Fundamentals of Video

Objectives

- Understand digital video terminology and standards
- Using video in multimedia project

Using Video

- Video is an excellent tool for delivering multimedia.
- Video places the highest performance demand on computer and its memory and storage.
- Digital video has replaced analog as the method of choice for making and delivering video for multimedia.

Using Video

- Digital video device produces excellent finished products at a fraction of the cost of analog.
- Digital video eliminates the image-degrading analog-to-digital conversion.
- Many digital video sources exist, but getting the rights can be difficult, time-consuming, and expensive.

Fundamentals of Digital Video

THE PROPERTIES OF BROADCAST VIDEO

Video

motion  a sequence of pictures

Video

Frame Rate

- How fast the pictures are captured
- How fast the frames are played back is determined by
- Frames per second (fps)

Broadcast Standards

- Digital video resolution
- Color spaces
- Frame rate
- Influenced by analog TV broadcast standards

Standards for Analog Color TV

- NTSC:
  - designated by U.S.'s National Television Systems Committee
  - U.S., Japan, Taiwan, parts of the Carribean, South America
- PAL:
  - Phase Alternating Line
  - Australia, New Zealand, Western Europe, Asian
- SECAM:
  - Séquentiel Couleur avec Mémoire
  - France, former Soviet Union, Eastern Europe

Frame Rates of Different Broadcast Standards

Video Type	Frame Rate (frames per second)
NTSC (black-and-white)	30
NTSC (color)	29.97
PAL	25
SECAM	25
Motion-picture film	24

How CRT Monitors and TVs Display Pictures

- Picture displayed on CRT is made up of horizontal lines
  - NTSC: 525 lines (about 480 lines are picture)
  - PAL and SECAM: 625 lines (about 576 lines are picture)

- Lines are traced across the screen
  - one line at a time
  - from top to bottom

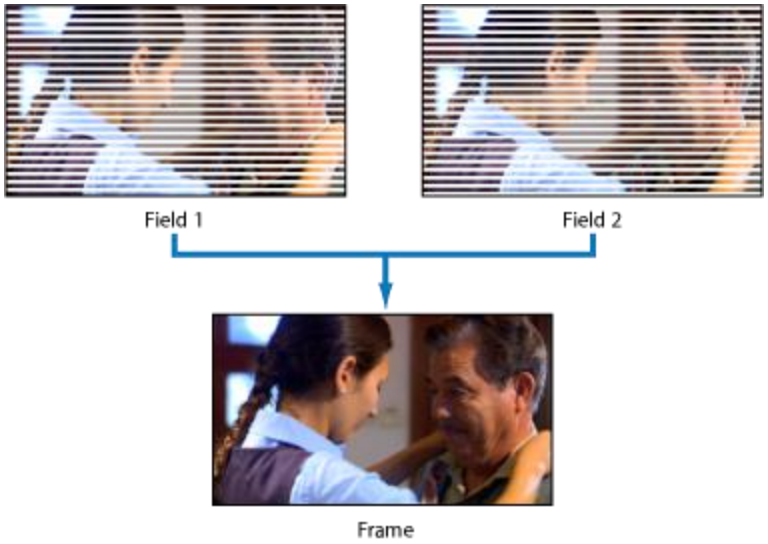
Ways of Tracing Lines From Top to Bottom

- *Progressive scan*:
  - from top to bottom in one pass

- *Interlaced scan*:
  - in two passes:
    1. even-numbered lines
    2. odd-numbered lines

Field

- Set of lines in the same pass
- 2 fields in interlaced scan:
  - even-numbered lines
  - odd-numbered lines
- Upper field:
  the field that contains the topmost scan line
- Lower field:
  - the other field



Source:
http://documentation.apple.com/en/finalcutpro/usermanual/index.html#chapter=C%26section=9%26tasks=true

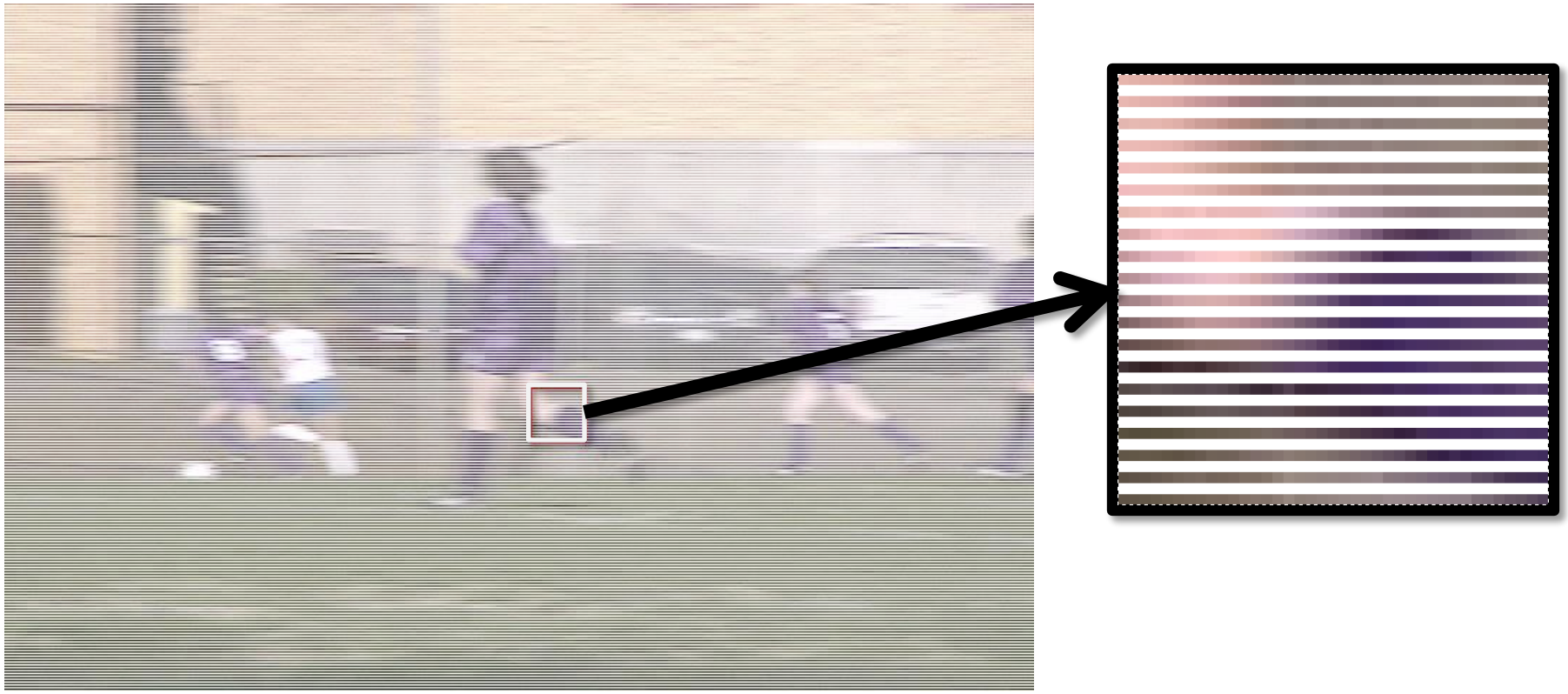
Undesirable Side Effects of Interlaced Scan

- The two fields in a frame are captured at a slightly different moment in time

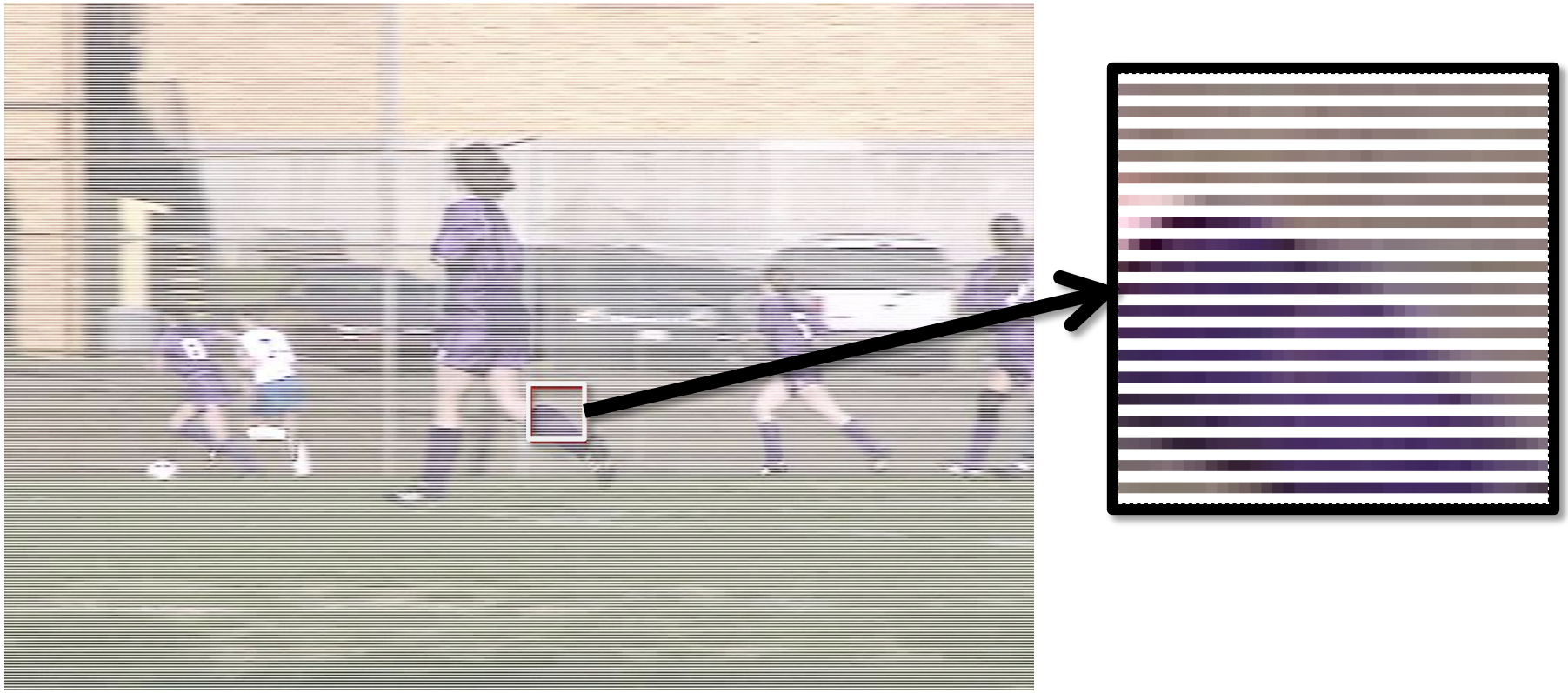
- Discontinuities will become apparent for fast moving objects in video shot in the interlaced mode

Comb-like Artifacts

Upper Field



Lower Field



Interlace Artifacts

- Not discernible during normal playback of most videos

Deinterlace

- To remove the interlace artifact

- Common method:
  - discard one field
  - fill in the gaps by duplicating or interpolating the other field

Deinterlaced Result

Color Format for Videos

- Luminance-chrominance color models

- Luminance: brightness
  Chrominance: color or hue

Luminance-chrominance Color Model Examples

- YUV:
  - Y: luminance component
  - U and V: chrominance components
  - used for PAL

- YIQ:
  - Y: luminance component
  - I and Q: chrominance components
  - used for NTSC

Review Question

Which of the following is the television broadcast standard for the U.S. and Japan?

A. NTSC
B. PAL
C. SECAM

Review Question

Which of the following is the television broadcast standard for most of the Asian countries?

A. NTSC
B. PAL
C. SECAM

Review Question

In the YUV color model, the Y-component is ___, the U-component is ___, and V-component is ___.

A. luminance; luminance; chrominance
B. luminance; chrominance; luminance
C. luminance; chrominance; chrominance
D. chrominance; chrominance; luminance
E. chrominance; luminance; luminance

Review Question

The frame rate for the NTSC system is ___ fps.

A. 24
B. 25
C. 28.9
D. 29.97
E. 30

Review Question

The frame rate for the PAL system is ___ fps.

A. 24
B. 25
C. 28.9
D. 29.97
E. 30

Review Question

The frame rate for the the motion-picture film is ___ fps.

A. 24
B. 25
C. 28.9
D. 29.97
E. 30

Review Question

The scan mode of a CRT computer monitor is ____.

A. interlaced
B. progressive

Review Question

The scan mode of a CRT television set is ___.

A. interlaced
B. progressive

Review Question

Interlaced scan displays the frame by scanning the lines of a frame ___.

A. in one pass from top to bottom
B. in two passes: even-numbered lines in one pass and odd-numbered lines in the second

Review Question

Progressive scan displays the frame by scanning the lines of a frame ___.

A. in one pass from top to bottom
B. in two passes: even-numbered lines in one pass and odd-numbered lines in the second

Review Question

The comb-like artifact in a digital video, as shown here, occurs in the ___ video.

A. interlaced
B. progressive
C. both A and B

Fundamentals of Digital Video

BASIC TERMINIOLOGY

In this lecture, you will learn:

These basic terminology in digital video:

- frame size
- frame aspect ratio
- pixel aspect ratio
- timecode

Sampling and Quantization of Motion

- Temporal:
  - sampling rate:
    - how frequent you take a snapshot of the motion
    - frame rate
    - higher sampling rate: higher frame rate
    - higher frame rate $\Rightarrow$ more frames for the same duration $\Rightarrow$ larger file size

Sampling and Quantization of Motion

- Each snapshot: a frame
  - an image
  - digitized based on the same concepts of sampling and quantization of images

Frame Size

- Resolution of the frame image
- Measured in pixel dimensions
- No ppi setting:
  Unlike digital images, there is no pixel per inch (ppi) setting for video because video is not intended for print but for on screen display.

Frame Size Examples

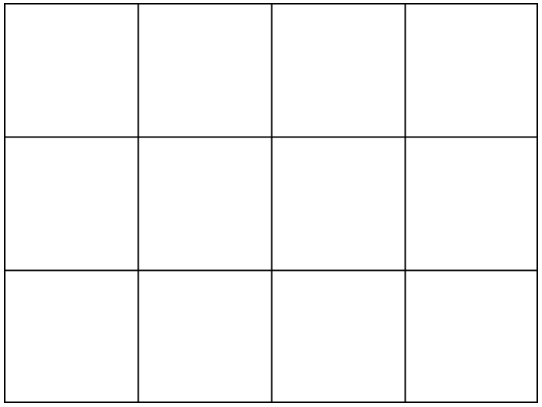
		Frame size
NTSC	standard definition	720 x 480 pixels
	high definition HDV format	1280 x 720 pixels 1440 x 1080 pixels
PAL	standard definition	720 x 576 pixels

Frame Aspect Ratio

- the ratio of a frame's *viewing* width to height

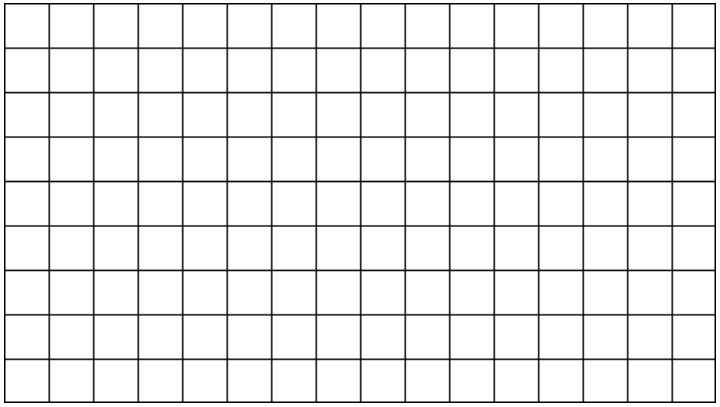
- NOT equivalent to ratio of the frame's *pixel* width to height.

Frame Aspect Ratio Examples



4:3

Example:
•Standard definition NTSC standard format



16:9

Examples:
•Standard definition NTSC wide-screen format

•High definition digital video

•High definition TV

Ratio Does Not Match Up?

- Frame size of a NTSC standard definition DV frame: 720 x 480
- 720 : 480 = 3 : 2
- NOT 4 : 3 or 16 : 9
- This is because the pixels are not square!

Pixel Shapes

- Digital images: square pixels
- Digital video: may not be square pixels

Pixel Aspect Ratio

- Ratio of pixel width : pixel height

Pixel Aspect Ratio	Pixel Shape
1	square
< 1	tall
> 1	wide

Pixel Aspect Ration Examples

Video Format	Pixel Aspect Ratio
Standard format of standard definition (e.g. standard format of the non-blu-ray movies DVD)	0.9
Wide-screen format of standard definition (e.g. wide-screen format of the non-blu-ray movies DVD)	1.2
HDV 720p, QuickTime movies	1.0
HDV 1080i and 1080p	1.333

Let's see if the ratios match up

Standard Format Standard Definition

- Pixel aspect ratio = 0.9
- Frame size = 720×480

- Frame aspect ratio = $720 \times 0.9 : 480$
  $= 648 : 480$
  $\cong 4 : 3$

Wide-screen Format Standard Definition

- Pixel aspect ratio = 1.2
- Frame size = 720×480

- Frame aspect ratio = $720 \times 1.2 : 480$
  $= 864 : 480$
  $\cong 16 : 9$

HDV 720p

- Pixel aspect ratio = 1.0
- Frame size = 1280×720

- Frame aspect ratio = $1280 \times 1.0 : 720$
  $= 1280 : 720$
  $= 16 : 9$

HDV 1080i and 1080p

- Pixel aspect ratio = 1.333
- Frame size = 1440×1080

- Frame aspect ratio = $1440 \times 1.333 : 1080$
  $\cong 1920 : 1080$
  $= 16 : 9$

Video image will be distorted if it is displayed on a system with a different pixel aspect ratio.

For a video of pixel aspect ratio of 1

Displayed correctly on a system of pixel aspect ratio of 1

Displayed incorrectly on a system of pixel aspect ratio of 0.9.
The image looks stretched vertically.

For a video of pixel aspect ratio of 1

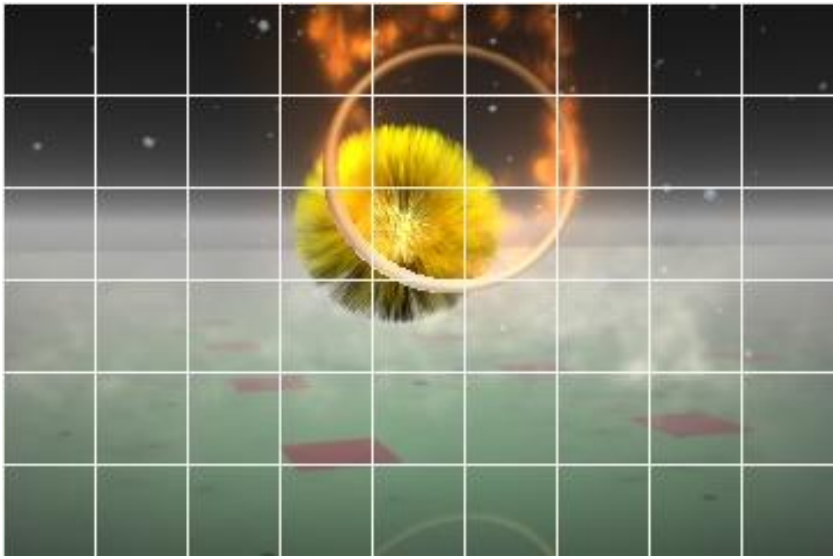
Displayed correctly on a system of pixel aspect ratio of 1

Displayed incorrectly on a system of pixel aspect ratio of 1.2.
The image looks stretched horizontally.

For a video of pixel aspect ratio of 0.9

Displayed correctly on a system of pixel aspect ratio of 0.9

Displayed incorrectly on a system of pixel aspect ratio of 1.
The image looks slightly stretched horizontally.



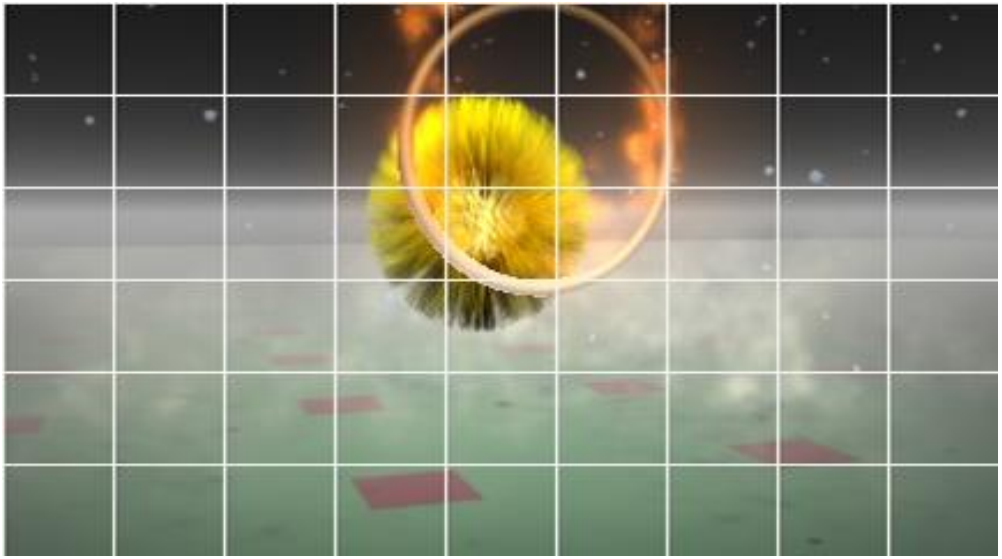
For a video of pixel aspect ratio of 0.9

Displayed correctly on a system of pixel aspect ratio of 0.9

Displayed incorrectly on a system of pixel aspect ratio of 1.2.
The image looks stretched horizontally.

For a video of pixel aspect ratio of 1.2

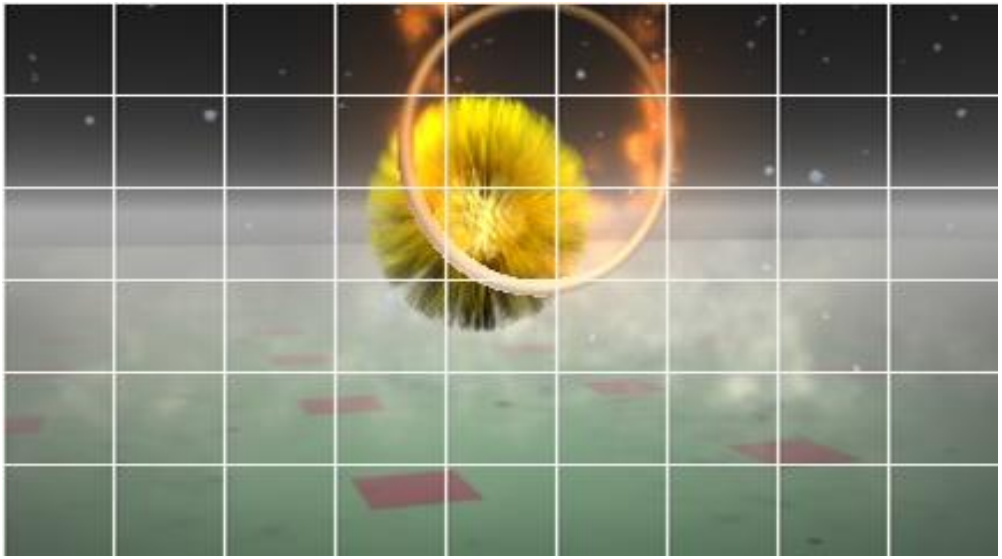
Displayed correctly on a system of pixel aspect ratio of 1.2



Displayed incorrectly on a system of pixel aspect ratio of 0.9.
The image looks stretched vertically.

For a video of pixel aspect ratio of 1.2

Displayed correctly on a system of pixel aspect ratio of 1.2



Displayed incorrectly on a system of pixel aspect ratio of 1.0.
The image looks slightly stretched vertically.

Distortion

Pixel Apect Ratios			Distortion
video frame's	=	display system's	none
video frame's	<	display system's	stretched horizontally
video frame's	>	display system's	stretched vertically

Review Question

True/False: There is no sampling and quantization involved in capturing motion in digital video.

Review Question

The frame size of a video refers to the video's ___.

A. aspect ratio
B. pixel aspect ratio
C. resolution
D. ppi

Review Question

True/False: The pixel per inch (ppi) is an important attribute for video resolution and should be set correctly when working with digital video in video-editing programs.

Review Question

Pixel aspect ratio means ___.

A. the ratio of a frame's width (in pixels) to the height (in pixels)
B. the ratio of a frame's height (in pixels) to the width (in pixels)
C. the ratio of a pixel's width to its height
D. the ratio of a pixel's height to its width

Review Question

The pixel aspect ratio of a wide-screen format standard definition video is ___.

A. 4:3

B. 16:9

C. 1.0

D. 0.9

E. 1.2

Review Question

The pixel aspect ratio of a standard format standard definition video is ___.

A. 4:3

B. 16:9

C. 1.0

D. 0.9

E. 1.2

Review Question

The frame aspect ratio of a wide-screen format standard definition video is ___.

A. 4:3
B. 16:9
C. 1.0
D. 0.9
E. 1.2

Review Question

The frame aspect ratio of a standard format standard definition video is ___.

A. 4:3

B. 16:9

C. 1.0

D. 0.9

E. 1.2

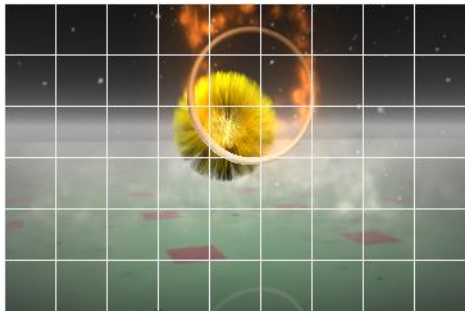
Review Question

If a frame with pixel aspect ratio 1.2 is displayed on a device using a pixel aspect ratio of 1.0, the image will be ___.

A. stretched horizontally
B. stretched vertically
C. cropped at the left and right edges
D. cropped at the top and bottom
E. displayed correctly

Review Question

If a frame with pixel aspect ratio of 1 is displayed on a device using a pixel aspect ratio of 1.2, the image will look like ___.



A. 

B. 

Fundamentals of Digital Video

DIGITAL VIDEO FILE TYPES

In this lecture, you will learn:

- Common file types of video
- General strategies for reducing video file size
- Effect of data rate vs. file size on video playback smoothness

Common Video File Types

File Type	Acronym For	Originally Created By	File Info & Compression	Platforms
.mov	QuickTime movie	Apple	• Also audio-only • Can be streamed • "Fast start" • Common compression methods: H.264, Sorenson Video, Animation	Apple QuickTime player, which is available for Mac and Windows
.avi	Audio Video Interleave	Intel	Common compression methods: Microsoft RLE, Intel Indeo Video	Primarily used on Windows but Apple QuickTime player can play AVI files
.mpg .mpeg	MPEG	Motion Picture Experts Group	• For DVD-video • High definition HDV	Cross-platform
.divx		DivX, Inc	• Uses DivX codec, which is based on MPEG-4 • Popular format for movies because of the high • image quality and small file size • AVI is a common container file format	• May require downloading DivX codec • Windows Media Player v11.0 comes with DivX codec

Common Video File Types

File Type	Acronym For	Originally Created By	File Info & Compression	Platforms
.mp4	MPEG-4	Moving Pictures Experts Group	• Video codec: H.264 • Audio codec: AAC • One of the **HTML5 video** formats	Plays in Web browsers that support the MP4 format of HTML5 video (Safari and IE)
.ogg or .ogv	Audio Video Interleave	Xiph.Org Foundation	• Video codec: Theora • Audio codec: Vorbis • One of the **HTML5 video** formats • Compared to the other two HTML5 video formats, it has lower quality for the same file size	Plays in Web browsers that support the OGG format of HTML5 video (Firefox, Chrome, Opera)
.webm		An open source video format from Google	• Video codec: VP8 • Audio codec: Vorbis • One of the **HTML5 video** formats	Plays in Web browsers that support the WebM format of HTML5 video (Firefox, Chrome, Opera)

Common Video File Types

File Type	Acronym For	Originally Created By	File Info & Compression	Platforms
.flv	Flash Video	Adobe	• Progressive download • Can be streamed • Common compression methods: H.264, Sorenson Spark, On2 VP6	• Cross-platform • Requires Adobe Media Player to play
.f4v	Flash Video	Adobe	• Builds on MPEG-4 Part 12 • Supports H.264/ACC-based content	• A newer Flash Video format than flv • Cross-platform • Requires Adobe Media Player to play • Can be embedded in Flash SWF files
.wmv	Windows Media	Microsoft		Requires Windows Media Player to play

Considerations for File Type

- File size restriction
- Intended audience
- Future editing

File Size Restriction

- For Web:
  - high compression
  - streaming video
- CD-ROM or DVD-ROM playback:
  - use data rate that can be handled by your target audience's computer
- DVD-video:
  - MPEG-2

Intended audience

- Multiple platforms
  - cross-platform formats: Apple QuickTime, MPEG, Flash video, Real Video
- How your target audience is going to watch your video?

Future Editing

- If the video will be used as a source for future editing:
  - Lower compression level
  - Choose uncompressed, if
    - the frame size is small
    - the video duration is extremely short
    - you have enough disk space

Digital Video File Size Optimization

- Video tends to have very large file size compared to other media.

- Why should we care file size optimization?
  - A large file requires more disk space.
  - A large file takes longer to transfer.
  - Data transfer can be expensive (because data plans are not unlimited)
  - High *data rate* may cause choppy playback of the video.
    (Data rate will be explained later in this lecture.)

To get a feel of the file size of uncompressed video, let's compute the file size of an uncompressed 1-second video with the same resolution and frame rate as HDV 1080i/p video.

The 1-second Video

- 1440×1080 pixels
- 24-bit color
- 30 fps
- 1 second long
- Audio: stereo (2 channels)
- Audio: 48 kHz, 16-bit

File Size Calculation

The picture component:

- Total pixels in each frame:
  1440×1080 pixels = 1,555,200 pixels/frames

- File size of a frame:
  1,555,200 pixels/frames $\times$ 24 bits/pixel
  = 37,324,800 bits/frame

- File size of 30 frames (1 second):
  37,324,800 bits/frame $\times$ 30 frames
  = 1,119,744,000 bits

File Size Calculation

1,119,744,000 bits

= 1,119,744,000 bits / (8 bits/bytes)

= 139,968,000 bytes

≅ 133 MB

File Size Calculation

Audio:

Sampling rate $\times$ length of the audio $\times$ bit-depth $\times$ number of channels

= 48,000 samples/sec $\times$ 1 second $\times$ 16 bits/sample $\times$ 2

= 1,536,000 bits

= 1,536,000 bits / (8 bits/byte)

= 192,000 bytes

$\cong$ 188 KB

File Size Calculation

Total file size of this 1-second uncompressed video

= size of the picture component + audio size

≅ 133 MB + 188 KB

= 133 MB

10 seconds would be 1.33 GB!

File Size Calculation

Total file size of this 1-second uncompressed video

= video size + audio size

≅ 133 MB + 188 KB

= 133 MB

Note that the audio size is insignificant compared to the picture component of the video.

10 seconds would be 1.33 GB!

Data Rate

- Amount of video data to be processed per second

$$\text{Average Data Rate} = \frac{\text{File Size}}{\text{Duration of Video (seconds)}}$$

Effect of File Size vs. Data Rate on Video Playback

- Data rate:
  - If high: choppy playback
  - Amount of data to be processed *per second*
    - Larger file size can have a low data rate if it is a long video
    - Smaller file size can have a high data rate if it is a short video
- File size:
  - If high:
    - Requires larger storage space
    - Not unnecessary choppy playback
  - The impact of file size on smoothness of playback also depends on the video duration.

Data Rate Example

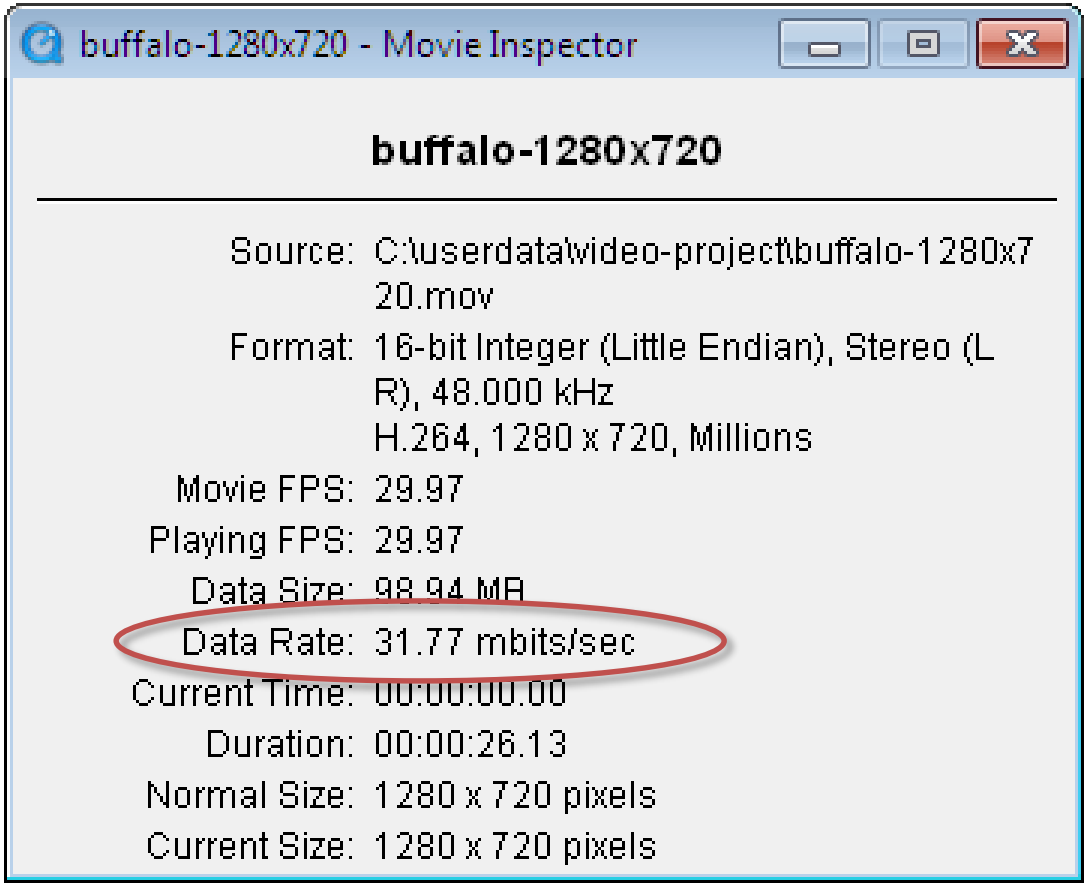
- Typical residential broadband speed:
  3 – 20 mbits/sec
- Average download speed of 3G wireless:
  about 1 mbits/sec
- Average download speed of 4G wireless:
  - laptop: 2 – 6 mbits/sec
  - smartphones 1 – 2 mbits/sec

- Previous video file size example:
  1-second uncompression video, 133 MB
  - Data rate = 133 MB / 1 second = 133 MB/sec = 1,064 mbits/sec
  - Way too high for these connections!
  - Impossible to play back smoothly via these connection

Finding out Data Rate in QuickTime

- Window > Show Movie Info

Finding out Data Rate in QuickTime

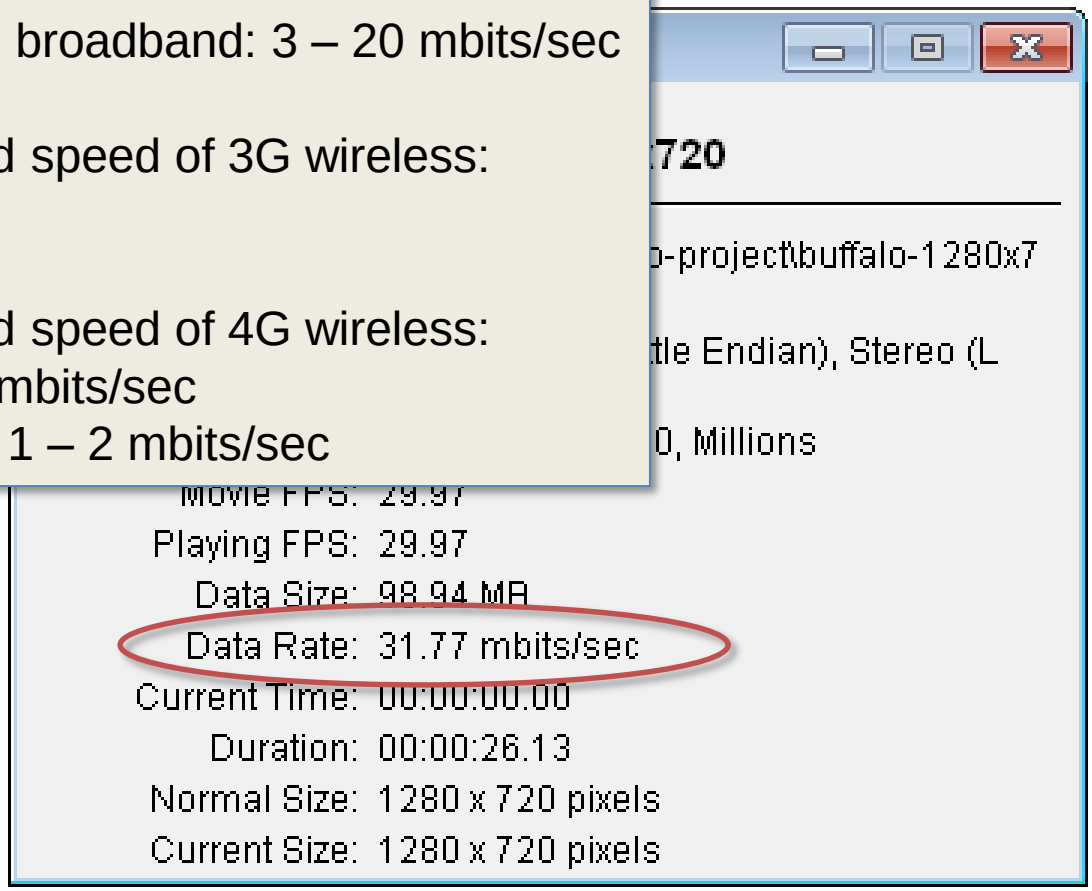


Finding out Data Rate in QuickTime

Reminder:
Typical residential broadband: 3 – 20 mbits/sec

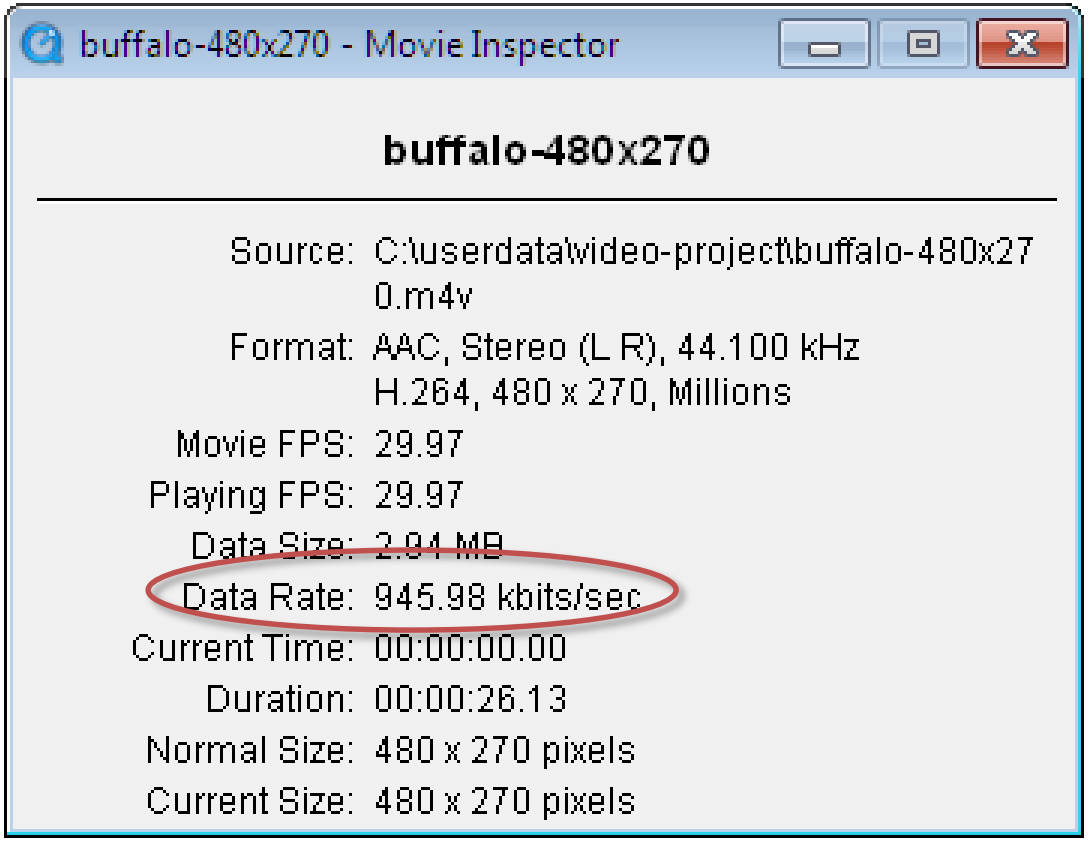
Average download speed of 3G wireless:
about 1 mbits/sec

Average download speed of 4G wireless:
laptop: 2 – 6 mbits/sec
smartphones 1 – 2 mbits/sec



With the typical residential broadband, 4G wireless, or even 3G wirelss, this video will have to pause frequently to wait for data.

Finding out Data Rate in QuickTime

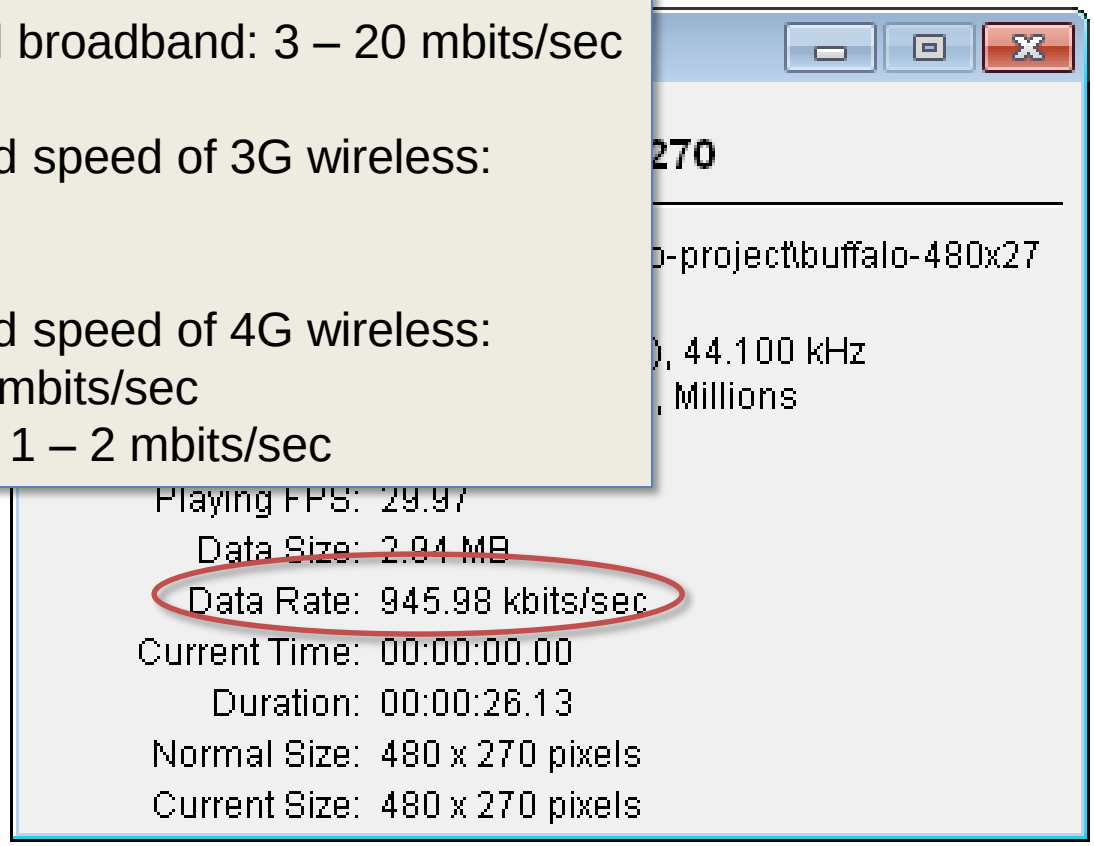


Finding out Data Rate in QuickTime

Reminder:
Typical residential broadband: 3 – 20 mbits/sec

Average download speed of 3G wireless:
about 1 mbits/sec

Average download speed of 4G wireless:
laptop: 2 – 6 mbits/sec
smartphones 1 – 2 mbits/sec



With the typical residential broadband, 4G wireless, or even 3G wirelss, this video should play without having to pause to wait for data.

General Strategies for Reducing Video Data Rate

Basic ideas:

A video is a sequence of images + audio

Apply strategies for reducing digital image and audio file size.

General Strategies for Reducing Video File Size

- General Strategies for reducing digital image file size
  - reduce frame size
  - reduce frame rate
  - choose a video compressor that allows higher compression
  - choose the lower picture quality option

- Reduce duration of the video so you have less frames
  - not always possible
  - will not impact data rate

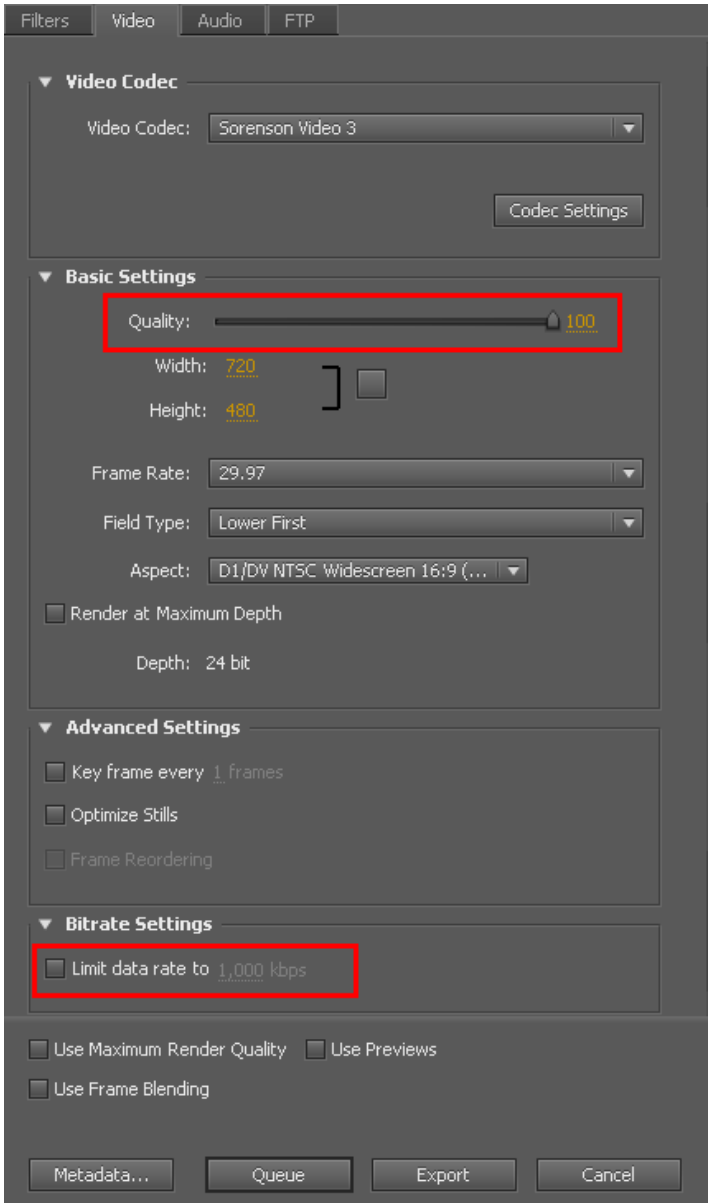
Why General Strategies for Reducing Digital Image File Size Work for Video

- Reduce frame size because:
  - you have less pixels for each frame
- Reduce frame rate because:
  - you have less frames
- Video compression with high compression because:
  - some data are discarded
- Lower picture quality option because:
  - some data are discarded

Most Common Choices of Compressor

- H.264
- Sorenson Video 3

Example of Picture Quality Option



Strategies Least Used for Reducing Video Data Rate

- Reduce bit depth
  - Not all video formats support lower bit depth
  - Live videos need 24-bit to look natural
  - Some compressors do not support lower bit depth

- Reduce sampling rate, bit depth, and channel numbers of the audio
  - size of the audio is insignificant compared to that of the picture component in a video

Review Question

True/False: A long video, even with low data rate, can have a large file size.

Review Question

For a one-minute QuickTime video file with a file size of 100 MB, its playback on a 48x CD-ROM drive very likely will be ___. (Hint: The data rate for a 48x CD-ROM drive is about 7 MB/s.).

A. smooth

B. choppy

Review Question

For a five-second QuickTime video file with a file size of 100 MB, its playback on a 48x CD-ROM drive very likely will be ___. (Hint: The data rate for a 48x CD-ROM drive is about 7 MB/s.).

A. smooth

B. choppy

Review Question

Which of the following factors has the most direct impact on the smoothness of video playback?
In other words, if the value of that property is too high for the playback device to handle, the playback of the video will be choppy.

A. file size
B. frame size
C. frame rate
D. frame aspect ratio
E. pixel aspect ratio
F. data rate

Review Question

Name several strategies to reduce the file size of a video.

Fundamentals of Digital Video

DIGITAL VIDEO COMPRESSION

In this lecture, you will learn:

- Basic ideas of video compression
- General types of compression methods

Compression

- Basic idea:
  Want to represent the same content by using less data

Compression and Decompression An Analogy

- Compression: Packing a suitcase
  - Packing your clothes neatly:
    - more compact
    - takes more time
- Decompression: unpacking a suitcase
  - Unpack or even iron your clothes before you wear them
  - How you unpack often depends on how the clothes are packed

Compression and Decompression

- Compression:
  - To reduce file size
  - Takes time
  - Often takes more time for higher compression

- Decompression:
  - A compression video file must be decompressed before it is played.
  - The decompression method or algorithm depends on how it is originally compressed.

Compression and Decompression

- Compression and decompression always go together as a pair.

- *Codec*: compressor/decompressor

Types of Compression Methods

- Spatial compression
- Temporal compression
- Lossless vs. lossy compression
- Symmetrical and asymmetrical compression

Spatial Compression

- Compact individual frames as if they are independent digital images

- Examples of algorithms:
  - Run-length encoding (RLE)
  - JPEG compression

- Example codecs:
  - QuickTime Animation
  - QuickTime PlanarRGB
  - Microsoft RLE

Spatial Compression

- Types of video that spatial compression is good for:
  - contain large areas of solid colors, such as cartoon animation
- Disadvantage:
  - Less compressed, i.e., relatively large file size compared to other types of compression

Temporal Compression

- Exploits the repetitious nature of image content over time in video
- Saving more information for selected frames, i.e. less compressed.
  These are called *key frames*.
- All other frames stores only the difference from the previous key frame, instead of full frame
- Advantage:
  - Effective if the change between a frame and its previous key frame is small

Temporal Compression

- Compressed well for:
  - video that contains continuous motion
- Not compressed well for:
  - video with frequent flickering and scene changes
- Example codecs that use temporal compression:
  - H.264
  - Sorenson Video

Lossy vs. Lossless Compression

- *Lossy compression*:
  Reduce data by discarding or altering some of the original data

- *Lossless compression*:
  Preserve the original data but reduce file size by encoding the data specially

Lossy Compression

- Usually much smaller file size than lossless compression
- Lower picture quality
- Often try to maintain perceptual quality when deciding what data are to be discarded
- Discarded data cannot be recovered

Lossless Compression

- Usually much larger file size than lossy compression

- Example codecs:
  - QuickTime Animation
  - PlanarRGB (set at the maximum quality setting)

Symmetrical and Asymmetrical Compression

- Symmetrical codec:
  Same amount of time in compression and decompression

- Asymmetrical codec:
  - Amount of time to compress and decompress are significantly different
  - Preferable: Fast decompression so less wait time to play back the video

Review Question

The term codec stands for ___.

Review Question

___ compression refers to the type of compression method that aims at compacting individual frames.

A. asymmetric

B. lossless

C. lossy

D. spatial

E. temporal

Review Question

___ compression refers to the type of compression method that exploits the similarity of the subsequent frame content.

A. asymmetric

B. lossless

C. lossy

D. spatial

E. temporal

Review Question

___ compression refers to the type of compression method that discards or alters the original data.

A. asymmetric

B. lossless

C. lossy

D. spatial

E. temporal

Review Question

___ compression refers to the type of compression method in which the amount of time and the complexity required to compress and decompress are significantly different.

A. asymmetric
B. lossless
C. lossy
D. spatial
E. temporal

Review Question

Which of the following types of video can be compressed the most with temporal compression?

A. fast action

B. slow continuous motion

Reference:

- Wong, Y.L. (2013), Digital Media Primer, Pearson Education, Chapter 6
- Vaughan, T (2011), Multimedia: Making it work, McGraw-Hill, USA, 8th Ed, Chapter 8