COMP 249 Advanced Distributed Systems
Multimedia Networking

The Video Data Type
Coding & Compression Basics

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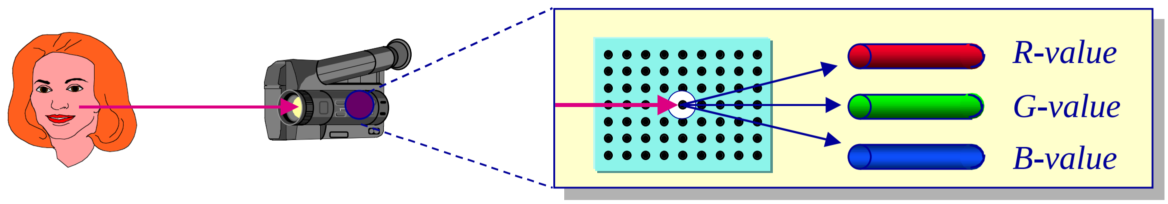
The Video Data Type
Outline

- What is video?
  - » Video components
  - » Representations of video signals
  - » Color spaces
- Digital Video
  - » Coding
- Compression basics
  - » Simple compression
  - » Interpolation-based techniques
  - » Predictive techniques
  - » Transforms
  - » Statistical techniques

Video Basics

The components of video

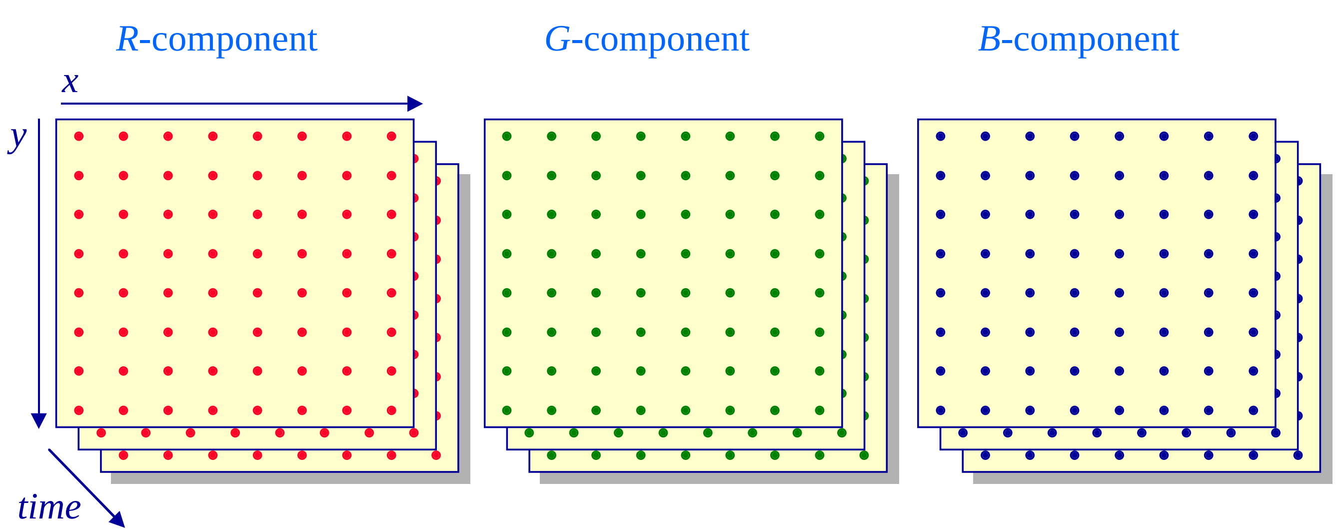


- Video deals with *absorbed* and *projected* light
  - » Cameras absorb light and monitors project light
- The primary colors in this domain are:
  - » red, green, and blue

Video Basics

The components of video transmission

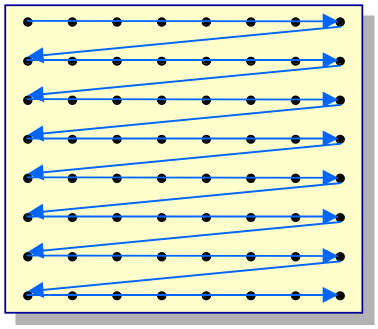
- Video is a multi-dimensional signal



Video Basics

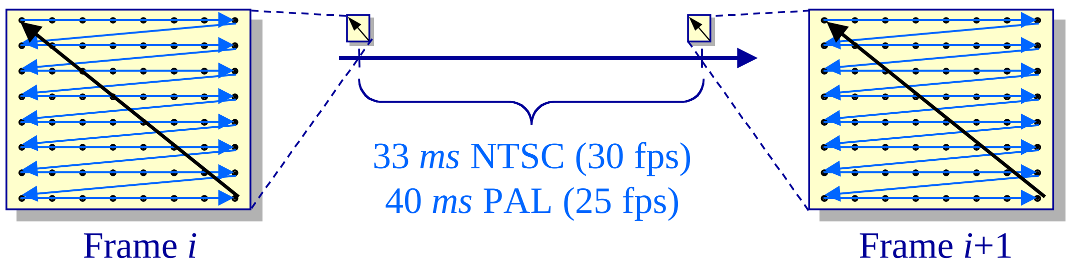
Video as a 1-dimensional signal

- Representation of a 2-dimensional image



$(R, G, B)_{11}, (R, G, B)_{12}, (R, G, B)_{13}, \ldots, (R, G, B)_{row,\, col}$

- Representation of motion (3-dimensional images)



Video Basics

Resolution

- Television broadcast standards
  - » NTSC — 525 lines
  - » PAL — 625 lines
- Computer graphics standards
  - » VGA — 640x480
  - » SVGA — 1024x768
- Multimedia standards
  - » CIF — 352x288
  - » QCIF — 176x144
- Digital video standards
  - » CCIR 601 — 720x480
  - » HDTV — 1440x1152

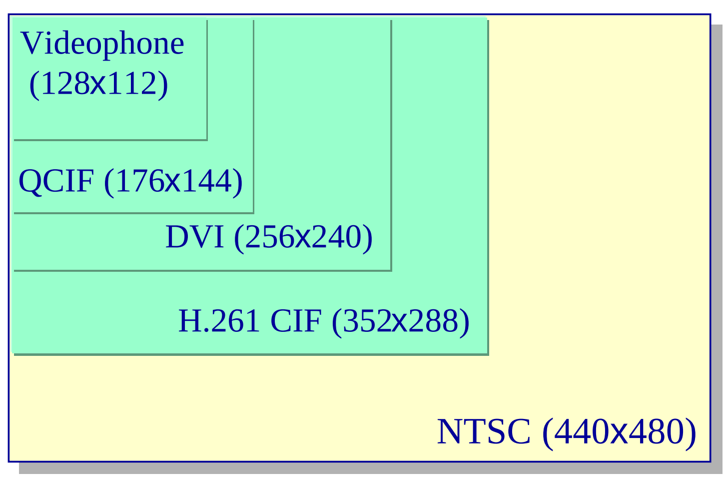


Image sizes
(in picture elements)

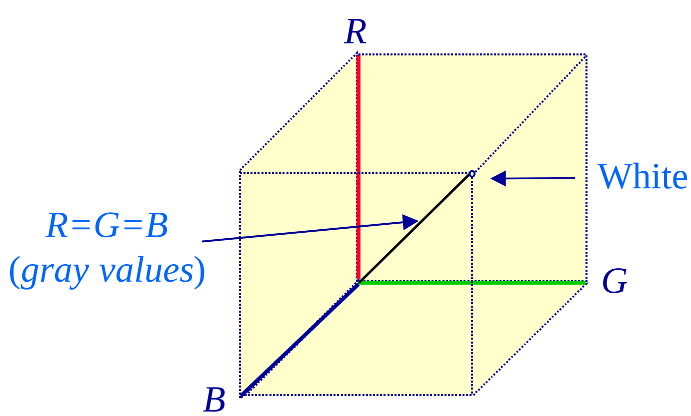
Video Basics

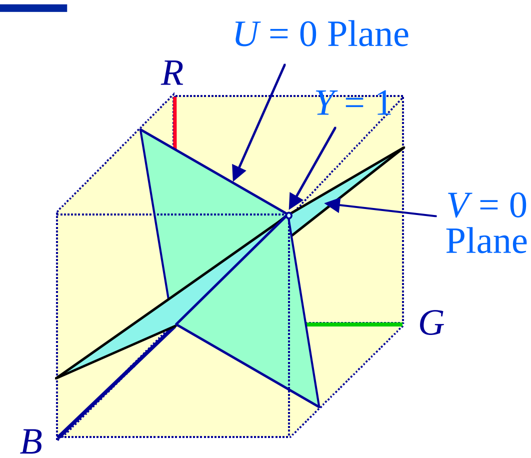
Color spaces

- *RGB* is not widely used for transmitting a signal between capture and display devices
  - » It's difficult to manage 3 separate inputs & outputs (and requires too much bandwidth)
- Composite formats are used instead
  - » Luminance ("*Y*") — the brightness of the monochrome signal
  - » Chrominance — the coloring information
  - » Chrominance is typically represented by two "color difference" signals:
    - "*U*" and "*V*" ("*hue* and *tint*") or
    - "*I*" and "*Q*" ("*saturation*" and "*color*")

Video Basics

Color spaces





- *NTSC* video
  - » $Y = 0.30R + 0.59G + 0.11B$
  - » $I = 0.60R - 0.28G - 0.32B$
  - » $Q = 0.21R - 0.52G + 0.31B$
- *PAL* video/Digital recorders
  - » $Y = 0.3R + 0.6G + 0.1B$
  - » $U = (B - Y) \times 0.493$
  - » $V = (R - Y) \times 0.877$

Video Basics
Digital video

- Sample an analog representation of video (*RGB* or *YUV*) & quantize
  - » Two dimensions of video are already discretized
  - » Sample in the horizontal direction according to the resolution of the media
- 8-bits per component per sample is common
  - » 24 bits per picture element (pixel)
- Storage/transmission requirements
  - » NTSC — 440 x 480 x 30 x 24 = 152×10^6 bits/sec (19 MB/s or 24 bits/pixel (bpp))

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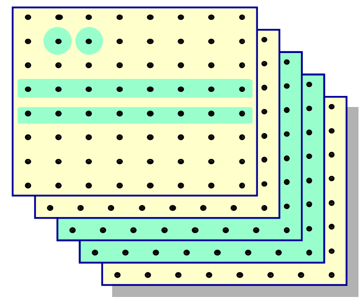
  - » Transforms
  - » Statistical techniques

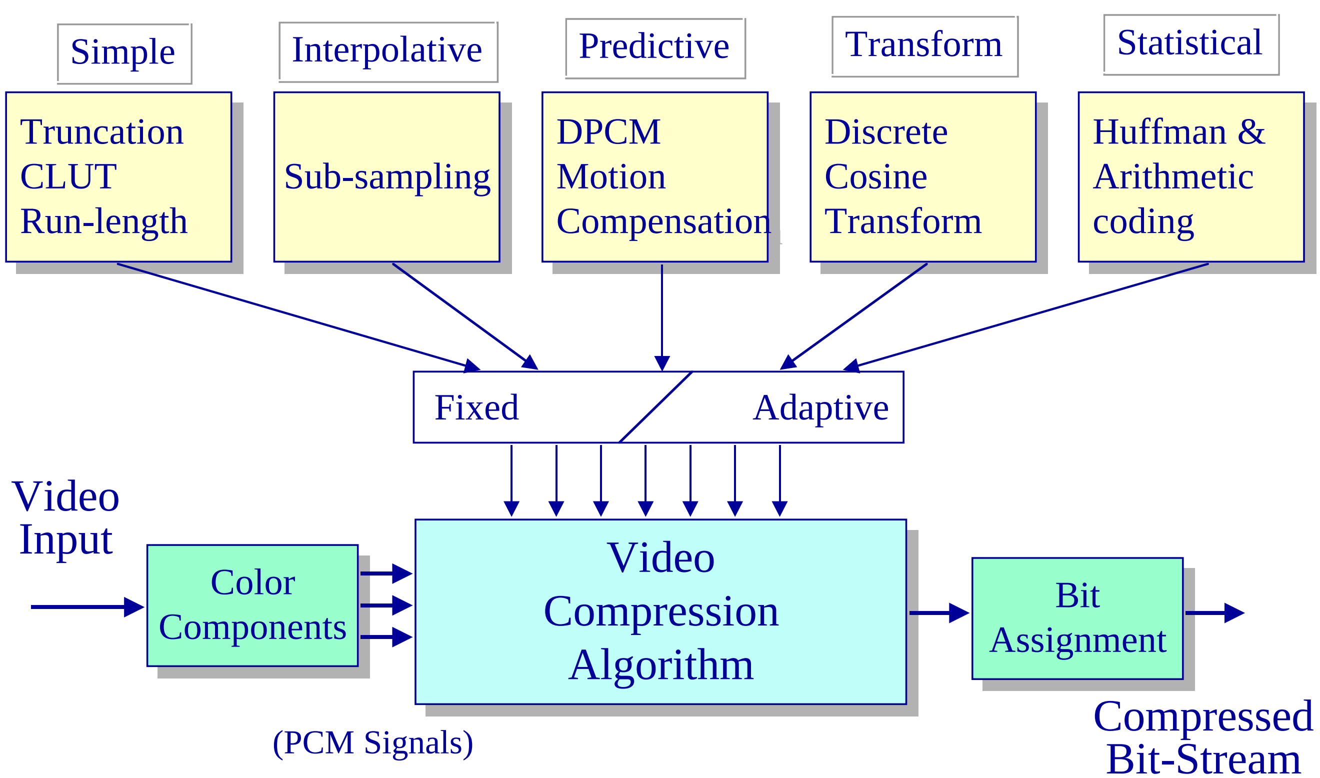
Digital Video
Compression Techniques

- Do we really need every “bit” of a video stream?
  - » Not if redundancy exists
  - » Not if we can’t perceive the effect of eliminating the bit



- Eliminating redundancy
  - » Spatial redundancy
  - » Temporal redundancy
- Eliminating imperceptible detail
  - » Coding
  - » Domain transformation

Digital Video
Compression Techniques



Adapted from Buford p.147

Video Compression
Issues

- Bandwidth requirements of resulting stream
  - » Bits per pixel (bpp)
- Image quality
- Compression/decompression speed
  - » Latency
  - » Cost
  - » Symmetry
- Robustness
  - » Tolerance of errors and loss
- Application requirements
  - » Live video
  - » Stored video

Simple Image Compression
Truncation

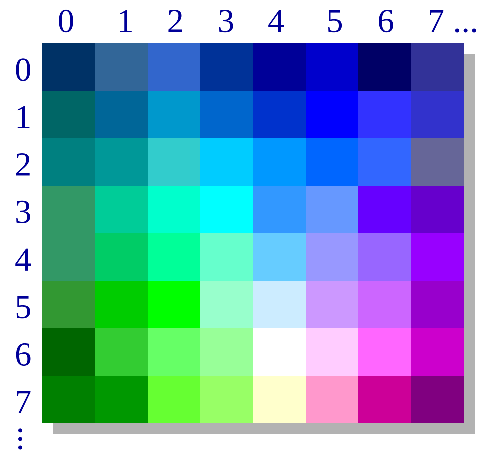
- Reducing the number of bits per pixel
  - » Throw away the least significant bits of each sample value
- Example
  - » Go from *RGB* at 8 bits/component sample (8:8:8) to 5 bits (5:5:5)
    - Go from 24 bpp to 15 bpp
    - This gives “acceptable results”
  - » Go from *YUV* at 8 bits/component sample 6:5:5 (16 bpp)
- Advantage — simple!

Simple Compression Schemes

Color-table lookup (CLUT)

- Quantize coarser in the color domain
  - » Pixel values represent indices into a color table
  - » Tables can be optimized for individual images

- Entries in color table stored at “full resolution” (*e.g.* 24 bits)

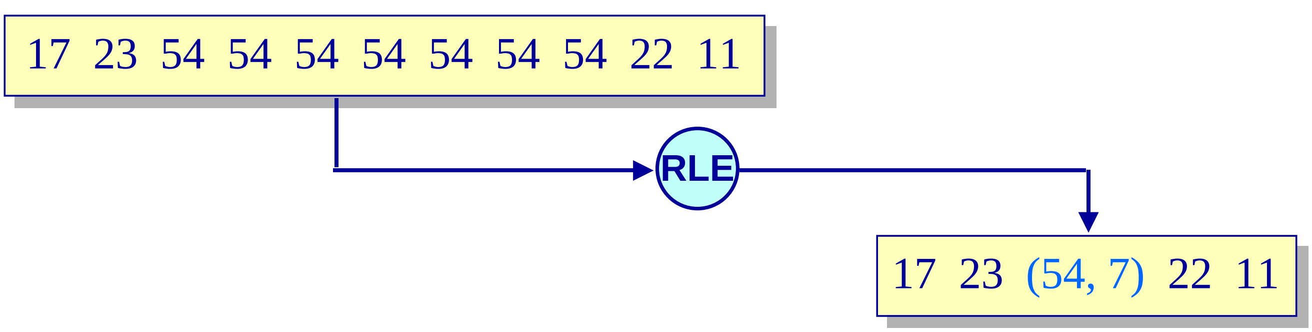


- Example:
  - » 8-bit indices (256 colors) gives

    $(440 \times 480) \times 8 + (24 \times 256) = 1.7 \times 10^6$ bits/sec

Simple Compression Schemes

Run-length encoding



- Replace sequences of pixel components with identical values with a pair (*value*, *count*)

- Works well for computer-generated images, cartoons. works less well for natural video

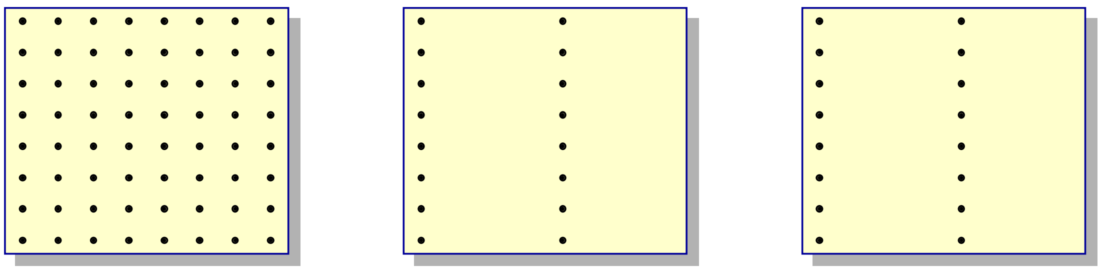
- Also works well with CLUT encoded images

  (*i.e., multiple techniques may be effectively combined*)

Interpolative Compression Schemes

Color sub-sampling

- Do not acquire chrominance component values at all sampling points
  - » Humans have poor acuity for color changes
  - » *UV* and *IQ* components were defined with this in mind
- <u>Example</u>: Color representation in digital tape recorders
  - » Subsampling by a factor of 4 horizontally is performed

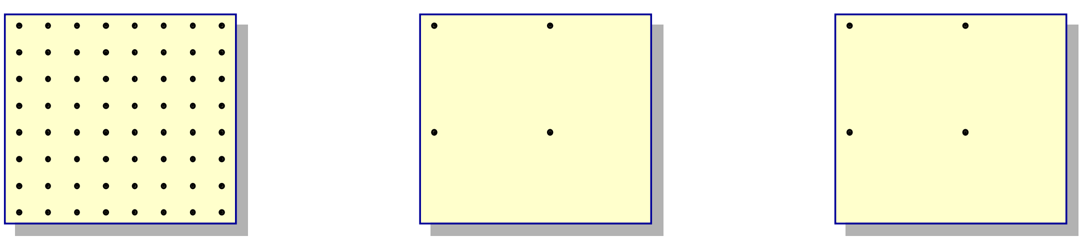


Y component *U* component *V* component

Interpolative Compression Schemes

Color sub-sampling

- Subsampling by a factor of 4 horizontally & vertically



Y component *U* component *V* component

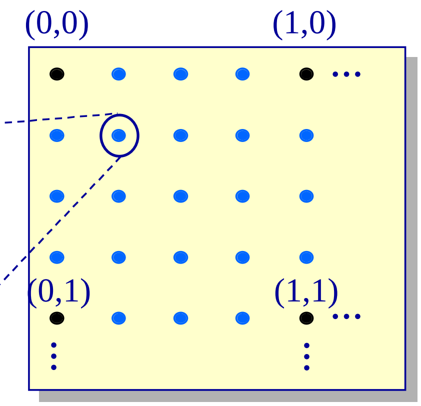
- Interpolating between samples provides “excellent” results
  - » Chrominance still sampled at 8 bpp

Interpolative Compression Schemes

Color sub-sampling

- Intermediate pixels either take on the value of nearest sampling point or their value is computed by interpolation
- Bi-linear interpolation:

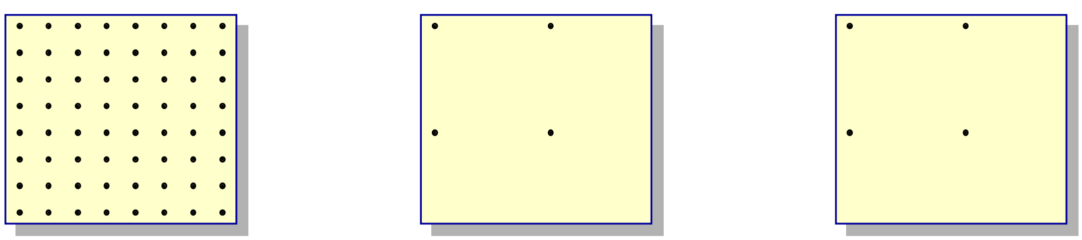
$$U(1,1) = U(0,0)\times 0.75 + U(1,0)\times 0.25 + U(0,1)\times 0.75 + U(1,1)\times 0.25$$



Sub-sampled
U or *V* component

Interpolative Compression Schemes

Color sub-sampling



Y component *U* component *V* component

- Storage/transmission requirements reduction:
  - » Within a 4x4 pixel block:

$$\text{bpp} = \frac{(8 \text{ bpp luminance})\times 16 \text{ samples} + (8 \text{ bpp chrominance})\times 2}{16}$$

$$= 9$$

  - » A 62.5% reduction overall

Predictive Compression Schemes

Exploiting spatial & temporal redundancy

- Adjacent pixels are frequently similar
  - » Do pixel-by-pixel DPCM compression
    - Leads to smearing of high-contrast edges
  - » ADPCM — a little better, a little worse
    - Introduces "edge quantization" noise
- Motion Estimation — If the future is the similar to the past, encode only the difference between frames
  - » This assumes we can store a previous frame to compare with a future one

Transform-Based Compression

Exploiting redundancy in other domains

- A simple linear transformation

2 x 2 array of pixels

A	B
C	D

1-D array of differences

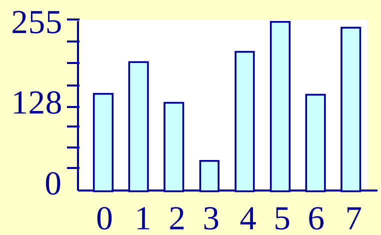
A	B–A	C–A	D–A

  - » Encode differences with less precision
- Storage savings
  - » Original array: 4 pixels x 8 bpp = 32 bits
  - » Transformed array: 8 bits + (3 pixels x 4 bpp) = 20 bits

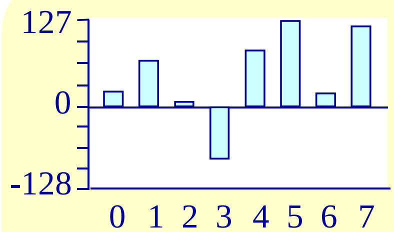
Transform-Based Compression

The Discrete Cosine Transform (DCT)

- A transformation into the frequency domain
- Example: 8 adjacent pixel values (*e.g.*, luminance)



Sample values



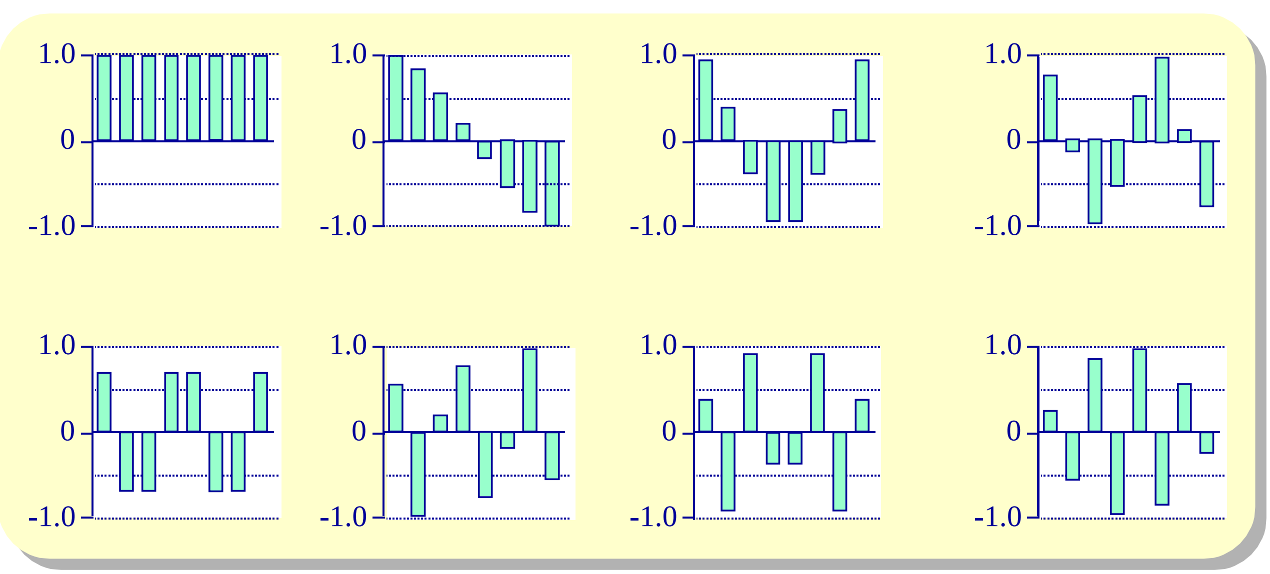
Level-shifted values

- What is the most compact way to represent this signal?

Transform-Based Compression

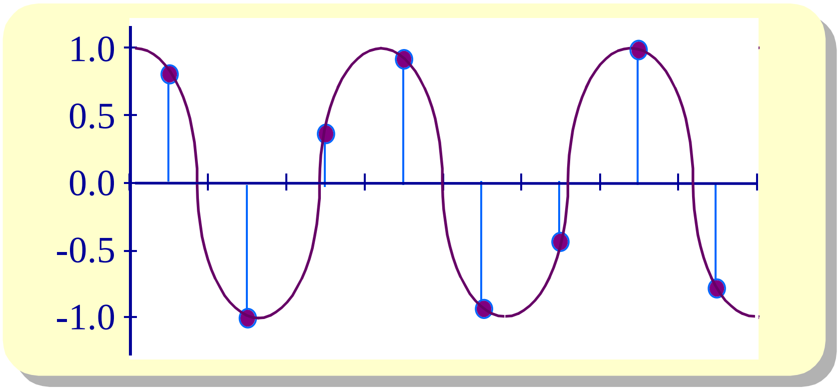
The Discrete Cosine Transform (DCT)

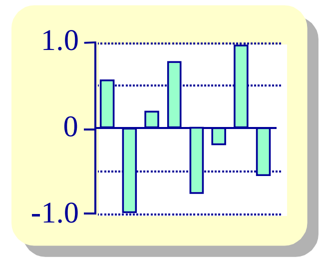
- Represent the signal in terms of a set of *cosine basis functions*



Transform-Based Compression

The Discrete Cosine Transform (DCT)



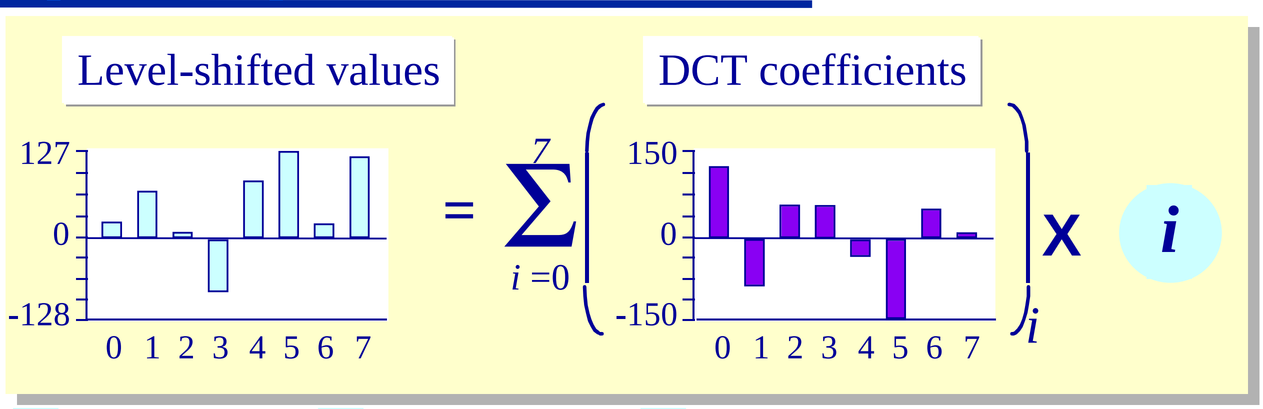


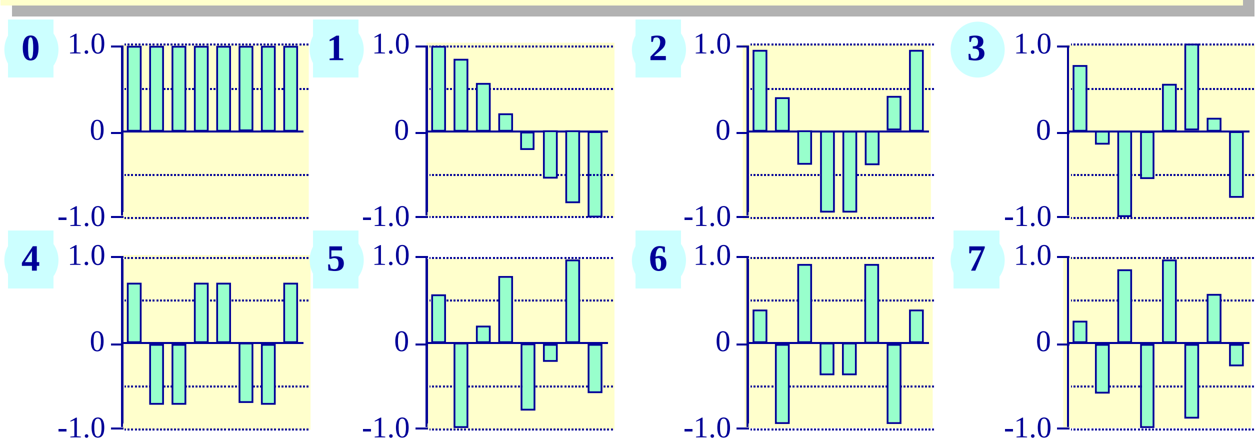
Sampled 2.5 Hz cosine wave

- The basis functions derive from sampling cosine functions of increasing frequency
  - » From 0-3.5 Hz
  - » Basis functions sampled at 8 discrete points

The Discrete Cosine Transform

Represent input as a sum of scaled basis functions





Transform-Based Compression

The Discrete Cosine Transform (DCT)

- The 1-dimensional transform:

$$F(\mu) = \frac{C(\mu)}{2} \sum_{x=1}^{7} f(x) \cos \frac{(2x+1)\mu\pi}{16}$$

  - » $F(\mu)$ is the DCT coefficient for $\mu = 0..7$
  - » $f(x)$ is the x^{th} input sample fot $x = 0..7$
  - » $C(\mu)$ is a constant (equal to $2^{-0.5}$ if $\mu = 0$ and 1 otherwise)

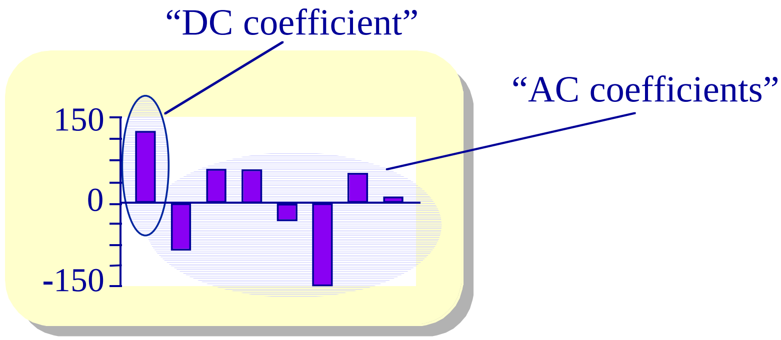
- The 2-dimensional (spatial) transform:

$$F(\mu,\nu) = \frac{C(\mu)}{2}\frac{C(\nu)}{2} \sum_{y=1}^{7} \sum_{x=1}^{7} f(x,y) \cos \frac{(2x+1)\mu\pi}{16} \cos \frac{(2y+1)\nu\pi}{16}$$

Transform-Based Compression

The Discrete Cosine Transform (DCT)

- DCT coefficients encode the spatial frequency of the input signal
  - » DC coefficient — zero spatial frequency (the "average" sample value)
  - » AC coefficients — higher spatial frequencies



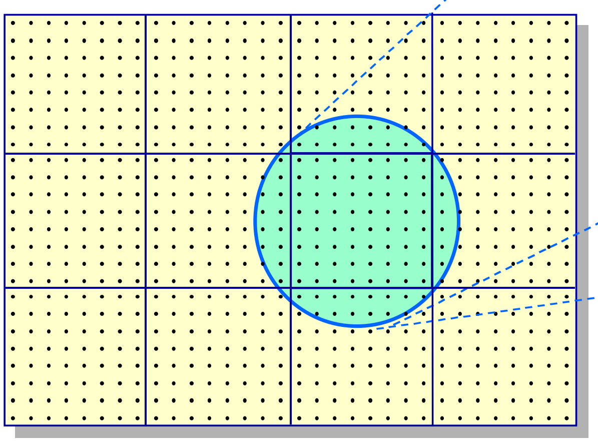
- Claim: Higher frequency coefficients will be zero and can be ignored

Transform-Based Compression

The two-dimensional DCT

- Apply the DCT in *x* and *y* dimensions simultaneously to 8x8 pixel blocks
  - » Code coefficients individually with fewer bits

Video Frame



172	-18	15	-8	23	-9	-14	19
21	-34	24	-8	-10	11	14	7
-9	-8	-4	6	-5	4	3	-1
-10	6	-5	4	-4	4	2	1
-8	-2	-3	5	-3	3	4	6
4	-2	-4	6	-4	4	2	-1
4	-3	-4	5	6	3	1	1
0	-8	-4	3	2	1	4	0

DCT Coefficients

Statistical Compression

Huffman coding

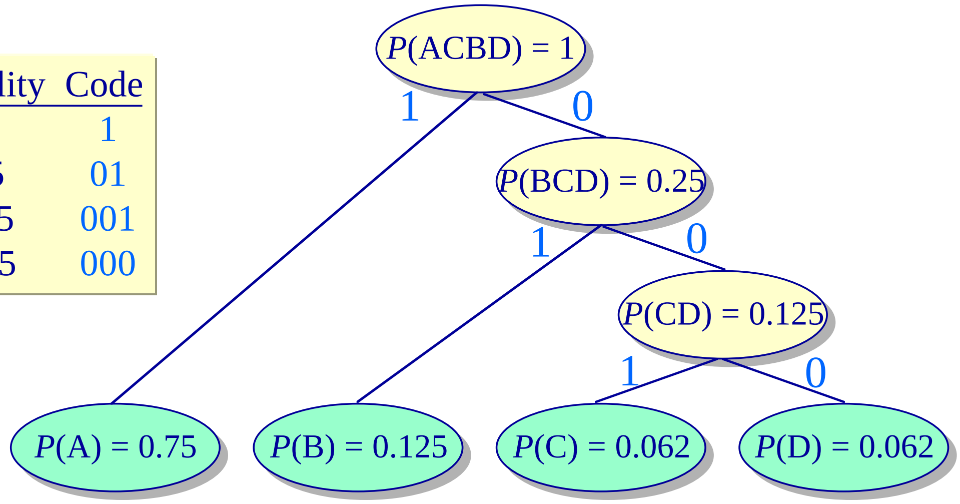
- Exploit the fact that not all sample values are equally likely
  - » Samples values are non-uniformly distributed
  - » Encode "common" values with fewer bits and less common values with more bits

- Process each image to determine the statistical distribution of sample values
  - » Generate a *codebook* — a table used by the decoder to interpret variable length codes
  - » Codebook becomes part of the compressed image

Statistical Compression

Huffman coding

Symbol	Probability	Code
A	0.75	1
B	0.125	01
C	0.0625	001
D	0.0625	000



- Order all possible sample values in a binary tree by combining the least likely samples into a sub-tree
- Label the branches of the tree with 1’s and 0’s
  - » Huffman code is the sequence of 1’s and 0’s on the path from the root to the leaf node for the symbol

Video Compression Standards

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The Video Data Type
Compression Standards

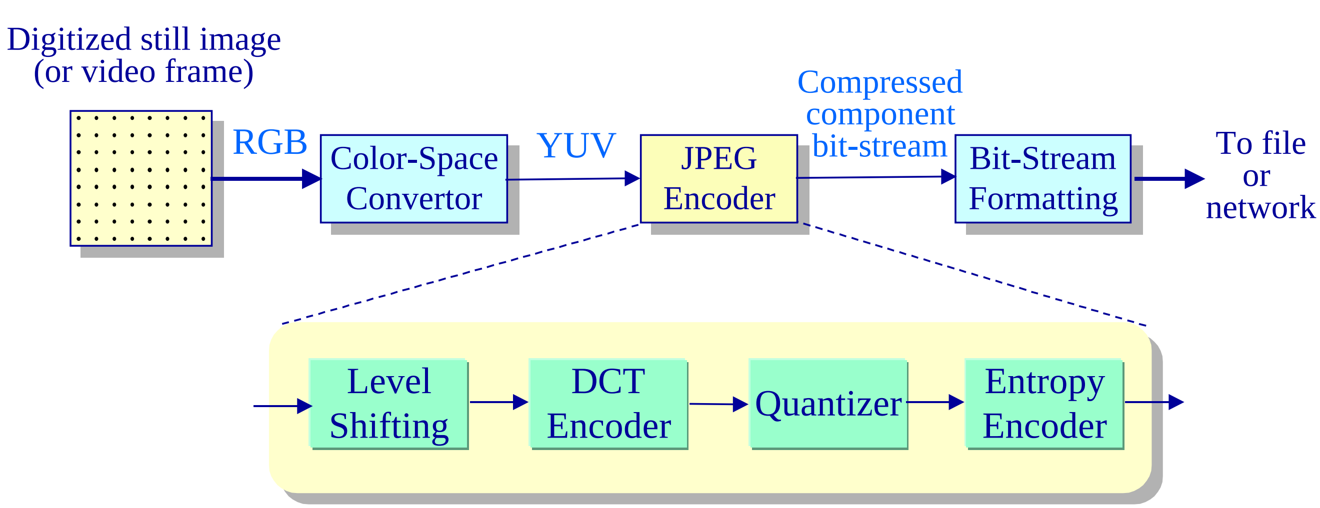
- Basic compression techniques
  - » Truncation, CLUT, run-length coding
  - » sub-sampling & interpolation
  - » DPCM
  - » DCT
  - » Huffman coding
- Common algorithms
  - » JPEG/MJPEG
  - » H.261/H.263
  - » MPEG-1,-2

Compression Algorithms
JPEG

- A still image ("continuous tone") compression standard
  - » DCT-based
- 4 Modes of compression
  - » *sequential* — image components coded in order scanned
    - ❖ Baseline — "default compression"
  - » *progressive* — image coded in multiple passes so partial images can be displayed during decoding
  - » *lossless* — guaranteed no loss
  - » *hierarchical* — image encoded at multiple resolutions
- Typical results
  - » 24:1 compression (1 bpp)

JPEG Compression
Encoder architecture — sequential mode

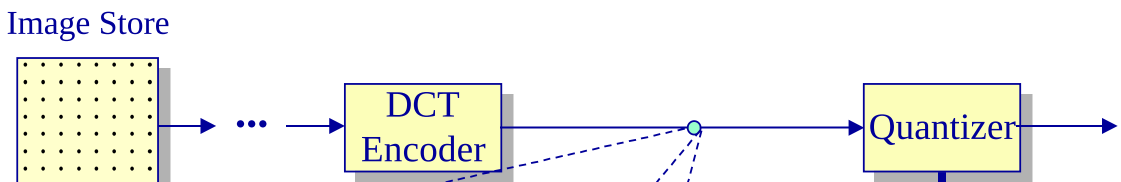
- Inputs are 8 or 12-bit samples
  - » baseline = 8-bit samples
- Image components are compressed separately
  - » DCT operates on 8x8 pixel blocks



JPEG Compression

Quantization

- DCT coefficient quantization is the key to compression
  - » Quantize according to the visual important of each coefficient
- The application specifies a *quantization table*
  - » A table of step-sizes from 1-255
  - » Default tables specified for the baseline coder



DCT coefficients

172	-18	15	-8	23	-9	-14	19
21	-34	24	-8	-10	11	14	7
-9	-8	-4	6	-5	4	3	-1
-10	6	-5	4	-4	4	2	1
-8	-2	-3	5	-3	3	4	6
4	-2	-4	6	-4	4	2	-1
4	-3	-4	5	6	3	1	1
0	-8	-4	3	2	1	4	0

Step-size table

4	7	10	13	16	19	22	25
7	10	13	16	19	22	25	28
10	13	16	19	22	25	28	31
13	16	19	22	25	28	31	34
16	19	22	25	28	31	34	37
19	22	25	28	31	34	37	40
22	25	28	31	34	37	40	43
25	28	31	34	37	40	43	46

JPEG Compression

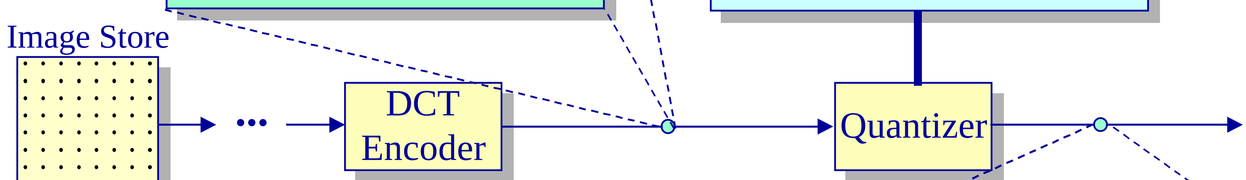
Quantization example

DCT coefficients

172	-18	15	-8	23	-9	-14	19
21	-34	24	-8	-10	11	14	7
-9	-8	-4	6	-5	4	3	-1
-10	6	-5	4	-4	4	2	1
-8	-2	-3	5	-3	3	4	6
4	-2	-4	6	-4	4	2	-1
4	-3	-4	5	6	3	1	1
0	-8	-4	3	2	1	4	0

Step-size table

4	7	10	13	16	19	22	25
7	10	13	16	19	22	25	28
10	13	16	19	22	25	28	31
13	16	19	22	25	28	31	34
16	19	22	25	28	31	34	37
19	22	25	28	31	34	37	40
22	25	28	31	34	37	40	43
25	28	31	34	37	40	43	46

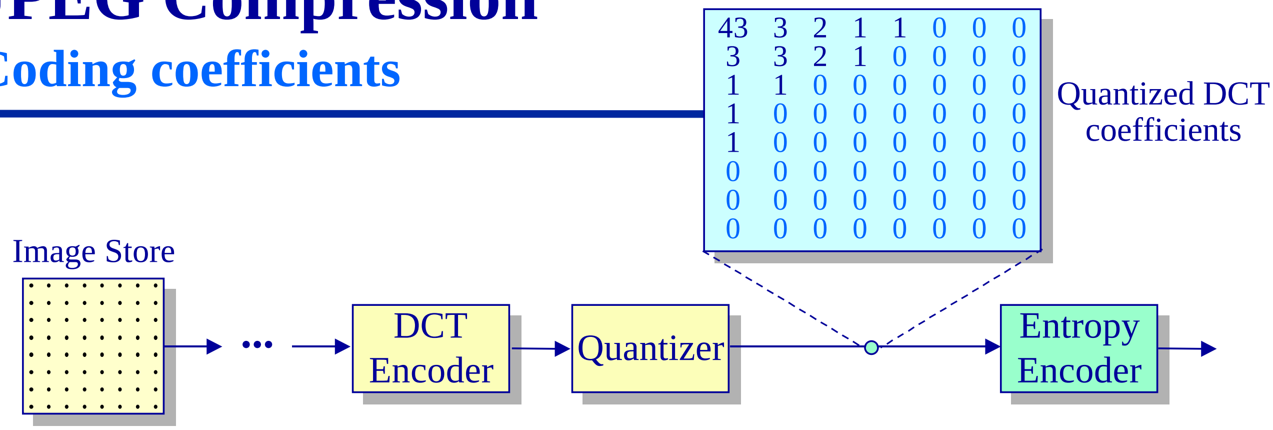


43	3	2	1	1	0	0	0
3	3	2	1	0	0	0	0
1	1	0	0	0	0	0	0
1	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

- Step-size table can be scaled to control degree of compression
  - » Scaling factor called the "*q-factor*"

JPEG Compression

Coding coefficients

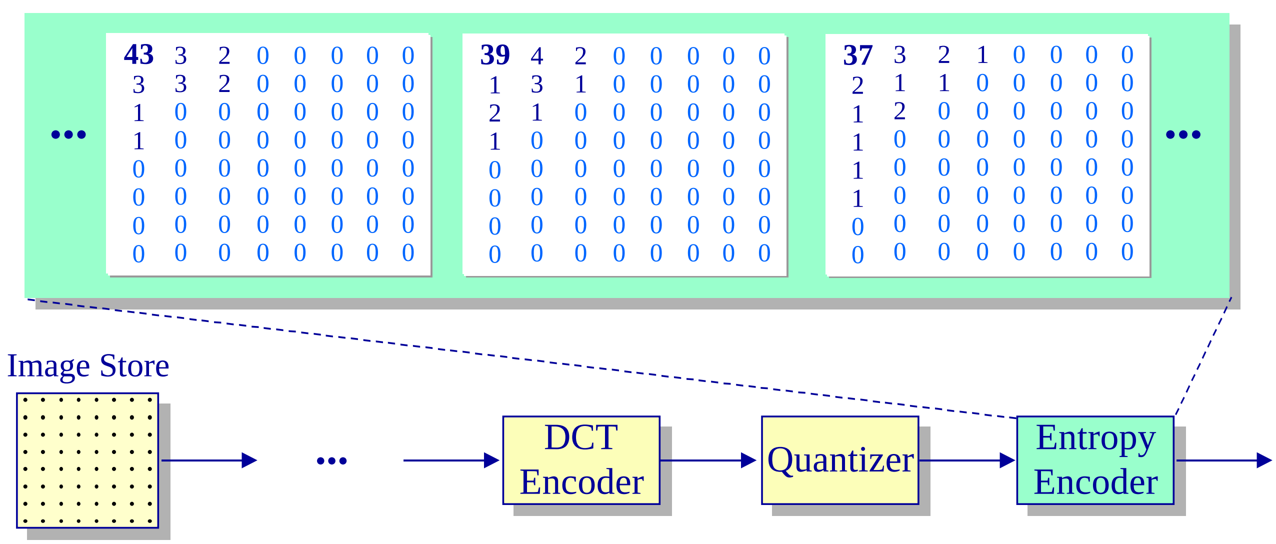


- DC coefficients difference-coded
  - » DC coefficients from adjacent 8x8 blocks strongly correlated
- AC coefficients run-length and Huffman coded

JPEG Compression

Coding DC coefficients

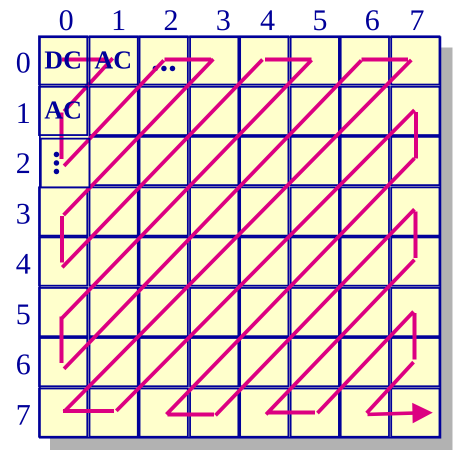
... (43-39), *ac*, *ac*, *ac*, ..., (39-37), *ac*, *ac*, *ac*, ...



- DC coefficients DPCM coded and recoded using a variable length entropy (Huffman) code

JPEG Compression
Coding AC coefficients

- "Zig-zag" order the AC coefficients to increase effectiveness of run-length coding
  - » DC,
    AC_{01}, AC_{10},
    AC_{02}, AC_{11}, AC_{20},
    AC_{03}, AC_{12}, AC_{21}, AC_{30},
    ...



- Run-length code the stream
  - » Each non-zero coefficient encoded as a pair:

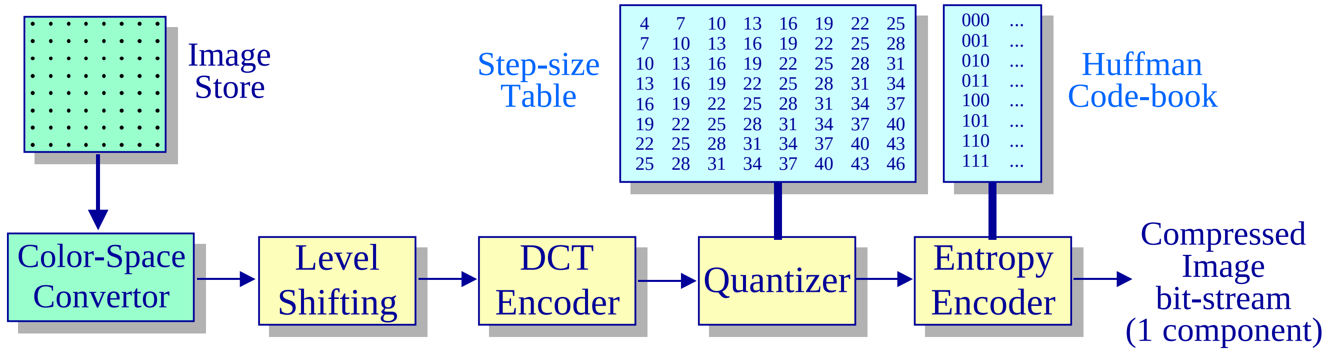
    (*run-length of preceding zero coefficients*, *amplitude of non-zero coefficient*)

JPEG Compression
Coding AC coefficients

- Each coefficient encoded as a variable length "pair"
  - » ([*run length*, *size*], *amplitude*)
- First element coded using a variable-length Huffman code
  - » A coding table ("code book") must be provided
    - Can be generated on-the-fly with an additional pass over the coefficients
    - Up to four code books per image may be specified
    - The codebook becomes part of the coded bit-stream
- Second element coded as a variable length integer
  - » whose length is specified in the previous "symbol"

Sequential JPEG Compression Summary

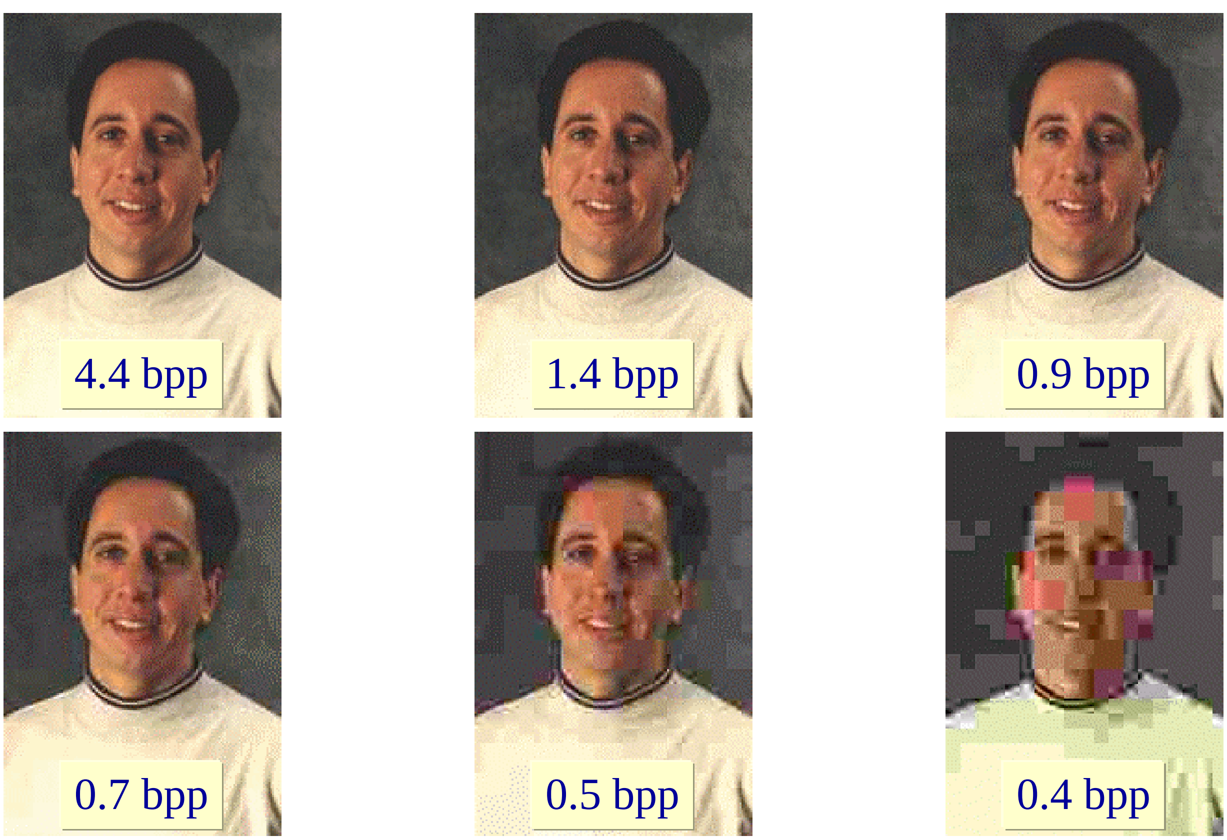
Complete compression pipeline



- Compression comes from:
  - » Chrominance subsampling
  - » DCT coefficient quantization
  - » Difference coding DC coefficients
  - » Statistical & run-length coding of AC coefficients
- Qualitative results:
  - » 0.25 - 0.5 bpp — ok for some applications
  - » 0.5 - 0.75 bpp — ok for many
  - » 0.75 - 1.5 bpp — excellent
  - » 1.5 - 2.0 — indistinguishable

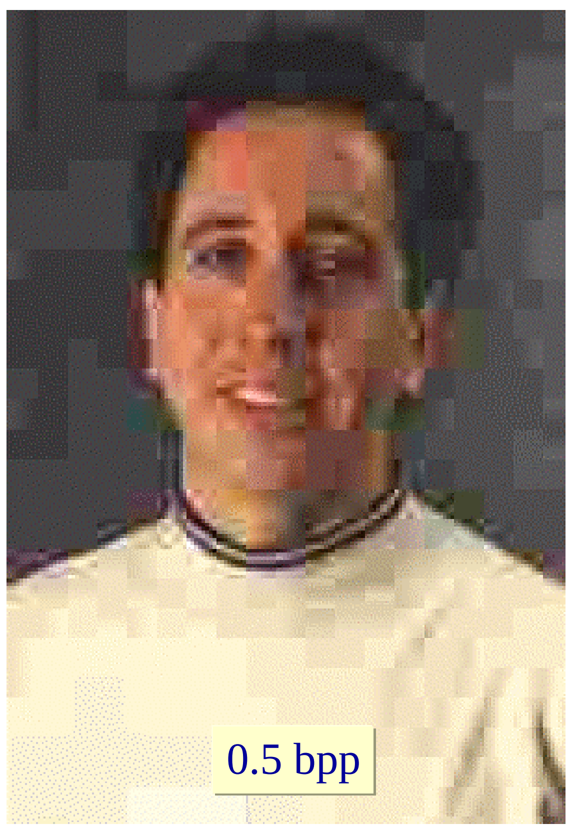
JPEG Compression

Examples of quality *v.* bpp



JPEG Compression
Examples of quality *v.* bpp

JPEG Compression
Examples of quality *v.* bpp



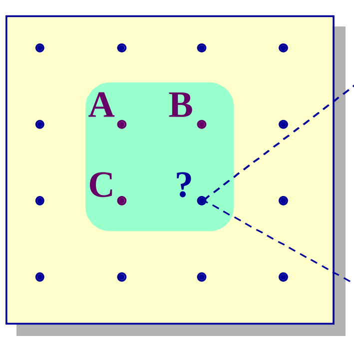
JPEG Compression

Other modes of operation

- Lossy compression modes
  - *sequential* — image components coded in order scanned
    - Default mode
  - *progressive* — image coded in multiple passes so partial images can be displayed during decoding
    - Useful for transmission of images over slow communications links
  - *hierarchical* — image encoded at multiple resolutions
    - Useful for images that will be displayed on heterogeneous displays
- Lossless mode
  - Guaranteed lossless
  - Uses DPCM encoding rather than DCT

JPEG Compression Modes

Loseless mode operation

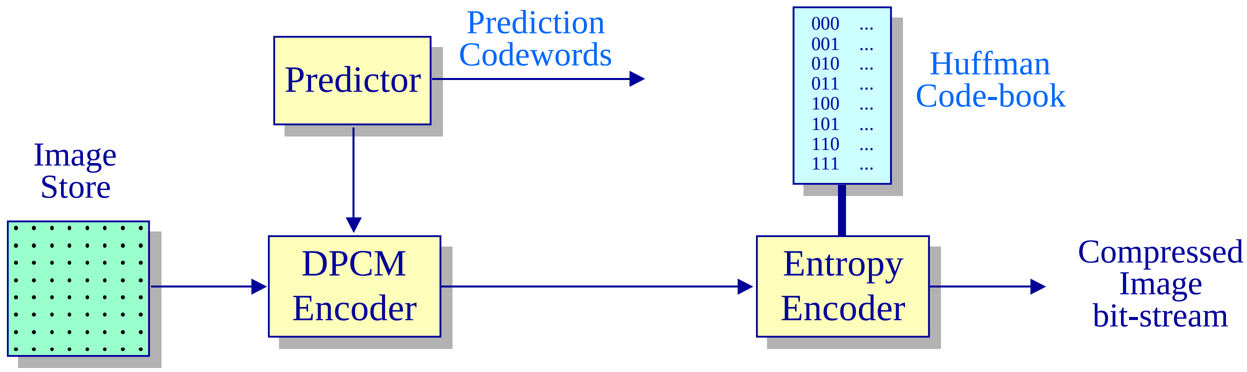


Predictor	Prediction Code
0	0
C	1
B	2
A	3
C + B – A	4
C + (B – A)/2	5
B + (C – A)/2	6
(C + B)/2	7

- Uses prediction instead of the DCT
  - Each pixel’s value is expressed as a function of neighboring pixels
  - A code word identifies the predictor being used

JPEG Compression Modes

Loseless mode operation

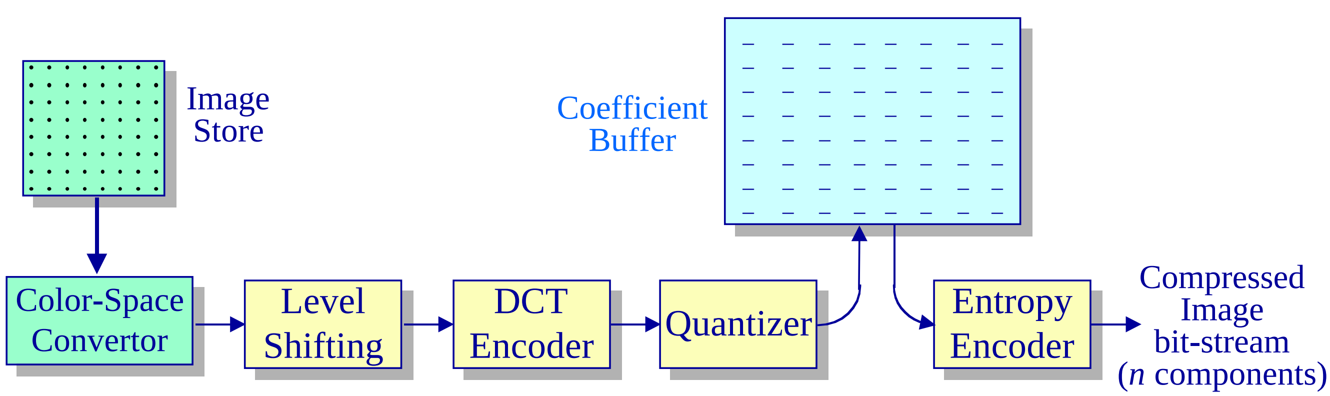


- Predicted samples are DPCM encoded
- Differences are entropy coded as before
- Achieves approximately 2:1 compression

JPEG Compression Modes

Progressive mode operation

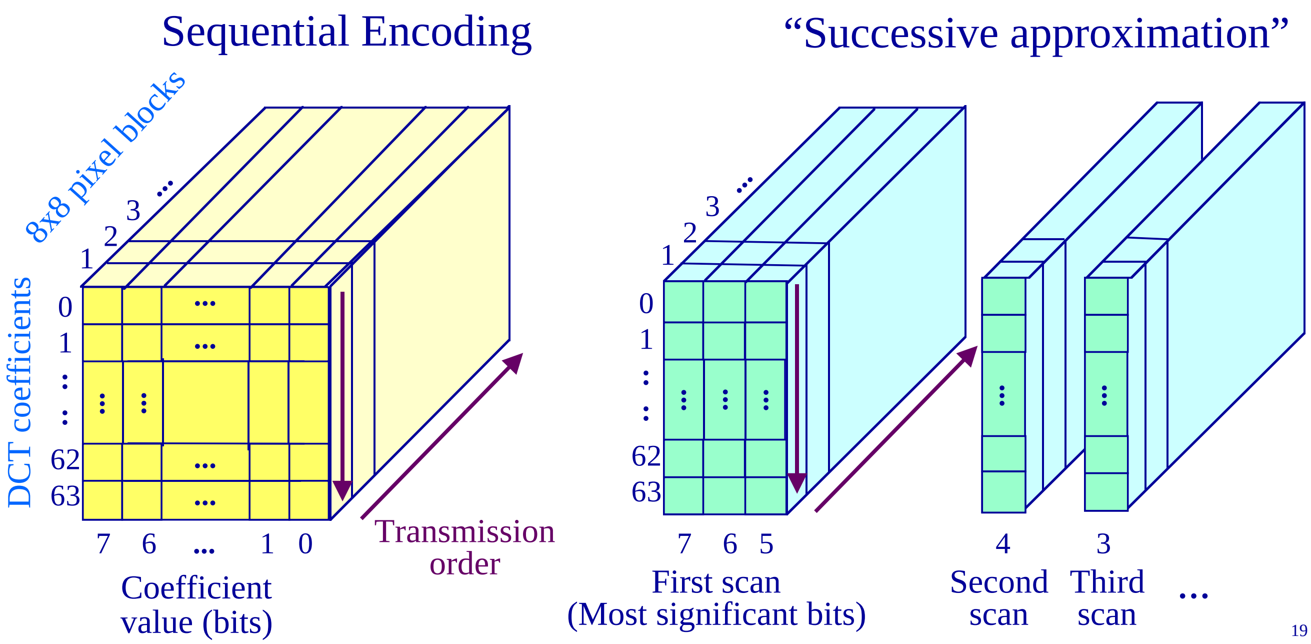
- Encode the image in scans to enable the display of a series of progressively refined images
  - » Requires an image-sized coefficient buffer between quantizer & entropy coder
  - » Scans of image components are also interleaved in bit-stream



JPEG Compression Modes

Progressive mode operation

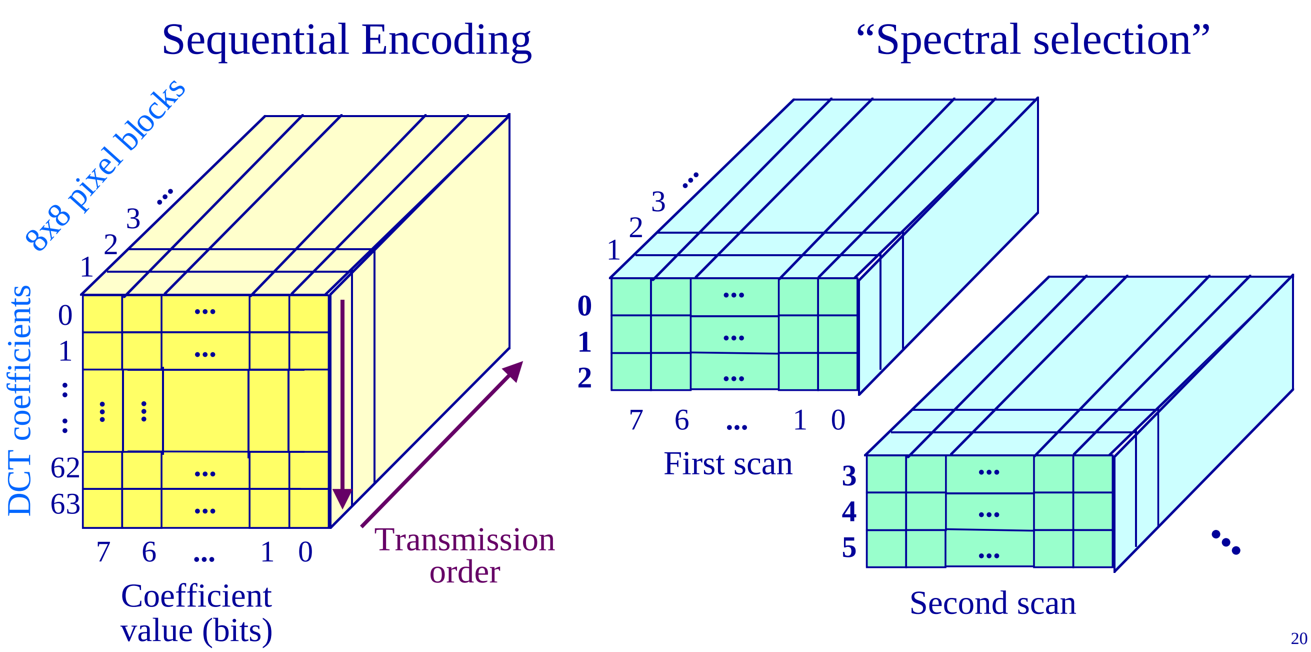
- Scan the coefficient buffer in multiple passes
  - » Transmit portions of each coefficient



JPEG Compression Modes

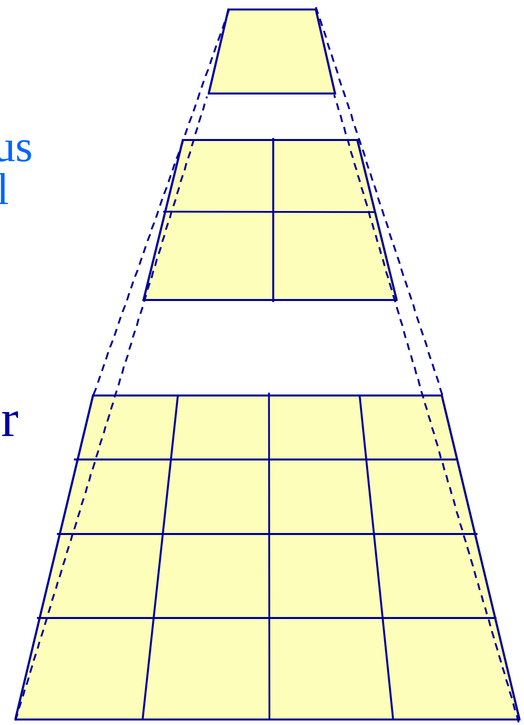
Progressive mode operation

- Scan the coefficient buffer in multiple passes
  - » Transmit portions of each coefficient



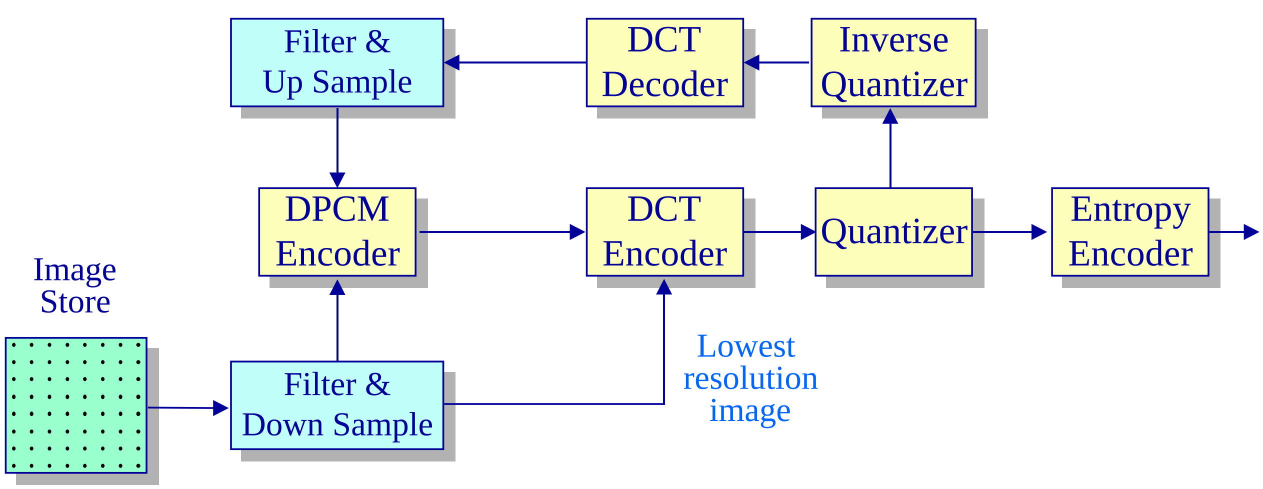
JPEG Compression Mode
Hierarchical mode operation

- Encode the image at multiple resolutions
  - » Each image differs from the previous by a factor of 2 in either the vertical or horizontal dimension
  - » Images created by filtering and subsampling
- Each resolution encoded by either the sequential or progressive algorithm



JPEG Compression Mode
Hierarchical mode operation

- Start with the lowest desired resolution & iteratively encode until the full image resolution has been coded
  - » Each iteration encodes an image with a factor of 2 higher resolution in one dimension



Motion JPEG
Applying JPEG to moving images

- Video can be (trivially) encoded as a sequence of stills
  - » This practice is routine in the digital video editing world
- The issue is how to encode and transmit "side information"
  - » Quantization tables, Huffman code-book may/may not change between frames

The Video Data Type
Compression Standards

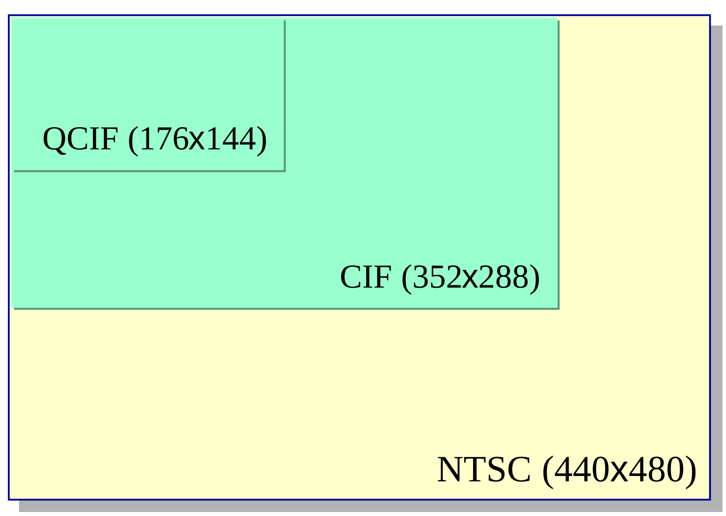
- Basic compression techniques
  - » Truncation, CLUT, run-length coding
  - » sub-sampling & interpolation
  - » DPCM
  - » DCT
  - » Huffman coding
- Common algorithms
  - » JPEG/MJPEG
  - » H.261/H.263
  - » MPEG-1,-2

Compression Algorithms
H.261 (*p*x64)

- A telecommunications (ITU) standard for audio & video transmission over digital phone lines (ISDN)
- H.261 primarily intended for interactive video applications
  - » Design of the standard driven by a 150 ms maximum encoding/decoding delay goal
- A scalable coding architecture capable of generating bit streams from 64 kbps (“1x64”) to 1,920 kbps (“30x64”) in 64 kbps increments
  - » p = 1, 2 produces a low res “videophone” (Common use is for ISDN BRI — 112 kbps video, 16 kbps audio)
  - » $p \geq 6$ produces an acceptable videoconference and allows multipoint communication

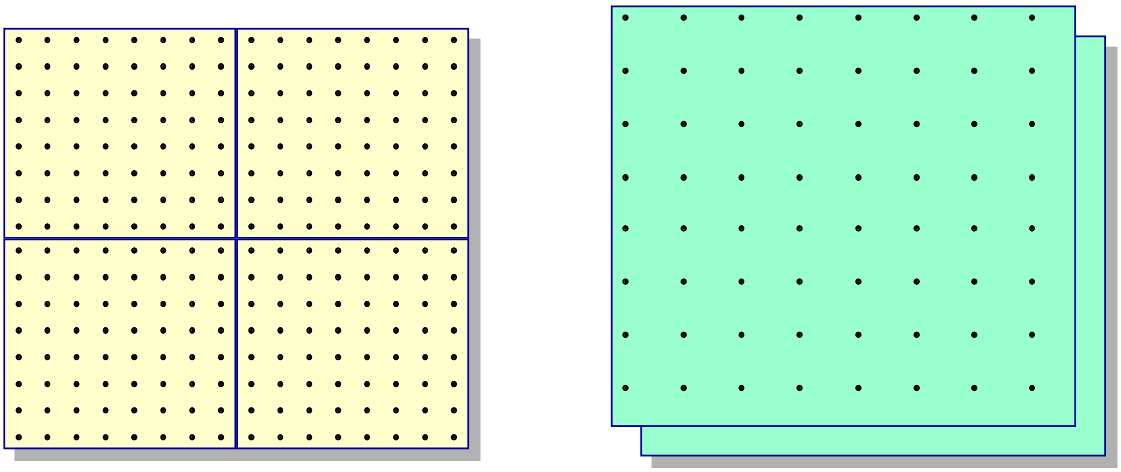
H.261
Video formats

- Inputs
  - » 525 or 625 line composite video
  - » 8 bits/sample
  - » 30 frames/second
- Color space
  - » *Y, Cr, Cb*
- Outputs
  - » CIF or QCIF
  - » 30, 15, 10, or 7.5 frames/second



H.261
Video frame representation

- Chrominance components are subsampled 2:1 horizontally & vertically
- Each video frame is subdivided into 16x16 *macroblocks*

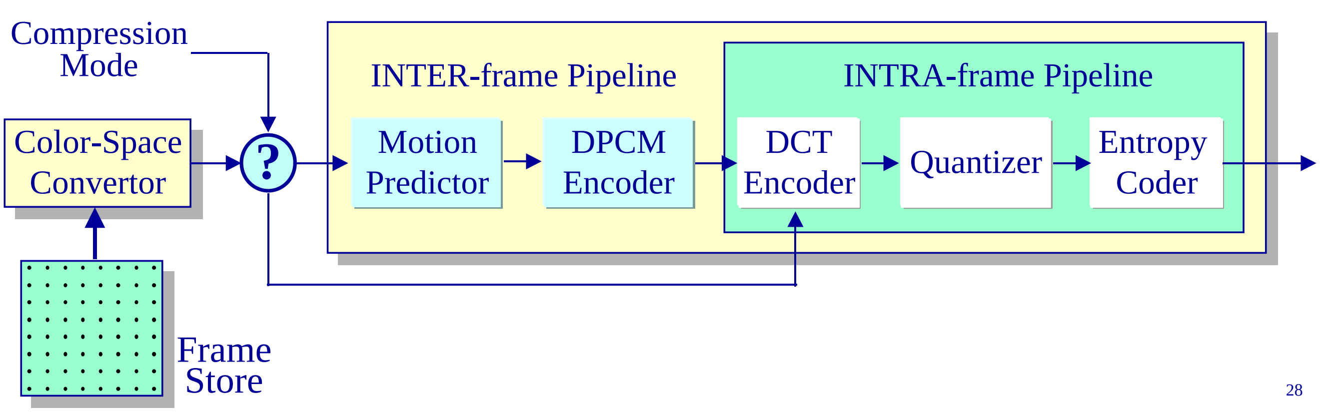


Y component: 4 8x8 blocks

Cr component: 1 8x8 block
(same for *Cb*)

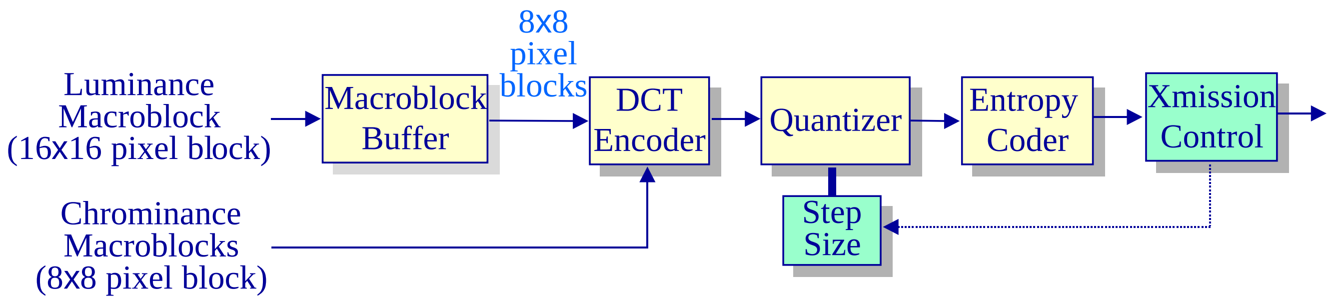
H.261
Video compression pipeline

- Two compression modes, selectable on a frame-by-frame basis
  - » INTRA-frame mode — DCT-based compression *á la* JPEG
    - video is treated as a sequence of stills
  - » INTER-frame mode — Incorporates motion estimation & DPCM prediction
    - temporal redundancy is eliminated to further improve compression



H.261 Video Compression

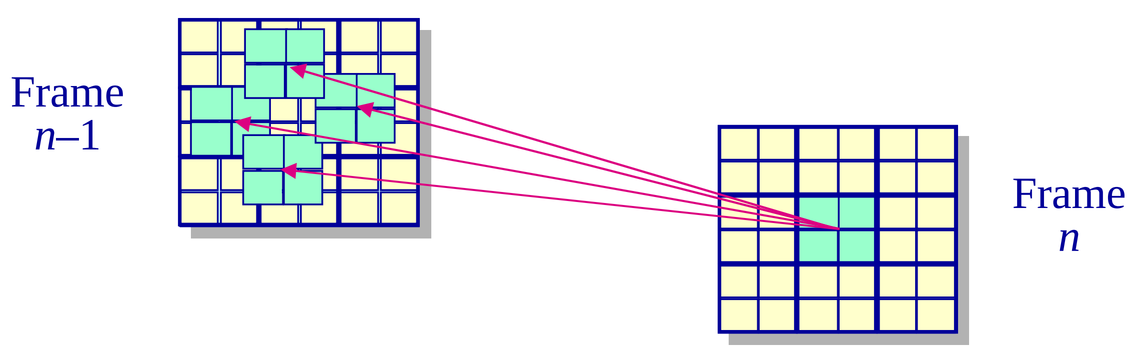
INTRA-frame mode



- Compression is similar to JPEG
  - » DCT encoding
  - » linear quantization
  - » entropy coding
- Quantization is uniform across all AC coefficients
  - » But is adaptive and driven by the space remaining in a transmission buffer

H.261 INTER-Frame Mode

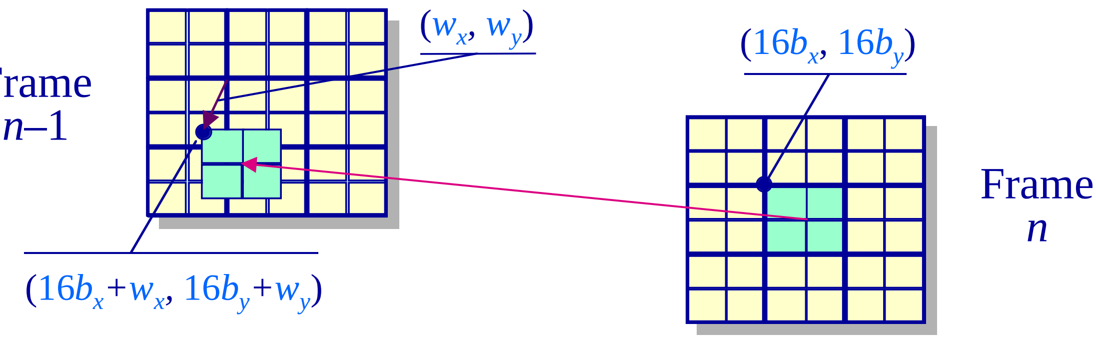
Motion estimation & prediction



- Motion estimation is performed only on luminance macroblocks
  - » Compare a luminance macroblock with its neighbors in the previous frame
  - » If the difference is small, do not compress the block, only record location of matching block
  - » If the difference is “large” send the *difference* between this macroblock and a previous neighboring macroblock into the DCT compression pipeline

H.261 INTER-Frame Mode

Motion estimation & prediction

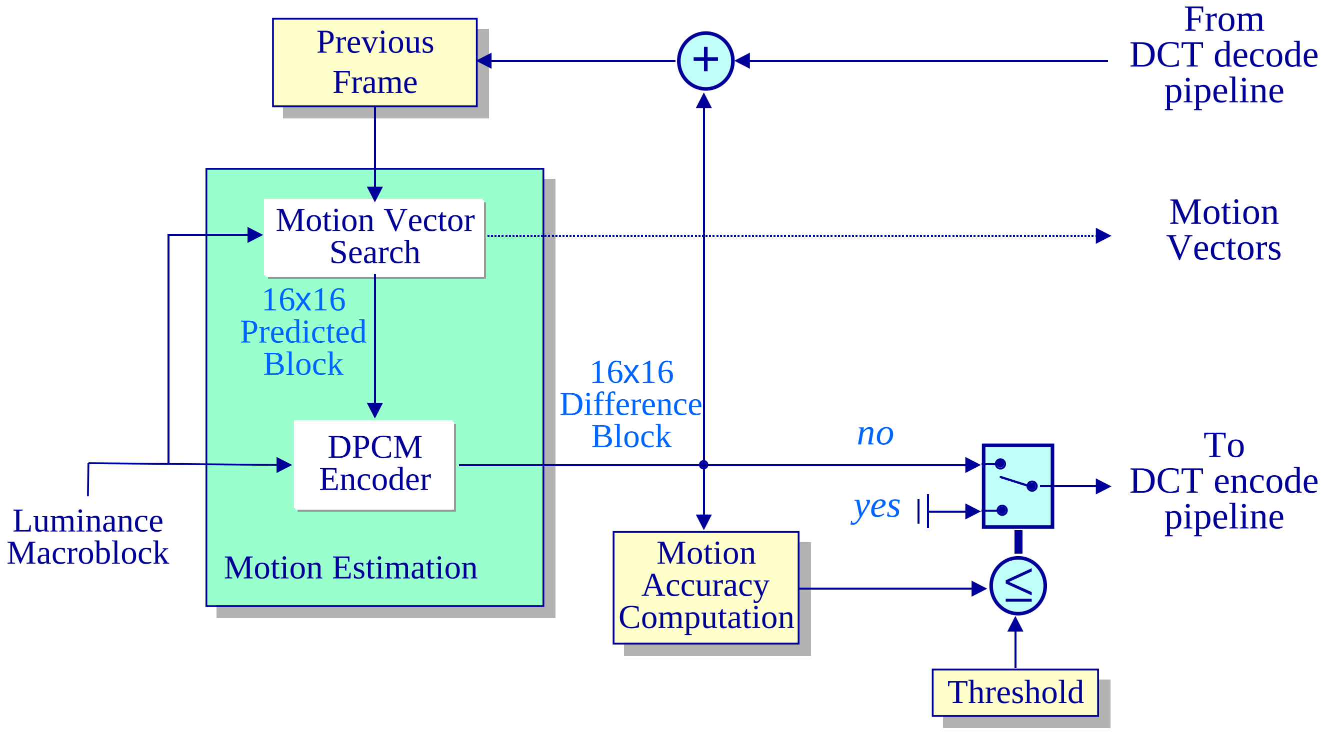


- Finding a predictor is the process of finding the minimally different adjacent 16x16 block in the previous frame
  - » Construct a "motion vector" — a relative displacement w for block b that minimizes the *mean absolute distortion* (*MAD*):

$$\frac{1}{256}\sum_{j=0}^{15}\sum_{i=0}^{15}\left|frame_n[16b_x+i,\ 16b_y+j]-frame_{n-1}[(16b_x+w_x)+i,\ (16b_y+w_y)+j]\right|$$

H.261 INTER-Frame Mode

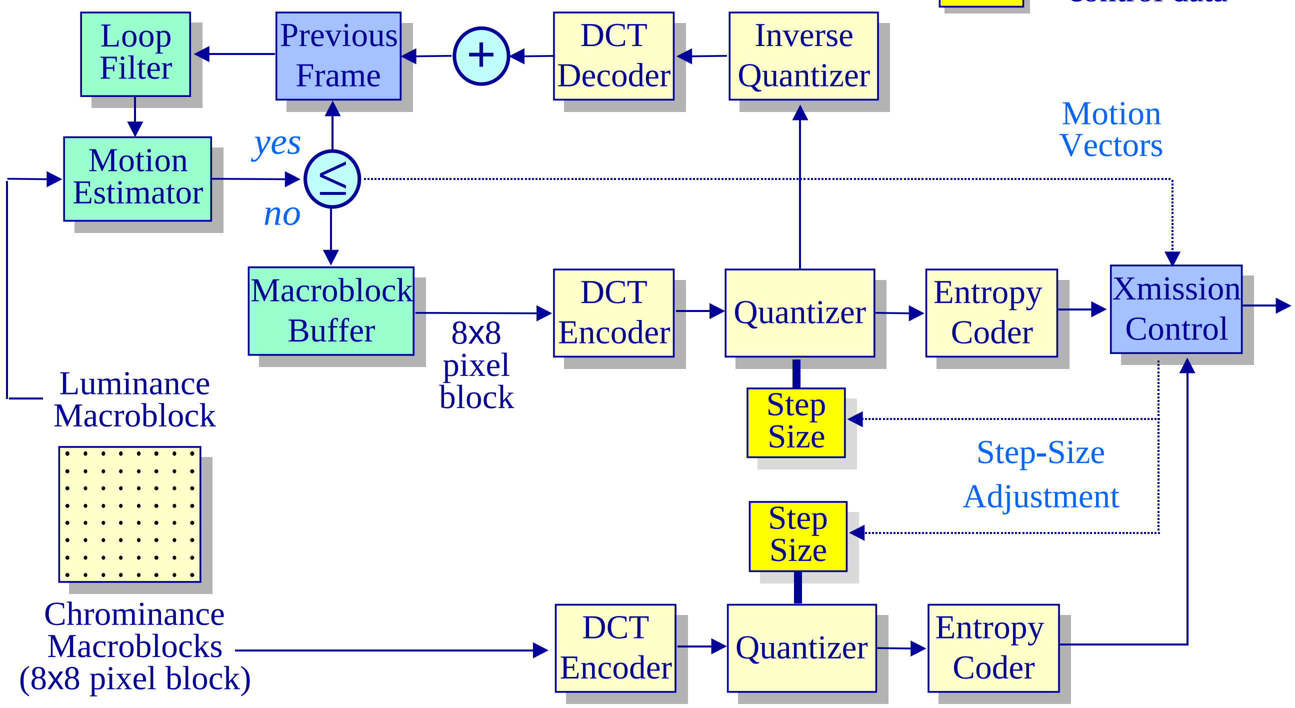
Motion compensated prediction



H.261 INTER-frame Mode

Complete pipeline

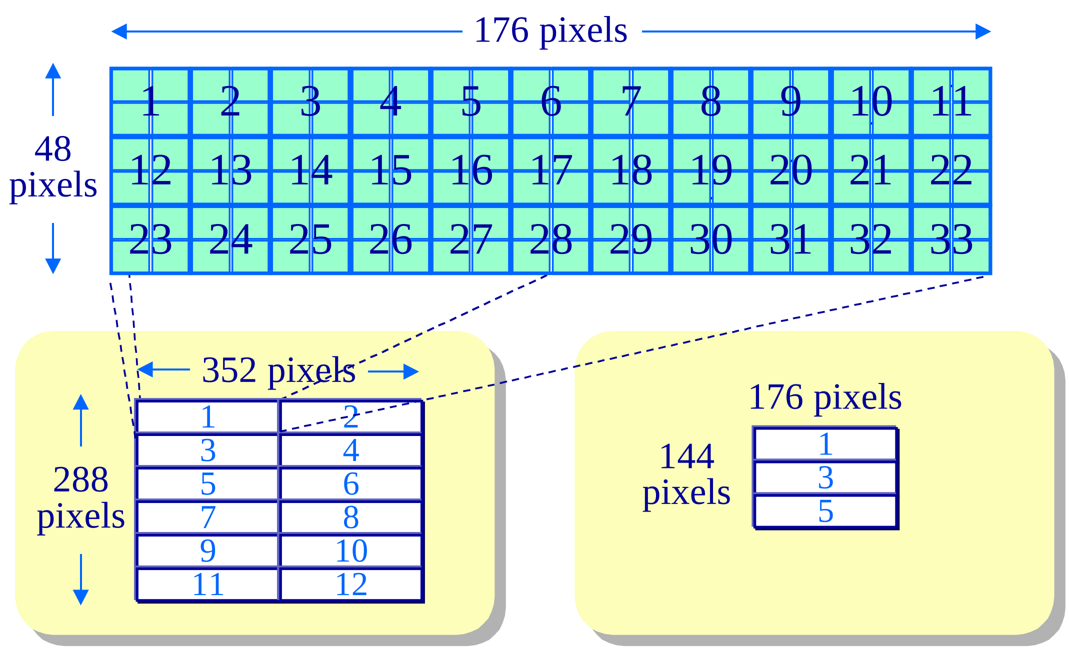
= video frame buffer
= 16x16 pixel block
= 8x8 pixel block
= control data



H.261

Video frame representation

- Macroblocks combined into *groups of blocks* (GOBs)
  - » An 11 by 3 array of macroblocks

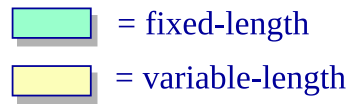


CIF Image: 12 GOBs

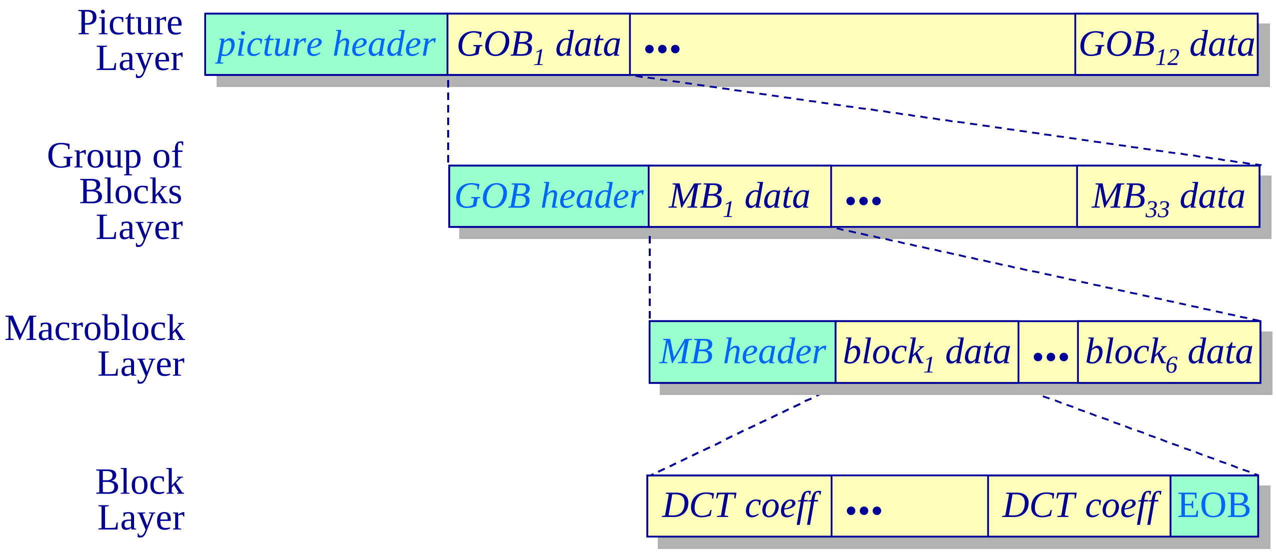
QCIF Image: 3 GOBs

H.261 Data Transmission

Bit-stream format



- Picture data is hierarchically transmitted



ITU H.320 Teleconferencing Standards

Teleconferencing over ISDN

- H.261 — Video communications at *p*x64 kbps
- H.221 — Syntax for multiplexing audio and video packets
- H.230 — Protocol for call setup and negotiation of end-system (“terminal”) capabilities
- H.242 — Conference control protocol
- G.711 — ISDN audio coding standard at 64 kbps
- G.722 — High-quality audio at 64 kbps
- G.728 — Reduced quality speech at 16 kbps

H.263 Video Compression

Low-bitrate video compression for data networks

- Based on H.261 (& MPEG-1, -2)
- Includes new image formats:

Format	Image Size	Maximum Number of coded bits/picture
sub-QCIF	128 x 96	64
QCIF	176 x 144	64
CIF	352 x 288	256
4CIF	704 x 576	512
16CIF	1,408 x 1,152	1024

- Added coding efficiency from:
  - » Unrestricted motion vectors
  - » Bi-directional motion estimation/prediction
  - » Arithmetic coding of AC coefficients

H.263 Video Compression

Companion standards

- H.263 — "Low bit-rate" video coding
- H.324 — Terminal systems
- H.245 — Conference control
- H.223 — Audio/video multiplexing
- G.723 — Audio coding 5.3 and 6.3 kbps

- For Internet conferencing there is also the related T.120 Document Conferencing standards family

The Video Data Type

Compression Standards

- Basic compression techniques
  - Truncation, CLUT, run-length coding
  - sub-sampling & interpolation
  - DPCM
  - DCT
  - Huffman coding
- Common algorithms
  - JPEG/MJPEG
  - H.261/H.263
  - MPEG-1,-2

Compression Algorithms

MPEG

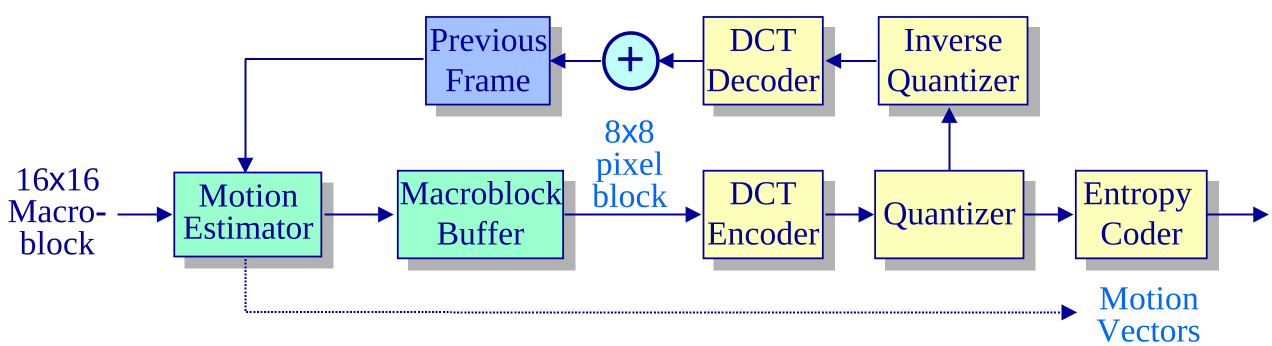
- A family of audio/video coding schemes
  - MPEG-1 —A video coding standard for digital storage/ retrieval devices
    - “VHS quality” video coded at approximately 1.5 Mbps
  - MPEG-2 — Video coding for digital television
    - SIF/CIF to HDTV resolutions at data rates up to 100 Mbps
  - MPEG-4 — Coding of audio/visual “objects” for multimedia applications
    - Coding of natural & synthetic images
    - Object-based encoding for content access & manipulation
  - MPEG-7 — A content/meta-data representation standard for content search and retrieval

MPEG-1 Video Compression
Requirements

- MPEG intended primarily for stored video applications
  - » A "generic" standard
  - » But a basic assumption is that video will be coded once and played multiple times
- Support for VCR-like operations
  - » Fast forward/forward scan
  - » Rewind/reverse scan
  - » Direct random access
  - » ...

MPEG-1 Video Compression
Relation to H.261

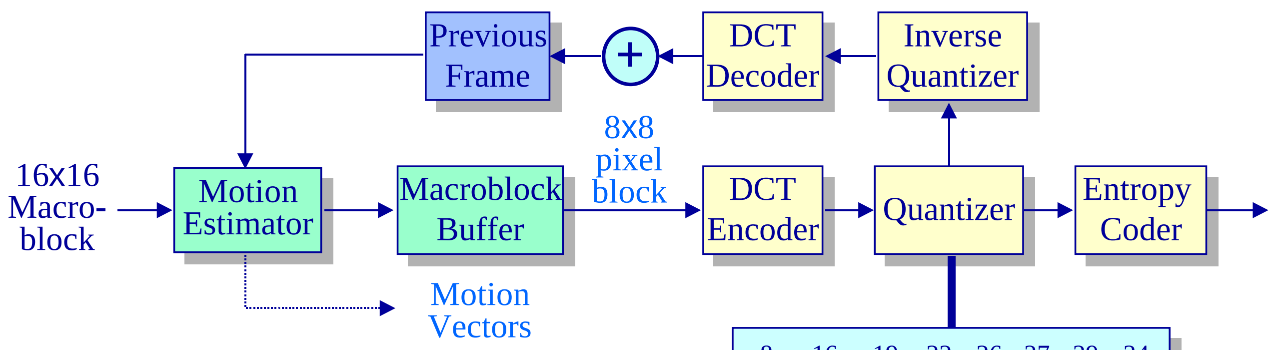
- Similar to H.261...
  - » INTER and INTRA picture types, entropy encoded, motion compensated, DCT-based compression...



- … but with more aggressive motion compensation:
  - » prediction — approximately the same as in H.261
  - » interpolation (bi-directional prediction)
  - » DPCM encoding of motion vectors

MPEG-1 Video Compression
Relation to JPEG

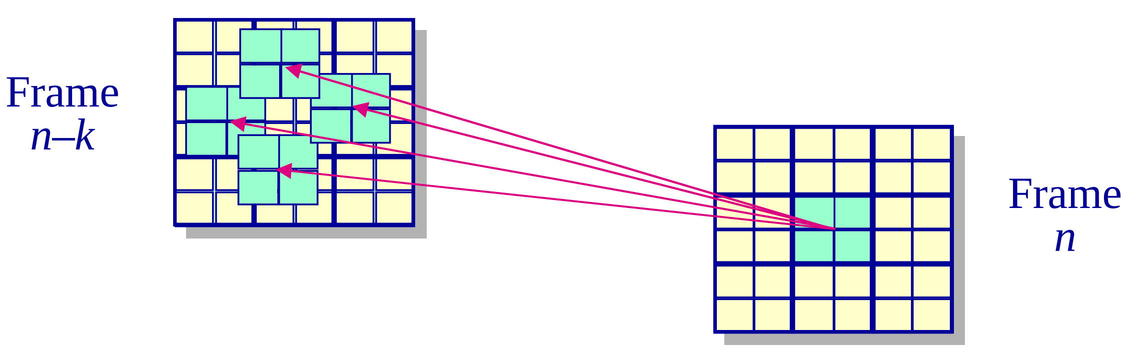
- Non-uniform quantization for intra-coded pictures
  - » Uniform quantization for inter-coded pictures



Step-size table

8	16	19	22	26	27	29	34
16	19	22	24	27	29	34	37
19	22	26	27	29	34	34	38
22	22	26	27	29	34	37	40
22	26	27	29	32	35	40	48
26	27	29	32	35	40	48	58
26	27	29	34	38	46	56	69
27	29	35	38	46	56	69	83

MPEG Video Compression
Motion compensated prediction

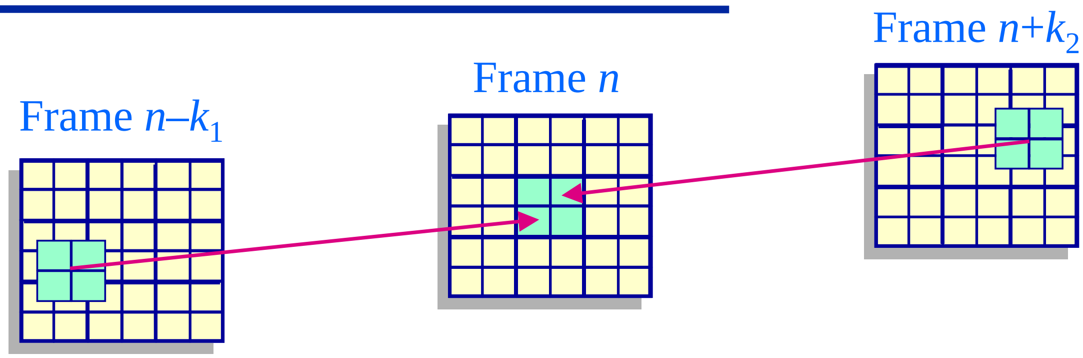


- The predictor search space is not specified in the standard
  - » Implementations can perform as exhaustive a search as they desire
- Find the motion vector w that minimizes some cost function f

$$\sum_{j=0}^{15}\sum_{i=0}^{15} f(frame_n[16b_x+i,\ 16b_y+j] - frame_{n-1}[16b_x+w_x+i,\ 16b_x+w_y+j])$$

MPEG Motion Compensated Prediction

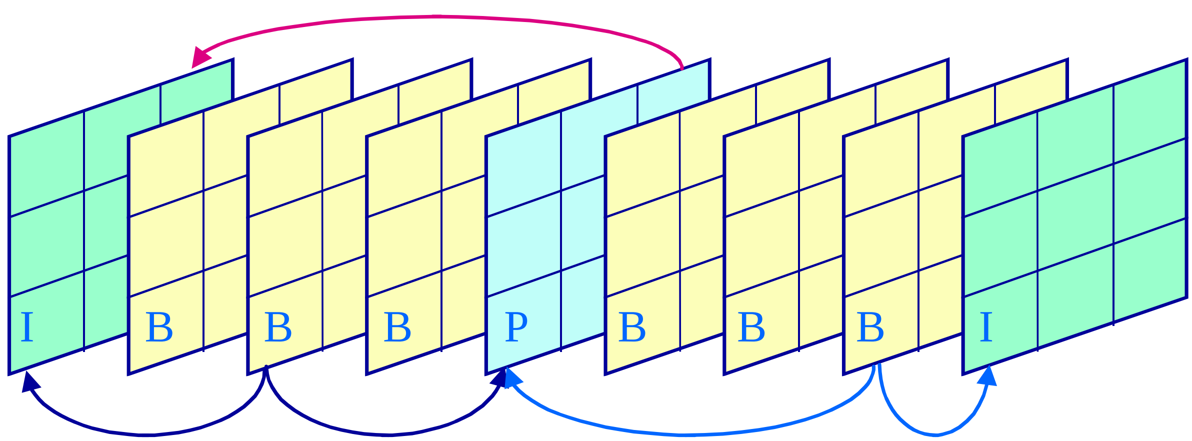
Bi-directional prediction



- Besides simple prediction, *interpolation* (bi-directional prediction) is used to achieve further compression
- A future frame *and* a past frame are used to predict the current frame
  - » Deals effectively with scene changes and new object appearances
  - » Produces predictors (pairs) with better statistical properties

MPEG Motion Compensated Prediction

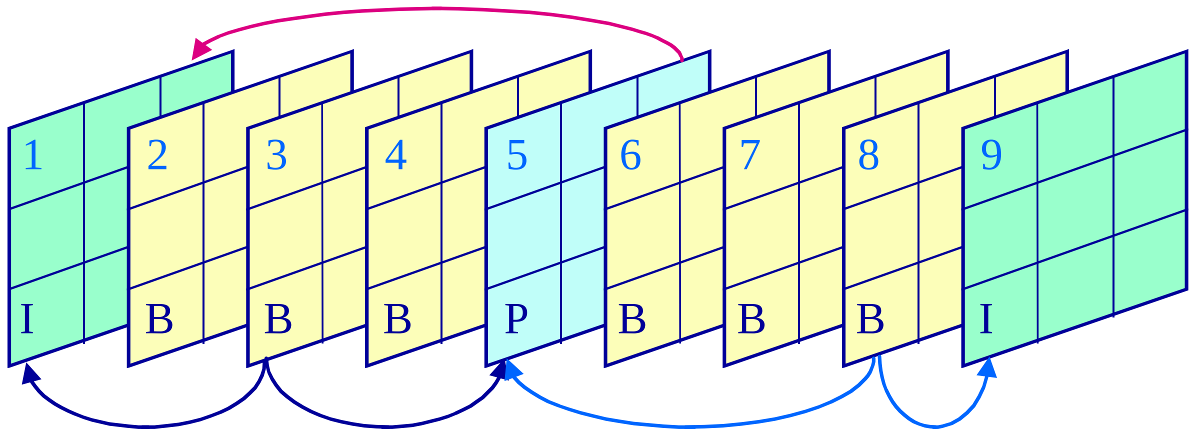
Bi-directional prediction



- MPEG defines three picture (frame) types:
  - » I — intracoded pictures coded as a still image
  - » P — predicted pictures predicted from the previous I or P picture
  - » B — interpolated pictures predicted from the previous I or P picture and the next I or P picture

MPEG Motion Compensated Prediction

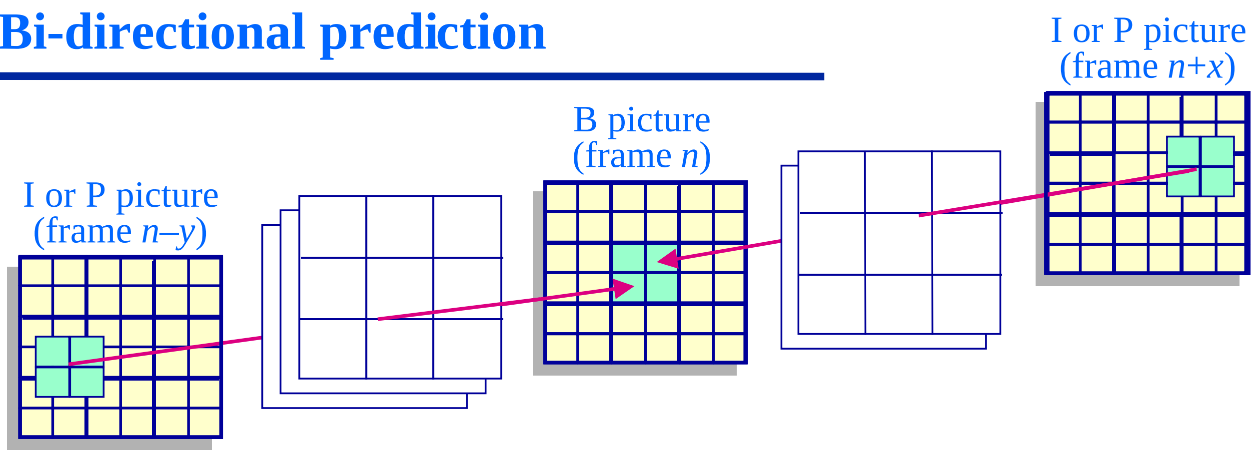
Bi-directional prediction



- Directional prediction implies that frames cannot be encoded or transmitted in the order they are scanned
- Encoding & transmission order:
  - $I_1\ P_5\ B_2\ B_3\ B_4\ I_9\ B_6\ B_7\ B_8\ P_{13}\ B_{10}\ B_{11}\ B_{12}\ I_{17}\ B_{14}\ B_{15}\ B_{16}$ ...

MPEG Motion Compensated Prediction

Bi-directional prediction



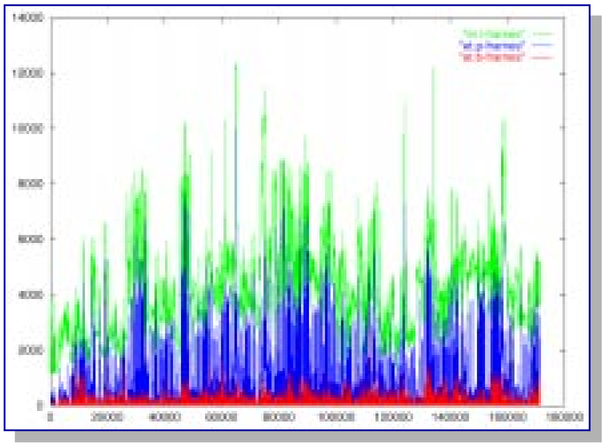
- Bi-directional prediction modes are selectable on a macroblock by macroblock basis within a B picture
- Macroblocks can be predicted by:
  - themselves: $frame'_n[i, j] = frame_n[i, j]$
  - a previous frame: $frame'_n[i, j] = frame_{n-y}[i+w_x, j+w_y]$
  - a future frame: $frame'_n[i, j] = frame_{n+x}[i+w_x, j+w_y]$
  - a previous & future frame: $frame'_n[i, j] = (frame_{n-y}[i+w_x, j+w_y] + frame_{n+x}[i+w'_x, j+w'_y])/2$

Bi-Directional Motion Compensation

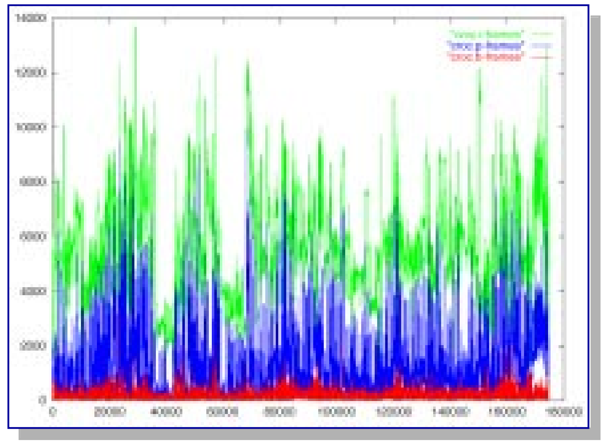
Compression rates

- Some prototypical results for 2 movies encoded at 320x240, 30 fps and constant quality

“Crocodile Dundee”



“ET”



MPEG Video Compression

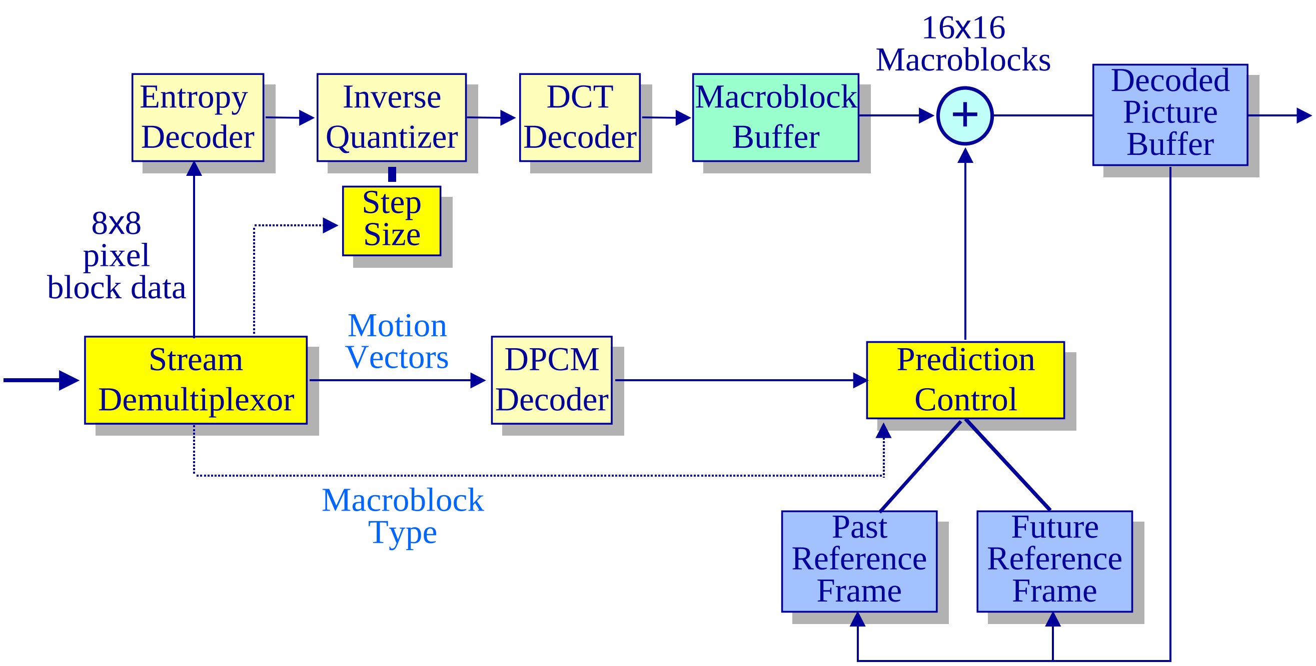
Decoder architecture

= video frame

= 16x16 pixel block

= 8x8 pixel block

= control data



MPEG Video Compression

Coded bit-stream

- MPEG has a layered bit-stream similar to H.261
- There are seven layers:
  - » Sequence Layer
    - ❖ decoding parameters (bit-rate, buffer size, picture resolution, frame rate, ...)
  - » Group of Pictures Layer
    - ❖ a random access point
  - » Picture Layer
    - ❖ picture type and reference picture information
  - » Slice Layer
    - ❖ position and state information for decoder resynchronization
  - » Macroblock Layer
    - ❖ coded motion vectors
  - » Block Layer
    - ❖ coded DCT coefficients, quantizer step size, *etc.*

MPEG-2

"New & Improved" MPEG-1

- A coding standard for the broadcast industry
  - » Coding for video that originates from cameras
  - » Offers little benefit for material originally recorded on film
- But included is support for:
  - » Higher (chrominance) sampling rates
  - » Resilience to transmission errors
  - » ...
- More mature and powerful coding/compression technology is used
  - » Unrestricted motion search with 1/2 pel resolution for motion vectors