Media Processing

ffmpeg

ffmpeg

- We sometimes want to process video files
- ffmpeg is *the* answer for video manipulation
- Need to install ffmpeg
  - Include the installation in your Dockerfile if using Docker
- Invoke ffmpeg
  - Command line examples today
  - Make system calls from your code
  - -or- use a client library that makes the sys calls for you (You still need to install ffmpeg)

ffmpeg

```
ffmpeg -i inputVideo.avi -f mp4 outputVideo.mp4
```

- Example of basic ffmpeg usage
  - Converts inputVideo.avi into an mp4
- The -i flag indicates the input filename
- The -f flag indicates the output format
- The last argument is always the output filename
  - No flag for the output filename

ffmpeg

```
ffmpeg -i inputVideo.avi -s 640x360 -f mp4 outputVideo.mp4
```

- We can add more arguments for more control
  - Output filename is still the last argument
- The -s flag is sets the resolution of the output file
  - We convert the file to 640x360

The Problem

- You host a video on your web app
- You want high quality so you host a large 1080p mp4
  - The entire file is 100's of MB
- Every user visiting your page has to download the entire video before playback can begin
  - Very slow to load
  - Entire file must download even for users who will only watch for a few seconds

Chunking

- Avoid the requirement of downloading the entire video before it plays
- Provided a way to request short segments of the video
- Download one "chunk" of the video at a time
  - Typically ~2-10 seconds of playback

- Advantages:
  - Only a few seconds need to be downloaded before playback starts
  - If the user skips around in the video, only request they chunk they skipped to
  - If the user leaves the page without finishing the video, the entire file doesn't have to be downloaded

Chunking - Range

- Even mp4 videos can be chunked
- The browser may end a request for a large file that includes a Range header
  - The Range header specifies a range of bytes being requested
  - eg. A request for "/video.mp4" with a header "Range: 10000-20000" is request the 9999th through 19999th bytes of video.mp4
- The response code should be 206 Partial content
- The response should contain a Content-Range header
  - Contains the range of bytes being sent and the to total size of the file
  - eg. Content-Range: 10000-20000/500000
  - eg. Content-Range: 0-499999/500000 if the entire file is sent

Chunking - Range

- Using the Range header can be effective in some cases, however:
  - It adds extra complexity to the server
  - It relies on the browser to request useful ranges
  - Some browsers might not implement Range and ask for the entire file

- We would like a more robust solution

Chunking - Multiple Files

- Instead of relying on the browser asking for a specific range of bytes..

- We host a single video in multiple files
- Each file contains a few seconds of playback
- The browser requests each segment as needed
  - User only watches a few seconds -> Only need to request the first few segments
  - User skips to the middle of the video -> Request the middle segment

HLS vs MPEG-DASH

- Two major protocols support the idea of breaking a video into smaller segments/chunks: HLS and MPEG-DASH
- **HTTP Live Streaming (HLS)**
  - Developed by Apple
  - Only supports the H.264 encoding for video
  - Wide-spread adaptation
  - Spec freely available in RFC8216
- **Dynamic Adaptive Streaming over HTTP (MPEG-DASH)**
  - Developed by Moving Picture Experts Group (MPEG)
  - Supports any video encodings
  - No support on Apple devices
  - Spec published as ISO/IEC 23009-1:2022 - Available for $245 (!)


```
#EXTM3U
#EXT-X-VERSION:3
#EXT-X-TARGETDURATION:8
#EXT-X-MEDIA-SEQUENCE:0
#EXTINF:6.773433,
space0.ts
#EXTINF:8.341667,
space1.ts
#EXTINF:8.341667,
space2.ts
#EXTINF:8.341667,
space3.ts
#EXTINF:8.341667,
space4.ts
#EXTINF:8.341667,
space5.ts
#EXTINF:8.341667,
space6.ts
#EXTINF:8.341667,
space7.ts
#EXTINF:8.341667,
space8.ts
#EXTINF:8.341667,
space9.ts
#EXTINF:8.341667,
space10.ts
#EXTINF:8.341667,
space11.ts
#EXTINF:6.973633,
space12.ts
#EXTINF:2.836167,
space13.ts
#EXT-X-ENDLIST
```

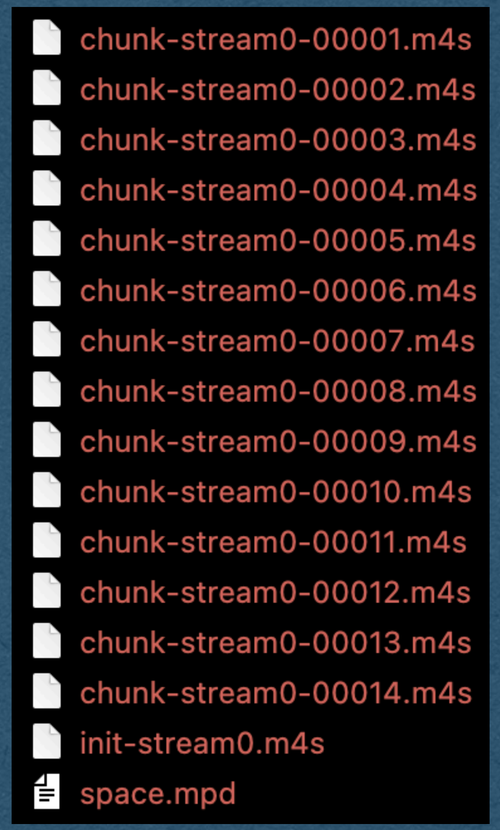
HLS

- Divide the video into multiple .ts files
  - MPEG Transport Stream files
- One .m3u8 index file containing information about each .ts file and how they combine into a single video
- Your server hosts all files
- Set the video source as the index file
- Browser reads the index file to know when to request each ts file

HLS - Transcoding

```
ffmpeg -i space.mp4 -hls_list_size 0 -f hls space.m3u8
```

- Use ffmpeg to convert to HLS
- "-f hls" to specify the output format as HLS
- "-hls_list_size 0" to keep all ts files in the index
  - By deafult, ffmpeg will only keep the last 5 ts files in the index file
  - This is good if you are live-streaming (This is the HTTP Live Streaming protocol after all)
  - Since our use case is hosting Video on Demand (VOD), we want to keep every ts file in the index
  - Setting the list size to 0 means the size is not limited




```
<?xml version="1.0" encoding="utf-8"?>
<MPD xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns="urn:mpeg:dash:schema:mpd:2011"
    xmlns:xlink="http://www.w3.org/1999/xlink"
    xsi:schemaLocation="urn:mpeg:DASH:schema:MPD:2011 http://
    profiles="urn:mpeg:dash:profile:isoff-live:2011"
    type="static"
    mediaPresentationDuration="PT1M48.3S"
    maxSegmentDuration="PT5.0S"
    minBufferTime="PT13.9S">
    <ProgramInformation>
    </ProgramInformation>
    <ServiceDescription id="0">
    </ServiceDescription>
    <Period id="0" start="PT0.0S">
        <AdaptationSet id="0" contentType="video" startWithSA
            <Representation id="0" mimeType="video/mp4" codec
                <SegmentTemplate timescale="30000" initializa
                    <SegmentTimeline>
                        <S t="0" d="203203" />
                        <S d="250250" r="10" />
                        <S d="209209" />
                        <S d="85085" />
                    </SegmentTimeline>
                </SegmentTemplate>
            </Representation>
        </AdaptationSet>
    </Period>
</MPD>
```

MPEG-DASH

- Divide the video into multiple files that can use a variety of formats (m4s by default in ffmpeg output which is mp4 encoded)
- One .mpd (Media Presentation Description) index file containing tons of information in an XML format
- Hosts all files and set the video source as the index file
- Browser reads the index file to find an init file and naming convention for content files to request

MPEG-DASH

- Full mpd file from the example

```
<?xml version="1.0" encoding="utf-8"?>
<MPD xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns="urn:mpeg:dash:schema:mpd:2011"
    xmlns:xlink="http://www.w3.org/1999/xlink"
    xsi:schemaLocation="urn:mpeg:DASH:schema:MPD:2011 http://standards.iso.org/ittf/PubliclyAvailableStandards/MPEG-DASH_schema_files/DASH-MPD.xsd"
    profiles="urn:mpeg:dash:profile:isoff-live:2011"
    type="static"
    mediaPresentationDuration="PT1M48.3S"
    maxSegmentDuration="PT5.0S"
    minBufferTime="PT13.9S">
    <ProgramInformation>
    </ProgramInformation>
    <ServiceDescription id="0">
    </ServiceDescription>
    <Period id="0" start="PT0.0S">
        <AdaptationSet id="0" contentType="video" startWithSAP="1" segmentAlignment="true" bitstreamSwitching="true" frameRate="30000/1001" maxWidth="1920" maxHeight="1080" par="16:9" lang="eng">
            <Representation id="0" mimeType="video/mp4" codecs="avc1.640028" bandwidth="2403076" width="1920" height="1080" sar="1:1">
                <SegmentTemplate timescale="30000" initialization="init-stream$RepresentationID$.m4s" media="chunk-stream$RepresentationID$-$Number%05d$.m4s" startNumber="1">
                    <SegmentTimeline>
                        <S t="0" d="203203" />
                        <S d="250250" r="10" />
                        <S d="209209" />
                        <S d="85085" />
                    </SegmentTimeline>
                </SegmentTemplate>
            </Representation>
        </AdaptationSet>
    </Period>
</MPD>
```

MPEG-DASH - Transcoding

```
ffmpeg -i space.mp4 -f dash space.mpd
```

- Use ffmpeg to convert to MPEG-DASH
- "-f dash" to specify the output format as MPEG-DASH
- Creates an mpd with the name you provide
  - All other files follow a default naming convention
  - May want to create a new directory for each video to avoid naming conflicts

Adaptive Bit-Rate Streaming

The Problem

- You host a video on your web app
  - You even use HLS or MPEG-DASH to segment the video into 2-10 seconds chunks
- You want high quality so you host chunks in 4K@60Hz
  - Can require ~25Mb/s bandwidth to stream
- And someone visits your site using eduroam on a bad day..
  - The video buffers, stutters, or doesn't play at all

- We need a solution that:
  - Allows users with slow connections to enjoy your content
  - Delivers high quality to users with high-speed Internet

Adaptive Bit-Rate

- Instead of hosting the a single video at a single resolution
  - Host multiple versions of the same video at different resolutions
  - Each resolution requires a different bit rate to stream

- User visits your page
  - Their browser adapts to the current download bandwidth available
  - Stream the highest bit rate video that fits the bandwidth

Adaptive Bit-Rate

- Using HLS or MPEG-DASH
  - Create chunks at several different resolutions/bit rates
  - Add information about all resolutions in the index file

- With the video segmented into ~2-10 second chucks
  - Easy for the browser to switch between resolutions

Adaptive Bit-Rate

- The browser can adapt the requested bit-rate based on current conditions
- Limited interruption for the user, though quality can change over time

Adaptive Bit-Rate - HLS

- Using HLS, m3u8 index files can be nested
- Convert your video into multiple HLS resolutions
- Combine them into a single index file with references to the others
- This example contains references to 3 different resolutions


```
#EXTM3U
#EXT-X-STREAM-INF:BANDWIDTH=5000000,RESOLUTION=1920x1080
party1080p.m3u8
#EXT-X-STREAM-INF:BANDWIDTH=2500000,RESOLUTION=1280x720
party720p.m3u8
#EXT-X-STREAM-INF:BANDWIDTH=1000000,RESOLUTION=854x480
party480p.m3u8
```

Adaptive Bit-Rate - MPEG-DASH

- The mpd file can contain multiple resolutions
- The media is represented in multiple layers
  - Period
  - Adaptation Set
  - Representation

```
15  <Period id="0" start="PT0.0S">
16      <AdaptationSet id="0" contentType="video" startWithSAP="1" segmentAlignment="true" bitstreamSwitching="true" frameRate="30/1" maxWidth="640" maxHeight="1138" par="9:16" lang="und">
17          <Representation id="0" mimeType="video/mp4" codecs="avc1.64001f" bandwidth="480684" width="540" height="960" sar="1:1"...>
25          <Representation id="2" mimeType="video/mp4" codecs="avc1.64001f" bandwidth="1000000" width="640" height="1138" sar="5121:5120"...>
33      </AdaptationSet>
34      <AdaptationSet id="1" contentType="audio" startWithSAP="1" segmentAlignment="true" bitstreamSwitching="true" lang="und">
35          <Representation id="1" mimeType="audio/mp4" codecs="mp4a.40.2" bandwidth="128000" audioSamplingRate="44100"...>
45      </AdaptationSet>
46  </Period>
```

Adaptive Bit-Rate

- Your task [For AO3]:
  - Programmatically convert an uploaded mp4 into hls with multiple resolutions
  - Serve those videos by setting the source of a video to the index file for that video

- Hint: Get ffmpeg to do all the work for you
  - You should not manually write any of these files
  - Do research to find the command(s)/flags you need to send to ffmpeg to do the job

Video Players

- Most built-in video players do not support HLS or MPEG-DASH
  - You cannot rely on the browser having a player for either of these formats (eg. During grading we will not use a browser with built-in support for HLS or MPEG-DASH)
- We must use a 3rd party video player or library
  - Several players available (eg. dash.js)
  - Examples in the following slides will use video.js

Video Players

- This example downloads the css and js for video.js from a CDN
- Uses "class" and "data-setup" attributes on a video element to tell the library to do its thing
- You now have a video player that supports both HLS and MPEG-DASH

```html
<!DOCTYPE html>
<html lang="en">
<head>
    <link href="https://vjs.zencdn.net/8.10.0/video-js.css" rel="stylesheet"/>
    <title>CSE312 Video Example</title>
</head>
<body>

<video class="video-js" width="300" controls autoplay data-setup="{}">
    <source src="main.m3u8"/>
    Your browser does not support video playback
</video>

<script src="https://vjs.zencdn.net/8.10.0/video.min.js"></script>
</body>
</html>
```

```html
<video class="video-js" width="300" controls autoplay data-setup="{}">
    <source src="output.mpd"/>
    Your browser does not support video playback
</video>
```

Video Players

- Your video player will now have a consistent look across all browsers
- Don't have to worry about what formats each browser supports
  - You support any format supported by video.js

```html
<!DOCTYPE html>
<html lang="en">
<head>
    <link href="https://vjs.zencdn.net/8.10.0/video-js.css" rel="stylesheet"/>
    <title>CSE312 Video Example</title>
</head>
<body>

<video class="video-js" width="300" controls autoplay data-setup="{}">
    <source src="main.m3u8"/>
    Your browser does not support video playback
</video>

<script src="https://vjs.zencdn.net/8.10.0/video.min.js"></script>
</body>
</html>
```

Live Streaming

Live Streaming

- We've talked about uploading and host mp4 videos using a streaming protocol
  - A VOD service

- What about live streaming?

- Most live streaming isn't truly live
  - There will be several seconds of delay in the stream
  - Acceptable loss to gain accuracy

Live Streaming

- Typical setup (eg. Twitch/YouTube Live/etc.)

- User streams their video into an ingest server using the Real-Time Messaging Protocol (RTMP)
  - RTMP is a container for any real-time communication
  - The content of RTMP happens to be a media stream in this case
- The server transcodes the video into a streaming format (eg. HLS/MPEG-DASH) and continually updates/ generates index files

Live Streaming

- When a viewer visits a live stream
  - The browsers asks for the latest index file and starts requesting content
  - When it nears the end of that index file, request a new index file
  - Repeat until the stream ends

- When a viewer visits the VOD of a past live-stream
  - Serve an index file for then entire stream
  - No different than watching the stream live

Live Streaming

- Since the transcoding process of the ingest server takes some time:
  - The stream is not truly live
- The streamed content is downloaded via TCP/HTTP
  - Reliable. You will not miss a second of video

- If the delay is unacceptable (eg. Zoom):
  - Use UDP instead of TCP
  - Do not transcode
  - Accept dropped packets as a part of life