EECS 489
Computer Networks

Winter 2025

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

Recap: Inserting RR into DNS

- Registrar inserts RR pairs into the .com TLD server:
  - (foobar.com, dns1.foobar.com, NS)
  - (dns1.foobar.com, 212.44.9.129, A)

- Human readability
  - Name of the nameserver doesn't change when it's IP changes
- Load balancing
  - + (dns1.foobar.com, 212.44.9.128, A)
  - Pick one at random for load balancing
- Support for IPv6
  - + (dns1.foobar.com, 2001:db8::1, AAAA)
  - Pick between IPv4 and IPv6

Agenda

- Video streaming
- Datacenter applications

Why is video important?

- Dominates the global Internet traffic landscape
  - About 65%, i.e., every 2 of 3 bytes in 2022!

- Major sources
  - Netflix
  - YouTube
  - TikTok
  - …

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 ⇒ 3 MB/image
  - Movies: 24 frames/sec ⇒ 72 MB/sec
  - TV: 30 frames/sec ⇒ 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 user network conditions

How to watch a video?

1. Download and watch

- Often too large to send in one GET
- Doesn't even make sense even if its possible
  - »Users must wait too long
  - »Users may skip forward! ⇒ bandwidth waste
  - »User's connection quality may change (e.g., switching from WiFi to LTE) ⇒ lower resolution to match bandwidth

- Our focus is *not* live video

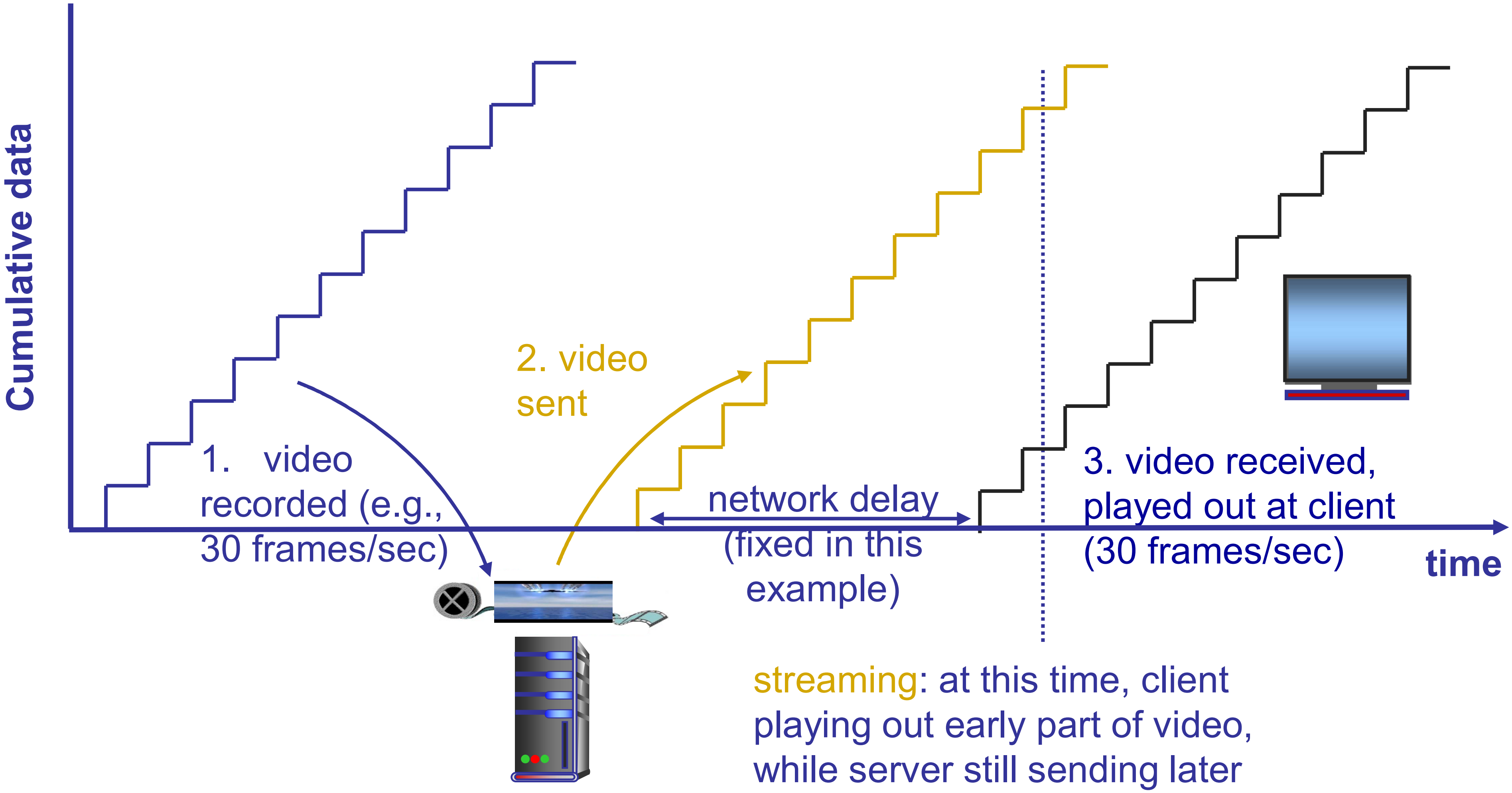
How to watch a video?

2. Video streaming over HTTP

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

HTTP streaming



streaming: at this time, client playing out early part of video, while server still sending later part of video

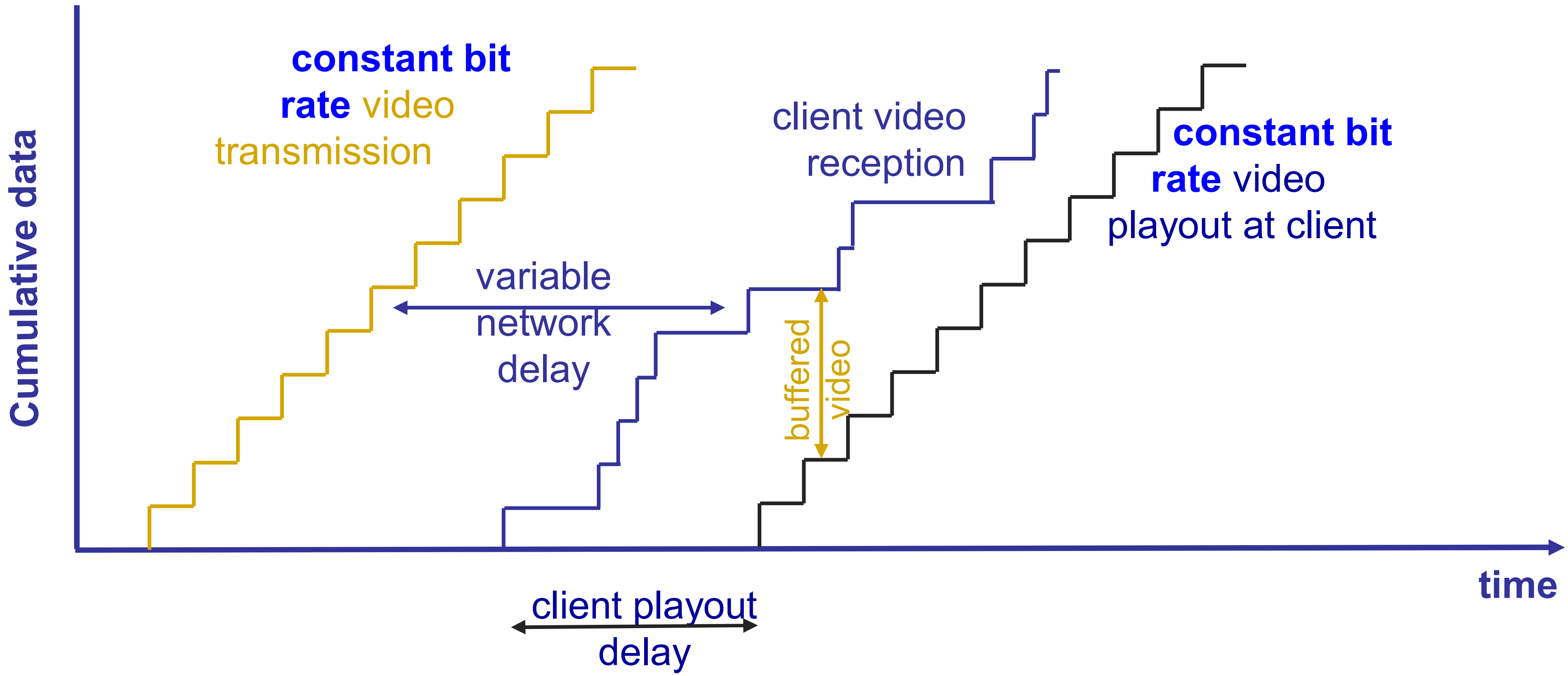
What if the latency is high?

- Client first buffers for a while
  - To minimize interruptions later
- Once the buffer reaches a threshold
  - The video plays in the foreground
  - More frames are downloaded in the background

Challenges

- What if network delay is not fixed?
  - i.e., How to absorb delay variations?
- What if users jump forward, fast-forward, rewind, pause?
  - i.e., How to handle user interactions?
- 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

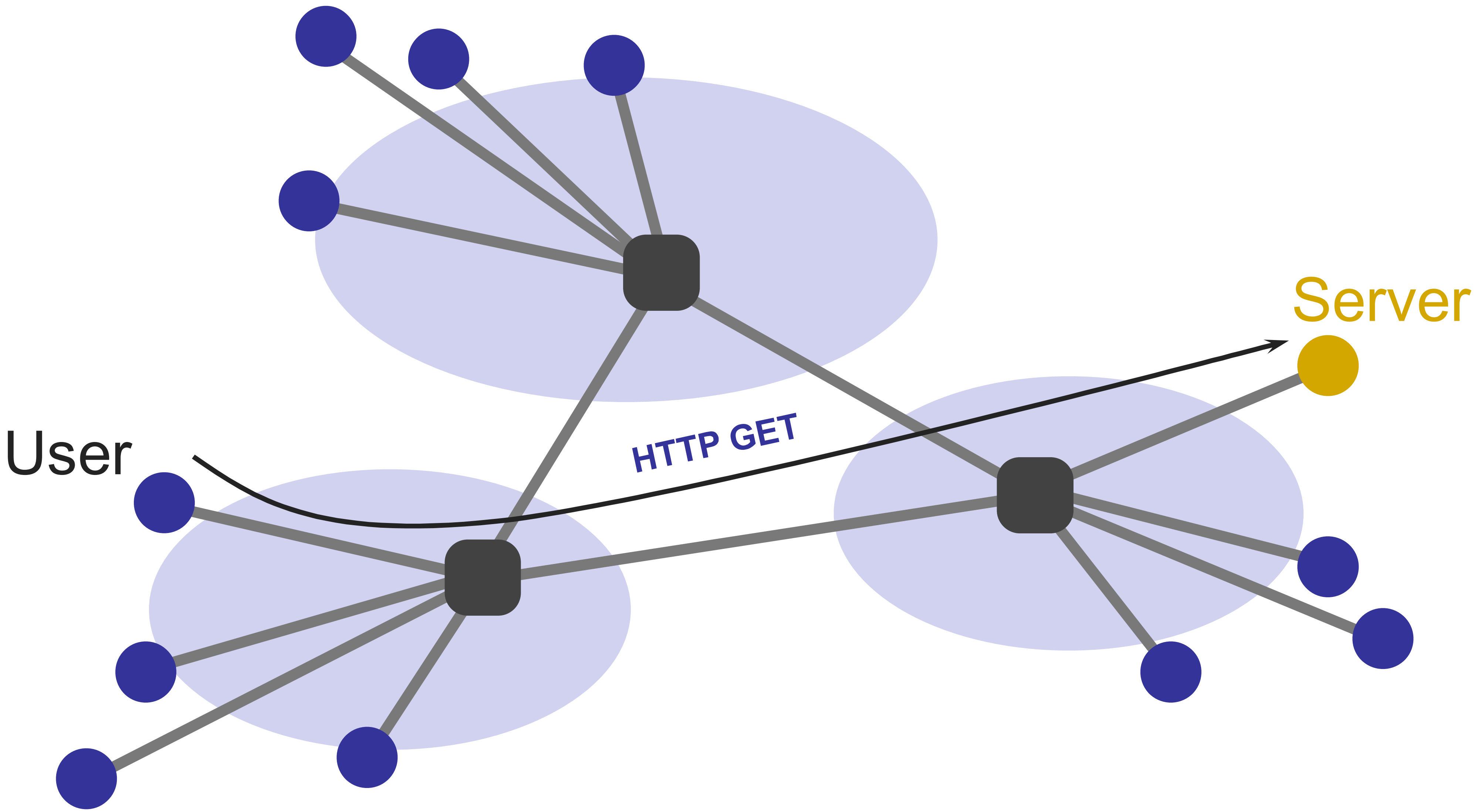
- Same bitrate for all clients
  - Clients can have very different network conditions
  - Clients network conditions can change over time
- Cannot dynamically adapt to conditions

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
- Adaptive bit rate (ABR)

CLOUD SYSTEMS

Who’s serving Web services?



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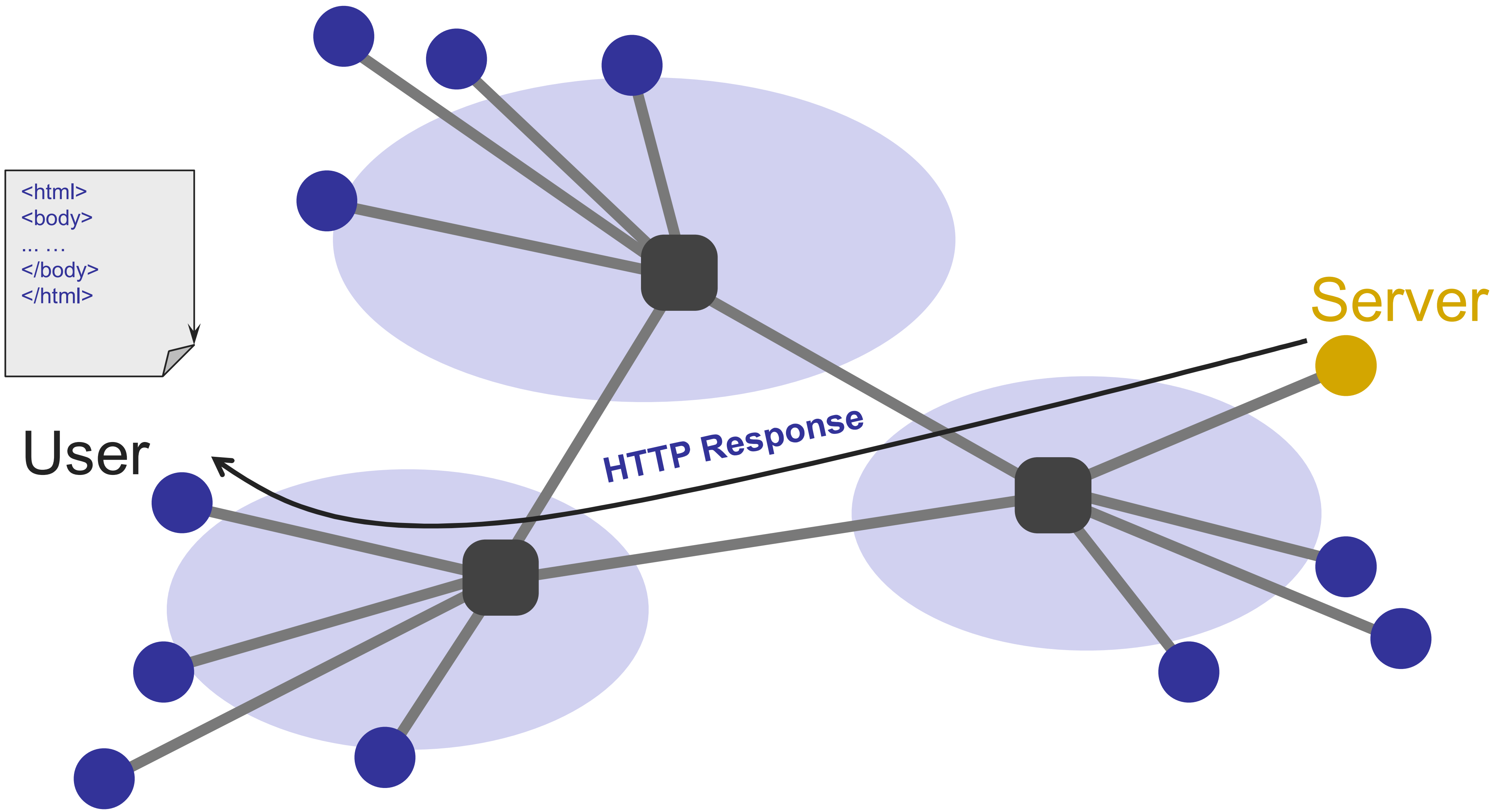
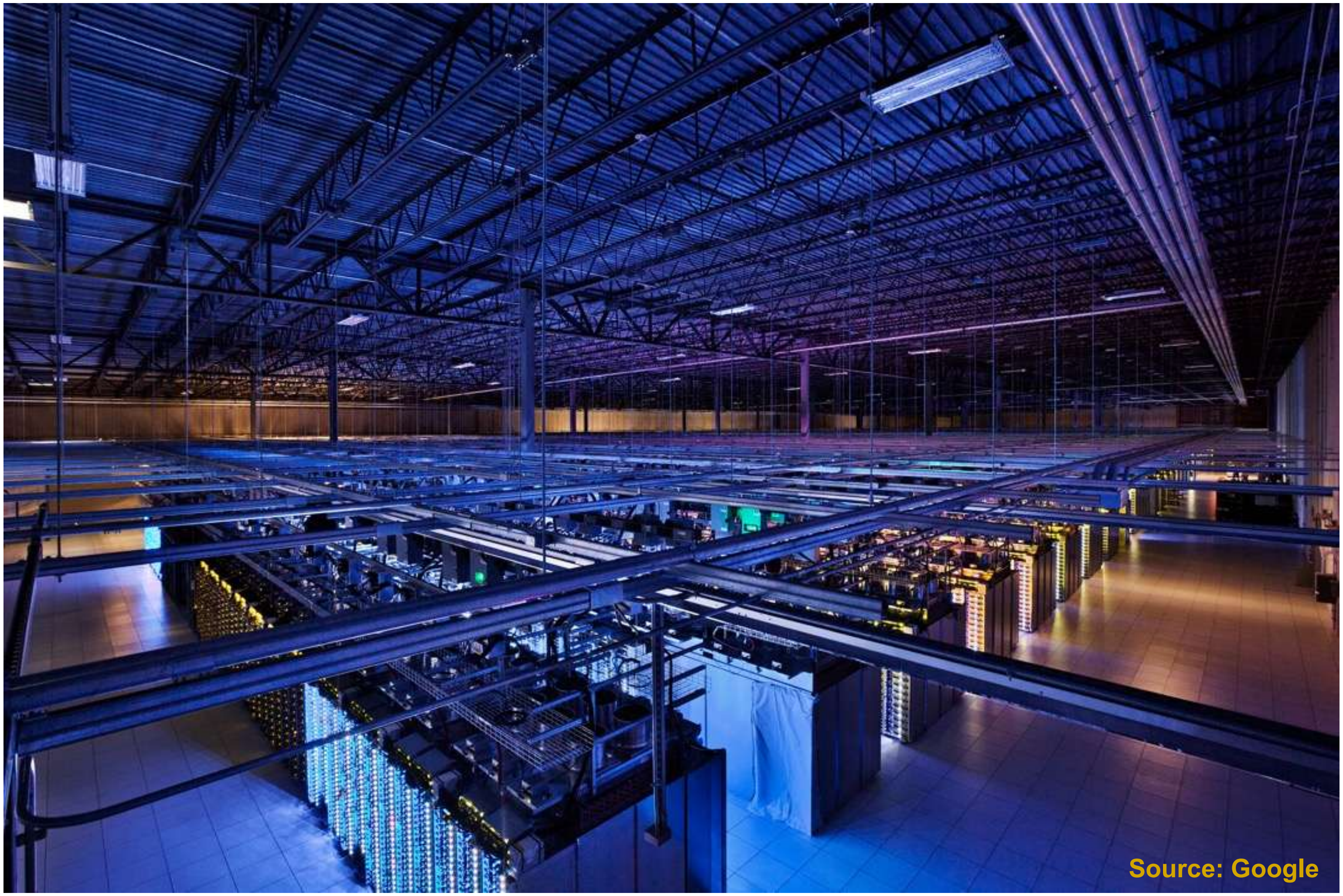


Cloud datacenters run the world

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 [UMich Datacenter!]
- >$20M/month/site operational costs [MS'09]
- Data center hardware spending grew to a record $282 billion in 2024. [Synergy Research Group report]

- But only O(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

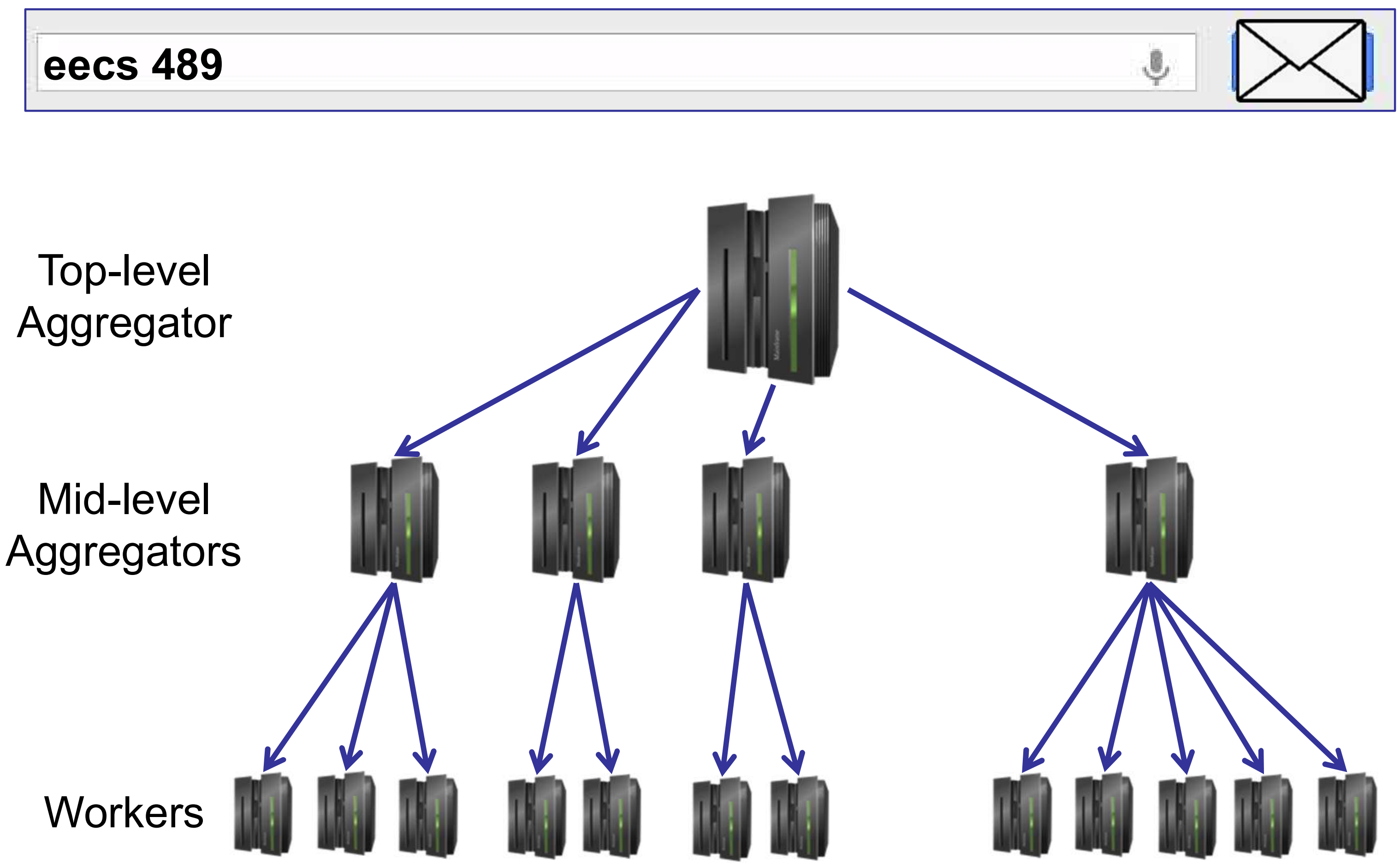
Implications (2)

- 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

eecs 489

GitHub - mosharaf/eecs489: EECS 489: Computer Networks @ the ...
https://github.com/mosharaf/eecs489
EECS 489: Computer Networks (F'18) ... **EECS 489** takes a top-down approach to explore how networks operate and how network applications are written. ... Kurose and Ross, Computer Networking: A Top-Down Approach, 7th.

UM EECS 489: Computer Networks
www.eecs.umich.edu/courses/eecs489/
Lecture: MWF 9:30 - 10:30 in 1500 **EECS**. Discussion/Lab: W 12:30 - 1:30 in 2166 DOW or W 4:30 - 5:30 in 1014 DOW. The discussion sessions will mostly be ...

EECS 489
www.eecs.umich.edu/courses/eecs489/f99/
News group umich.**eecs**.class.**489**. Everything posted here will be automatically forwarded to the **eecs489staff@eecs**.umich.edu mailing list hourly.

EECS 489 - EECS @ Michigan - University of Michigan
https://www.eecs.umich.edu/eecs/academics/courses/eecs-489.html
Course Homepage: http://www.**eecs**.umich.edu/courses/**eecs489**/w10/. Coverage We study how networks operate and how network applications are written.

Revamping EECS 489: A Retrospective | Mosharaf Chowdhury
https://www.mosharaf.com/blog/2017/05/07/revamping-eecs-489-a-retrospective/
May 7, 2017 - A couple of weeks ago, we wrapped up the Spring 2017 offering of the **EECS 489**:

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 ☺

5-MINUTE BREAK!

Applications

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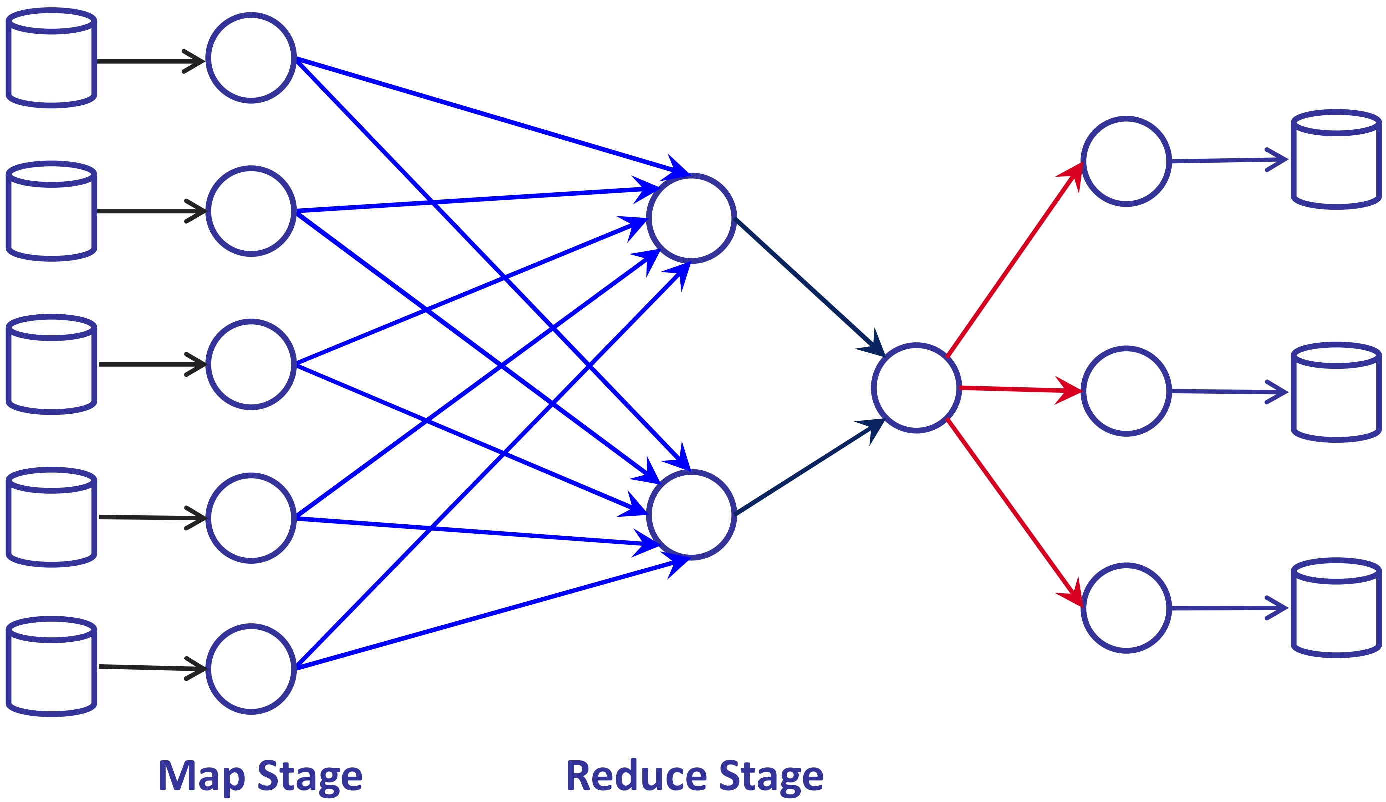
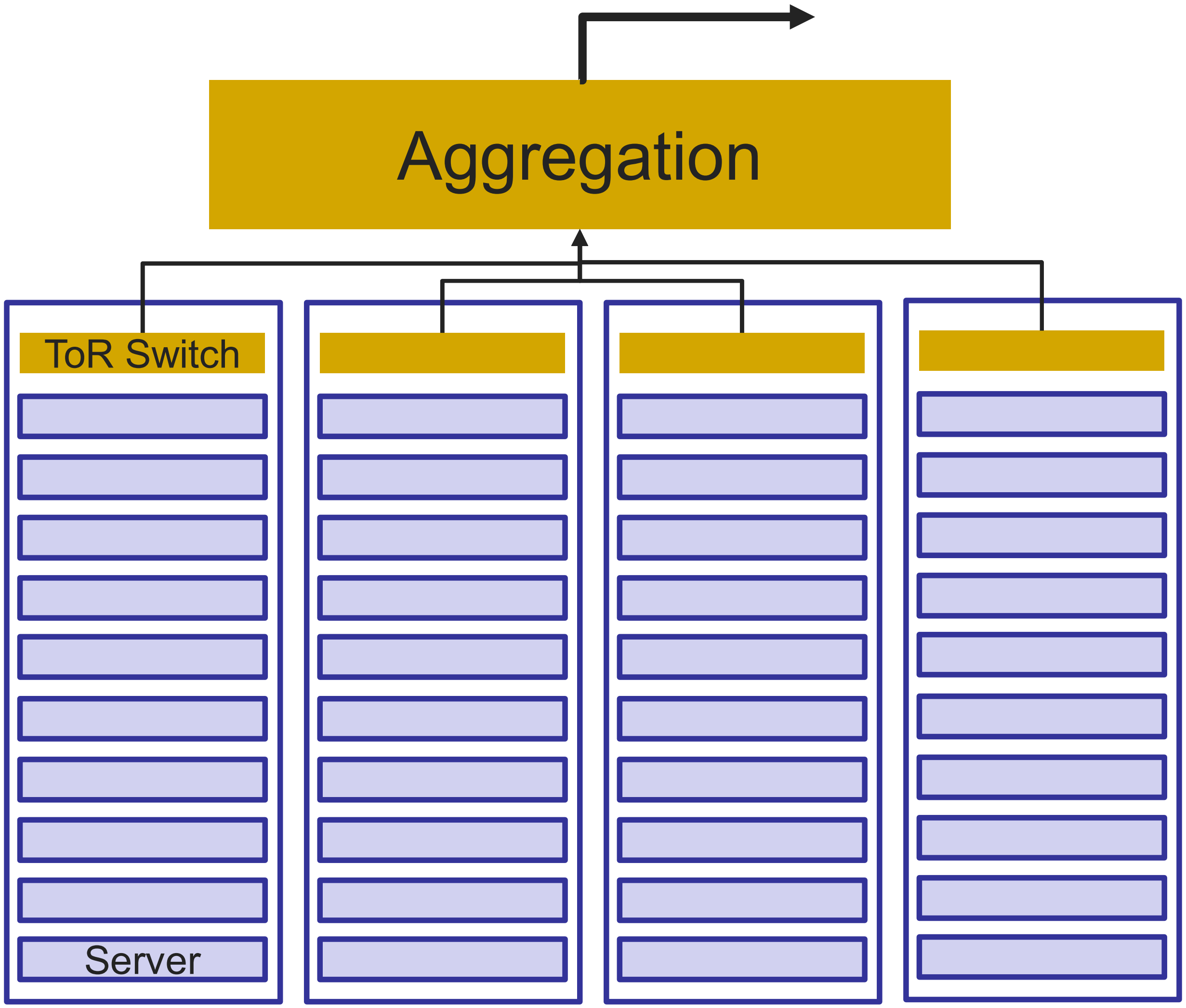
Map-Reduce

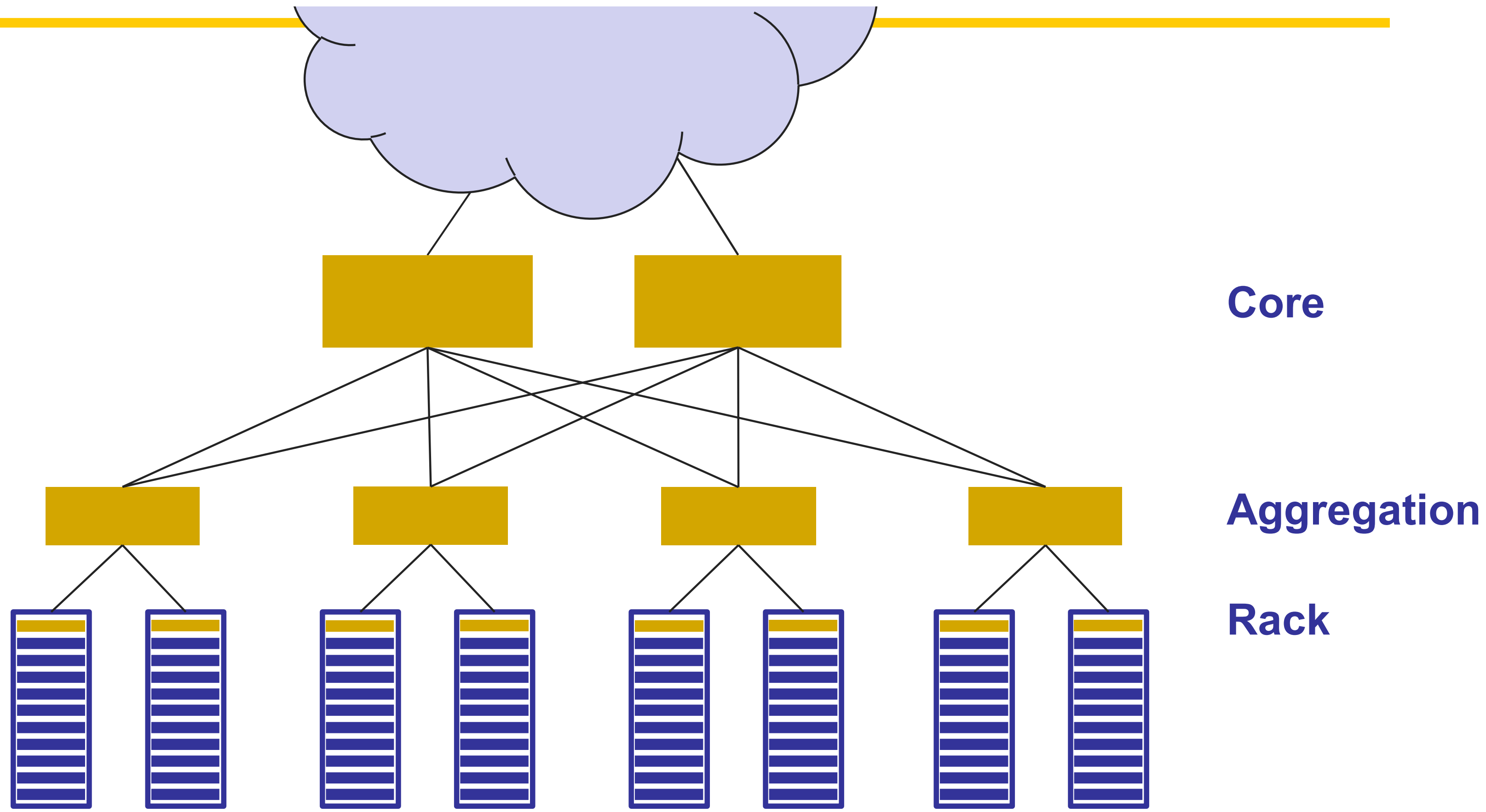


The most popular software that follows this paradigm is Apache Spark

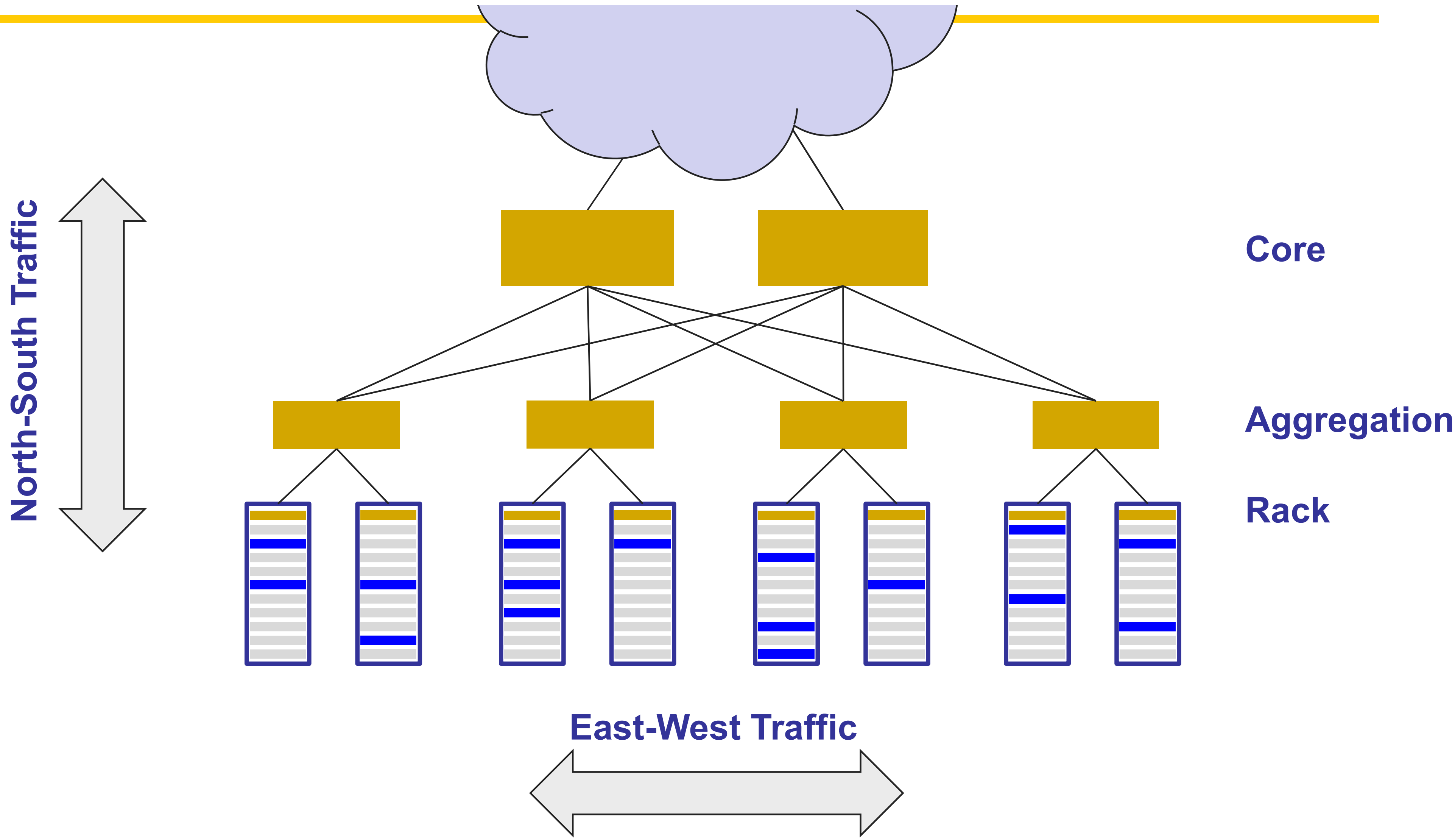
Datacenter networks



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

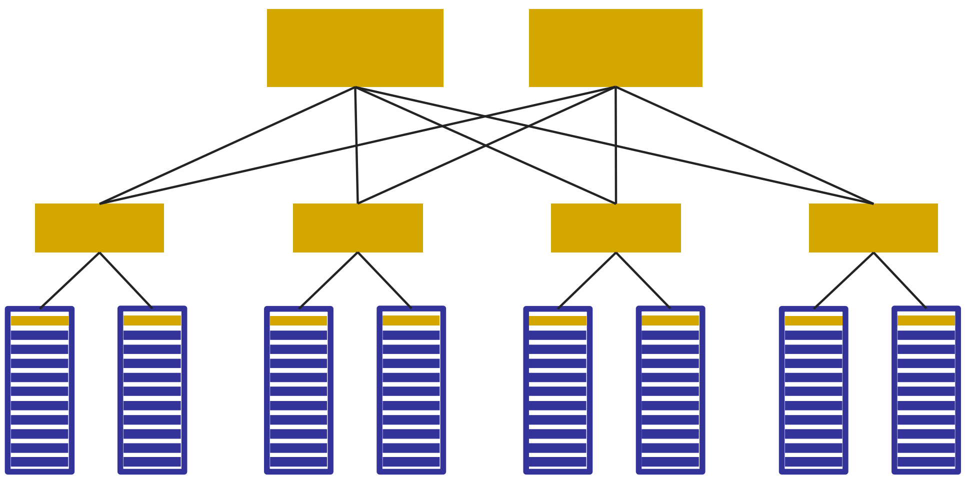
- Two key characteristics
  - Most flows are small
  - Most bytes come from large flows

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

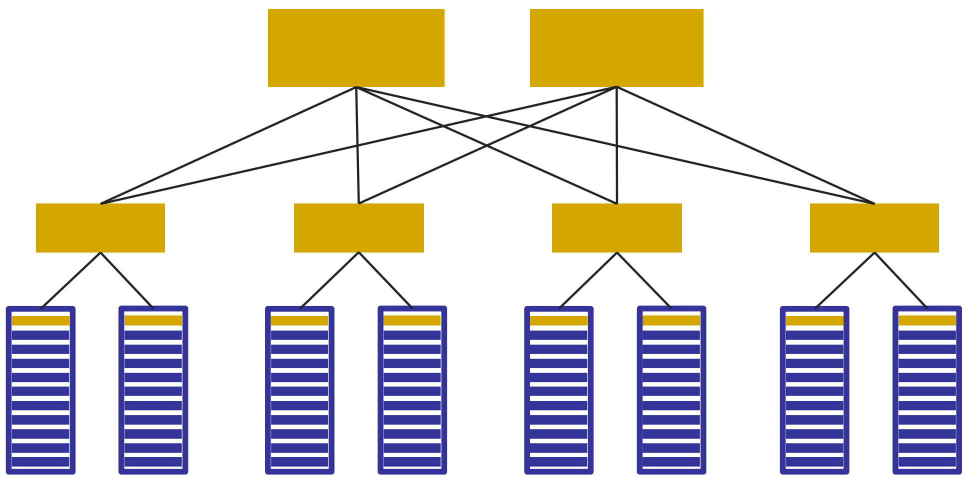
High bandwidth

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

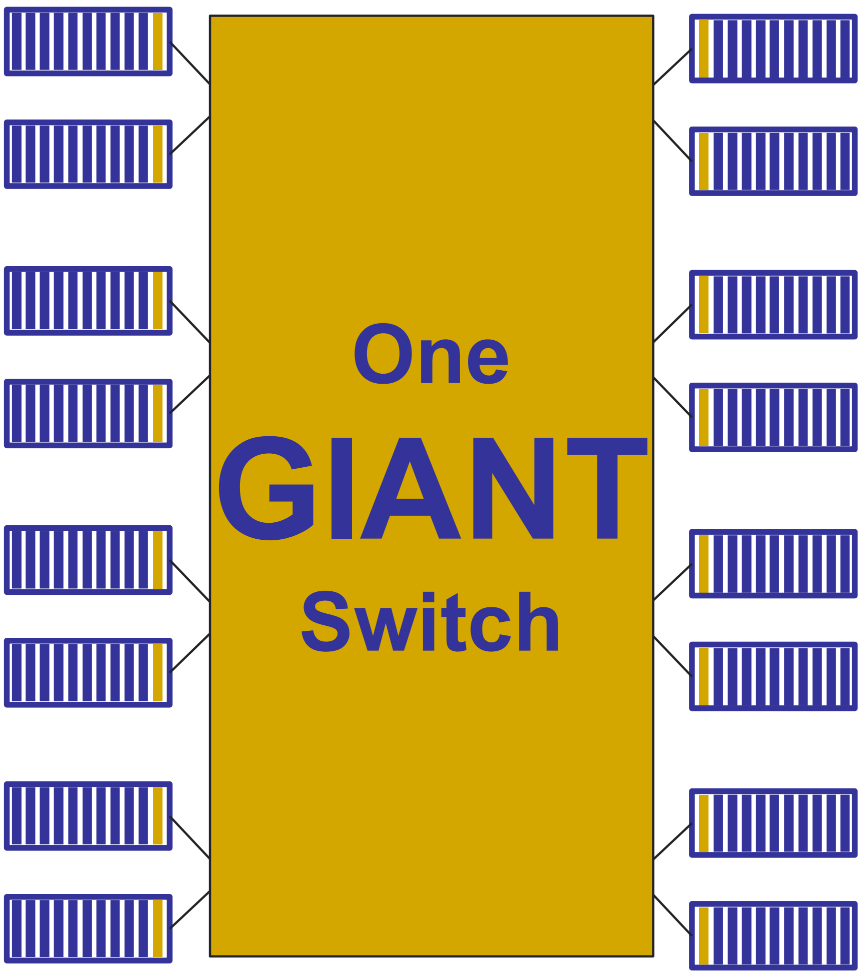
Datacenter network as one giant switch



Datacenter network as one giant switch



Datacenter network as one giant switch



High bandwidth

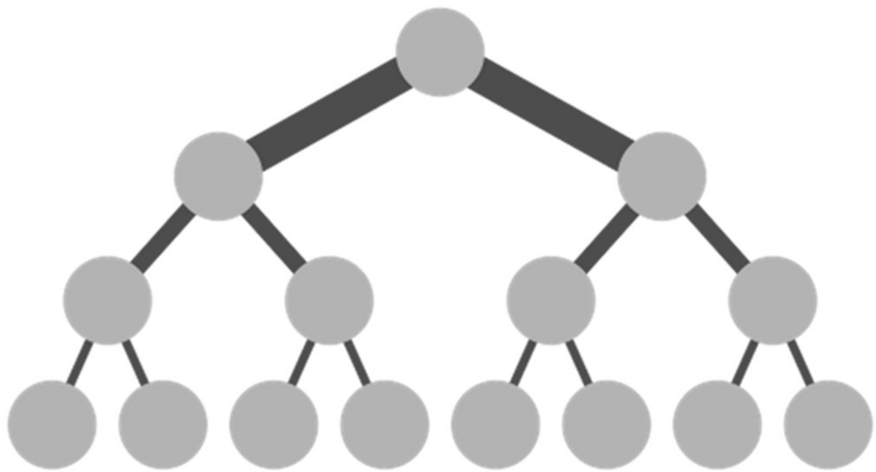
- Ideal: Each server can talk to any other server at its full access link rate
- Conceptually: Datacenter network as one giant switch
  - Would require a 10 Pbits/sec switch!
    - 1M ports (one port/server)
    - 10Gbps per port
- Practical approach: build a network of switches (“fabric”) with high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

Bisection bandwidth

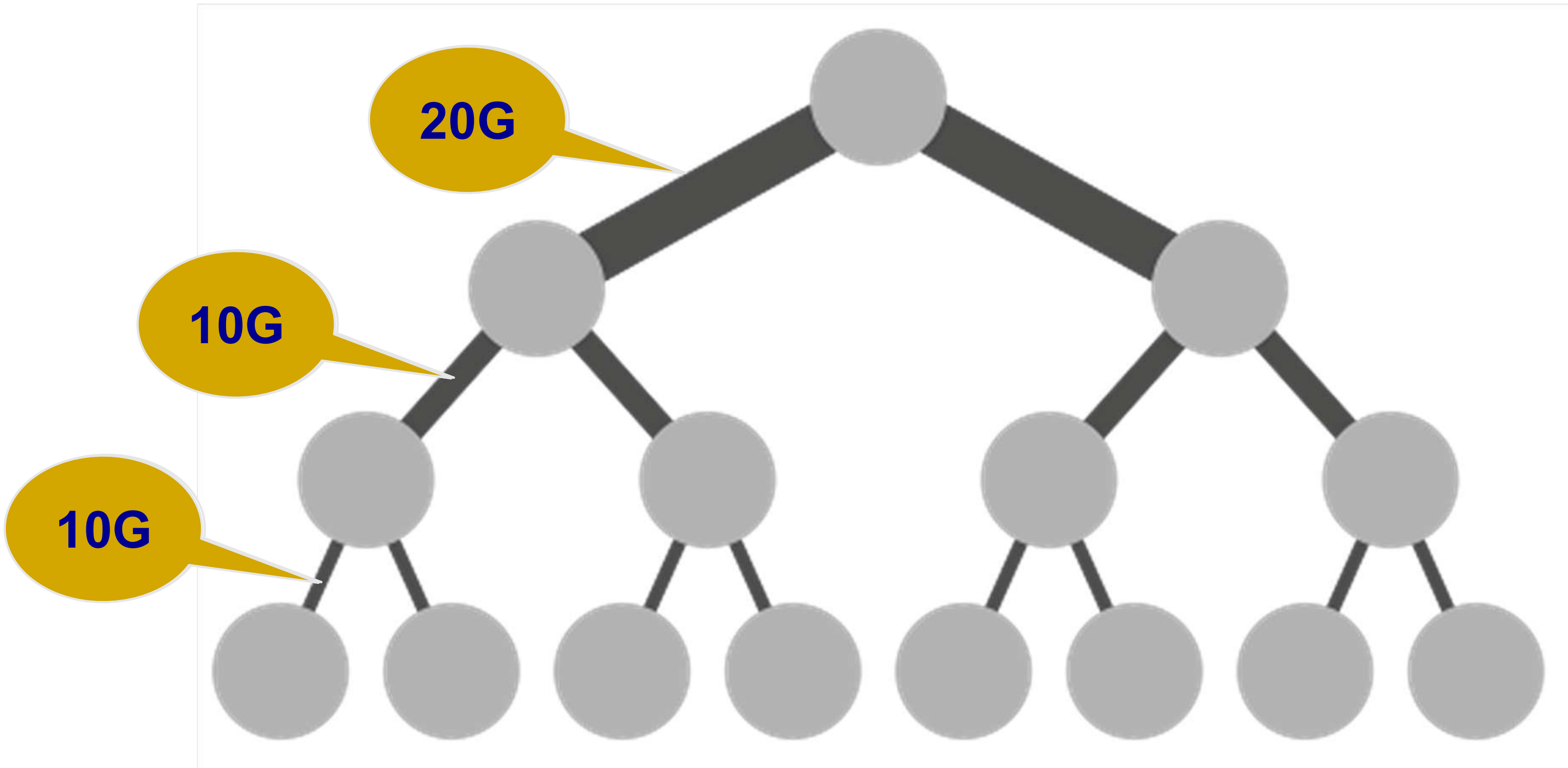
- Partition a network into two equal parts
- Minimum bandwidth between the partitions is the bisection bandwidth
- Full bisection bandwidth: bisection bandwidth in an N node network is N/2 times the bandwidth of a single link
  - Nodes of any two halves can communicate at full speed with each other

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

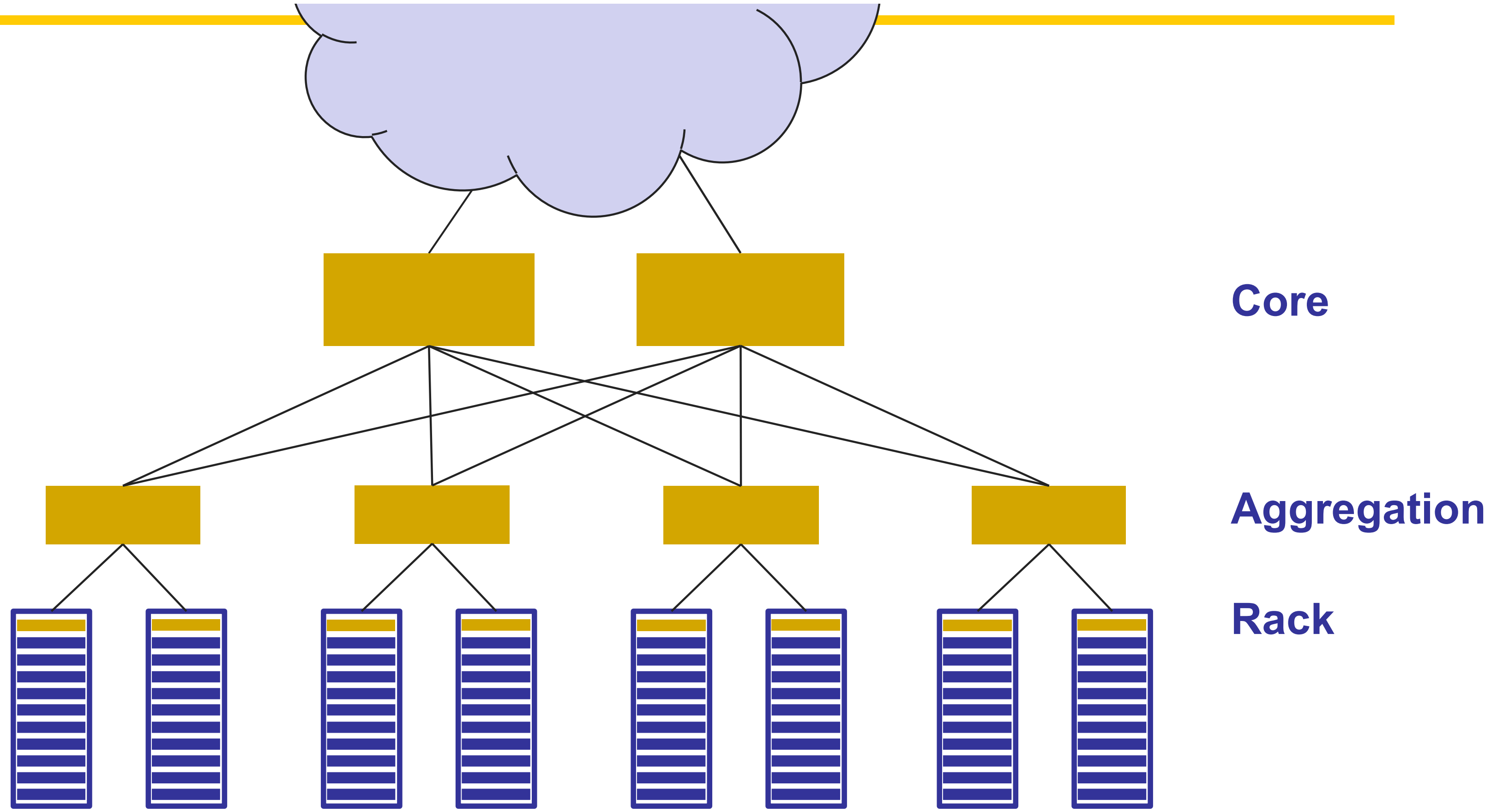


Need techniques to avoid congesting oversubscribed links!

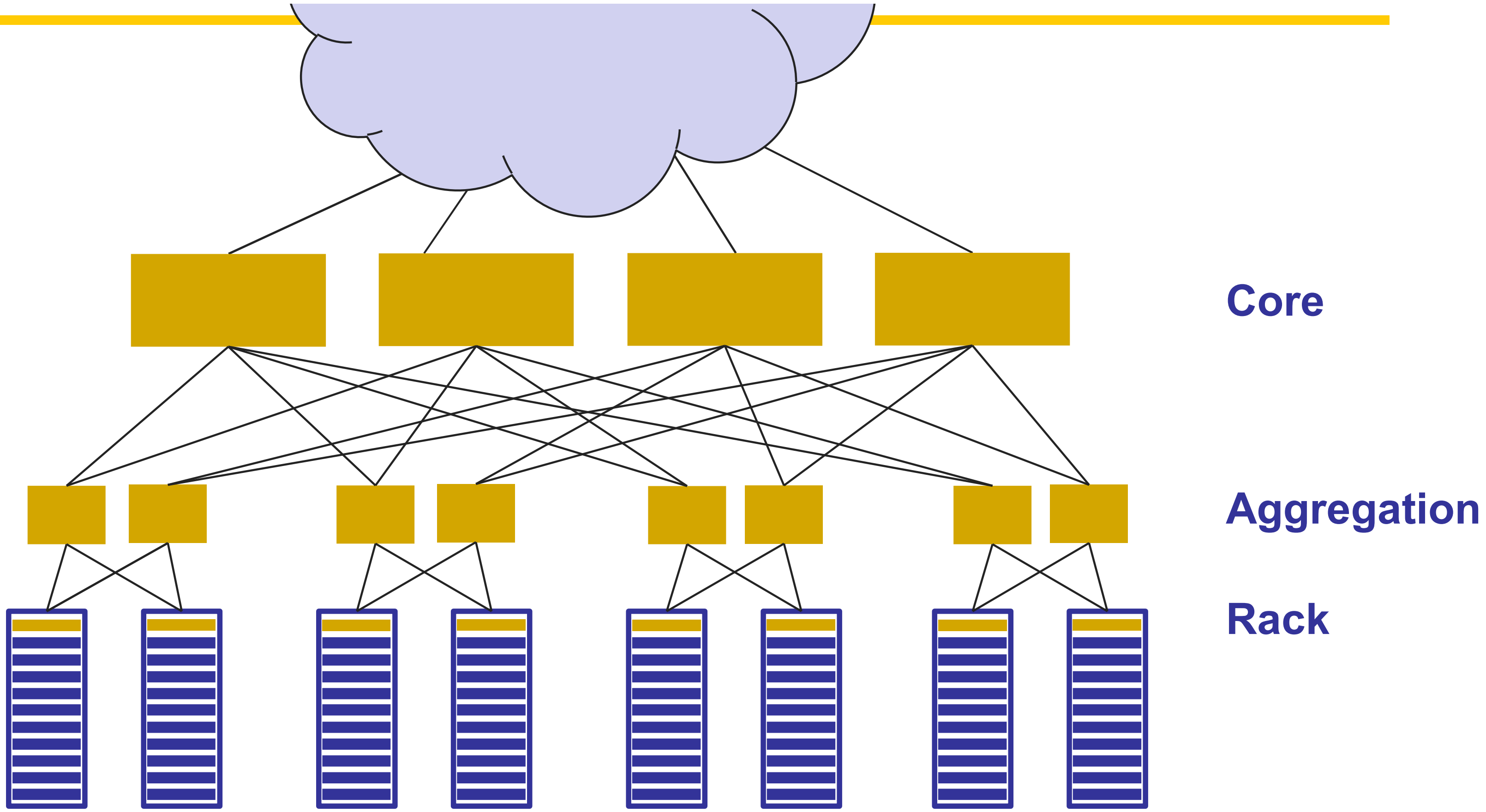
Oversubscription

- 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



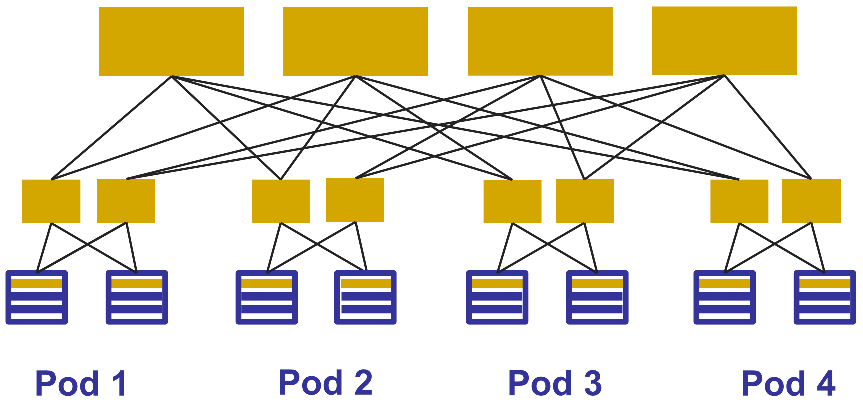
Better topologies



Clos topology

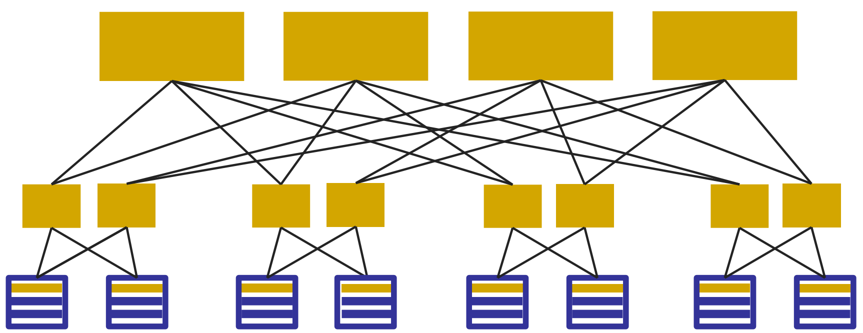
- Multi-stage network
- k pods, where each pod has two layers of k/2 switches
  - k/2 ports up and k/2 down
- All links have the same b/w
- At most $k^3/4$ machines

- 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