Media Compression Techniques

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JPEG Compression: Basics

- Human vision is insensitive to high spatial frequencies
- JPEG Takes advantage of this by compressing high frequencies more coarsely and storing image as frequency data
- JPEG is a “lossy” compression scheme.

Losslessly compressed image, ~150KB

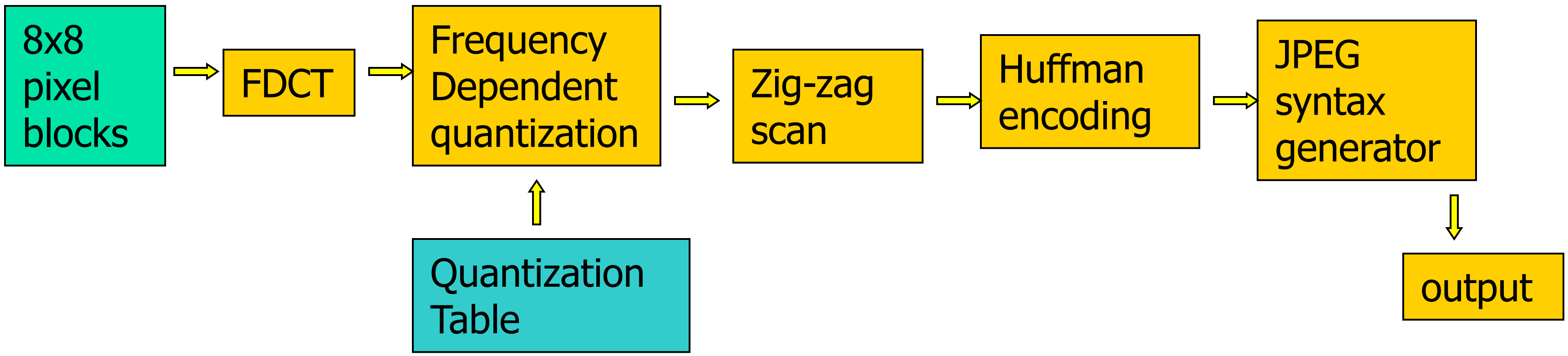
JPEG compressed, ~14KB

Digital Image Representation

- JPEG can handle arbitrary color spaces (RGB, CMYK, YC_bC_r (separates colors into grayscale components)
- Luminance/Chrominance commonly used, with Chrominance subsampled due to human vision insensitivity
- Uncompressed spatial color data components are stored in quantized values (8, 16, 24bit, etc).

Flow Chart of JPEG Compression Process

- Divide image into 8x8 pixel blocks
- Apply 2D Fourier Discrete Cosine Transform (FDCT) Transform
- Apply coarse quantization to high spatial frequency components
- Compress resulting data losslessly and store



Example of Frequency Quantization with 8x8 blocks

128	128	128	128	128	128	128	128
118	111	112	117	120	123	123	122
125	121	115	111	119	119	118	117
120	121	113	113	125	124	115	108
120	120	116	119	124	120	115	110
117	113	111	122	120	110	116	119
109	113	111	122	120	110	116	119
111	121	124	118	115	121	117	113

Color space values (spatial data)

-80	4	-6	6	2	-2	-2	0
24	-8	8	12	0	0	0	2
10	-4	0	-12	-4	4	4	-2
8	0	-2	-6	10	4	-2	0
18	4	-4	6	-8	-4	0	0
-2	8	6	-4	0	-2	0	0
12	0	6	0	0	0	-2	-2
0	8	0	-4	-2	0	0	0

Color space values (spatial data)

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

Quantization Matrix to divide by

-5	0	0	0	0	0	0	0
2	-1	1	1	0	0	0	0
1	0	0	-1	0	0	0	0
1	0	0	0	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

Quantized spatial frequency values

Scanning and Huffman Encoding

- Spatial Frequencies scanned in zig-zag pattern (note high frequencies mostly zero)
- Huffman encoding used to losslessly record values in table

-5	0	0	0	0	0	0	0
2	-1	1	1	0	0	0	0
1	0	0	-1	0	0	0	0
1	0	0	0	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

0,2,1,-1,0,0,1,0,1,1,0,0,1,0,0,0,-1,0,0,… 0

Can be stored as:

(1,2),(0,1),(0,-1),(2,1),(1,1),(0,1),(0,1),(2,1),(3,1),EOB

Examples of varying JPEG compression ratios

500KB image, minimum compression

40KB image, half compression

11KB image, max compression

Close-up details of different JPEG compression ratios

Uncompressed image (roughness between pixels still visible)

Half compression, blurring & halos around sharp edges

Max compression, 8-pixel blocks apparent, large distortion in high-frequency areas

JPEG Encoding modes

- Sequential mode
  - Image scanned in a raster scan with single pass, 8-bit resolution
- Sequential mode
  - Step-by-step buildup of image from low to high frequency, useful for applications with long loading times (internet, portable devices, etc)
- Hierarchical mode
  - Encoded using low spatial resolution image and encoding higher resolution images based on interpolated difference, for display on varying equipment

GIF 89a Image Compression

- Compuserve's image compression format
- Best for images with sharp edges, low bits per channel, computer graphics where JPEG spatial averaging is inadequate
- Usually used with 8-bit images, whereas JPEG is better for 16-bit images.

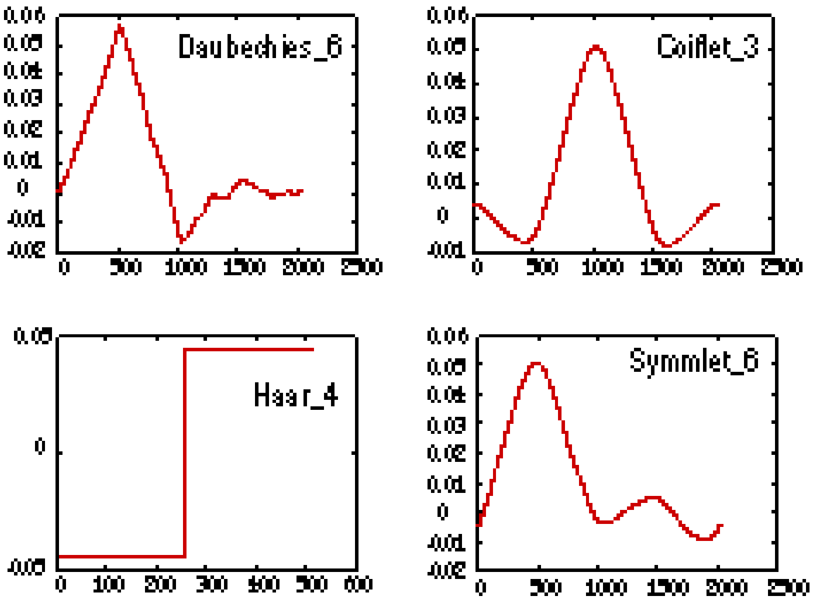
GIF 89a examples vs. JPEG

GIF Image, 7.5KB, optimal encoding

JPEG, blotchy spots in single-color areas

Wavelet Image Compression

- Optimal for images containing sharp edges, or continuous curves/lines (fingerprints)
- Compared with DCT, uses more optimal set of functions to represent sharp edges than cosines.
- Wavelets are finite in extent as opposed to sinusoidal functions



Several different families of wavelets.

Source: "An Introduction to Wavelets". http://www.amara.com/IEEEwave/IEEEwavelet.html#contents

Wavelet vs. JPEG compression

Wavelet compression
file size: 1861 bytes
compression ratio - 105.6

JPEG compression
file size: 1895 bytes
compression ratio - 103.8

Source: “About Wavelet Compression”. http://www.barrt.ru/parshukov/about.htm.

Wavelet compression advantages

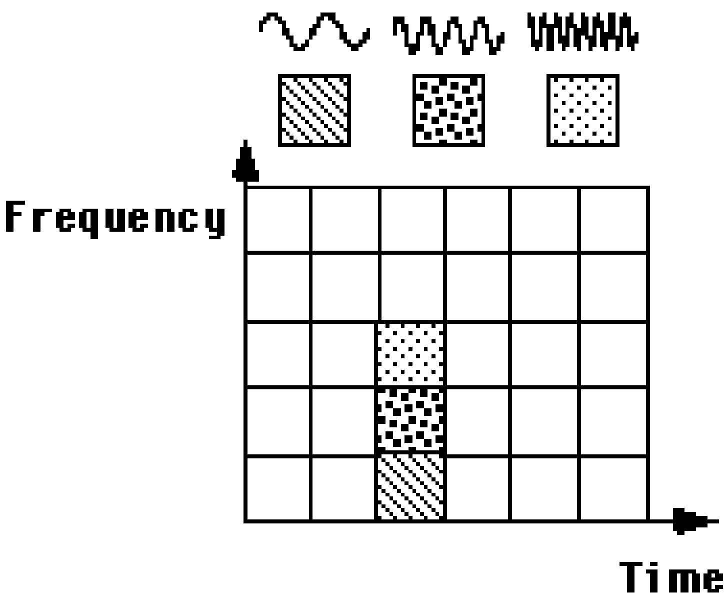


Fig. 1. Fourier basis functions, time-frequency tiles, and coverage of the time-frequency plane.

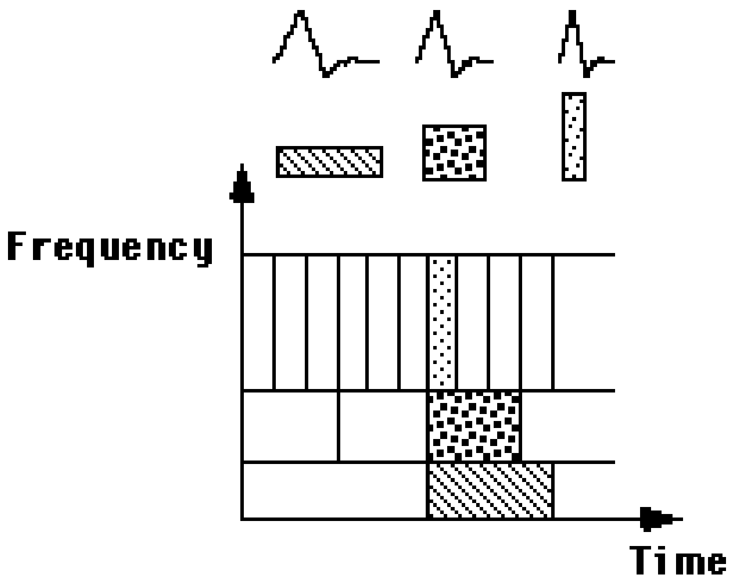


Fig. 2. Daubechies wavelet basis functions, time-frequency tiles, and coverage of the time-frequency plane

Source: “An Introduction to Wavelets”. http://www.amara.com/IEEEwave/IEEEwavelet.html#contents

Fractal Based Image Compression

- Image compressed in terms of self-similarity rather than pixel resolution
- Can be digitally scaled to any resolution when decoded

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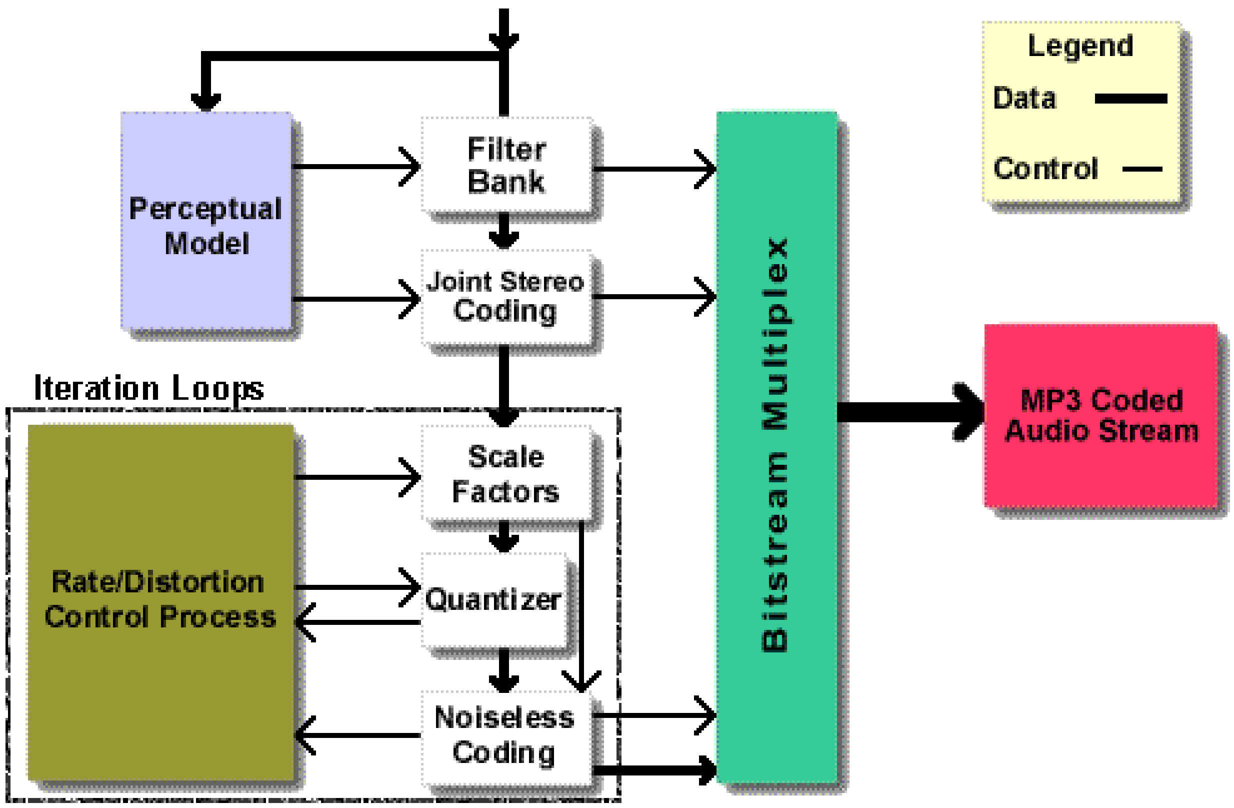
MPEG Audio basics & Psychoacoustic Model

- Human hearing limited to values lower than ~20kHz in most cases
- Human hearing is insensitive to quiet frequency components to sound accompanying other stronger frequency components
- Stereo audio streams contain largely redundant information
- MPEG audio compression takes advantage of these facts to reduce extent and detail of mostly inaudible frequency ranges

MPEG-Layer3 Overview



MP3 Compression Flow Chart

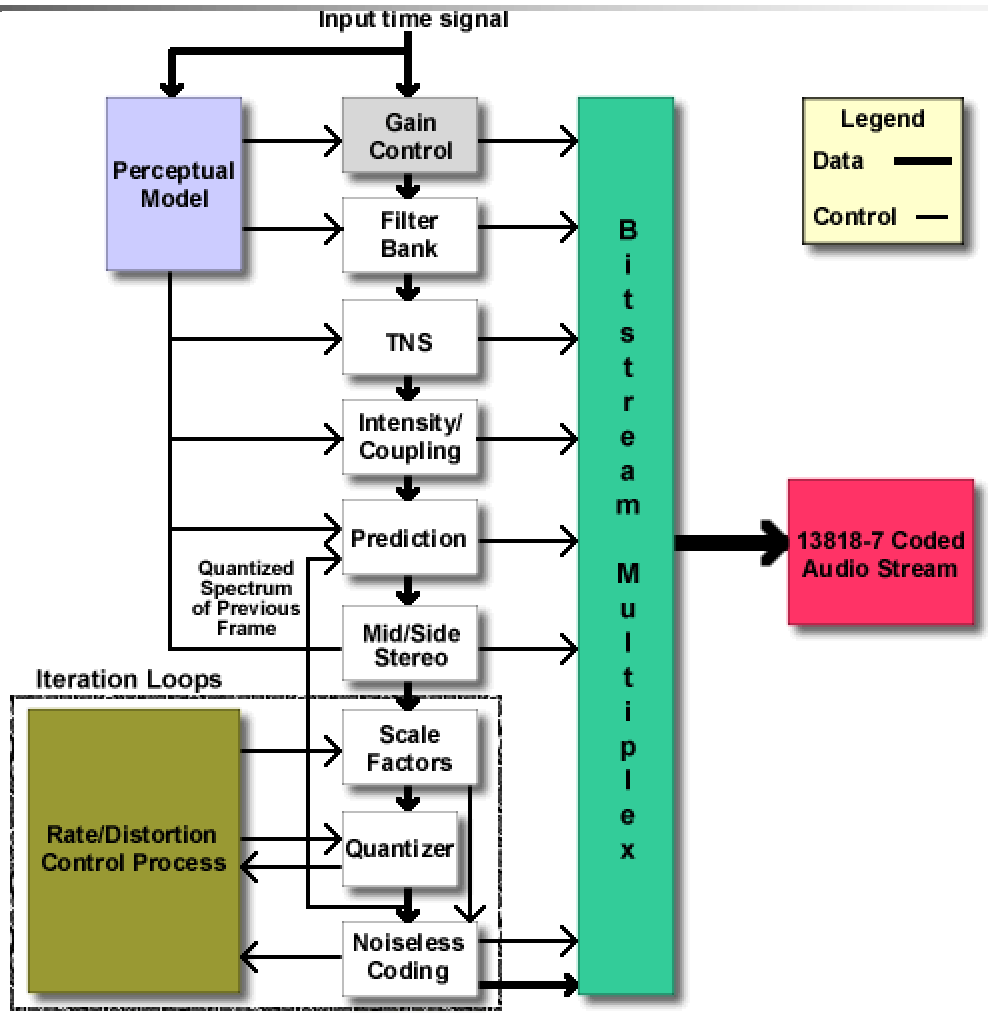
MPEG Layer-3 performance

sound quality	bandwidth	mode	bitrate	reduction ratio
telephone sound	2.5 kHz	mono	8 kbps *	96:1
better than short wave	4.5 kHz	mono	16 kbps	48:1
better than AM radio	7.5 kHz	mono	32 kbps	24:1
similar to FM radio	11 kHz	stereo	56...64 kbps	26...24:1
near-CD	15 kHz	stereo	96 kbps	16:1
CD	>15 kHz	stereo	112..128kbps	14..12:1

MPEG-2 Advanced Audio Coding (AAC) codec (next generation)

- Sampling frequencies from 8kHz to 96kHz
- 1 to 48 channels per stream
- Temporal Noise Shaping (TNS) smooths quantization noise by making frequency domain predictions
- Prediction: Allows predictable sound patterns such as speech to be predicted and compressed with better quality

MPEG-2 AAC Flowchart



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Video Compression with Temporal Redundancy

- Using strictly spatial redundancy (JPEG) gives video compression ratios from 7:1 to 27:1
- Taking advantage of temporal redundancy in video gives 20:1 to 300:1 compression for H.261, or 30:1 to 100:1 for high quality MPEG-2

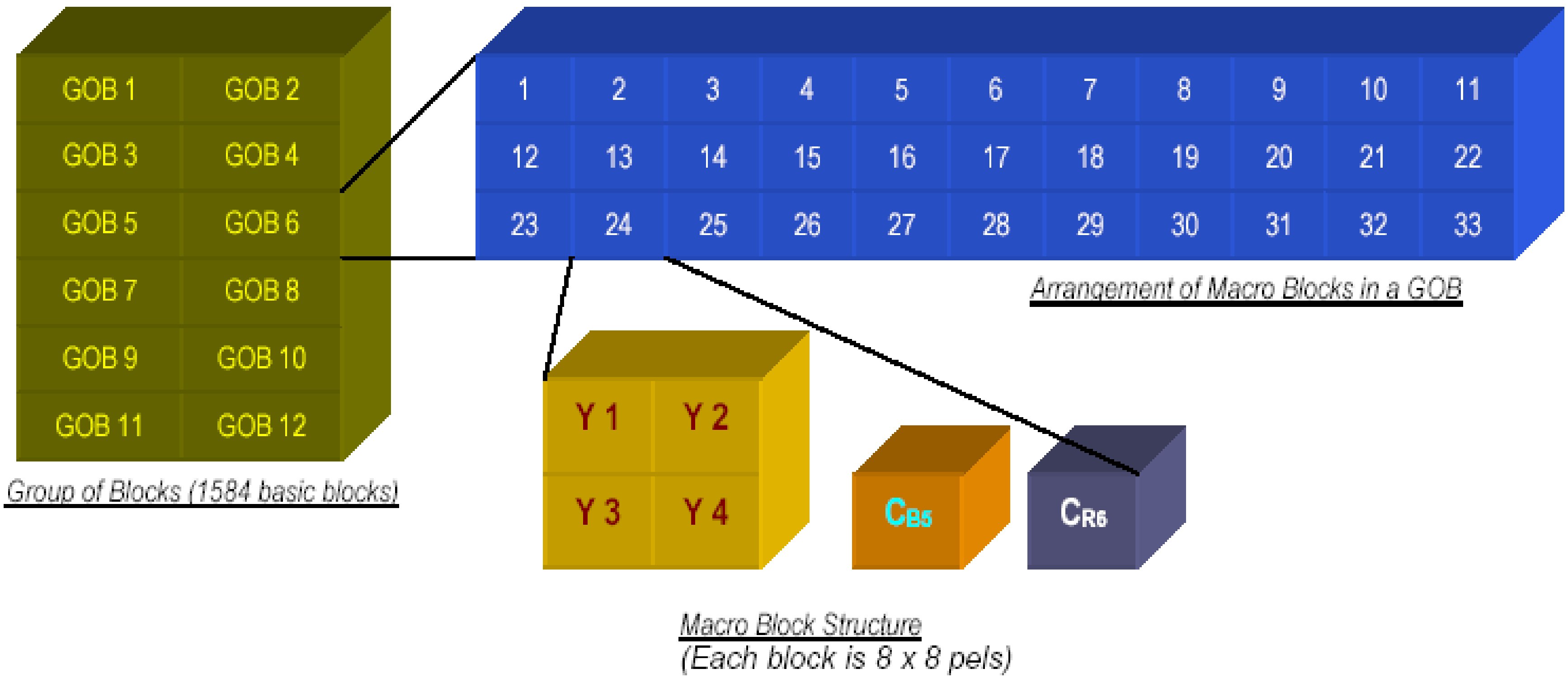
Videoconferencing Compression with H.261

- H.261 is standard recommended for videoconferencing over ISDN lines.
- Takes advantage of both spatial and temporal redundancy in moving images
- Extremely similar to JPEG, but uses initial frame plus motion vectors to predict subsequent frames

H.261 Block Structure

- Basic unit of processing is in 8x8 pixel blocks.
- Macro Blocks (MB, 16x16 pixels) are used for motion estimation, 4 blocks of luminance, 2 of chrominance
- Groups of Blocks (GOB) of 3x11 MB’s are stored together with a header in stream.

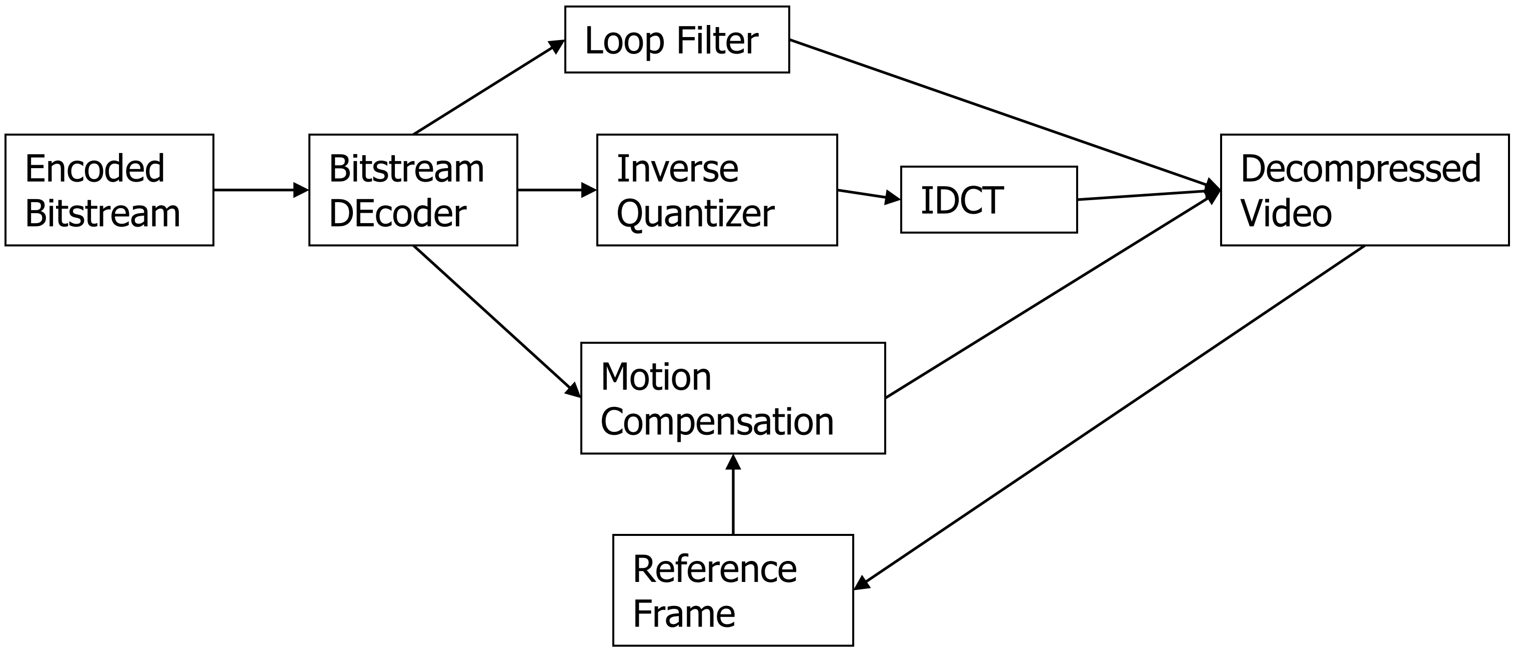
H.261 Block Structure of bitstream



Block structure of H.261 video bitstream, Common Intermediate Format (CIF), 360x288 pixels luminance, 180x144 pixels chrominance

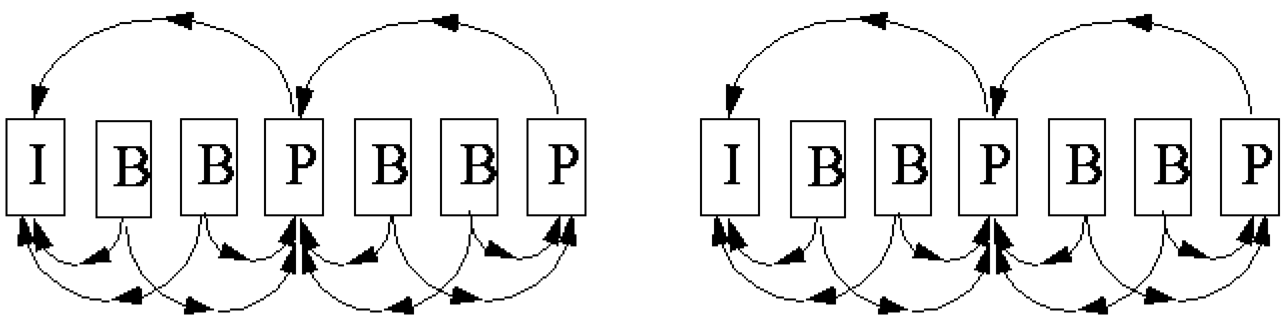
Source: “H.261 Videoconferencing Codec” http://www.uh.edu/~hebert/ece6354/H261-report.pdf

H.261 Decoding (Similar to encoding process)



MPEG Video Compression

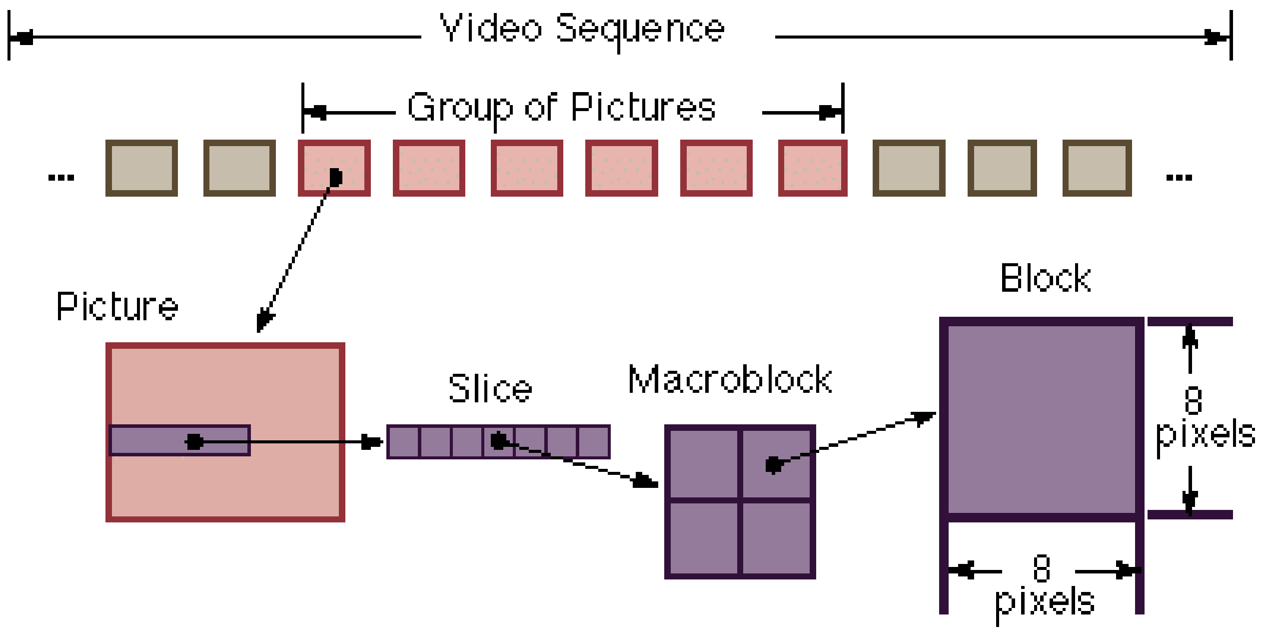
- Supports JPEG and H.261 through downward compatibility
- Supports higher Chrominance resolution and pixel resolution (720x480 is standard used for TV signals)
- Supports interlaced and noninterlaced modes
- Uses Bidirectional prediction in “Group Of Pictures” to encode difference frames.



“Group Of Pictures” inter-frame dependencies in a stream

Source: “Parallelization of Software Mpeg Compression” http://www.evl.uic.edu/fwang/mpeg.html

MPEG 1 & 2 Bitstream



The MPEG data hierarchy

Source: http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol4/sab/report.html

MPEG-4

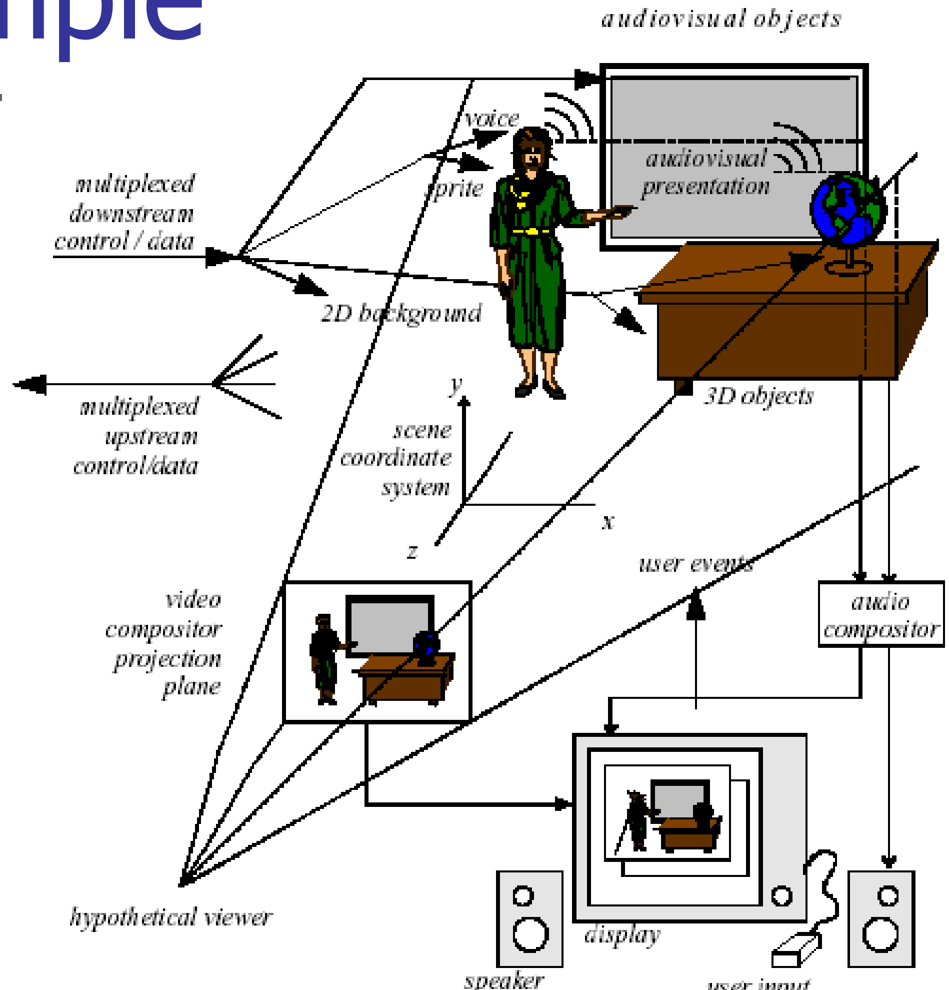
- Original goal was for 10 times better compression than H.261
- Goals shifted to
  - Flexible bitstreams for varying receiver capabilities
  - Stream can contain new applications and algorithms
  - Content-based interactivity with data stream
  - Network independence (used for Internet, Wireless, POTS, etc)
- Object based representations

MPEG-4 audio-visual scene composition

- Can place media objects anywhere in a scene
- Apply transforms to change appearance or qualities of an object
- Group objects to form compound objects
- Apply streamed data to objects
- Interactively change viewer's position in the virtual scene

http://www.iis.fraunhofer.de/amm/techinf/mpeg4/mp4_overv.pdf

MPEG-4 “Audiovisual Scene” Example



an example of an MPEG-4 Scene

Source: “MPEG-4 Overview” http://www.chiariglione.org/mpeg/standards/mpeg-4/mpeg-4.htm

MPEG-7

- Media tagging format for doing searches on arbitrary media formats via feature extraction algorithms
- Visual descriptors such as:
  - Basic Structures
  - Color
  - Texture
  - Shape
  - Localization of spatio-temporal objects
  - Motion
  - Face Recognition
- Audio descriptors such as :
  - Sound effects description
  - Musical Instrument Timbre Description
  - Spoken Content Description
  - Melodic Descriptors (search by tune)
  - Uniform Silence Segment
- Example application: Play a few notes on a keyboard and have matched song retrieved.

Conclusion

- Media compression is indispensable even as storage and streaming capacities increase
- Future goals oriented towards increasing ease of access to media information (similar to google for text based information)