CS 414 – Multimedia Systems Design

Lecture 10 – MPEG-1 Video and MP3 Audio) (Part 5)

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Administrative

- MP2 was posted on Monday, February 9th and deadline will be Monday, March 2nd
  - Please, start early – we will have two discussion sections for MP2
  - The first discussion section will be on next Monday

Motion Picture Expert Group (MPEG)

- General Information about MPEG
  - Began in 1988; Part of Same ISO as JPEG
- MPEG-1/Video
- MPEG/Audio – MP3
- MPEG-2
- MPEG-4
- MPEG-7

MPEG General Information

- Goal: data compression 1.5 Mbps
- MPEG defines video, audio coding and system data streams with synchronization
- MPEG information
  - Aspect ratios: 1:1 (CRT), 4:3 (NTSC), 16:9 (HDTV)
  - Refresh frequencies: 23.975, 24, 25, 29.97, 50, 59.94, 60 Hz

MPEG Image Preparation (Resolution and Dimension)

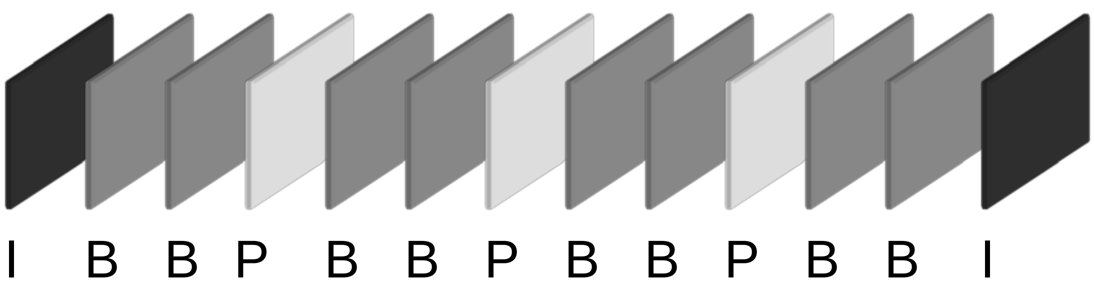
- MPEG defines exactly format
  - Three components: Luminance and two chrominance components (2:1:1)
  - Resolution of luminance comp:$X1 \le 768$; $Y1 \le 576$ pixels
  - Pixel precision is 8 bits for each component
- Example of Video format: 352x240 pixels, 30 fps; chrominance components: 176x120 pixels

MPEG Image Preparation - Blocks

- Each image is divided into **macro-blocks**
- Macro-block : 16x16 pixels for luminance; 8x8 for each chrominance component
- Macro-blocks are useful for Motion Estimation
- No MCUs which implies sequential non-interleaving order of pixels values

MPEG Video Processing

- Intra frames (same as JPEG)
  - typically about 12 frames between I frames
- Predictive frames
  - encode from previous I or P reference frame
- Bi-directional frames
  - encode from previous and future I or P frames

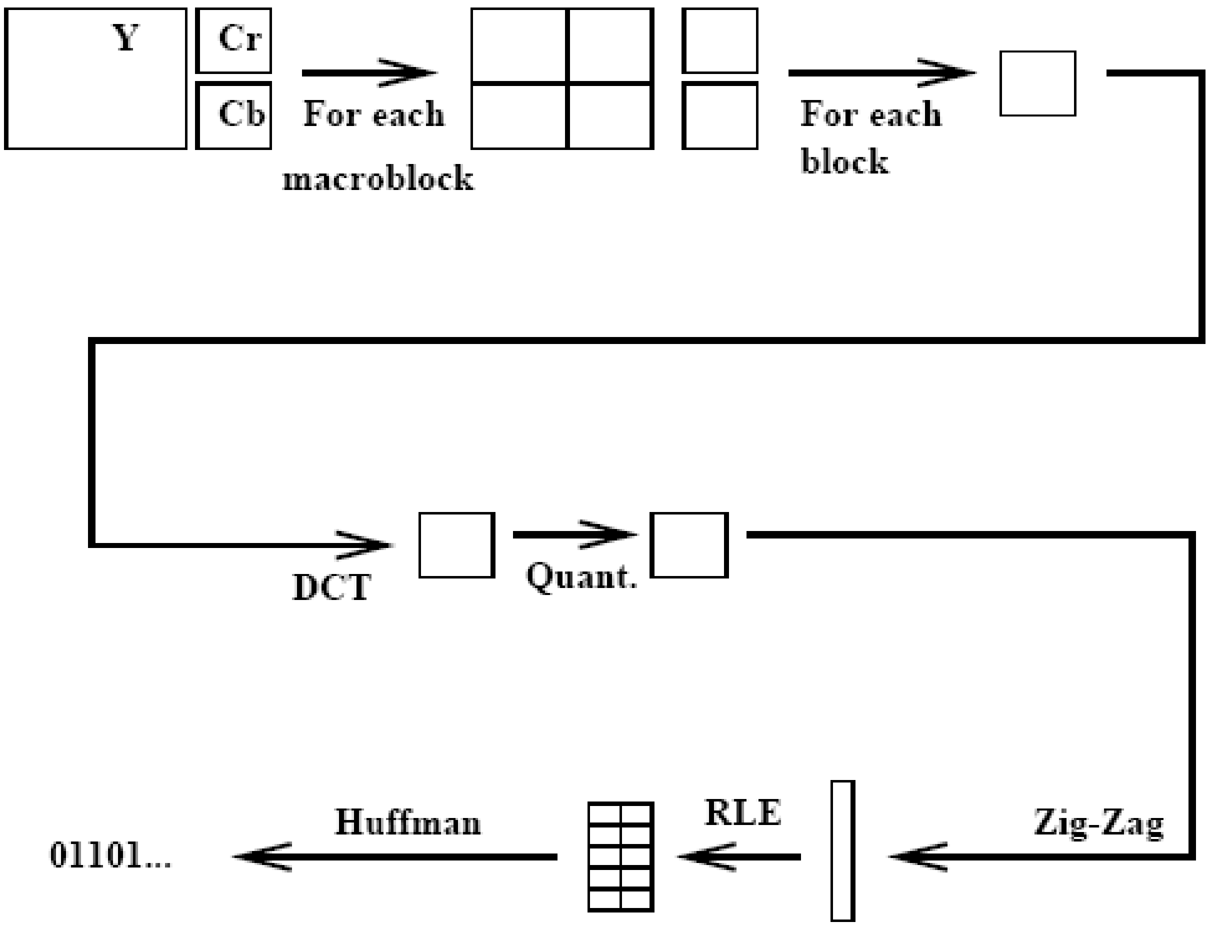


Selecting I, P, or B Frames

- Heuristics
  - change of scenes should generate I frame
  - limit B and P frames between I frames
  - B frames are computationally intense

Type	Size	Compress
I	18K	7:1
P	6K	20:1
B	2.5K	50:1
Avg	4.8K	27:1

MPEG Video I-Frames



Intra-coded images

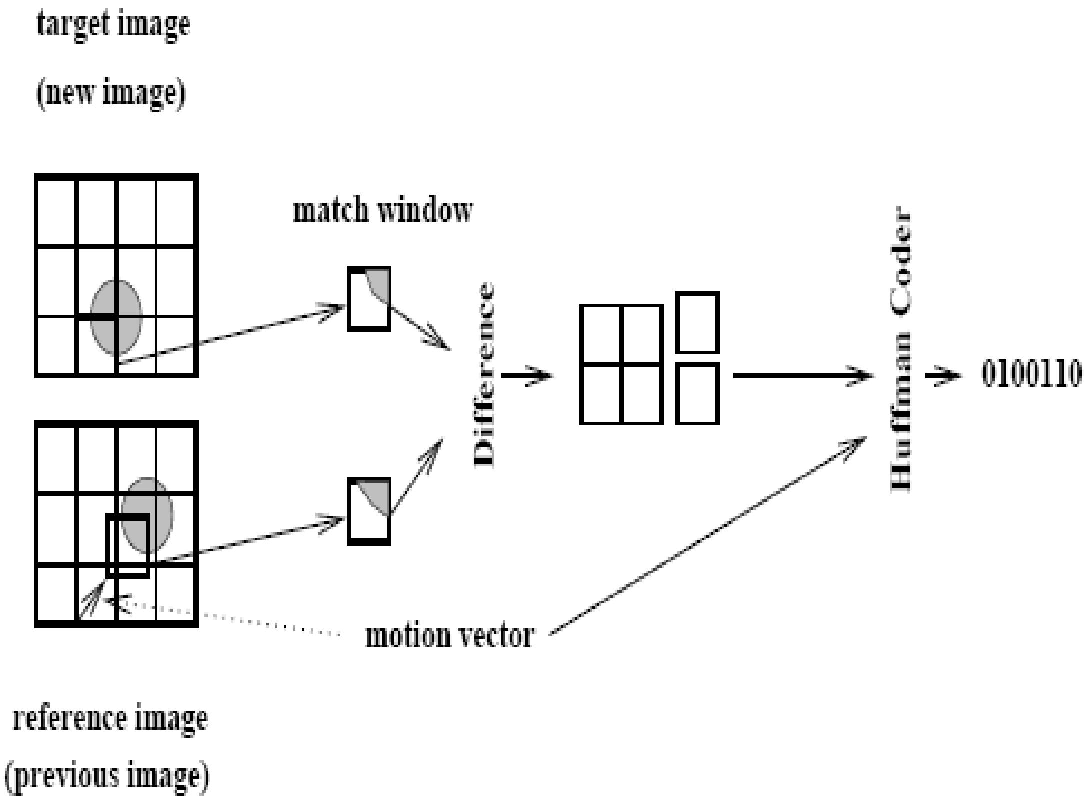
I-frames – points of random access in MPEG stream

I-frames use 8x8 blocks defined within Macro-block

No quantization table for all DCT coefficients, only quantization factor

MPEG Video P-Frames

Motion Estimation Method



Predictive coded frames require information of previous I frame and or previous P frame for encoding/decoding

For **Temporary Redundancy** we determine last P or I frame that is most similar to the block under consideration

Motion Computation for P Frames

- Predictive search
- Look for match window within a given search window
  - Match window – macro-block
  - Search window – arbitrary window size depending how far away are we willing to look
- Displacement of two match windows is expressed by motion vector

Matching Methods

- SSD metric

$$SSD = \sum_{i=0}^{N-1} (x_i - y_i)^2$$

- SAD metric

$$SAD = \sum_{i=0}^{N-1} | x_i - y_i |$$

- Minimum error represents best match
  - must be below a specified threshold
  - error and perceptual similarity not always correlated

Example of Finding Minimal SSD

$$\begin{matrix} 7 & 9 & 8 \\ 5 & 4 & 6 \\ 9 & 8 & 2 \end{matrix} \quad \text{versus} \quad \begin{matrix} 8 & 7 & 9 \\ 7 & 5 & 4 \\ 7 & 5 & 4 \end{matrix} \rightarrow$$

$$\begin{aligned} SSD = \; & (7-8)^2 + (9-7)^2 + (8-9)^2 + \\ & (5-7)^2 + (4-5)^2 + (6-4)^2 + \\ & (9-7)^2 + (8-5)^2 + (2-4)^2 \end{aligned}$$

$$= 1 + 4 + 1 + 4 + 1 + 4 + 4 + 9 + 4$$

$$= 32$$

$$\begin{matrix} 7 & 9 & 8 \\ 5 & 4 & 6 \\ 9 & 8 & 2 \end{matrix} \quad \text{versus} \quad \begin{matrix} 8 & 7 & 10 \\ 6 & 5 & 4 \\ 10 & 7 & 1 \end{matrix} \rightarrow \quad SSD = 18$$

min SSD = 18 =>

take match windows:

$$\begin{matrix} 7 & 9 & 8 \\ 5 & 4 & 6 \\ 9 & 8 & 2 \end{matrix} \quad \text{and} \quad \begin{matrix} 8 & 7 & 10 \\ 6 & 5 & 4 \\ 10 & 7 & 1 \end{matrix}$$

Example of Comparing Minimal SSD and SAD

SSD:

7	9	8		8	7	10	
5	4	6	versus	6	5	4	-> SSD = 18
9	8	2		10	7	1	

7	9	8		8	7	10	
5	4	6	versus	6	5	4	-> SSD = 40,017
9	8	2		10	7	202 (Outlier)	

SAD:

7	9	8		8	7	10	
5	4	6	versus	6	5	4	-> SAD = 211
9	8	2		10	7	202	

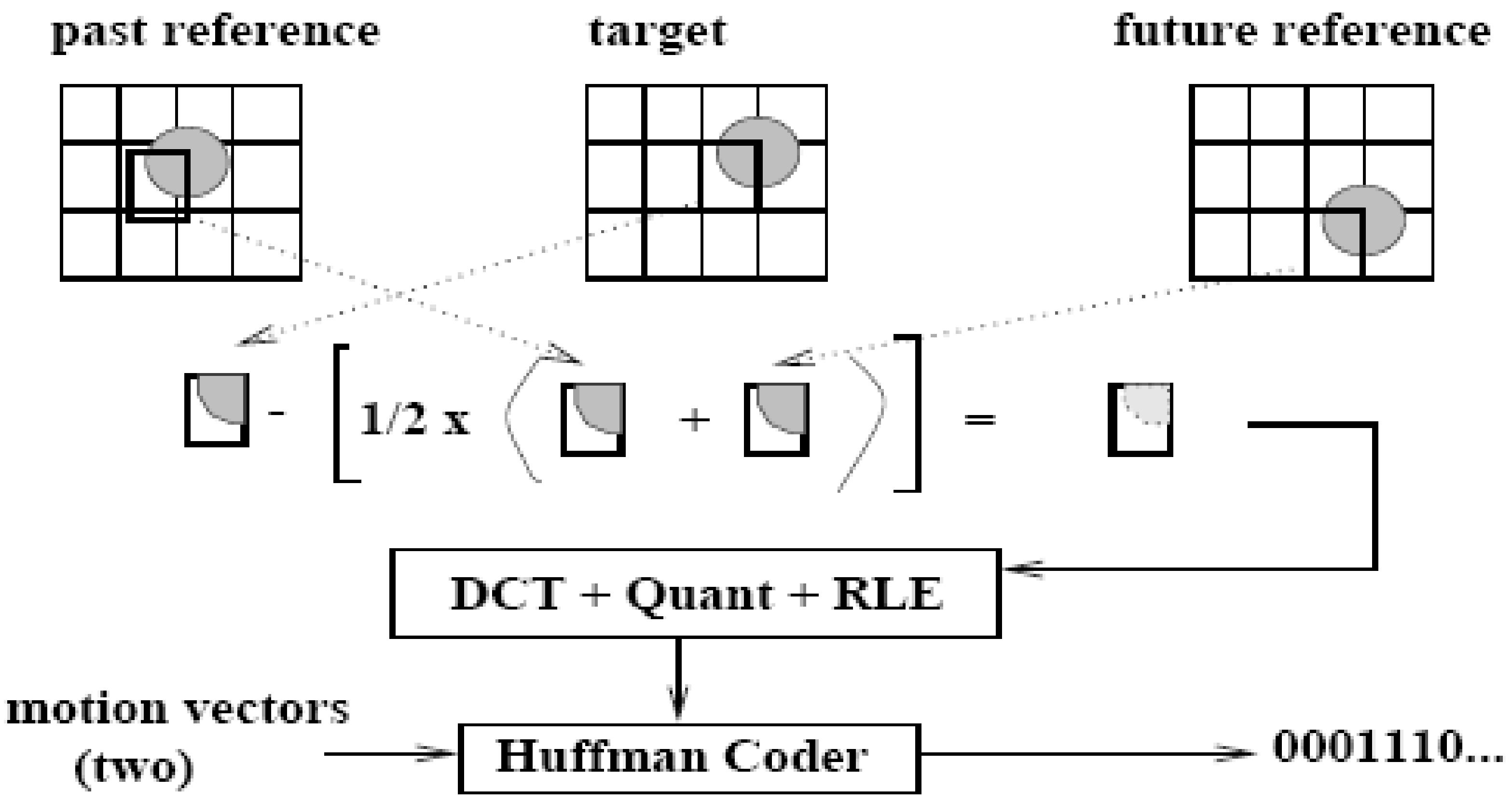
Syntax of P Frame

Addr	Type	Quant	Motion Vector	CBP	b0	b1	...	b5

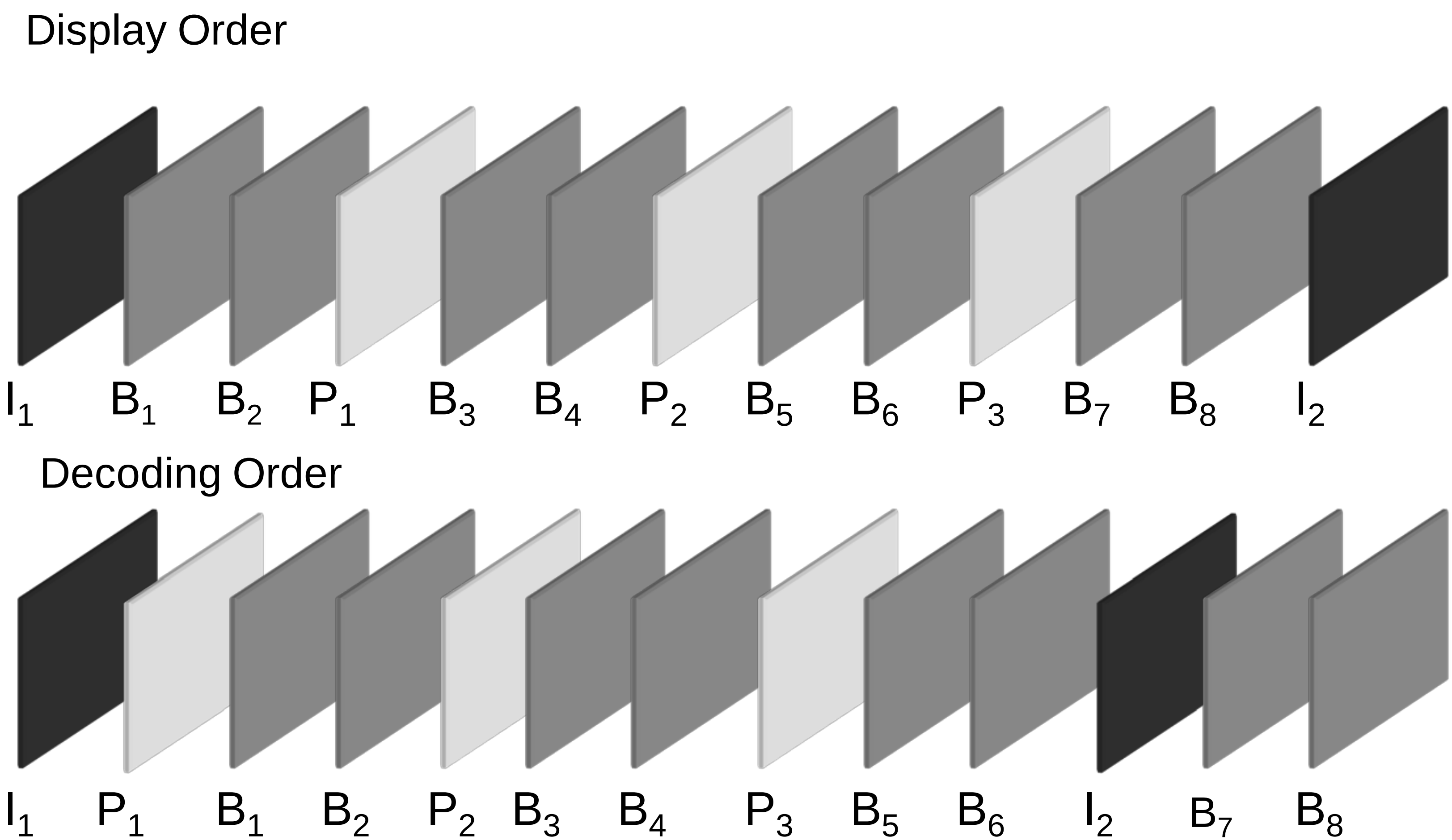
Addr: address the syntax of P frame
Type: INTRA block is specified if no good match was found
Quant: quantization value per macro-block (vary quantization to fine-tune compression)
Motion Vector: a 2D vector used for motion compensation provides offset from coordinate position in target image to coordinates in reference image
CBP(Coded Block Pattern): bit mask indicates which blocks are present

MPEG Video B Frames

Bi-directionally Predictive-coded frames



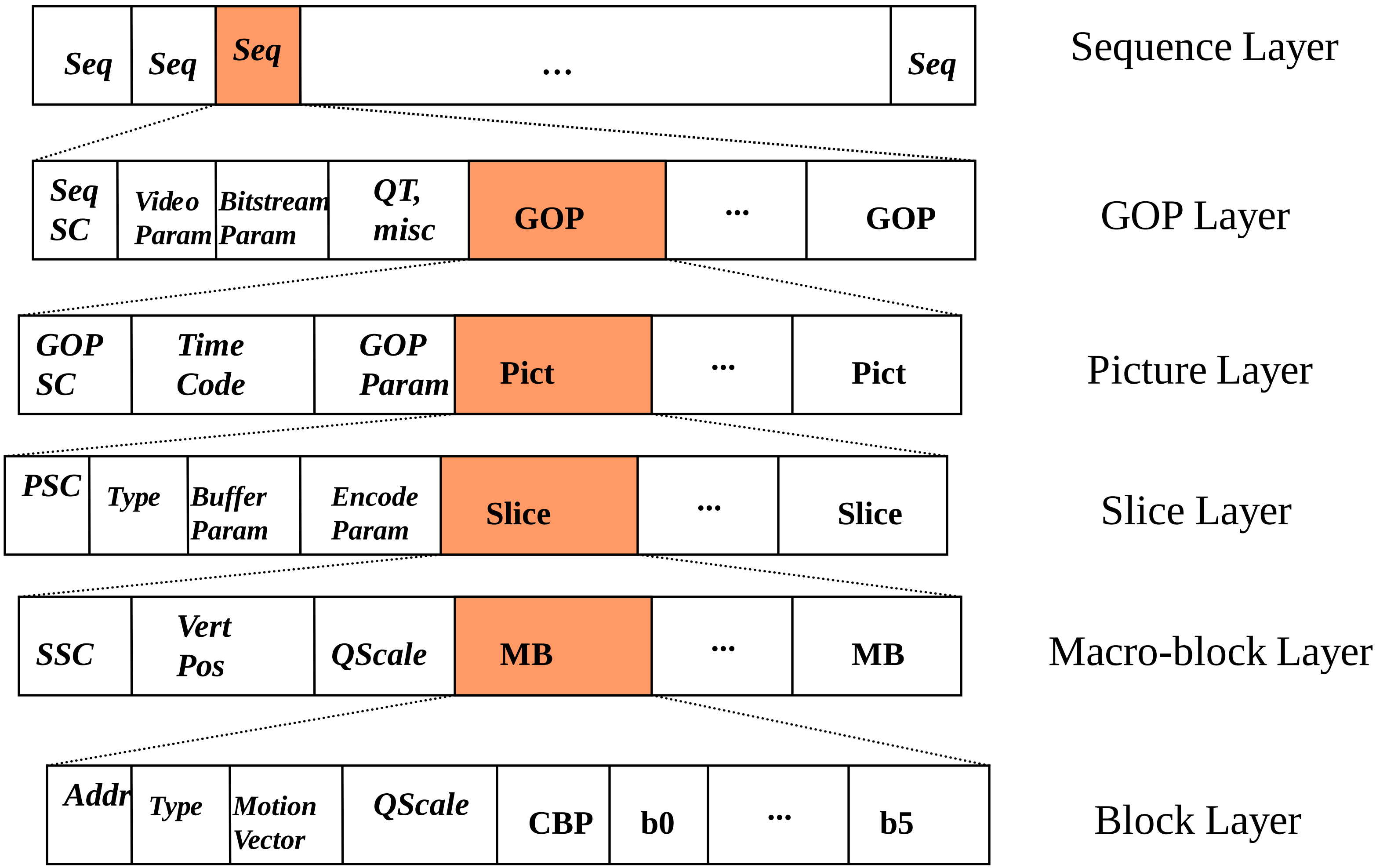
MPEG Video Decoding



MPEG Video Quantization

- AC coefficients of B/P frames are usually large values, I frames have smaller values
  - Adjust quantization
- If data rate increases over threshold, then quantization enlarges step size (increase quantization factor Q)
- If data rate decreases below threshold, then quantization decreases Q

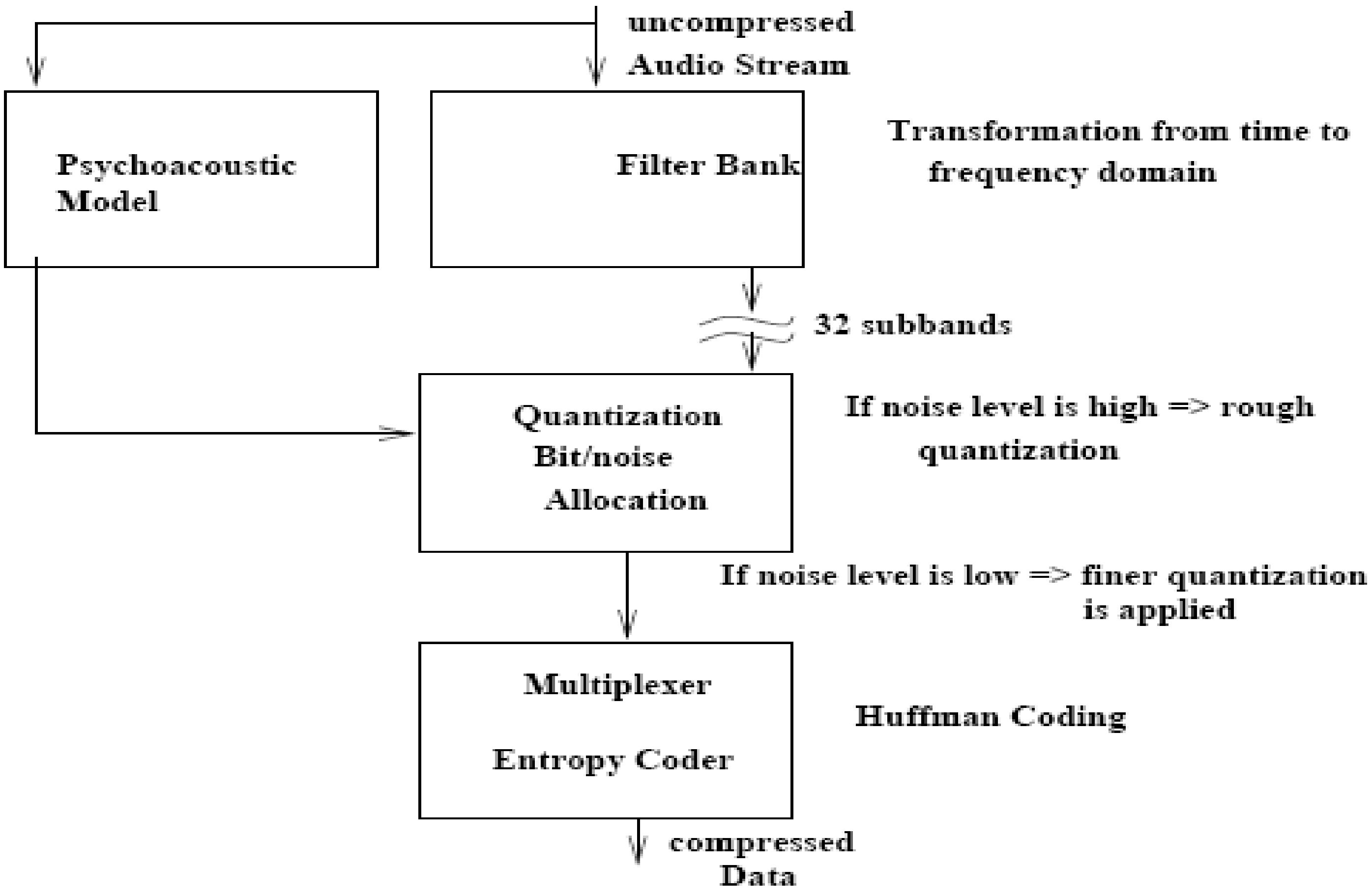
MPEG-1 Interchange Format



MPEG Audio Encoding

- Characteristics
  - Precision 16 bits
  - Sampling frequency: 32KHz, 44.1 KHz, 48 KHz
  - 3 compression layers: Layer 1, Layer 2, Layer 3 (MP3)
    - Layer 3: 32-320 kbps, target 64 kbps
    - Layer 2: 32-384 kbps, target 128 kbps
    - Layer 1: 32-448 kbps, target 192 kbps

MPEG Audio Encoding Steps



MPEG Audio Filter Bank

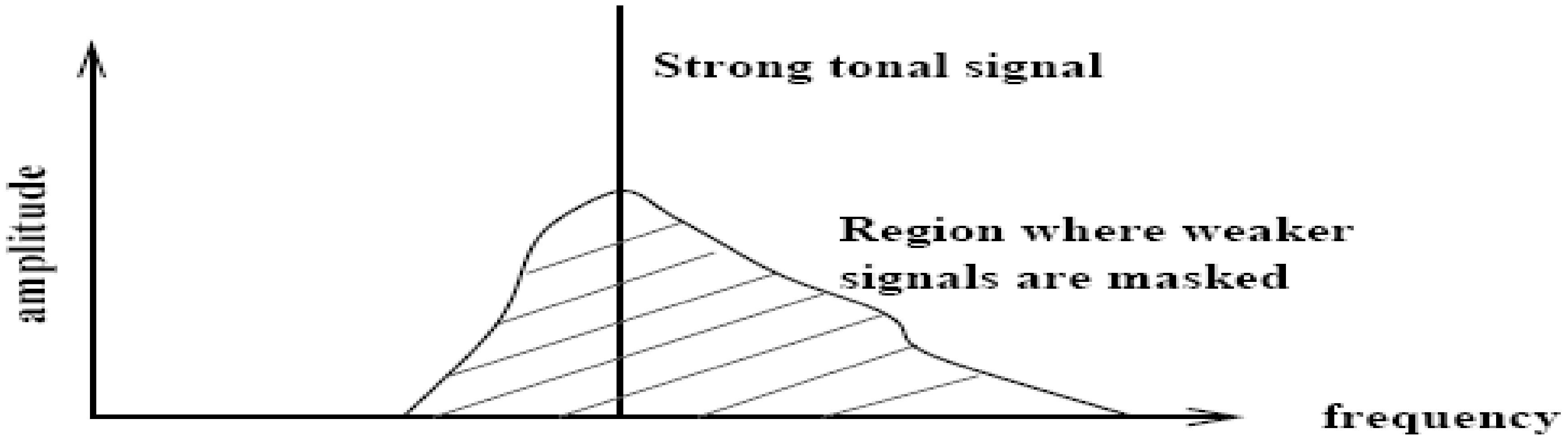
- Filter bank divides input into multiple sub-bands (32 equal frequency sub-bands)
- Sub-band i defined

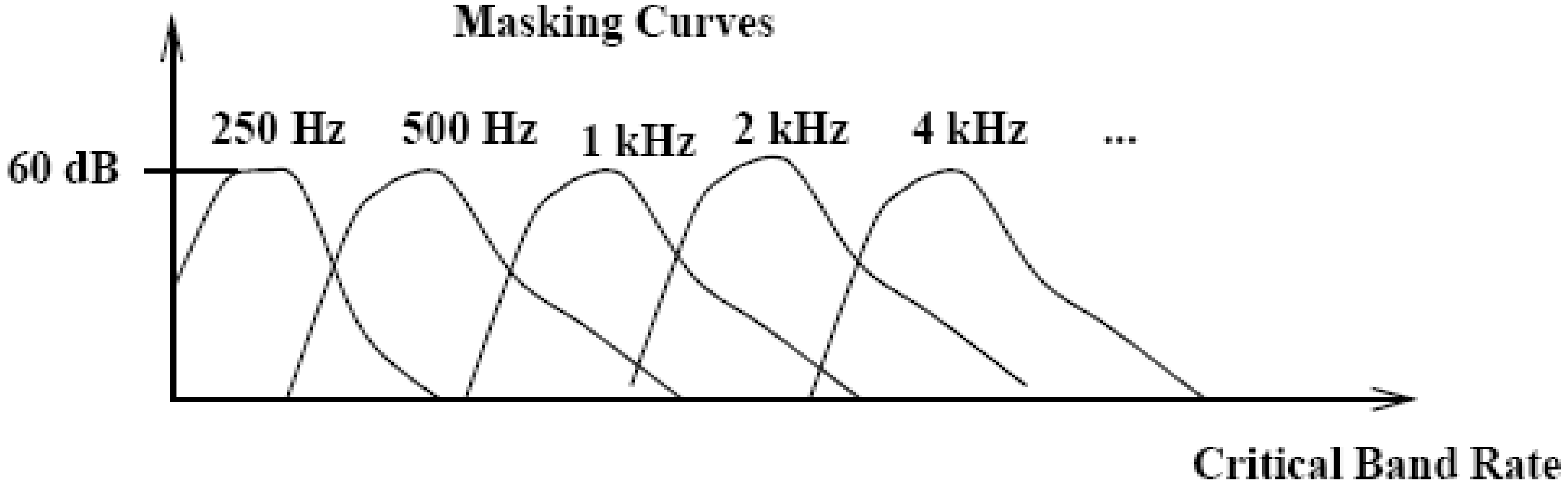
$$S_t[i] = \sum_{k=0}^{7} 3 \sum_{j=0}^{7} \cos\left(\frac{(2i+1)(k-16)\pi}{64} * (C[k+64j] * x[k+64j]\right]$$

- $i \in [0,31], S_t[i]$ - filter output sample for sub-band I at time t, C[n] – one of 512 coefficients, x[n] – audio input sample from 512 sample buffer

MPEG Audio Psycho-acoustic Model

- MPEG audio compresses by removing acoustically irrelevant parts of audio signals
- Takes advantage of human auditory systems inability to hear quantization noise under auditory masking
- Auditory masking: occurs when ever the presence of a strong audio signal makes a temporal or spectral neighborhood of weaker audio signals imperceptible.





MPEG/audio divides audio signal into frequency sub-bands that approximate critical bands. Then we quantize each sub-band according to the audibility of quantization noise within the band

MPEG Audio Bit Allocation

- This process determines number of code bits allocated to each sub-band based on information from the psycho-acoustic model
- Algorithm:
  1. Compute mask-to-noise ratio: MNR=SNR-SMR
     - Standard provides tables that give estimates for SNR resulting from quantizing to a given number of quantizer levels
  2. Get MNR for each sub-band
  3. Search for sub-band with the lowest MNR
  4. Allocate code bits to this sub-band.
     - If sub-band gets allocated more code bits than appropriate, look up new estimate of SNR and repeat step 1

MPEG Audio Comments

- Precision of 16 bits per sample is needed to get good SNR ratio
- Noise we are getting is quantization noise from the digitization process
- For each added bit, we get 6dB better SNR ratio
- Masking effect means that we can raise the noise floor around a strong sound because the noise will be masked away
- Raising noise floor is the same as using less bits and using less bits is the same as compression

Conclusion

- MPEG system data stream
  - Interchange format for audio and video streams
  - Interleave audio and video packets; insert time stamps into each “frame” of data
- Synchronization
  - SRC – system clock reference; DTS – decoding time stamp; PTS – presentation time stamp
- During encoding
  - Insert SCR values into system stream
  - Stamp each frame with PTS and DTS
  - Use encode time to approximate decode time
- During decoding
  - Initialize local decoder clock with start values
  - Compare PTS to the value of local clock
  - Periodically synchronize local clock to SCR