Network Applications: Load Balancing among Homogeneous Servers

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https://sngroup.org.cn/courses/cnns-xmuf25/index.shtml

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This deck of slides are heavily based on CPSC 433/533 at Yale University, by courtesy of Dr. Y. Richard Yang.

Outline

- Admin and recap
- Application overlays (distributed network applications) to
  - scale bandwidth/resource (BitTorrent)

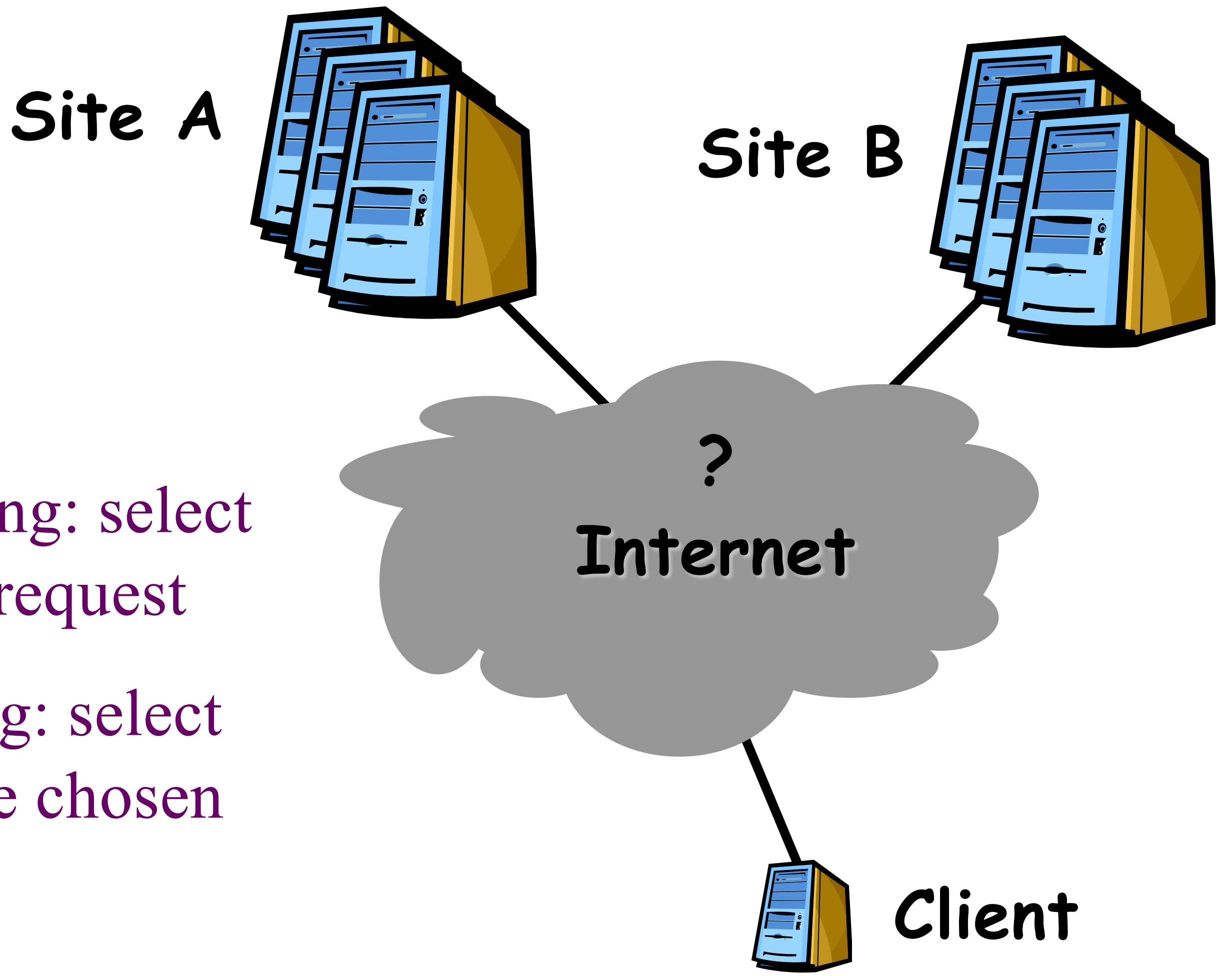
Admin

- Midterm exam on Oct. 28 (during lab class)
  - cover from introduction to application layer
  - 15-16 subjective questions over 100 minutes
  - 1-page cheat sheet allowed

Recap: Why Multiple Servers?

- Scalability
  - Scaling beyond single server throughput
    - There is a fundamental limit on what a single server can
      - process (CPU/bw/disk throughput)
      - store (disk/memory)
  - Scaling beyond single geo location latency
    - There is a limit on the speed of light
    - Network detour and delay further increase the delay

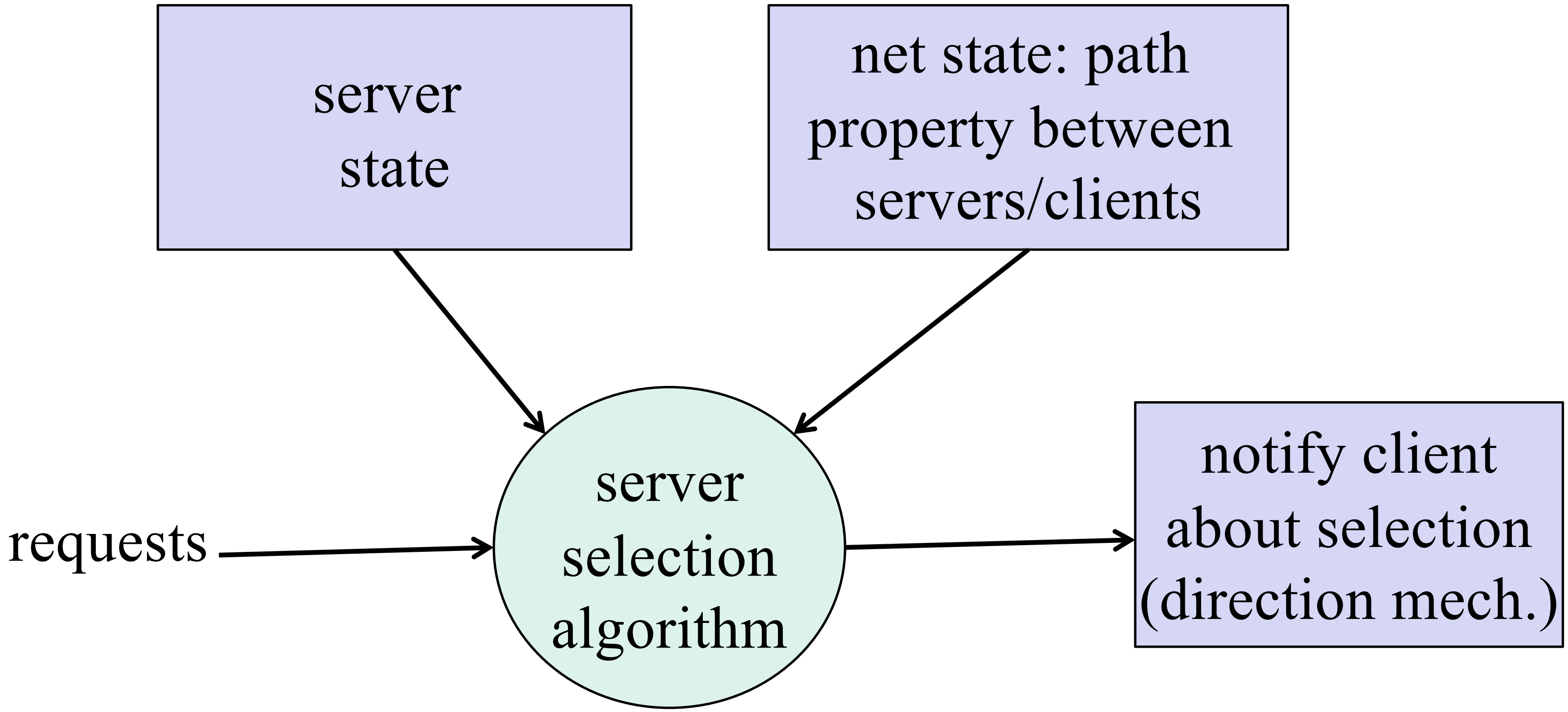
Recap: Request Routing



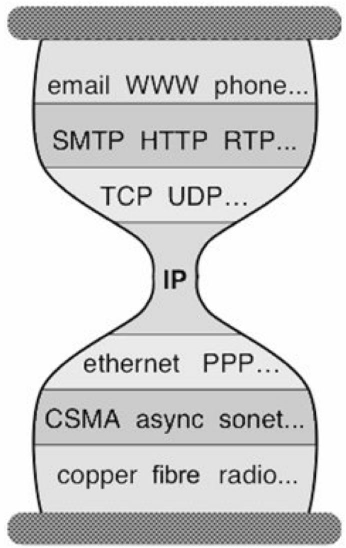
- Global request routing: select a server site for each request

- Local request routing: select a specific server at the chosen site

Request Routing: Basic Architecture

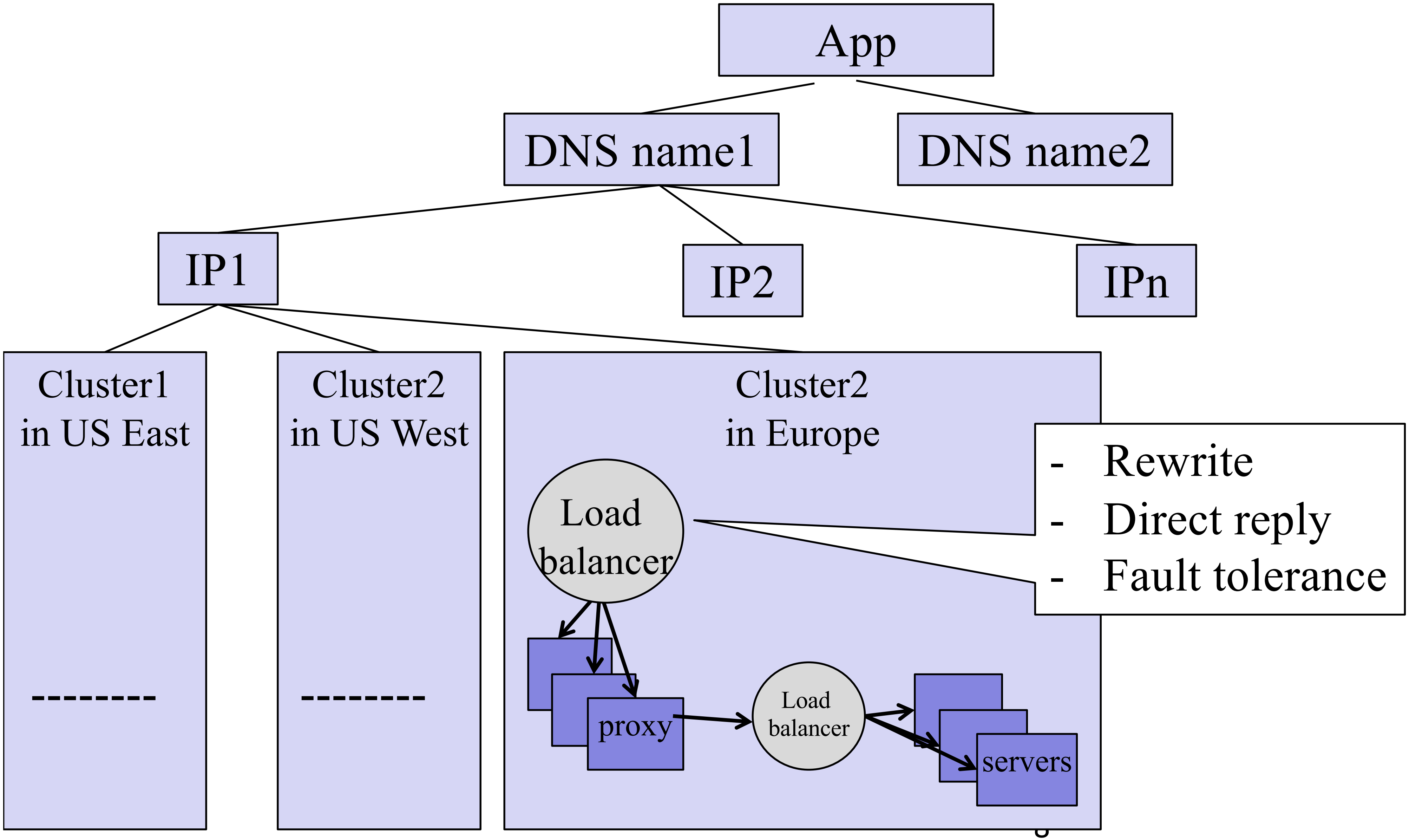


Client Direction Mechanisms

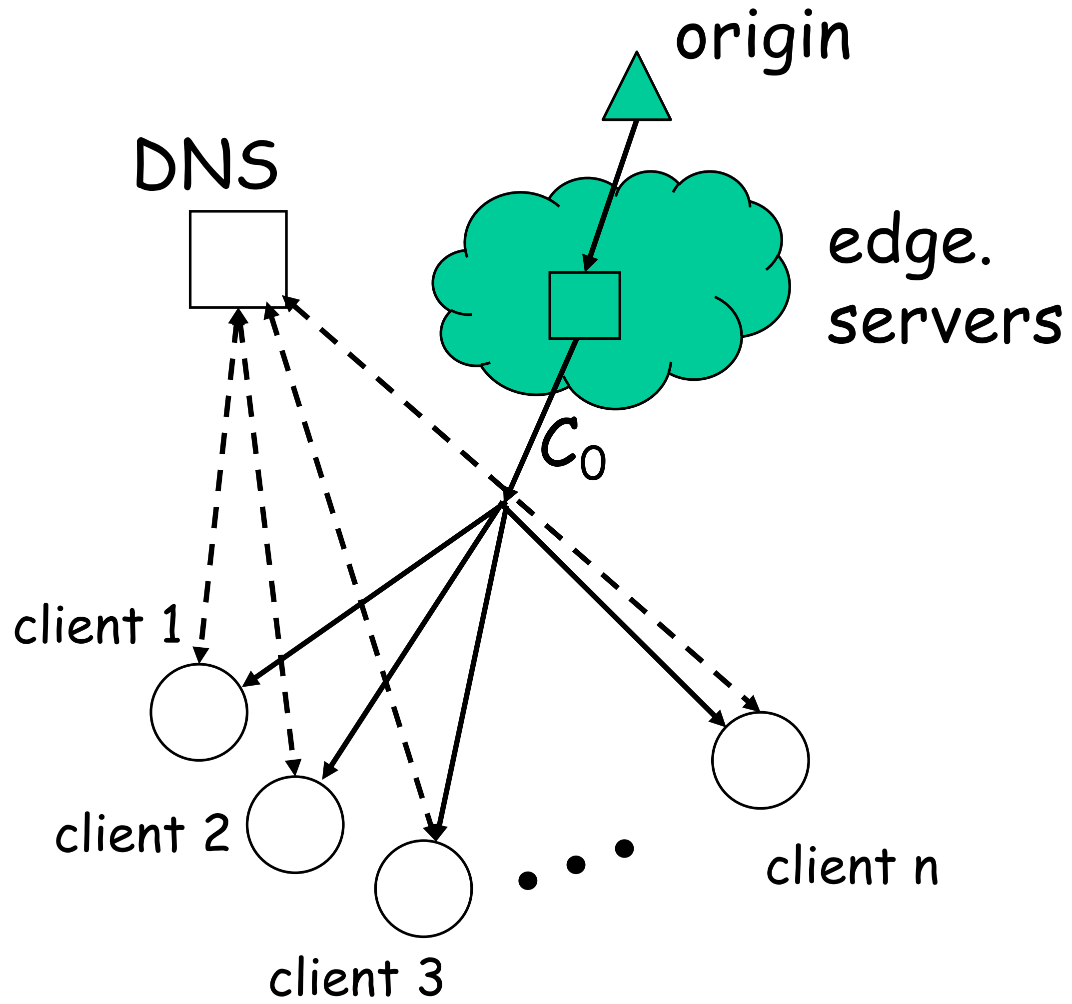


- Key difficulty
  - May need to handle a large of clients
- Basic types of mechanisms
  - Application layer, e.g.,
    - App/user is given a list of candidate server names
    - HTTP redirector
  - DNS: name resolution gives a list of server addresses
  - IP layer: Same IP address represents multiple physical servers
    - IP anycast: Same IP address shared by multiple servers and announced at different parts of the Internet. Network directs different clients to different servers
    - Smart-switch indirection: a server IP address may be a virtual IP address for a cluster of physical servers

Recap: Direction Mechanisms



Scalability of Server-Only Approaches

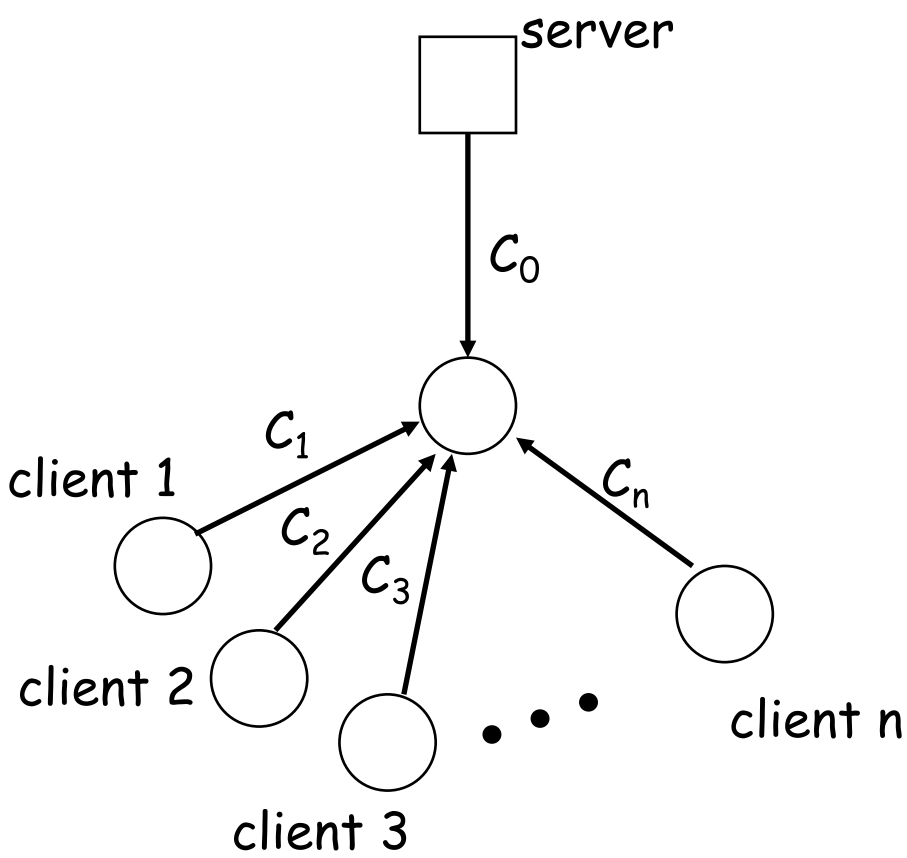


Outline

- Admin and recap
- Multiple servers
- Application overlays
    - potential

An Upper Bound on Scalability

- Idea: use resources from both clients and the server
- Assume
  - need to achieve same rate to all clients
  - only uplinks can be bottlenecks
- What is an upper bound on scalability?

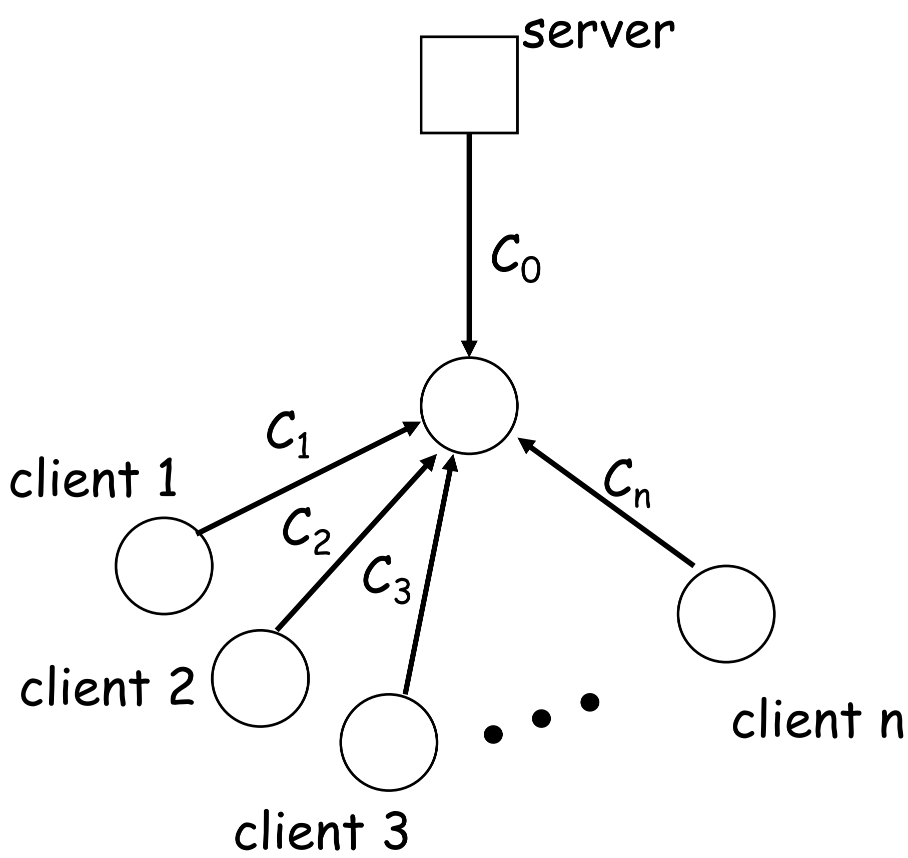


The Scalability Problem

- Maximum throughput

  $R = \min\{C_0, (C_0+\Sigma C_i)/n\}$

- The bound is theoretically approachable



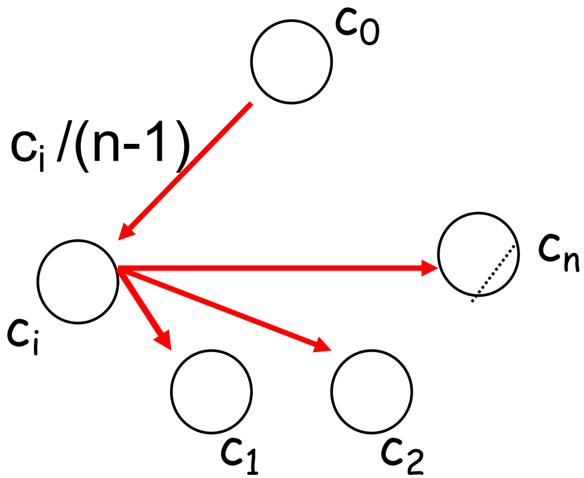
Theoretical Capacity: upload is bottleneck

$R = \min\{C_0, (C_0+\Sigma C_i)/n\}$

- Assume $c_0 > (C_0+\Sigma C_i)/n$
- Tree i:

  server → client i: $c_i/(n-1)$

  client i → other n-1 clients

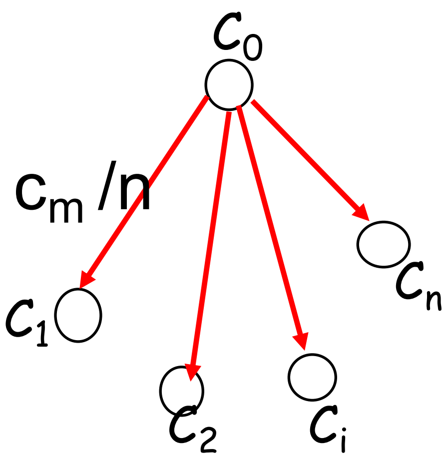


- Tree 0:

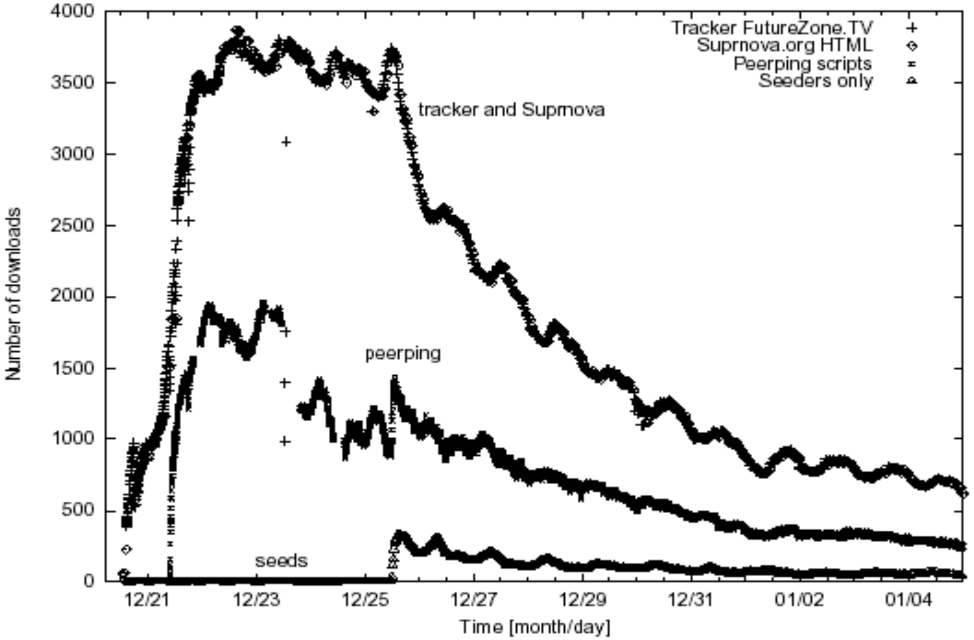
  server has remaining

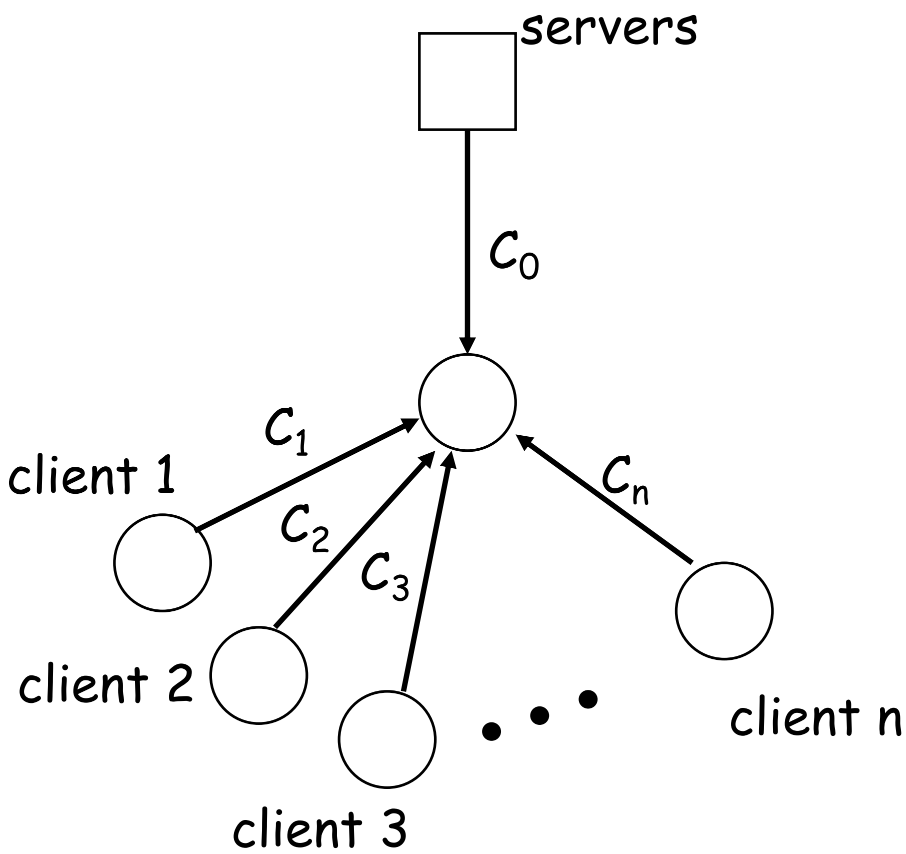
  $c_m = c0 - (c1 + c2 + \ldots cn)/(n-1)$

  send to client i: c_m/n



Why not Building the Trees?

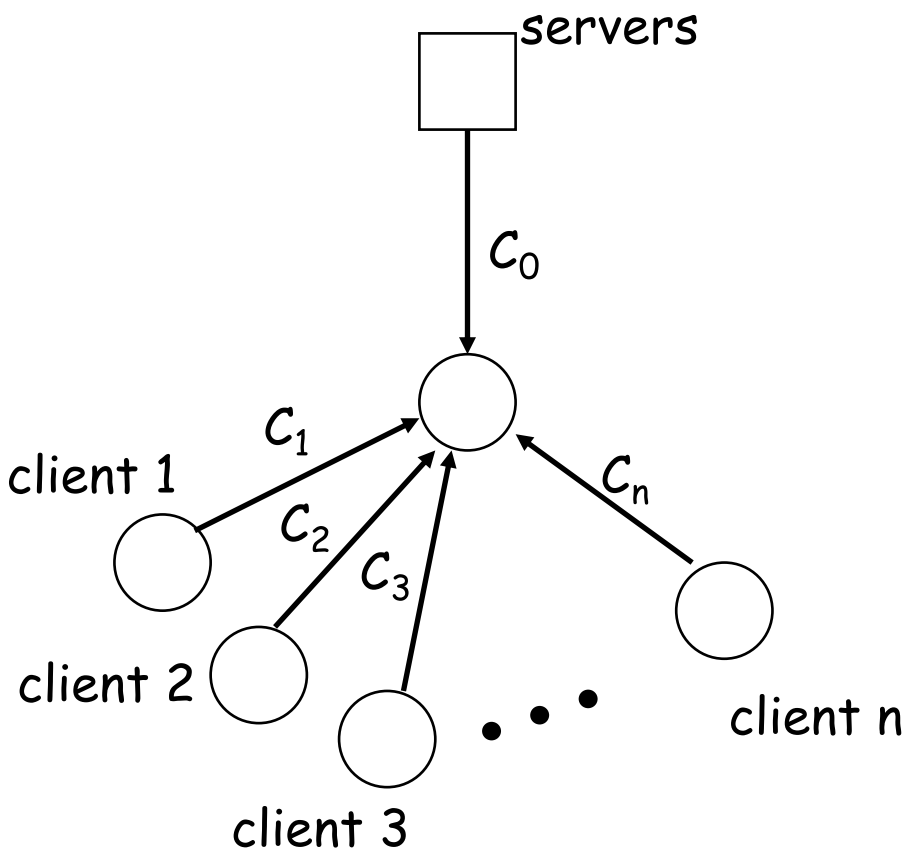




- Clients come and go (churns): maintaining the trees is too expensive
- Each client needs N connections

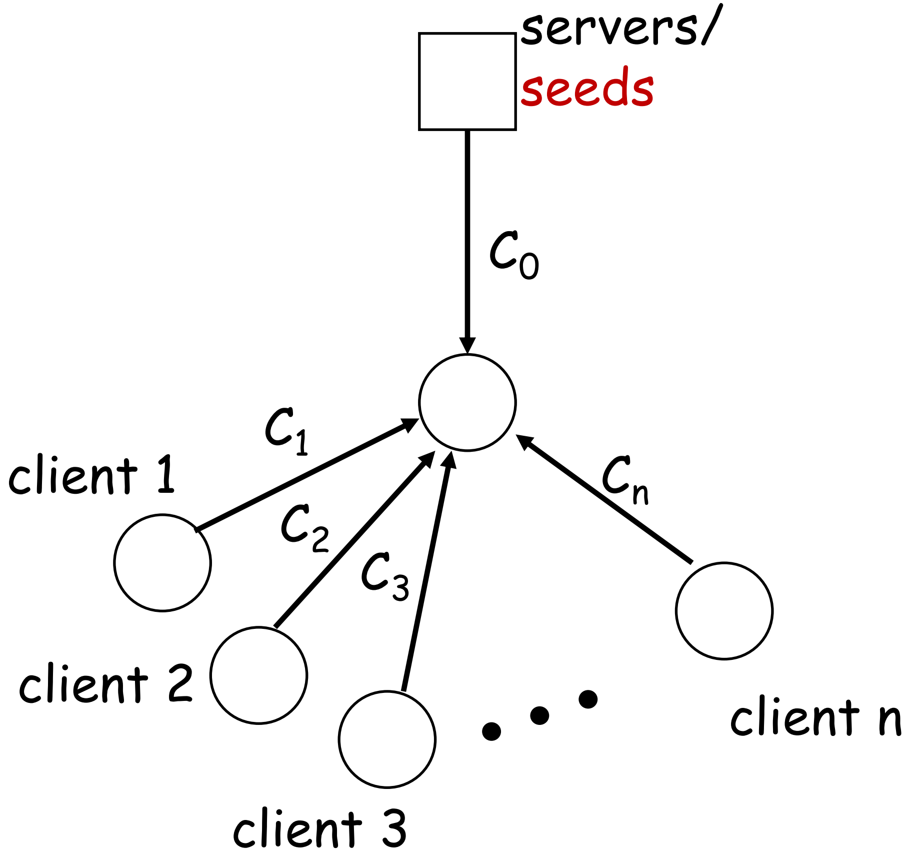
Server+Host (P2P) Content Distribution: Key Design Issues

- Robustness
  - Resistant to churns and failures
- Efficiency
  - A client has content that others need; otherwise, its upload capacity may not be utilized
- Incentive: clients are willing to upload
  - Some real systems nearly 50% of all responses are returned by the top 1% of sharing hosts



Discussion: How to handle the issues?

- Robustness
- Efficiency
- Incentive



Example: BitTorrent

- A P2P file sharing protocol
- Created by Bram Cohen in 2004
  - Spec at bep_0003: http://www.bittorrent.org/beps/bep_0003.html

BitTorrent: Lookup

webserver

HTTP GET MYFILE.torrent

MYFILE.torrent

http://mytracker.com:6969/
S3F5YHG6FEB
FG5467HGF367
F456JI9N5FF4E
...

user

Metadata (.torrent) File Structure

- Meta info contains information necessary to contact the tracker and describes the files in the torrent
  - URL of tracker
  - file name
  - file length
  - piece length (typically 256KB)
  - SHA-1 hashes of pieces for verification
  - also creation date, comment, creator, …

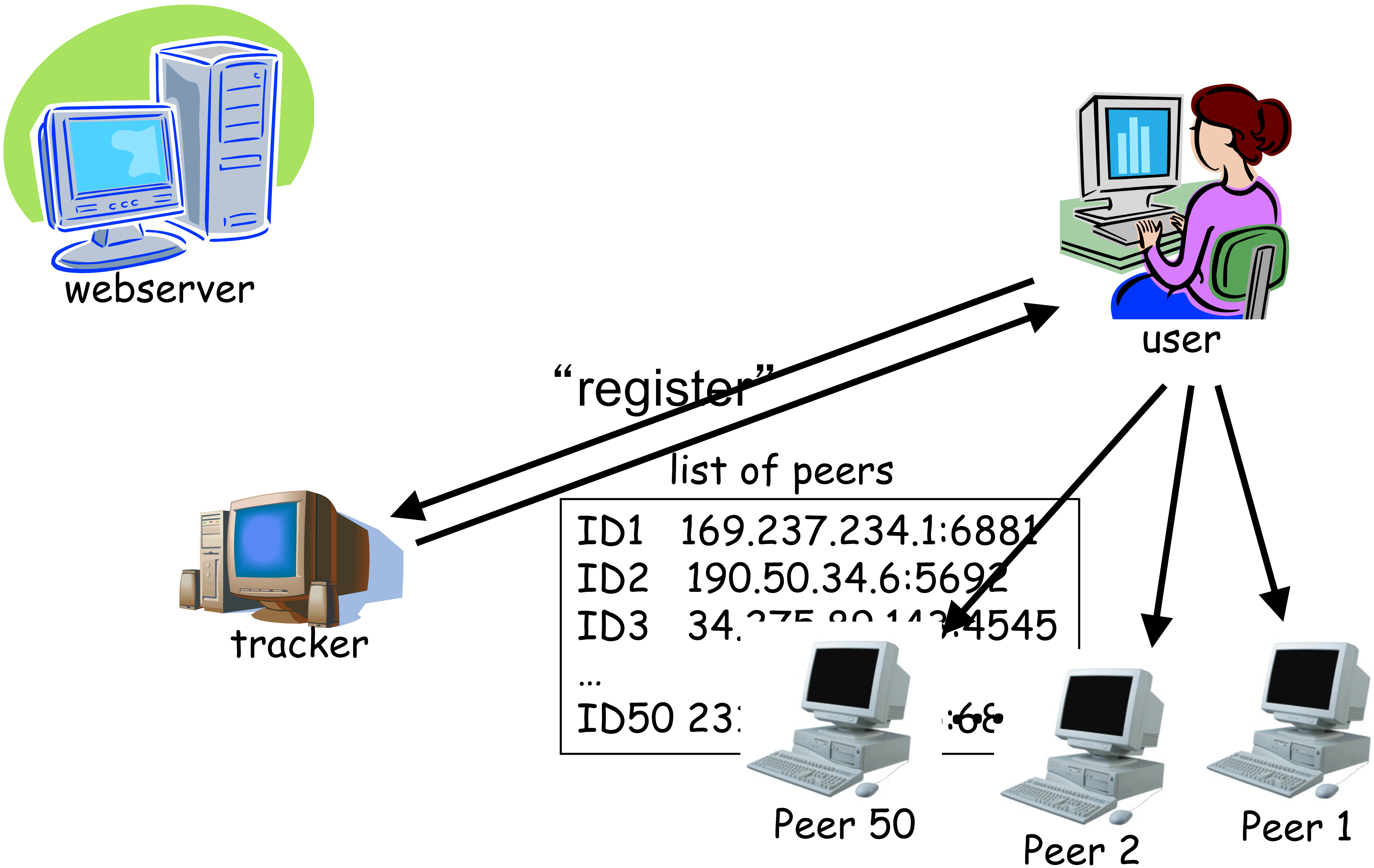
Tracker Protocol

- Communicates with clients via HTTP/HTTPS

- Client GET request
  - info_hash: uniquely identifies the file
  - peer_id: chosen by and uniquely identifies the client
  - client IP and port
  - numwant: how many peers to return (defaults to 50)
  - stats: e.g., bytes uploaded, downloaded

- Tracker GET response
  - interval: how often to contact the tracker
  - list of peers, containing peer id, IP and port
  - stats

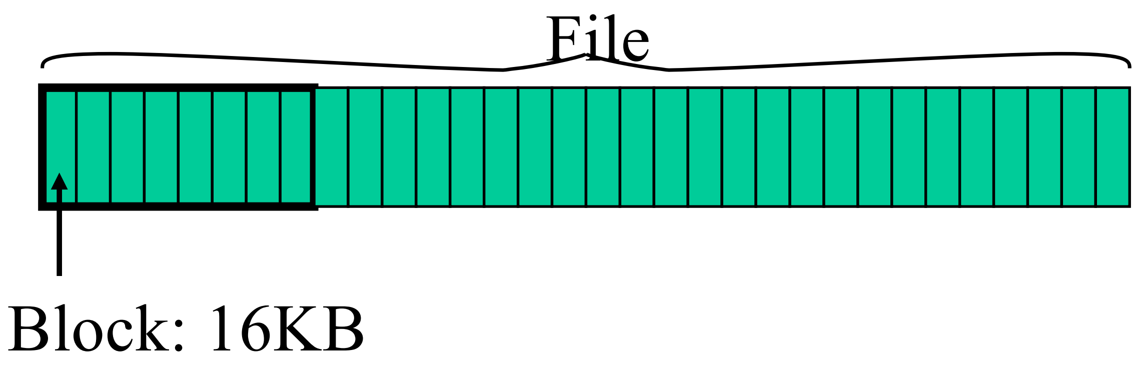
Tracker Protocol



Robustness and efficiency: Piece-based Swarming

- Divide a large file into small blocks and request block-size content from different peers (why?)

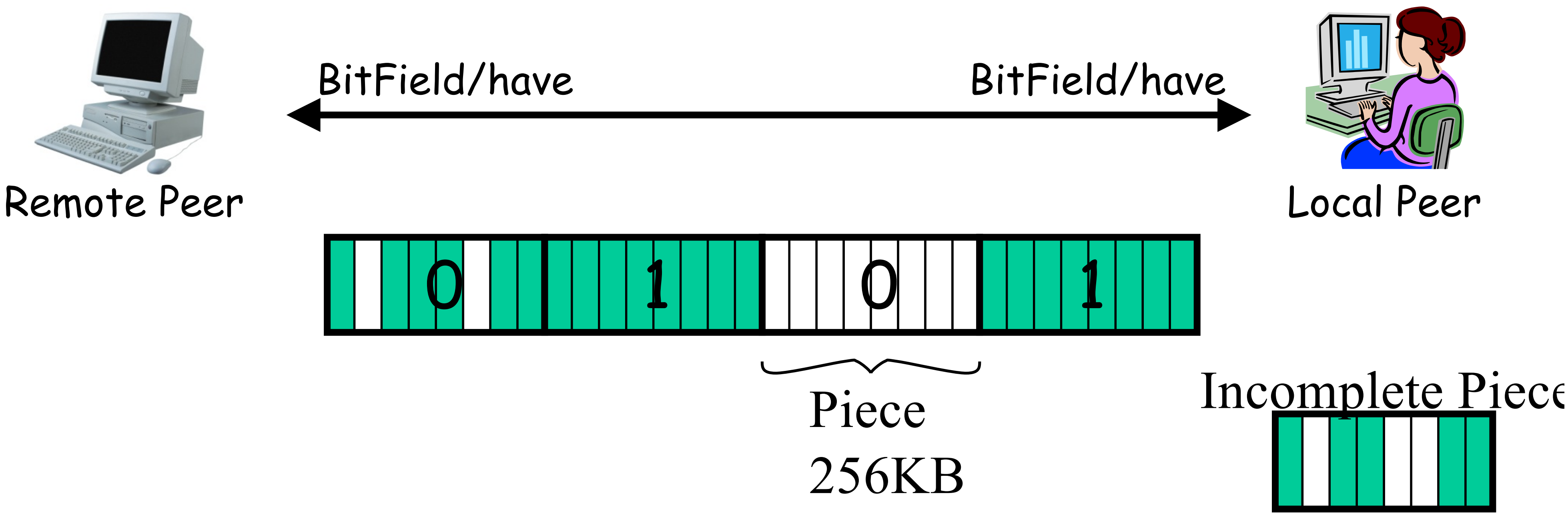
Block: unit of download



- If do not finish downloading a block from one peer within timeout (say due to churns), switch to requesting the block from another peer

Detail: Peer Protocol

(Over TCP)

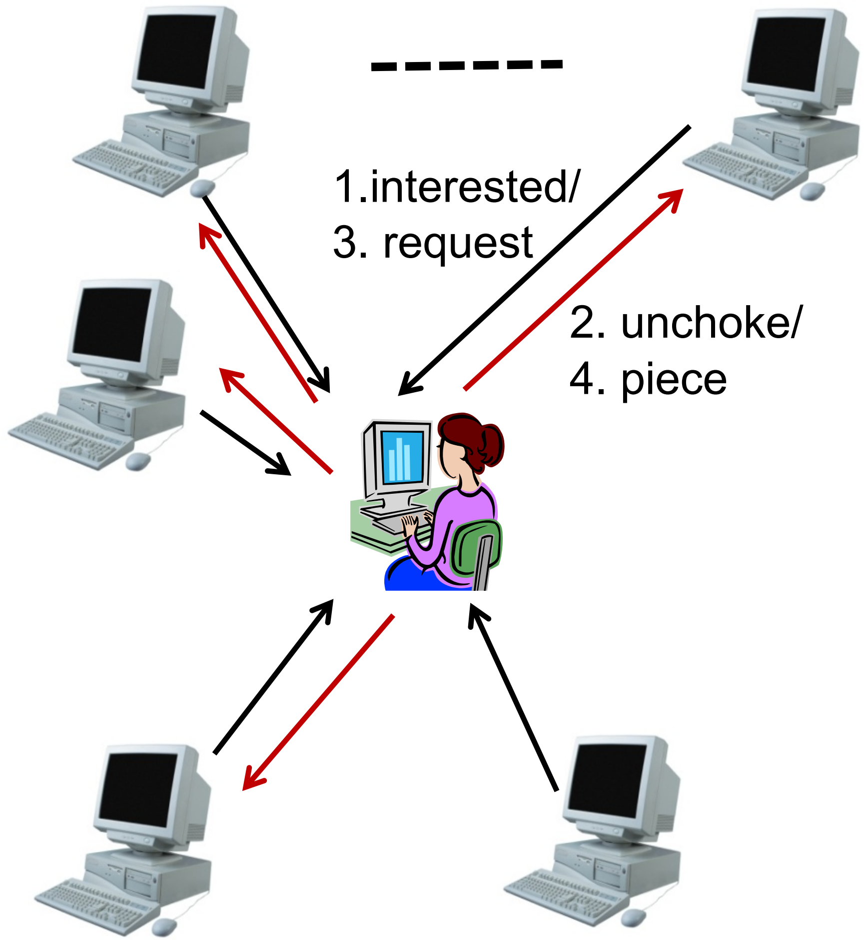


- Peers exchange bitmap representing content availability
  - `bitfield` msg during initial connection
  - `have` msg to notify updates to bitmap
  - to reduce bitmap size, aggregate multiple blocks as a piece

Peer Request

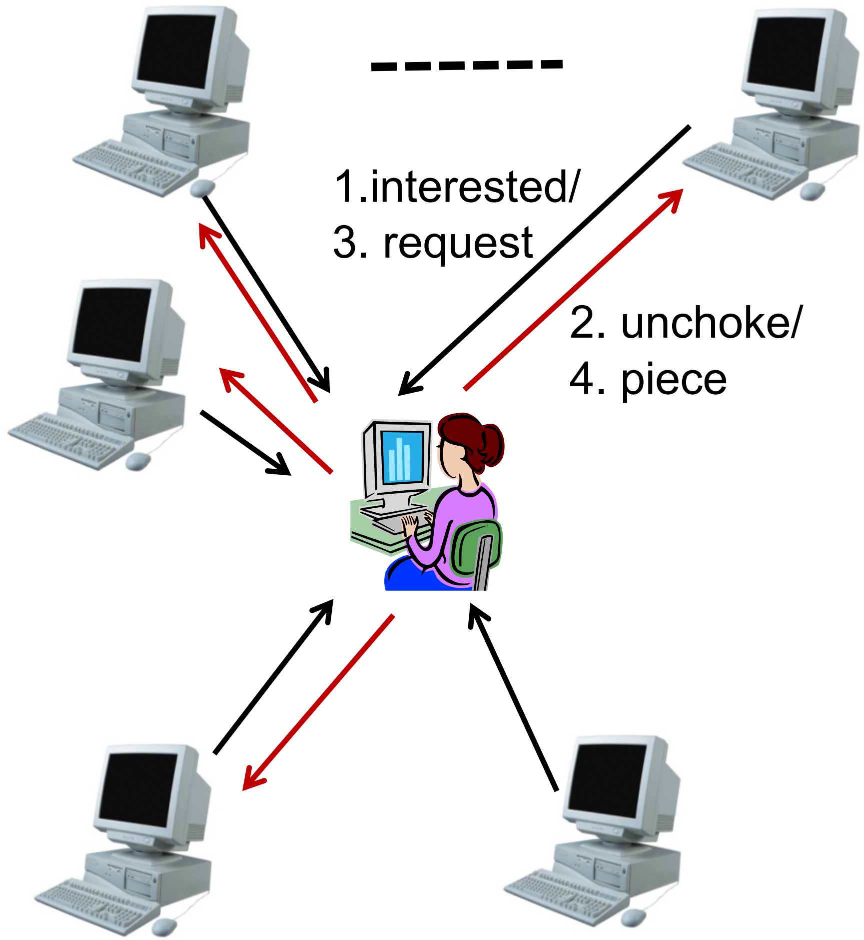
http://www.bittorrent.org/beps/bep_0003.html

- If peer A has a piece that peer B needs, peer B sends `interested` to A
- `unchoke`: indicate that A allows B to request
- `request`: B requests a specific block from A
- `piece`: specific data



Key Design Points

- request:
  - which data blocks to request?
- unchoke:
  - which peers to serve?



Request: Block Availability

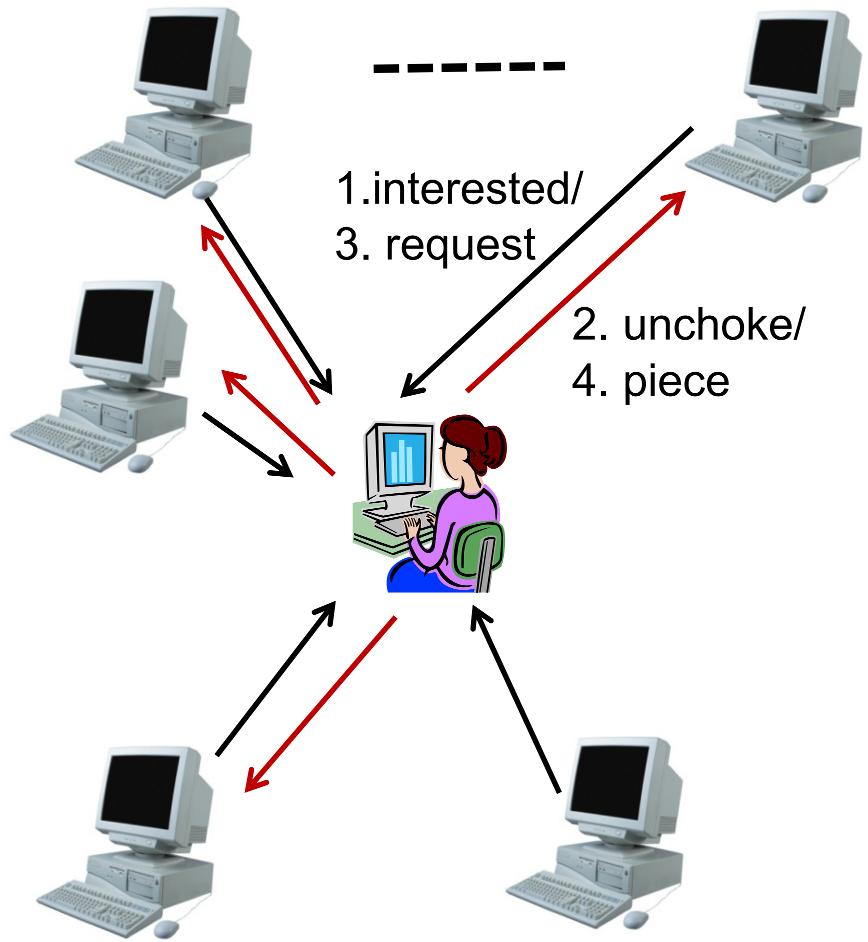
- Request (local) rarest first
  - achieves the fastest replication of rare pieces
  - obtain something of value

Block Availability: Revisions

- When downloading starts (first 4 pieces): choose at random and request them from the peers
  - get pieces as quickly as possible
  - obtain something to offer to others
- Endgame mode
  - defense against the "last-block problem": cannot finish because missing a few last pieces
  - send requests for missing pieces to all peers in our peer list
  - send `cancel` messages upon receipt of a piece

BitTorrent: Unchoke

- Periodically (typically every 10 seconds) calculate data-receiving rates from all peers
- Upload to (*unchoke*) the fastest
    - constant number (4) of unchoking slots
    - partition upload bw equally among unchoked



commonly referred to as "tit-for-tat" strategy

Optimistic Unchoking

- Periodically select a peer at random and upload to it
  - typically every 3 unchoking rounds (30 seconds)

- Multi-purpose mechanism
  - allow bootstrapping of new clients
  - continuously look for the fastest peers (exploitation vs exploration)

BitTorrent Fluid Analysis

- Normalize file size to 1
- $x(t)$: number of downloaders (also known as leechers) who do not have all pieces at time t.
- $y(t)$: number of seeds in the system at time t.
- λ: the arrival rate of new requests.
- μ: the uploading bandwidth of a given peer.
- c: the downloading bandwidth of a given peer, assume $c \geq \mu$.
- θ: the rate at which downloaders abort download.
- γ: the rate at which seeds leave the system.
- η: indicates the effectiveness of downloader sharing, η takes values in [0, 1].

System Evolution

$$\begin{aligned}\frac{\mathrm{d}x}{\mathrm{d}t} &= \lambda - \theta x(t) - \min\{cx(t), \mu(\eta x(t) + y(t))\}, \\ \frac{\mathrm{d}y}{\mathrm{d}t} &= \min\{cx(t), \mu(\eta x(t) + y(t))\} - \gamma y(t),\end{aligned}$$

Solving steady state: $\frac{\mathrm{d}x(t)}{\mathrm{d}t} = \frac{\mathrm{d}y(t)}{\mathrm{d}t} = 0$

Define $\frac{1}{\beta} = \max\{\frac{1}{c}, \frac{1}{\eta}(\frac{1}{\mu} - \frac{1}{\gamma})\}$

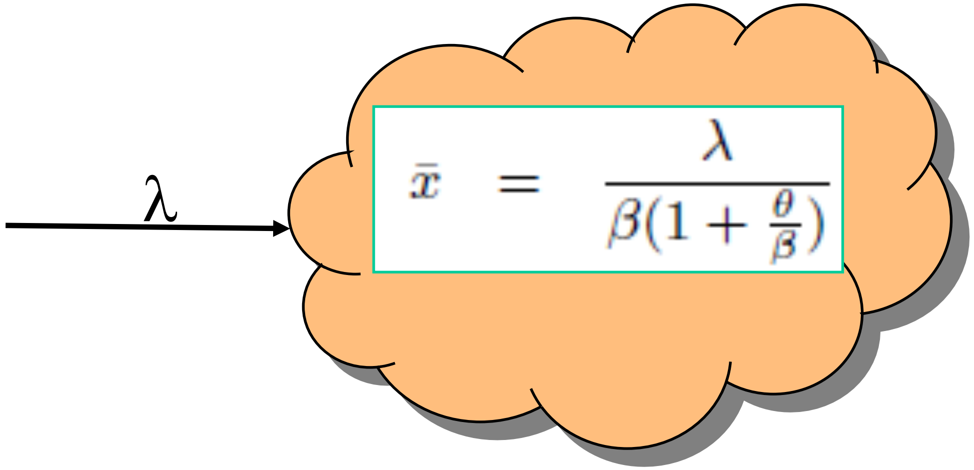
$$\boxed{\begin{aligned}\bar{x} &= \frac{\lambda}{\beta(1 + \frac{\theta}{\beta})} \\ \bar{y} &= \frac{\lambda}{\gamma(1 + \frac{\theta}{\beta})}.\end{aligned}}$$

"Modeling and Performance Analysis of BitTorrent-Like Peer-to-Peer Networks", SIGCOMM'04
https://conferences.sigcomm.org/sigcomm/2004/papers/p444-qiu1.pdf

System State

$$\bar{x} = \frac{\lambda}{\beta(1+\frac{\theta}{\beta})}$$
$$\bar{y} = \frac{\lambda}{\gamma(1+\frac{\theta}{\beta})}.$$

Q: How long does each downloader stay as a downloader?



$$T = \frac{1}{\theta + \beta}$$

$$\frac{1}{\beta} = \max\{\frac{1}{c}, \frac{1}{\eta}(\frac{1}{\mu} - \frac{1}{\gamma})\}$$

Key take-away: not scaling inverse with system size (x)

- New requests comes, new bandwidth also comes

Recap

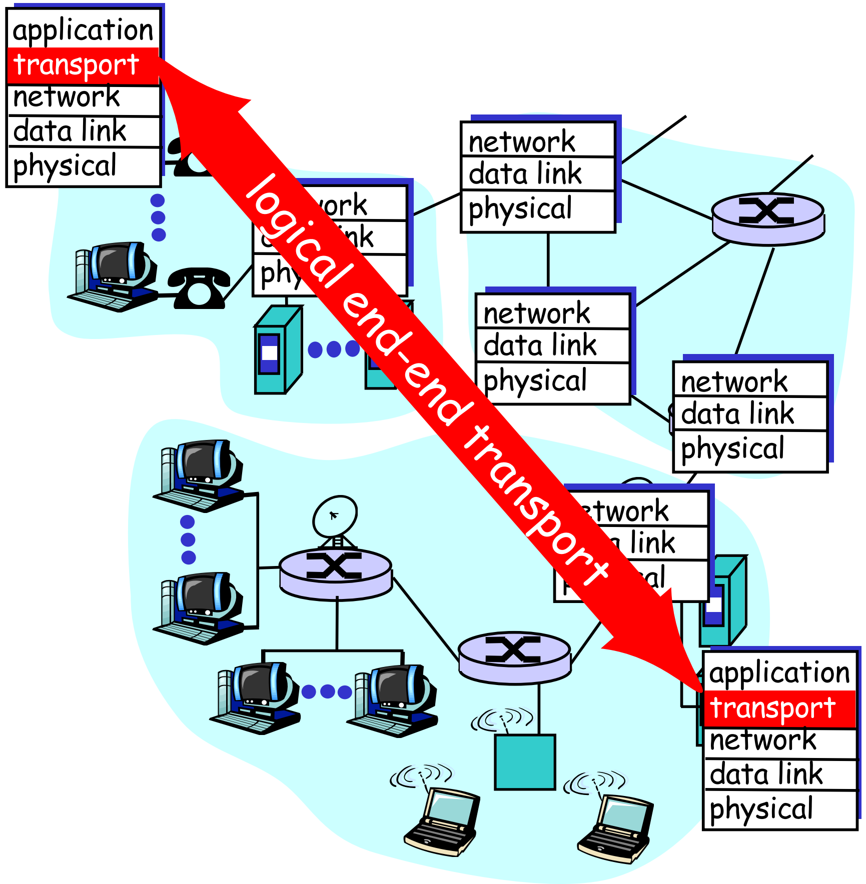
- Applications
  - Client-server applications
    - Single server
    - Multiple servers load balancing
  - Application overlays (distributed network applications) to
    - scale bandwidth/resource (BitTorrent)
    - distribute content lookup (Freenet, DHT, Chord) [optional]
    - distribute content verification (Block chain) [optional]
    - achieve anonymity (Tor) [optional]

Outline

- Admin and recap
- *Overview of transport layer*
- UDP
- Reliable data transfer, the stop-and-go protocols

Overview

- Provide *logical communication* between app' processes
- Transport protocols run in end systems
  - send side: breaks app messages into segments, passes to network layer
  - rcv side: reassembles segments into messages, passes to app layer
- Transport vs. network layer services:
  - *Network layer:* data transfer between end systems
  - *Transport layer:* data transfer between processes
    - relies on, enhances network layer services



Transport Layer Services and Protocols

- Reliable, in-order delivery (TCP)
  - multiplexing
  - reliability and connection setup
  - congestion control
  - flow control
- Unreliable, unordered delivery: UDP
  - multiplexing
- Services not available:
  - delay guarantees
  - bandwidth guarantees

Transport Layer: Road Ahead

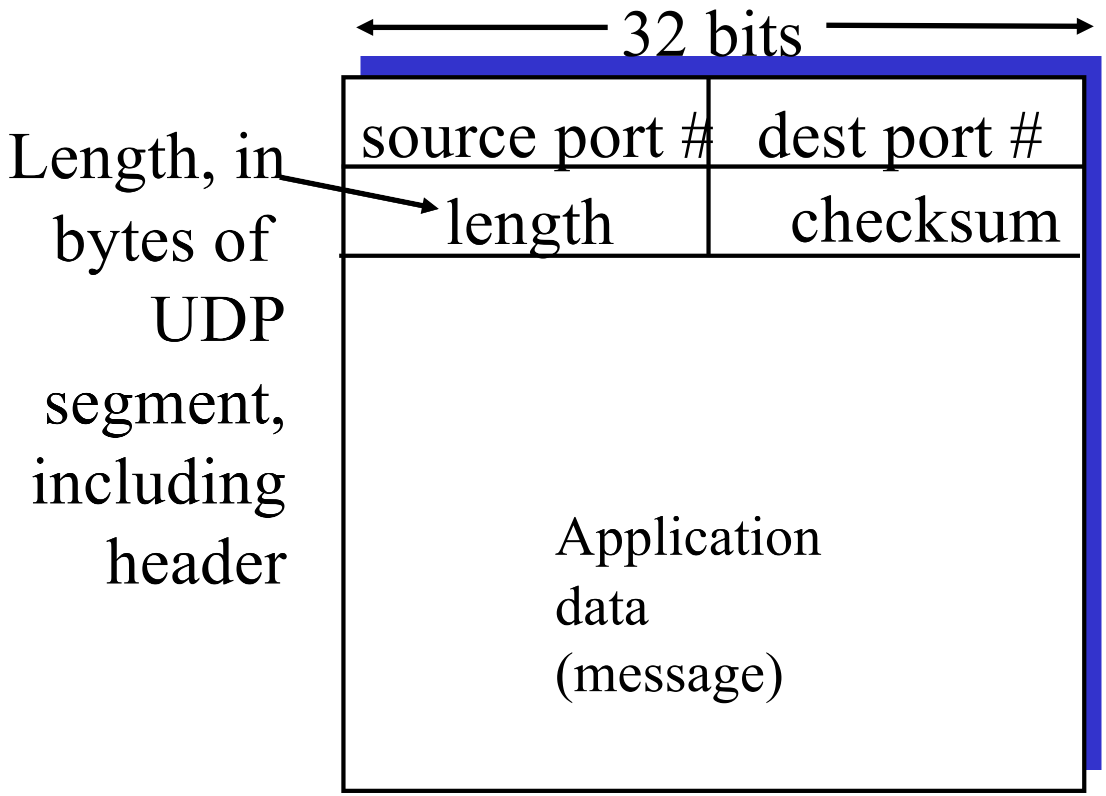
- Class 1 (today):
  - transport layer services
  - connectionless transport: UDP
  - reliable data transfer using stop-and-wait/alternating-bit protocol
- Class 2 (ready for lab assignment 4/part 1):
  - sliding window reliability
  - TCP reliability
    - overview of TCP
    - TCP RTT measurement
    - TCP connection management
- Class 3 (ready for lab assignment 4/part 2 [optional]):
  - principles of congestion control
  - TCP congestion control; AIMD; TCP Reno
- Class 4:
  - TCP Vegas, performance modeling; Nash Bargaining solution
- Class 5:
  - primal-dual as a resource allocation and analysis framework
- ...

Outline

- Admin and recap
- Overview of transport layer
- *UDP and error checking*
- Reliable data transfer, the stop-and-go protocols

UDP: User Datagram Protocol [RFC 768]

- Often used for streaming multimedia apps
  - loss tolerant
  - rate sensitive
- Other UDP uses
  - DNS
  - SNMP



UDP segment format