Chapter 2
Application Layer

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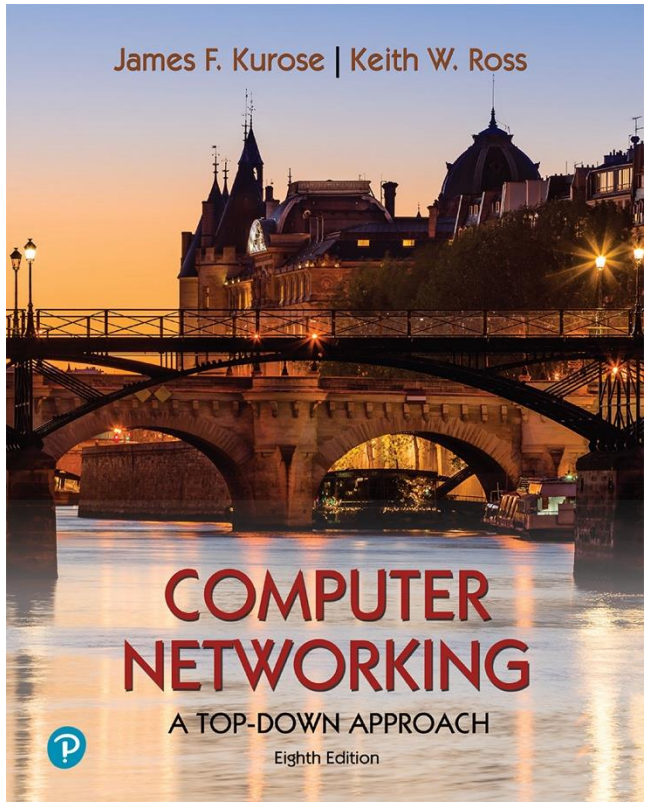


Computer Networking: A Top-Down Approach
8th edition n
Jim Kurose, Keith Ross
Pearson, 2020

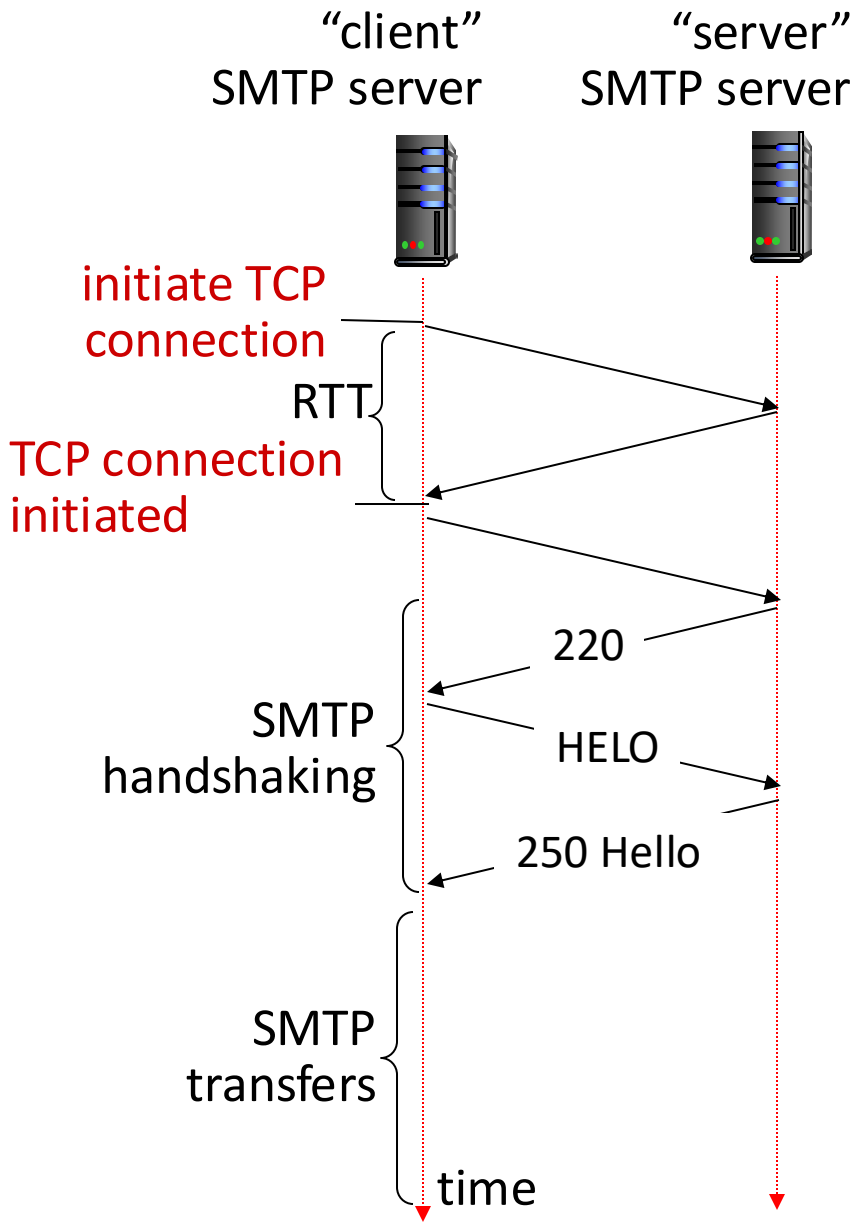
Adapted from the slides of the book's authors

Application layer: overview

- Principles of network applications
- socket programming with UDP and TCP
- Web and HTTP
- E-mail, SMTP, IMAP
- The Domain Name System DNS
- video streaming and content distribution networks

SMTP RFC (5321)

- uses TCP to reliably transfer email messages from client (mail server initiating connection) to server, port 25
  - direct transfer: sending server (acting like client) to receiving server
- three phases of transfer
  - SMTP handshaking (greeting)
  - SMTP transfer of messages
  - SMTP closure
- command/response interaction (like HTTP)
  - commands: ASCII text
  - response: status code and phrase



Video Streaming Applications

- stream video traffic: major consumer of Internet bandwidth
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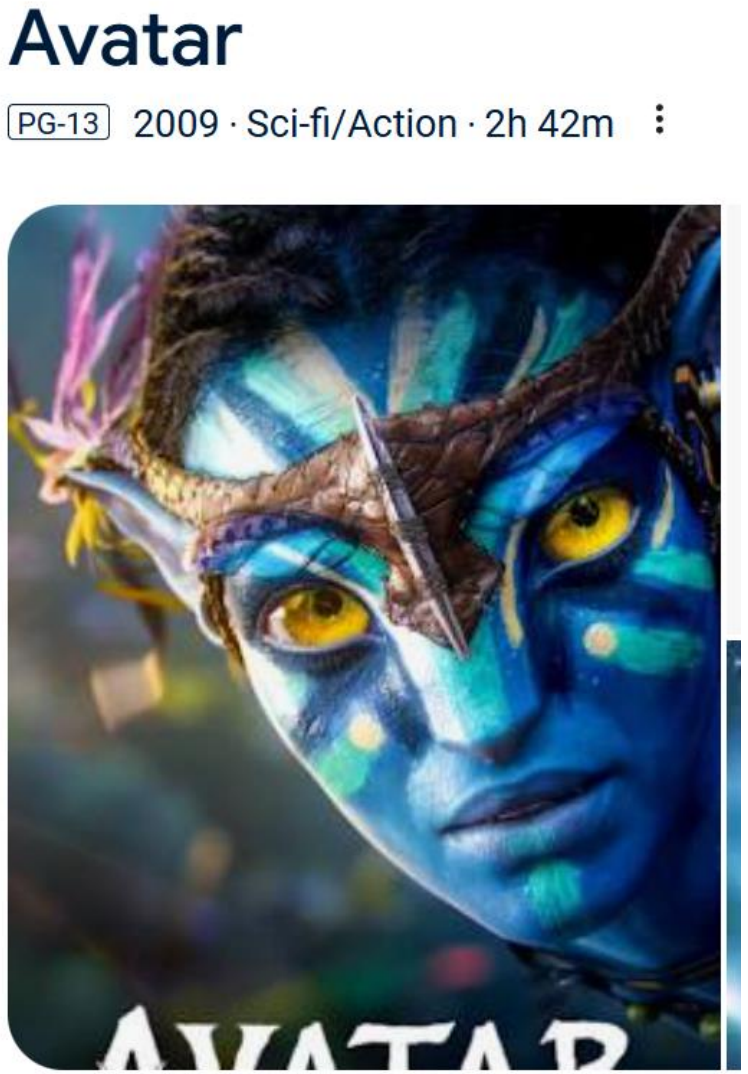
- **<u>Challenge:</u>** long videos and thus large video size
  - Downloading the whole video before playing



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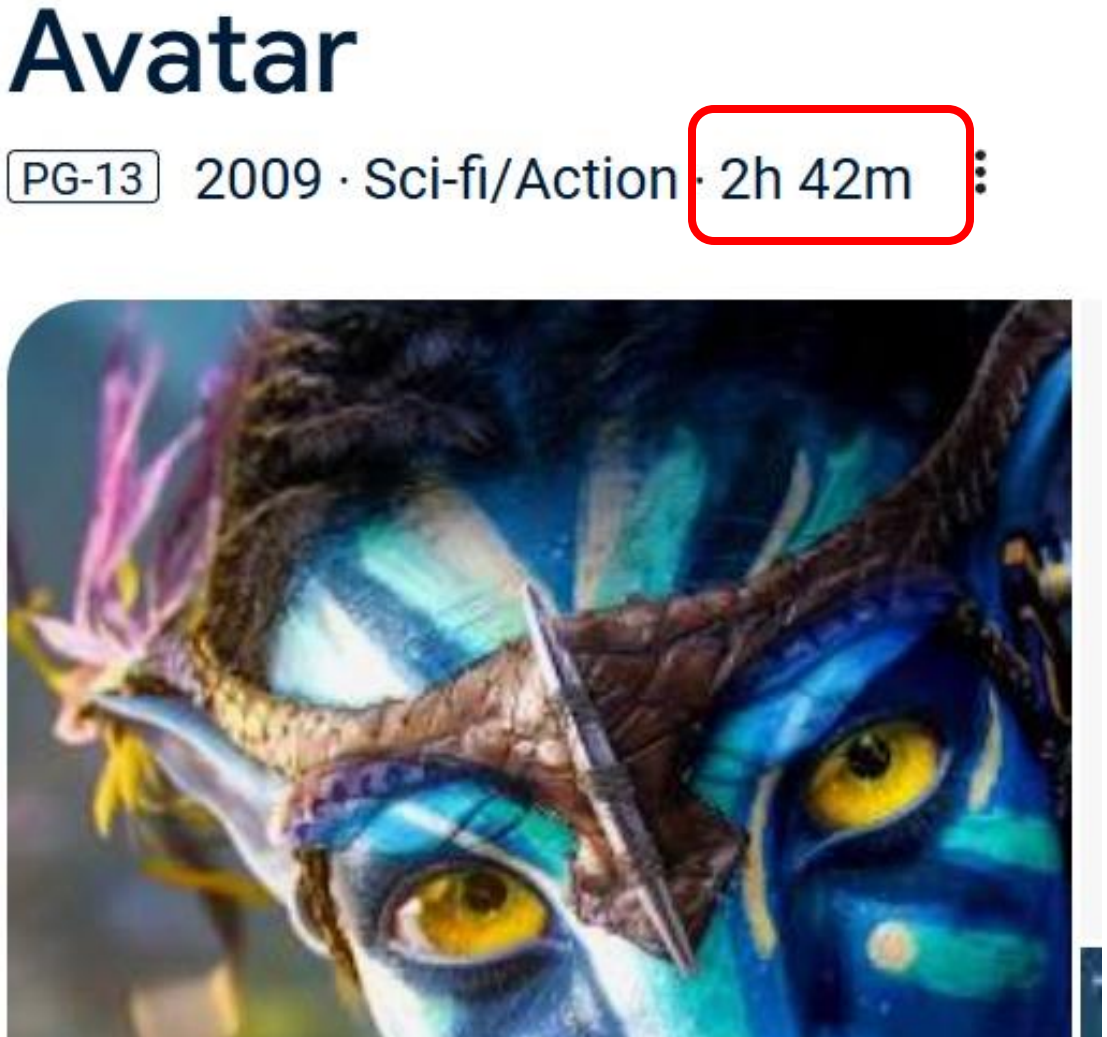
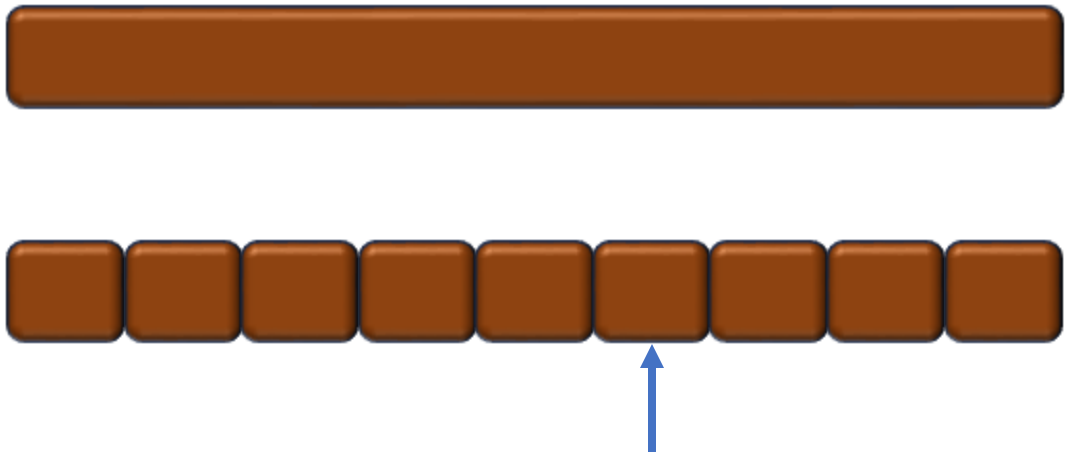


Video Streaming Applications

- **Challenge:** long videos and thus large video size
  - Downloading the whole video before playing
- **Solution:** divide the video into chunks
  - We can start to play the video after downloading a video chunk



Video Streaming Applications

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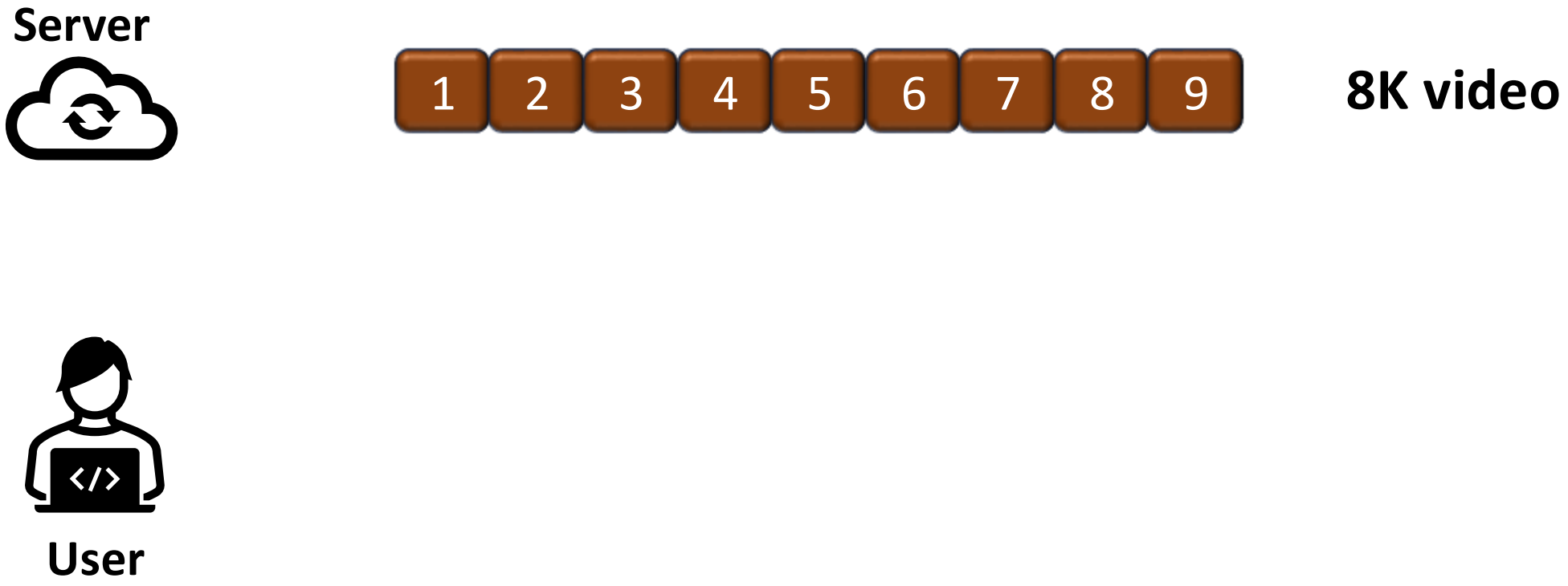

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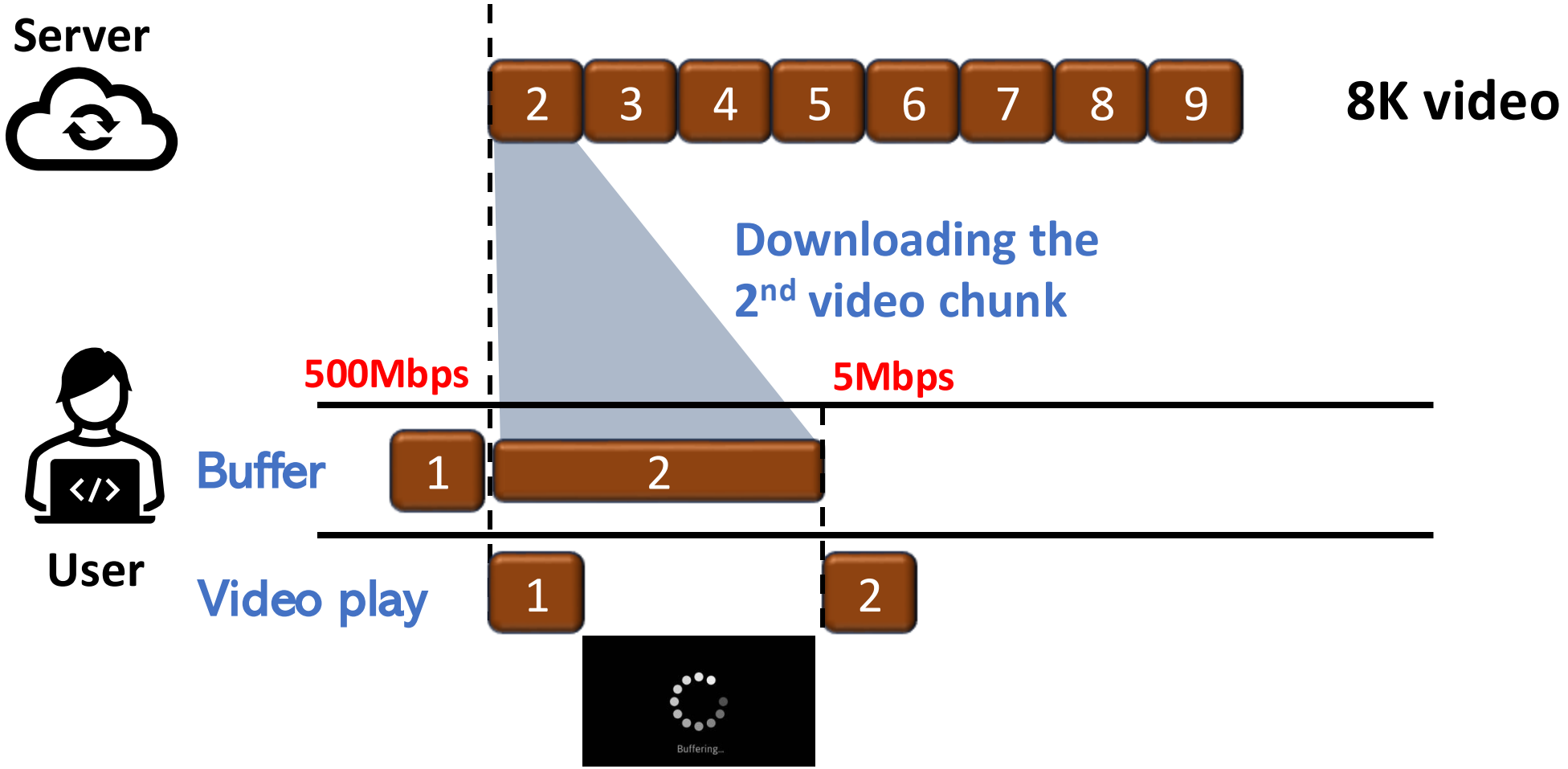

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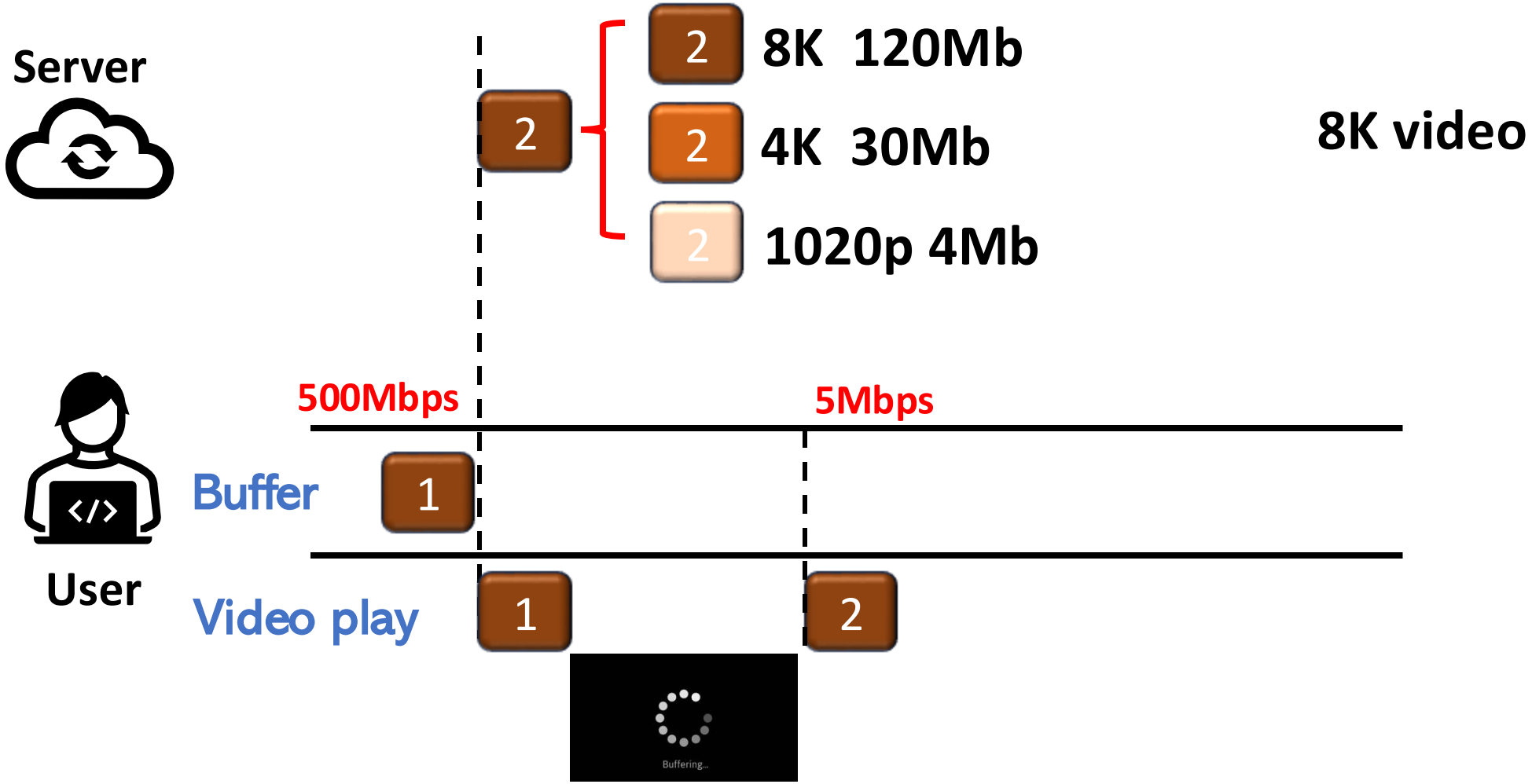

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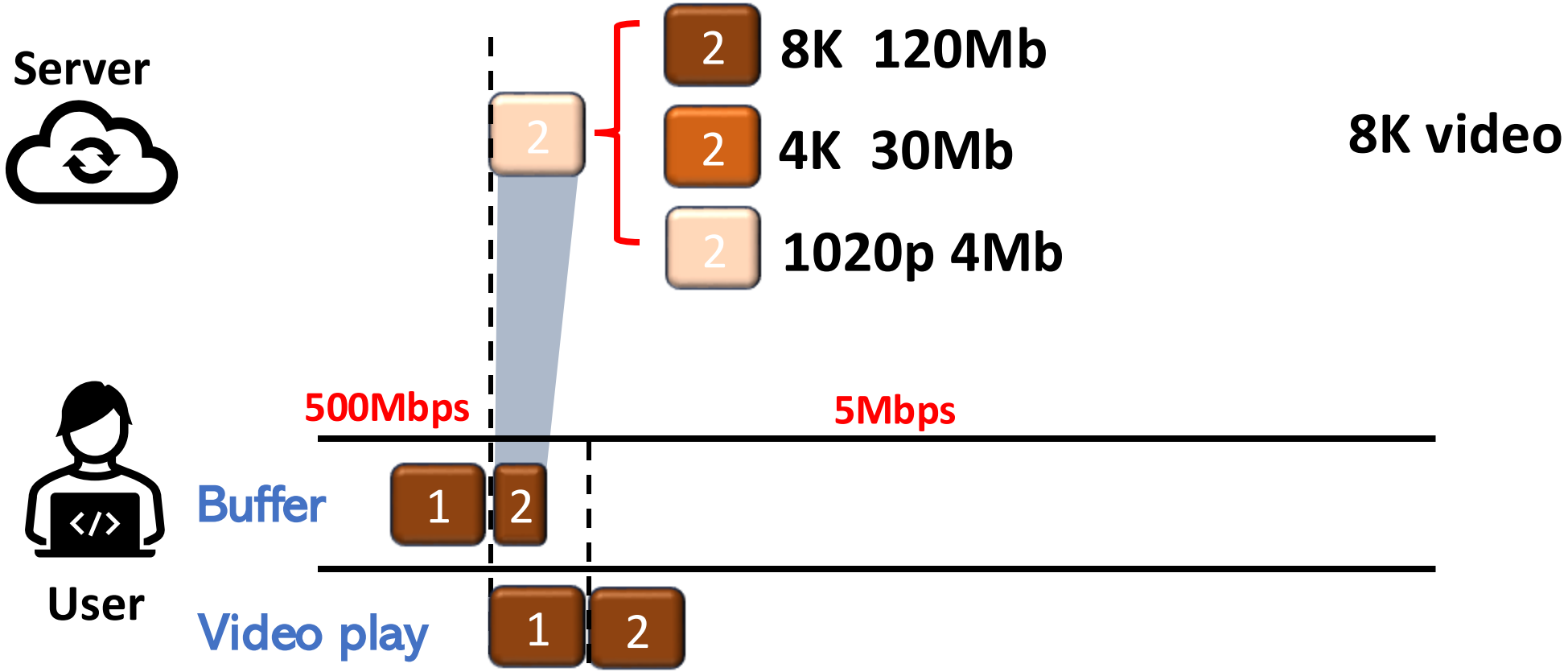
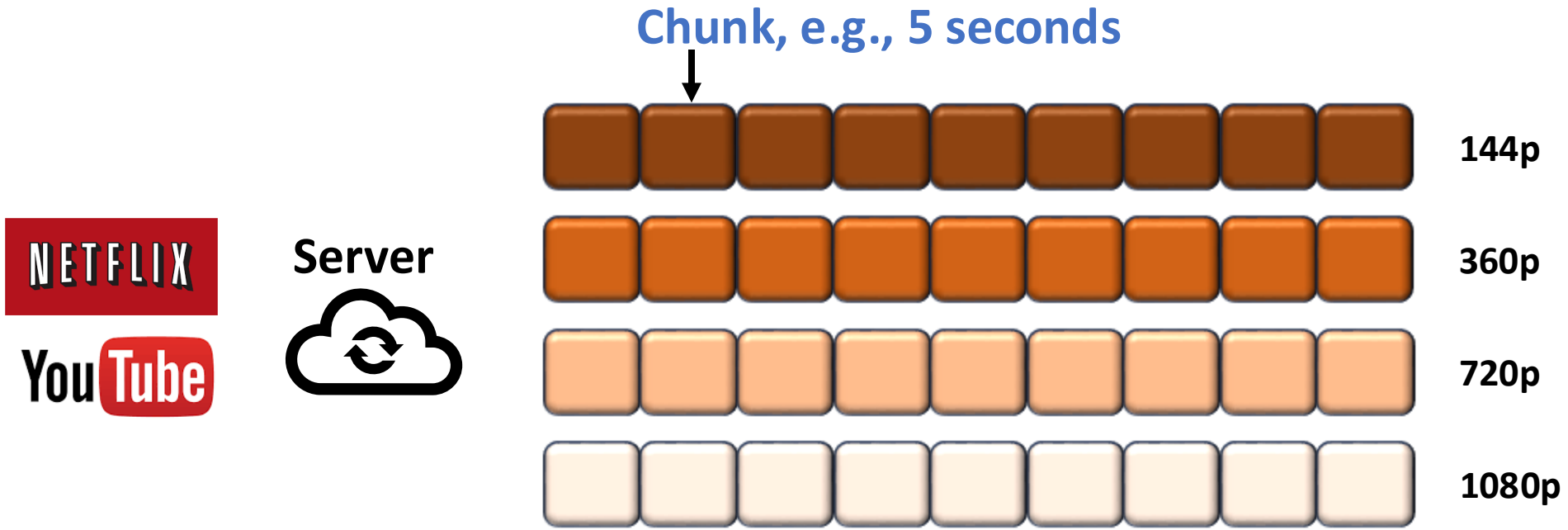


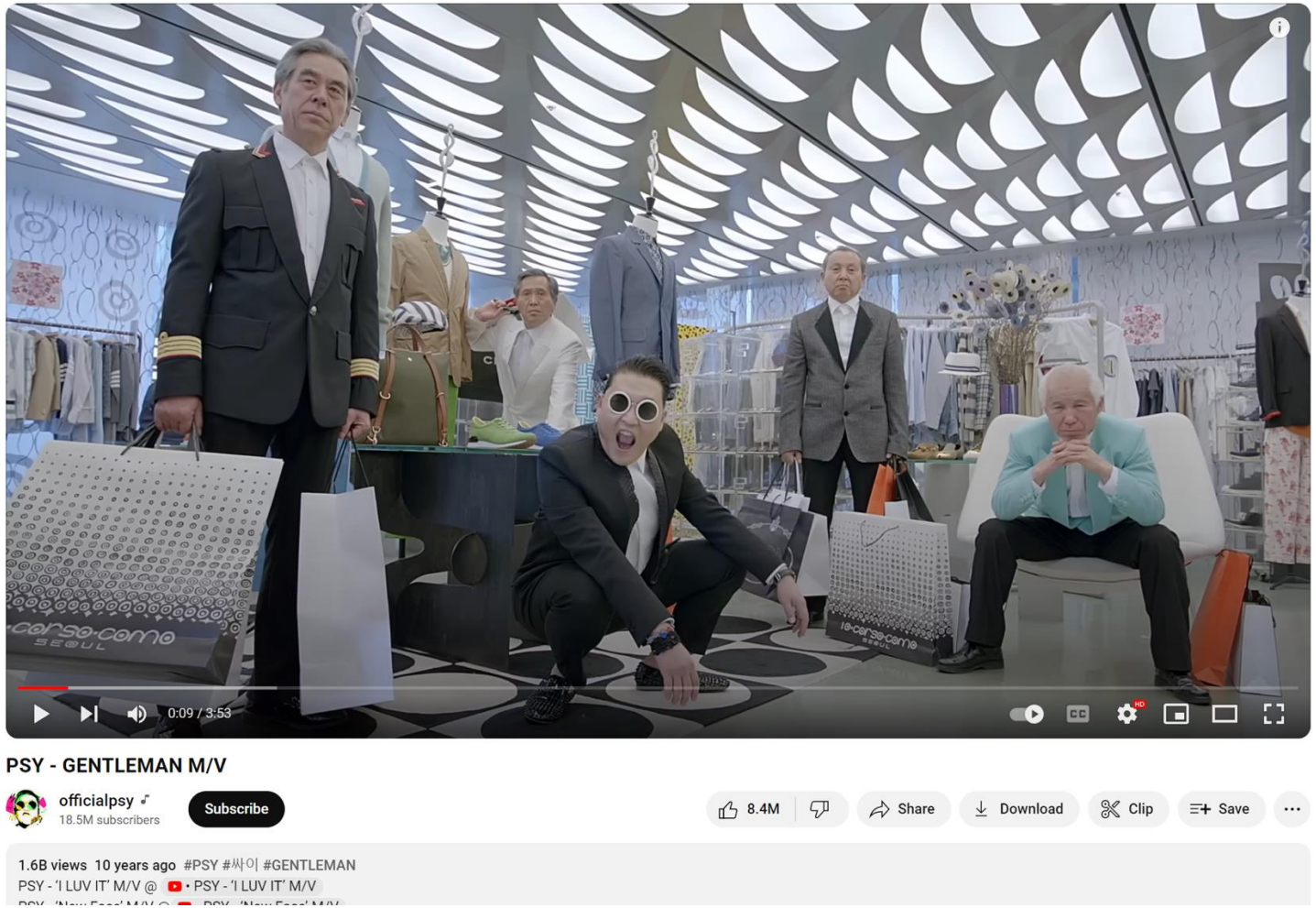
Video Streaming Applications

- **Challenge:** video quality and channel capacity
- **Solution:** multiple encoded video copies



Streaming multimedia: DASH

*D*ynamic, *A*daptive
*S*treaming over *H*TTP



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PSY - GENTLEMAN M/V

officialpsy
18.5M subscribers
Subscribe
8.4M
Share
Download
Clip
Save

Streaming multimedia: DASH

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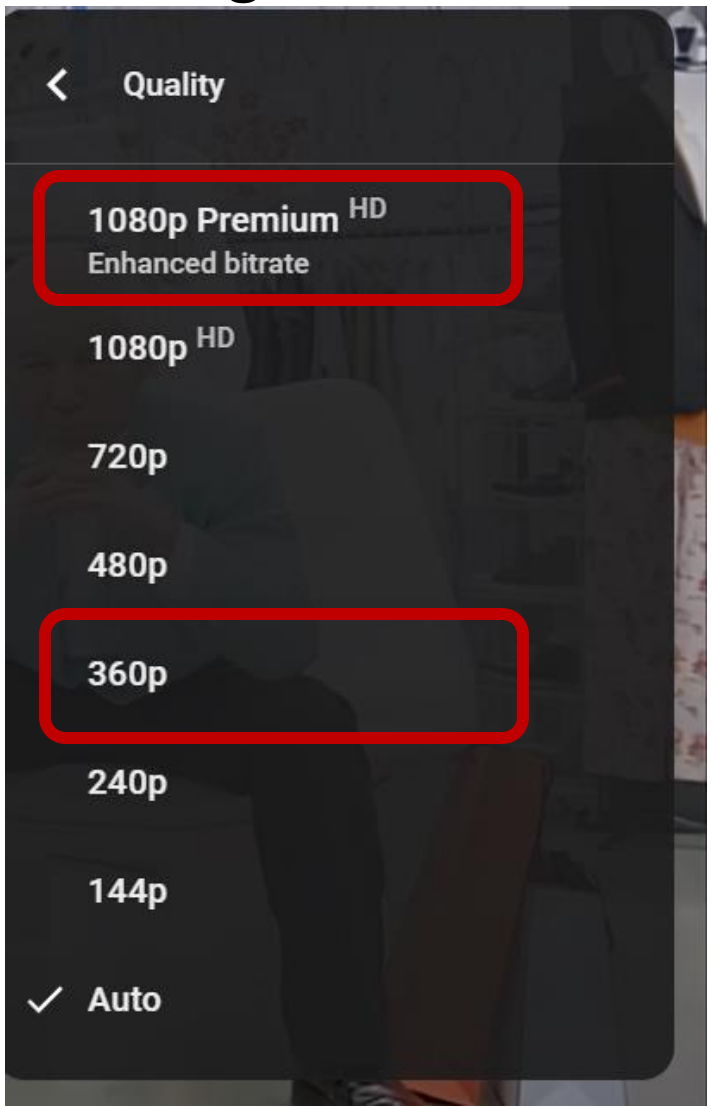
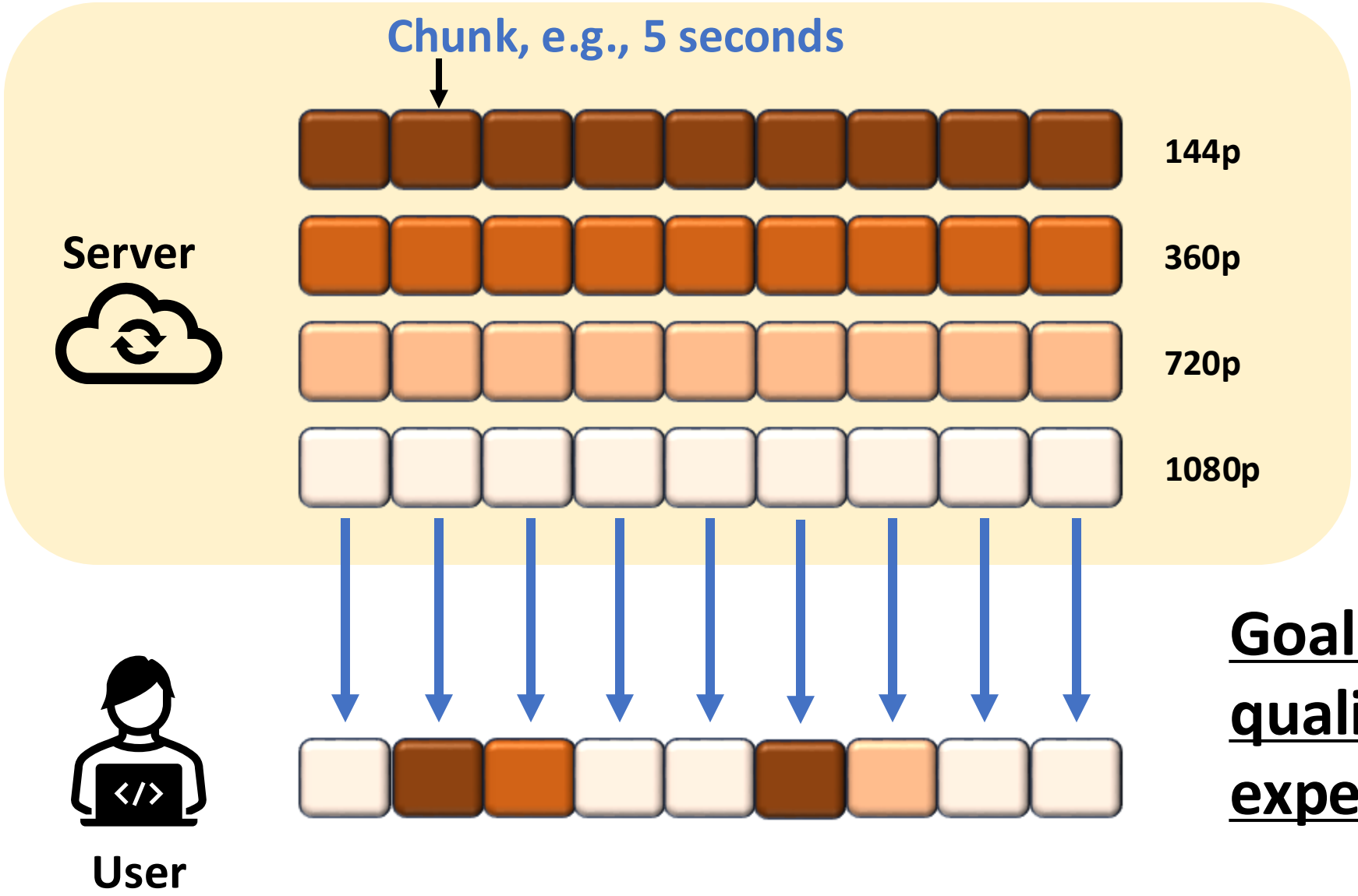


Video Streaming: adaptive video bitrate（ABR）



Goal: Maximize quality of user experience (QoE)

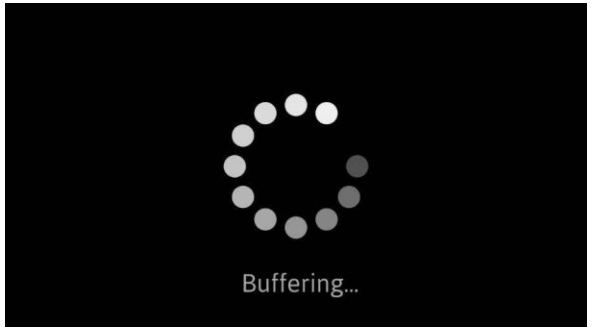
Video Streaming Applications: QoE (Quality of User Experience)

Video Start Time

The time between your click of the video and the playing of the video

Video Quality

Rebuffering Event



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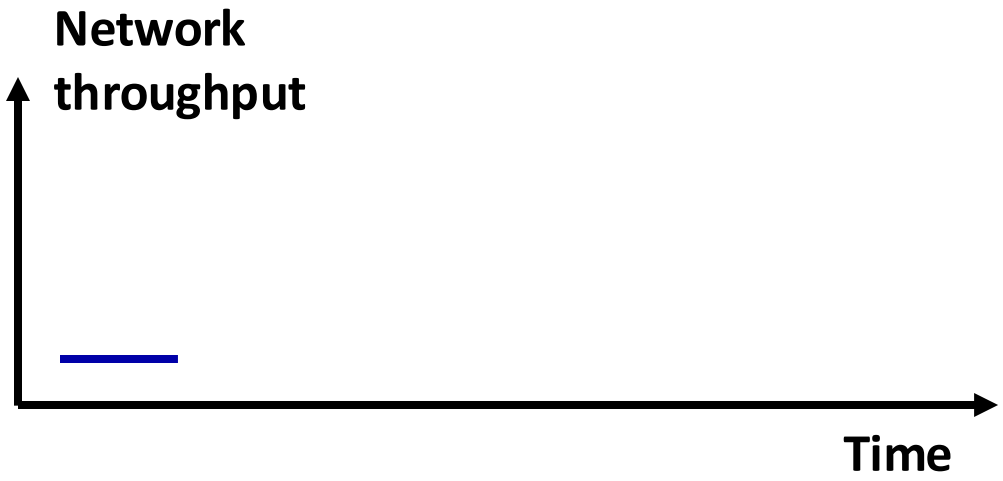

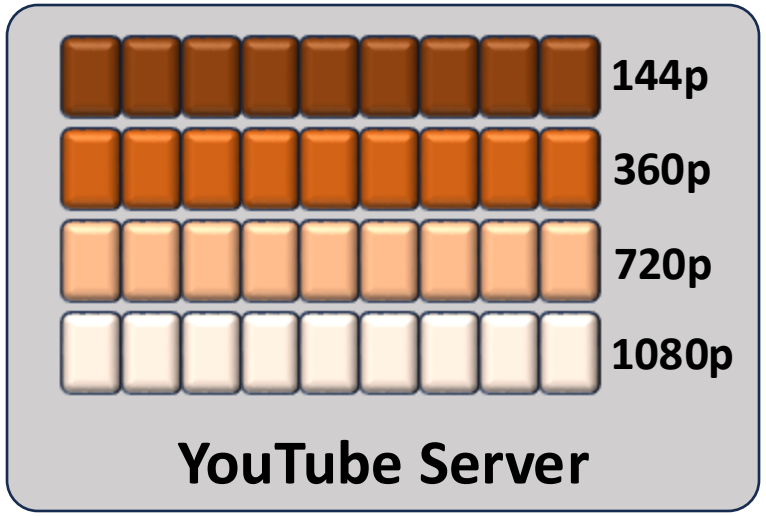

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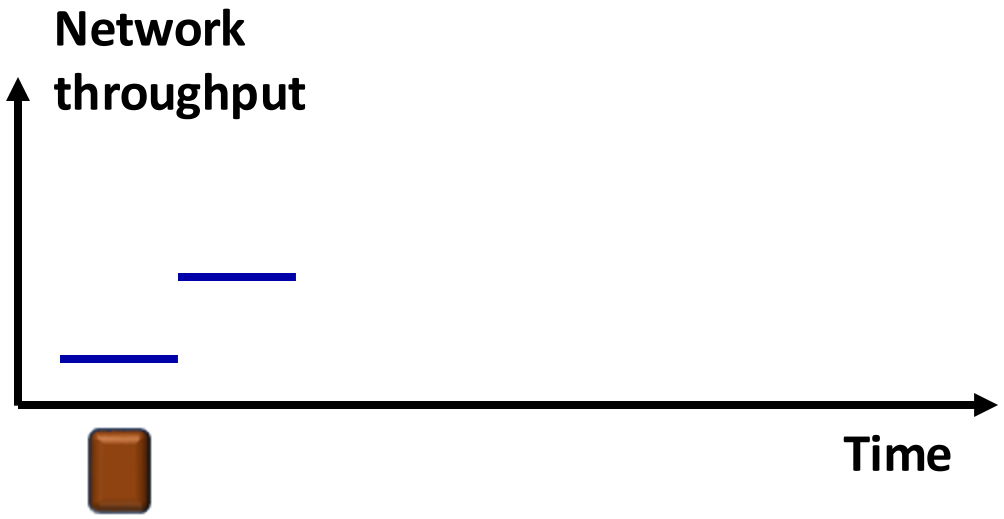

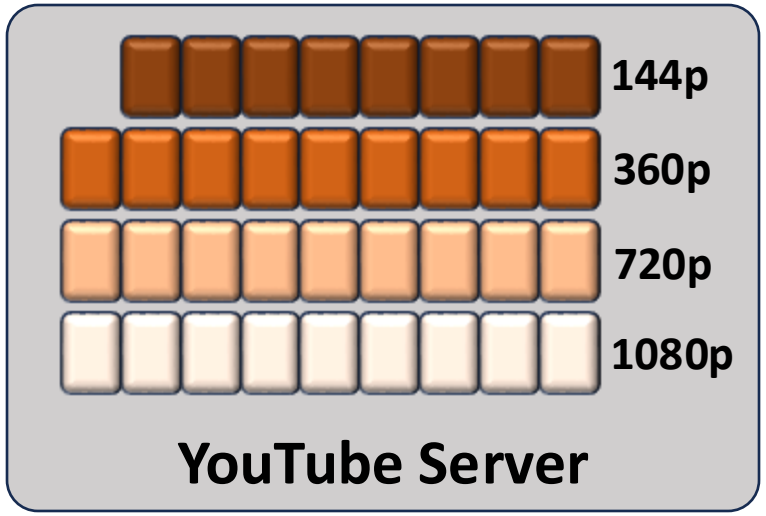

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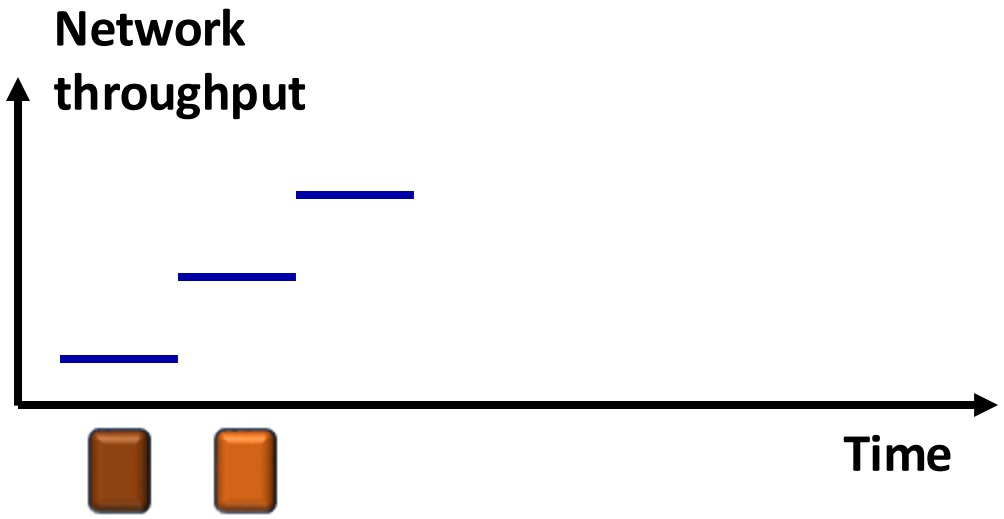

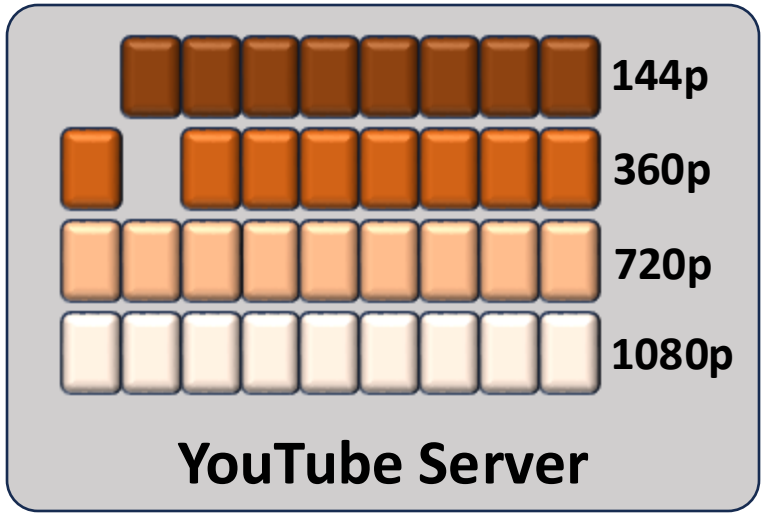

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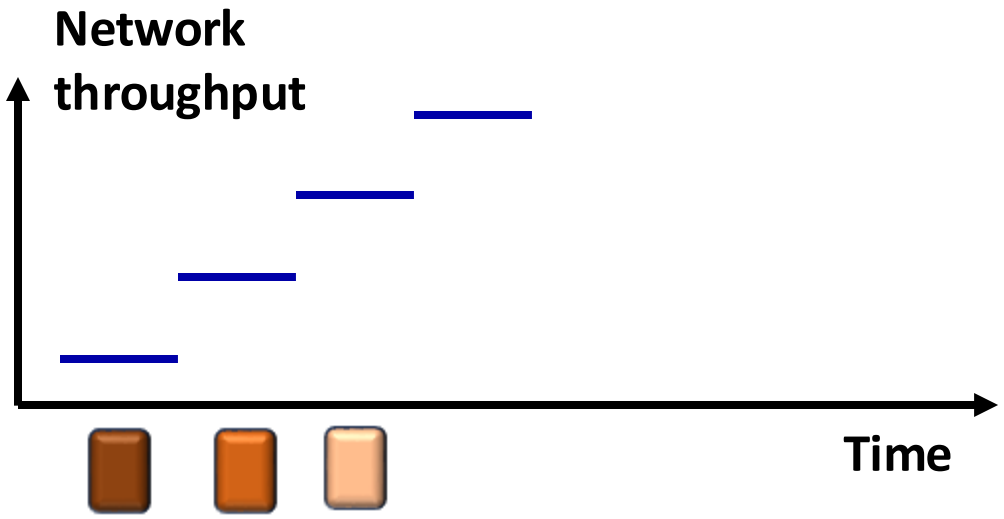

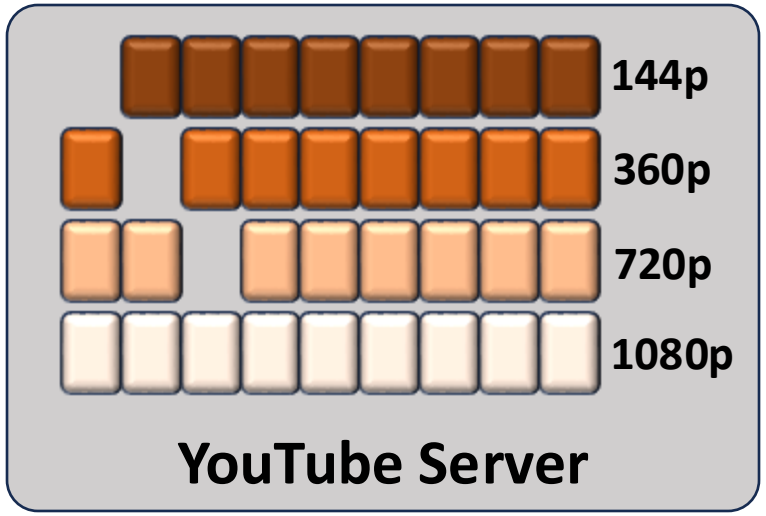

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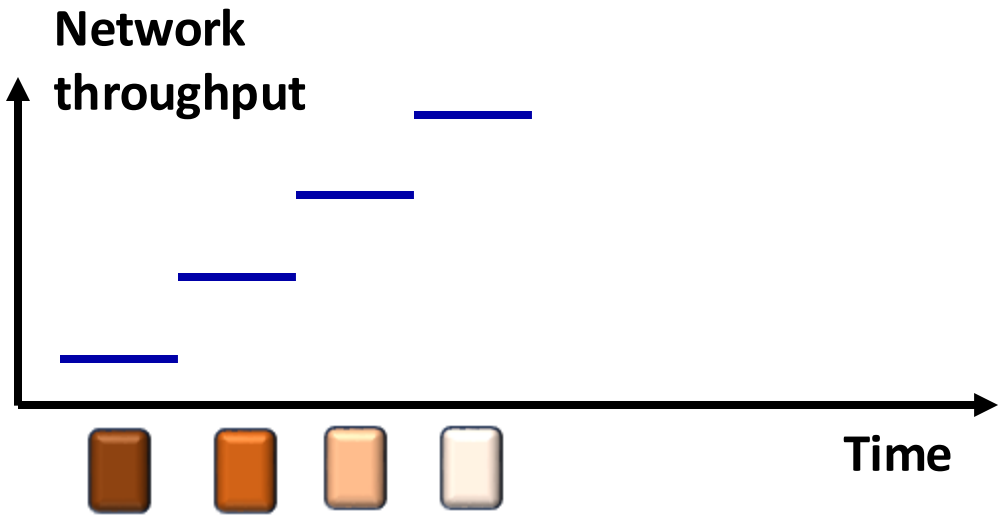

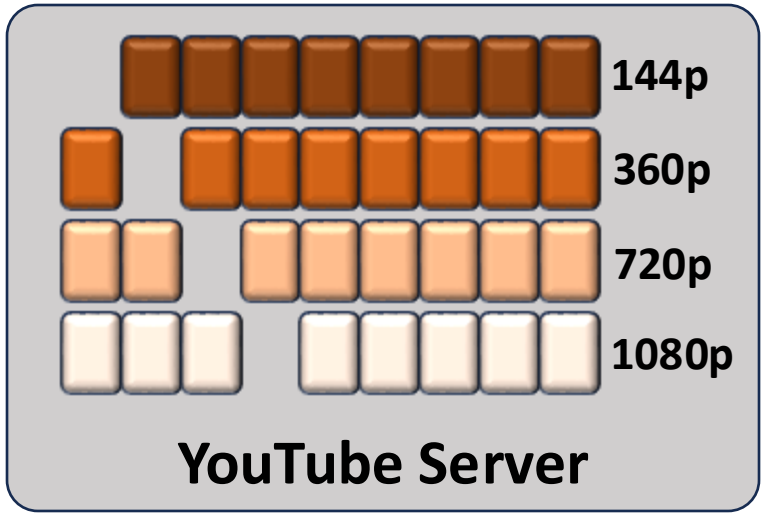

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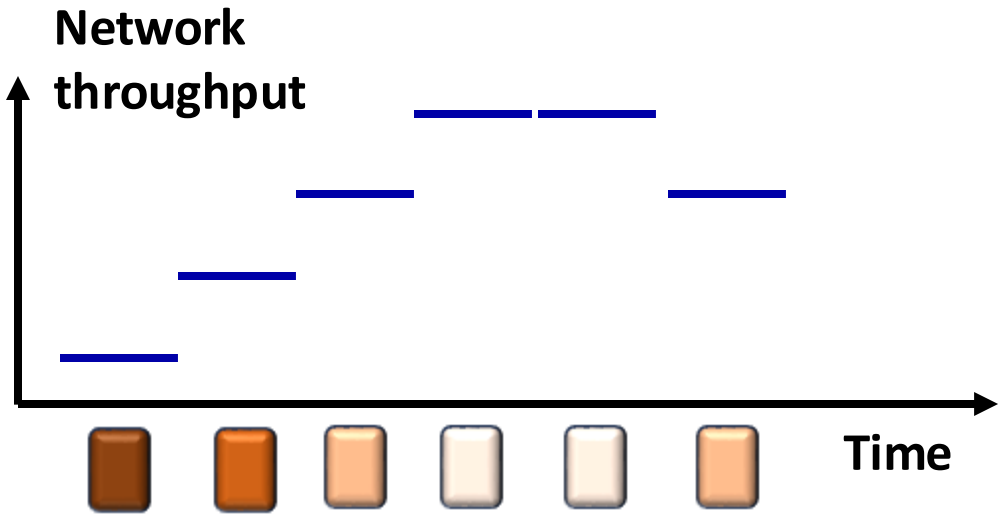

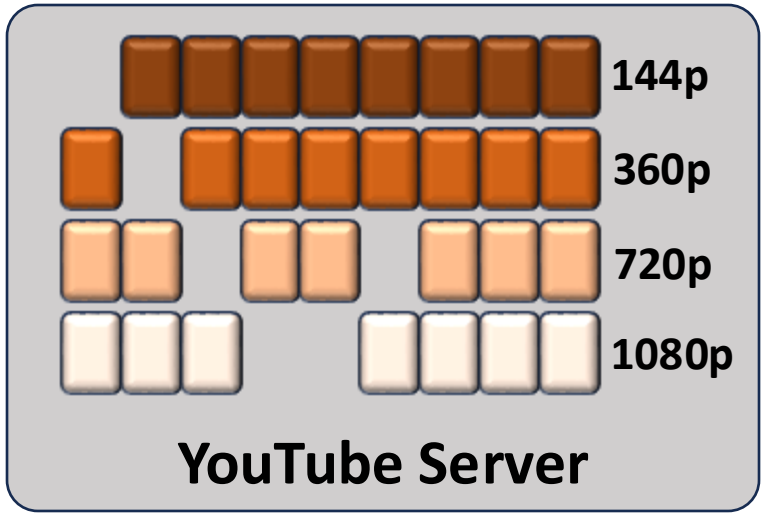

Video Streaming Applications: short video

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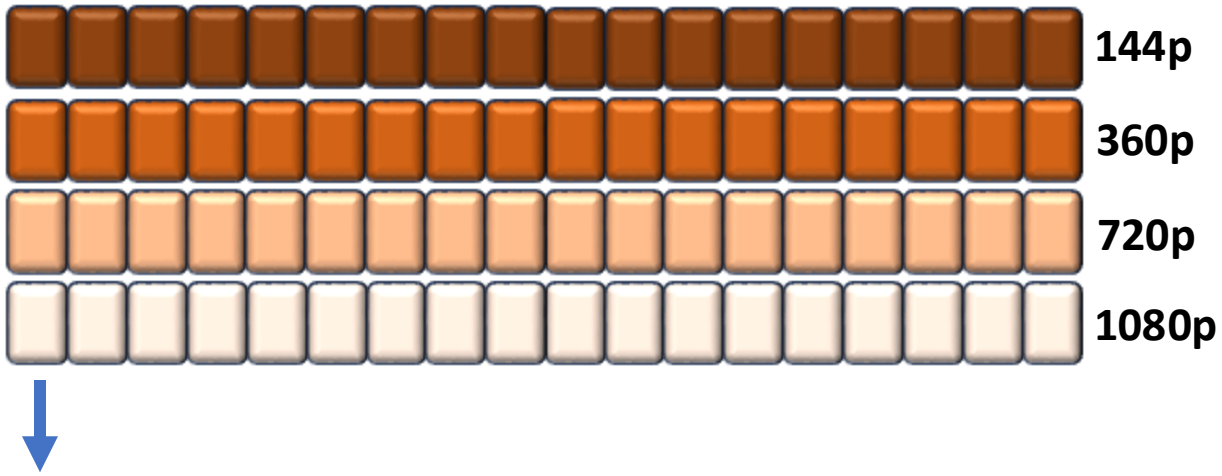

- **Long video:** always downloading the next video chunk
  - The only problem is to determine the quality of each video chunk

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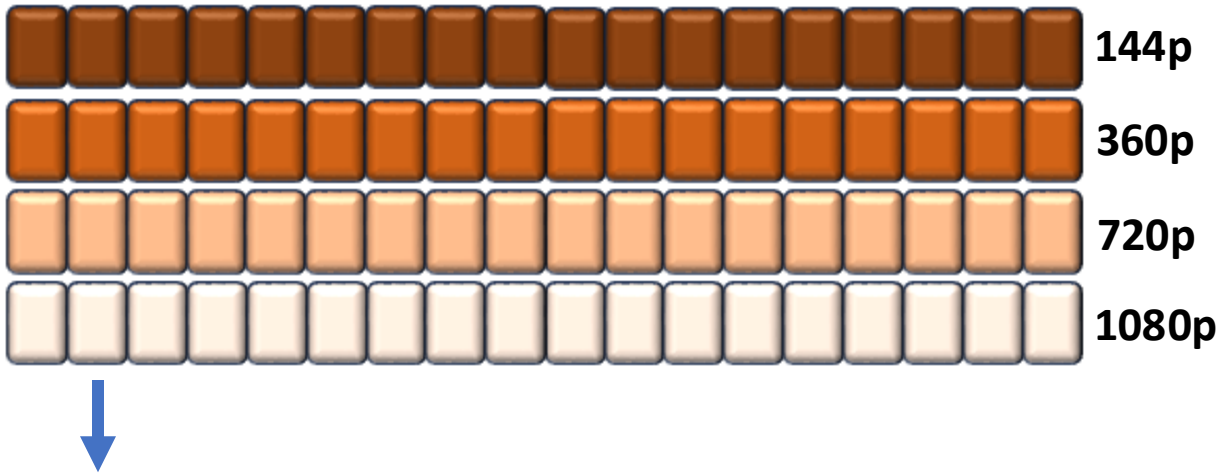

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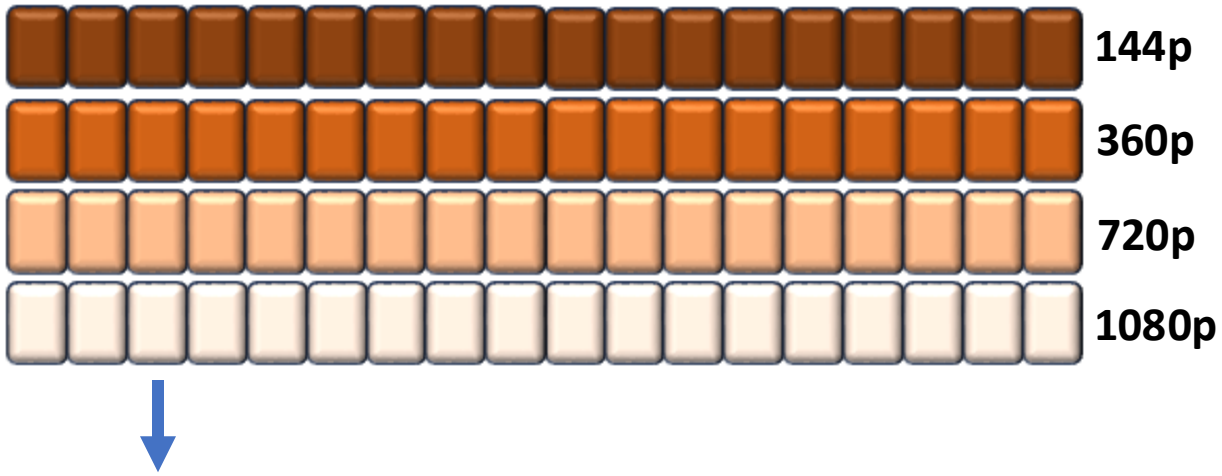

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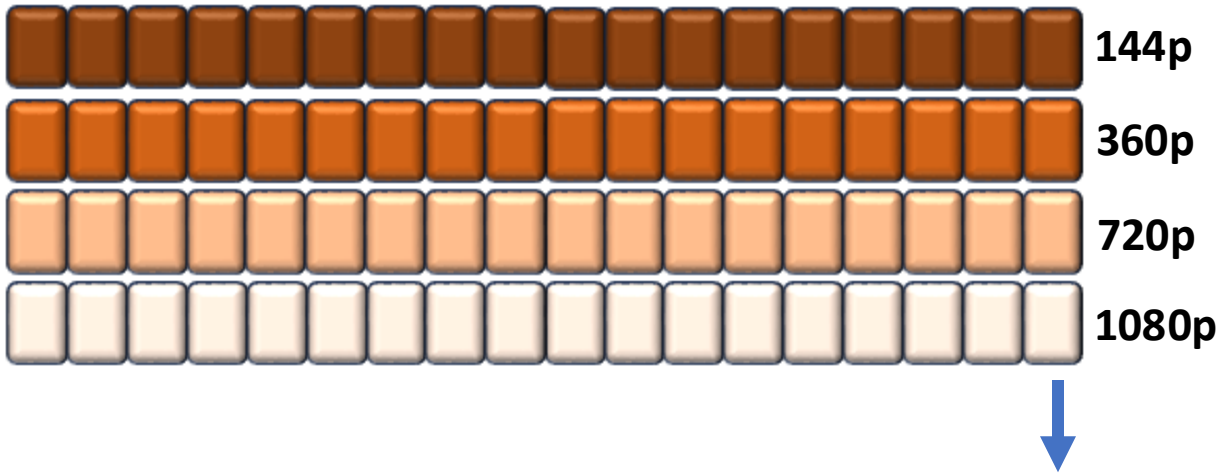

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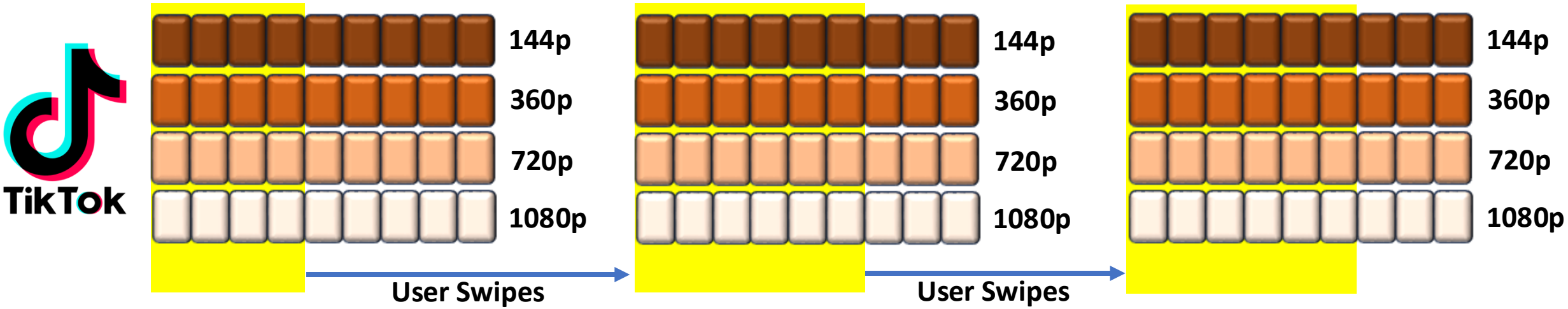

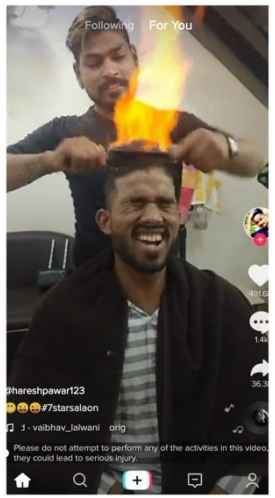

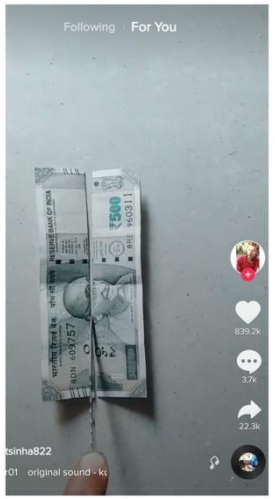

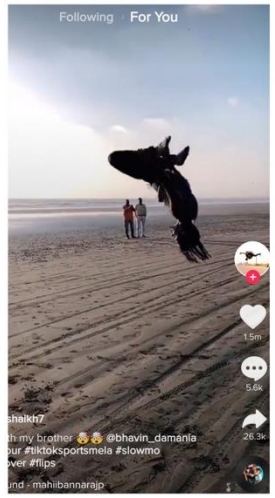

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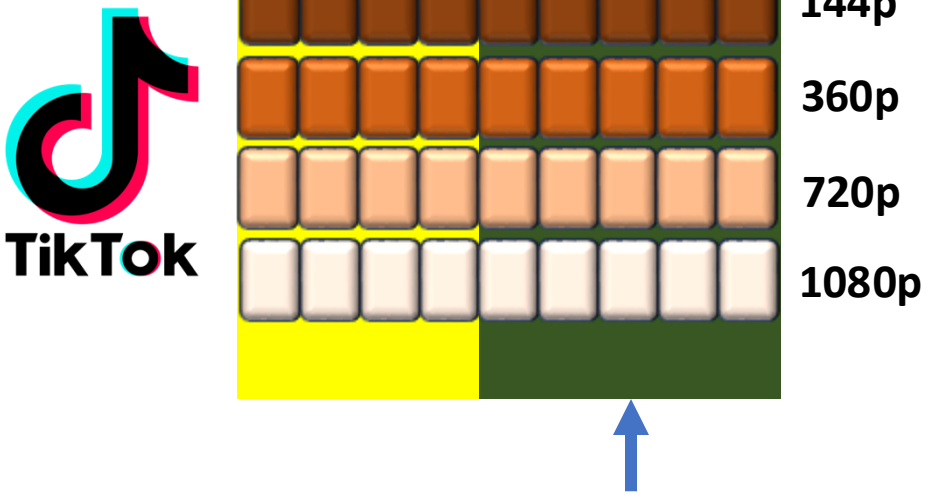
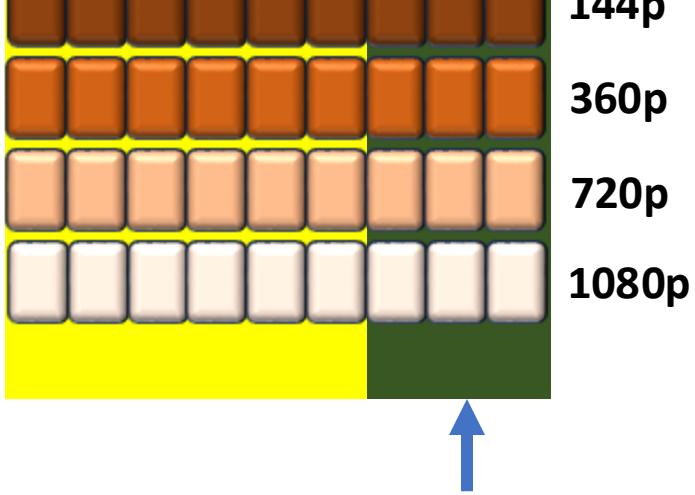
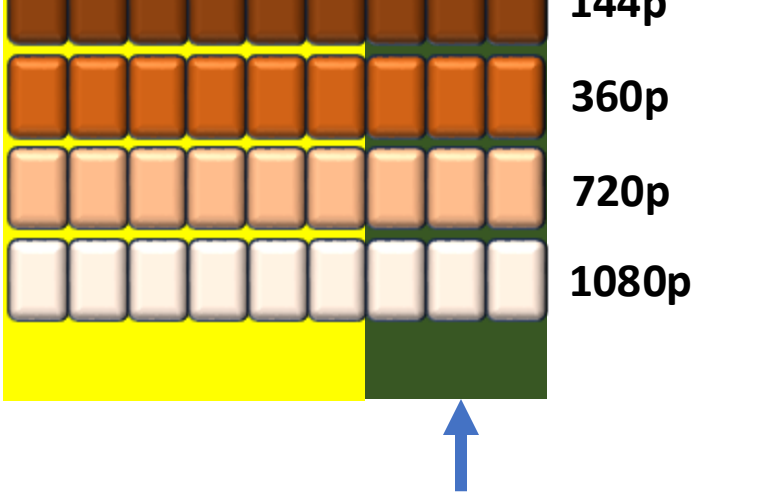
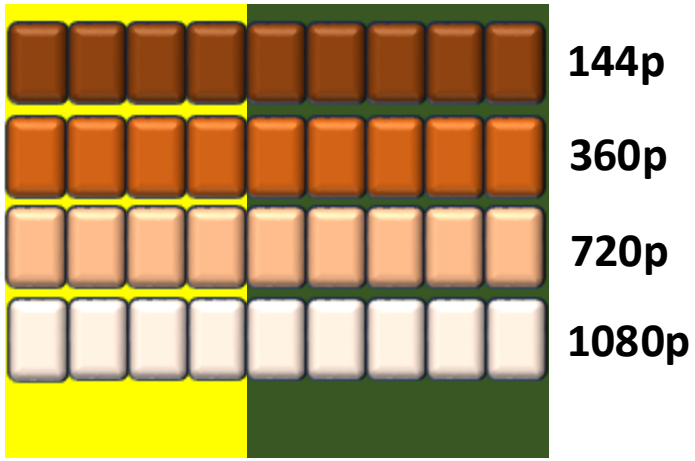


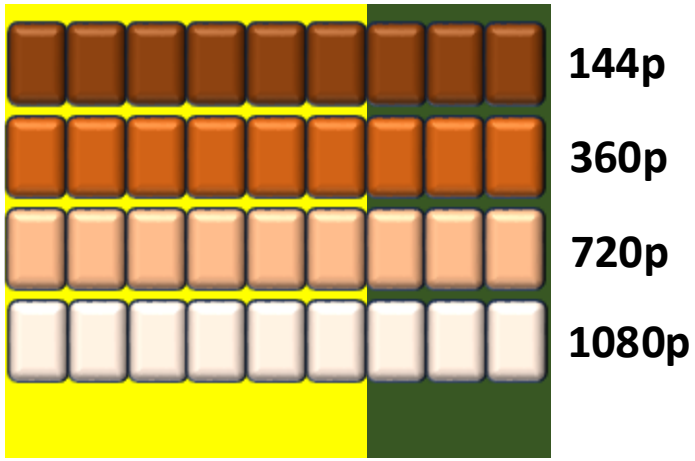


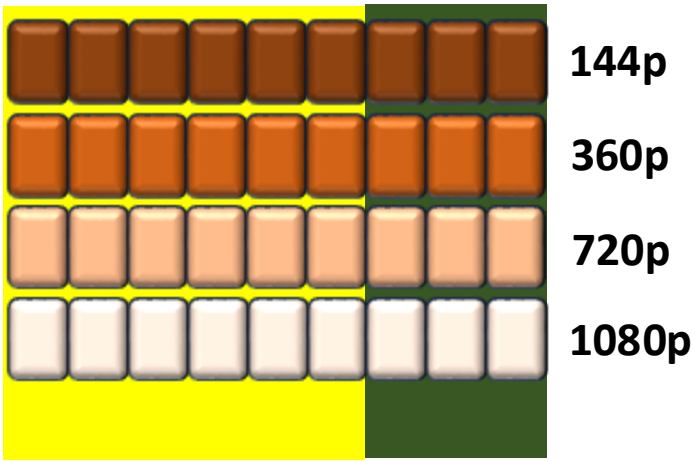


Video Streaming Applications: short video

TikTok







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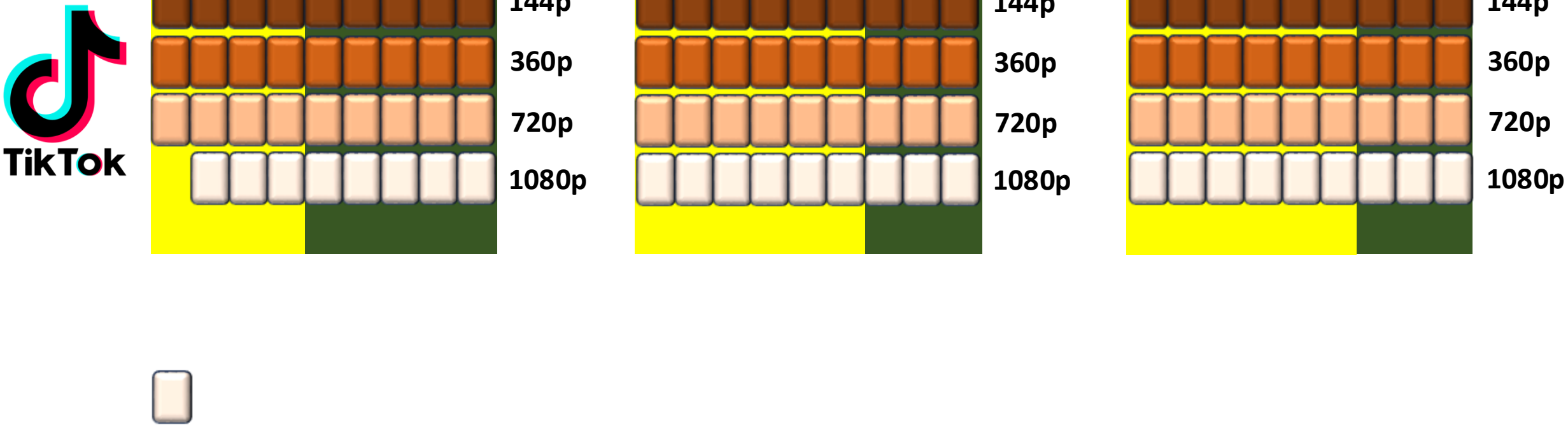

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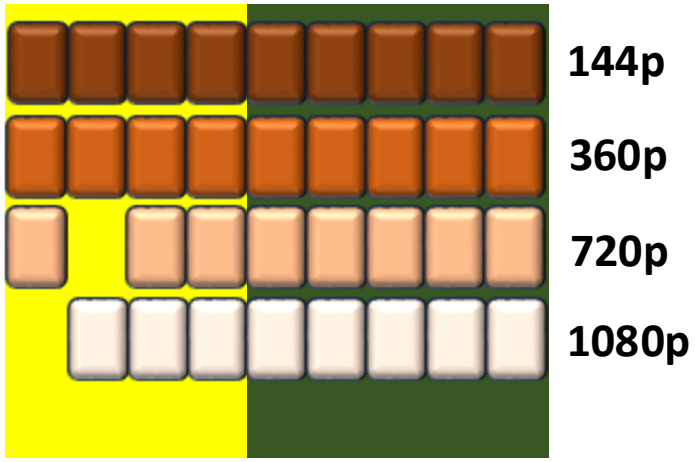

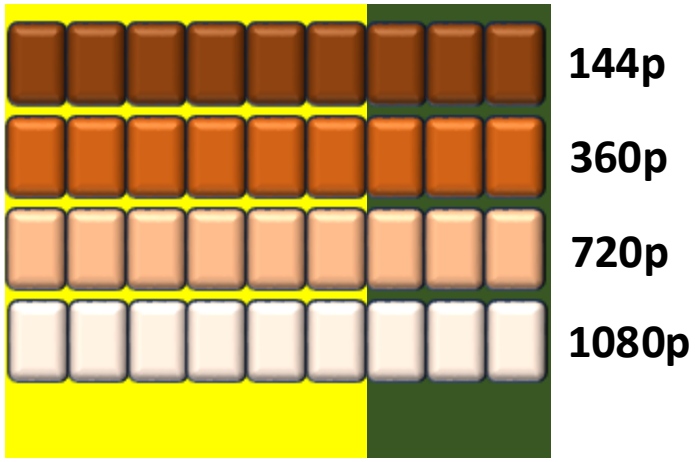

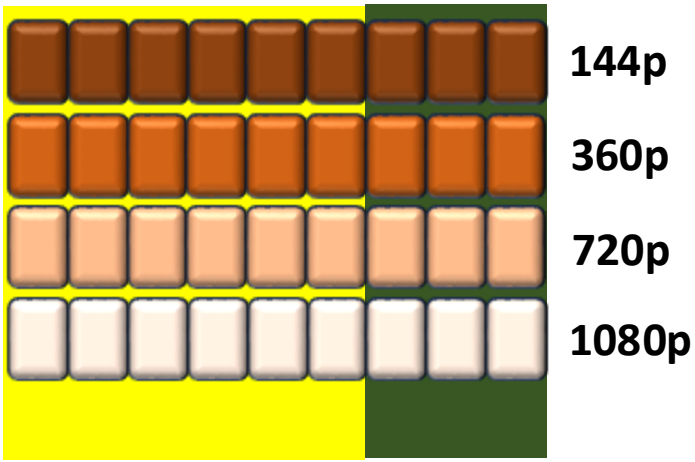

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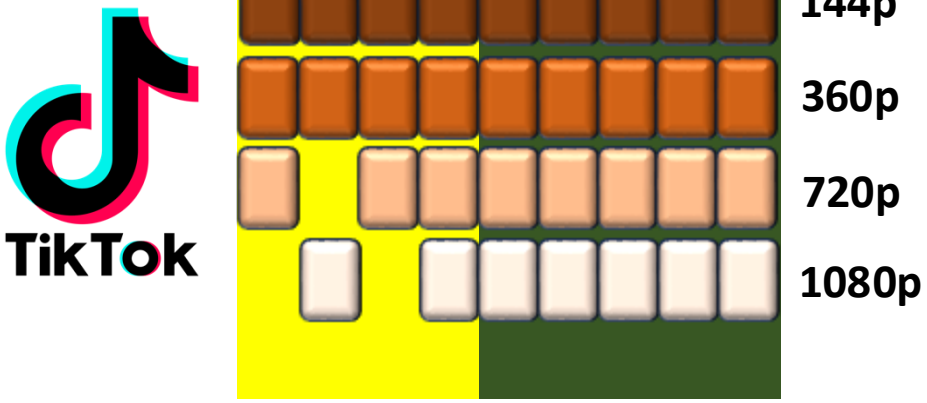
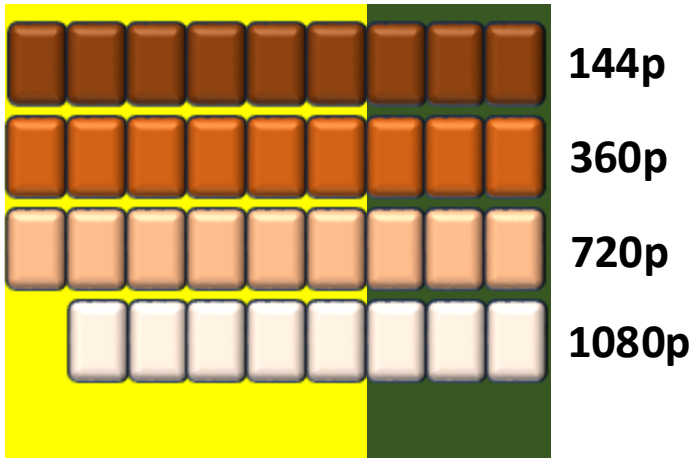
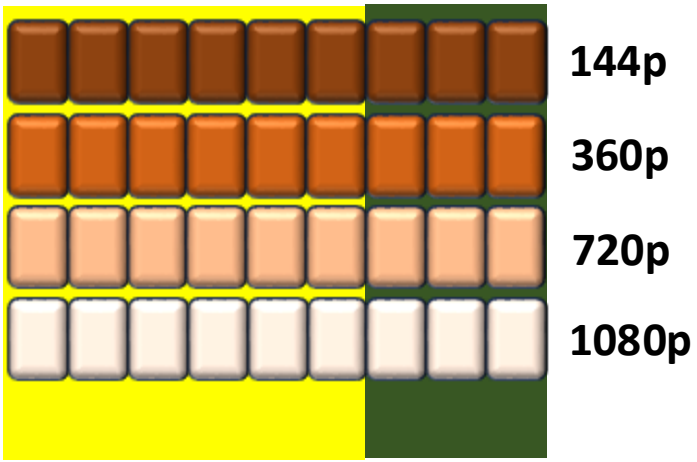
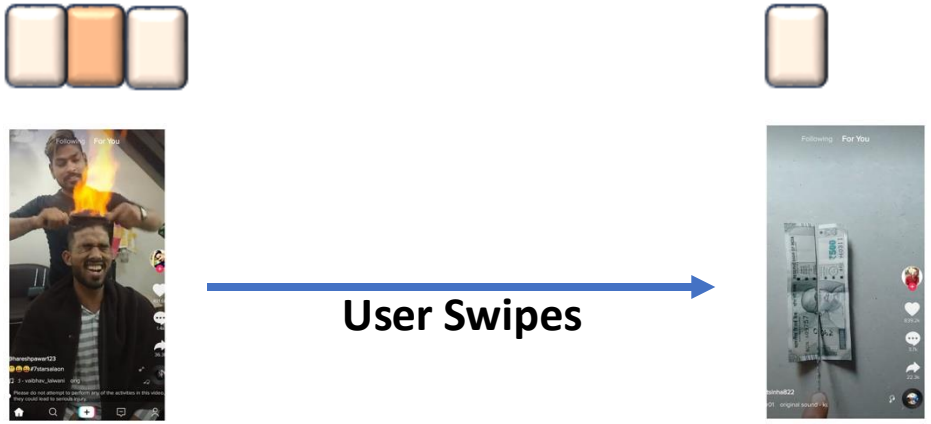


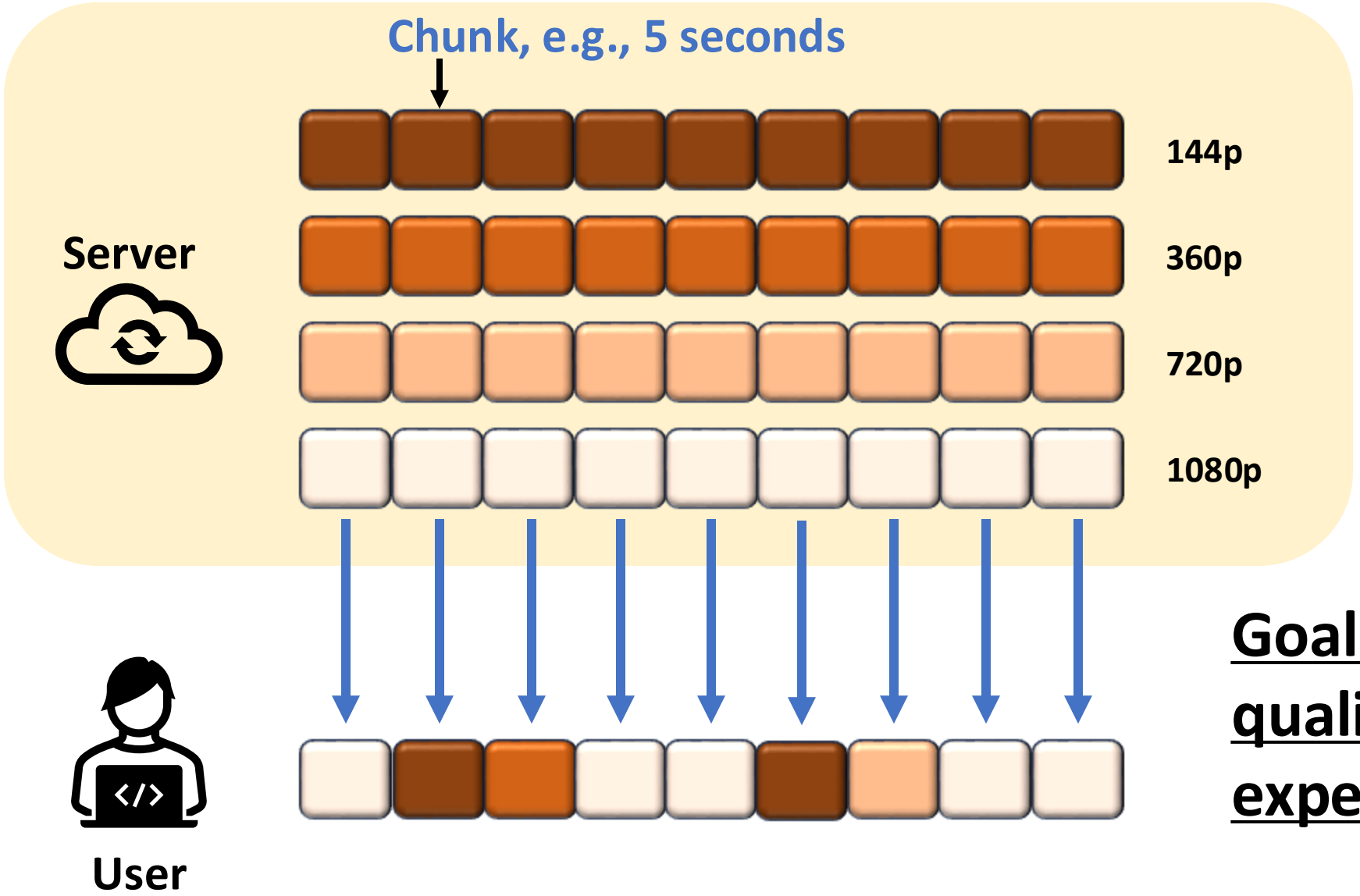






We can immediately play the second video when the user swipes

Video Streaming: adaptive video bitrate（ABR）



Goal: Maximize quality of user experience (QoE)

Where should we host the videos

- stream video traffic: major consumer of Internet bandwidth
  - Netflix, YouTube, Amazon Prime: 80% of residential ISP traffic (2020)

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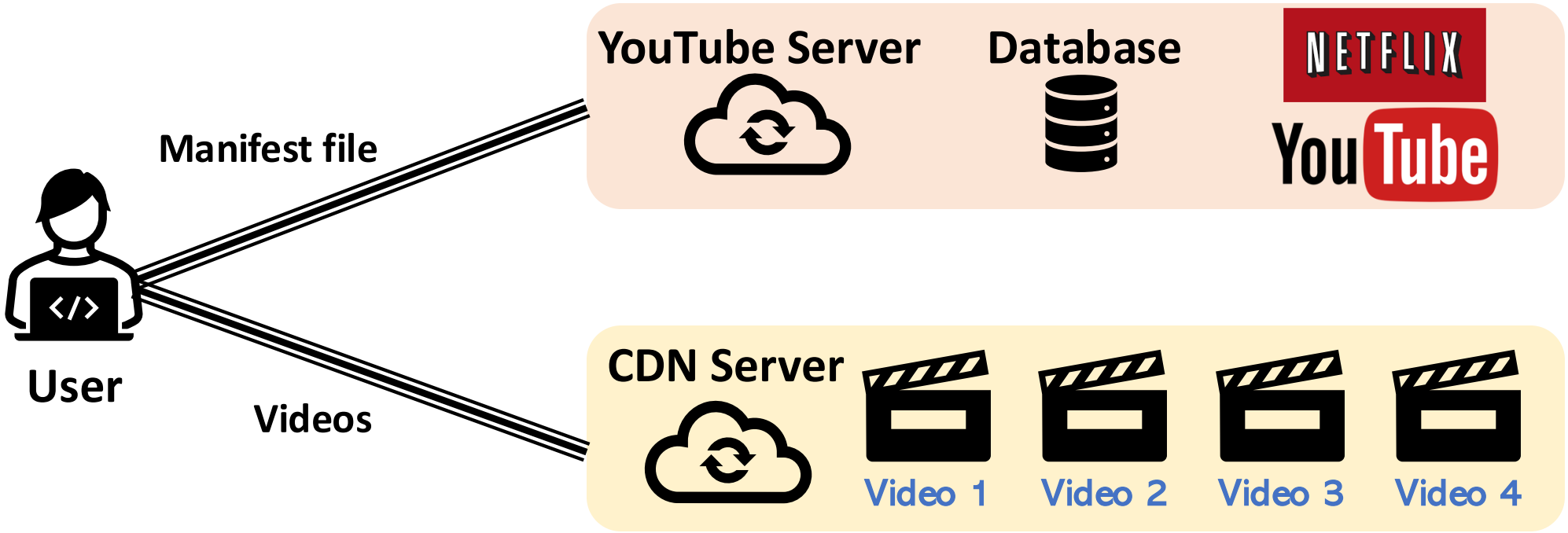


Content distribution networks (CDNs)

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*

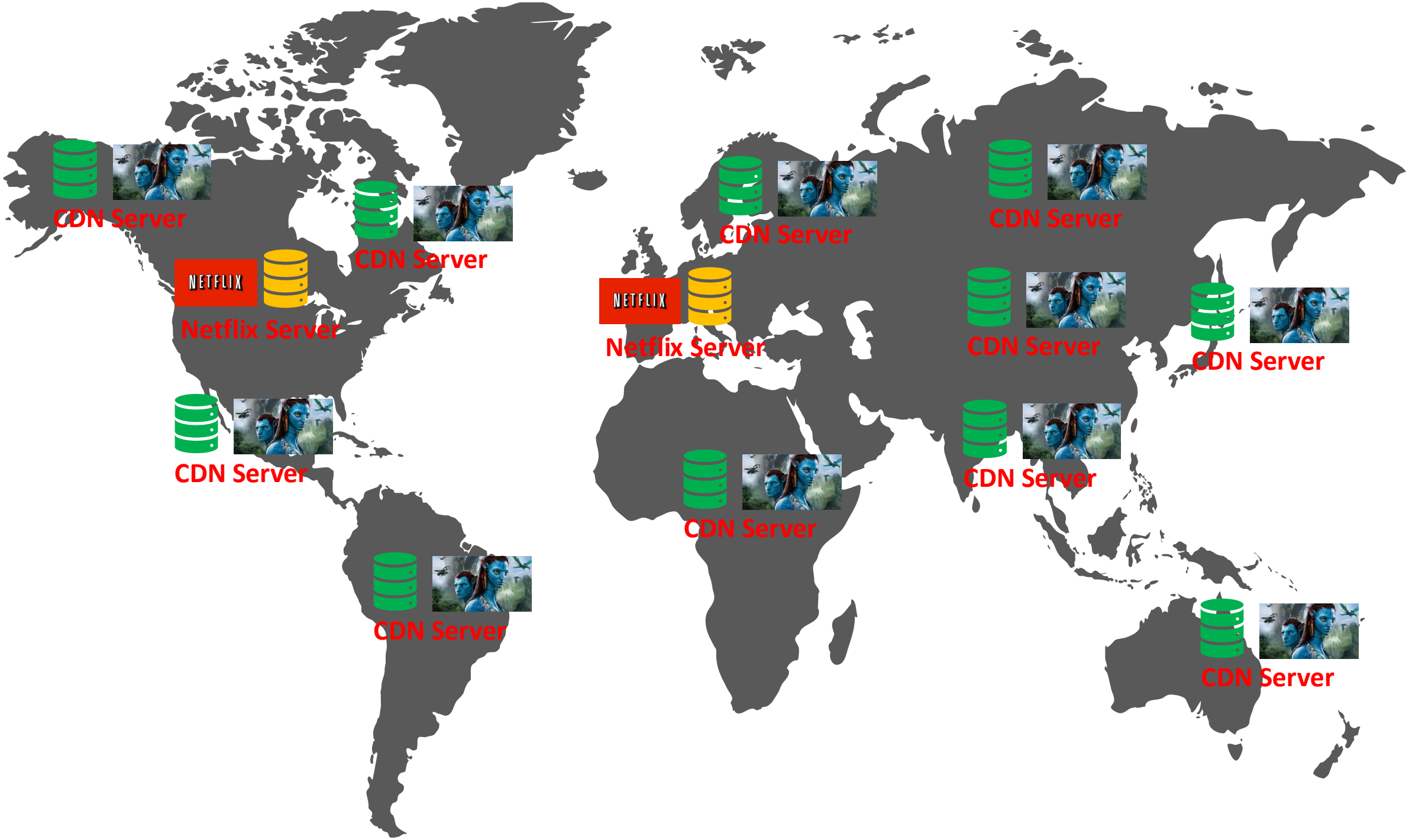
Content distribution networks (CDNs)

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)*

Content distribution networks (CDNs)

- Definition: A **Content Delivery Network (CDN)** is a distributed network of servers that helps deliver content (web pages, videos, images, software) efficiently.
  - Reduces latency by caching content closer to users.
  - Improves website performance, reliability, and security.
- Key Benefits:
  - Faster content delivery
  - Reduced bandwidth costs
  - Load balancing & DDoS protection
  - Enhanced user experience


CDN Server
CDN Server
NETFLIX
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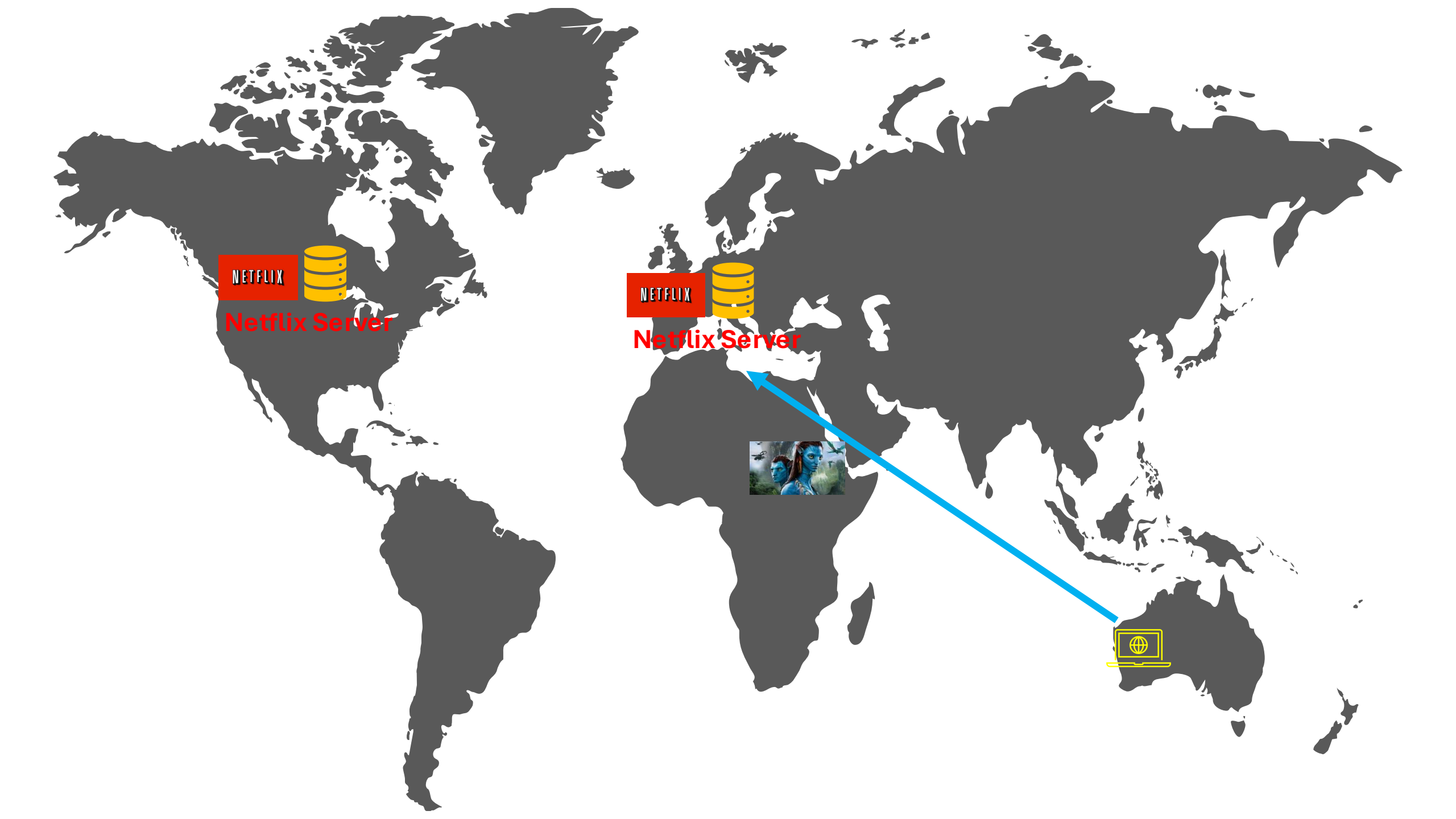
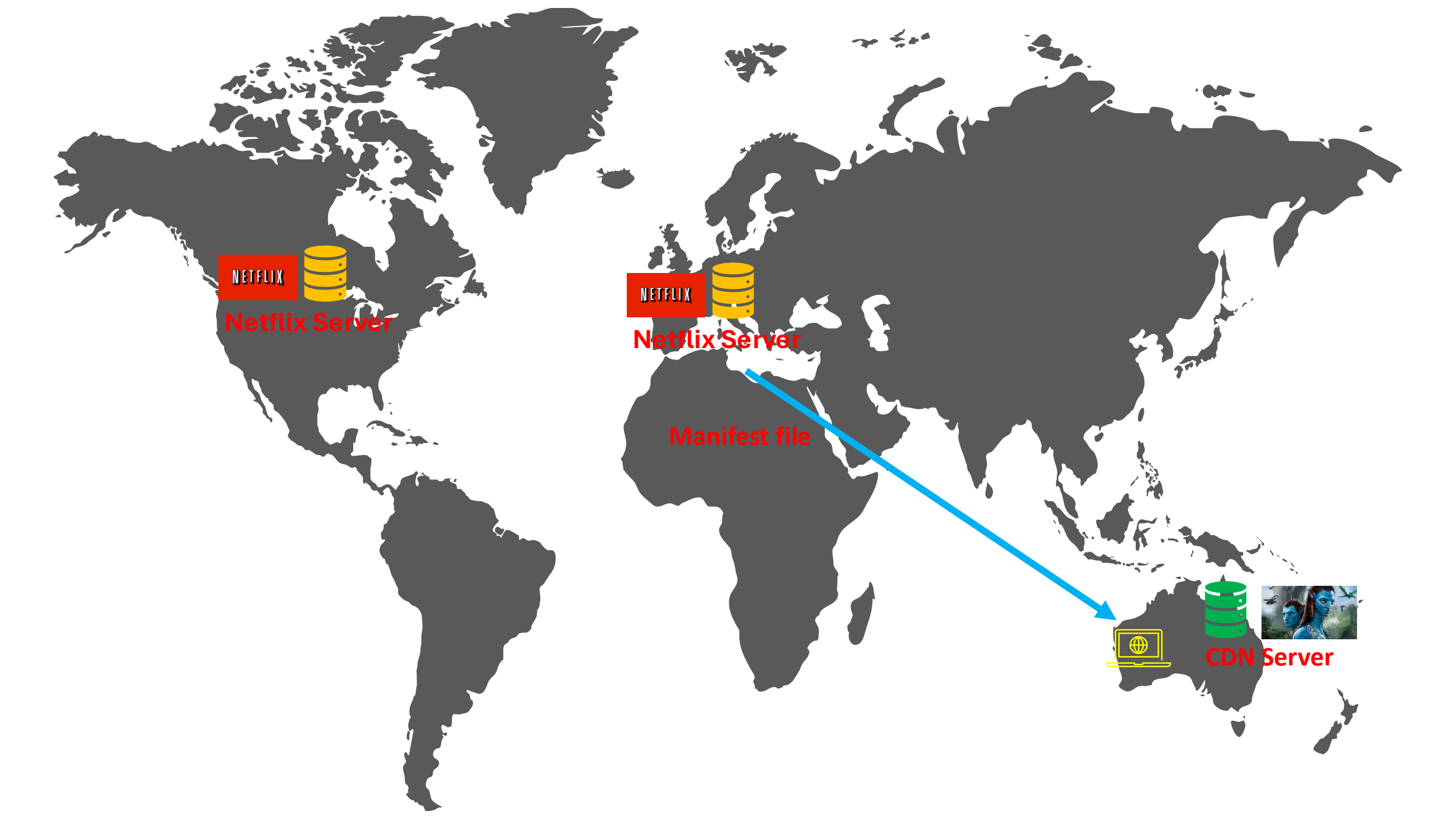
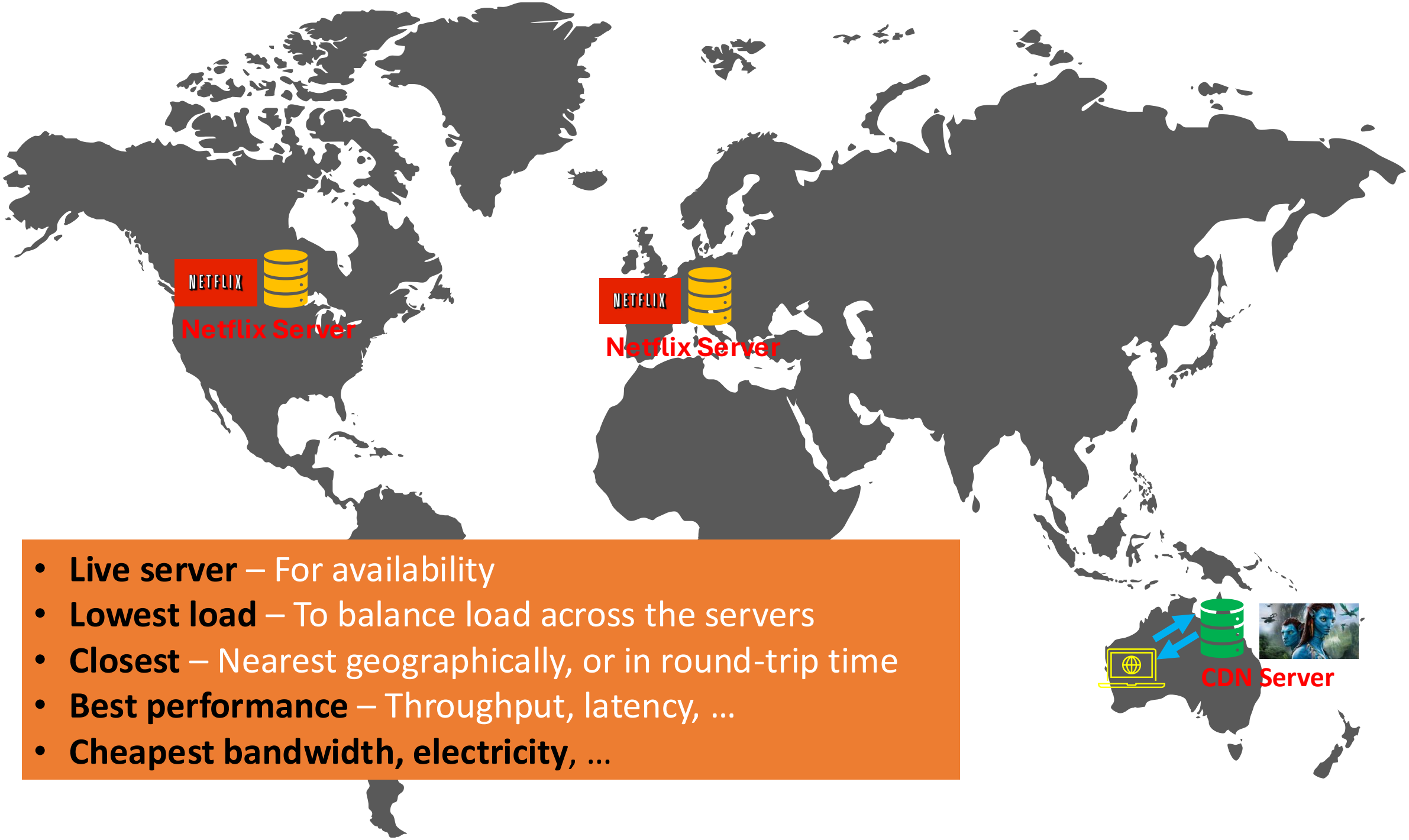
CDN Server
CDN Server


NETFLIX
Netflix Server
NETFLIX
Netflix Server


NETFLIX
Netflix Server
NETFLIX
Netflix Server
Manifest file
CDN Server

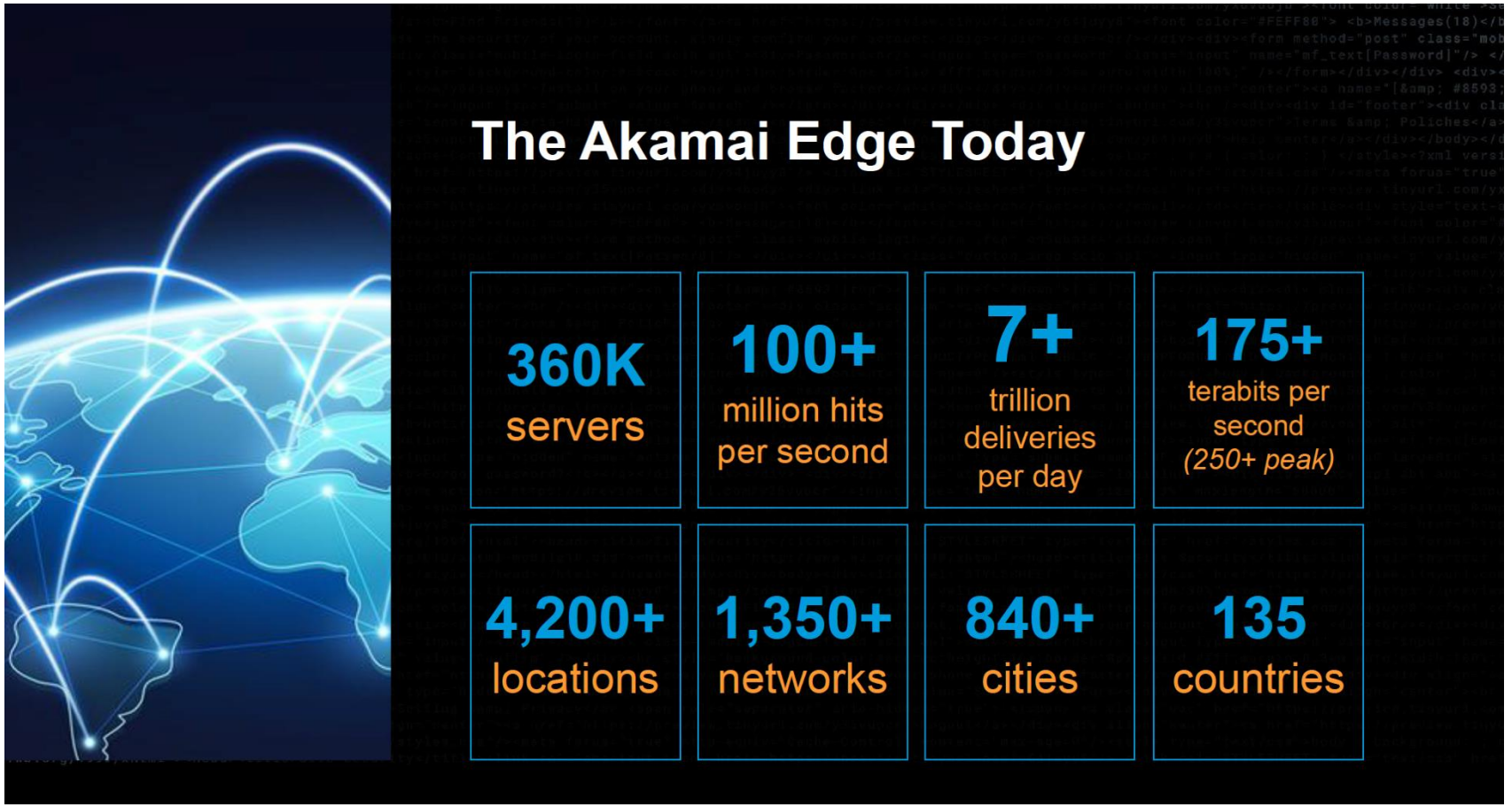


- **Live server** – For availability
- **Lowest load** – To balance load across the servers
- **Closest** – Nearest geographically, or in round-trip time
- **Best performance** – Throughput, latency, …
- **Cheapest bandwidth, electricity**, …

Major Public CDN Providers

- Akamai
  - One of the largest CDN providers.
  - Used by **Disney+, ESPN, PayPal, Microsoft, Sony PlayStation, etc.**
- Cloudflare
  - Offers CDN with built-in DDoS protection.
  - Used by **Medium, Discord, Shopify, IBM, etc.**
- Amazon CloudFront
  - Amazon's CDN service, part of AWS.
  - Used by **Amazon Prime Video, Twitch, Slack, etc.**
- Fastly
  - Popular for low-latency edge computing.
  - Used by **Reddit, The New York Times, Hulu, and GitHub.**

Public CDN: Akamai today:



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

Private CDN

Companies with Their Own CDN Infrastructure

Company	Private CDN	Purpose
Google	Google Global Cache (GGC)	YouTube, Search, Drive
Netflix	Open Connect	Video streaming
Amazon	AWS CloudFront	Prime Video, e-commerce
Apple	Apple Edge Cache	App Store, iCloud, TV+
Microsoft	Xbox CDN, Azure Front Door	Windows Updates, Xbox Live
Meta (Facebook, Instagram, WhatsApp)	Facebook Edge Network	Social media content delivery
TikTok	ByteDance CDN	Short video delivery

Why Build a Private CDN?

- Reduces costs for large-scale content providers.
- Optimized for specific needs (e.g., Netflix Open Connect is built for streaming).
- Improves performance and security control.

Chapter 2: Summary

our study of network application layer is now complete!

- application architectures
  - client-server
  - P2P
- application service requirements:
  - reliability, bandwidth, delay
- Internet transport service model
  - connection-oriented, reliable: TCP
  - unreliable, datagrams: UDP
- socket programming: TCP, UDP sockets
- specific protocols:
  - HTTP
  - SMTP, IMAP
  - DNS
  - P2P: BitTorrent
- video streaming, CDNs