EECS 489
Computer Networks

Winter 2023

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Material with thanks to Aditya Akella, Sugih Jamin, Philip Levis, Sylvia Ratnasamy, Peter Steenkiste, and many other colleagues.

Agenda

- Video streaming
- Datacenter applications

How is video different?

- Often too large to send in one GET
- Doesn't even make sense even if it's possible
  - Users may skip forward! ⇒ save bandwidth wastage
  - Users' connection quality may change (e.g., switching from WiFi to LTE) ⇒ lower resolution to save bandwidth
- Our focus is on stored video (i.e., not live)

Why video is important?

- Dominates the global Internet traffic landscape
  - About 60%, i.e., every 3 of 5 bytes in 2020!
- Major sources
  - Netflix
  - YouTube
  - …

The video medium

- Video is a sequence of images/frames displayed at a constant rate (moving pictures)
- Digital image is an array of pixels, each pixel represented by bits
- Examples:
  - Single frame image encoding: 1024x1024 pixels, 24 bits/pixel $\Rightarrow$ 3 MB/image
  - Movies: 24 frames/sec $\Rightarrow$ 72 MB/sec
  - TV: 30 frames/sec $\Rightarrow$ 90 MB/sec

The video medium (cont'd)

- Compression is key
  - Lots of algorithms to compress
- The same video can be (and typically is) compressed to multiple quality levels
  - E.g., 480p, 720p, 1080p, 4K
- Why multiple resolutions?
  - Adapt to conditions

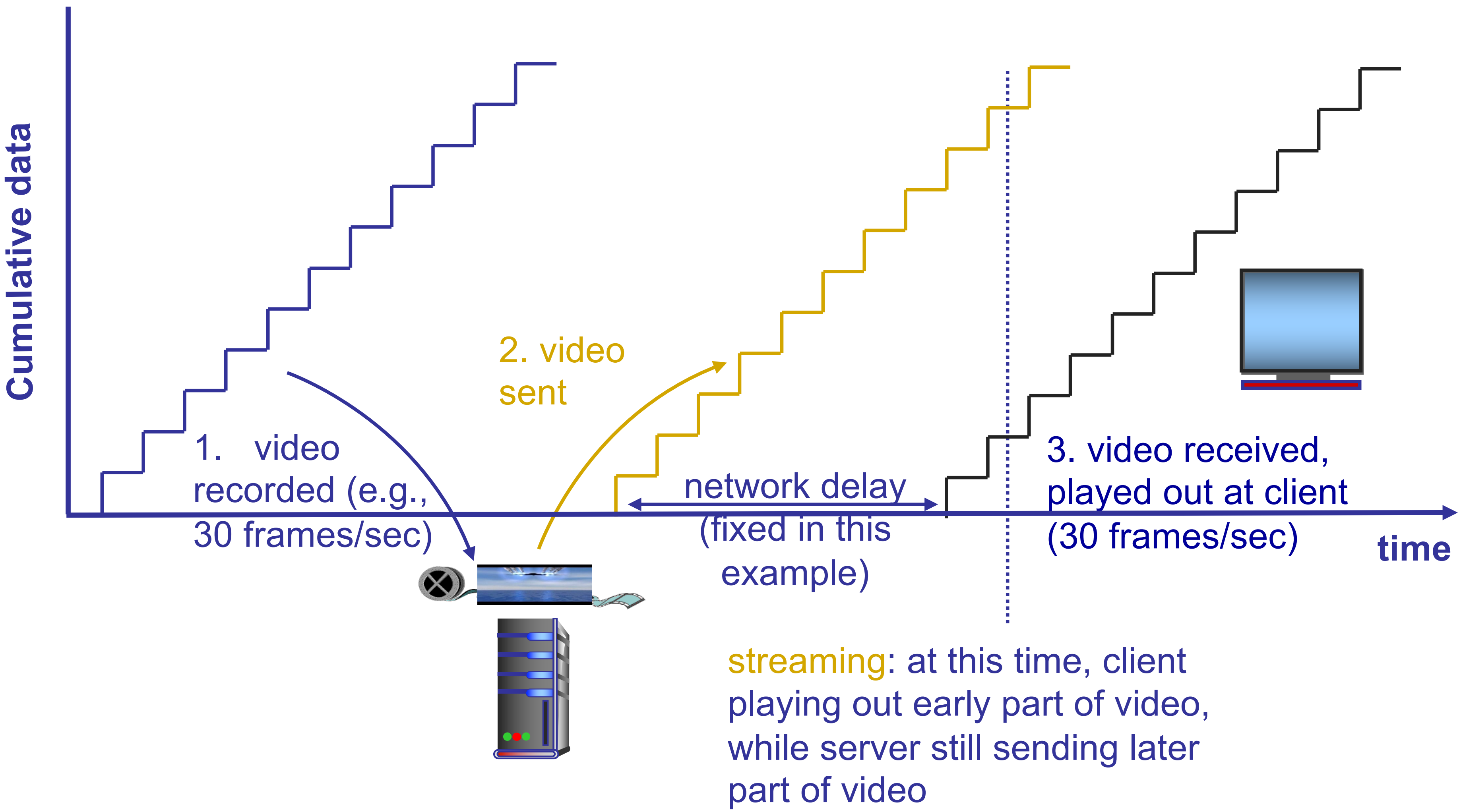
How do we serve video?

- It's in the name!
  - Video streaming

HTTP streaming

- Video is stored at an HTTP server with a URL
- Clients send a GET request for the URL
- Server sends the video file as a stream
- Client first buffers for a while. Why?
  - To minimize interruptions later
- Once the buffer reaches a threshold
  - The video plays in the foreground
  - More frames are downloaded in the background

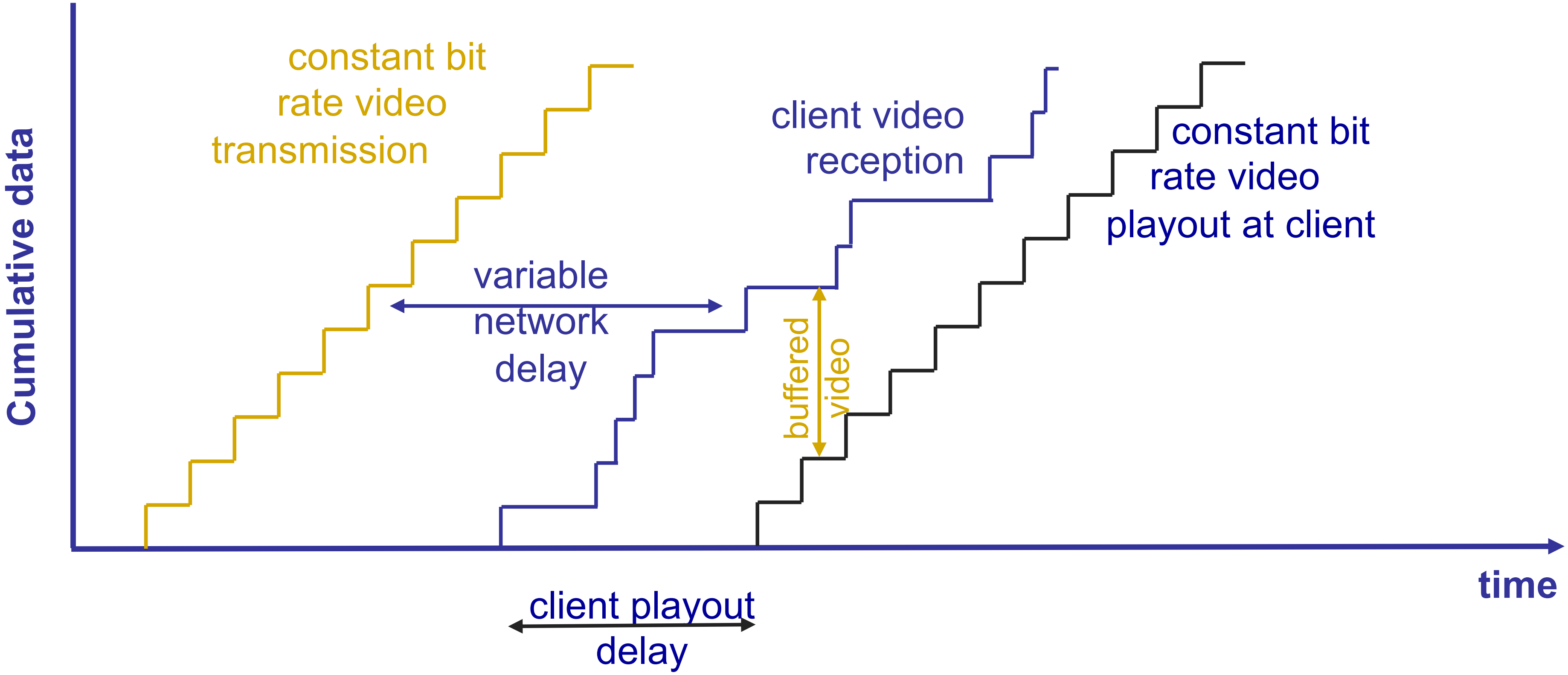
HTTP streaming



Challenges

- Absorb network delay variations
- Handle user interactions
  - Jump forward, fast-forward, rewind, pause
- Handle packet loss, retransmission etc.

HTTP streaming: Revisited



- Client-side buffering and playout delay: compensate for network-added delay, delay jitter

Issues with HTTP streaming

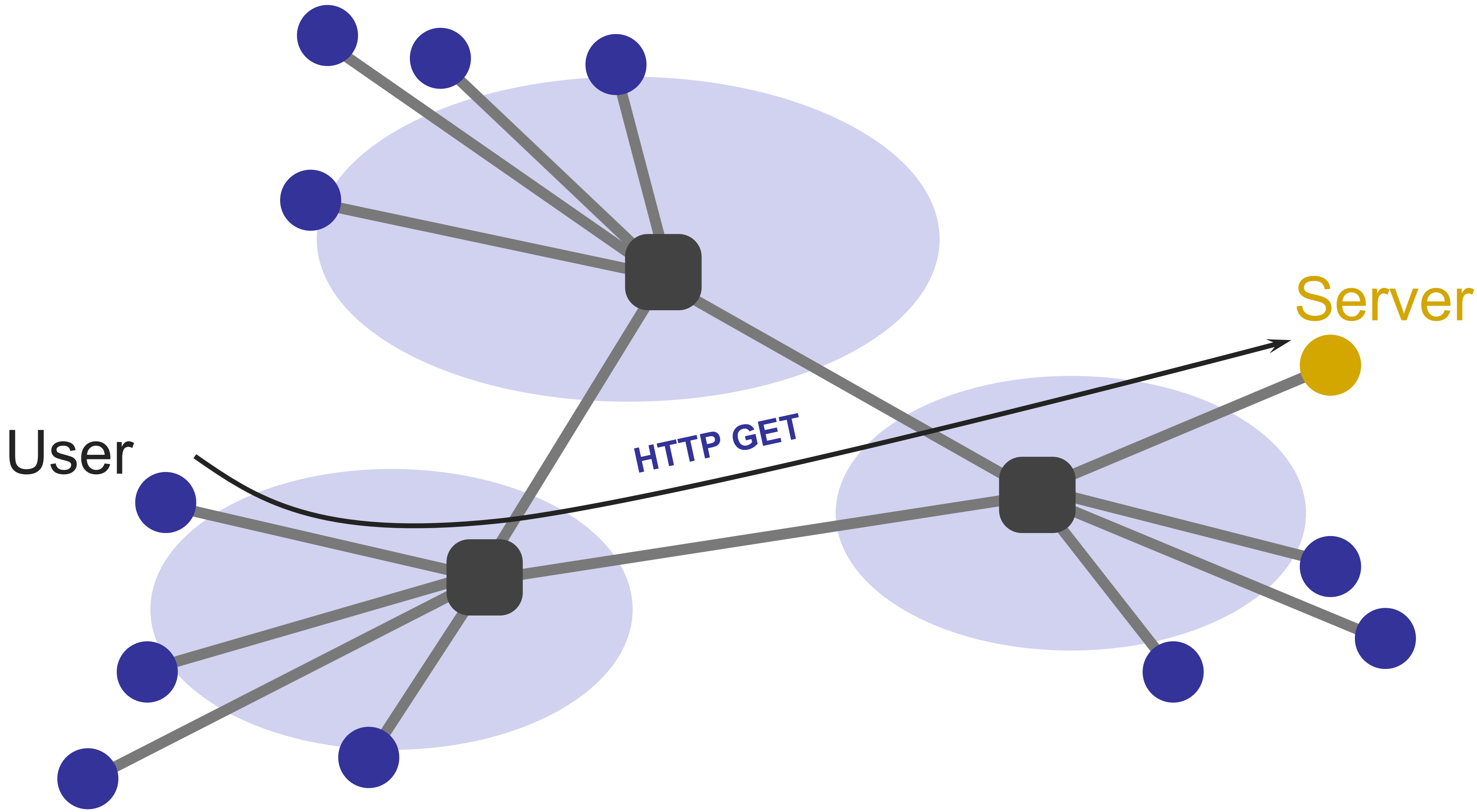
- Same bitrate for all clients
  - Clients can have very different network conditions
  - Clients network conditions can change over time
- Cannot dynamically adapt to conditions

DASH : Dynamic Adaptive Streaming over HTTP

- Keep multiple resolutions of the same video
  - Stored in a manifest file in the HTTP server
- Client asks for the manifest file first to learn about the options
- Asks for chunks at a time and measures available bandwidth while they are downloaded
  - Low bandwidth $\Rightarrow$ switch to lower bitrate
  - High bandwidth $\Rightarrow$ switch to higher bitrate

CLOUD SYSTEMS

Who’s serving Web services?



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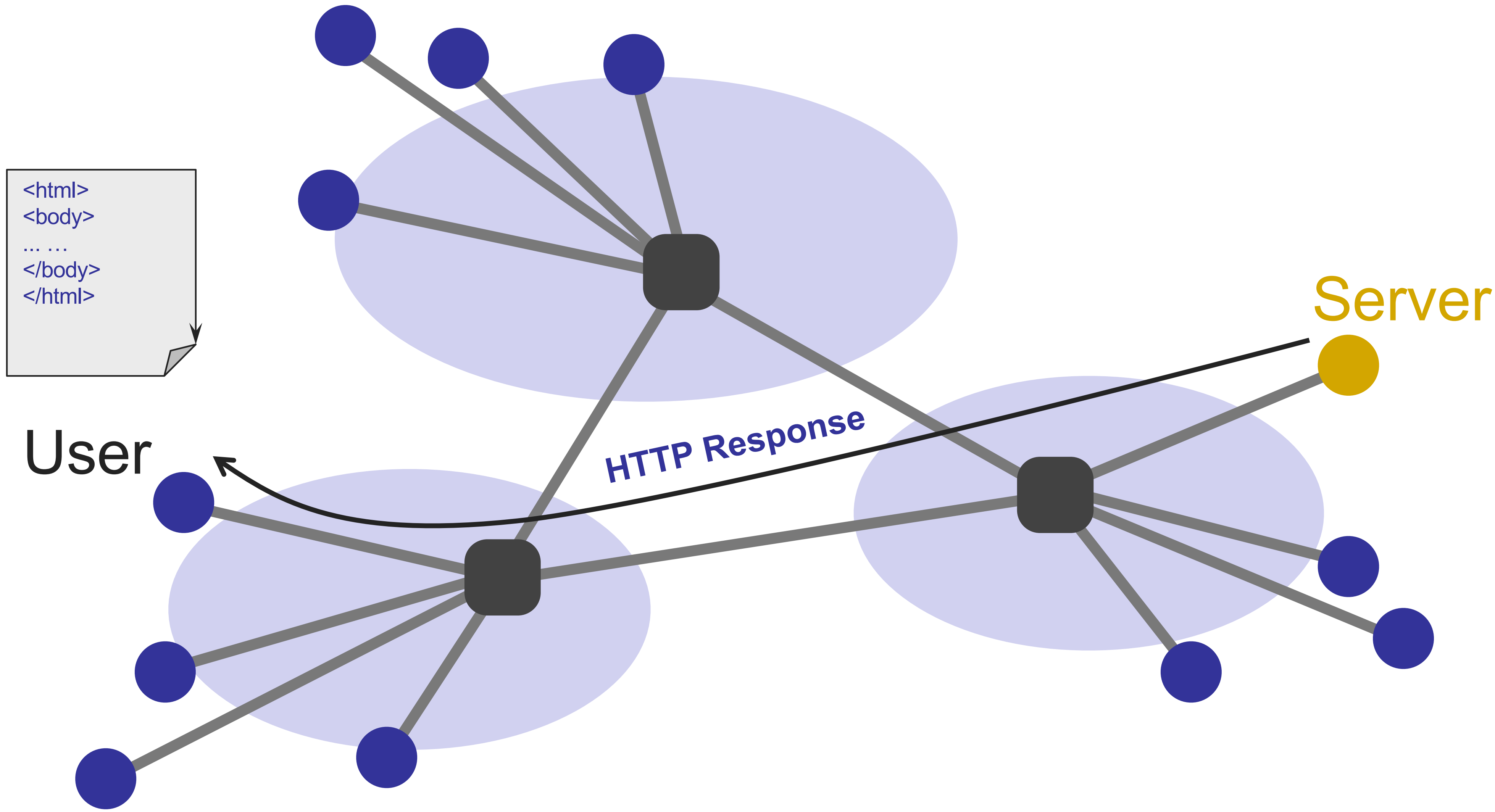
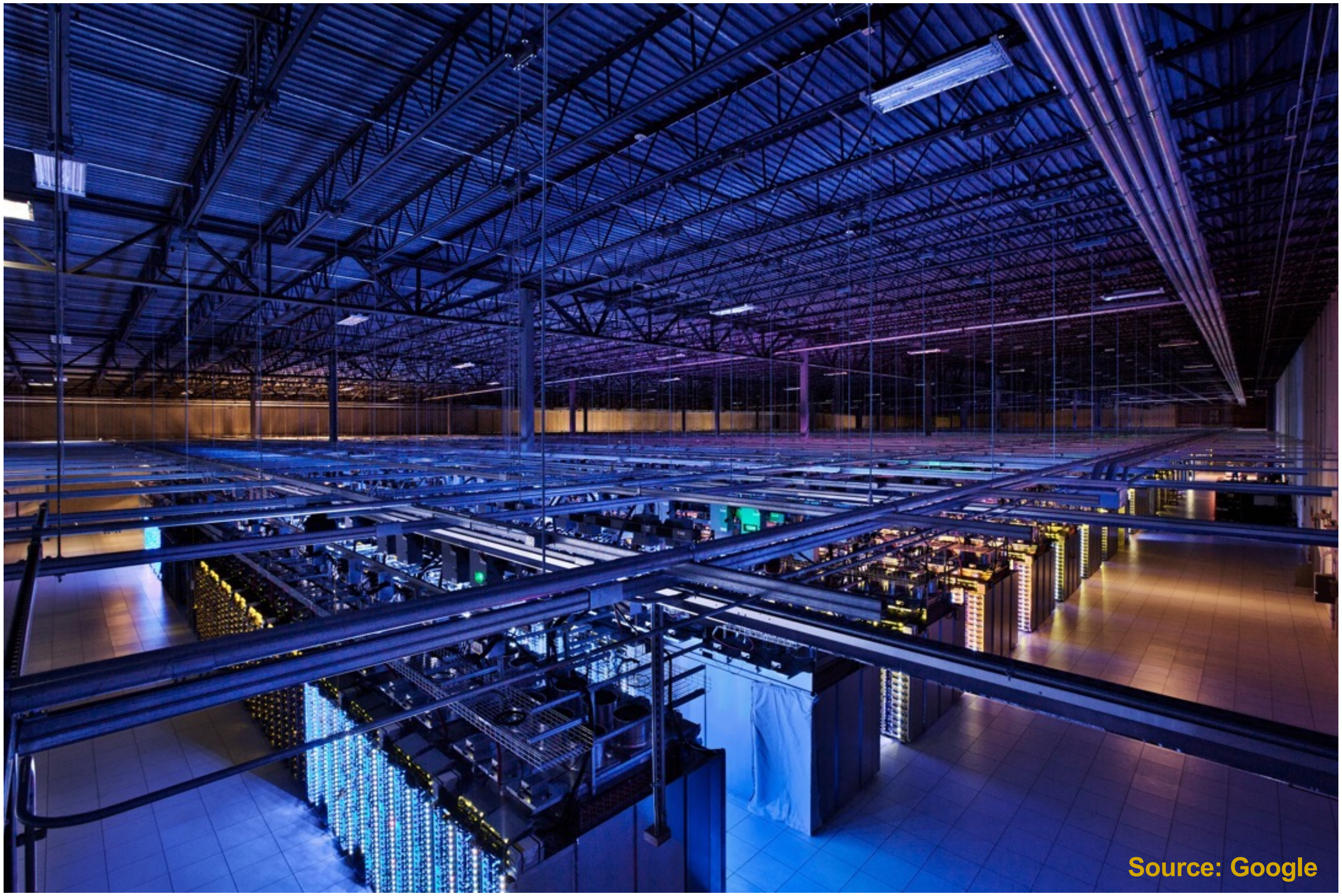


Cloud datacenters run the world

Cloud datacenters run the world



Cloud datacenters run the world

How big is a datacenter (DC)?

- 1M servers/site [Microsoft/Amazon/Google]
- > $1B to build one site [Facebook]
- >$20M/month/site operational costs [MS'09]
- Data center hardware spending grew to $177 billion in 2017. [Gartner report]

- But only O(10-100) sites

Implications (1)

- Scale
  - Need scalable designs
  - Low-cost designs: e.g., use commodity technology
  - High utilization (efficiency): e.g., >60% avg. utilization
    - Contrast: avg. utilization on Internet links often ~30%
  - Tolerate frequent failure
    - Large number of (low cost) components
  - Automate

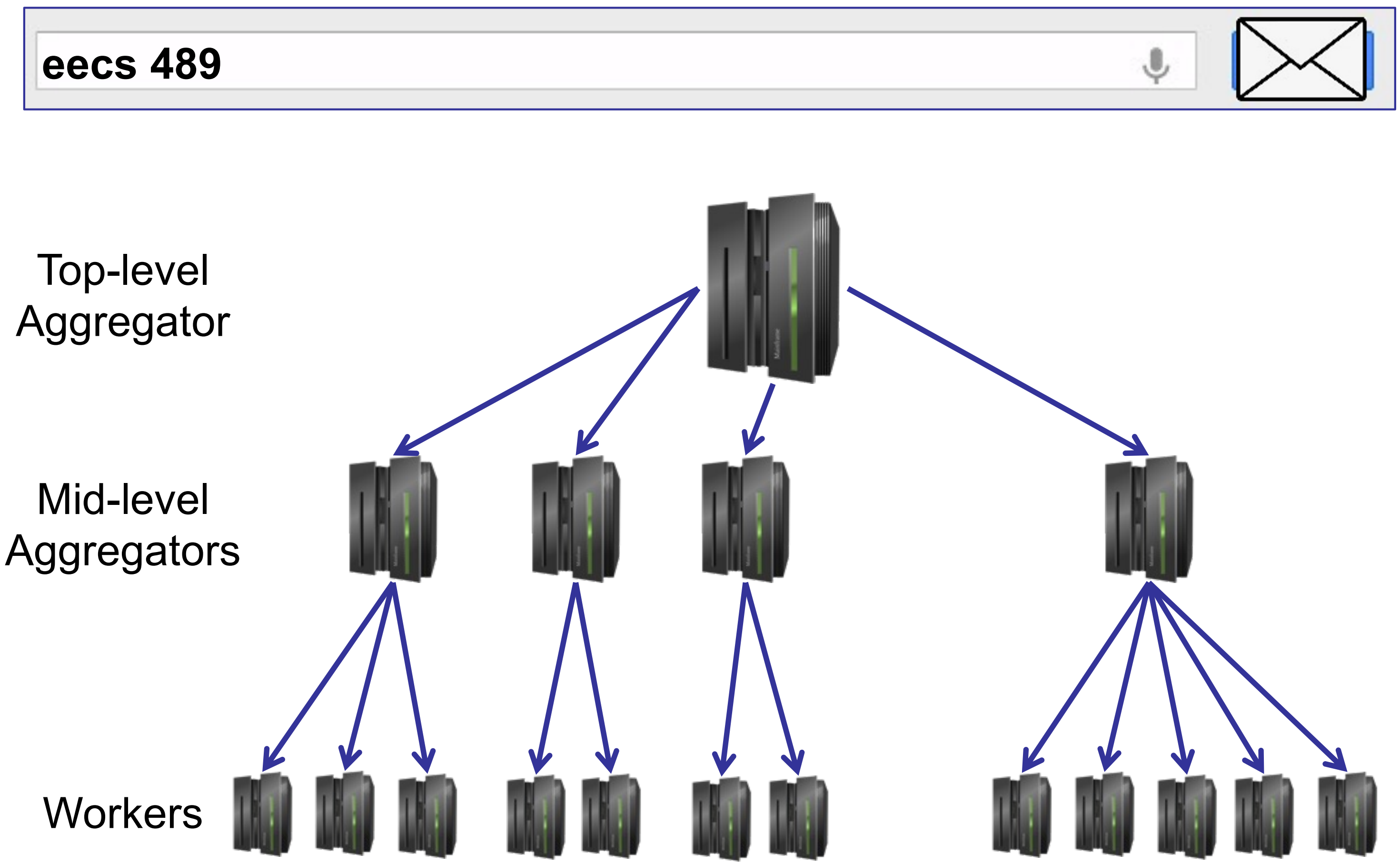
Implications (2)

- Service model: clouds / multi-tenancy
  - Performance guarantees
  - Isolation guarantees
  - Portability

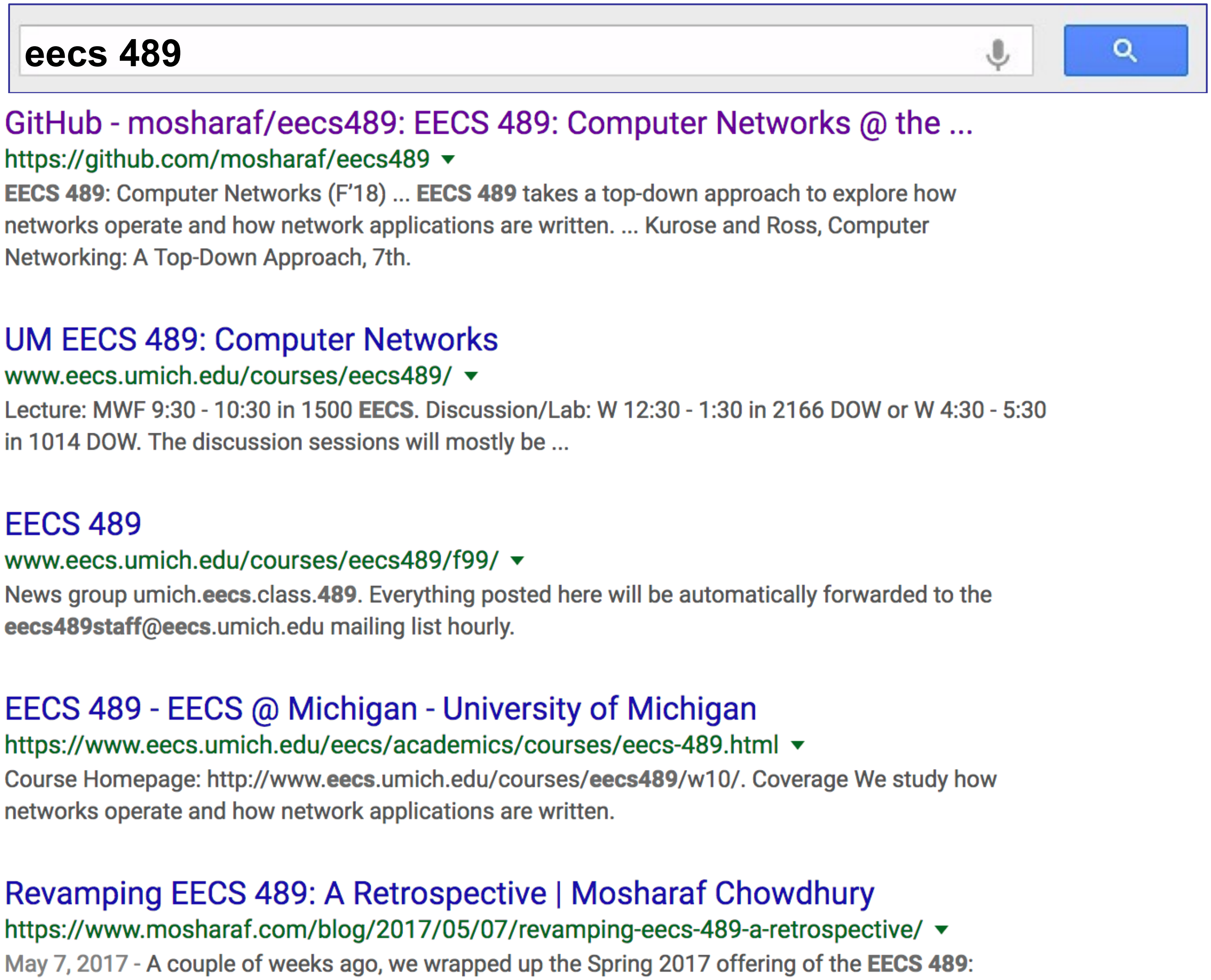
Applications

- Common theme: parallelism
  - Applications decomposed into tasks
  - Running in parallel on different machines
- Two common paradigms
  - Partition-Aggregate
  - Map-Reduce

Partition-Aggregate



Partition-Aggregate



End-to-end response time

- Less than 200 milliseconds between receiving user query in the browser and displaying the results
  - RTT = O(10) to 100 milliseconds
  - What remains?

- Next time, when the page is not loading fast enough, think about the poor servers working for you ☺

Announcements

- Midterm is Wed Feb 22 2023
  - 9AM (everyone is expected to take it at this time)
- Assignment 1 due this Fri Jan 27, 2023, 11:59 PM.
- Deadline for forming project groups was yesterday.
- Quiz 5 will be released today (due within 48 hours).

5-MINUTE BREAK!

Applications

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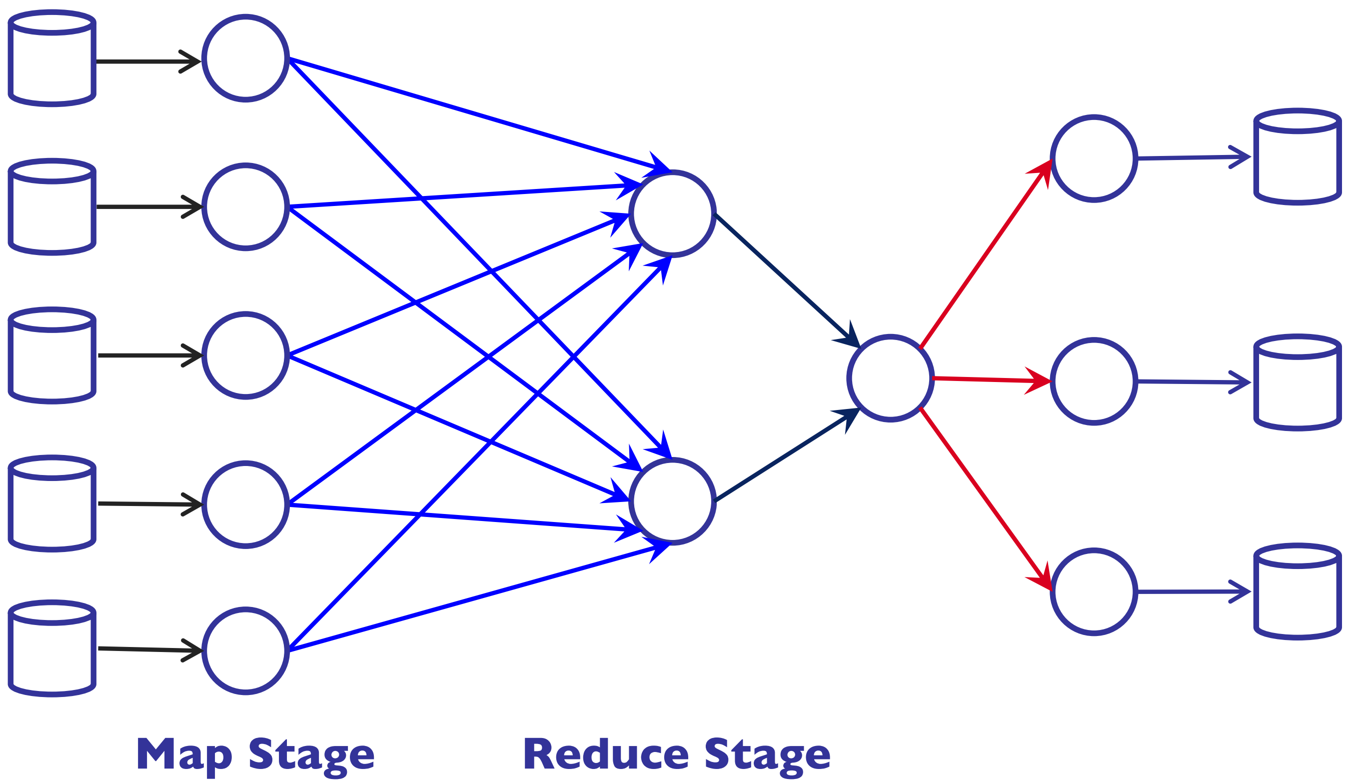
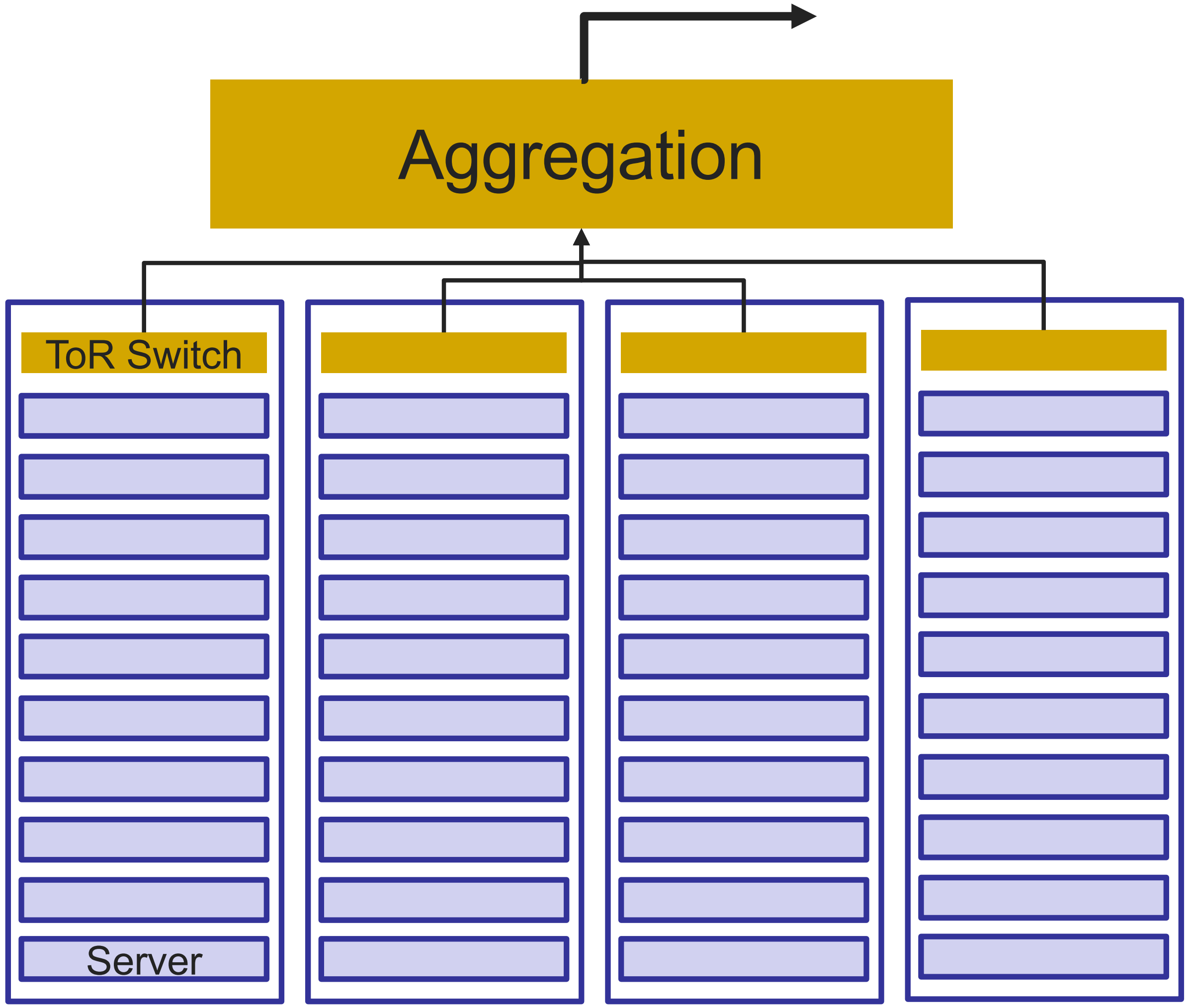
Map-Reduce

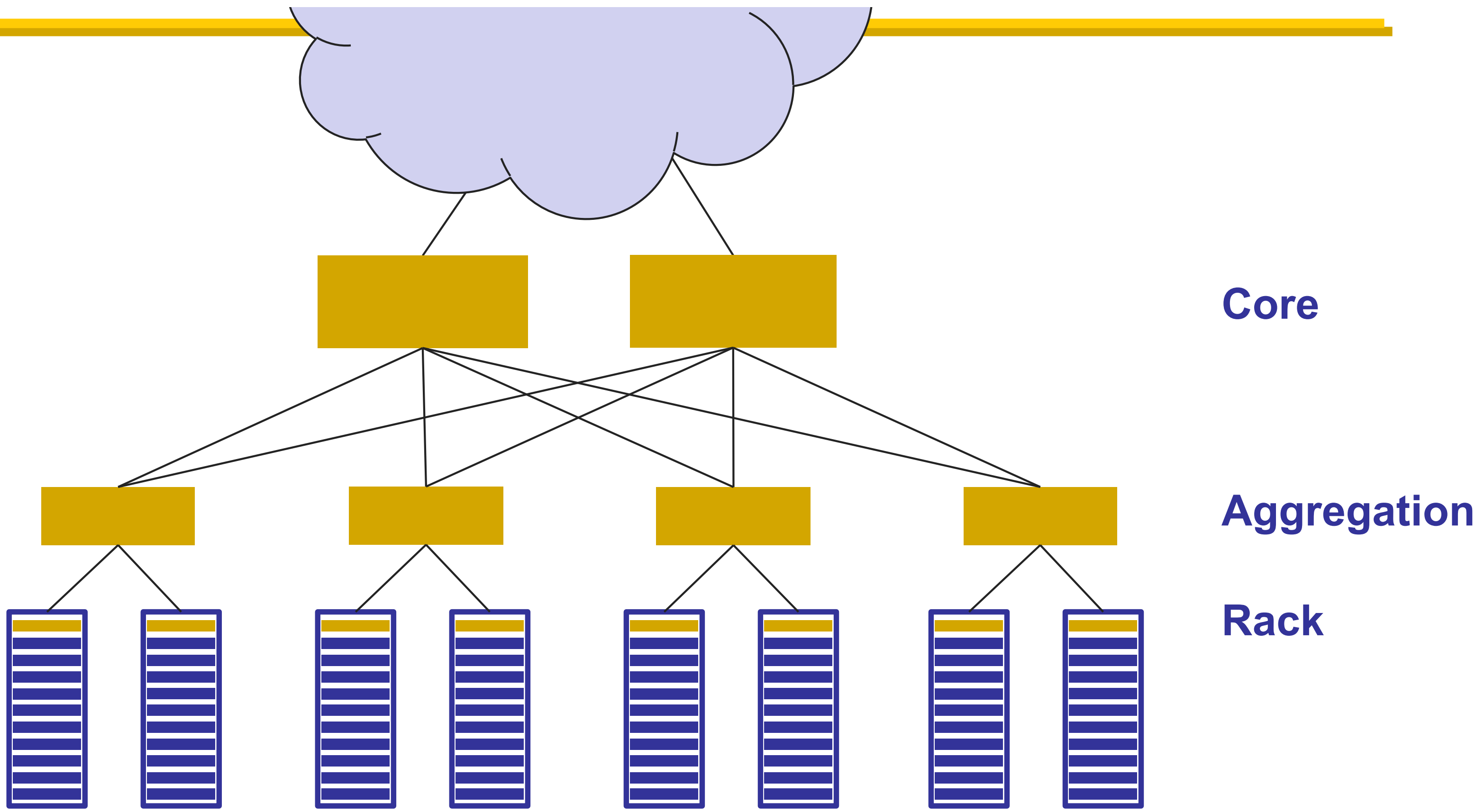


The most popular software that follows this paradigm is Apache Spark

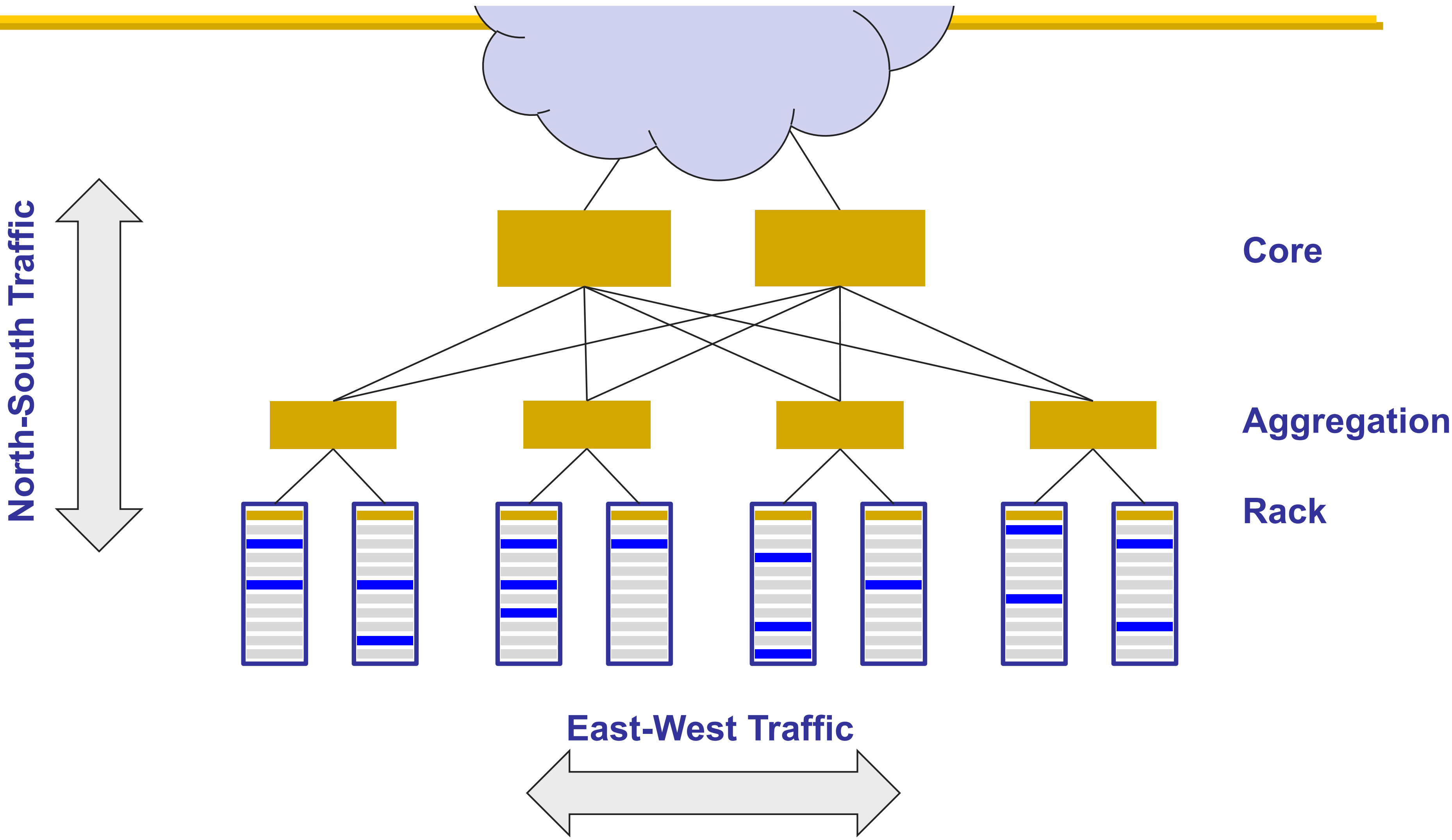
Datacenter networks



Datacenter networks (Cont.)



Datacenter traffic



East-West traffic

- Traffic between servers in the datacenter
- Communication within “big data” computations
- Traffic may shift on small timescales (< minutes)

Datacenter traffic characteristics

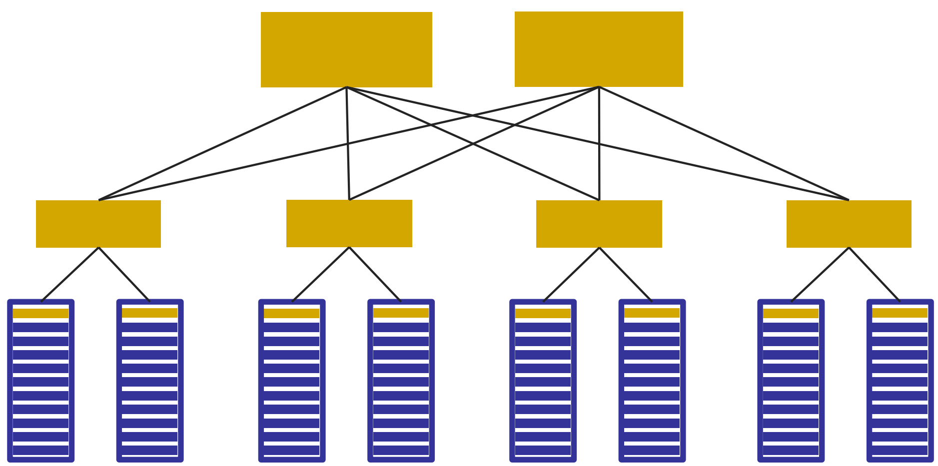
- Two key characteristics
  - Most flows are small
  - Most bytes come from large flows

- Applications want
  - High bandwidth (large flows)
  - Low latency (small flows)

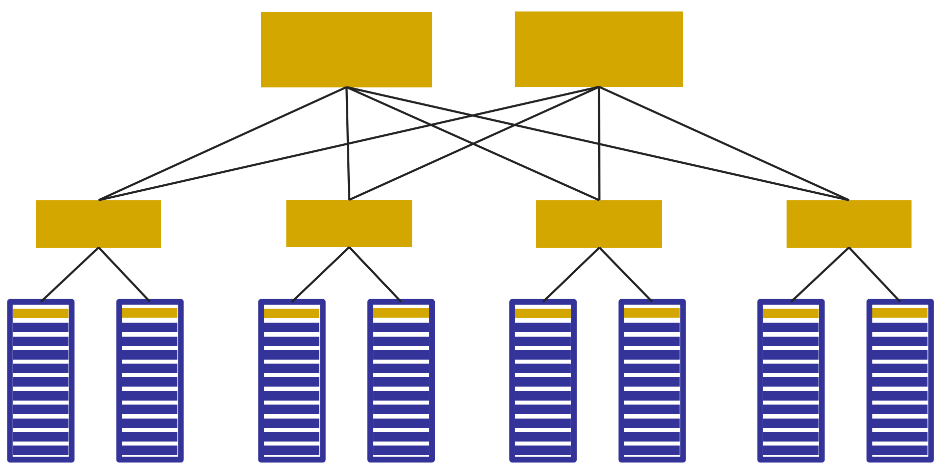
High bandwidth

- Ideal: Each server can talk to any other server at its full access link rate
- Conceptually: Datacenter network as one giant switch

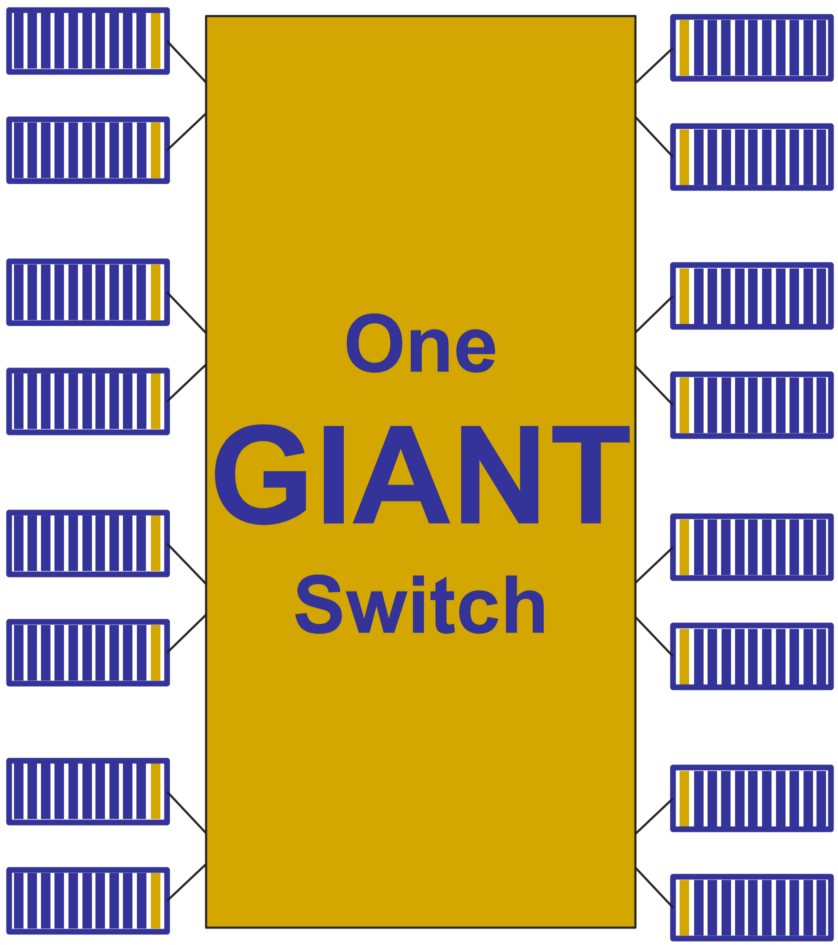
Datacenter network as one giant switch



Datacenter network as one giant switch



Datacenter network as one giant switch



High bandwidth

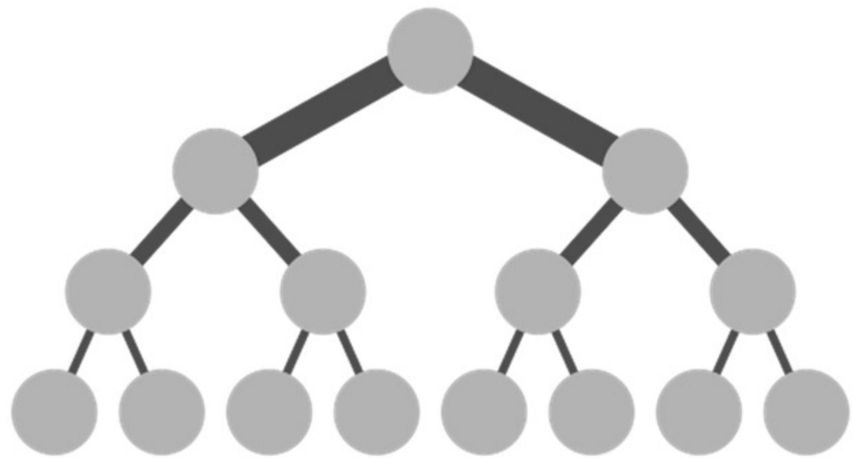
- Ideal: Each server can talk to any other server at its full access link rate
- Conceptually: Datacenter network as one giant switch
  - Would require a 10 Pbits/sec switch! (10^15 bps)
    - 1M ports (one port/server)
    - 10Gbps per port
- Practical approach: build a network of switches ("fabric") with high "bisection bandwidth"
  - Each switch has practical #ports and link speeds

Bisection bandwidth

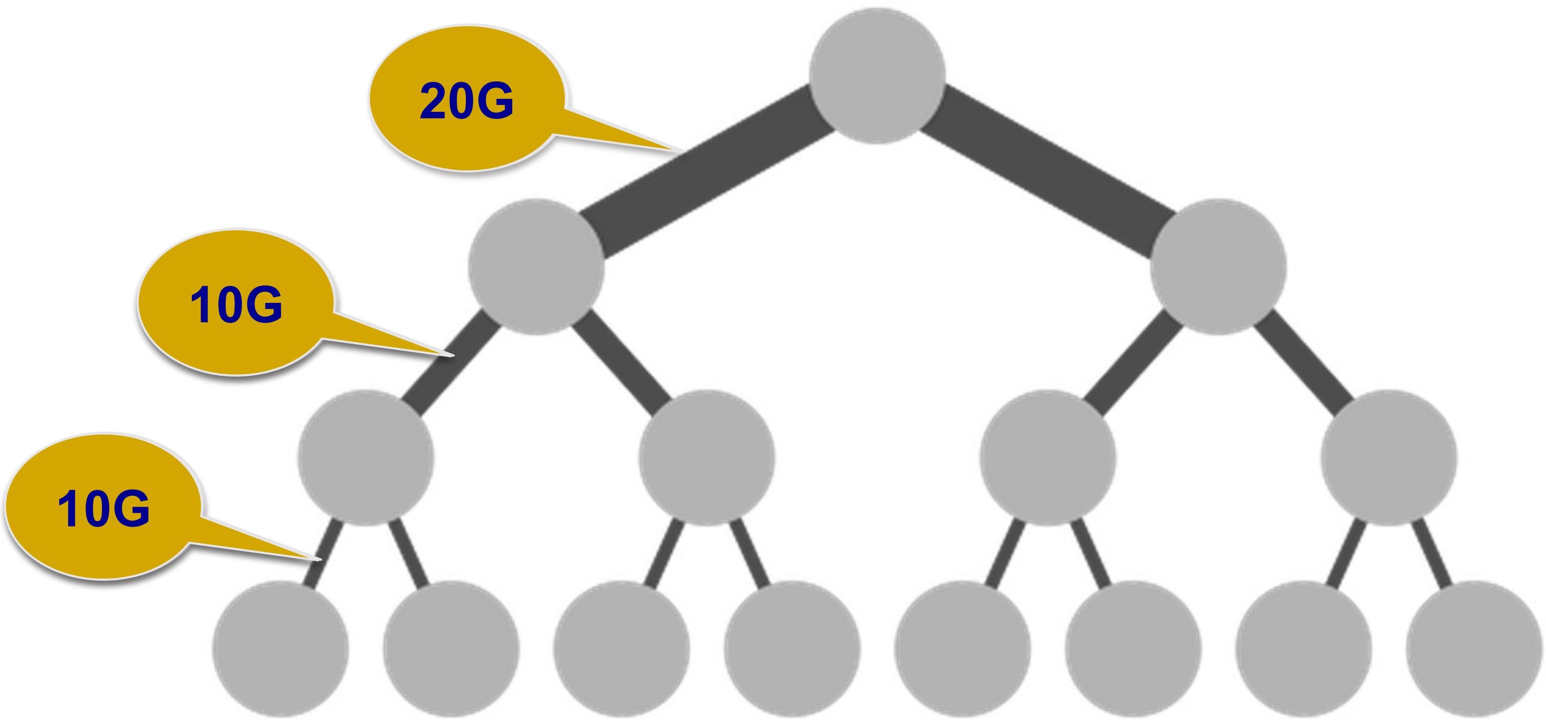
- Partition a network into two equal parts
- Minimum bandwidth between the partitions is the bisection bandwidth
- Full bisection bandwidth: bisection bandwidth in an N node network is N/2 times the bandwidth of a single link
  - Nodes of any two halves can communicate at full speed with each other

Achieving full bisection bandwidth

- Scale up
  - Make links fatter toward the core of the network
- Problem: Scaling up a traditional tree topology is expensive!
  - Requires non-commodity / impractical / link and switch components
- Solutions?
  - Over-subscribe (i.e., provision less than full BBW)
  - Better topologies



Oversubscription

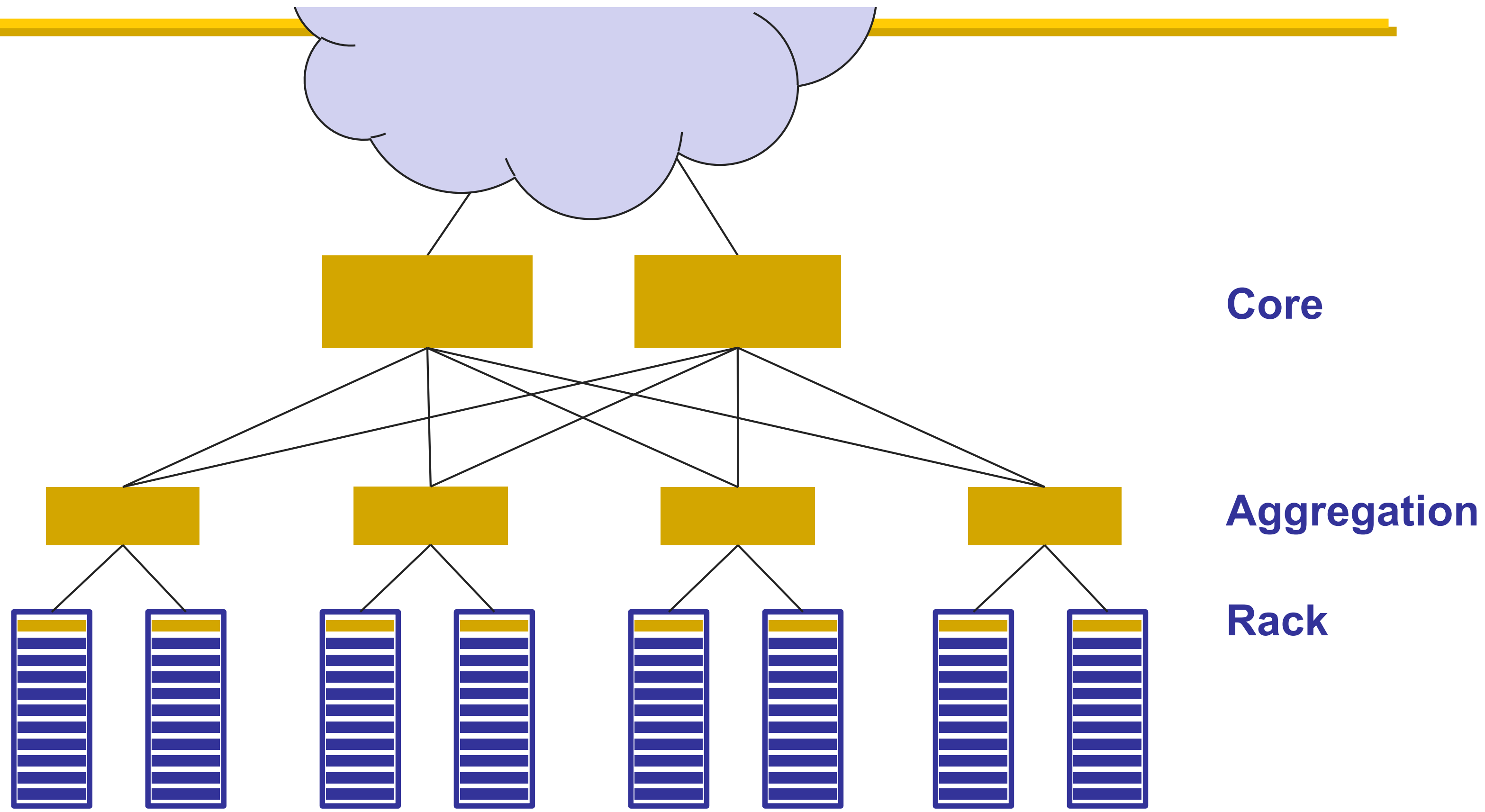


Need techniques to avoid congesting oversubscribed links!

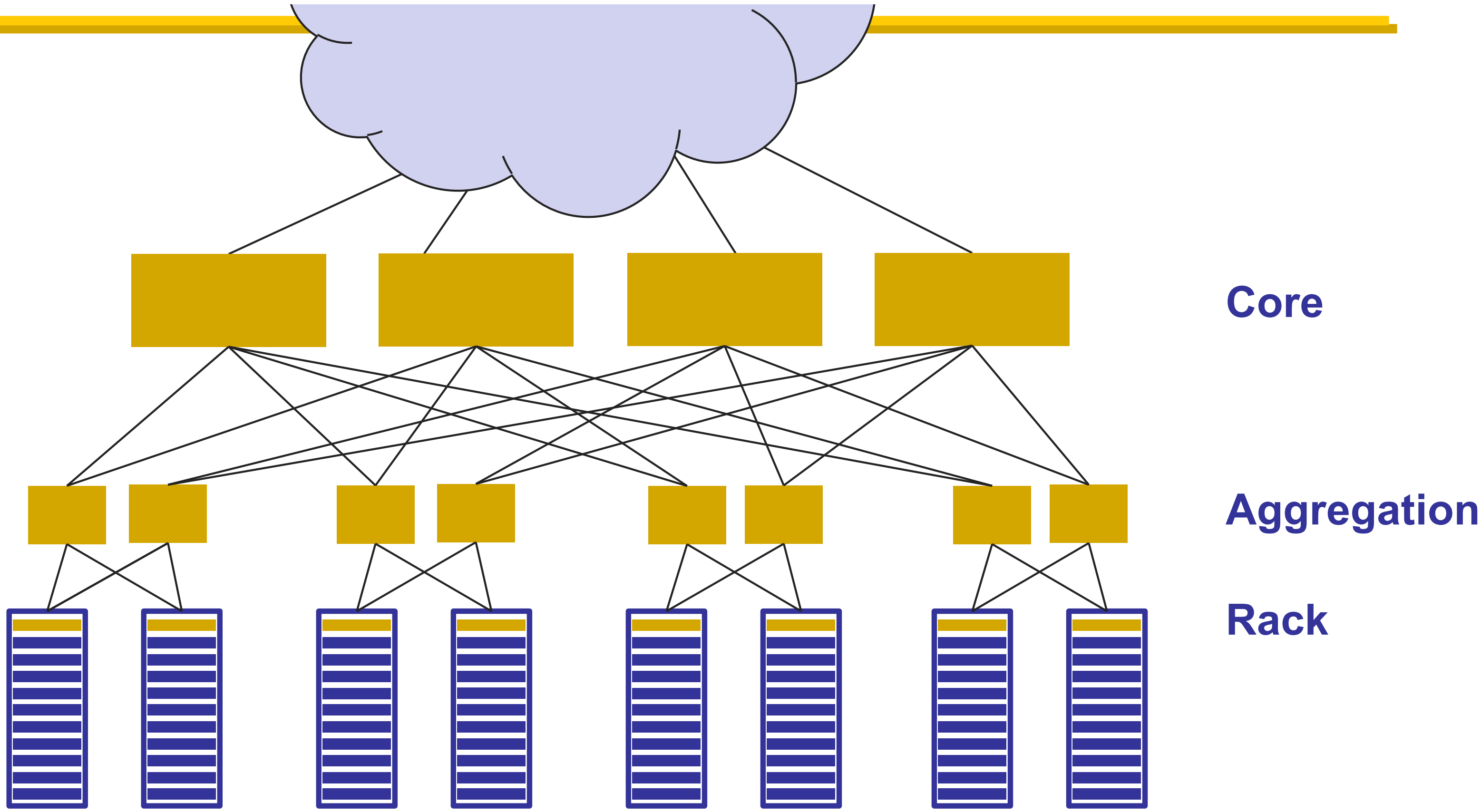
Oversubscription

- Not enough bandwidth
  - Oversubscription: Less bandwidth in the ToR-Agg links than all the servers bandwidth in the rack
  - Oversubscription ratio: Ratio between bandwidth underneath and bandwidth above
- Not enough paths between server pairs
  - Load balancing issues
  - Failure recovery issues

Better topologies



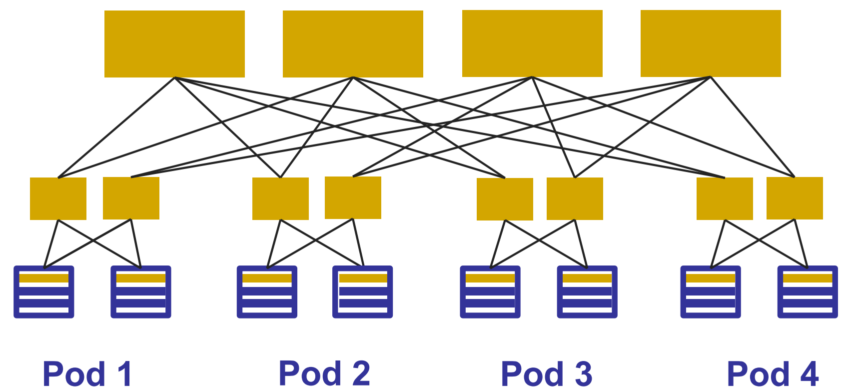
Better topologies



Clos topology

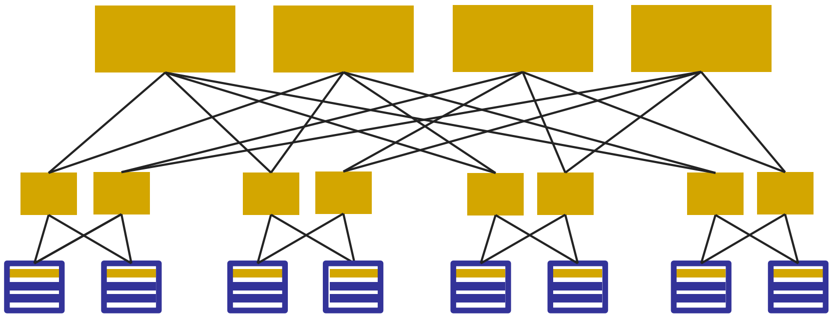
- Multi-stage network
- k pods, where each pod has two layers of k/2 switches
  - k/2 ports up and k/2 down
- All links have the same b/w
- At most $k^3/4$ machines

- Example
  - k = 4
  - 16 machines
- For k=48, 27648 machines



Challenges in scale-out designs?

- Topology offers high bisection bandwidth
- All other system components must be able to exploit this available capacity
  - Routing must use all paths
  - Transport protocol must fill all pipes (fast)



Summary

- Video streaming
  - Too large to send, so stream it
  - Dynamically adapt to the network and users
- Cloud systems
  - Forms the backend of modern web services
  - Runs in datacenters where all the processing happens