is likely to be a **SIP invite message**
- **Via:** header in this example identifies the **device** from which this message originated
- **Content-Type:** and **Content-Length:** headers describe the contents of the message following the header

```
INVITE sip:larry@princeton.edu SIP/2.0
Via: SIP/2.0/UDP bsd-pc.cisco.com;branch=z9hG4bK433yte4
To: Larry <sip:larry@princeton.edu>
From: Bruce <sip:bruce@cisco.com>;tag=55123
Call-ID: xy745jj210re3@bsd-pc.cisco.com
CSeq: 271828 INVITE
Contact: <sip:bruce@bsd-pc.cisco.com>
Content-Type: application/sdp
Content-Length: 142
```

# Session Control and Call Control (SIP)

- **100 trying:** Indicates that the message was received **without error**



# Session Control and Call Control (SIP)

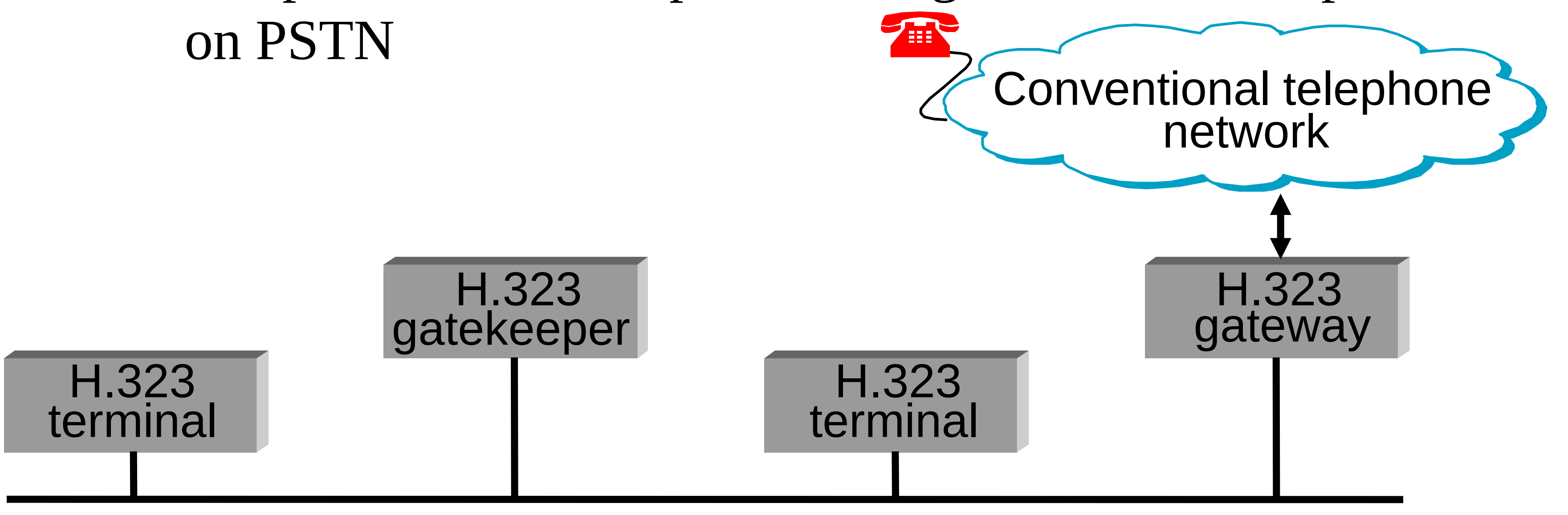
- **180 ringing:** is a sign that it can generate a **"ringtone"**
- **200 OK:** is sent when Larry pick up his phone
- **ACK:** Bruce's computer responds with an ACK
  - At this point the parties know each other's addresses, so the ACK can be sent **directly**, **bypassing the proxies**
- At this point media (e.g., an RTP-encapsulated audio stream) can begin to flow between the two parties
  - The **proxies** are **no longer involved** in the call
  - The media will typically **take a different path** through the network than the original signalling messages
- Even if one or both of the proxies were to **crash** at this point
  - The call could continue on **normally**
- **BYE:** when one party wishes to end the session

# Session Control and Call Control (H.323)

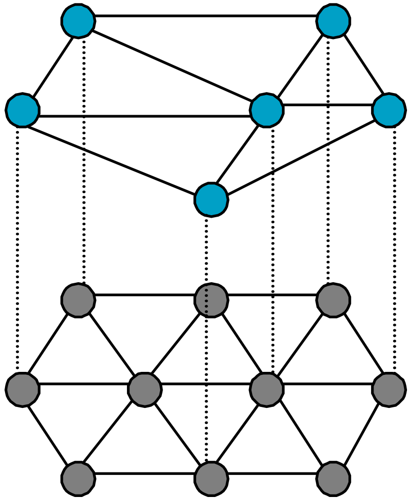
- **H.323:** The major **ITU** recommendation for multimedia communication over packet networks
  - H.323 is popular as a protocol for **Internet telephony**
- **H.323 terminal:** a device that originates or terminates calls
- The calls are frequently mediated by a **gatekeeper**
  - H.323 terminals can also talk to each other **directly**
- Gatekeepers perform a number of functions
  - **Translating** among the various **address formats**
  - **Controlling** how many calls can be placed at a given time to limit the **bandwidth** used by the H.323 applications
  - One useful function performed by the gatekeeper is to help a terminal **find a gateway**

# Session Control and Call Control (H.323)

- A **gateway** of H.323 connects the H.323 network to **other types of networks**
  - Connects an H.323 network to the **public switched telephone network (PSTN)**
  - Enables a user running an H.323 application on a computer to talk to a person using a conventional phone on PSTN



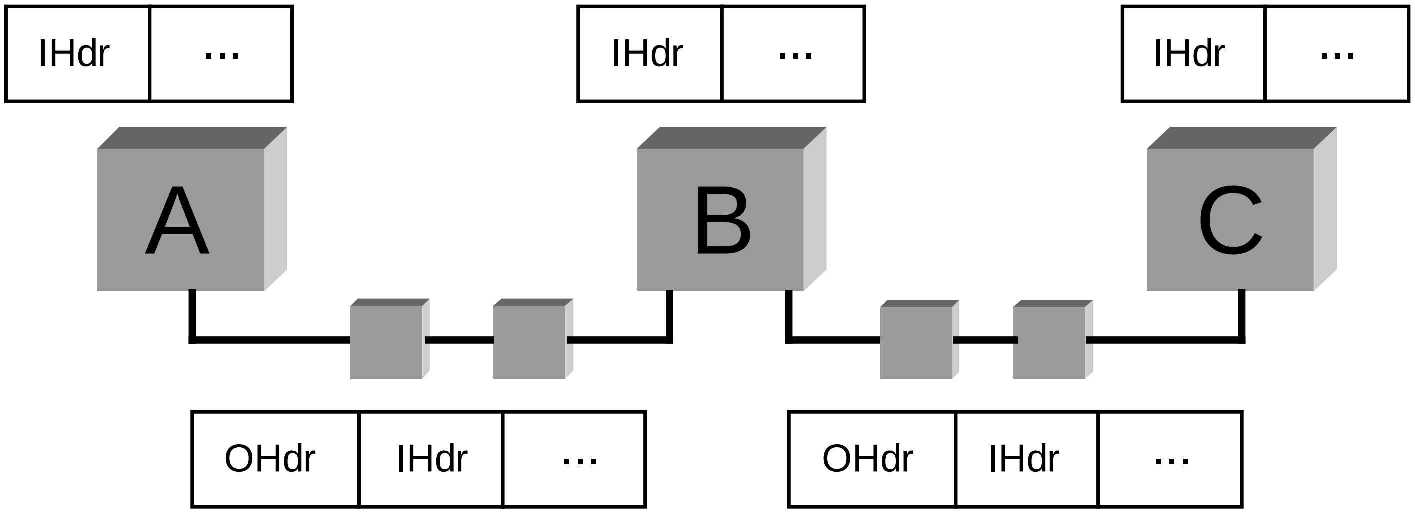
# Overlay networks



- Building a network on the top of the Internet
- Virtual private networks (VPN)

•Experimental networks for new ideas (IPv6, M-bone, Q-bone)

# Tunneling



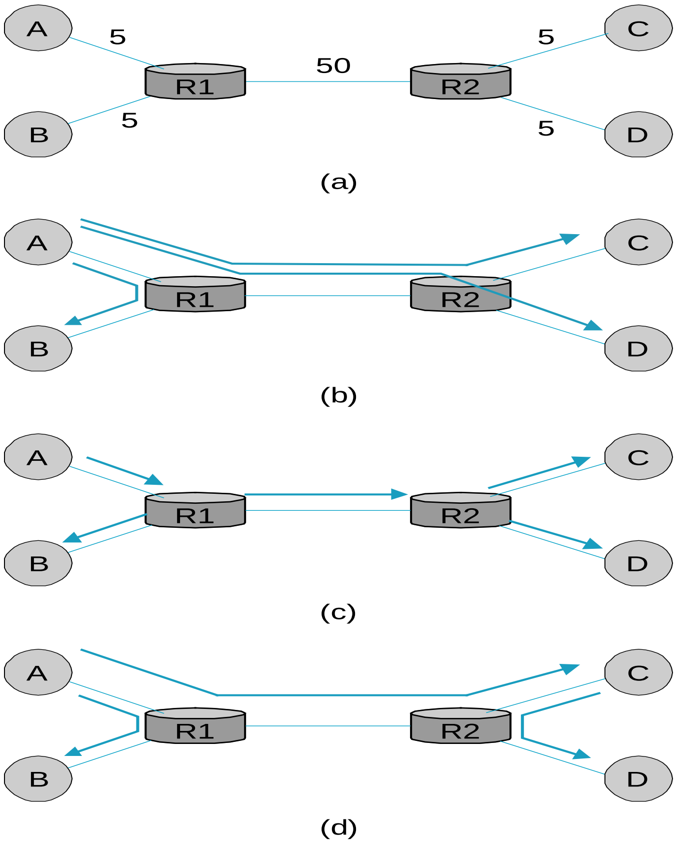

- Use Inner Header Address for the overlay netowrk

- Use the Outer Header Address for the Internet

# Routing Overlays

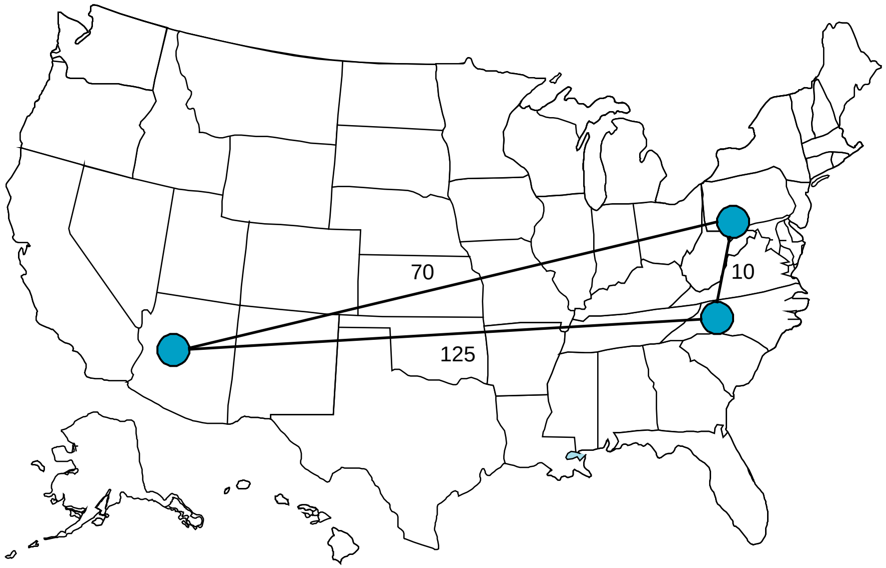
- Support an alternative routing strategy by using overlays
- Experimental versions of IP
  - The multicast backbone (MBone)
  - IPv6 (6-BONE)

# End System Multicast




- IP multicast failed
- Long delay between R1 and R2
- (a) Physical topology
- (b) Naïve unicast
- © IP multicast
- (d) End system multicast

# Resilient Overlay Networks




- Triangle inequality does not necessarily hold

•BGP dies select the best route and it is slow to adapt to outage

•RON uses an NxN monitoring for N nodes: latency, available bandwidth, and loss probability

# Content Distribution Networks

Outline

- Implementation Techniques
- Hashing Schemes
- Redirection Strategies

# Potential bottlenecks

- The first mile: slow access link, e.g., 56Kbps modem
- The last mile: server is overloaded by too many requests.
- Peering points: little motivation to provide high-capacity connectivity to other peers.

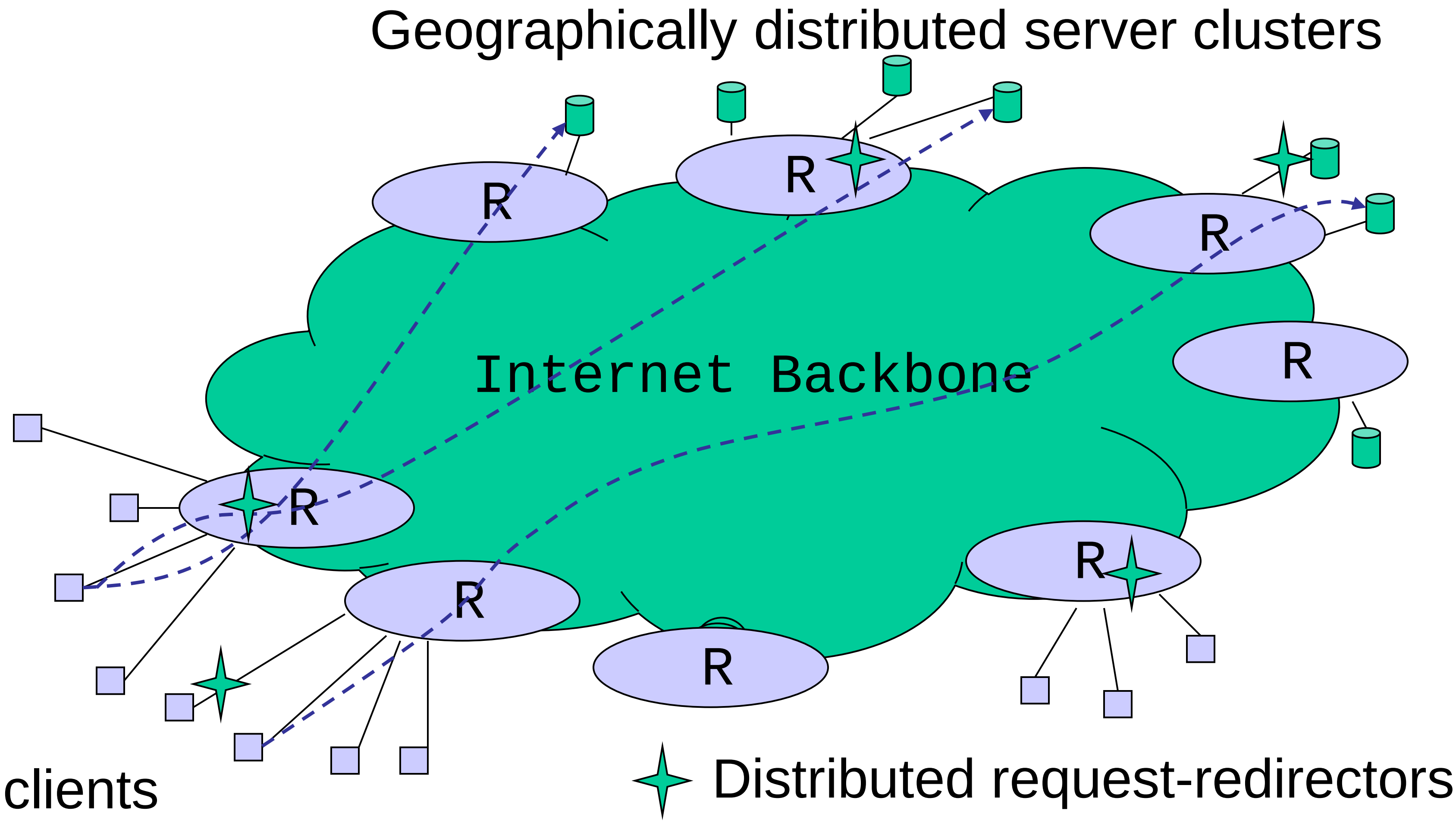
# Design Space

- Caching
  - explicit
  - transparent (hijacking connections)
- Replication
  - server farms
  - geographically dispersed (CDN)

# CDNs

- Flash crowd
- Redirectors (that forward client requests to the most appropriate server)
- The primary objective: the best response time
- A secondary objective:  system throughput
- Factors for redirection:
  - Network proximity
  - Load balance

# Redirection Overlay



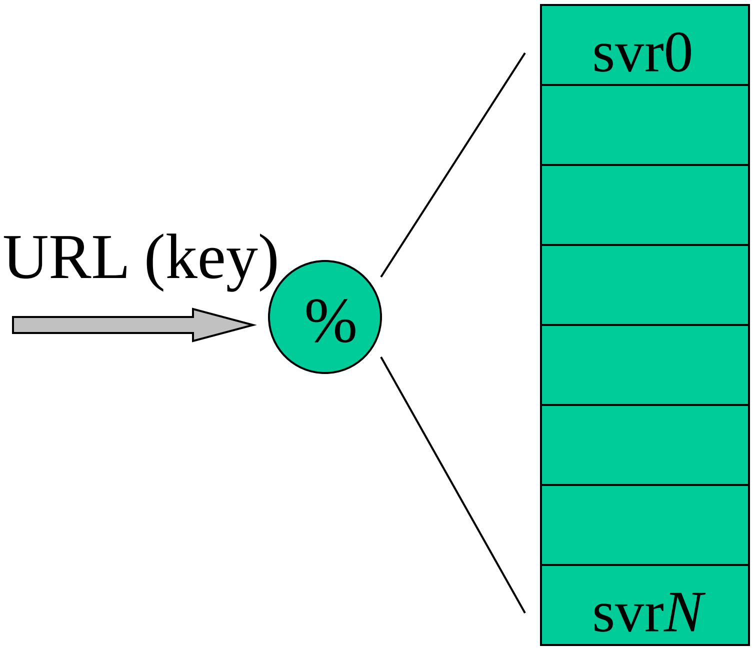
# Redirection Mechanisms

- DNS
  - one name maps onto many addresses
  - Return the IP address of the most appropriate server (e.g., the server with the lightest load)
- URL Rewriting
  - embedded links pointing the client at the most appropriate server
- HTTP
  - requires an extra round trip
  - vulnerable to being overloaded by the redirection task itself

# Redirection Policies

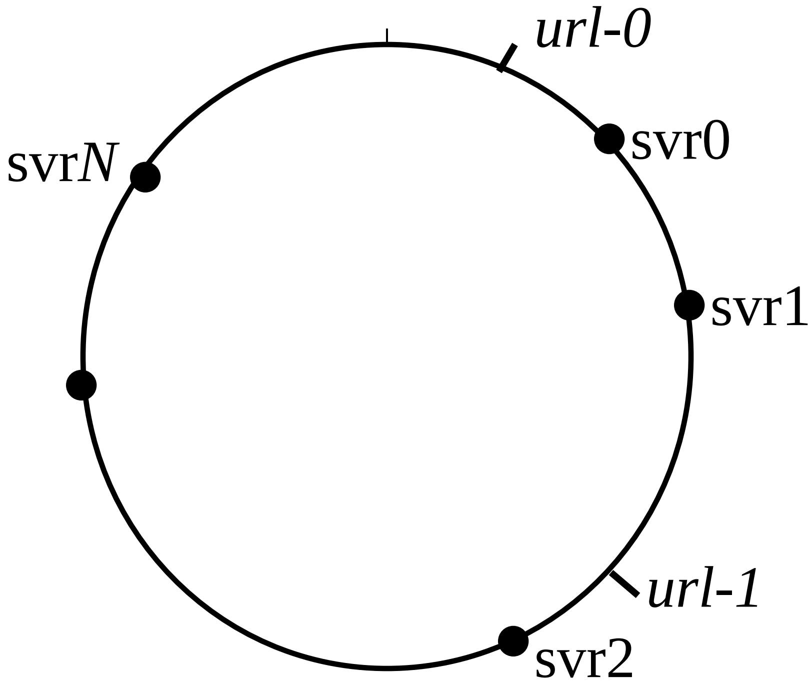
- Round-robin
- Random selection
- Need to take into network proximity and locality
- Redirect the same URL requests to go to the same server
  - Hashing (modulo)
  - Consistent hashing

# Hashing Schemes: Modulo




- Easy to compute
- Evenly distributed
- Good for fixed number of servers
- Many mapping changes after a single server change

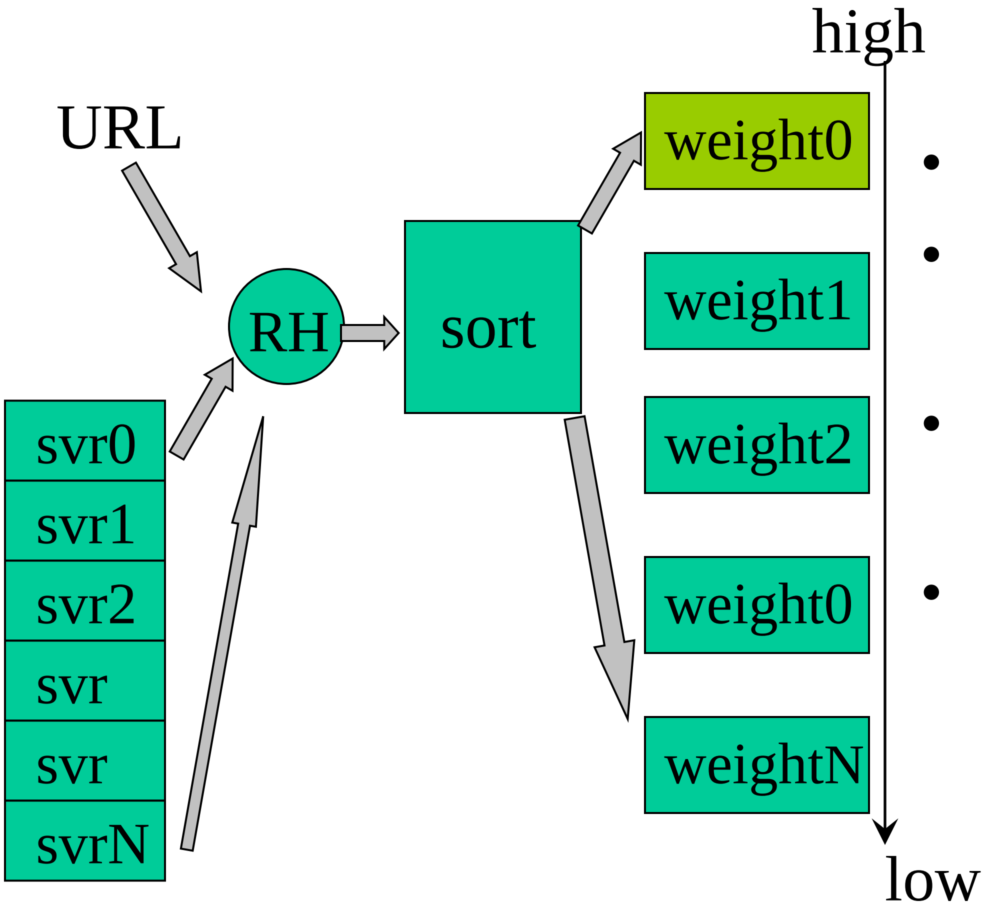
# Consistent Hashing (CHash)




Unit circle

- Hash server, then URL
- Closest match
- Only local mapping changes after adding or removing servers
- Used by State-of-the-art CDNs

# Highest Random Weight (HRW)




- Hash(url, svrAddr)
- Deterministic order of access set of servers
- Different order for different URLs
- Load evenly distributed after server changes

# Cache Array Routing Protocol (CARP)

- SelectServer(URL,S)

  for each server $s_i$ in server set S

  weight$_i$ =hash(URL,address($s_i$))

  sort weight

  for each server $s_j$ in decreasing order of weight$_j$

  If load($s_j$) < threshold then

  Return $s_j$

  Return server with highest weight

# CARP

- As the load increase. This scheme changes from using the first server on the sorted list to spreading requests across several servers.
- Adding network proximity into the equation: use the measured response time as the “server load.”