MPEG Video Compression

Lecture 10

IMAGE SEQUENCE COMPRESSION

- The Need for Compression
  - Image sequences must be significantly compressed for efficient storage and transmission as well as for efficient data transfer among various components of a video system.
- Examples
  - Motion Picture:
    - » One frame of a Super 35 format motion picture may be digitized (via Telecine equipment) to a 3112 lines by 4096 pels/color, 10 bits/color image.
    - » As a result, 1 sec. of the movie takes ~1 Gbytes !

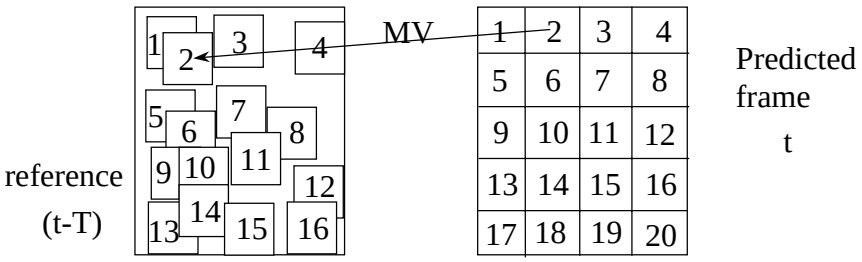
The Need for Compression - Examples

- HDTV:
  - A typical progressive scan (non-interlaced) HDTV sequence may have 720 lines and 1280 pixels with 8 bits per luminance and chroma channels.
  - The data rate corresponding to a frame rate of 60 frames/sec is 720 x 1280 x 3 x 60 = 165 Mbytes/sec!

Approaches to Image Sequence Compression

- Intraframe compression treats each frame of an image sequence as a still image.
  - Intraframe compression, when applied to image sequences, reduces only the spatial redundancies present in an image sequence.
- Interframe compression employs temporal predictions and thus aims to reduce temporal as well as spatial redundancies, increasing the efficiency of data compression.
  - Example: Temporal motion-compensated predictive compression.

Approaches to Image Sequence Compression



- The reference frame is available at the decoder;
- MV's and Prediction Error Blocks (PEB) are encoded and transmitted;
- From MV's and PEB's the predicted frame can be reconstructed at the decoder

Approaches to Image Sequence Compression

- Some application specific requirements, such as random access capability at all frames, may require the use of intraframe compression rather than interframe compression, at the expense of decreased compression efficiency.

Standards Relevant to Image Sequence Compression

Standard Activity	Description
JPEG	Joint (CCITT-ISO) Photographic Expert Group; Primarily designed for still images; Applicable to intraframe coding of sequences (standardized in 1993).
H.261	Recommendation of CCITT Expert Group on Visual Telephony; Designed for ISDN applications at p x 64 kbits/sec (p = 1,2,---,30); (standardized in December 1990).

Standards Relevant to Image Sequence Compression

Standard Activity	Description
MPEG	ISO Moving Picture Expert Group MPEG 1: Storage and retrieval of video + audio at about 1.5 Mbits/sec; (International Standard status.). MPEG 2: Storage and retrieval of video + audio at higher bit rates. (International Standard status in November 1994) MPEG 4: Video &Audio compression at very low data rates (from 4800 baud) (Final Date 11/98)

Standards Relevant to Image Sequence Compression

- CCIR: International Consultive Committee on Broadcasting
- CCITT: International Committee on Telegraph and Telephones
- CMTT: Joint committee of CCIR-CCITT on TV and Telephony
- ISO: International Standards Organization.

Importance of Standards

- Standardization of compression algorithms helps reduce the cost of codecs, triggers product development and industrial growth, and enables the compatibility among products from different manufacturers.
- (A good example is the standards for facsimile.)

Importance of MPEG in Particular

- Numerous possible consumer/comrnercial applications ranging from personal audiovisual communications to multimedia entertainment.
- The video compression system used in the US Grand Alliance HDTV system is fully compatible with the MPEG-2 standard.

Is There Life After Standards ?

- YES.
  - There is a significant amount of flexibility in designing an encoder that will generate a standard bitstream.
    - » Hence, improved encoder design remains to be an important area of work.
- Another challenging area is the development of systems that integrate components that use the standards, as well as individual components for such systems.

MPEG-1: General Remarks

- MPEG-1 standardization activities are based on the premise that video and its associated audio, at satisfactory quality, can be stored and retrieved at about 1.5 Mbits/sec.
- Among the factors motivating this bit rate are:
  - CD-ROM is an inexpensive storage medium capable of delivering data at about 1.2 Mbits/sec.

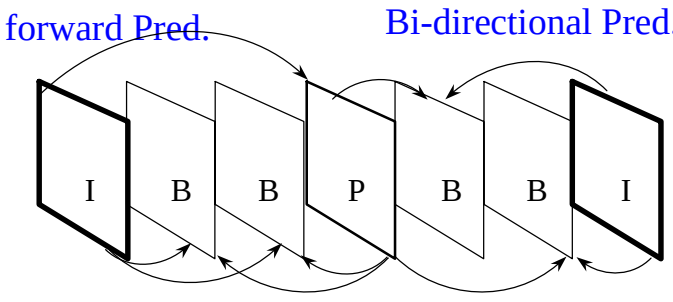
MPEG-1: General Remarks

- The MPEG-1 standard simultaneously supports both interframe and intraframe compression modes.
- The MPEG-1 standard considers:
  - Progressive-format video only:
  - Luminance and two chroma channels representation where chroma channels are subsampled by a factor of 2 in both directions;
  - 8 bit/pixel video
- Otherwise, appropriate pre- and post-processing steps should be carried out.

MPEG-1: General Remarks (cont'd.)

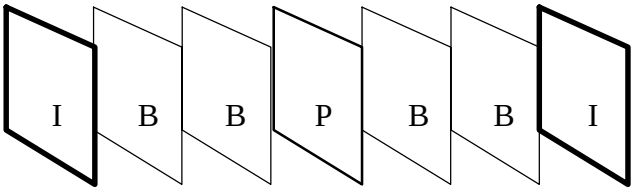
- MPEG-1 standardizes a syntax for the representation of encoded bit-stream and a method of decoding.
  - The standard syntax supports the operations of
    - » discrete cosine transformation (DCT),
    - » motion-compensated prediction,
    - » quantization, and
    - » variable length coding.
  - Substantial flexibility, is allowed in designing the encoder.
    - » For example, MPEG-1 does not standardize the motion estimation algorithm.

MPEG-1: Basic Compression Modes



- A typical assignment of compression modes for the frames of an image sequence.

MPEG-1: Basic Compression Modes (cont'd.)

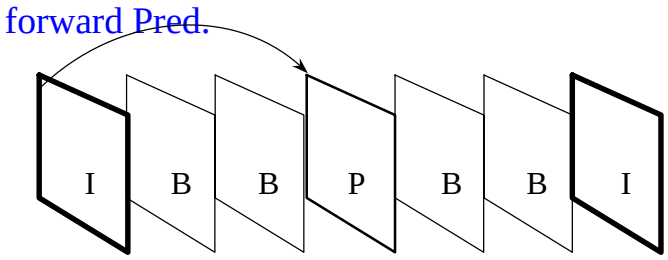


- A typical assignrnent of compression modes for the frames of an image sequence.

MPEG-1: Basic Compression Modes (cont'd.)

- Intraframe Compression
  - Frames marked by (I) denote the frames that are strictly intraframe compressed.
  - The purpose of these frames, called the "I pictures", is to serve as random access points to the sequence.

MPEG-1: Basic Compression Modes (cont'd.)

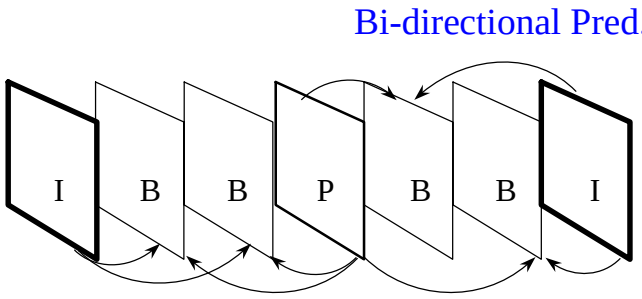


- A typical assignment of compression modes for the frames of an image sequence.

Non-Intra (Motion-Compensated Predictive) Compression

- In frames marked by (P), motion-compensated forward predictive compression is performed on a block basis.
  - Predicting blocks from closest (most recently decoded) I and P pictures are utilized.
  - Motion vectors and prediction errors are coded.
- In P pictures, blocks are allowed to be intra compressed if the prediction is deemed to be poor.

MPEG-1: Basic Compression Modes (cont'd.)



- A typical assignment of compression modes for the frames of an image sequence.

Non-intra (Motion-Compensated Predictive) Compression (cont'd)

- In frames marked by (B), motion-compensated bi-directional predictive compression is performed on a block basis.
  - Predicting blocks from closest (most recently decoded) I and P pictures are utilized.
  - Motion vectors and prediction errors are coded.
- In B pictures, blocks are allowed to be intra compressed if the prediction is deemed to be poor.

MPEG 1: Basic Compression Modes (cont'd.)

- Relative number of (I), (P), and (B) pictures can be arbitrary.
  - It depends on the nature of the application.
    - » For instance it depends on fast access and compression ratio requirements; relatively smaller amount of compression is expected to be achieved at (I) pictures compared to (P) and (B) pictures.
- The (B) pictures are expected to provide relatively the largest amount of compression under favorable predictability conditions.

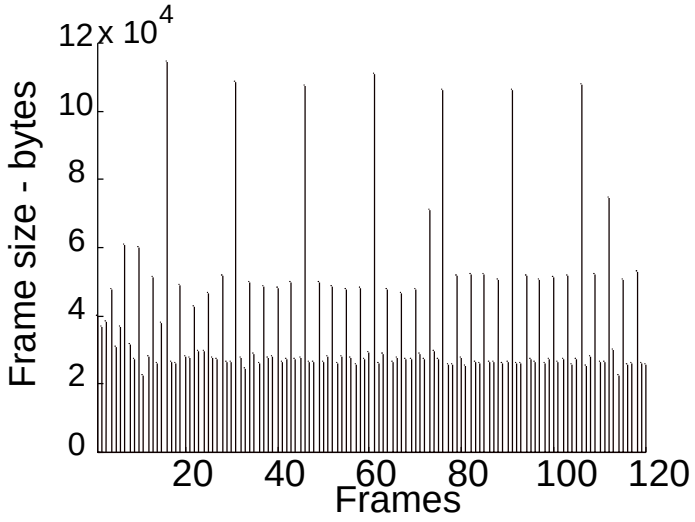
MPEG 1: Basic Compression Modes (cont'd.)

- Some possibilities:

```
I B B P B B I B B P B B I

I I I I I I I I I I I I I

I P I P I P I P I P I P I

I P I P I I I P I P I I I
```

- An I picture is mandatory at least once in a sequence of 132 frames (period_max= 132)

MPEG Frame Size



MPEG-1: Basic Compression Modes (cont'd.)

- Display and Encoding/Decoding order:

Encoder In./Decoder Out./Display: 1 2 3 4 5 6 7

I B B P B B I

Encoder Out./Bitstream/Decoder In.: 1 3 4 2 6 7 5

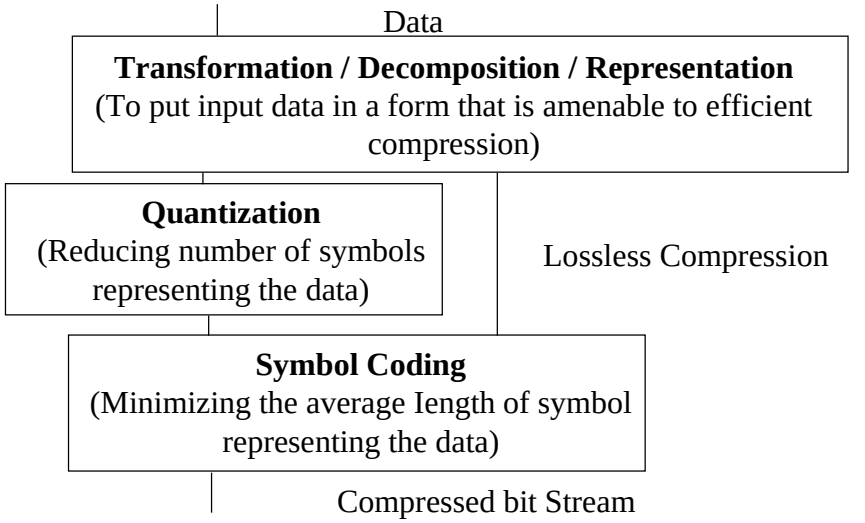
Outline of the MPEG-1 Discussion

- Intra Compression
  - Transformation
  - Quantization and Coding
- Non-Intra (Motion-Compensated, Predictive) Compression
  - Motion Estimation
  - Motion-Compensated Forward Prediction
  - Motion-Compensated Bi-directional Prediction
  - Transformation
  - Quantization and Coding

Outline of the MPEG-1 Discussion

- For an extensive discussion of the MPEG-1 algorithm, refer to "ISO CD 11172: Coding of Moving pictures and Associated Audio for Digital Storage Media at up to 1.5 Mbits/sec.".

Basic Steps of Data Compression



MPEG-1: Intra Compression

- Transformation
  - Discrete cosine transformation (DCT) is applied to 8 x 8 blocks of luma and chroma data.
  - DCT of an 8 x 8 Block:

$$F(u,v) = \frac{1}{4}C(u)C(v)\sum_{m=0}^{7}\sum_{n=0}^{7} f(m,n)\cos\left(\frac{\pi(2m+1)u}{16}\right)\cos\left(\frac{\pi(2n+1)v}{16}\right)$$

where $u, v, m, n = 0,1,\ldots,7$, *an*

$C(w) = 1/\sqrt{2}$ *for* $w = 0$; *and* $C(w) = 1$ *otherwise.*

MPEG-1: Intra Compression

- ASIDE: Energy Compaction Property of DCT
  - Example: An 8 x 8 block of the Lena image.

Image Block

139	144	149	153	155	155	155	155
144	151	153	156	159	156	156	156
150	155	160	163	158	156	156	156
159	161	162	160	159	l59	158	159
159	160	161	162	162	155	155	155
161	161	161	161	160	157	157	157
162	162	161	163	162	157	157	157
162	162	161	161	163	158	158	158

MPEG-1: Intra Compression

- NINT denotes nearest integer truncation.

NINT[DCT Block] =

1260	-1	-12	-5	2	-2	-3	1
-23	-17	-6	-3	-3	0	0	-1
-11	9	-2	2	0	-1	-1	0
-7	-2	0	1	1	0	0	0
-1	-1	1	2	0	-1	1	1
2	0	2	0	-1	1	1	-1
-1	0	0	-1	0	2	1	-1
-3	2	-4	-2	2	1	-1	0

Intra Compression

- Quantization
  - The DCT coefficients are uniformly quantized.
- The DC Coefficient
  - The DC coefficient is divided by 8, and the result is truncated to the nearest integer in [-256 255]
  - QF(O 0) = NINT[F(0,0)/8],

Intra Compression

- AC Coefficients
  - Each AC coefficient, F(U, V) is first multiplied by 16 and the result is divided by a weight. w(u, v). times the quantizer_scale.
    - » QF(u,v) = NINT[16 * F(u,v)/w(u,v) * quantizer_scale].
  - The result is then truncated to [-256,255].
  - The 8 x 8 array of weights, w(u,v), is called the quantization matrix.
  - The parameter quantizer_scale facilitates adaptive quantization.

Intra Compression Quantization (cont'd.)

- MPEG-1 specifies the following default quantization matrix:

8	16	19	22	26	27	29	34
16	16	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

Intra Compression Quantization (cont'd.)

- Coarser quantization, hence larger weights, is used for high frequency coefficients in order to exploit the insensitivity of the visual system to high-frequency quantization noise.

An Example of a Quantized DCT Block with quantizer scale of 2

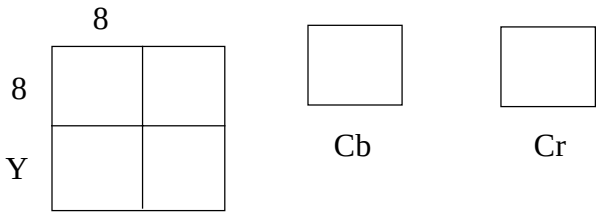
158	-1	-5	-2	1	-1	-1	0
-12	9	-2	-1	-1	0	0	0
-5	-6	-2	-1	-1	0	0	0
-3	-1	0	0	0	0	0	0
0	0	0	1	0	0	0	0
1	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0
-1	1	-1	0	0	0	0	0

Intra Compression Quantization (cont'd.)

- MPEG-1 allows to use/download any application-specific matrix in the bitstream, other than the default.
- Visual quantization matrix; in general, depends on noise level of the source, and the viewing conditions.
- The weights are 8-bit integers.

Intra Compression

- Spatially-Adaptive Quantization
  - Spatially-adaptive quantization is made possible by the scale factor quantizer_scale, that scales the values of w(u, v).
    - » This parameter is allowed to vary from one "macroblock" to another within a picture to adaptively adjust the quantization on a macroblock basis.



Intra Compression

- The quantizer_scale is chosen from a specified set of values on the basis of spatial activity of the block (e.g., macroblocks containing busy, textured areas are quantized relatively coarsely), and on the basis of buffer fullness in constant bitrate applications.

Intra Compression

- NOTE that the JPEG standard (for intraframe compression) does not allow for spatially-adaptive quantization, and hence the advantage of MPEG-2 even when all frames- are intraframe compressed
  - Due to the lack of quantizer_scale in JPEG constant bit rate cannot be achieved.
    - » Adaptive quantization is among the possible future extensions planned for JPEG

Intra Compression

- Spatially-Adaptive Quantization (cont'd)
  - The allowed set of quantizer_scale values:

2	22	42	62
4	24	44	
6	26	46	
7	28	48	
10	30	50	
12	32	52	
14	34	54	
l6	36	56	
18	38	58	
20	40	60	

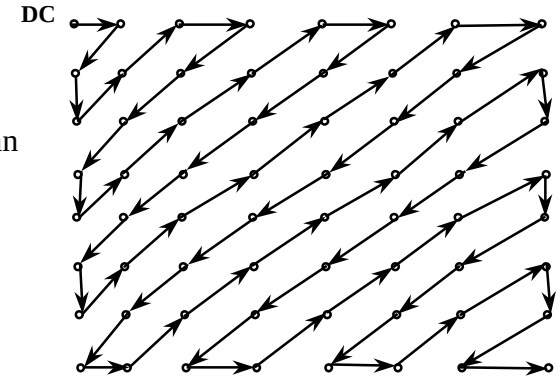
MPEG-1: Intra Compression

- Coding: AC Coefficients
  - The main idea is based on the fact that most of the quantized coefficients are zero and hence it is more efficient to represent the data by location and value of the nonzero coefficients.
  - The quantized AC coefficients are scanned in a zigzag fashion and ordered into *symbol = [Run, level]* pairs and then coded using variable length (Huffman) codes (VLC) (longer codes for less frequent pairs and vice versa).
    - » (The VLC tables are standardized.)

MPEG-1: Intra Compression

- level: is the value of a nonzero coefficient;
- run: is the number of zero coefficients preceding it.

Zigzag Scan



MPEG-1: Intra Compression

- Coding AC Coefficients: An Example

158	-1	-5	-2	1	-1	-1	0
-12	9	-2	-1	-1	0	0	0
-5	-6	-2	-1	-1	0	0	0
-3	-1	0	0	0	0	0	0
0	0	0	1	0	0	0	0
1	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0
-1	1	-1	0	0	0	0	0

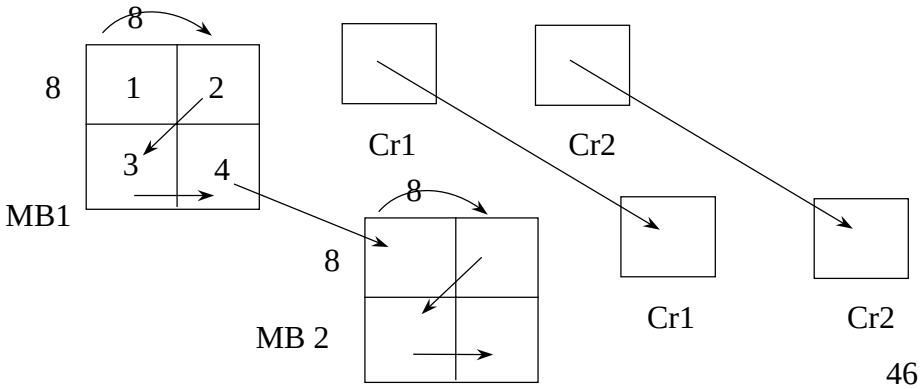
run	level
0	-1
0	-12
0	-5
0	9
0	-5
…..	
0	-1
EOB	

MPEG-1: Intra Compression

- Coding: DC Coefficients
  - Redundancy among quantized DC coefficients of 8 x 8 blocks is reduced via differential pulse coded modulation (DPCM).
  - The resulting differential signal (whose range is (-255, 255)) is coded using variable length codes.
    - » Standard VLC tables are specified.
    - » In fact, these tables are the only standard tables in MPEG-1 that make a distinction between luminance and chrominance components of the data.)

Prediction Paths For The DC Coefficients

- Macroblocks are 16x16, but DCT is done on 8x8 blocks.



MPEG-1: Motion-Compensated, Predictive (Non-Intra) Compression

- Motion Estimation
  - Motion-compensated prediction is performed on the basis of the macroblocks.
  - Displacement vectors are assumed to be constant over a macroblock.
  - Thus, a common displacement vector is estimated for and assigned to 16 x 16 luma and the two associated 8 x 8 chroma blocks.

MPEG-1: Motion-Compensated, Predictive (Non-Intra) Compression

- Motion Estimation
  - In case of bi-directional prediction, (i.e., in the case of B pictures) two vectors - one pointing to the past and the other pointing to the future - are estimated for each macroblock.
- Half (1/2) pixel accuracy is allowed for motion vectors.
- Redundancy among the displacement vectors of neighboring macroblocks is reduced by considering their consecutive differential values (i.e., applying DPCM to vector components).

MPEG-1: Motion-Compensated, Predictive (Non-Intra) Compression

- Remark:
  - Although, block matching seems to be a natural choice for what is described above, MPEG-1 does not specify (or standardize) the motion estimation algorithm.
  - Any algorithm that is appropriate for the particular application can be wed.

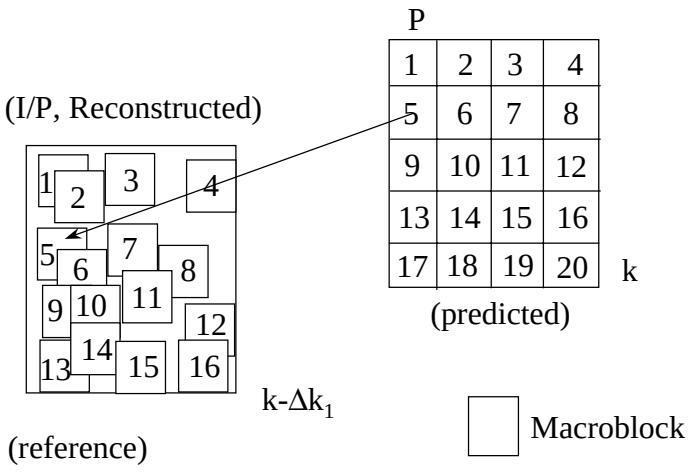
Motion-Compensated, Predictive Compression

- Forward Prediction and P pictures
  - A displacement vector is estimated for the current macroblock in the predicted (k) th picture to determine its corresponding macroblock in the reconstructed ($k-\Delta k_1$) th picture --the reference picture.

Motion-Compensated, Predictive Compression

- The current macroblock in the kth picture is predicted by its corresponding macroblock at the $(k-\Delta k_1)^{th}$ picture.
- The difference (luma and chroma) between the current macroblock at the k^{th} picture and its prediction forms the motion-compensated prediction error macroblock.

Motion-Compensated, Predictive Compression



Motion-Compensated, Predictive Compression

- Forward Prediction (cont'd.)
  - The displacement vector and the prediction error macroblock represent the information that is needed for reconstructing the current macroblock at the k th picture from the already reconstructed macroblock at the $(k-\Delta k_1)^{th}$ picture.
  - DCT is applied to 8 x 8 blocks of the prediction-error macroblock, prior to quantization and coding.

Motion-Compensated, Predictive Compression

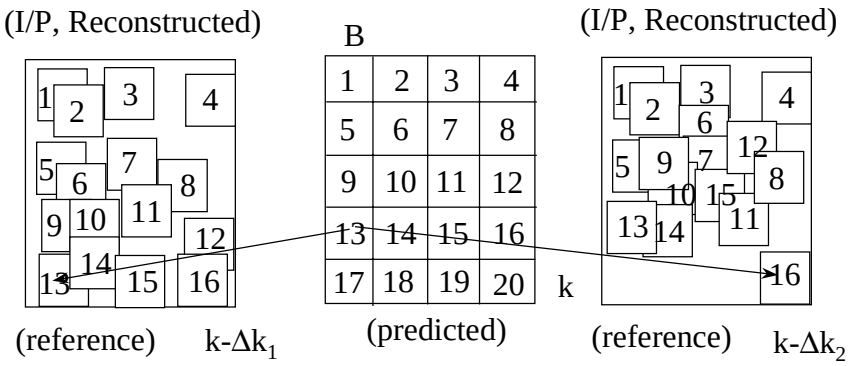
- Definition of P Pictures
  - P Pictures are composed of macroblocks that are either
    - » forward predictive (non-intra) coded . or
    - » intra coded (using the same quantization and VLC as macroblocks of the I pictures).
  - The encoder is allowed to make an Intra/Non-lntra decision depending on the accuracy of the prediction.
  - This decision can be made in many different ways and the choice is up to the encoder.

Motion-Compensated, Predictive Compression

- A possible simple decision mechanism compares the variance of the luminance component of the original macroblock with that of the prediction error macroblock.
- If the variance of the prediction error macroblock is higher, then the macroblock is intra coded.

Motion-Compensated, Predictive Compression

- Bi-directional Prediction and B Pictures



Bi-directional Prediction and B Pictures

- For each current macroblock, at predicted picture k, two displacement vectors are estimated (one to a reference picture in the past and one to a reference picture in the future).
- Bi-directional prediction is particularly suited for predicting uncovered areas and results in high compression.

MPEG-1: Motion-Compensated, Predictive Compression

- Bi-directional Prediction (cont'd.)
  - pred = NINT [(a1) pred_forward + (a2) pred_backward)

$$\begin{pmatrix} \alpha_1 = 0.5 \text{ and } \alpha_2 = 0.5 \Rightarrow \text{Bi} - \text{directional Prediction} \\ \alpha_1 = 1 \text{ and } \alpha_2 = 0 \Rightarrow \text{Forward Prediction} \\ \alpha_1 = 0 \text{ and } \alpha_2 = 1 \Rightarrow \text{Backward Prediction} \end{pmatrix}$$

Bi-directional Prediction (cont'd.)

- The two displacement vectors and the prediction error macroblock represent the information that are needed for reconstructing the current macroblock at the k th picture from the already reconstructed macroblocks at the two reference pictures.
- DCT is applied to 8 x 8 blocks of the prediction-error macroblock, prior to quantization and coding.

Definition of B Pictures

- B Pictures are composed of macroblocks that are
  - bi-directional predictive coded, or
  - backward predictive coded, or
  - forward predictive coded, or
  - intra coded
- A possible decision mechanism is picking the mode that results in the least macroblock (luminance component) variance.
- The macroblocks in the B pictures are not used as references.

Motion-Compensated, Predictive Compression

- Quantization and Coding of DCT of Prediction Error MB'S
  - Steps that are different than those for the Intra Macroblocks:
- The DC coefficient is quantized as the AC coefficients.
- The overall quantization is expected to have a dead-zone around zero.

Motion-Compensated, Predictive Compression

- The default quantization weight matrix is the following:

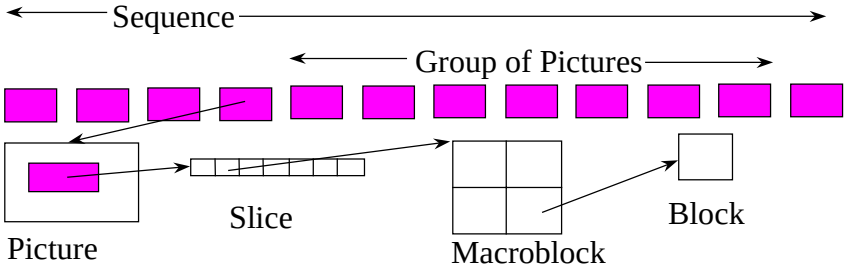
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16

Motion-Compensated, Predictive Compression

- All DCT coefficients, including the DC coefficient, are scanned to form [run, level] pairs which are then coded using a standard VLC table.
- Single choice for the VLC table, unlike intra blocks.

MPEG-1- Bit Stream Hierarchy

- Main Hierarchy



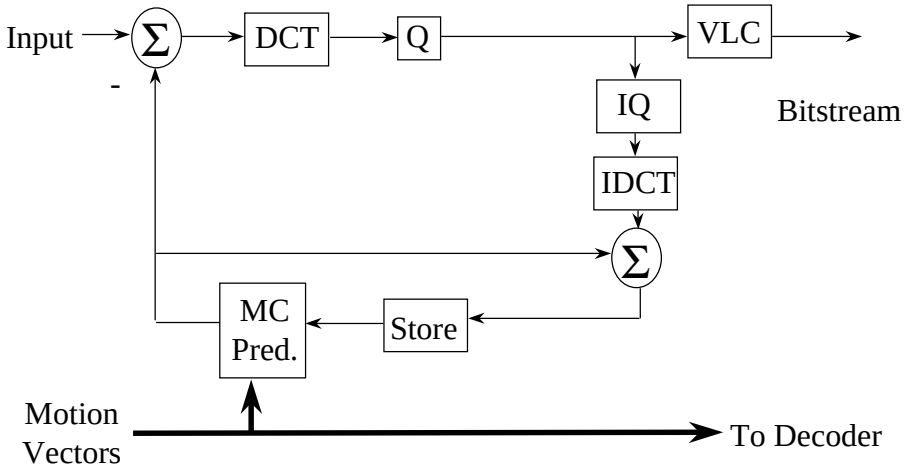
The Bit Stream

Sequence 1 Level	GOP Level	Picture Level	Slice Level	MB Level	Block Level	Sequence 2 Level

A Typical MPEG-1 Encoder

- A typical MPEG encoder includes modules for motion estimation, motion-compensated prediction (predictors and framestores), quantization and dequantization, DCT and IDCT, variable length coding, a multiplexer, a buffer and a buffer regulator.
- A simplified diagram is given on the next chart.

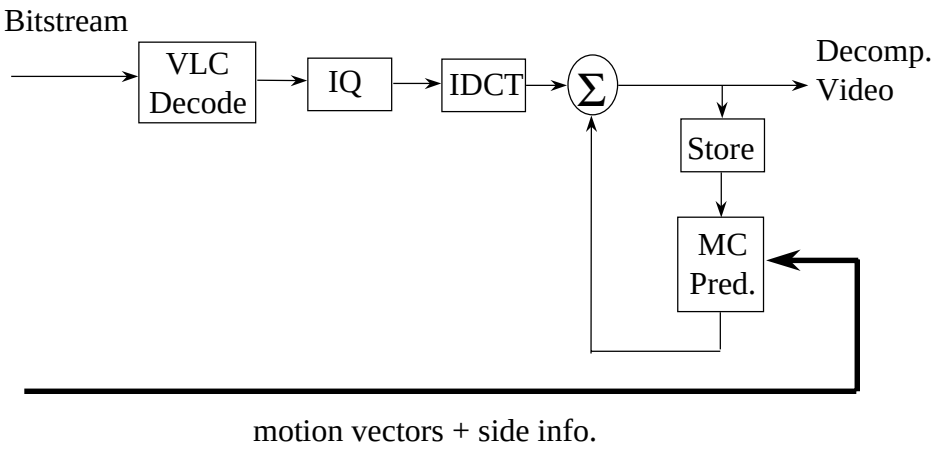
A Typical MPEG-1 Encoder



MPEG-1 Decoder

- The decoder basically reverses the operations of the encoder.
  - A block diagram of a simplified generic decoder is shown on the next chart.
- The incoming bit stream (with a standard syntax) is demultiplexed into DCT coefficients and side information such as displacement vectors, quantization parameter, etc.
  - In the case of B pictures, two reference frames are used to decode the frame.

MPEG-1 Decoder



The MPEG-2 Standard

- A Summary:
  - MPEG-2 is intended for higher data rates than MPEG-1.
  - MPEG-2 allows for higher quality source material by supporting 4:2:2 (chroma channels subsampled in the horizontal dimension only), and 4:4:4 (no subsampling of chroma) formats, in addition to 4:2:0 (Chroma channels subsampled by 2 in both directions.)
  - A step is taken by the MPEG committee towards a possible future extension for compression of 10 bit/pixel video (March 1994).

MPEG-2 Parameters

- High
  - 1920 samples/line
  - 1152 lines per frame
  - 60 frames/sec
  - 80 Mbits/s

MPEG-2 Parameters

- High 1440
  - 1440 samples/line
  - 1152 lines per frame
  - 60 frames/sec
  - 60 Mbits/s

MPEG-2 Parameters

- Main
  - 720 samples/line
  - 576 lines per frame
  - 30 frames/sec
  - 15 Mbits/s

MPEG-2 Parameters

- Low
  - 352 samples/line
  - 288 lines per frame
  - 30 frames/sec
  - 4 Mbits/s

MPEG-2 Algorithms and Profiles

- MAIN - Nonscalable coding algorithm supporting functionality for:
  - Coding interlaced video
  - Random access
  - B-picture prediction modes
  - 4:2:0 YUV representation

Non Scalable MPEG 2

- Introduces Field and Frame Pictures
  - Interlace fields and frames are coded seperately
  - Separate Prediction
- New Motion Compensation modes to explore temporal redundancy between fields
  - Dual Prime prediction
  - 16x8 block motion compensation

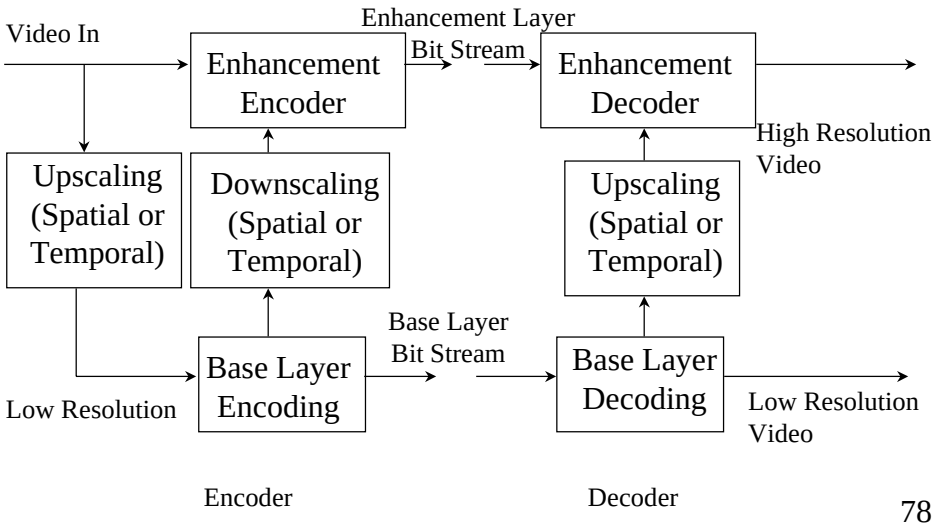
MPEG-2 Algorithms and Profiles

- SIMPLE - Includes all functionality provided by the MAIN profile but:
  - Does not support B-picture prediction modes
  - 4:2:0 YUV representation

MPEG-2 Algorithms and Profiles

- SNR Scalable - Supports all functionality provided by the MAIN Profile plus an algorithm for:
  - SNR Scalable Coding (2 Layers Allowed)
    - » Support receivers with different display capability
    - » Based on classical Pyramidal approach for progressive image coding
  - 4:2:0 YUV representation

Scalable Coding of Video



MPEG-2 Algorithms and Profiles

- SPATIAL Scalable - Supports all functionality provided by the SNR Scalable Profile plus an algorithm for :
  - Spatial Scalable Coding (2 Layers Allowe
    - Provide interoperability between different services
    - Support receivers with different display capability
  - 4:0:0 YUV representation

MPEG-2 Algorithms and Profiles

- HIGH - Supports all functionality provided by the SPATIAL Scalable Profile plus an algorithm for :
  - 3 layers with the SNR and Spatial Scalable coding modes
  - 4:2:2 YUV representation for improved quality requirements

The MPEG-2 Standard 4:2:2 Format

X + X + X +

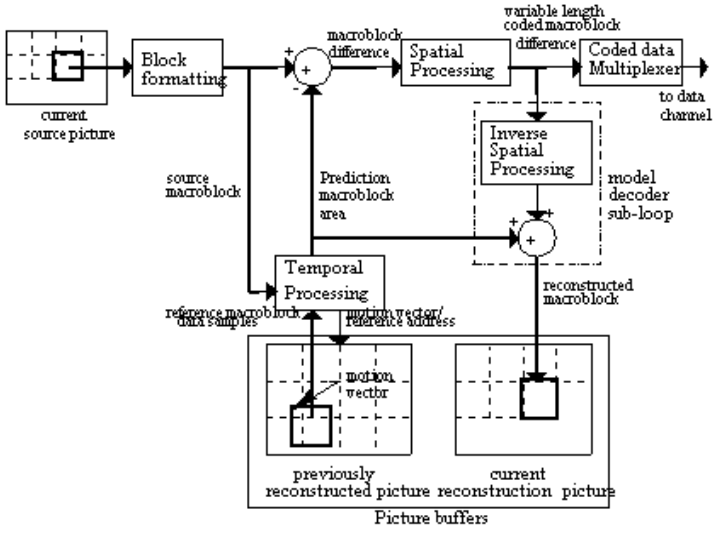
\+ + + + + +

X + X + X +

\+ + + + + +

X : Choma Samples + : Luma Samples

MPEG-2 Decoder Pipeline

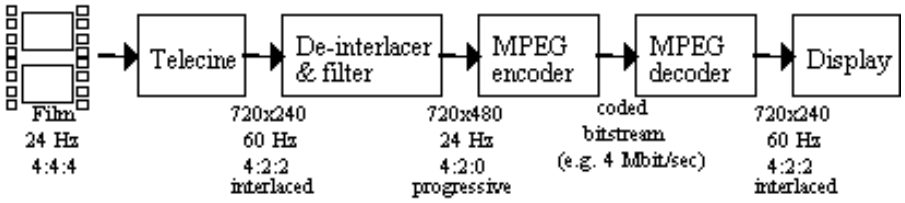


Difference Between MPEG-1 and MPEG-2

- Sequence Layer:
  - MPEG-2 can represent interlaced or progressive video
  - MPEG-1 is strictly meant for progressive sequences
  - MPEG-2 changed the meaning behind aspect_ratio_information variable
    - » MPEG-2 - aspect_ratio_information refers to the overall display aspect ratio (4:3, 16:9), it also refers to a particular pixel
  - Optional picture header variables (display_horizontal_size and display_vertical_size) can be used to code unusual display sizes

Difference Between MPEG-1 and MPEG-2

- Frame_rate_code - MPEG-2 refers to intended display rate, MPEG-1 refers to coded frame rate



Difference Between MPEG-1 and MPEG-2

- Group of Pictures layer does not exist in MPEG-2
  - It is an optional header useful for establishing a SMPTE time code base or indicating that certain B pictures at the beginning of an edited sequence comprise a broken link.
  - In MPEG-1 Group of pictures is mandatory.

Difference Between MPEG-1 and MPEG-2

- Picture Layer
  - In MPEG-2, a frame may be coded progressively or interlaced
  - Interlaced frames may then be coded as either a frame picture or as two separately coded field pictures
    - » Progressive frames are logical for video that originates from film
    - » Interlace is logical for video cameras

Difference Between MPEG-1 and MPEG-2

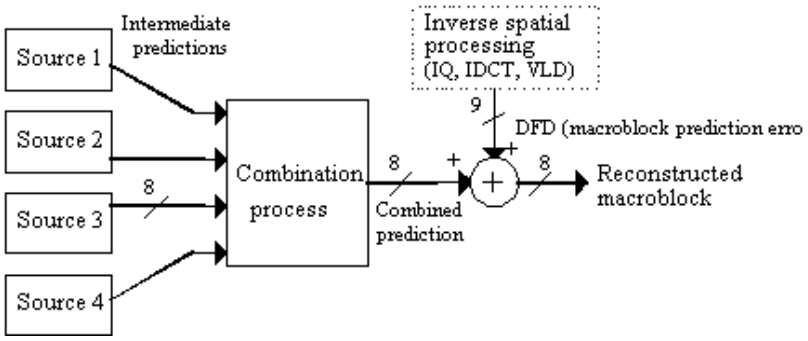
- Repeat_first_field is new to MPEG-2 to signal a field or frame that is repeated for purposes of frame rate conversion
  - This method has been used to change the 24frame/sec movies to 30 frames a second video.

Difference Between MPEG-1 and MPEG-2

- Changes in motion estimation:
  - Motion vectors are now always represented along half-sample grid
  - Increased flexibility in coding motion vectors
    - » can change from +/- 16 pixels to +/- 64 pixels without large increase in overhead.
  - Restricted vertical motion vector range
    - » Motion is more prominent across the screen than up or down.

Difference Between MPEG-1 and MPEG-2

- Prediction modes now include field, frame, Dual Prime and 16x8 MC
- Combinations for Main Profile and Simple Profile:



More Differences

- The list is very long
- There are some excellent references on MPEG-2:
  - Digital Video: An Introduction to MPEG-2 by Barry Haskell, Atul Puri and Arun Netravali
  - MPEG Video: Compression Standard by Joan Mitchell, William Pennebaker and Chad Fogg