南京大学
NANJING UNIVERSITY

应用层

殷亚凤
智能软件与工程学院
苏州校区南雍楼东区225
yafeng@nju.edu.cn，https://yafengnju.github.io/

Internet Applications

- Internet Applications Overview
- WWW and HTTP
- Electronic Mail
- Domain Name Service (DNS)
- File Transfer Protocol (FTP)
- Content Distribution Networks (CDNs)

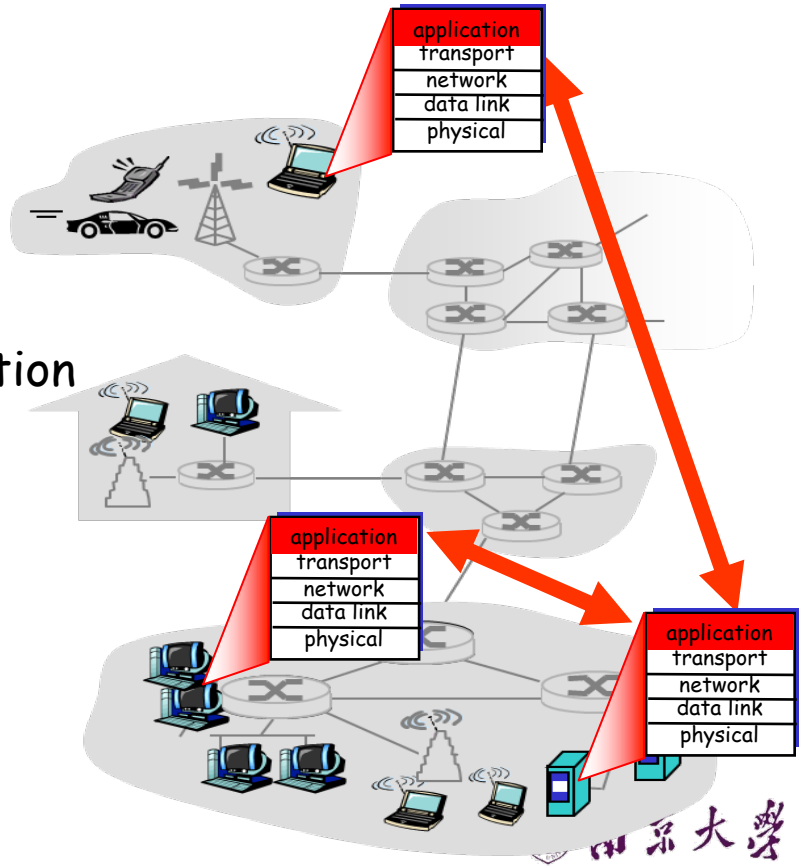
Internet Applications Overview

Application: communicating, distributed processes

- e.g., Email, Web, P2P file sharing, instant messaging
- Running in end systems (hosts)
- Exchange messages to implement application

Application-layer protocols

- One "piece" (agent) of an app
- Define messages exchanged by apps and actions taken
- Use communication services provided by lower layer protocols (TCP, UDP, RTP)



Application Architectures

possible structure of applications:

- client-server (CS)
- peer-to-peer (P2P)

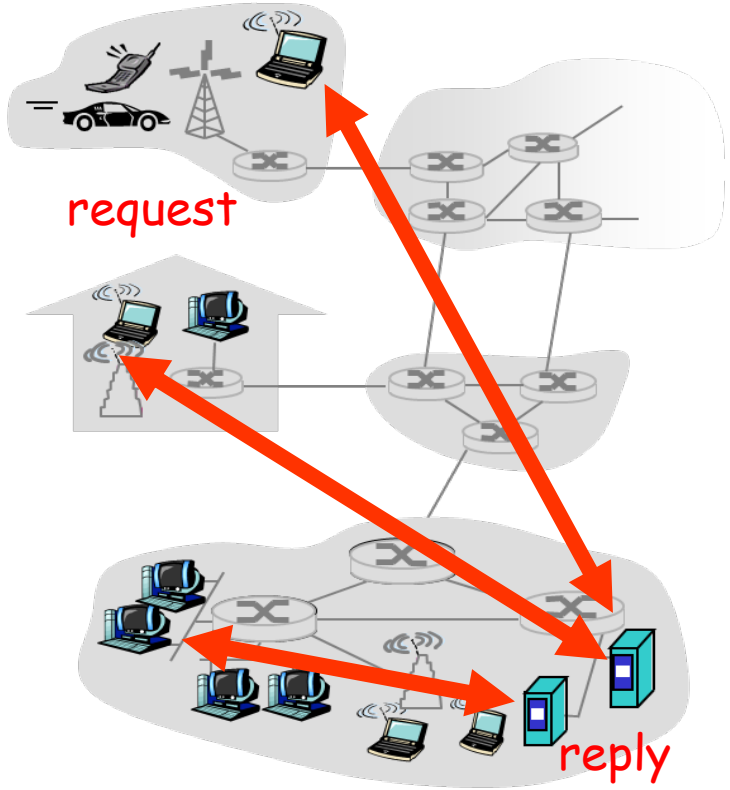
Client-Server Paradigm

Client:

- Start as required
- Initiates contact with server, "speaks first"
- Host may have dynamic IP addresses
- e.g. Web: client implemented in browser; Email: in mail reader

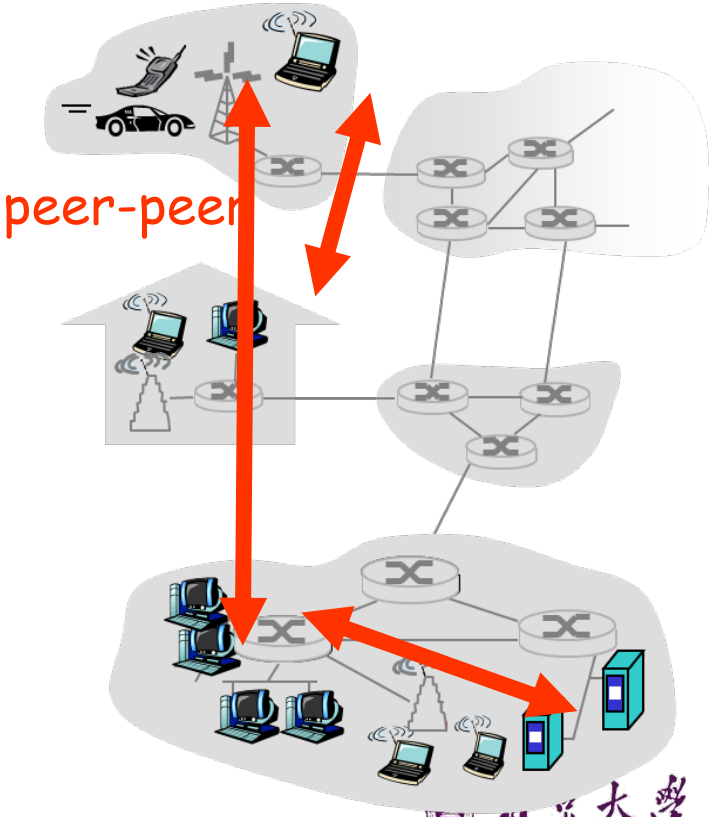
Server:

- Run as daemon (always-on)
- Provides requested service to Client
- Host has permanent IP address
- e.g. Web server sends requested Web page, mail server delivers Email



Peer-to-Peer Paradigm

- No always-on server
- Arbitrary end systems directly communicate
- peers request service from other peers, provide service in return to other peers
  - self scalability – new peers bring new service capacity, as well as new service demands
- Peers are intermittently connected and change IP addresses
  - Highly scalable but difficult to manage
- Examples: Gnutella, BitTorrent, Skype



Client-Server and P2P

Skype

- Voice-over-IP P2P application
- Centralized server: finding address of remote party
- Direct client-client connection

Instant messaging

- Chatting between two users is P2P
- Centralized service: user presence detection/location
- User registers its IP address with central server when it comes online
- User contacts central server to find IP addresses of parties

Jargons of Internet Applications

- Process: program running within a host
  - Within same host, 2 processes communicate using inter-process communication (defined by OS)
  - Processes running in different hosts communicate with an app-layer protocol

- User agent: interfaces with app "above" and network "below"
  - Implements user interface & app-layer protocol, e.g.
  - Web: browser, web server
  - Email: mail reader, mail server
  - Streaming audio/video: media player, media server

Typical Applications

- Web and HTTP
- Email
- DNS
- FTP
- CDN

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Web components

- Infrastructure:
  - Clients
  - Servers (DNS, CDN, Datacenters)
- Content:
  - URL: naming content
  - HTML: formatting content
- Protocol for exchanging information: HTTP

URL – Uniform Resource Locator

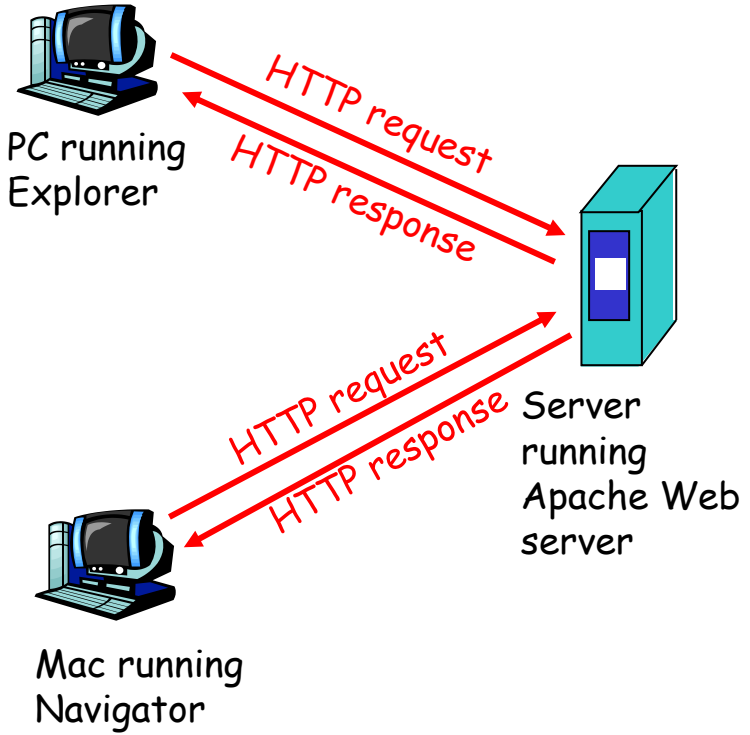
- A unique identifier for an object on WWW
- URL format

  <protocol>://<host>:<port>/<path>?query_string
  - Protocol: method for transmission or interpretation of the object, e.g. http, ftp, Gopher
  - Host: DNS name or IP address of the host where object resides
  - Path: pathname of the file that contains the object
  - Query_string: name/value pairs sent to app on the server
- An example

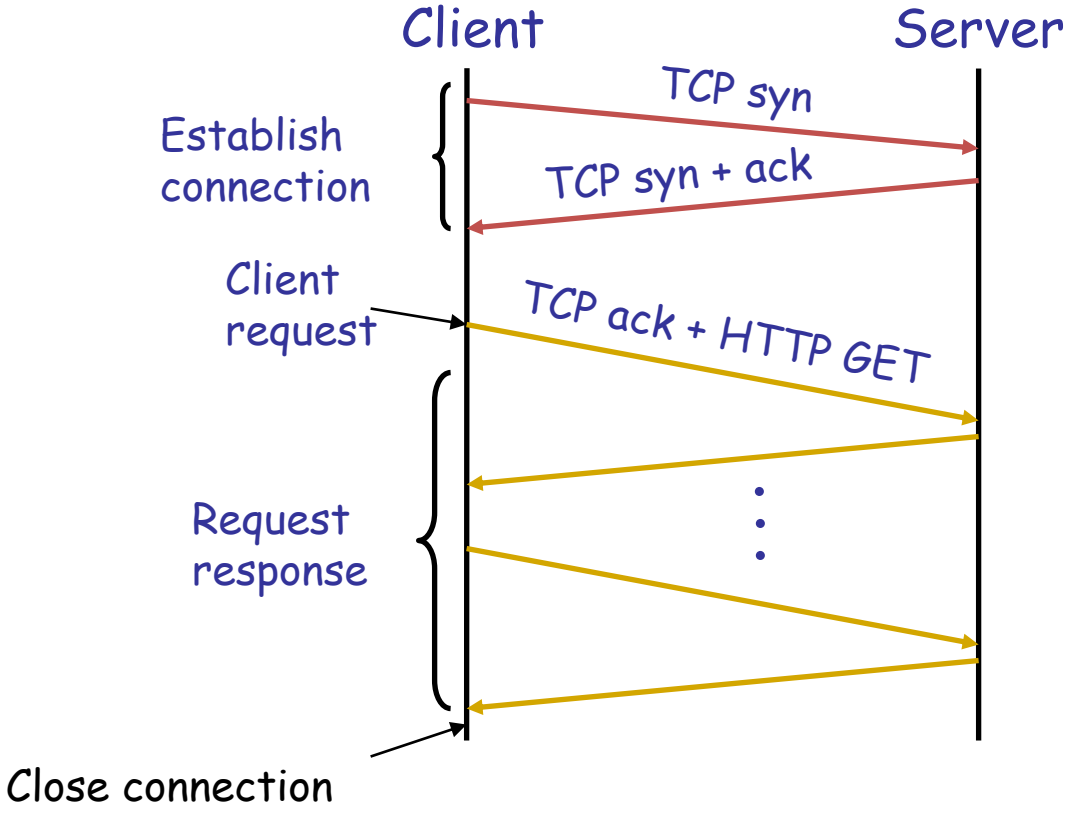
  http://www.nju.edu.cn:8080/somedir/page.htm

Hyper Text Transfer Protocol (HTTP)

- Client-server architecture
  - Server is "always on" and "well known"
  - Clients initiate contact to server
- Synchronous request/reply protocol
  - Runs over TCP, Port 80
- Stateless
- ASCII format
  - Before HTTP/2



Steps in HTTP request/response

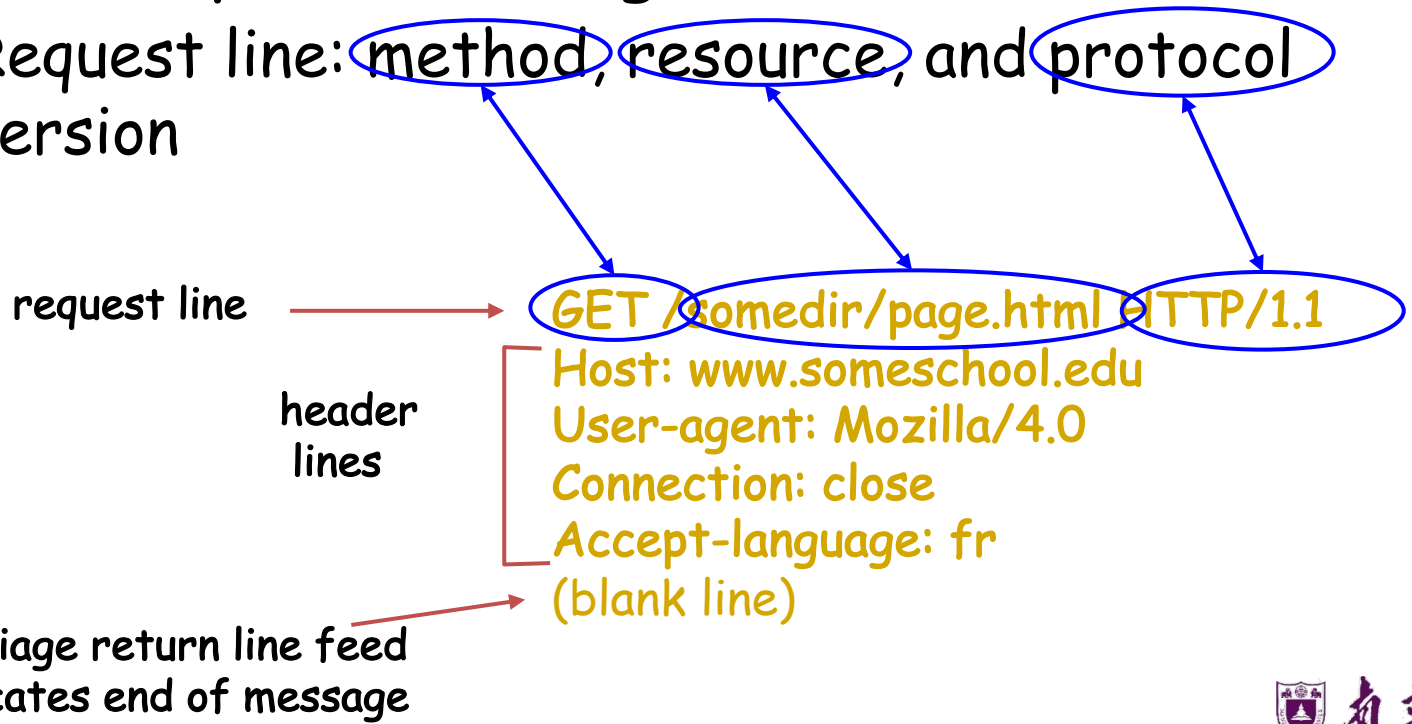


Method types (HTTP 1.1)

- GET, HEAD
- POST
  - Send information (e.g., web forms)
- PUT
  - Uploads file in entity body to path specified in URL field
- DELETE
  - Deletes file specified in the URL field

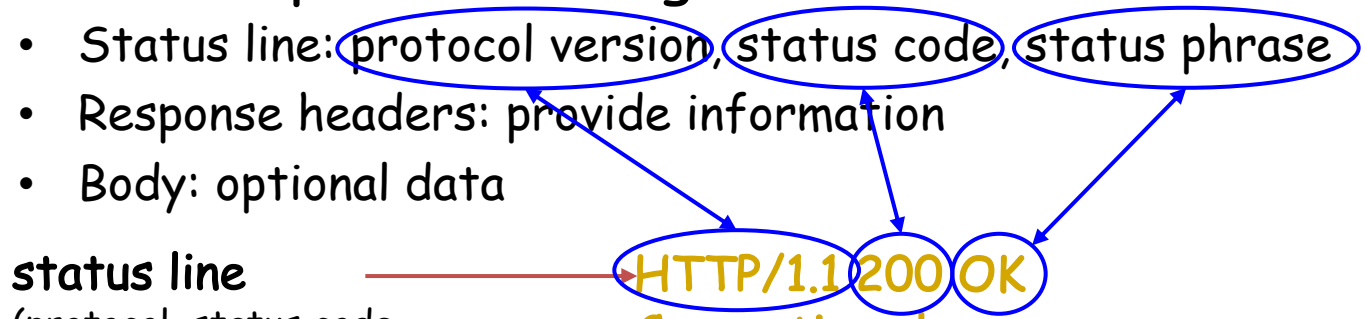
Client-to-server communication

- HTTP Request Message
  - Request line: method, resource, and protocol version



Server-to-client communication

- HTTP Response Message
  - Status line: protocol version, status code, status phrase
  - Response headers: provide information
  - Body: optional data



HTTP is stateless

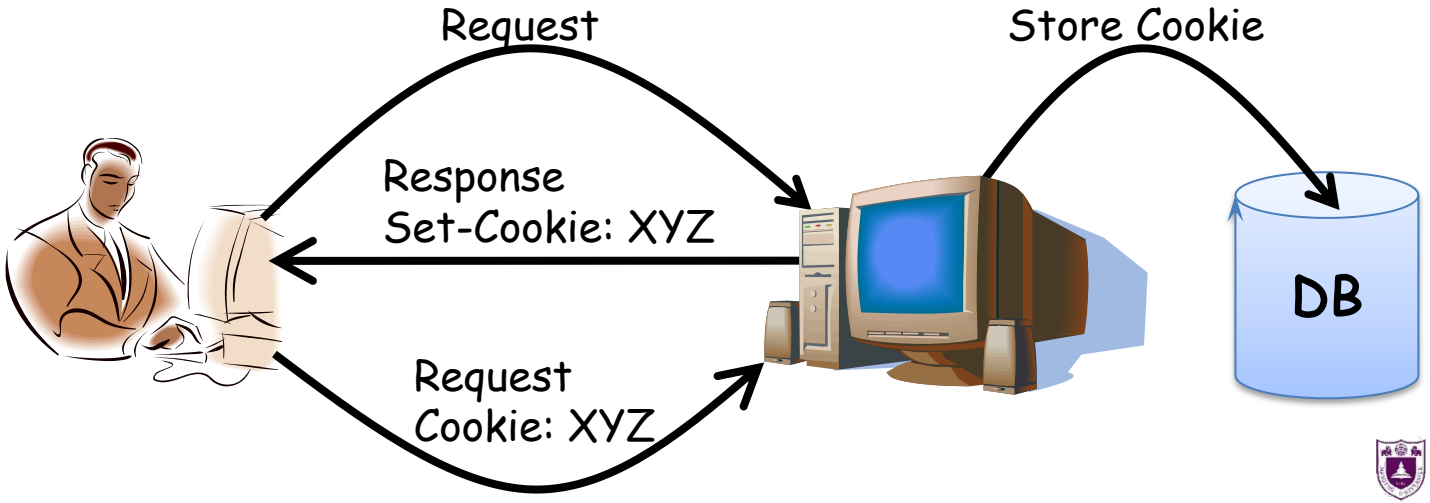
- Each request-response treated independently
  - Servers not required to retain state
- Good: Improves scalability on the server-side
  - Failure handling is easier
  - Can handle higher rate of requests
  - Order of requests doesn't matter
- Bad: Some applications need persistent state
  - Need to uniquely identify user or store temporary info
  - e.g., Shopping cart, user profiles, usage tracking, …

Question

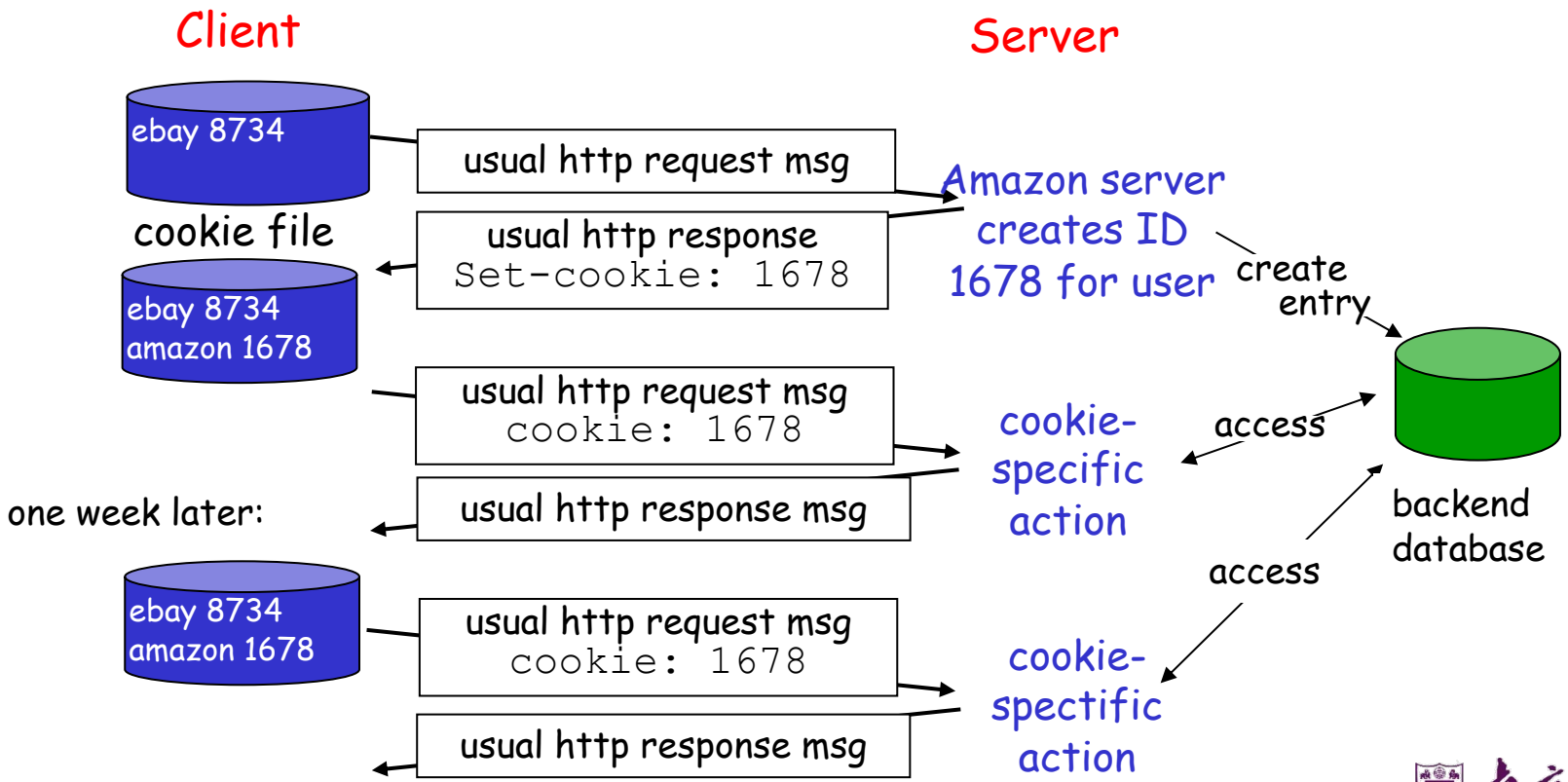
- How does a stateless protocol keep state?

State in a stateless protocol: Cookies

- Client-side state maintenance
  - Client stores small state on behalf of server
  - Client sends state in future requests to the server
- Can provide authentication

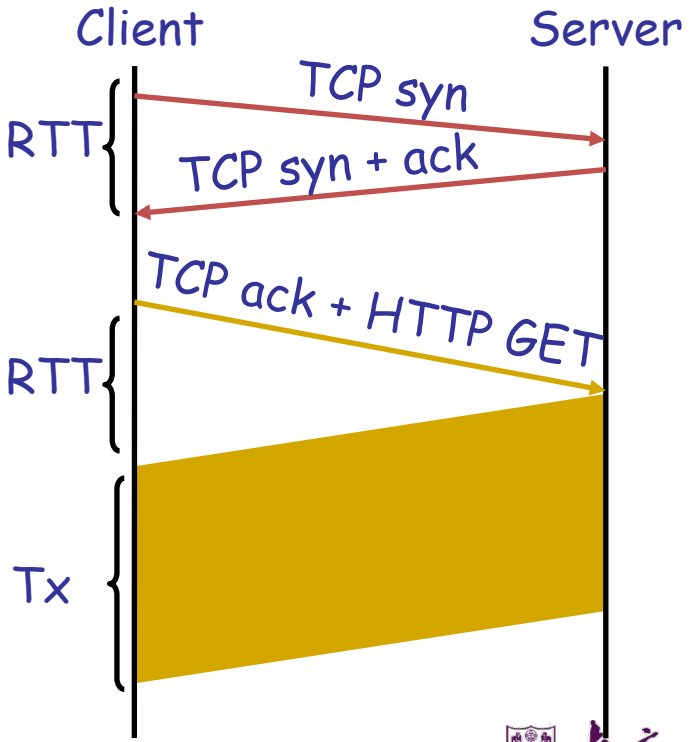


A Cookies Example



HTTP performance: Object request response time

- RTT (round-trip time)
  - Time for a small packet to travel from client to server and back
- Response time
  - 1 RTT for TCP setup
  - 1 RTT for HTTP request and first few bytes
  - Transmission time
  - Total = 2RTT + Transmission Time



Non-persistent connections

- Default in HTTP/1.0
- 2RTT+Δ for each object in the HTML file!
  - One more 2RTT+Δ for the HTML file itself
- Doing the same thing over and over again
  - Inefficient

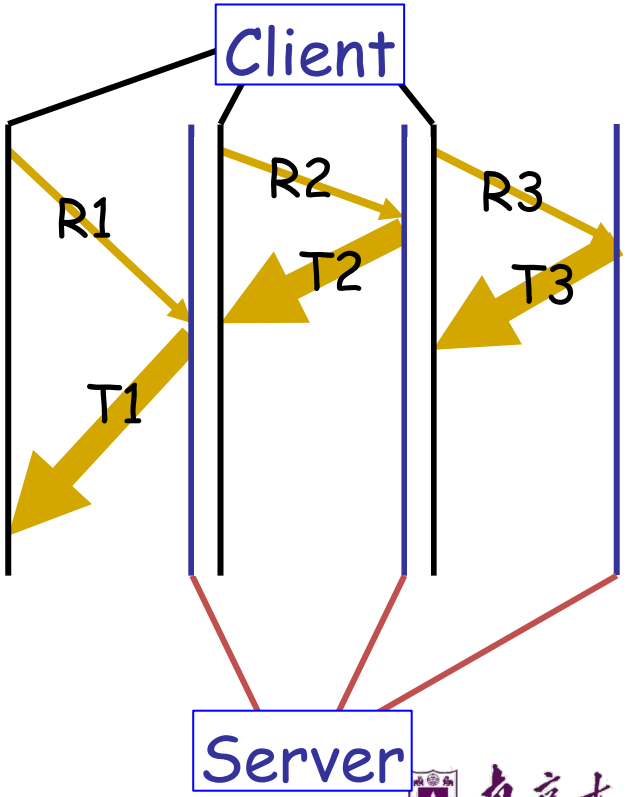
Concurrent requests and responses

- Use multiple connections in parallel
- Does not necessarily maintain order of responses

➢ Client = ☺

➢ Content provider = ☺

➢ Network = ☹ Why?

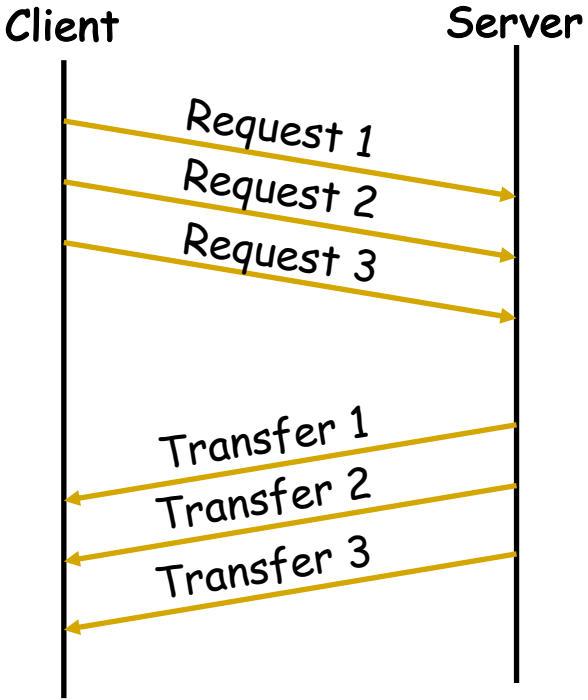


Persistent connections

- Maintain TCP connection across multiple requests
  - Including transfers subsequent to current page
  - Client or server can tear down connection
- Advantages
  - Avoid overhead of connection set-up and tear-down
  - Allow underlying layers (e.g., TCP) to learn about RTT and bandwidth characteristics
- Default in HTTP/1.1

Pipelined requests & responses

- Batch requests and responses to reduce the number of packets
- Multiple requests can be contained in one TCP segment



Caching

- Why does caching work?
  - Exploits locality of reference
- How well does caching work?
  - Very well, up to a limit
  - Large overlap in content
  - But many unique requests
    - ✓ A universal story!
    - ✓ Effectiveness of caching grows logarithmically with size

Caching: How

- Modifier to GET requests:
  - If-modified-since – returns "not modified" if resource not modified since specified time

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
If-modified-since: Wed, 18 Jan 2017 10:25:50 GMT
(blank line)
```

Caching: How

- Modifier to GET requests:
  - If-modified-since – returns "not modified" if resource not modified since specified time
- Client specifies "if-modified-since" time in request
- Server compares this against "last modified" time of resource
- Server returns "Not Modified" if resource has not changed
- …. or a "OK" with the latest version otherwise

Caching: How

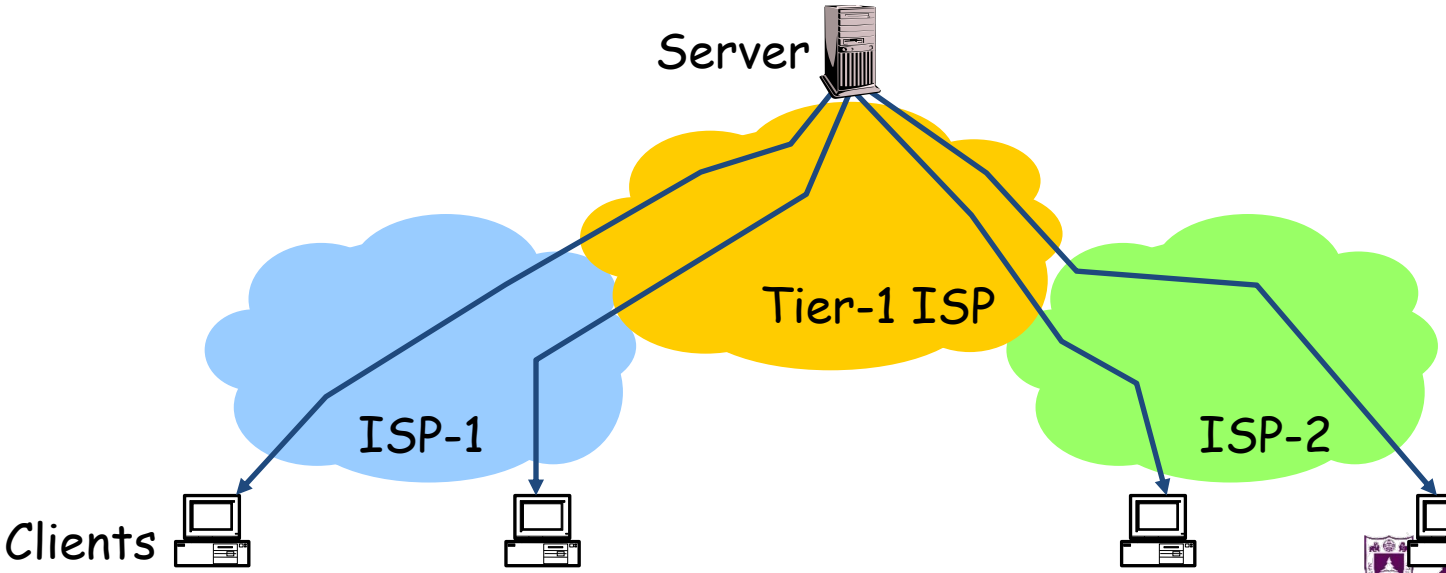
- Modifier to GET requests:
  - If-modified-since – returns "not modified" if resource not modified since specified time
- Response header:
  - Expires – how long it's safe to cache the resource
  - No-cache – ignore all caches; always get resource directly from server

Caching: Where?

- Options
  - Client (browser)
  - Forward proxies
  - Reverse proxies
  - Content Distribution Network

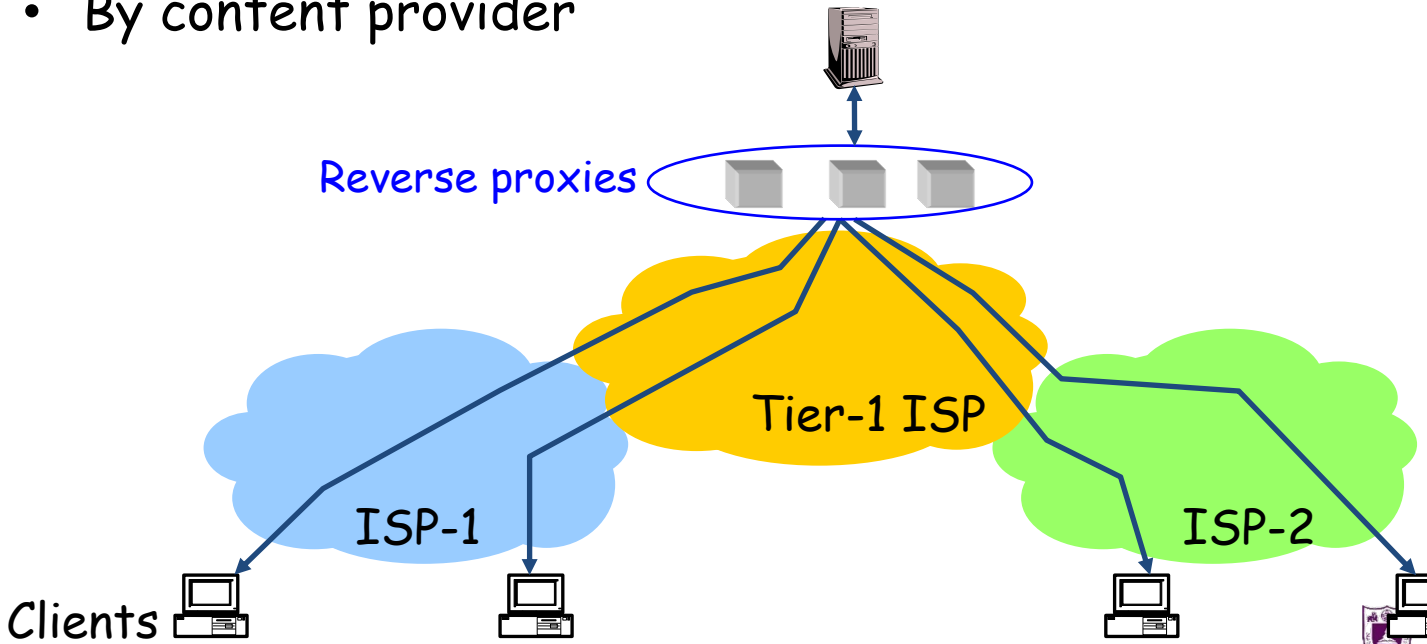
Caching: Where?

- Many clients transfer same information
  - Generate unnecessary server and network load
  - Clients experience unnecessary latency



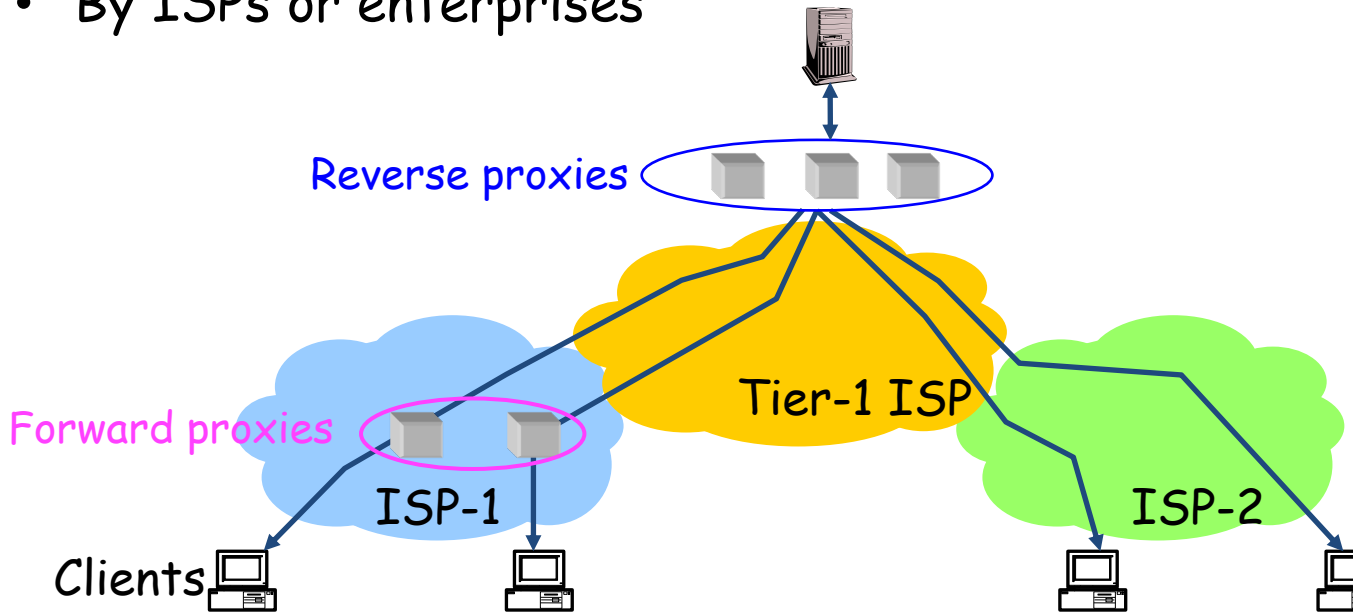
Caching with Reverse Proxies

- Cache documents close to server
  - Decrease server load
  - By content provider



Caching with Forward Proxies

- Cache documents close to clients
  - Reduce network traffic and decrease latency
  - By ISPs or enterprises



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Electronic Mail

- One of most heavily used apps on Internet
- SMTP: Simple Mail Transfer Protocol
  - Delivery of simple text messages
- MIME: Multi-purpose Internet Mail Extension
  - Delivery of other types of data, e.g. voice, images, video clips
- POP: Post Office Protocol
  - Msg retrieval from server, including authorization and download
- IMAP: Internet Mail Access Protocol
  - Manipulation of stored msgs on server

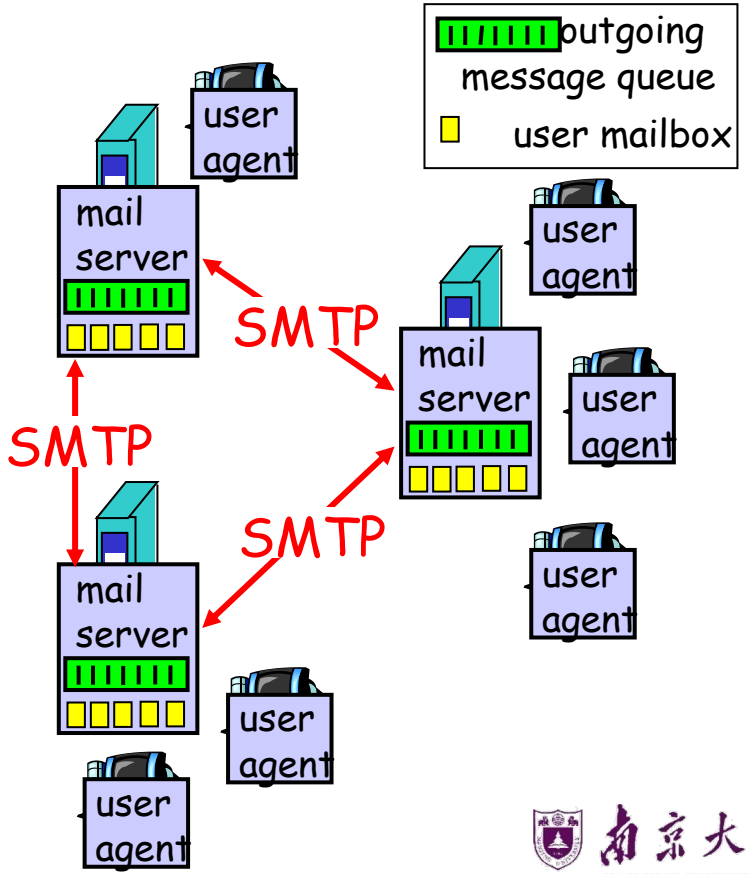
Components of Email System

User Agent

- Composing, editing, reading mail messages
- e.g. Eudora, Outlook, Foxmail, Netscape Messenger
- Outgoing, incoming mail messages stored on server

Mail Servers (Host)

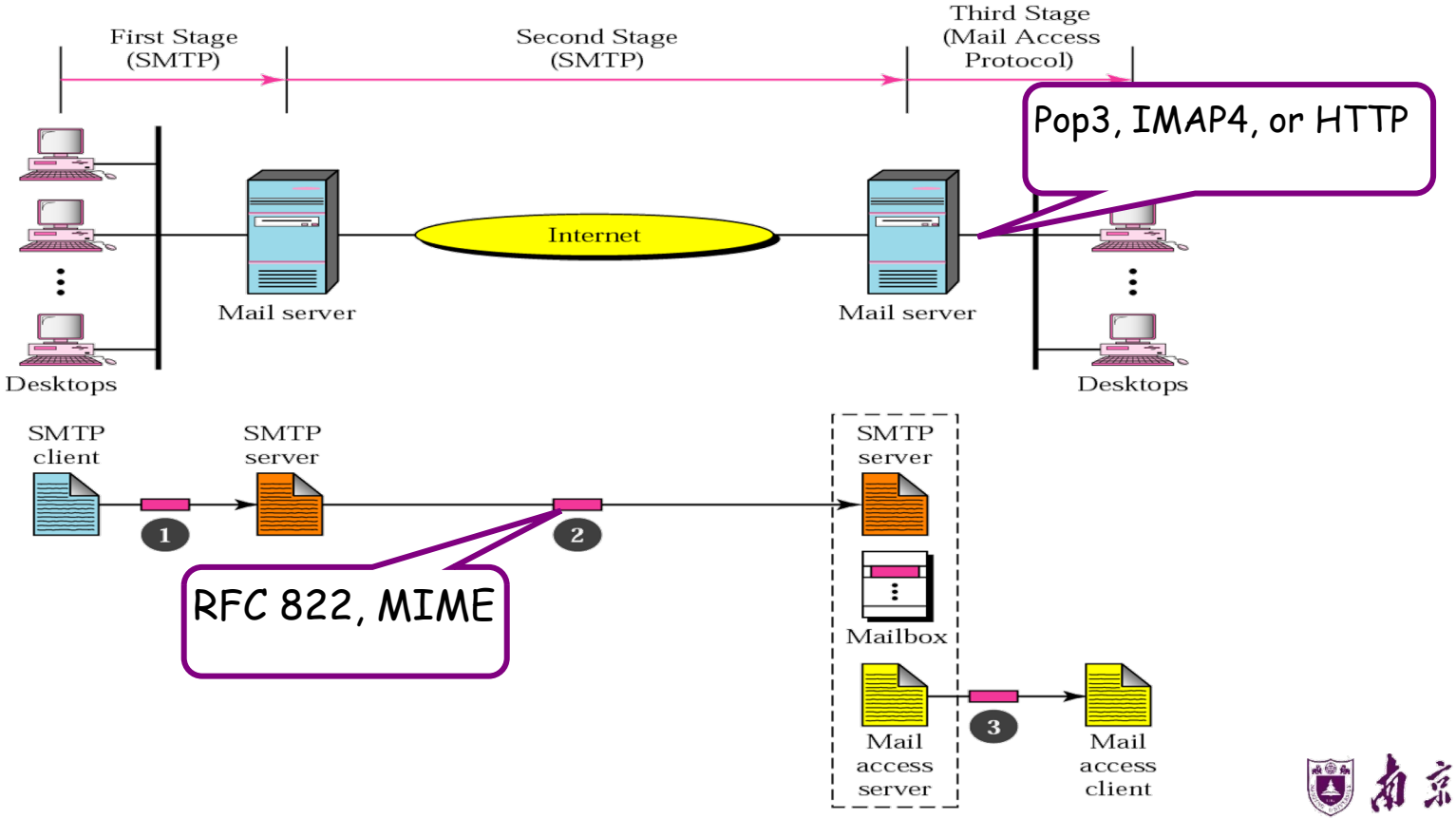
- Mailbox contains incoming mail messages for user
- Message queue of outgoing mail messages
- SMTP protocol between mail servers to send mail messages



3 Stages of Mail Delivery

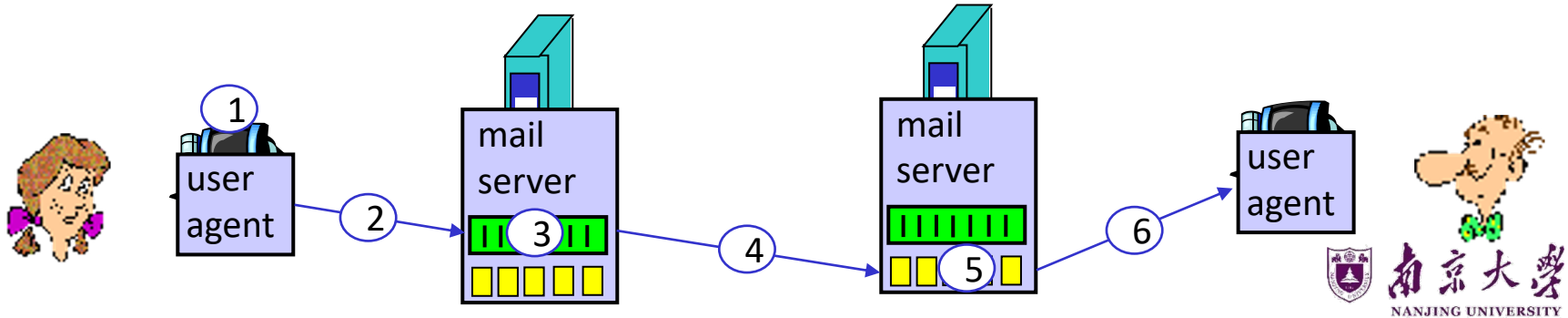
- 1st Stage
  - Email goes from local user agent to the local SMTP server
  - User agent acts as SMTP client
  - Local server acts as SMTP server
- 2nd Stage
  - Email is relayed by the local server to the remote SMTP server
  - Local server acts as SMTP client now
- 3rd Stage
  - The remote user agent uses a mail access protocol to access the mailbox on remote server
  - POP3 or IMAP4

Illustration of Mail Delivery



A Mail Delivery Scenario

- 1) Alice uses UA to compose a mail message and to bob@someschool.edu
- 2) Alice's UA sends mail to her mail server using SMTP, mail placed in message queue
- 3) Client side of SMTP opens TCP connection with Bob's mail server
- 4) SMTP client sends Alice's mail over the TCP connection
- 5) Bob's mail server places the mail in Bob's mailbox
- 6) Bob invokes his UA to read the mail, e.g. by Pop3



SMTP Transaction

3 phases of transfer

- Handshaking (greeting)
- Transfer of one or more mails data
- Close connection

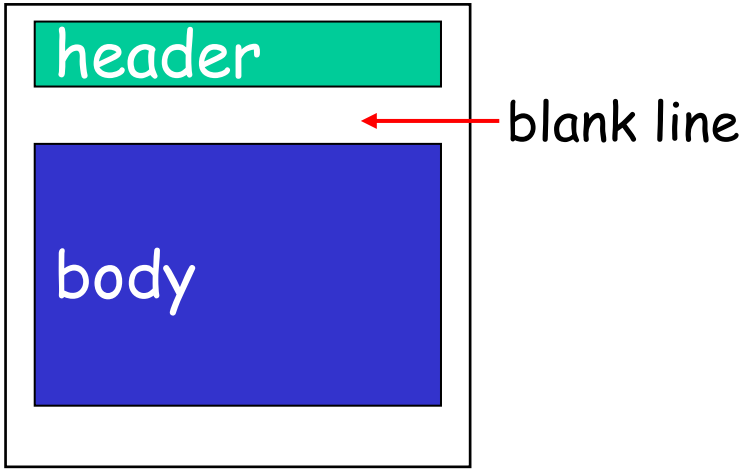
Command/response interaction

- Commands: ASCII text
- Response: status code and phrase

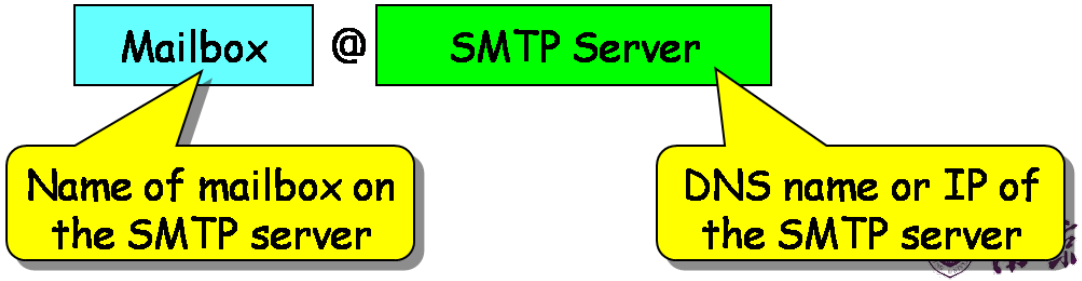
```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250 Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr … Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu … Recipient ok
C: RCPT TO: <Johm@hamburger.edu>
S: 550 No such user here
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: Do you like ketchup?
C:    How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

An Email Message

- Header lines, e.g.
  - To: Alice@sina.com
  - From: Bob@gmail.com
  - Subject: Dinner tonight
- Body
  - Mail contents, ASCII characters only

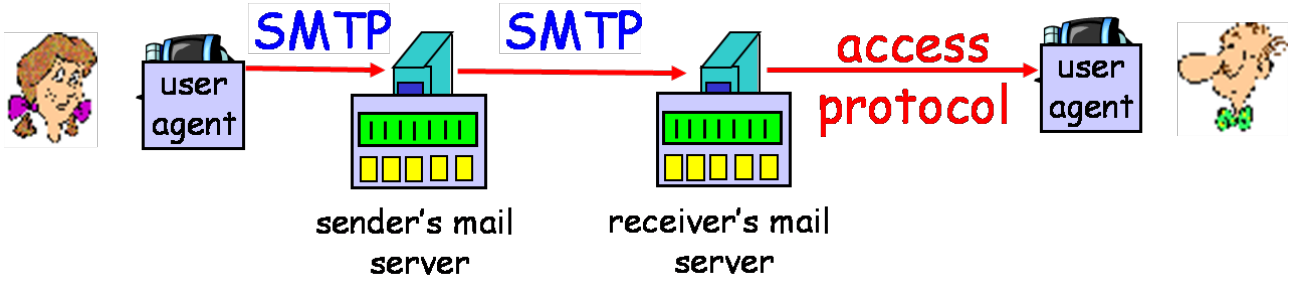


- Mail destinations



Mail Access Protocols

- SMTP: delivery/storage to receiver's server
- Mail access protocol: mail retrieval from server
- POP: Post Office Protocol [RFC 1939]
  - Authorization (agent <-->server) and download
- IMAP: Internet Mail Access Protocol [RFC 1730]
  - more features, including manipulation of stored mails on server
- HTTP: gmail, Hotmail, Yahoo!, etc.



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Domain Name Service (DNS)

- Function
  - Map "domain names" into IP addresses
  - e.g. www.baidu.com → 119.75.217.109
- Domain Name System
  - Distributed database implemented in hierarchy of many name servers
  - App-layer protocol host and name servers to communicate to resolve "domain names"
  - Load balancing: set of IP addresses for one server name

Q: why not centralize DNS?

- single point of failure
- traffic volume
- distant centralized database
- maintenance

A: doesn't scale!

Goals

- Uniqueness: no naming conflicts
- Scalable
  - Many names and frequent updates (secondary)
- Distributed, autonomous administration
  - Ability to update my own (machines') names
  - Don't have to track everybody's updates
- Highly available
- Lookups are fast
- Perfect consistency is a non-goal

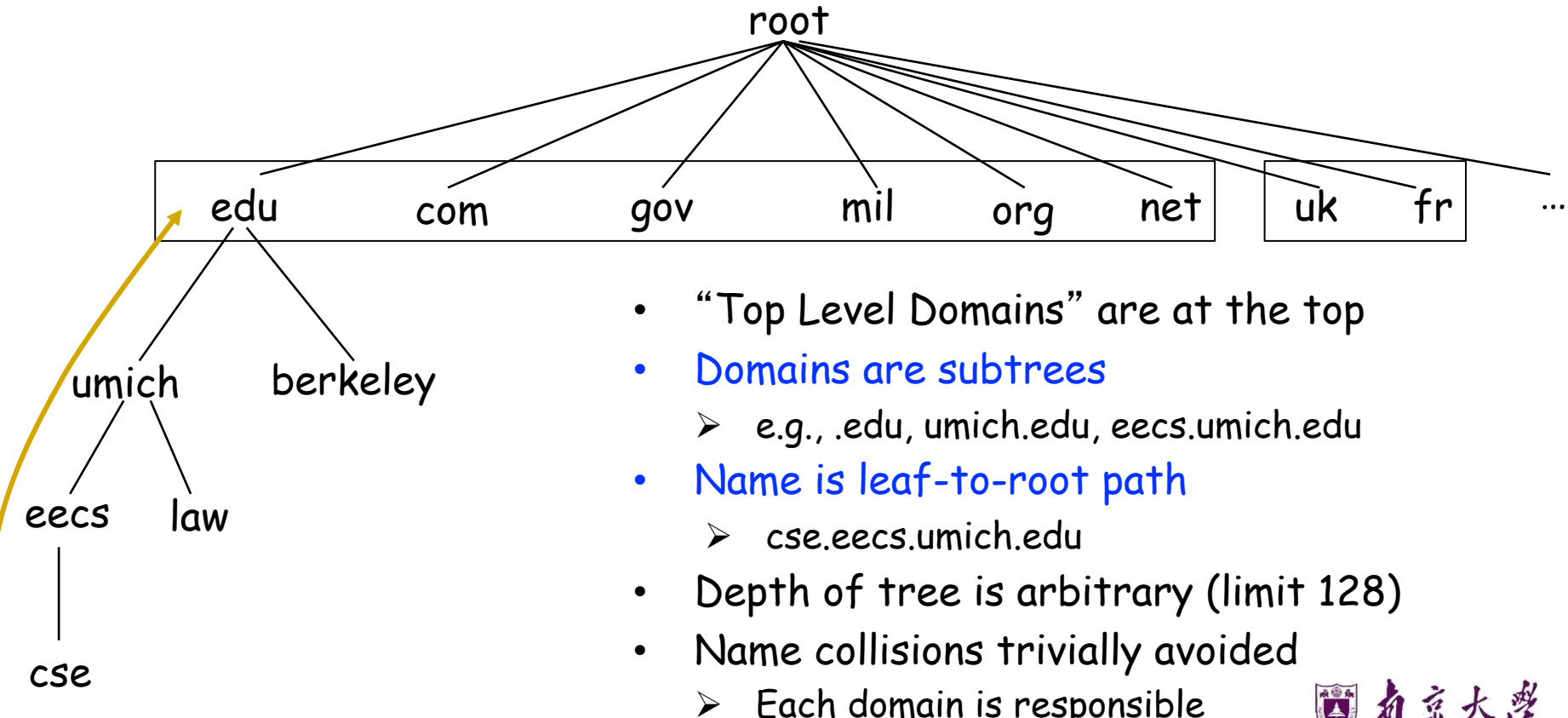
How?

- Partition the namespace
- Distribute administration of each partition
  - Autonomy to update my own (machines') names
  - Don't have to track everybody's updates
- Distribute name resolution for each partition
- How should we partition things?

Key idea: Hierarchy

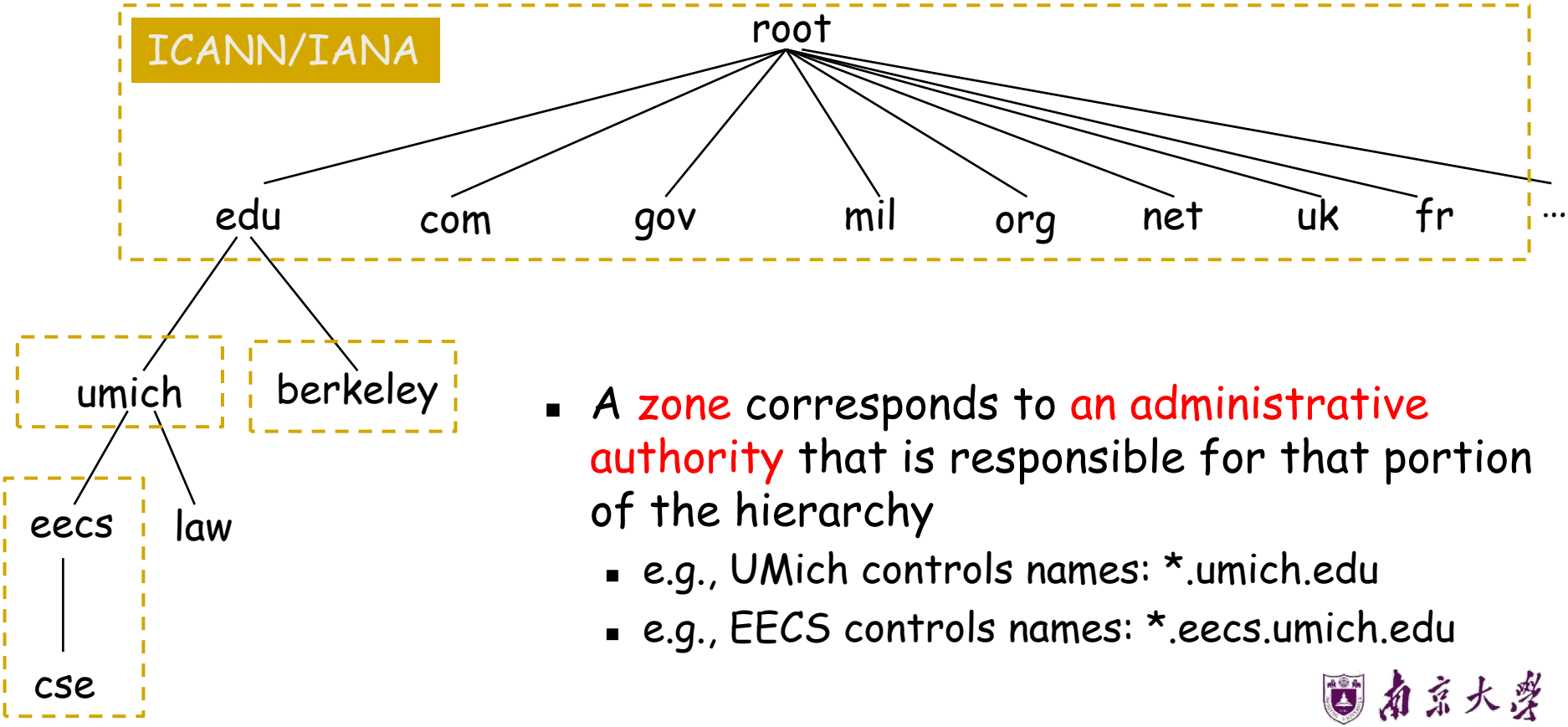
- Three intertwined hierarchies
  - Hierarchical namespace
    - ✓ As opposed to original flat namespace
  - Hierarchically administered
    - ✓ As opposed to centralized
  - (Distributed) hierarchy of servers
    - ✓ As opposed to centralized storage

Hierarchical namespace



- "Top Level Domains" are at the top
- Domains are subtrees
  - e.g., .edu, umich.edu, eecs.umich.edu
- Name is leaf-to-root path
  - cse.eecs.umich.edu
- Depth of tree is arbitrary (limit 128)
- Name collisions trivially avoided
  - Each domain is responsible

Hierarchical administration



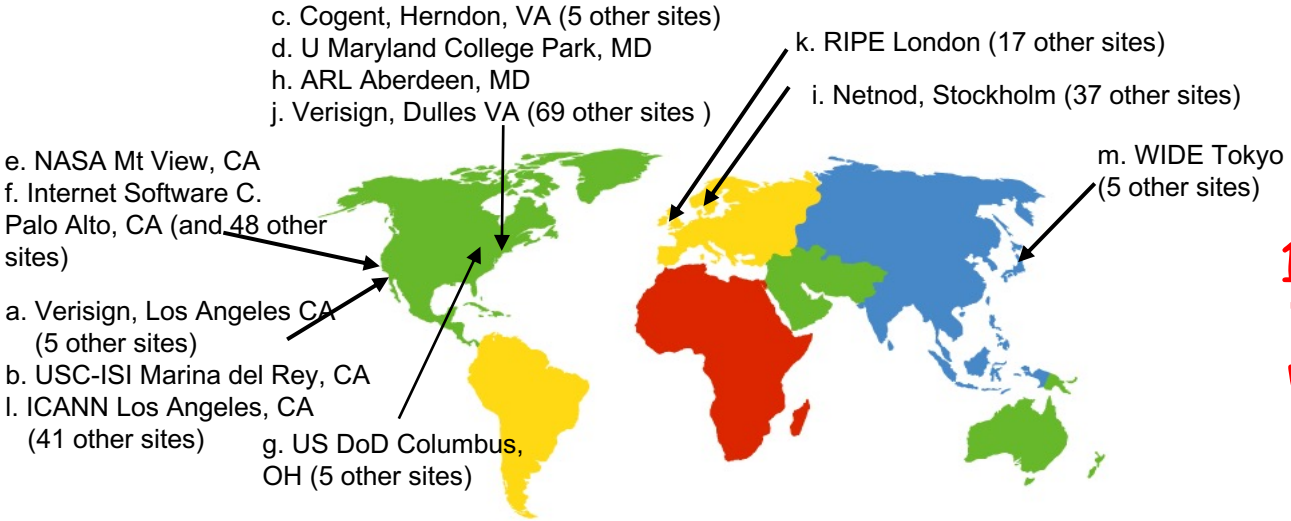
- A zone corresponds to an administrative authority that is responsible for that portion of the hierarchy
  - e.g., UMich controls names: *.umich.edu
  - e.g., EECS controls names: *.eecs.umich.edu

Hierarchy of DNS Servers

- Root name servers
  - Contacted by local name server that can not resolve name
- Top-level domain servers
  - Responsible for com, org, net, edu, etc, and all top-level country domains, e.g. cn, uk, fr
- Authoritative DNS servers
  - Organization's DNS servers, providing authoritative hostname to IP mappings
- Local Name Servers
  - Maintained by each residential ISP, company, university
  - When host makes DNS query, query is sent to its local DNS server

DNS: root name servers

- root name server:
  - returns IP mappings of TLD servers



13 root name "servers" worldwide

TLD, authoritative servers

- Top-level domain (TLD) servers:
  - responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g.: uk, fr, ca, jp
  - Network Solutions maintains servers for .com TLD
  - Educause for .edu TLD

- 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

Local DNS name server

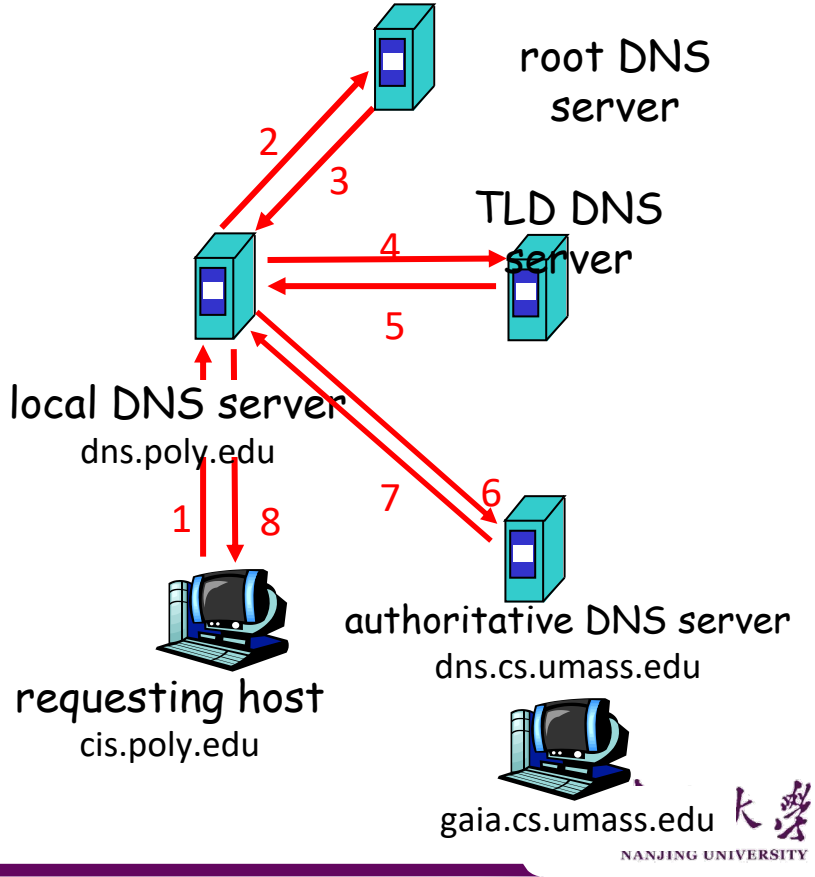
- Does not strictly belong to hierarchy
- Each ISP (residential ISP, company, university) has one
  - also called "default name server"
- When host makes DNS query, query is sent to its local DNS server
  - has local cache of recent name-to-address translation pairs (but may be out of date!)
  - acts as proxy, forwards query into hierarchy

DNS Name Resolution Example

- Bob at cis.poly.edu wants IP address for Alice at gaia.cs.umass.edu

- Iterated query:
- Contacted server replies with name of next server to contact

- Host-Server: recursive query
- Server-Server: iterative query



DNS Records

- A DNS resource record (RR)

RR format: (name, value, type, ttl)

- "Name" is the domain name, "type" denotes how "value" is explained
  - e.g. Name Server records (NS), Mail Exchangers (MX), Host IP Address (A), Canonical name (CNAME)
- Examples
  - (networkutopia.com, dns1.networkutopia.com, NS, 32768)
  - (dns1.networkutopia.com, 212.212.212.1, A, 5600)

DNS protocol

- Query and Reply messages; both with the same message format
  - Header: identifier, flags, etc.
  - Plus resource records
  - See text/section for details
- Client-server interaction on UDP Port 53
  - Spec supports TCP too, but not always implemented

DNS caching

- Performing all these queries takes time
  - Up to 1-second latency before starting download
- Caching can greatly reduce overhead
  - The top-level servers very rarely change
  - Popular sites (e.g., www.cnn.com) visited often
  - Local DNS server often has the information cached
- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a "time to live" (TTL) field
  - Server deletes cached entry after TTL expires

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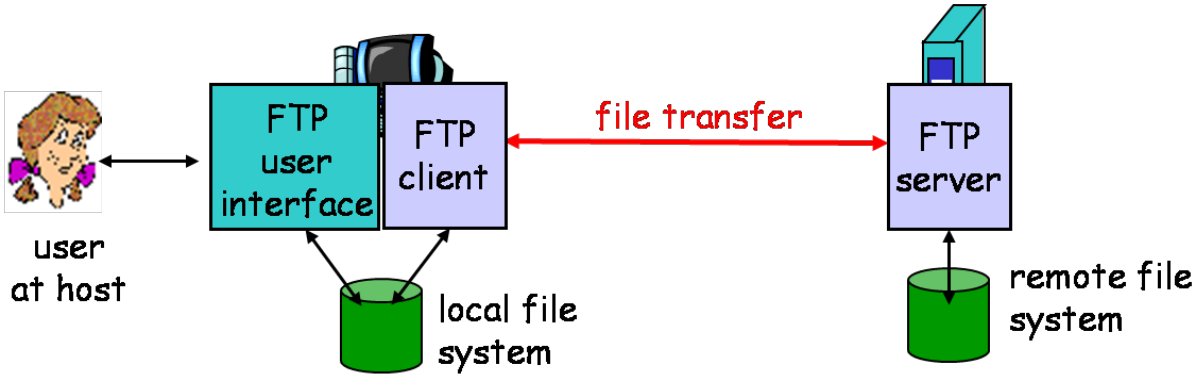
File Transfer Protocol (FTP)

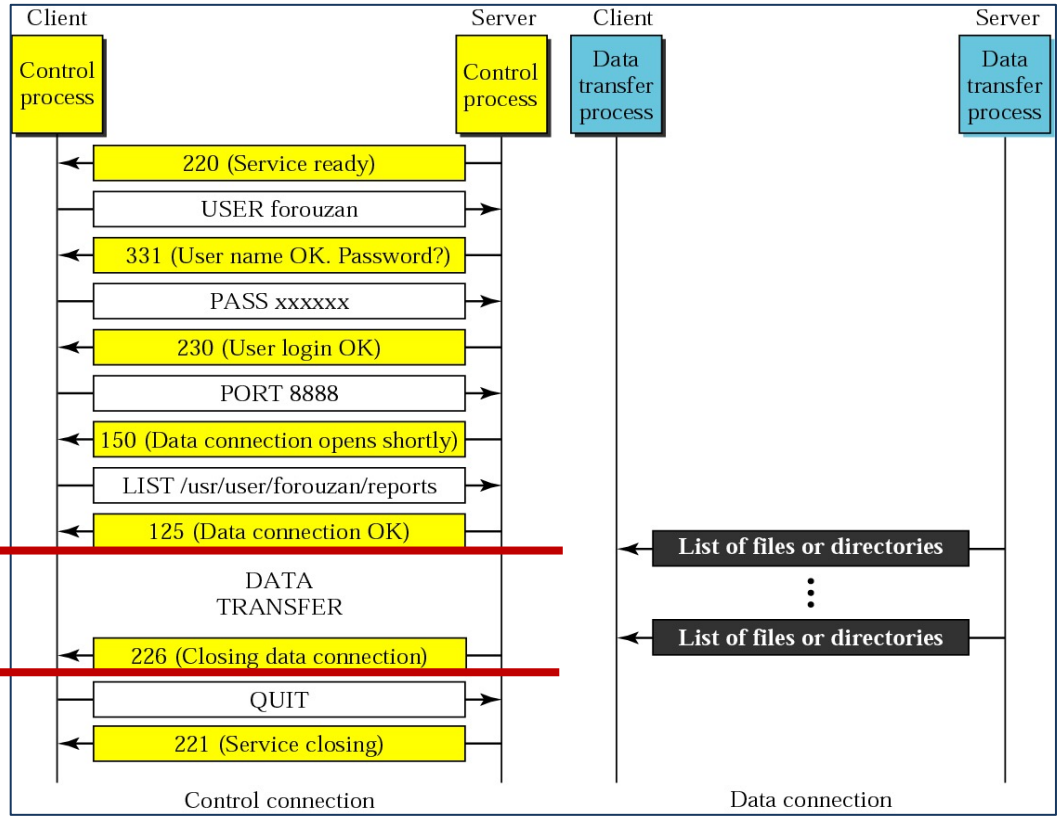
- RFC 959, use TCP, port 21/20
- Transfer file to/from remote host
- Client/Server model, client side initiates file transfer (either to/from remote)
- Deals with heterogeneous OS and file systems
- Needs access control on remote file system



Control and Data Connections

- FTP client contacts FTP server at port 21, opens a control connection
- Client authorized over control connection
- Client browses remote directory by sending commands over control connection
- When server receives file transfer command, server opens 2nd TCP data connection (for file) to client
  - One connection for each file transferred
- After transferring one file, server closes data connection
- Control connection stays "out of band"
- FTP server maintains "user state": current directory, earlier authentication

Illustration of FTP Session



FTP Commands and 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 server

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

BitTorrent

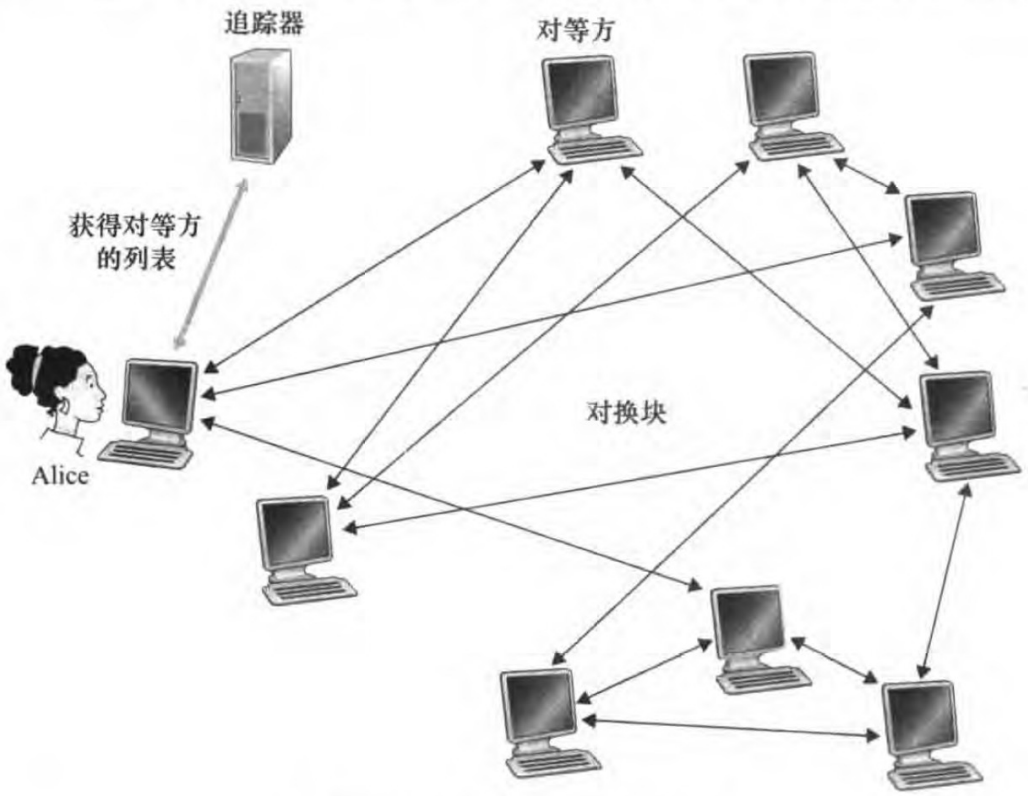


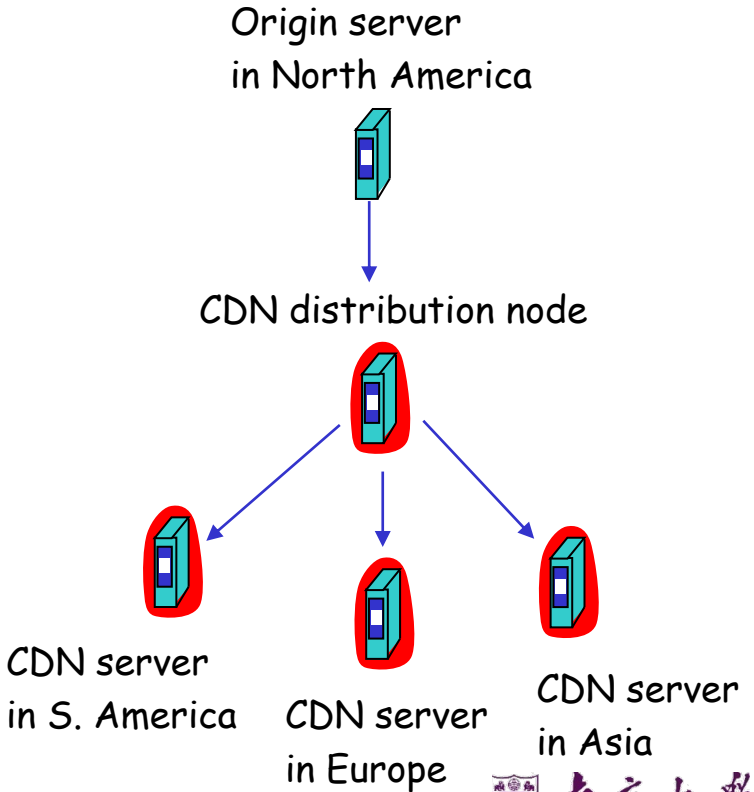
图 2-23　用 BitTorrent 分发文件

Internet Applications

- Internet Applications Overview
- Domain Name Service (DNS)
- Electronic Mail
- File Transfer Protocol (FTP)
- WWW and HTTP
- Content Distribution Networks (CDNs)

Content Distribution Networks (CDNs)

- Challenge
  - Stream large files (e.g. video) from single origin server in real time
  - Protect origin server from DDOS attacks
- Solution
  - Replicate content at hundreds of servers throughout Internet
  - CDN distribution node coordinate the content distribution
  - Placing content close to user



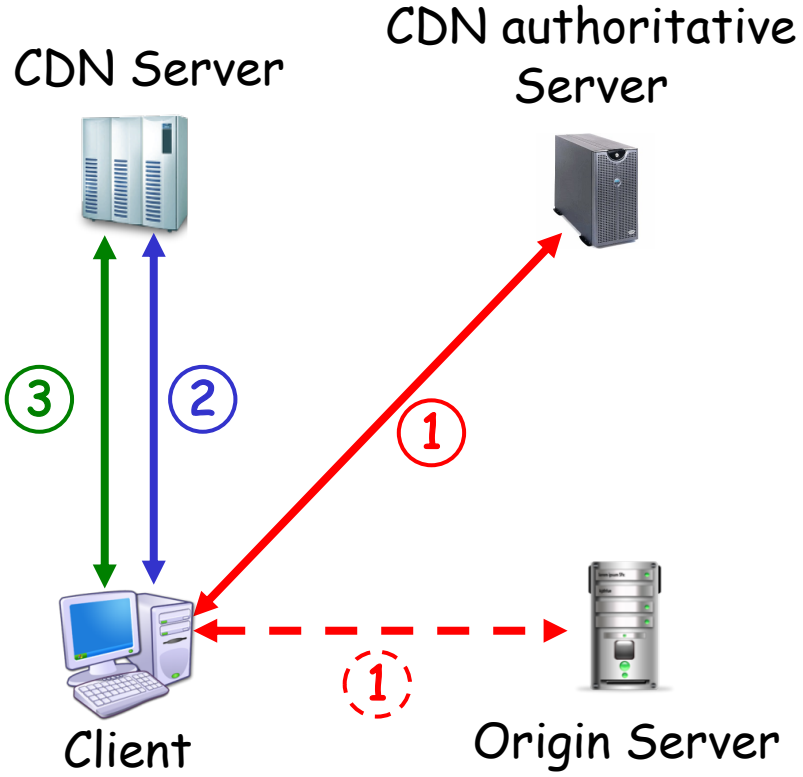
Content Replication

- Content provider (origin server) is CDN customer
- CDN replicates customers' content in CDN servers
- When provider updates content, CDN updates its servers
- Use authoritative DNS server to redirect requests

Supporting Techniques

- DNS
  - One name maps onto many addresses
- Routing
  - Content-based routing (to nearest CDN server)
- URL Rewriting
  - Replaces "http://www.sina.com/sports/tennis.mov" with "http://www.cdn.com/www.sina.com/sports/tennis.mov"
- Redirection strategy
  - Load balancing, network delay, cache/content locality

CDN Operation



1′ URL rewriting – get authoritative server

1. Get near CDN server IP address
2. Warm up CDN cache
3. Retrieve pages/media from CDN Server

课程习题（作业）——截止日期：3月11日晚23:59

- **课本110-115页**：第R3、R5、R16、P9、P22题
- 提交方式：https://selearning.nju.edu.cn/（教学支持系统）

- 命名：学号+姓名+第*章。
- 若提交遇到问题请及时发邮件或在下一次上课时反馈。

课程习题（作业）——截止日期：3月11日晚23:59

R3. 对两进程之间的通信会话而言，哪个进程是客户，哪个进程是服务器？

R5. 运行在一台主机上的一个进程，使用什么信息来标识运行在另一台主机上的进程？

R16. 假定 Alice 使用一个基于 Web 的电子邮件账户（例如 Hotmail 或 Gmail）向 Bob 发报文，而 Bob 使用 IMAP 从他的邮件服务器访问自己的邮件。讨论该报文是如何从 Alice 主机到 Bob 主机的。要列出在两台主机间移动该报文时所使用的各种应用层协议。

课程习题（作业）——截止日期：3月11日晚23:59

P9. 考虑图 2-12，其中有一个机构的网络和因特网相连。假定对象的平均长度为 850 000 比特，从这个机构网的浏览器到初始服务器的平均请求率是每秒 16 个请求。还假定从接入链路的因特网一侧的路由器转发一个 HTTP 请求开始，到接收到其响应的平均时间是 3 秒（参见 2.2.5 节）。将总的平均响应时间建模为平均接入时延（即从因特网路由器到机构路由器的时延）和平均因特网时延之和。对于平均接入时延，使用 $\Delta/(1-\Delta\beta)$，式中 Δ 是跨越接入链路发送一个对象的平均时间，β 是对象对该接入链路的平均到达率。

a. 求出总的平均响应时间。

b. 现在假定在这个机构 LAN 中安装了一个缓存器。假定命中率为 0.4，求出总的响应时间。

P22. 考虑向 N 个对等方分发 F =20Gb 的一个文件。该服务器具有 u_s = 30Mbps 的上载速率，每个对等方具有 d_i = 2Mbps 的下载速率和上载速率 u。对于 N = 10、100 和 1000 并且 u = 300kbps、700kbps 和 2Mbps，对于 N 和 u 的每种组合绘制出确定最小分发时间的图表。需要分别针对客户－服务器分发和 P2P 分发两种情况制作。

助教信息

甘世维	博士	计算机学院	sw@smail.nju.edu.cn
刘晓	博士	智能软件与工程学院	602024720002@smail.nju.edu.cn
郭博文	博士	智能软件与工程学院	bowen@smail.nju.edu.cn
德斯别尔	硕士	智能如软件与工程学院	522024720002@smail.nju.edu.cn

提问

Q & A

殷亚凤
智能软件与工程学院
苏州校区南雍楼东区225
yafeng@nju.edu.cn，https://yafengnju.github.io/

南京大学 NANJING UNIVERSITY