FUNDAMENTALS OF DIGITAL VIDEO

Video signal

- Any sequence of time varying images
- Still image is a spatial distribution of intensities that remain constant with time
- Video signal is treated as a series of images called frames
- An illusion of continuous video is obtained by changing the frames in a faster manner which is generally termed as frame rate
- Real world scene is a 3D signal changing in time f(x, y, z, t)
  - At time, t, f(x, y, z) are 3D spatial coordinates of a frame
  - Where z is intensity of a pixel at x^{th} row and y^{th} column of frame at time, t

Digital Video

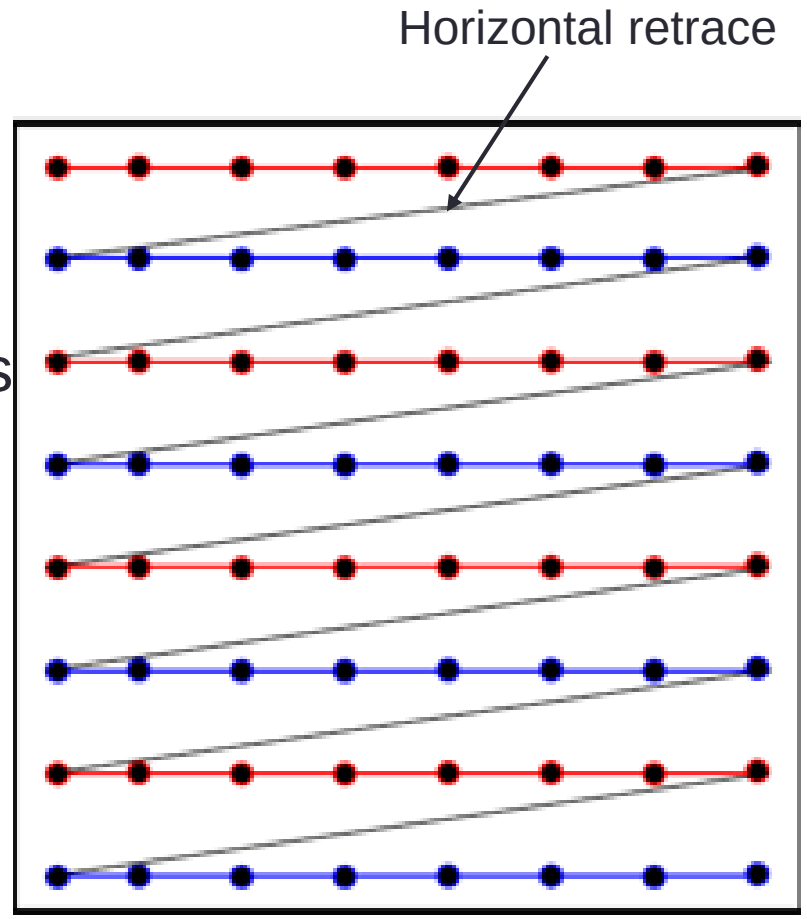
- Picture information is digitized (sampling) both spatially and temporally
- Digitization of temporally provides frame rate
- Spatial digitization included quantization of coordinates and pixel intensity

Digital Video Sampling

- Spatial sampling
  - Frame size: Number of pixels per frame
- Temporal Sampling
  - Frame rate: Number of frames per sec
  - Most video formats use temporal sampling rate of 24 frames per sec and above

Scanning of each frame

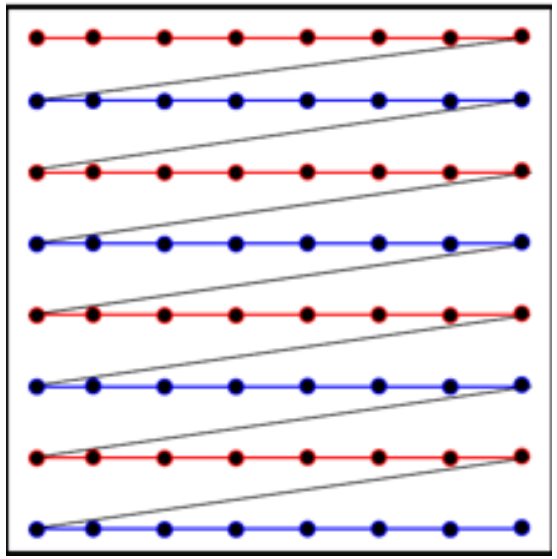
- Is a process of converting optical images into electrical signals
- During the scanning process, an electronic sensing spot moves across the image in a pattern known as a *raster*
- Starting at the upper left corner of the image, the spot moves in a horizontal direction across the frame to produce a scanning line
- It then quickly returns to the left edge of the frame (a process called *horizontal retrace*)
- A complete scan of the image is called a *frame*



Raster

Characterization of video raster (frame)

- Frame rate = f_t (frames/sec)
- Temporal sampling interval or frame time = $\Delta_t = \frac{1}{f_t}$
- Number of lines/frame = f_y (lines/picture height)
- Line rate = f_l (lines/sec) = $f_t f_s$
- Line spacing in terms of distance = $\Delta_y = \frac{picture\ height}{f_y}$
- Number of pixels/line = f_x
- Pixel spacing $\Delta_x = \frac{picture\ width}{f_x}$



Raster

Parameters of digital video

- Frame rate = f_t
- Number of lines/frame = f_y
- Number of pixels/line = f_x
- Number of bits per pixel N_b
  - $N_b = 8\ bits$ for monochrome and $N_b = 24$ bits for colour video
- Data rate R of digital video is given by

  $R = f_t * f_x * f_y * N_b\ bits/sec$

Quality of video raster

- Quality of a video raster is determined by the frame rate and resolution
- TV
  - Frame rate 25-30Hz
  - Temporal refresh rate of 50- 60Hz
  - Number of lines 560-600
- Computer
  - Frame rate of 72Hz
  - Number of lines 1024
- Higher frame rates and line numbers are used for computer applications to
  - accommodate a shorter viewing distance
  - higher frequency contents (Line graphics & texts)

Video Formats

Luminance Pixel Resolution	Typical Applications
128 X 96	Mobile Multimedia
176 X 144	Video conferencing and Mobile Mulimedia
352 X 288	Video conferencing
704 X 576	SDTV and DVD-Video
1408 X 1152	HDTV and DVD-Video

- Increase in resolution requires large bandwidth (data rate)
- To reduce data rate, each frame can be compressed
- The process is called chroma subsampling

Chroma subsampling

- Human visual system is much more sensitive to variations in brightness than color
- Video system can be optimized by allocating more bandwidth to
  the luminence component (usually denoted Y')

  than to the color difference components (ex: Cb and Cr)
- Provide less resolution for chroma information than for luma information
- This reduces file size and save transmission time
- Chroma subsampling is used in many video and still image encoding schemes
- Also used in JPEG encoding
- In compressed images, for example, the 4:2:2 Y'CbCr scheme requires two-thirds the bandwidth of non-subsampled 4:4:4
- This reduction results in almost no visual difference as perceived by the viewer

Chroma subsampling

- A video signal is split into two different aspects: luminance information and color information
- Human eye is more sensitive to changes in luminance than to chromaticity changes
- Luminance (brightness) defines details of the picture
- It shows contrast and shapes of objects
- Color information, chrominance (chroma) has less visual impact
- Chroma subsampling reduces the amount of color information in the signal to allow more luminance data
- This maintains picture clarity while effectively reducing the file size up to 50%

Chroma Subsampling

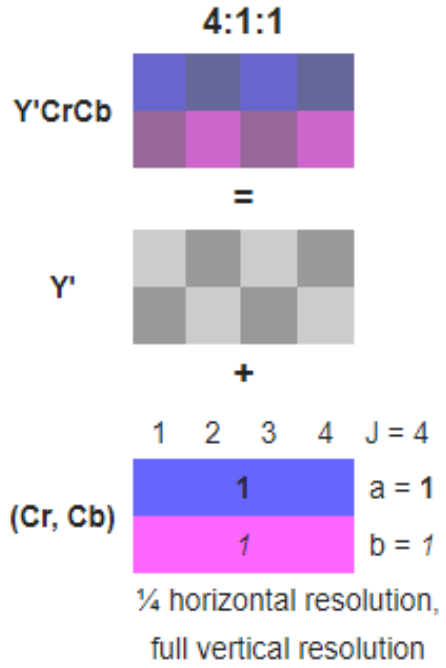
- Reduces dimension of video (horizontal or vertical dimension)
- Compressed images are interpolated for display
- RGB format is not preferred because R, G, B components are correlated
- To overcome this, the RGB images are converted to YCbCr components (one luminance and two chrominance components)
- And these components can be sampled to reduce the number of pixels
- Subsampling for PC uses YCbCr or YUV format as RGB does not support it

Chroma (C_r and C_b) subsampling format

- The subsampling scheme is commonly expressed as a three-part ratio *J*:*a*:*b* (e.g. 4:2:2)
- *J*: horizontal sampling reference (number of pixels), usually, 4
- *a*: number of chrominance samples (Cr, Cb) in the first row of *J* pixels
- *b*: number of changes of chrominance samples (Cr, Cb) between first and second row of *J* pixels
- Parameter *b* is either zero or equal to *a*

Chroma (for C_r and C_b) subsampling format

Parameters are J:a:b
J is number of samples
a and b are related to chroma signal and define horizontal and vertical sampling respectively
= number of chrominance samples having same chroma sample in first row
b= number of changes in pixel intensity from first to second row



Formats that use 4:1:1 chroma subsampling include:

- DVCPRO (NTSC and PAL)
- NTSC DV and DVCAM
- D-7

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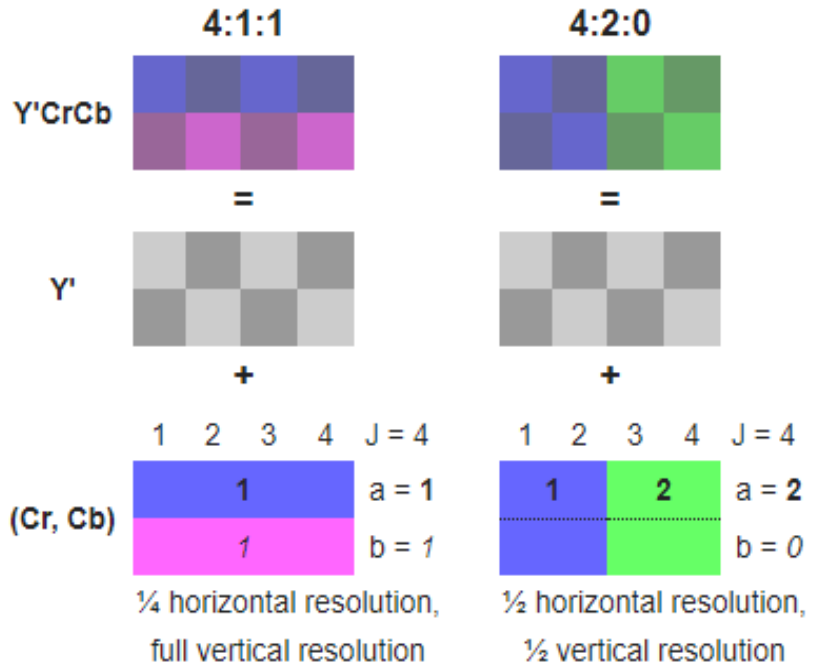

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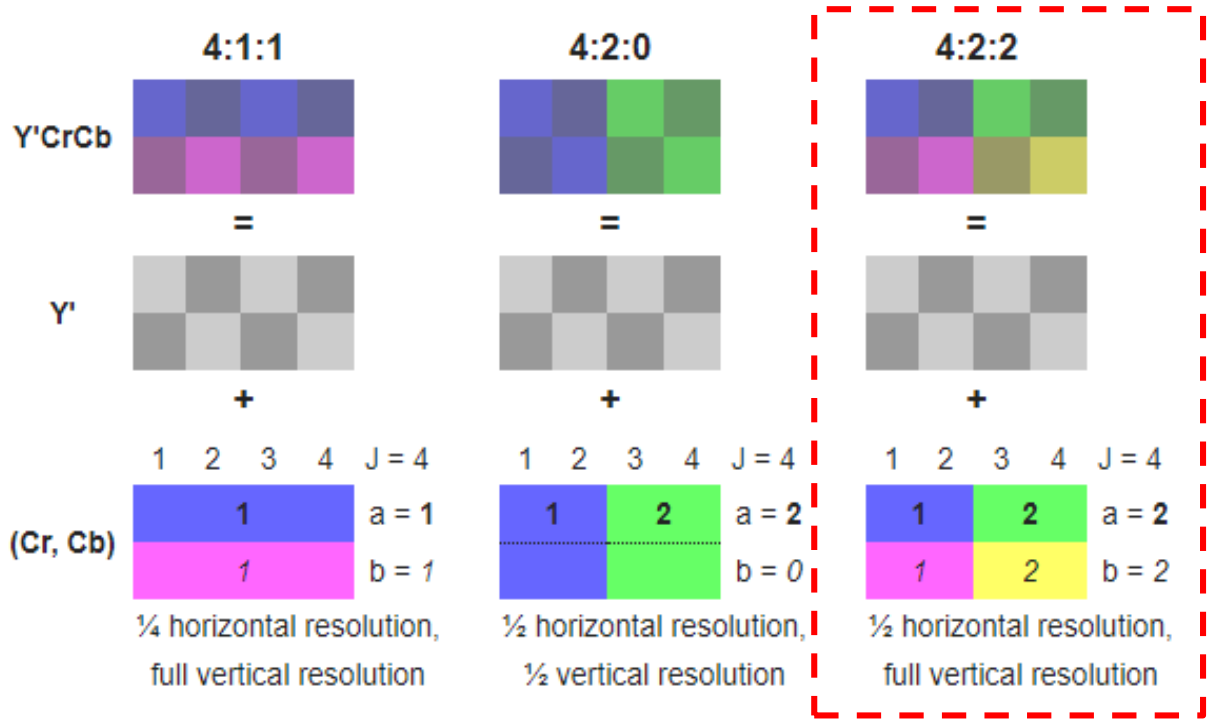
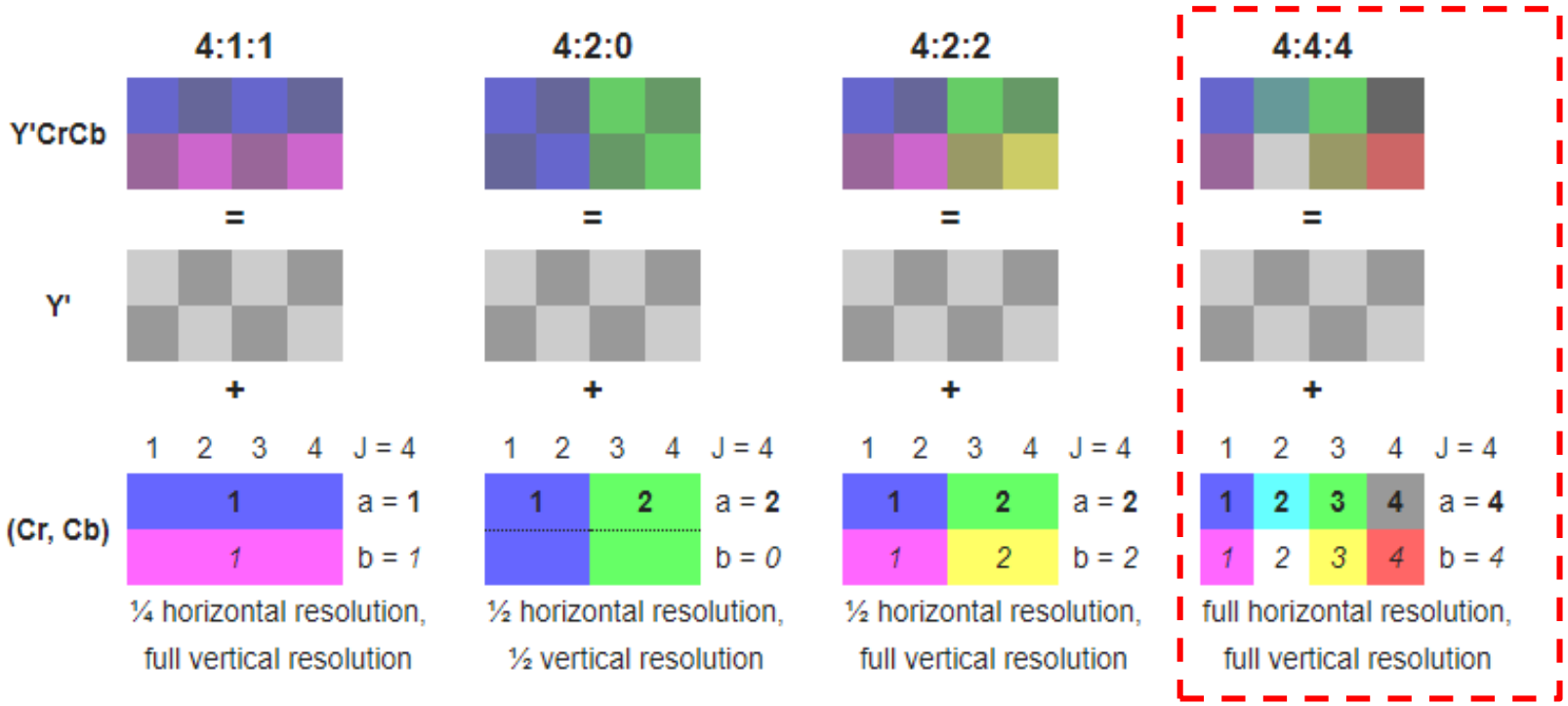


- Reduces the bandwidth of an uncompressed video signal by one-third
- Many high-end digital video formats and interfaces use this scheme:
  - AVC-Intra 100
  - Digital Betacam
  - Betacam SX
  - DVCPRO50 and DVCPRO HD
  - Digital-S
  - CCIR 601 / Serial Digital Interface / D1
  - ProRes (HQ, 422, LT, and Proxy)
  - XDCAM HD422
  - Canon MXF HD422

Chroma subsampling format

- A signal with chroma 4:4:4 has no chroma subsampling
- Therefore no compression and transports both luminance and color data entirely
- Sometimes used in high-end film scanners and cinematic post-production.



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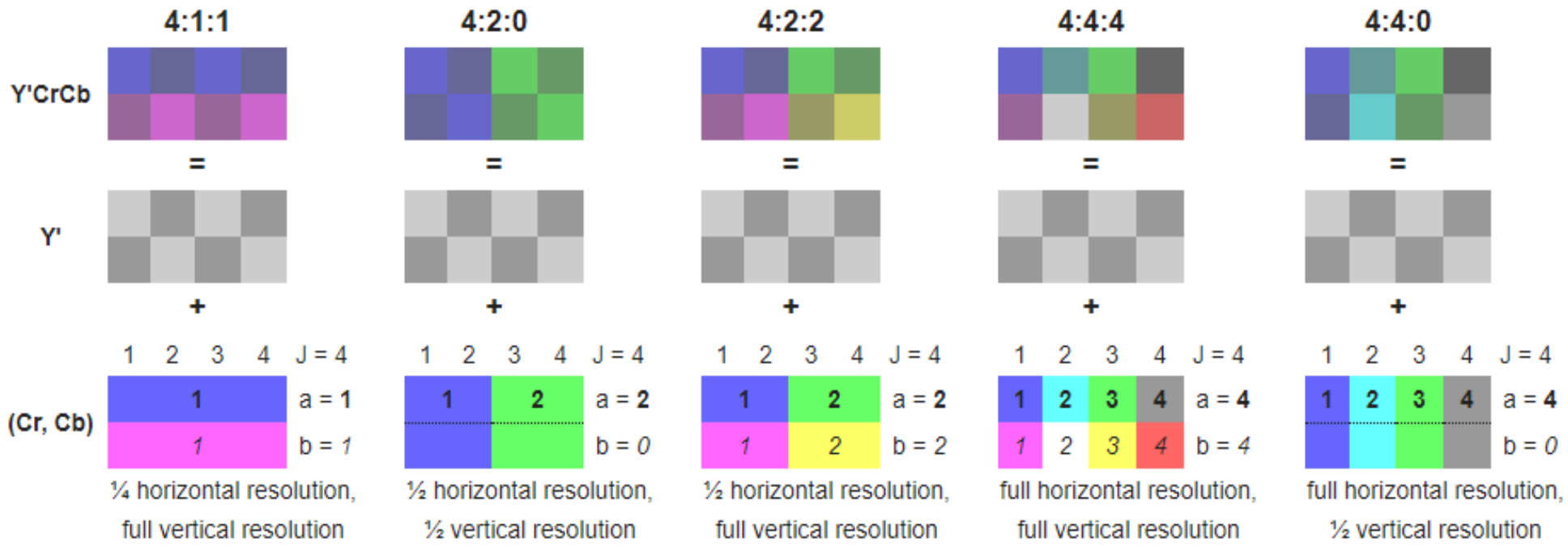

Applications of Chroma subsampling

	Subsampling	Visual Impact
PC	4:4:4	Major
Movies	4:2:0	None
Video Games	4:4:4	Minor
Sports	4:2:0	None
TV Shows	4:2:0	None

Chroma 4:4:4

- Chroma 4:4:4 does not use subsampling
- Therefore all the lines are clear

Chroma 4:2:2

- Lack of detail is apparent in the bottom two rows
- The text is not clear and is completely unreadable

- Artifacts from chroma subsampling are noticeable with text atop a flat color
- Impact is less visible in videos and photos
- This matters when TV is connected to a computer
- Text may be blurry and unreadable

Chroma 4:2:0

- 4:2:2 fares better than 4:2:0 but not acceptable

Chroma Subsampling for Movies and TV shows

- 4:2:0 subsampling has been an industry standard for a long time
- The benefits of having full color in video are debatable
- It is tough to recognize the difference between a full 4:4:4 sequence and the same content in 4:2:0
- 4:2:0 is almost lossless visually, which is why it can be found used in Blu-ray discs and a lot of modern video cameras
- There is virtually no advantage to using 4:4:4 for consuming video content
- Higher the resolution and pixel density of future displays, the less apparent subsampling artifacts become
- Video games
  - Some PC games that have a strong focus on text suffer from using chroma subsampling
  - Most of them are either designed accordingly