ANALOG AND DIGITAL VIDEO

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with material from Mark Handley

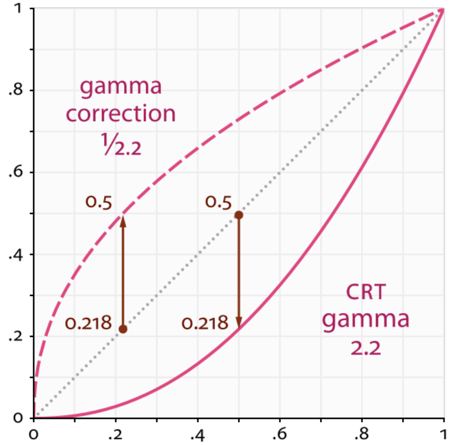
Objectives

- Understand the concept of display gamma
- How are video pixels represented?
- What is lossless coding?
- How do JPEG, PNG and GIF work?
- How does MPEG reduce the bit rate?

Gamma correction

- non-linear transformation between value and brightness $V_{\text{out}} = AV_{\text{in}}^{\gamma}$
- similar to μ-law in audio
  - brightness sensitivity differs non-linearly

$$\gamma = \frac{\mathrm{d}\log(V_{\text{out}})}{\mathrm{d}\log(V_{\text{in}})}$$



Wikipedia

Video types

- Bi-level images: black and white
  - fax, printed output (at pixel level)
- Gray level (monochrome) images
- Color (continuous tone)

Image type	pixels per frame	bits/pixel	uncompressed size
fax (200 dpi)	1700x2200	1	3.75 Mb
VGA	640x480	8	2.46 Mb
XVGA	1024x768	24	18.87 Mb

Video formats

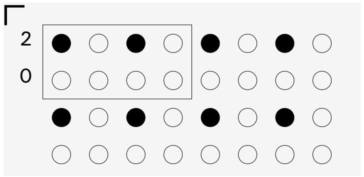
- SD (standard def. NTSC) = 646 x 486
- HDTV
  - progressive (“p”) vs. interlaced (“i”)
  - 480p = 852 x 480 pixels
  - 720p = 1280 x 720
  - 1080p = 1920 x 1080
- Aspect ratio:
  - TV: 4:3 (classical TV)
  - widescreen: 16:9 (HDTV, DVD)

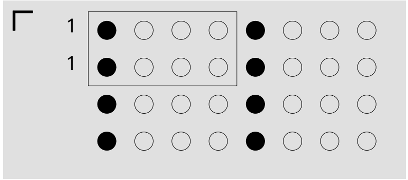
Chroma subsampling

- Human eye more sensitive to luminance than chrominance details
- J:a:b = Pattern size (4) : chrominance first row : second row
- Should average, rather than just replicate

YUV Formats

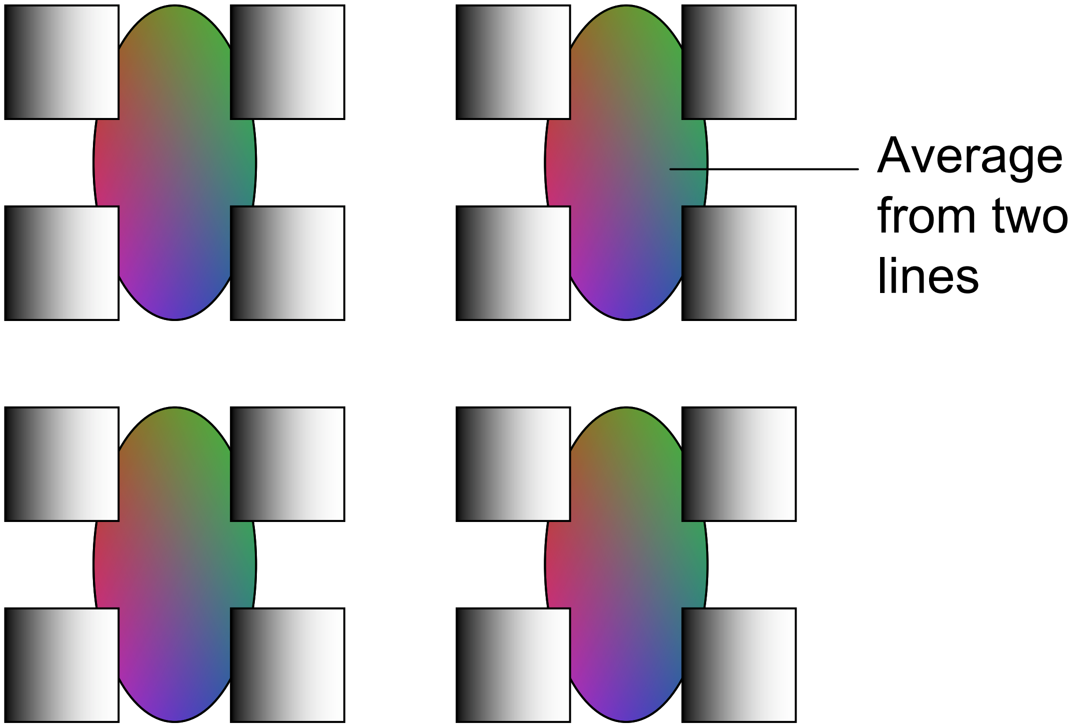
- YUV 4:4:4
  - 8 bits per Y,U,V channel (no chroma subsampling)
- YUV 4:2:2
  - 4 Y pixels sample for every 2 U and 2V
  - 2:1 horizontal downsampling, no vertical downsampling
- YUV 4:2:0
  - 2:1 horizontal downsampling
  - 2:1 vertical downsampling
- YUV 4:1:1
  - 4 Y pixels sample for every 1 U and 1V
  - 4:1 horizontal downsampling, no vertical downsampling





YUV 4:2:0

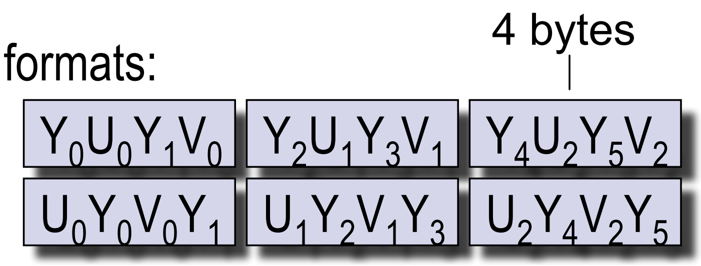
YUV 4:2:0 (MPEG1/H.261/H.263)



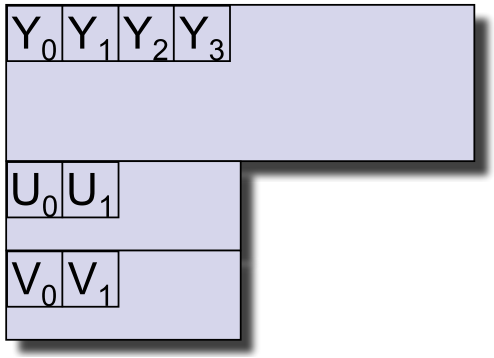
Video stream format

Video Stream Format

- YUV 4:2:2 formats:
  - YUV2:
  - UYVY:



- YUV 4:2:0 formats (12 bits per pixel packed format)
  - YV12



All the Y samples precede all the U samples, then all the V samples

Uncompressed video rates

Format	resolution	sampling	bits/pixel	fps	rate
PAL	684x625	4:2:2	20	25	270 Mb/s
PAL	684x625	4:2:2	16	25	216 Mb/s
PAL	720x576	4:2:2	16	25	166 Mb/s
720p	1280x720	4:2:0	24	60	663 Mb/s
1080p	1920x1080	4:2:0	24	60	1.49 Gb/s

Thunderbolt: 20 Gb/s PCIe
USB: < 4 Gb/s

Image & video compression – in brief

- unlike audio, no physiological model (masking)
  - except lower color resolution than luminance
- statistical redundancy
  - background correlation
  - correlations across an image
  - nearby pixel correlation
  - frame correlation (motion compensation)
- subjective redundancy
  - impact of different impairments
  - block artifacts, noise, stair step (“jaggies”), …

Image compression

- TIFF (tagged image file format) – container file
- XBM, BMP (bitmap image format) - uncompressed
- GIF (Graphics Interchange Format)
    - including “animated GIF”
- PNG (Portable Network Graphics)
- MNG (Multiple-image Network Graphics)
- JPEG (Joint Picture Expert Group)
- JPEG-2000

GIF (Graphics Interchange Format)

- Lossless compression for computer-generated images
- CompuServ 1987 (GIF87a)
- GIF89a: metadata, multiple images ("animated")
- Indexed image format:
  - 256 colors from palette → not suitable for photography
  - one color index may indicate *transparency*
  - lossless LZW compression
  - interlacing optional
- First image format for NCSA Mosaic
- Good for diagrams, logos, icons, …
  - avoids speckling of sharp edges (writing)

GIF patent issues

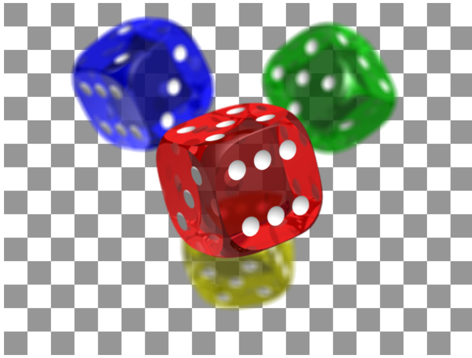
- 1984: algorithm published in *IEEE Computer* magazine
- 1985: LZW patent US 4558302 issued to Unisys
- 1987: CompuServ develops GIF
- 1994: license agreement, controversy
- 1995: PNG developed in response
- 2003/2004: patent expires

LZW compression

- dictionary contains longer and longer strings
- send dictionary index
  - possibly entropy-encoded

```
dictionary = one entry per byte
string = ''
foreach ($input as $ch) {
  if (input + char in dictionary) {
    string += char
  } else {
    emit dictionary code for string
    add string + char to dictionary
    string = char
  }
}
output code for string
```

PNG (Portable Network Graphics)



PNG with alpha channel

alpha = 0.3

- Lossless image format:
  - Palette-based (24 bit RGB)
  - RGB
  - Grayscale
- Does not support other color spaces (e.g., CMYK)
- RFC 1951
- Compression:
  - line-by-line filter (predictor) → see DPCM
    - byte to left, byte above, average of left & above, Paeth filter
  - DEFLATE (zlib, LZ77 + Huffman)

LZ77

- Abraham Lempel and Jacob Ziv in 1977
- dictionary code
- sliding window compression
- "each of the next length characters is equal to the characters exactly distance characters behind it in the uncompressed stream" (Wikipedia)

Huffman coding

- Goal: get close to entropy $H(x) = \sum p(x) \log(1/p(x))$
- Source coding theorem: exists coding $[H(x), H(x)+1)$
- Uniquely decodable
- Easy to decode → prefix code (“self-punctuating”)
  - no code word is a prefix of another code word
  - otherwise, would need delimiters
- Huffman: 1951 student paper

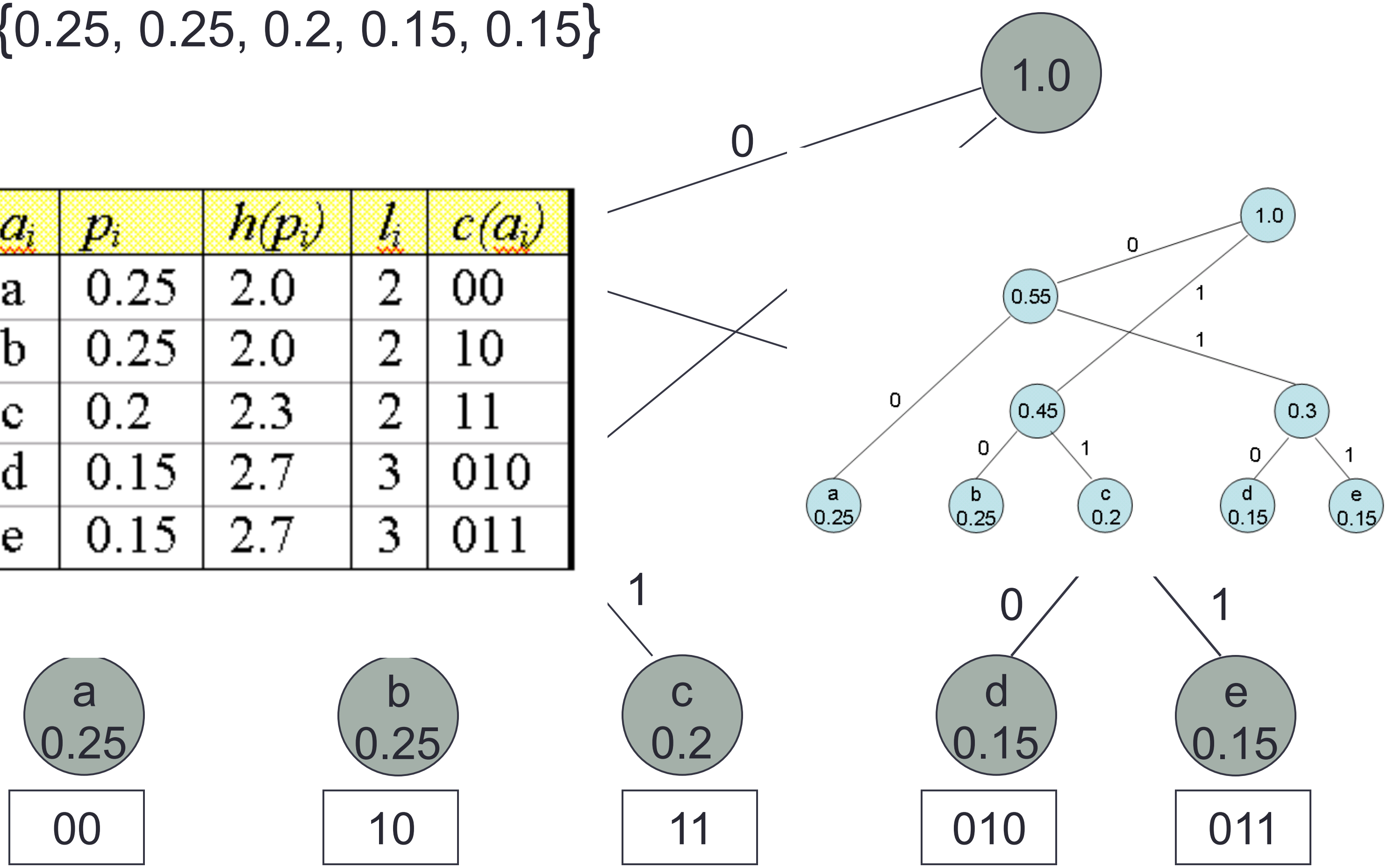
Huffman algorithm

- Take the two least probable symbols in the alphabet
  - become longest code words, differing in last bit
- Combine into single symbol
- Repeat

Example

- A_x={ a , b , c , d , e }
- P_x={0.25, 0.25, 0.2, 0.15, 0.15}

a_i	p_i	$h(p_i)$	l_i	$c(a_i)$
a	0.25	2.0	2	00
b	0.25	2.0	2	10
c	0.2	2.3	2	11
d	0.15	2.7	3	010
e	0.15	2.7	3	011



Huffman limitations

- Optimal only for independent symbols
  - but most sources have correlated symbols (e.g., within word)
- Changing ensemble

Run-length encoding (RLE)

- Value (repeat)
  - 1110011111 → 1 3 0 2 1 5
  - Common for images (e.g., line)
    - horizontal and vertical
  - JPEG DCT output
  - easily reversible, lossless

GIF, PNG

GIF: 30,000 bytes

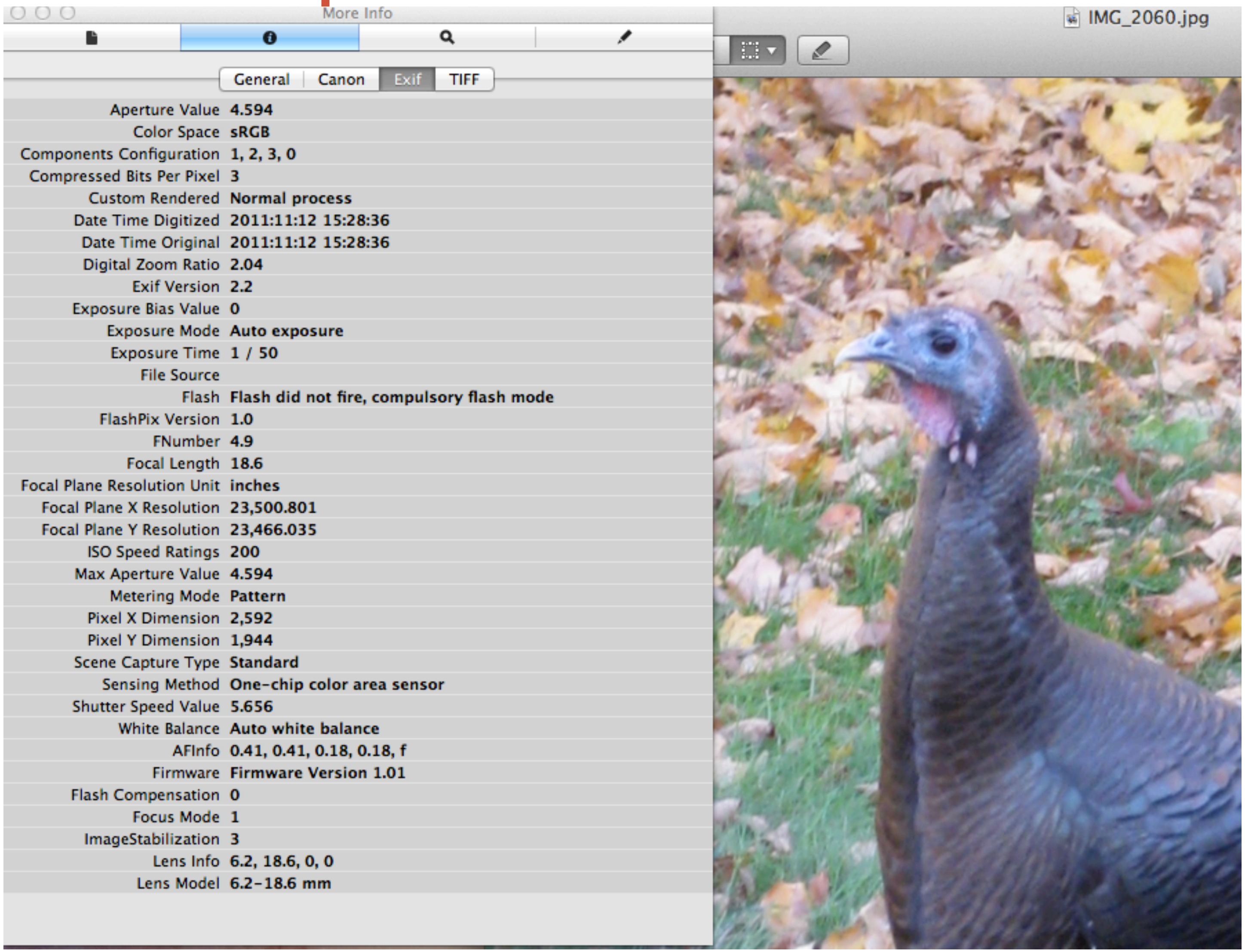
PNG: 83,257 bytes

JPEG: 53,401 bytes

JPEG (Joint Photographic Experts Group)

- Good for compressing photographic images
  - gradual changes in pixel chrominance & luminance
- not good for line-style graphics
  - edges in image (text, sharp lines)
- compression ratio of 10:1 achievable without visible loss.
- uses JFIF or EXIF file format for meta information:
  - Application Segment #0
  - include photographic, author and geo data
  - http://www.cipa.jp/english/hyoujunka/kikaku/pdf/DC-008-2010_E.pdf

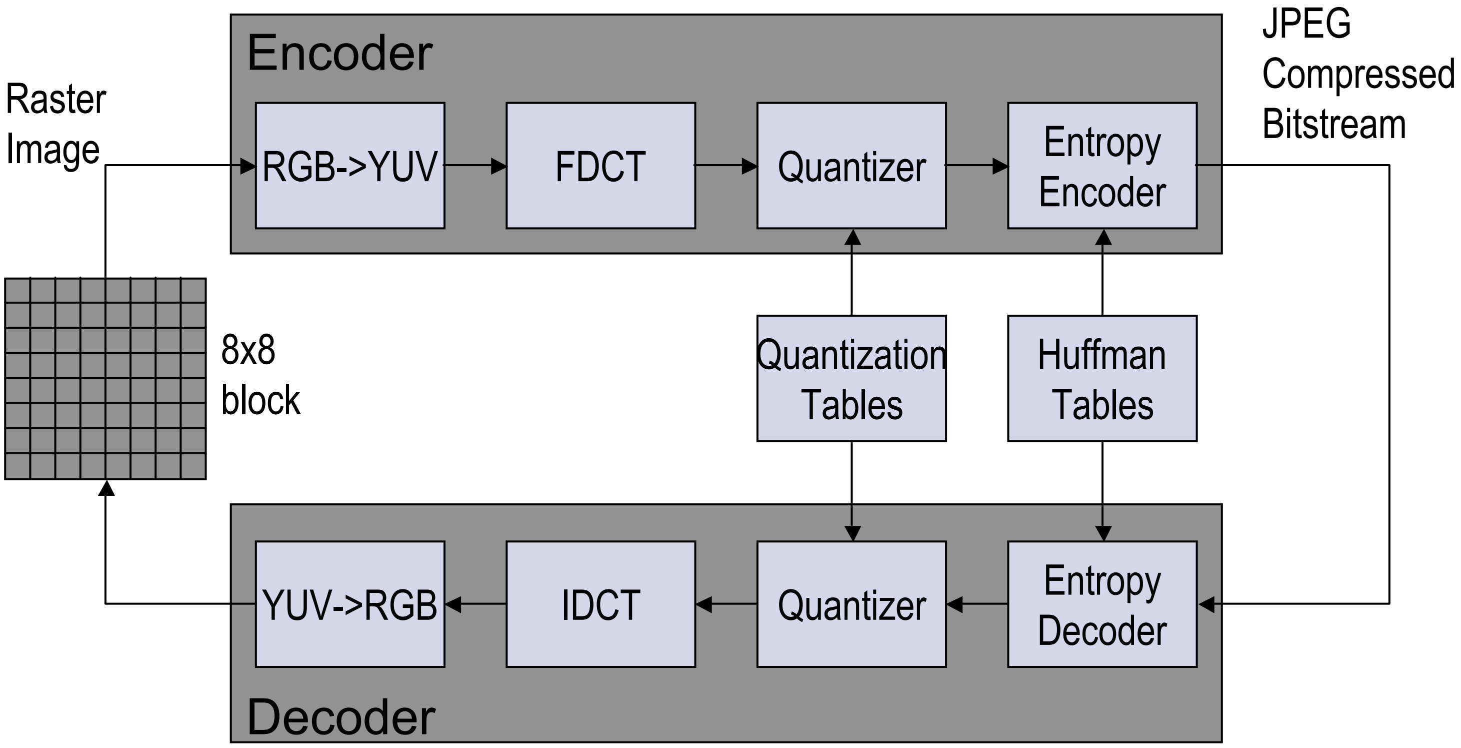
EXIF example



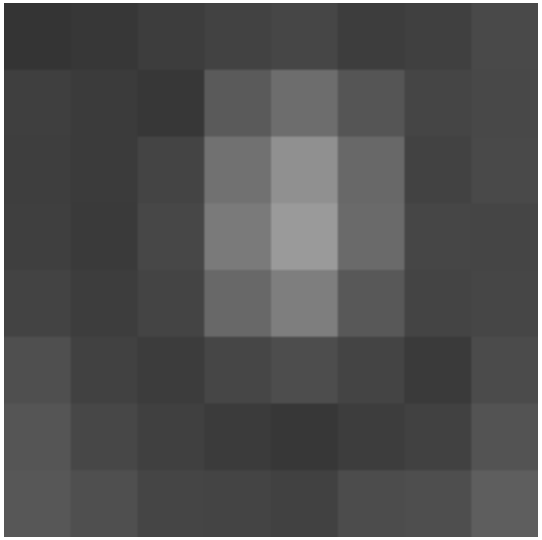
JPEG

- Convert RGB (24 bit) data to YUV
  - typically, 4:2:0
  - → three sub-images: Y, Cb, Cr
  - Cb, Cr half the width & height of Y image
- Divide each image into 8x8 tiles
- Convert into frequency space: two-dimensional DCT
- Quantize in frequency domain
  - lower frequencies → more bits/value
- Encode quantized values using Huffman and RLE zig-zag manner

JPEG Diagram



JPEG example



original 8x8 luminance block

52	55	61	66	70	61	64	73
63	59	55	90	109	85	69	72
62	59	68	113	144	104	66	73
63	58	71	122	154	106	70	69
67	61	68	104	126	88	68	70
79	65	60	70	77	68	58	75
85	71	64	59	55	61	65	83
87	79	69	68	65	76	78	94

sample values

Wikipedia

Subtract 128 from each value to convert to signed

Then apply FDCT:

$$T(i,j) = c_i c_j \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} V(y,x) cos \frac{(2y+1)i\pi}{2N} \cos \frac{(2x+1)j\pi}{2N}$$

$$c_i = \sqrt{1/N} \;\text{ if }\; i = 0,\;\; c_i = \sqrt{2/N} \;\text{ otherwise. Similarly }\; c_j$$

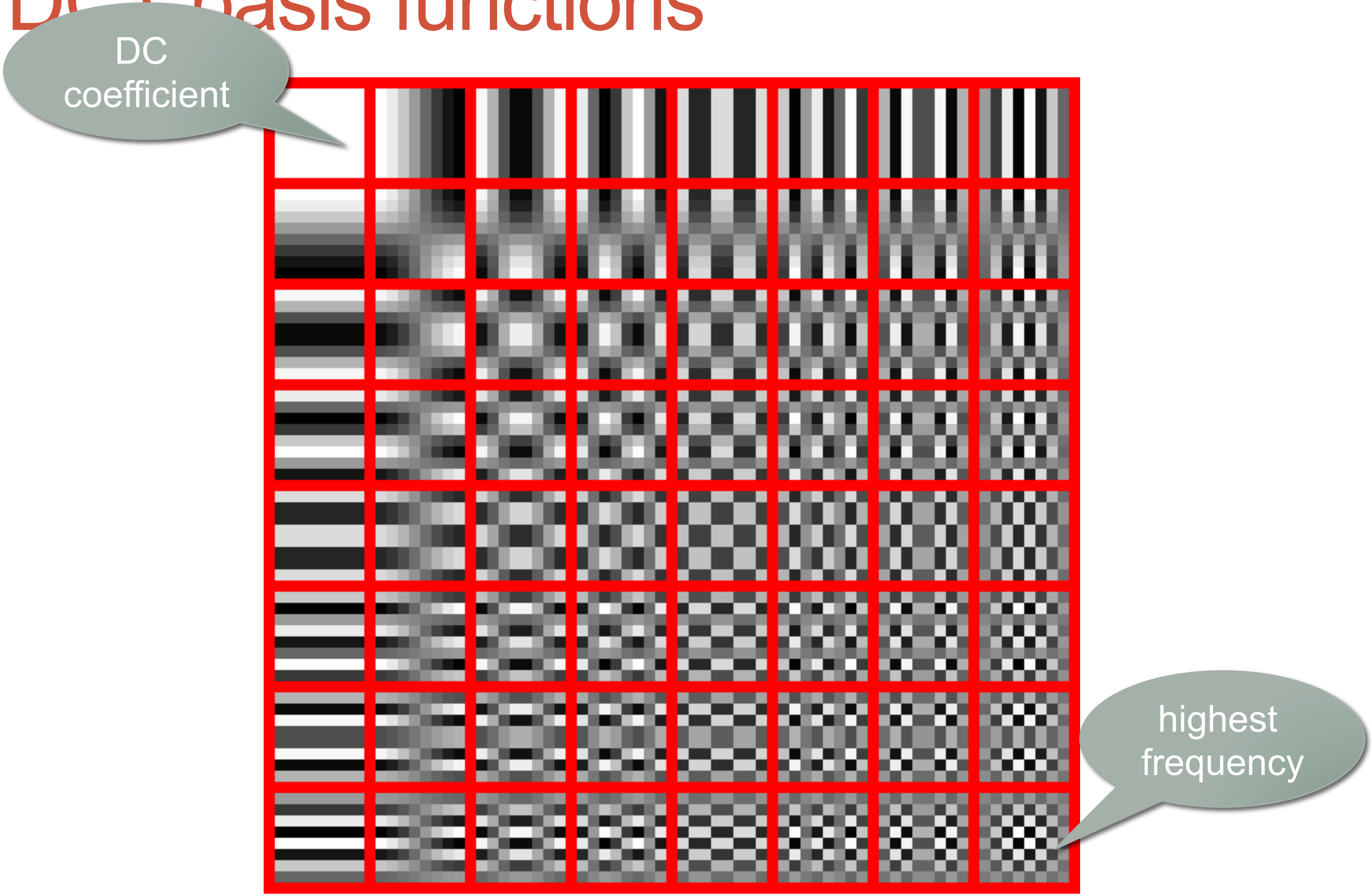
Giving:

-415	-30	-61	27	56	-20	-2	0
5	-22	-61	10	13	-7	-8	5
-47	7	77	-24	-29	10	5	-6
-49	12	34	-15	-10	6	2	2
12	-7	-13	-4	-2	2	-3	3
-8	3	2	-6	-3	1	4	2
-1	0	0	-3	-1	-3	4	-1
0	0	-1	-4	-1	0	0	2

Note DC Coefficient has lots of power

Very little power in high frequencies

DCT basis functions



Wikipedia

Quantize using a quantization matrix such as:

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Better quantization at low frequencies

Coarse quantization at high frequencies

Eg round(-415/16) = -26

Giving:

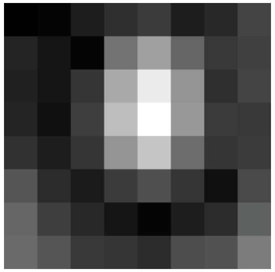
-26	-3	-6	2	2	-1	0	0
0	-2	-4	1	1	0	0	0
-3	1	5	-1	-1	0	0	0
-4	1	2	-1	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

High frequencies often quantize to zero

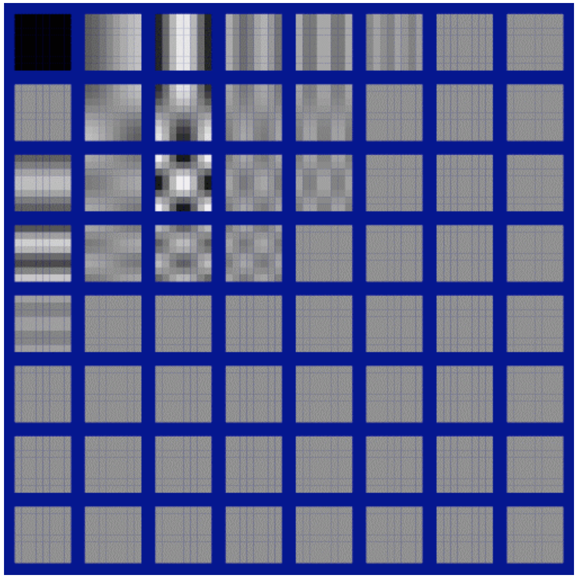
Quantized DCT coefficients:

-26	-3	-6	2	2	-1	0	0
0	-2	-4	1	1	0	0	0
-3	1	5	-1	-1	0	0	0
-4	1	2	-1	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Original Image:

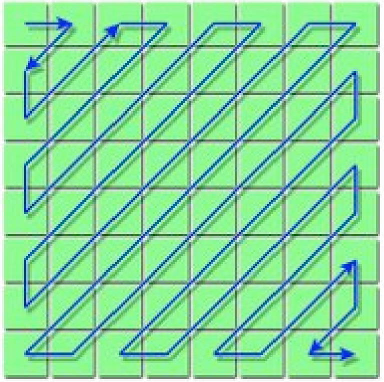


Scaled DCT basis functions that make up the (quantized) image



Order the coefficients in zig-zag order:

−26	−3	−6	2	2	−1	0	0
0	−2	−4	1	1	0	0	0
−3	1	5	−1	−1	0	0	0
−4	1	2	−1	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0



−26, −3, 0, −3, −2, −6, 2, −4, 1, −4, 1, 1, 5, 1, 2, −1, 1, −1, 2, 0, 0, 0, 0, 0, −1, −1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,

Run-length encode:

−26, −3, 0, −3, −2, −6, 2, −4, 1, −4, {2 x 1}, 5, 1, 2, −1, 1, −1, 2, {5 x 0} , −1, −1, EOB

Huffman code what remains.   Encoding is complete.

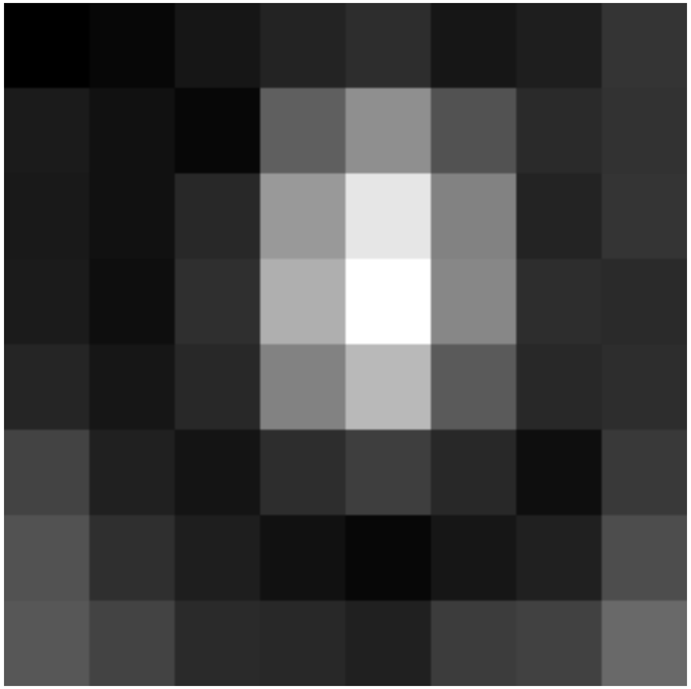
JPEG Decoding

- Decoding is simply the reverse of encoding.
- Reverse the huffman, RLE encodings.
- Dequantize.
- Apply inverse DCT (IDCT):

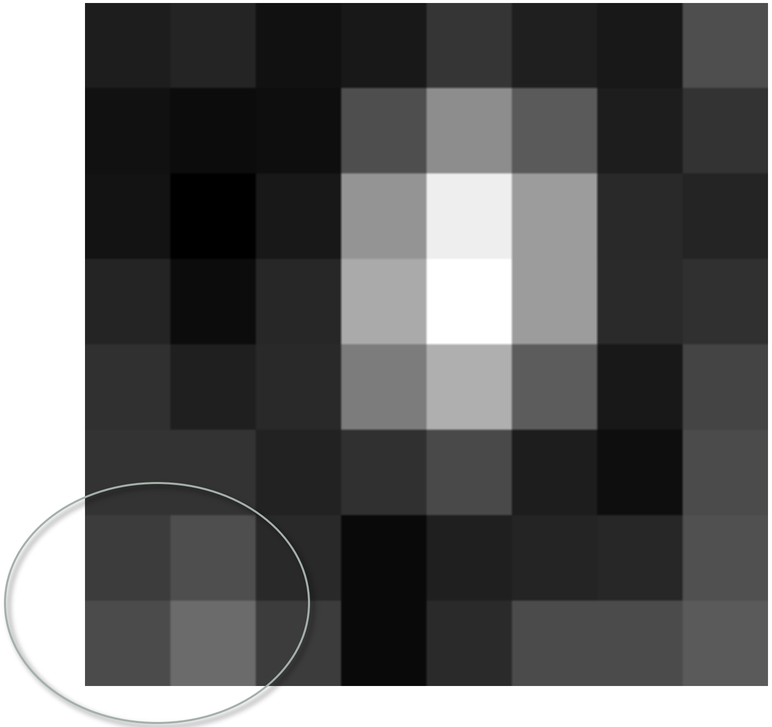
$$V(x,y) = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} c_i c_j T(i,j) cos \frac{(2y+1)i\pi}{2N} \cos \frac{(2x+1)j\pi}{2N}$$

- Add 128 to convert back to unsigned.

Original & decompressed



original image



decompressed image

JPEG compression ratio

- compression ratio depends on quantization matrix
- effect depends on rendering size and image content
- 10:1 typical
- 100:1 with artifacts (blockiness)

Lenna

PNG 473,481 bytes
(512x512)

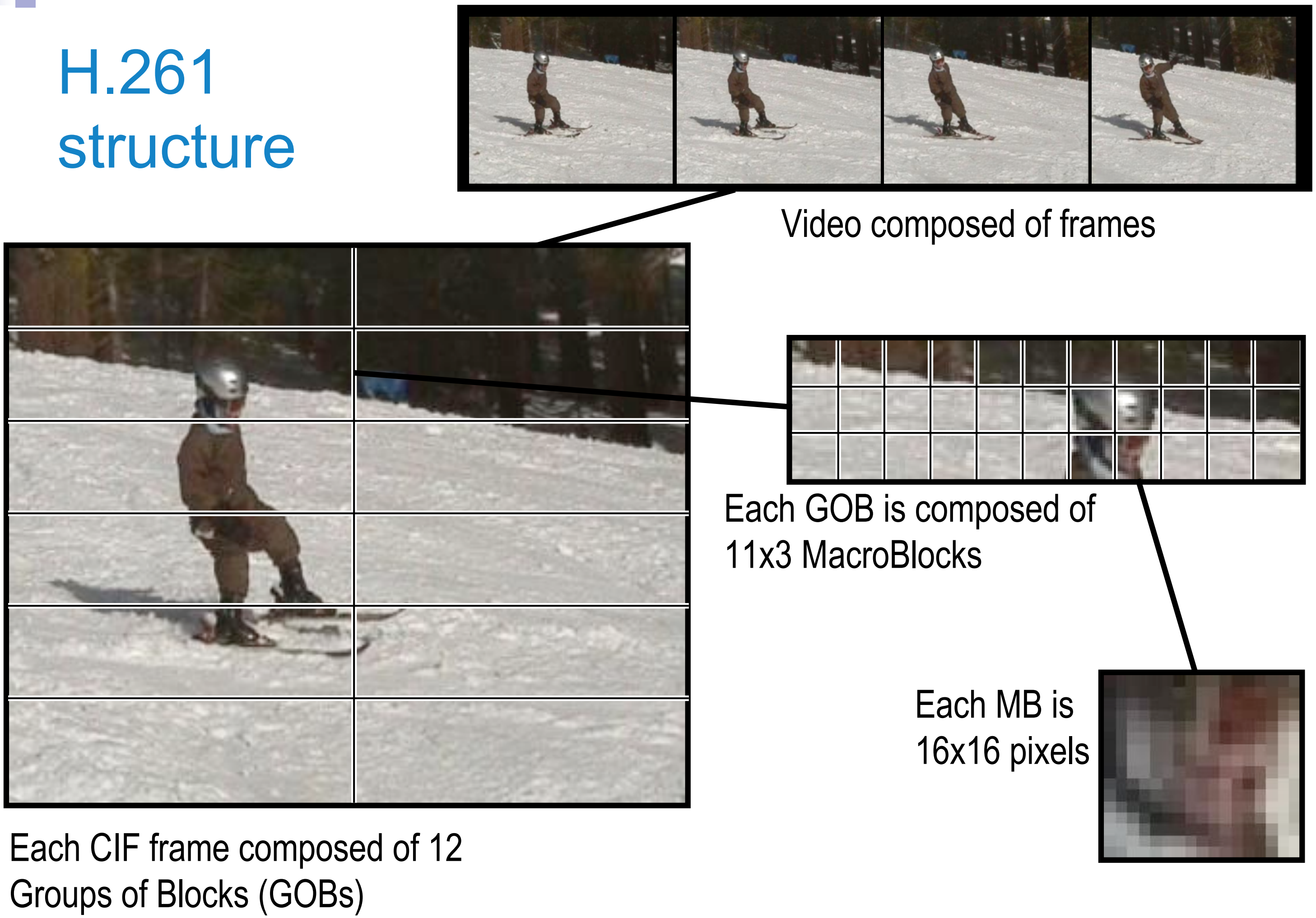
JPEG, lowest quality, 19,100 bytes

H.261 VIDEO

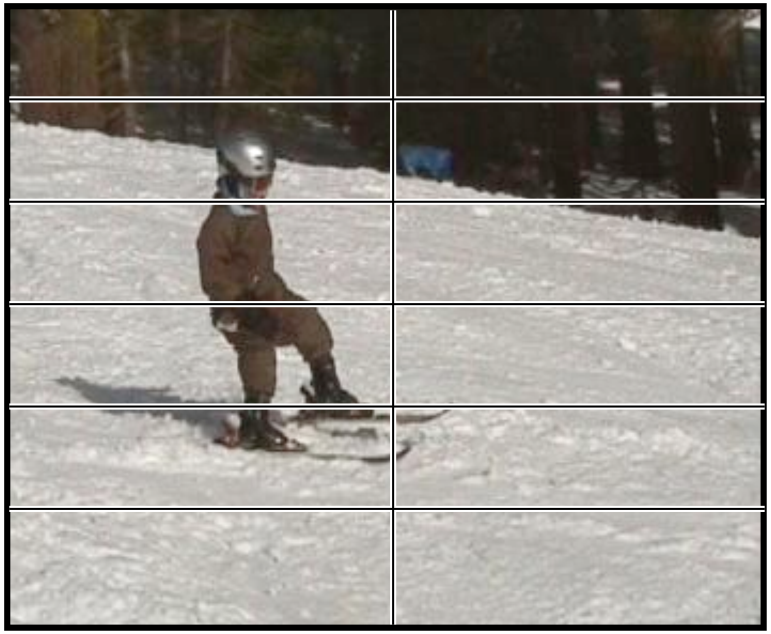
H.261 Video

- H. 261 Compression was designed for videotelephony and videoconferencing applications.
  - Developed by CCITT (now ITU-T) in 1988-1990
  - Intended for use over ISDN telephone lines, as part of the H.320 protocol suite.
  - Datarate was specified as multiples of 64Kb/s ("p x 64")
- Goals for ISDN videotelephony:
  - Low end-to-end delay.
  - Constant bit rate.

H.261 structure



CIF and QCIF Frame Formats



Each CIF frame (352x288 pixels) is composed of 12 Groups of Blocks (GOBs)

Each QCIF frame (176x144 pixels) is composed of 3 Groups of Blocks (GOBs)

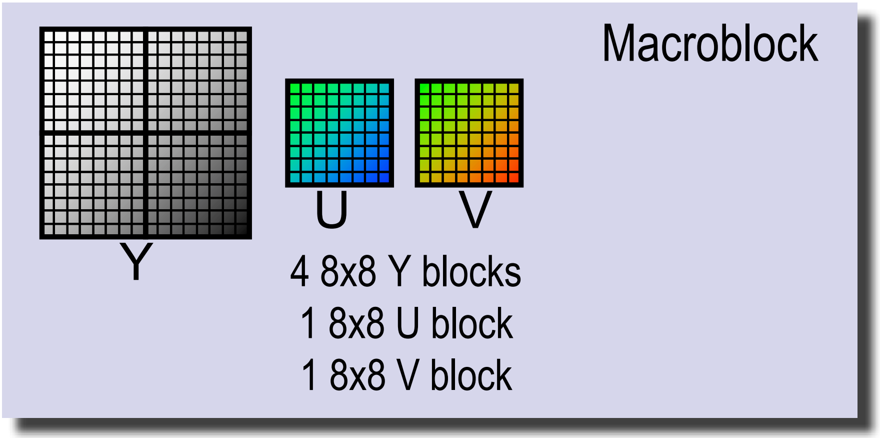
GOB and MacroBlock format is identical in both frame formats.

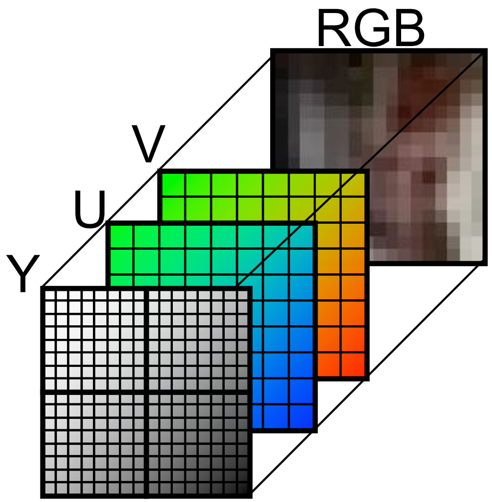
GOB and Resynchronization

- Purpose of Group of Blocks is resynchronization.
- GOB starts with a sync code (binary: 00000000 00000001)
- Within a GOB, encoded MBs don't even start on byte boundaries.
  - If there's a bit error and you lose sync, or you join in the middle, you can't decode the next bits (you don't know where you are in the bitstream).
  - Scan for the next GOB sync code, and then you can start decoding.

Macroblocks

- Macroblock is basic unit for compression.
- Each macroblock is 16x16 pixels.
  - Represent as YUV 4:2:0 data.
  - 16x16 Luminance (Y) and subsampled 8x8 C_r, 8x8 C_b
- Represent this as 6 Blocks of 8x8 pixels:





Macroblock coding

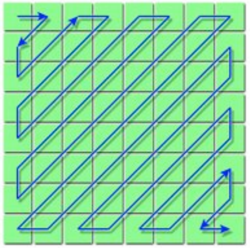
Three ways to code a Macroblock:

1. Don't.
   - If it hasn't changed since last frame, don't send it.
2. Intra-frame compression
   - Do DCT, Quantize, Zig-zag, Run-length encoding, and Huffman coding. Just like JPEG.
3. Inter-frame compression
   - Calculate difference from previous version of same block.
   - Can use motion estimation to indicate block being differenced can from a slightly different place in previous frame.
   - Same DCT/quant/huffman coding as Intra, but data is differences rather than absolute values.

H.261 intra-frame compression

Intra-coding of blocks is very similar to JPEG:

- DCT.
- Quantize DCT.
  - Unlike JPEG, H.261 uses the same quantizer value for all coefficients.
  - Feedback loop changes quantizer to achieve target bitrate.
- Order coefficients in zig-zag order.
- Run-length encode.
- Huffman code what remains.

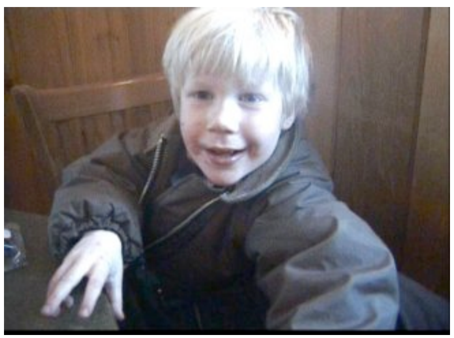


H.261 inter-frame compression

- Basic compression process is the same as intra-frame compression, but the data is the differences from the immediately preceding frame rather than the raw samples themselves.

Frame Differencing

Often the amount of information in the difference between two frames is a lot less than in the second frame itself.



Frame 1

Frame 2

Difference:
Frame 2 - 1

Motion

- Motion in the scene will increase the differences.
- If you can figure out the motion (where each block came from in the previous frame):
  - Encode the motion as a motion vector (two small integers indicating motion in x and y directions)
  - Encode the differences from the *moved* block using DCT + quantization + RLE + Huffman encoding.

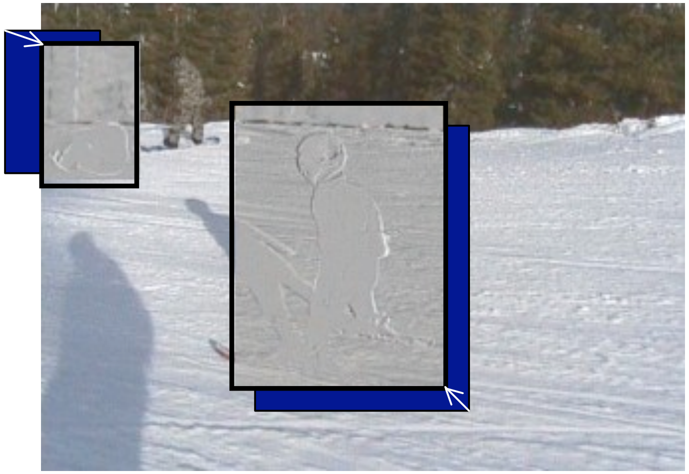
Motion

Frame 1

Frame 2

Coding from moved part of previous image can reduce the differences

Frame 2 - 1
(lots of motion)



Motion Compensation in H.261

- Each inter-coded 16x16 pixel macroblock has its own motion vector.
  - Applies to all six 8x8 blocks in the macroblock.

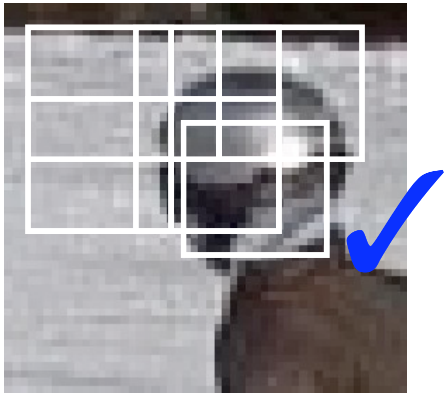
- Encoder must search the image surrounding the MB to discover where it came from.
  - Don't care whether it's really motion or not - only that differencing reduces the data to send.
  - Motion Vector search can be the most CPU-intensive part of H.261.
  - Standard doesn't say how to do this - only how to decode the results. Plenty of room for innovation.

Motion Vector Search

Where did this Macroblock come from in the previous frame?

Motion Vector Search

Where did this Macroblock come from in the previous frame?

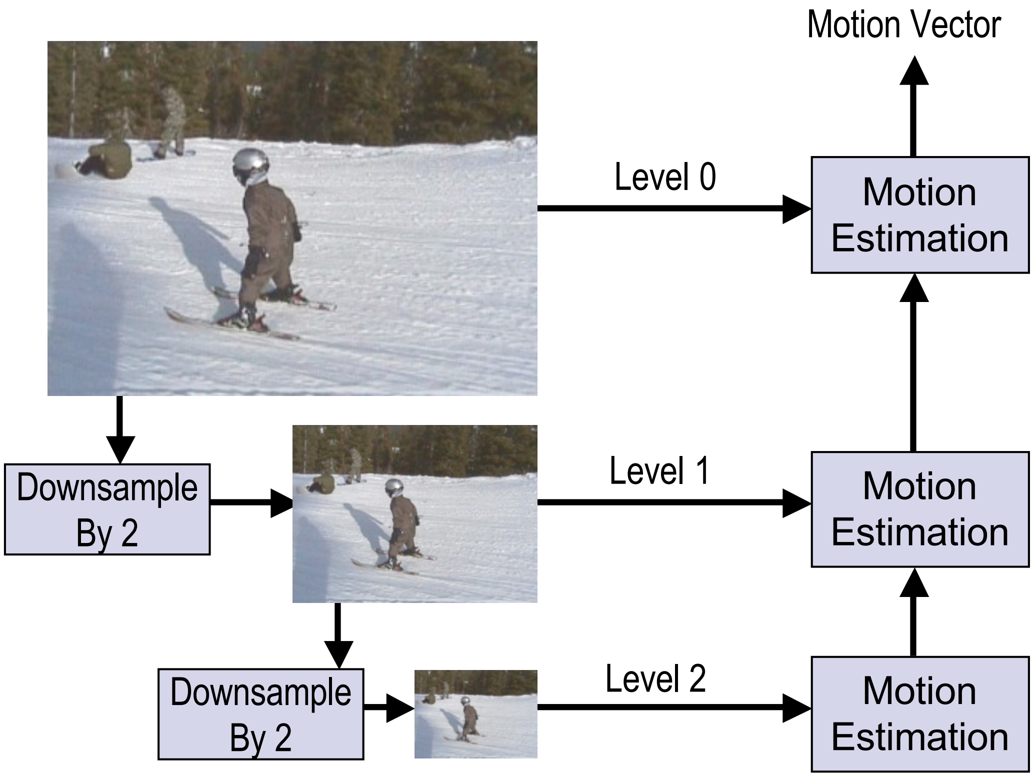


Motion Vector Search: Brute Force

- Each motion vector can encode motions of ±15 pixels in both x and y direction.
- $30^2 = 900$ possible vectors for each Macroblock.

- Calculate mean difference for each possible vector. Choose vector with least mean difference.
  - ⇒256 subtractions and 256 additions per possible vector
  - ⇒ 460K calculations per MB,
  - ⇒ 182M calculations per frame (CIF),
  - ⇒ 5.5 billion calculations per second (30fps NTSC video).
  - ⇒
- Not possible on today's CPUs.

Hierarchical Search



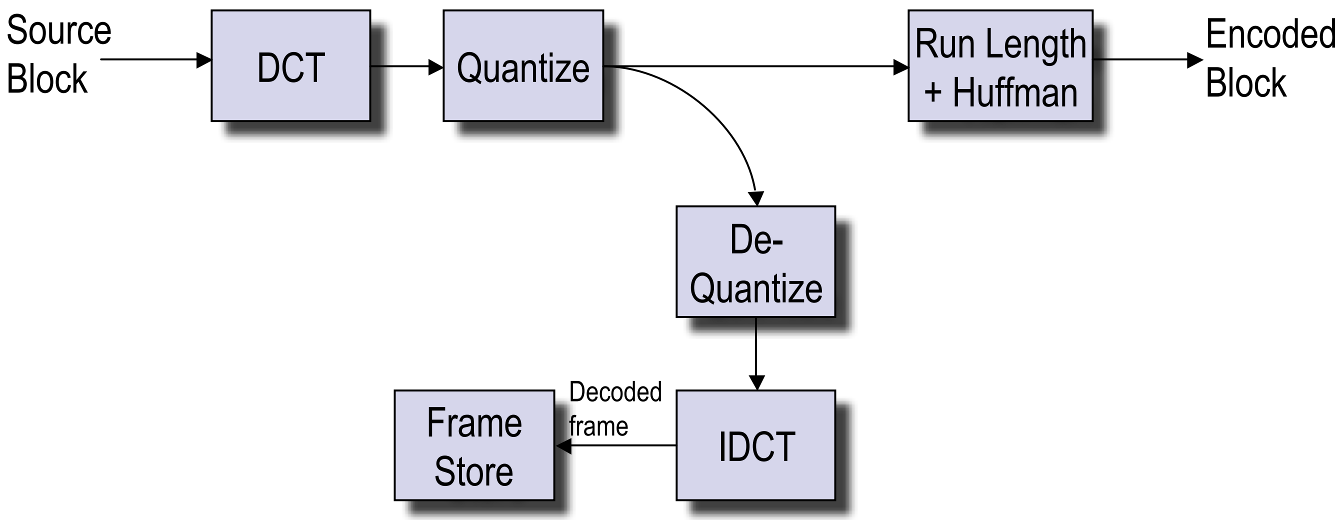
Motion vectors: ±1
around level 2 result
⇒9 positions checked
⇒16^2*2 ops per check
⇒ 4608 ops

Motion vectors: ±1
around level 2 result
⇒9 positions checked
⇒8^2*2 ops per check
⇒ 1152 ops

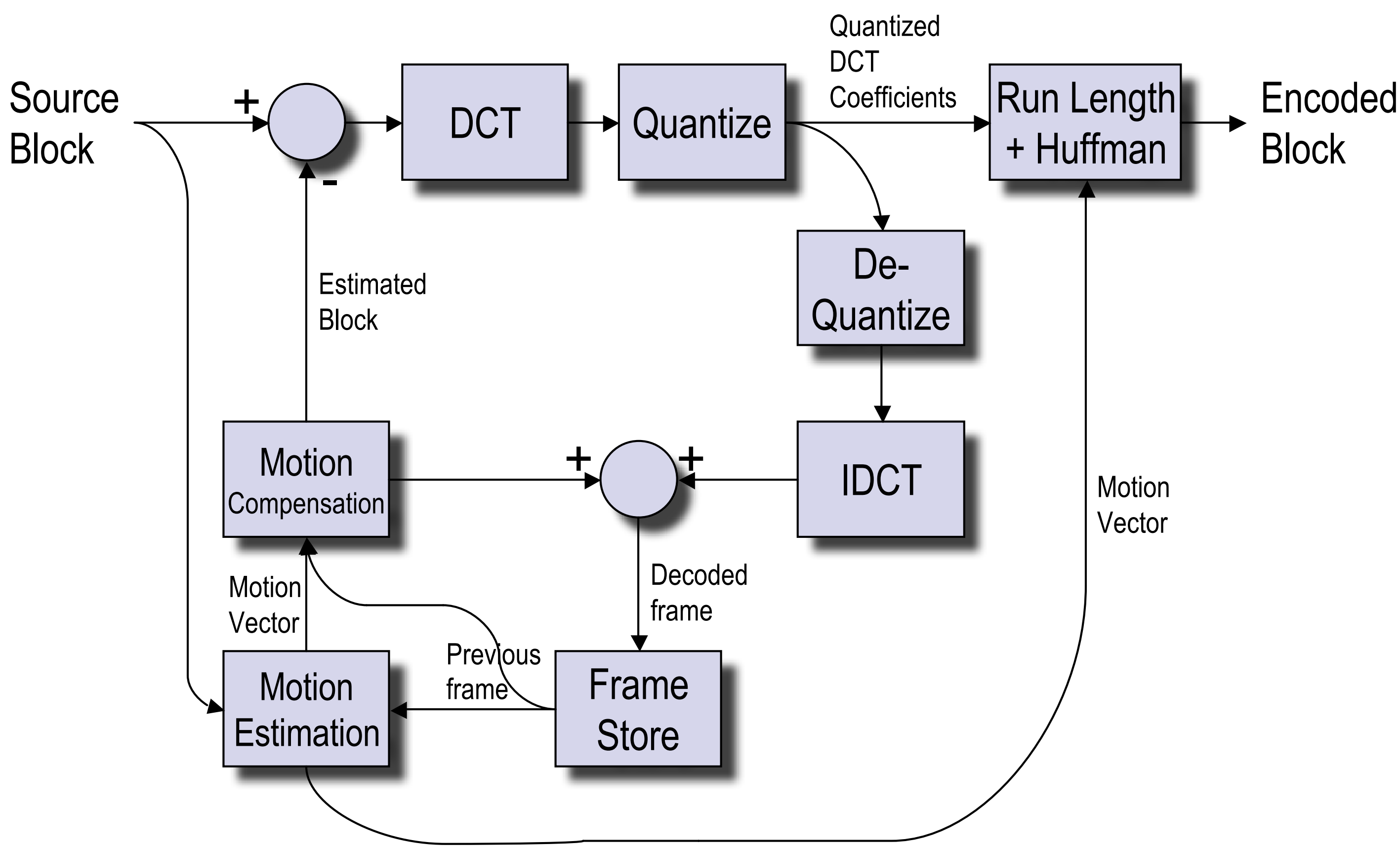
Motion vectors: ±4
⇒64 positions checked
⇒4^2*2 ops per check
⇒2048 ops

Total: 90M ops/sec for 30fps

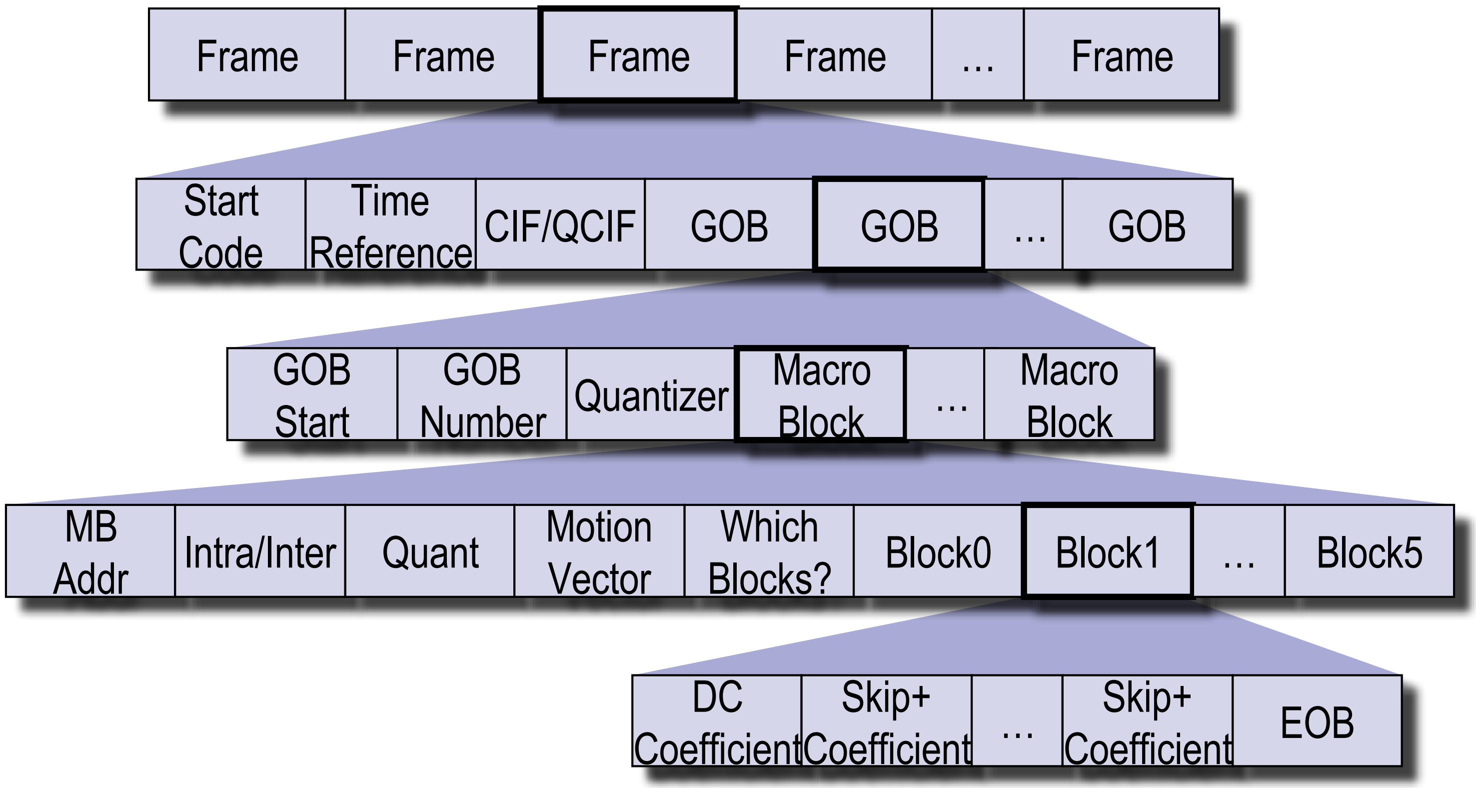
Intra-Block Encoding



Inter-Block Encoding



Bitstream Structure



H.261 Design Goals

Intended for videotelephony.

- Low delay.
  - Each frame coded as it arrives.
  - Only need a small bitstream buffer on output to smooth to CBR (adds a little delay)
- Constant Bit Rate (CBR)
  - Only send a small number of intra-coded blocks in each frame, so data rate variation is only a function of video content.
  - Adjust the quantization based on occupancy of the bitstream buffer.

H.261 Non-design Goals

- Not intended for recording and playback.
- No way to seek backwards or forwards because you don't normally encode any frames with entirely intra-coded blocks.
  - Could do this, but wouldn't give CBR flow needed for ISDN usage.
- Limited robustness to bit errors.
  - Errors cause corruption (incorrect huffman decoding of rest of GOB). Possibly detected by hitting a illegal state in decoder.
  - Stop decoding, search for next GOB. Start decoding again.
  - Intra blocks recover damage slowly over next few seconds.

H.263

- Son of H.261.
  - Standardized in 1996.
  - Replacing H.261 in many applications.
- Basic design is very similar to H.261 (DCT/Quantization based, using intra or inter frame coding).
  - Numerous optional improvements to improve compression, robustness, and flexibility of use.

H.263 Improvements

- Half-pixel precision in motion vectors (vs full-pixel precision for H.261).
- New options:
  - Unrestricted Motion Vectors,
  - Syntax-based arithmetic coding (replace RLE/Huffman)
  - Advance prediction (uses 4 8*8 blocks instead of 1 16*16: gives better detail.)
  - Forward and backward frame prediction similar to MPEG
- Five resolutions (H.261 only does QCIF and CIF):

SQCIF: 128x96	4CIF: 704x576
QCIF: 176x144	16CIF: 1408x1152
CIF: 352x288	

MPEG

MPEG Family

- MPEG-1
  - Similar to H.263 CIF in quality
- MPEG-2
  - Higher quality: DVD, Digital TV, HDTV
- MPEG-4/H.264
  - More modern codec.
  - Aimed at lower bitrates.
  - Works well for HDTV too.

MPEG-1 Compression

- MPEG: Motion Pictures Expert Group
- Finalized in 1991
- Optimized for video resolutions:
  - 352x240 pixels at 30 fps (NTSC)
    352x288 pixels at 25 fps (PAL/SECAM)
- Optimized for bit rates around 1-1.5Mb/s.
- Syntax allows up to 4095x4095 at 60fps, but not commonly used.
- Progressive scan only (not interlaced)

MPEG Frame Types

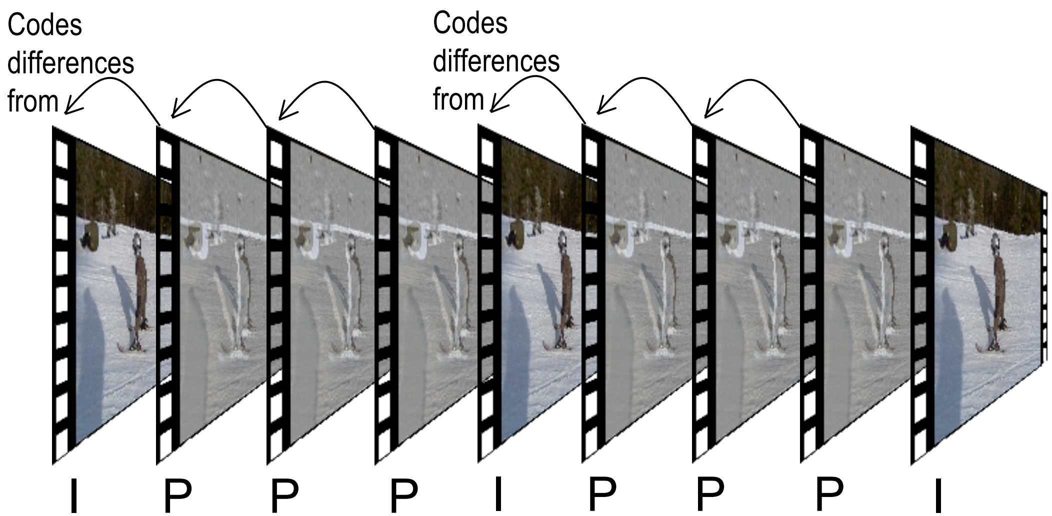
- Unlike H.261, each frame must be of one type.
  - H.261 can mix intra and inter-coded MBs in one frame.
- Three types in MPEG:
  - I-frames (like H.261 intra-coded frames)
  - P-frames (“predictive”, like H.261 inter-coded frames)
  - B-frames (“bidirectional predictive”)

MPEG I-frames

- Similar to JPEG, except:
  - Luminance and chrominance share quantization tables.
  - Quantization is adaptive (table can change) for each macroblock.
- Unlike H.261, every *n* frames, a full *intra-coded frame* is included.
  - Permits skipping. Start decoding at first I-frame following the point you skip to.
  - Permits fast scan. Just play I-frames.
  - Permits playing backwards (decode previous I-frame, decode frames that depend on it, play decoded frames in reverse order)
- An I frame and the successive frames to the next I frame (n frames) is known as a Group of Pictures.

MPEG P-Frames

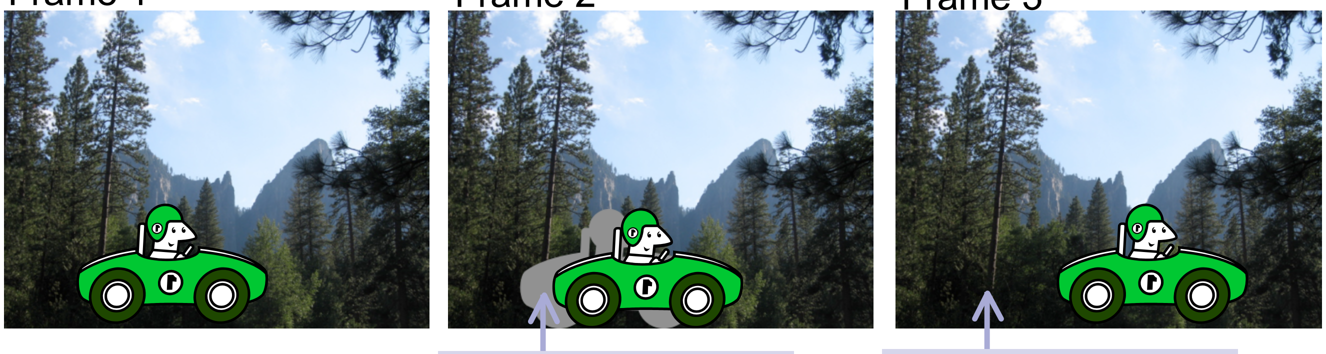
- Similar to an entire frame of H.261 inter-coded blocks.
  - Half-pixel accuracy in motion vectors (pixels are averaged if needed).
- May code from previous I frame or previous P frame.



Object occlusion

- Often an object moves in front of a background.
- P frames code the object fine, but can't effectively code the revealed background.

Frame 1 Frame 2 Frame 3



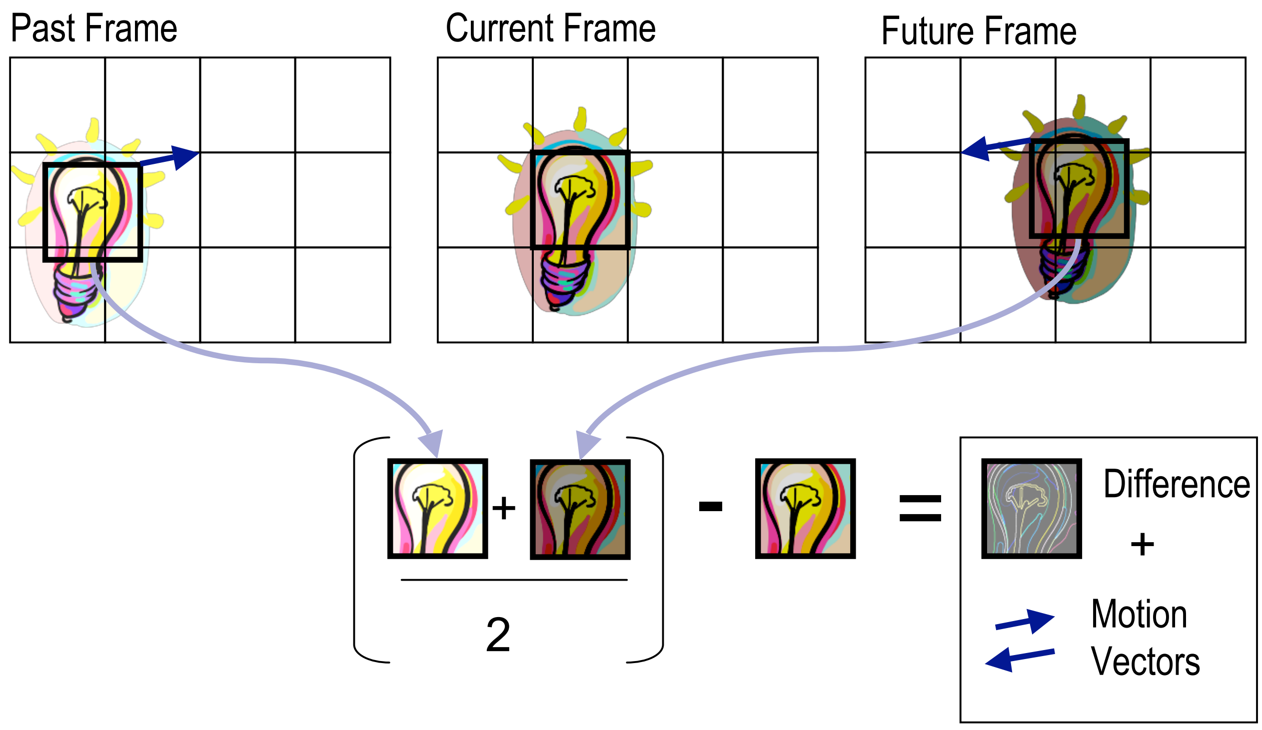
Previous frame doesn't contain this information

Next frame does. Can we code from this?

B-frames

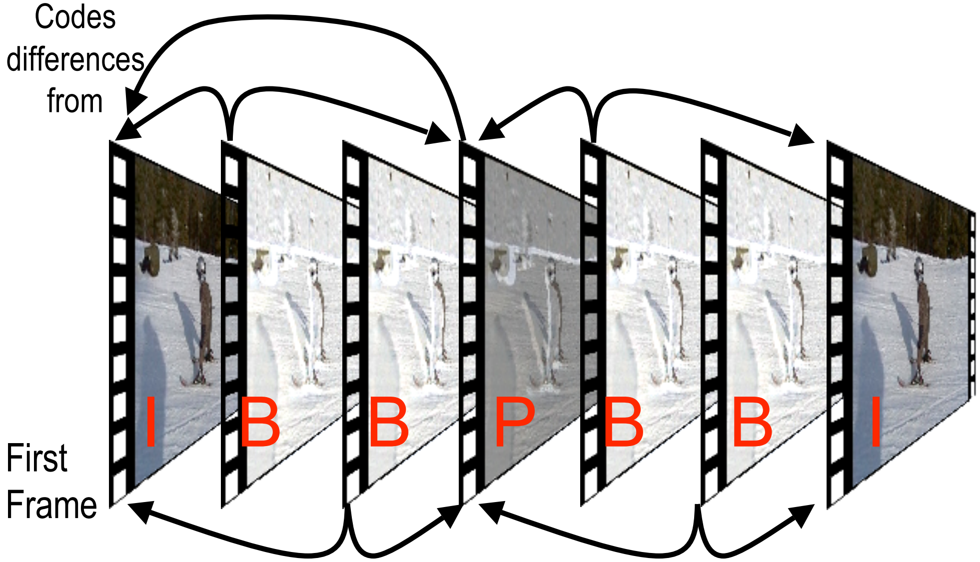
- Bidirectional Predictive Frames.
- Each macroblock contains two sets of motion vectors.
- Coded from one previous frame, one future frame, or a combination of both.
  1. Do motion vector search separately in past reference frame and future reference frame.
  2. Compare:
     - Difference from past frame.
     - Difference from future frame.
     - Difference from average of past and future frame.
  3. Encode the version with the least difference.

B-frames: Macroblock averaging

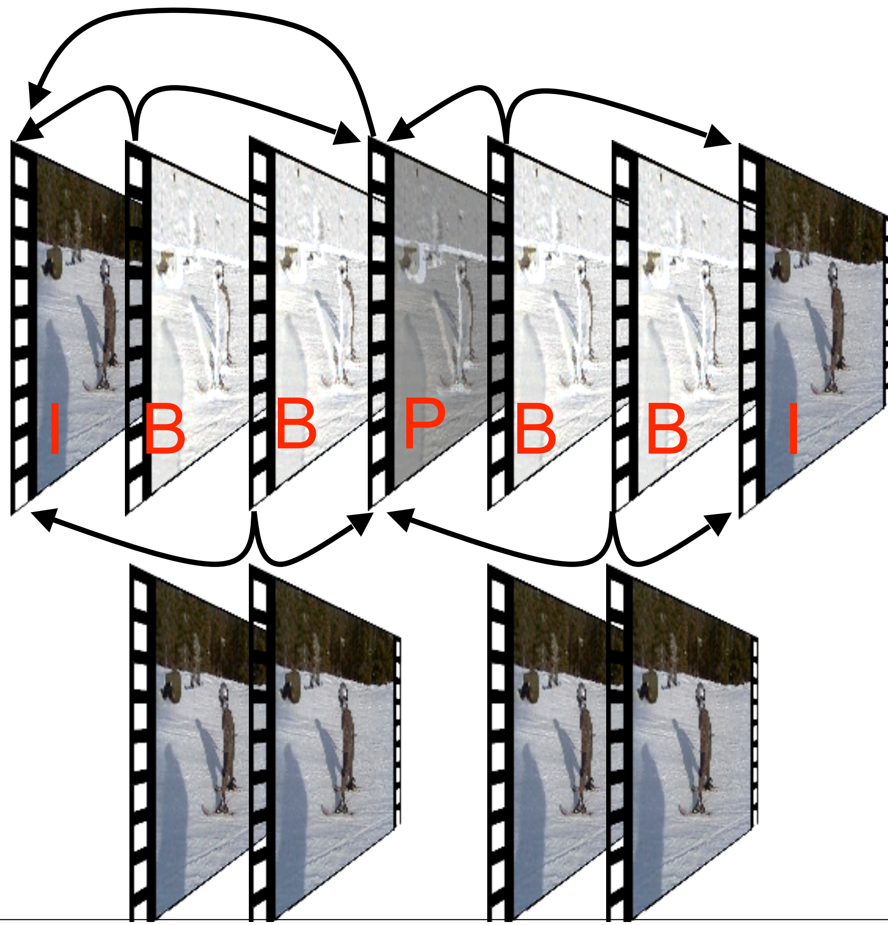


Frame Ordering

- Up to encoder to choose I, P, B frame ordering.
- Eg IBBPBBIBBPBBPI…



Encoding Order



1. Encode I-frame 1
2. Store frame 2
3. Store frame 3
4. Encode P frame 5
5. Encode B frame 2
6. Encode B frame 3
7. Store frame 5
8. Store frame 6
9. Encode I frame 7
10. Encode B frame 5
11. Encode B frame 6

Transmission Order

- Frames are encoded out of order
- Need to be decoded in the order they're encoded.
  - Common to send out of order.

Eg: $I_1B_2B_3P_4B_5B_6I_7B_8B_9P_{10}B_{11}B_{12}I_{14}$

sent in the order

$I_1P_4B_2B_3I_7B_5B_6P_{10}B_8B_9I_{14}B_{11}B_{12}$

- Allows decoder to decode as data arrives, although it still has to hold decoded frames until it has decoded prior B frames before playing them out.

B-frame disadvantages

- Computational complexity.
  - More motion search, need to decide whether or not to average.
- Increase in memory bandwidth.
  - Extra picture buffer needed.
  - Need to store frames and encode or playback out of order.
- Delay
  - Adds several frames delay at encoder waiting for need later frame.
  - Adds several frames delay at decoder holding decoded I/P frame, while decoding and playing prior B-frames that depend on it.

B-frame advantage

- B-frames increase compression.
- Typically use twice as many B frames as I+P frames.

Type	Size	Compression
I	18KB	7:1
P	6KB	20:1
B	2.5KB	50:1
Average	4.8KB	27:1

Typical MPEG-1 values.

Really depends on video content.

MPEG-2

- ISO/IEC standard in 1995
- Aimed at higher quality video.
- Supports interlaced formats.
- Many features, but has profiles which constrain common subsets of those features:
  - Main profile (MP): 2-15Mb/s over broadcast channels (eg DVB-T) or storage media (eg DVD)
  - PAL quality: 4-6Mb/s, NTSC quality: 3-5Mb/s.

MPEG-2 Levels

Level	Max Resolution	Max FPS	Max Coded Data Rate (Mb/s)	Application
Low	352x288	30	4	Consumer tape equiv.
Main	720x576	30	15	Studio TV
Main 1440	1440x1152	60	60	Consumer HDTV
High	1920x1152	60	80	Film production

MPEG-2 vs MPEG-1

Sequence layer

- progressive vs interlaced
- More aspect ratios (eg 16x9)
- Syntax can now signal frames sizes up to 16383x16383
- Pictures must be a multiple of 16 pixels

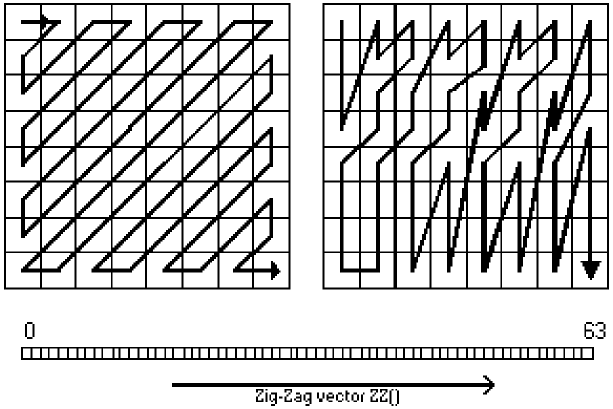
MPEG-2 vs MPEG-1

Picture Layer:

- All MPEG-2 motion vections are always half-pixel accuracy
  - MPEG-1 can opt out, and do one-pixel accuracy.
- DC coefficient can be coded as 8, 9, 10, or 11 bits.
  - MPEG-1 always uses 8 bits.
- Optional non-linear macroblock quantization, giving a more dynamic step size range:
  - 0.5 to 56 vs 1 to 32 in MPEG-1.
  - Good for high-rate high-quality video.

Interlacing

- MPEG-2 codes a frame. May include both interlaced fields.
- Fields may differ, so compression suffers.
  - More high frequencies in vertical dimension.
- MPEG-2 can use a modified zig-zag for run-length encoding of the coefficients:



Typical MPEG-2 Frame Sizes

Type	Size (KB)	Compression
I-frame	50	10:1
P-frame	25	20:1
B-frame	10	50:1
Ave:	18	29:1

Average sizes for ~4Mb/s video, Main Profile at Main Level (MP@ML)

Actual frame sizes will vary a lot depending on content

MPEG-4

- ISO/IEC designation 'ISO/IEC 14496': 1999
- MPEG-4 Version 2: 2000
- Aimed at low bitrate (10Kb/s)
- Can scale very high (1Gb/s)
- Based around the concept of the composition of basic video objects into a scene.

Media Objects

- Still images (e.g. as a fixed background);
- Video objects (e.g. a talking person - without the background;
- Audio objects (e.g. the voice associated with that person, background music);
- Text and graphics;
- Talking synthetic heads and associated text used to synthesize the speech and animate the head; animated bodies to go with the faces;
- Synthetic sound.

- Also 3-D objects.

Composition of Media Objects

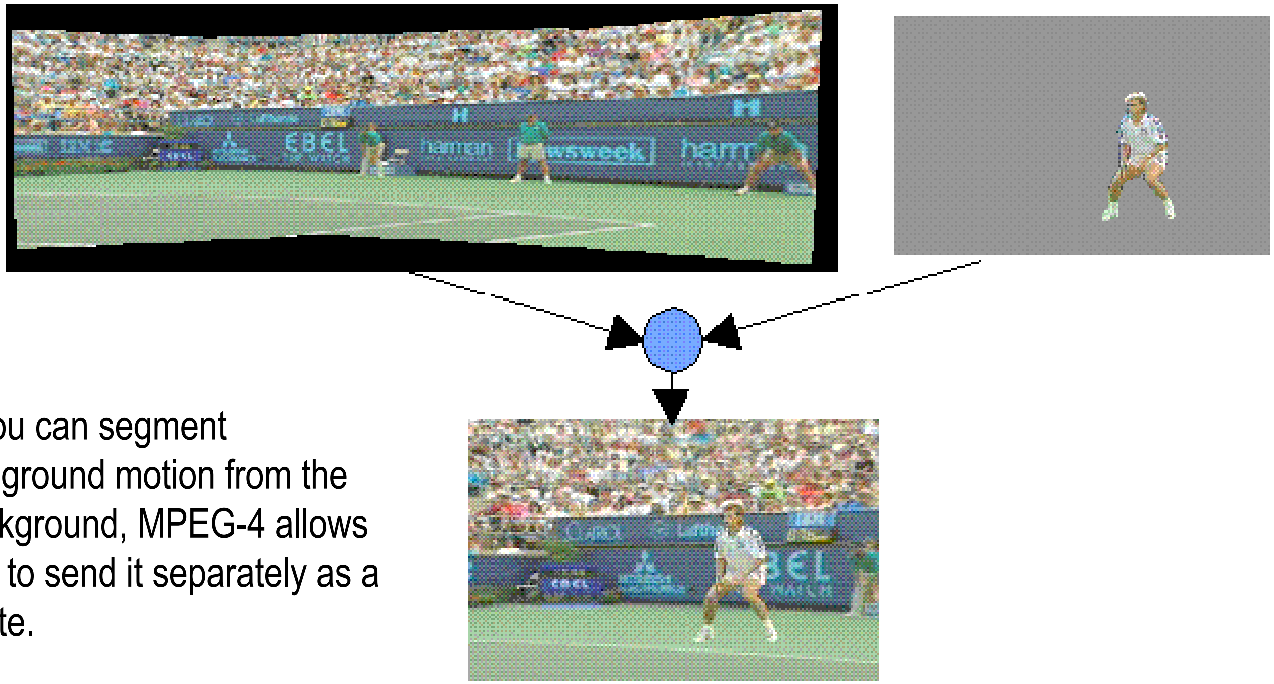
MPEG-4 provides a standardized way to describe a scene

- Place media objects in a coordinate system;
- Apply transforms to change the geometrical or acoustical appearance of a media object;
- Group primitive media objects to form compound media objects;
- Apply streamed data to media objects

  Eg: animation parameters driving a synthetic face

- Can change, interactively, the user's viewing and listening points anywhere in the scene.
- Builds on concepts from the Virtual Reality Modelling Language (VRML)

MPEG-4 Sprites



If you can segment foreground motion from the background, MPEG-4 allows you to send it separately as a sprite.

H.264 (MPEG-4, Part 10)

- MPEG-4, Part 10 is also known as H.264.
- Advanced video coding standard, finalized in 2003.

H.264 vs MPEG-2

- Multi-picture motion compensation.
  - Can use up to 32 different frames to predict a single frame.
  - B-frames in MPEG-2 only code from two.
- Variable block-size motion compensation
  - From 4x4 to 16x16 pixels.
  - Allows precise segmentation of edges of moving regions.
- Quarter-pixel precision for motion compensation.
- Weighted prediction (can scale or offset predicted block)
  - Useful in fade-to-black or cross-fade between scenes.
- Spatial prediction from the edges of neighboring blocks for "intra" coding.
- Choice of several more advanced context-aware variable length coding schemes (instead of Huffman).

H.264 performance

- Typically half the data rate of MPEG-2.
- HDTV:
  - MPEG-2: 1920x1080 typically 12-20 Mbps
  - H.264: 1920x1080 content at 7-8 Mbps

H.264 Usage

- Pretty new, but expanding use.
- Included in MacOS 10 (Tiger) for iChat video conferencing.
- Used by Video iPod.
- Adopted by 3GPP for Mobile Video.
- Mandatory in both the HD-DVD and Blu-ray specifications for High Definition DVD.