

CS 43: Computer Networks

10: Content Delivery Networks

October 7, 2026



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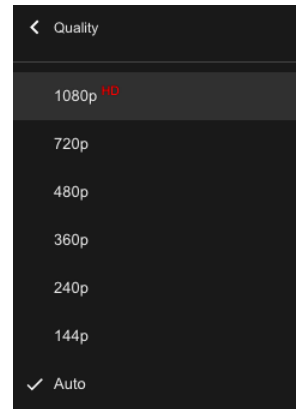
Announcements

- Quiz 4 Grades posted; median was an 8.5/9
- Final Exam Dec 16th @ 9am-12pm
- TLC coming to get your feedback on class during last 15 minutes
- I've been putting additional reference slides at the end of slide-decks that you may find useful for studying since we do not cover everything in the reading in detail in lecture.

Let's finish talking about video streaming from last time...

Adaptive bit-rate video

- Motivation: Want to provide high quality video experience, without stalls
- Observations:
 - Videos come in different qualities (average bit rates)
 - Versions of the video for different quality levels readily available
 - Different segments of video can be downloaded separately
- **Adapt bitrate per segment** through collaboration between the video client (e.g., your browser) and the server (e.g., @ Netflix)
- **Adaptive bitrate (ABR) video**: change the bitrate (quality) of next video segment based on network and client conditions



A client is streaming at 4 Mbps and has 30 seconds of video buffered. The last segment downloaded slowly: the client measured the throughput was 1 Mbps. What should it request for the next segment?

- A. The 1 Mbps version. The measurement says that's what the network can deliver
- B. Stay at 4 Mbps. With 30 seconds buffered it can afford to wait and see
- C. The 2 Mbps version, as a compromise
- D. The lowest version available, to be safe
- E. I don't know

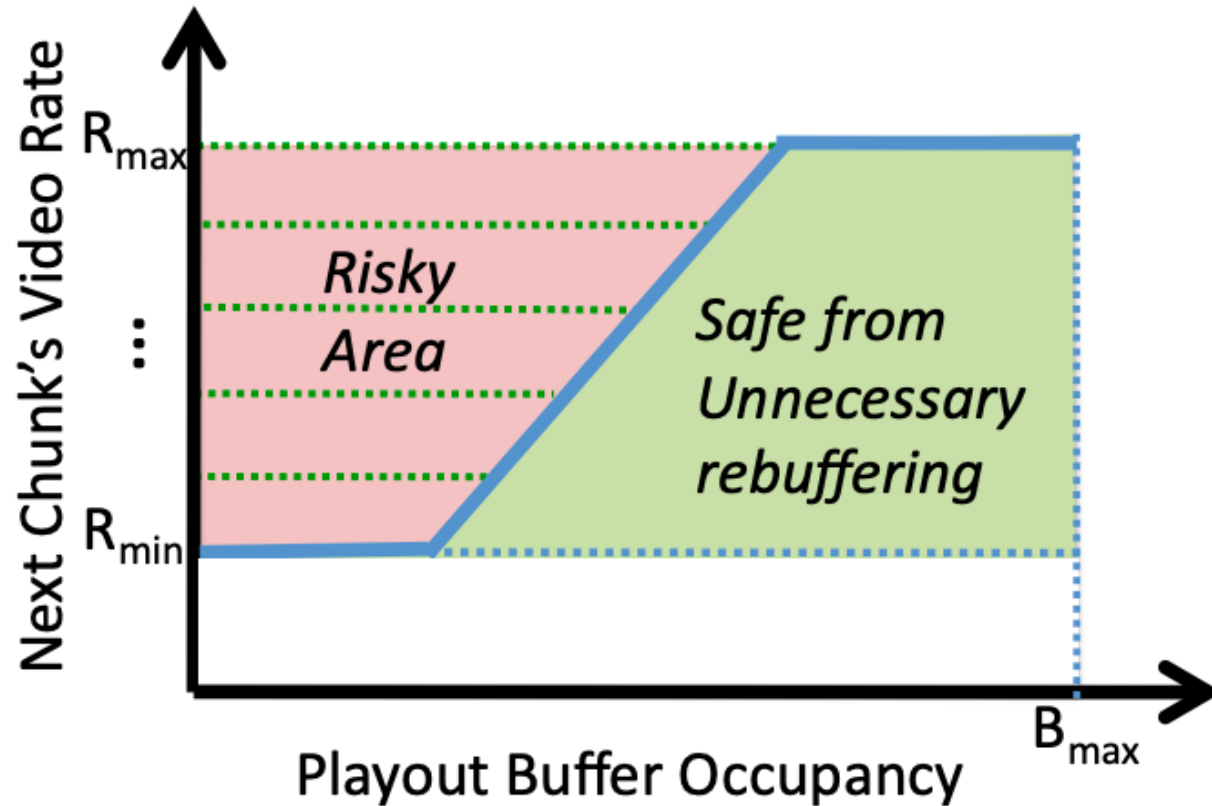
In practice: Today's buffer-based approaches choose B.

Typical strategy:

Buffer-based bitrate adaptation

- Key idea: If there is a large stored buffer of video at the client, **optimize for video quality**, i.e., high bit rates
- Else (i.e., client video buffer has low occupancy), **avoid stalls** by being conservative and asking for a lower quality (bitrate)
 - The hope: the lower bandwidth requirement of a lower-quality stream is more easily met; stalls averted
- Buffer is measured in seconds of playout left before stalling

Buffer-based bitrate adaptation



Provide high video quality overall despite variable and intermittently poor network conditions.

<http://yuba.stanford.edu/~nickm/papers/sigcomm2014-video.pdf>

A Buffer-Based Approach to Rate Adaptation
(used by Netflix)

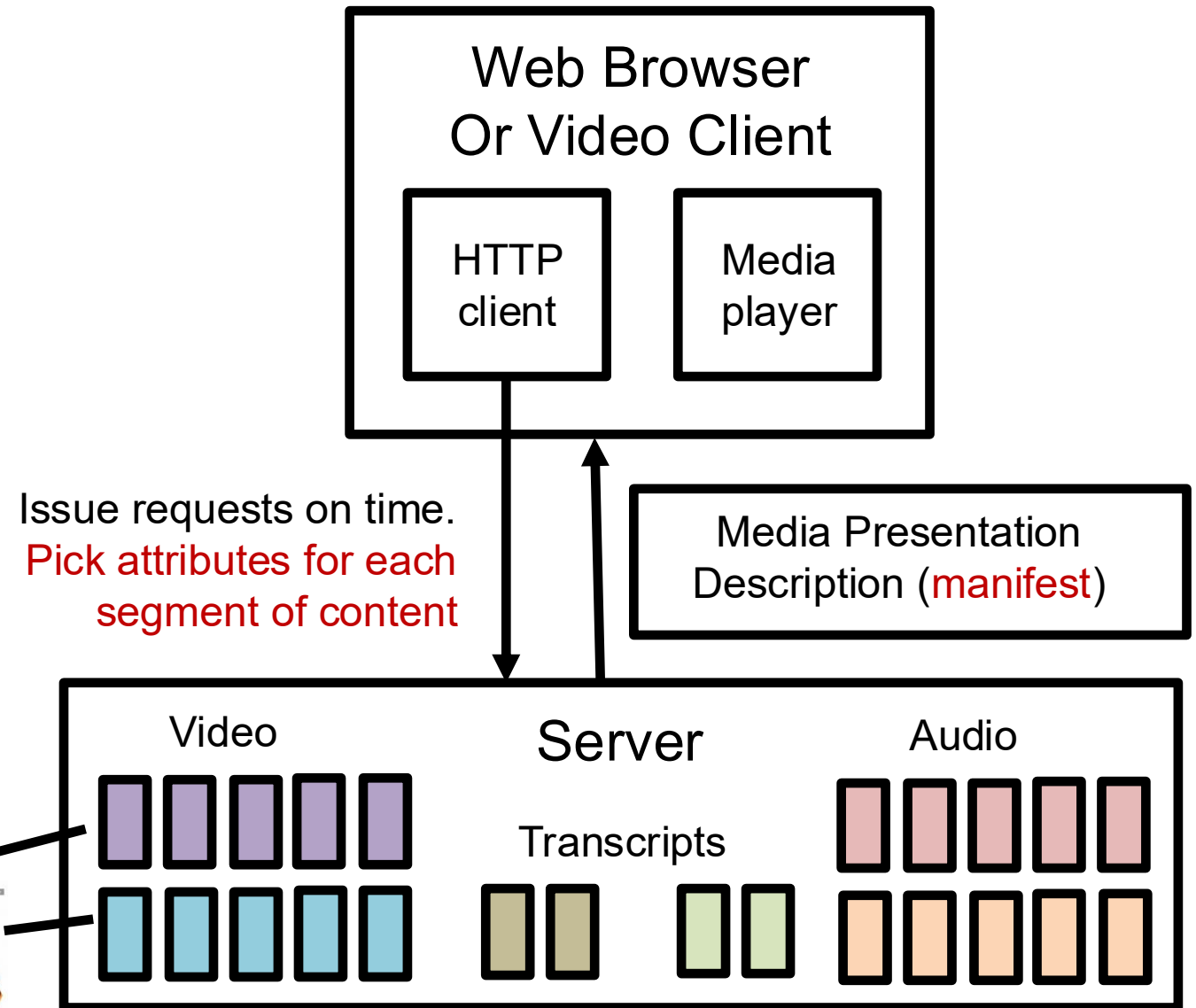
DYNAMIC ADAPTIVE STREAMING OVER HTTP (DASH)

Streaming multimedia with HTTP

- Early video: basic UDP
 - Problems: reliability, blocking
- Today: repurpose **web** infrastructure and protocols for video
- **DASH: Dynamic Adaptive Streaming over HTTP**
 - Used by Netflix, YouTube, and other video streaming services

DASH: Key ideas

- Content (video, audio, transcript, etc.) divided into **segments (time)**
- Algorithms to determine and request **varying** attributes (e.g., bitrate, language) for each segment
- Goal: ensure good quality of service, match user preferences, etc.



Streaming multimedia with HTTP

- Dividing up a video into multiple segments enables a few things
- Possible to decide the quality **per segment**
 - Enables **bit rate adaptation**
 - Typically done on the client, but possible on the server (with feedback)
 - Change language, receive sub-titles, etc. mid-stream
- Retrieve segments of a single video from multiple sources
- DASH video server is just a standard HTTP server
 - Client issue HTTP GET requests (typically with the **Range** request header)
 - Leverage existing web infrastructure (CDN, DNS)
- Send different clients to different video sources (CDN)

[DEMO] Let's take a look at the DASH player again...

<https://reference.dashif.org/dash.js/latest/samples/dash-if-reference-player/index.html>

In the demo, the player downshifted from 4K to lower quality when the link bandwidth was lower. Which of these did the server do to make that happen?

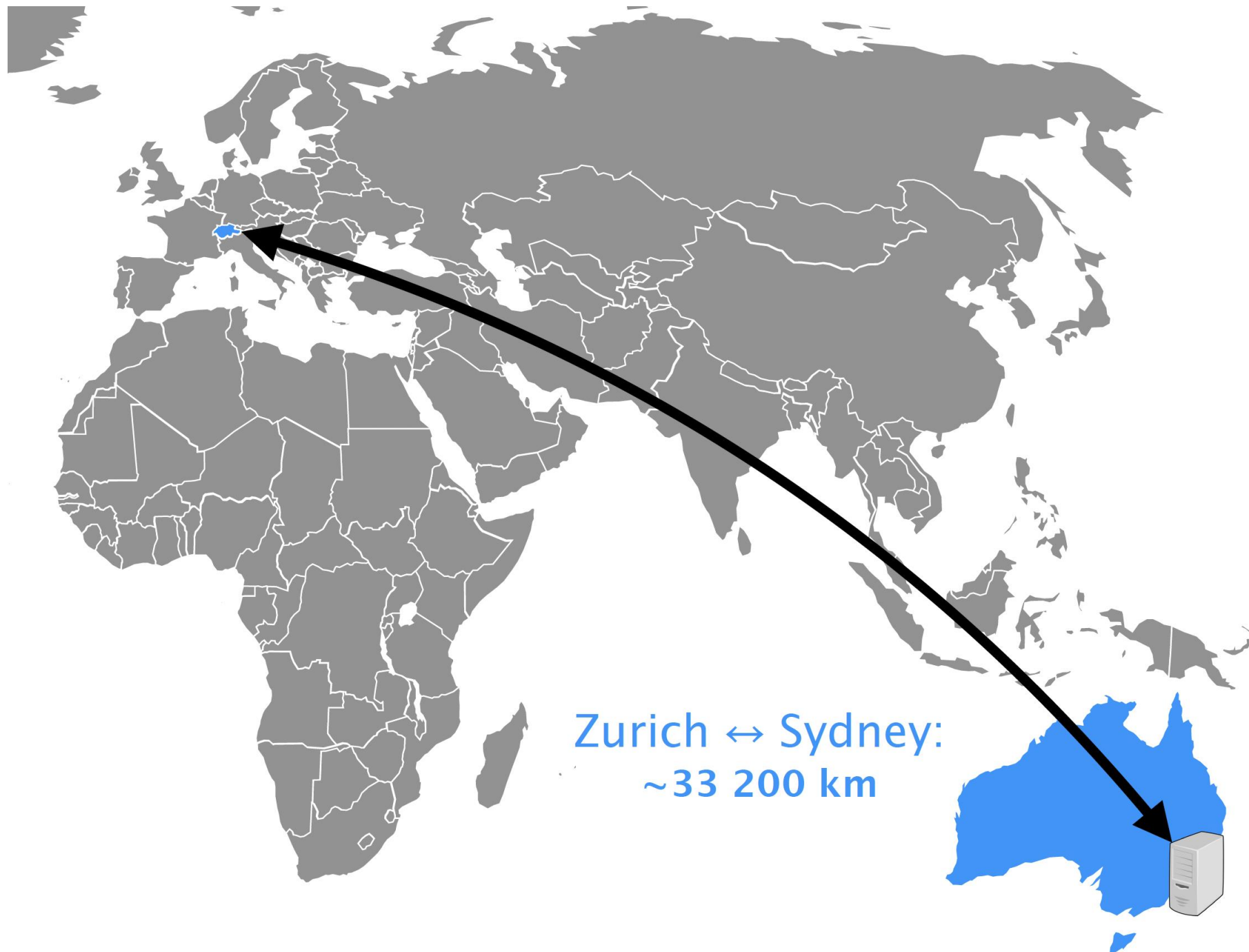
- A. Measured the client's throughput and chose a lower representation
- B. Re-encoded the next segment at a lower bitrate
- C. Read the client's buffer level from the HTTP request
- D. Nothing beyond answering HTTP GETs for files that already existed
- E. I don't know

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DASH Summary

- Piggyback video on HTTP: **widely used**
- Enables independent HTTP requests per segment
 - Works well with CDNs
 - Adapt quality with time, location per client, possibly location over time
 - May use HTTP range requests to ask byte ranges in a segment URL
 - Fetch segments from locations other than the origin server
- More resources on DASH
 - https://www.w3.org/2010/11/web-and-tv/papers/webtv2_submission_64.pdf
 - <https://www.youtube.com/watch?v=xgowGnH5kUE>



$$\begin{array}{rcl}
 & & \text{speed of light in} \\
 & & \text{optical fiber} \\
 & & | \\
 \frac{299,792,458 \text{ m/s}}{\text{refractive index} \quad \text{optical fiber} \quad \text{— } 1.468} & = & 204,218,296 \text{ m/s}
 \end{array}$$

$$\begin{array}{rcl}
 \frac{33,200,000 \text{ m}}{204,218,296 \text{ m/s}} & = & 163 \text{ ms} \\
 & & | \\
 & & \text{theoretical} \\
 & & \text{round-trip time}
 \end{array}$$

Because of propagation delays,
Content Delivery Networks move content closer to you



Demo: How much faster is a website using a CDN?

- Look at ping time for a website in various countries:

<https://tools.keycdn.com/ping>

<https://tools.keycdn.com/performance>

– Hosted by a CDN: nbcnews.com

- Check if a website uses a CDN

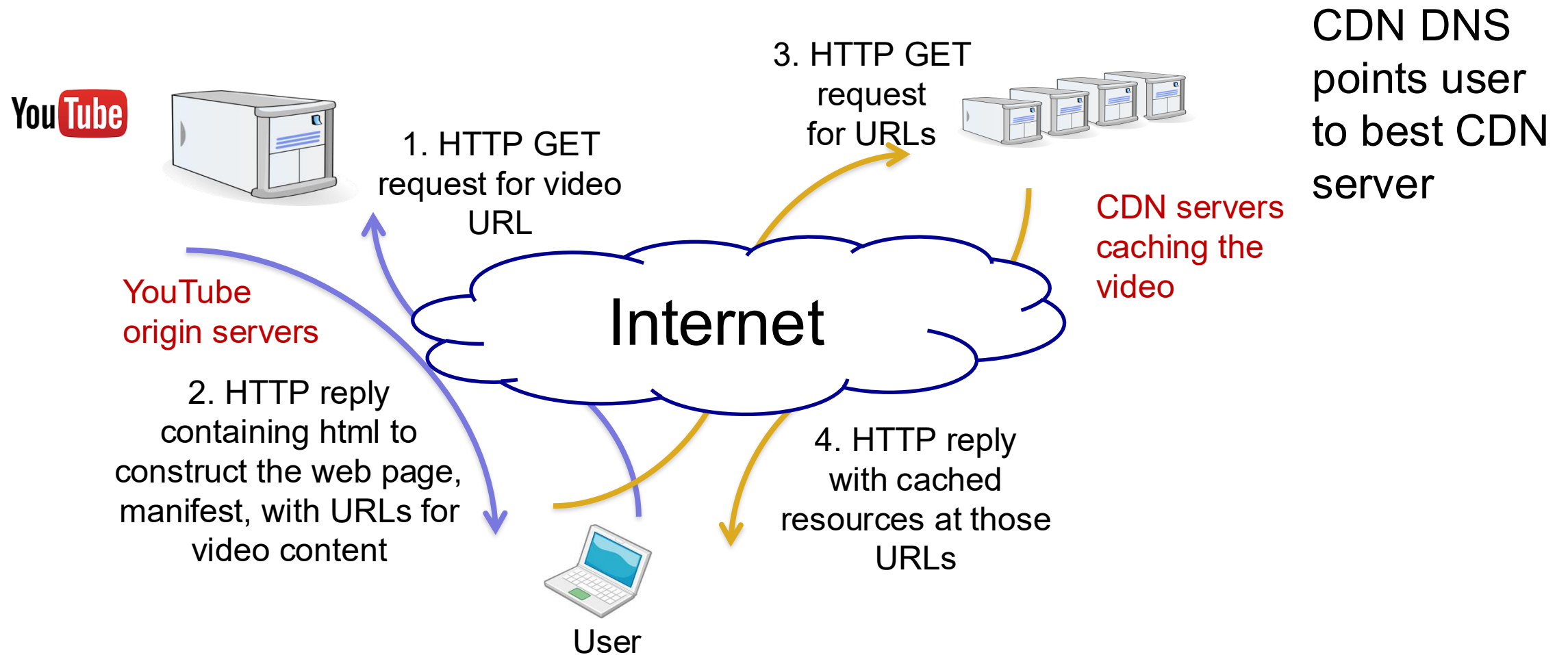
<https://www.cdnplanet.com/tools/cdnfinder>

Examples of CDNs

- Akamai
 - Pioneer in building CDNs at scale
- Cloudflare
 - Rising to be largest CDN
 - Emphasis on cybersecurity and DDoS mitigation
 - Shares data collected from CDN: <https://radar.cloudflare.com/>
- Fastly
- Others
 - Google, Facebook, AWS, AT&T, Level3

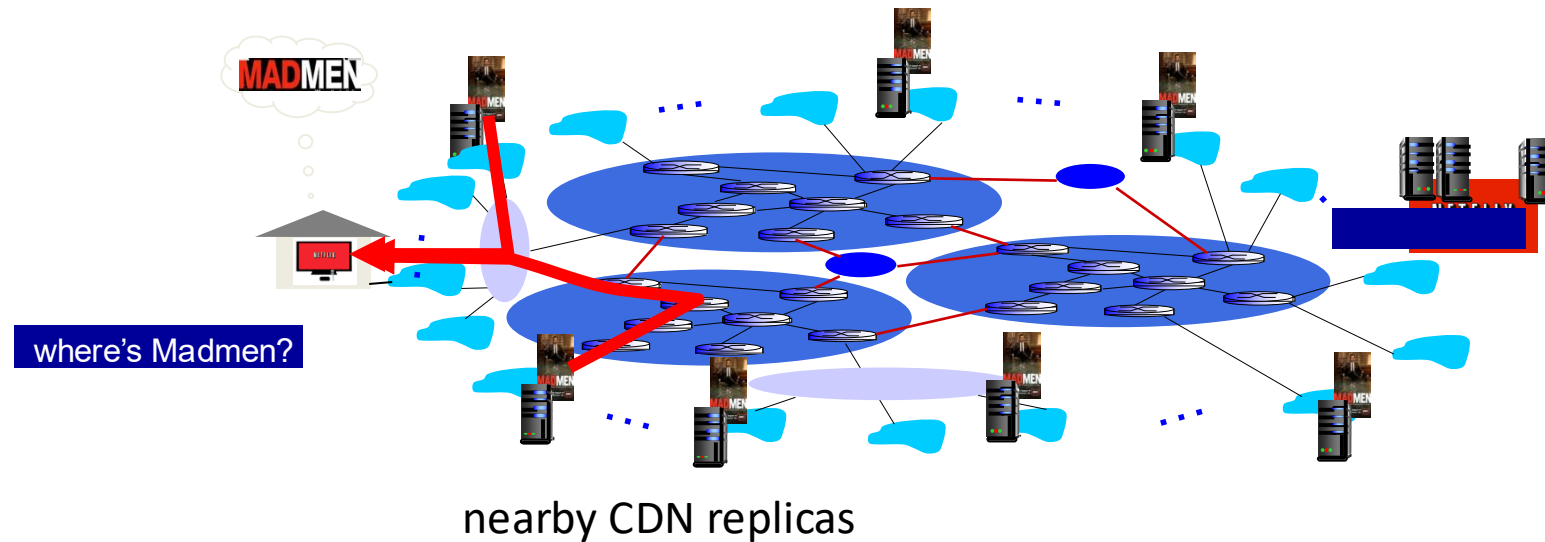
Dynamic server selection based on client

- Just an HTTP request for an HTTP object



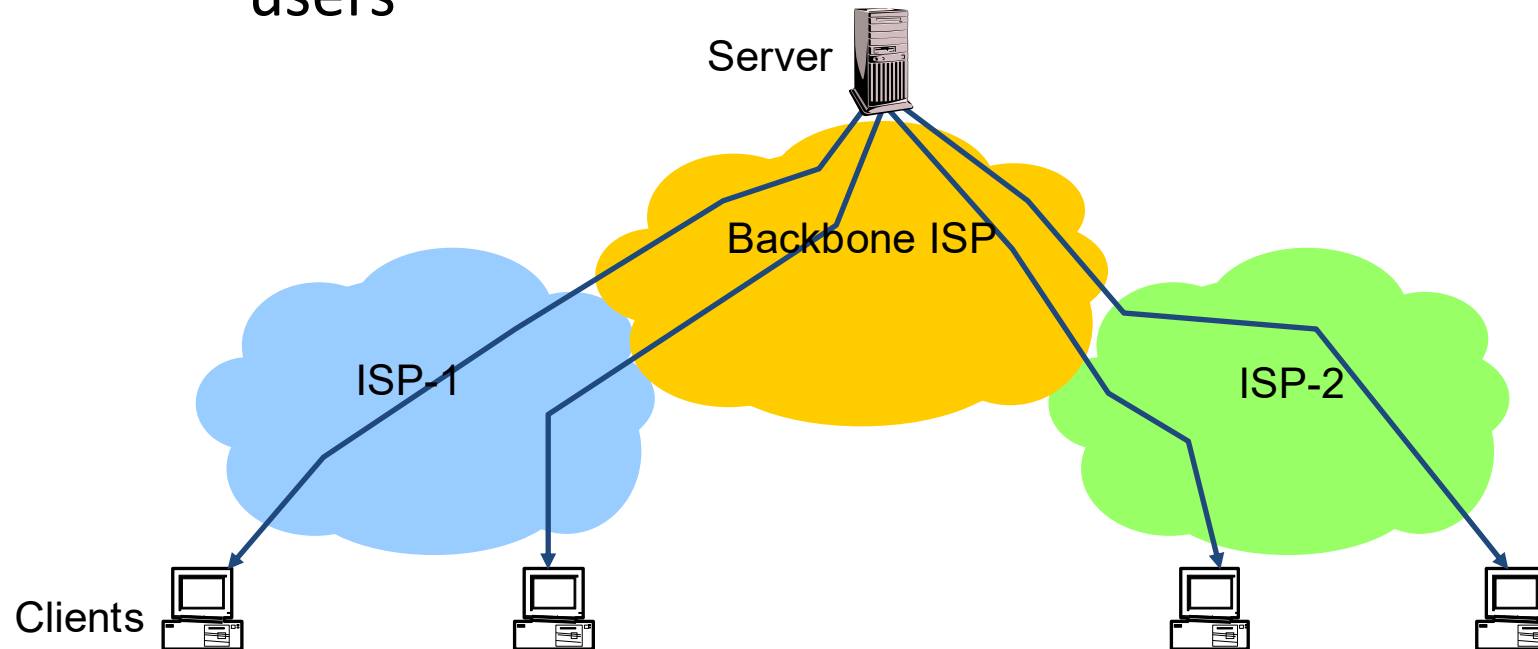
Content distribution networks (CDNs)

- CDN: stores copies of content (e.g. MADMEN) at CDN nodes



CDN caching

- Locality of reference:
 - Users tend to request the same object in succession
 - Some objects are popular: requested by many users

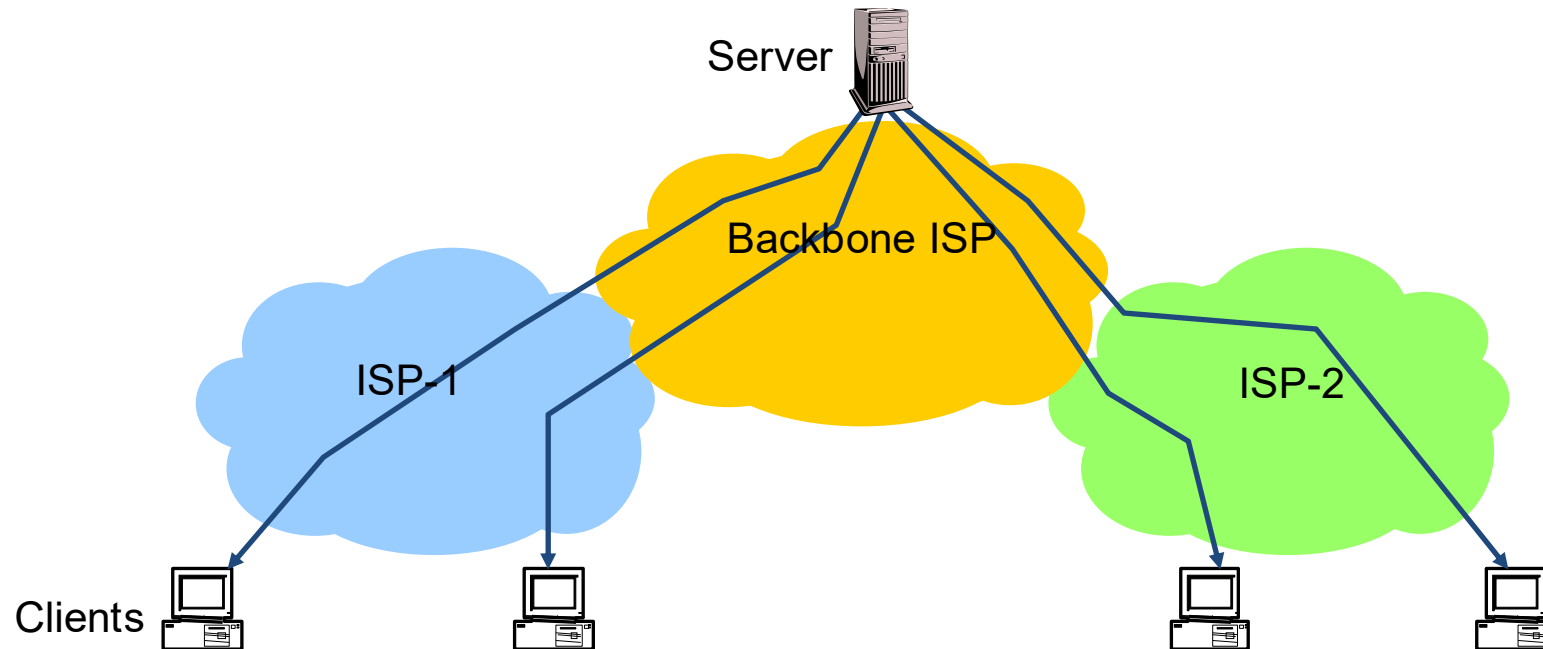


A Netflix cache box inside an ISP's network holds about 5% of the Netflix catalog. Roughly what fraction of that ISP's Netflix requests can it serve from the box?

- A. About 5%
- B. Well under 5%, since the box also has to hold manifests and metadata
- C. Well over 5%, because a small number of titles account for most viewing
- D. 100% because the box fetches anything missing before the viewer notices.
- E. I don't know

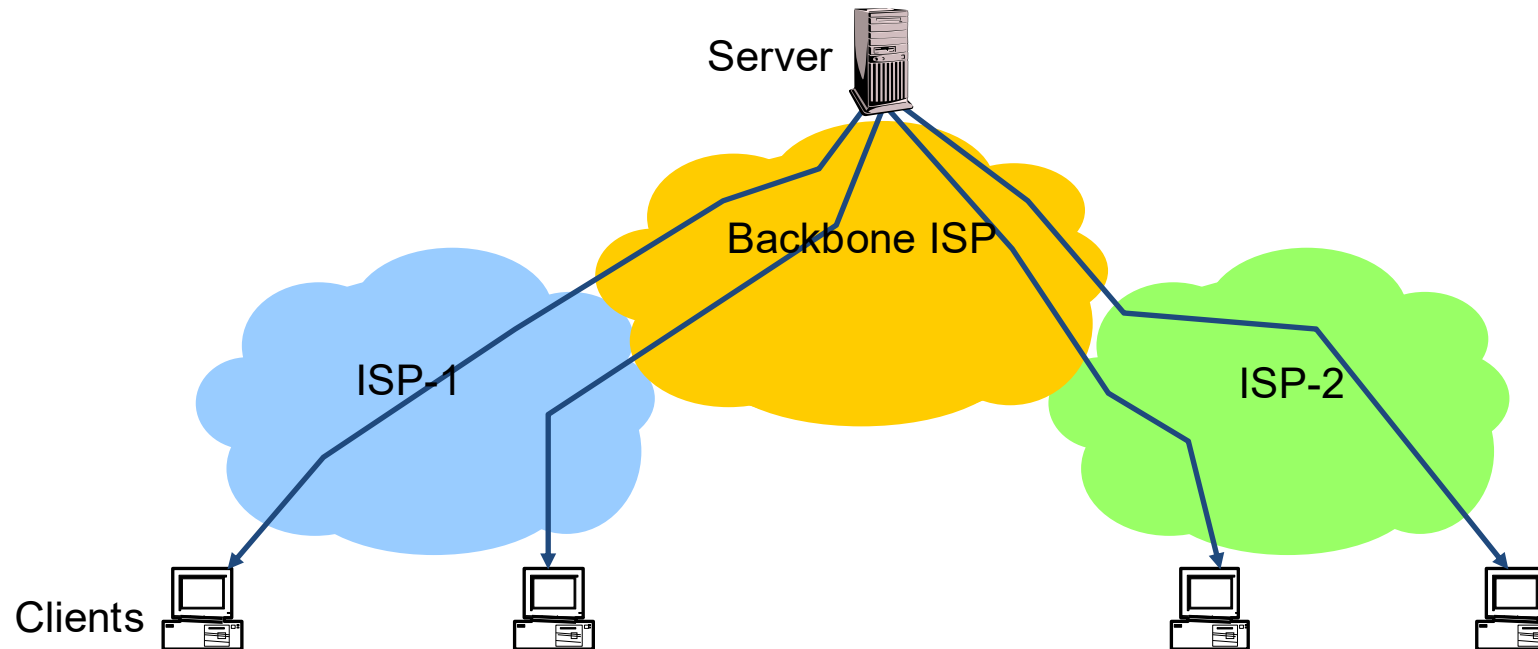
Where to cache content?

- A. At the client
- B. At the server (distributed server load)
- C. At the Service Providers (ISPs)



Where to cache content?

- A. At the client (browser) – avoid extra network transfers
- B. At the server (distributed server load) – reduce load
- C. At the Service Providers (ISPs) – reduce external traffic



Key Components of a CDN

- Distributed servers
 - Usually located inside of other ISPs
 - Often located in IXPs
- High-speed network connecting them
- Clients (eyeballs)
 - Can be located anywhere in the world
 - They want fast web performance
- Glue
 - Something that binds clients to “nearby” replica servers

High-Performance Content Distribution

- Major challenges:
 - How do we direct the user to a nearby replica instead of the centralized source?
 - How do we determine which replica is the best to send them to?
 - Ensure that replicas are always available?

Challenge: Finding the CDN

- Three main options:
 - Application redirect (e.g., HTTP)
 - “Anycast” routing
 - DNS resolution (most popular in practice)
- Example: NBC News + Akamai
- See reference material at end of these slides

Let's use dig to see how Akamai uses DNS redirection...

When you looked up `www.nbcnews.com`, Akamai's DNS server chose which Akamai cluster to send you to. Your laptop asked the campus resolver, which did the lookup on your behalf. Whose IP address does Akamai's DNS server actually see when it makes that choice?

- A. The laptop's
- B. The campus DNS resolver's
- C. NBC's web server's
- D. The .com TLD server
- E. I don't know

Which metric is most important when choosing a server? (CDN or otherwise)

- A. RTT latency
- B. Data transfer rate / throughput
- C. Hardware ownership
- D. Geographic location
- E. Some other metric(s) (such as?)

This is the CDN
operator's secret sauce!

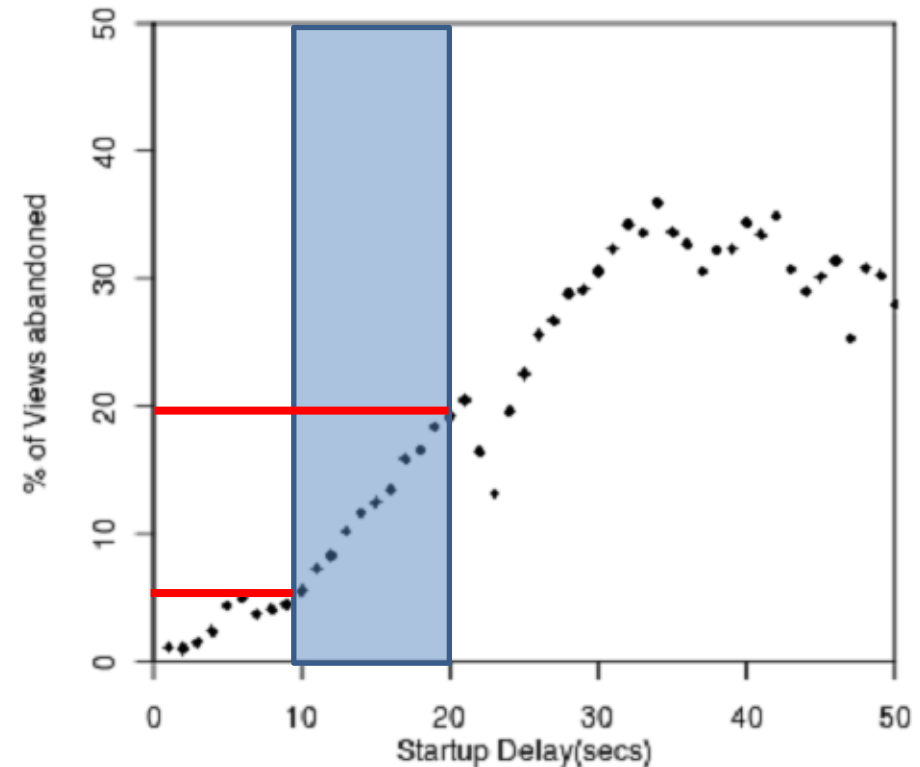
Summary

- DASH: streaming despite dynamic conditions
- CDNs: locating “good” replica for media server
 - Challenges: which content to cache, and which server to direct clients to?

Reference material (not covered in class)

Speed is Important!

- Impact on user experience
 - Users navigating away from pages
 - Video startup delay
- 4x increase in abandonment with 10s increase in delay



Content distribution networks (CDNs)

challenge: how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?

- *option 1:* single, large “mega-server”
 - single point of failure
 - point of network congestion
 - long (and possibly congested) path to distant clients

....quite simply: this solution *doesn't scale*

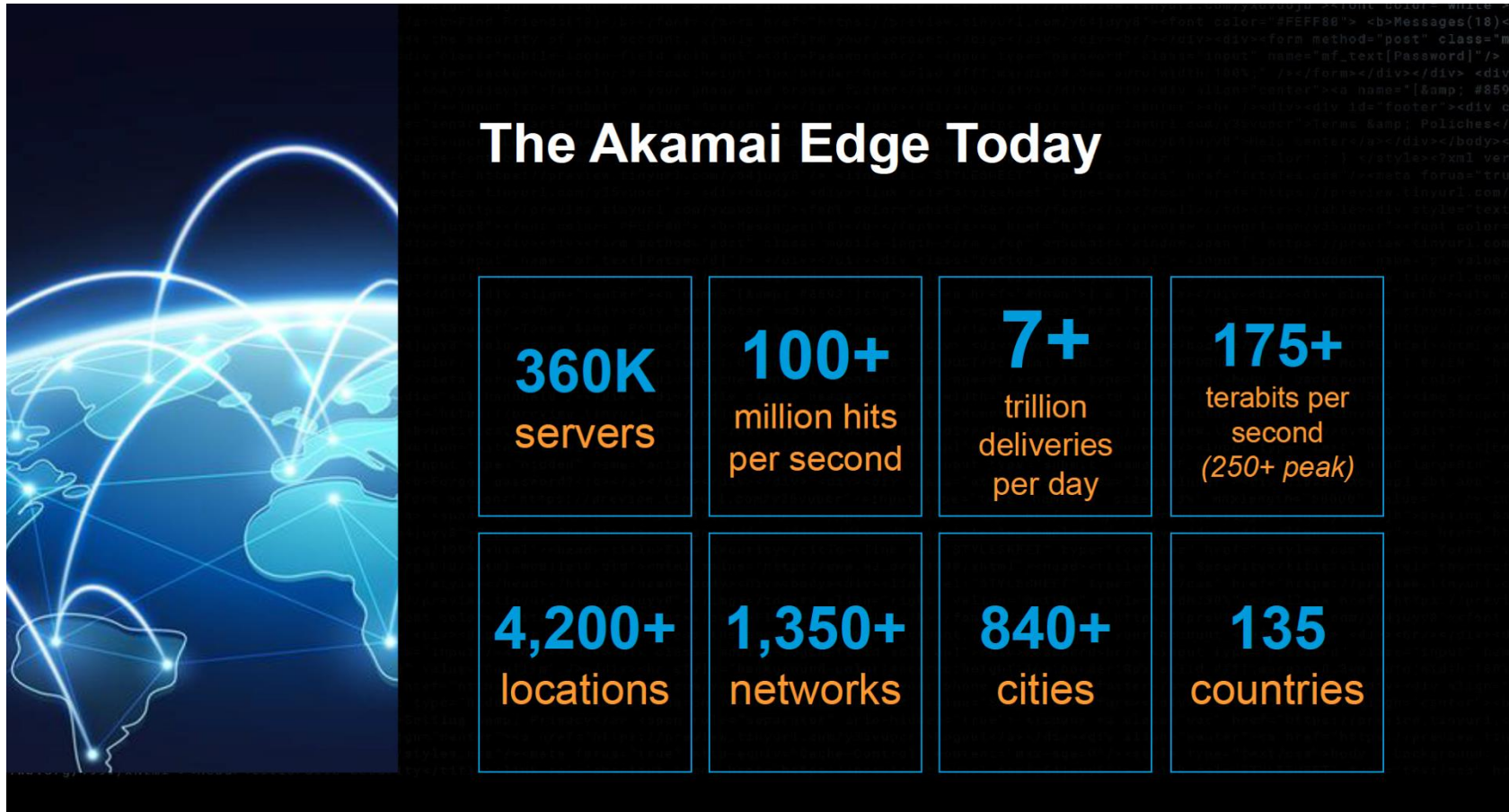
Content distribution networks (CDNs)

challenge: how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?

- *option 2:* store/serve multiple copies of videos at multiple geographically distributed sites (*CDN*)
- At least 70% of the world's bits are delivered by a CDN!
 - *enter deep:* push CDN servers deep into many access networks
 - “Go to the user”
 - Akamai: 240,000 servers deployed in > 120 countries (2015)
 - *bring home:* smaller number (10's) of larger clusters in POPs near access nets
 - “Bring the users to our data”
 - Cloudflare, Fastly



Akamai today:



Source: <https://networkingchannel.eu/living-on-the-edge-for-a-quarter-century-an-akamai-retrospective-downloads/>

Cloudflare today:

The Cloudflare global network

Our vast global network, which is one of the fastest on the planet, is trusted by millions of web properties.

With direct connections to nearly every service provider and cloud provider, the Cloudflare network can reach about 95% of the world's population within approximately 50 ms.



330

cities in 125+ countries, including mainland China

13,000

networks directly connect to Cloudflare, including every major ISP, cloud provider, and enterprise

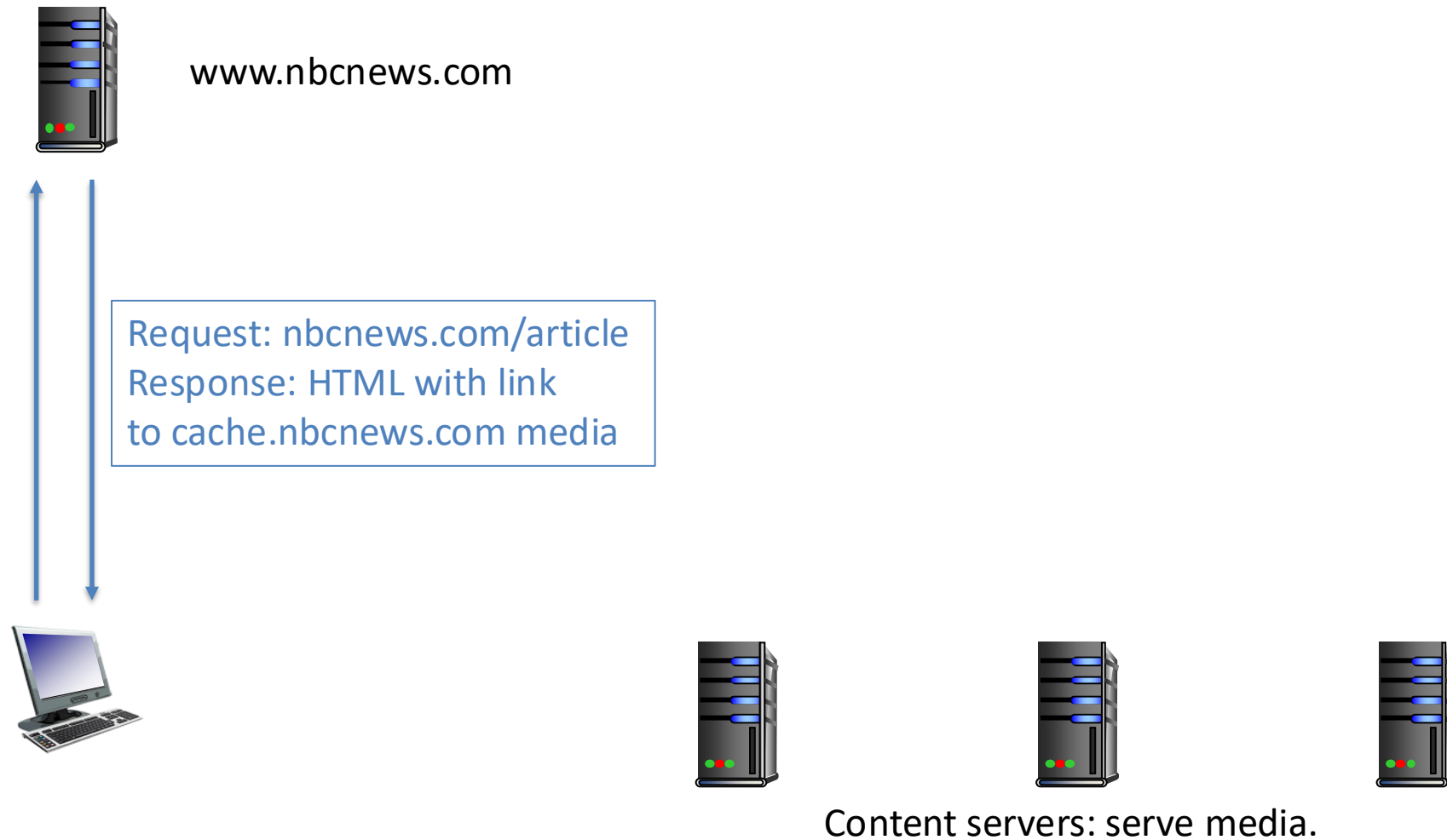
405 Tbps

global network edge capacity, consisting of transit connections, peering and private network interconnects

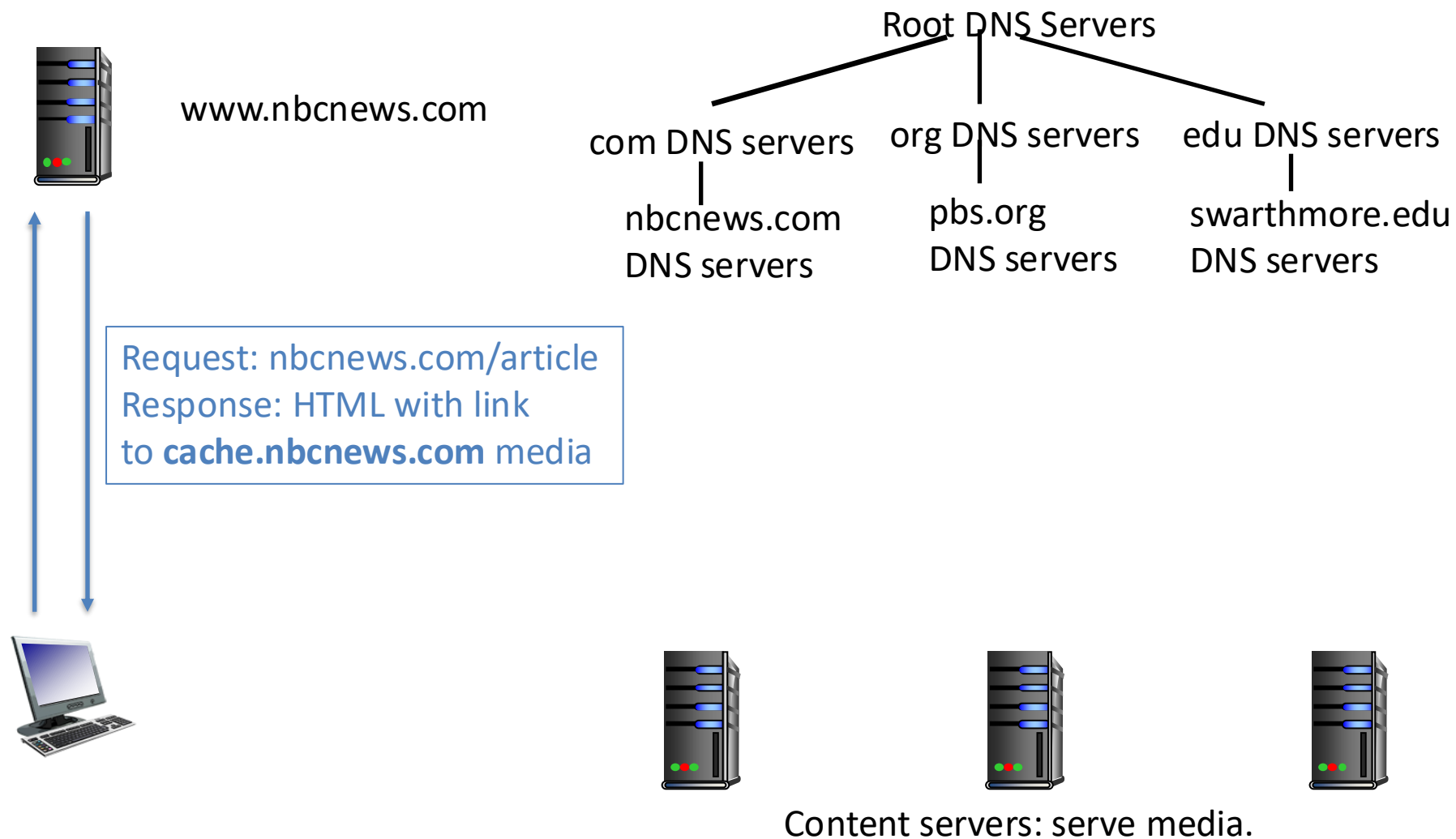
~50 ms

from about 95% of the world's Internet-connected population

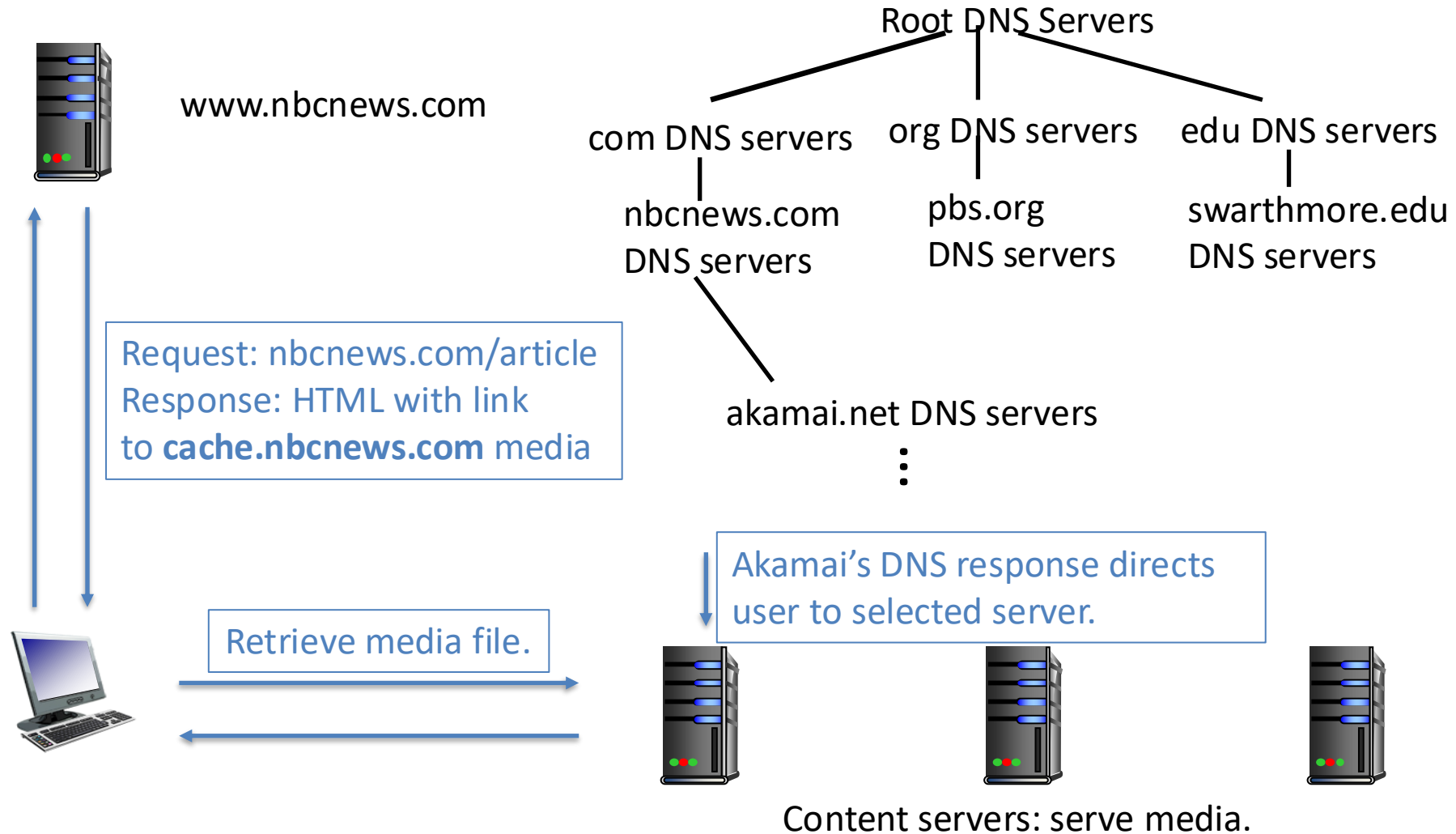
NBC News + Akamai



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