Multimedia Systems and Applications

Video Compression

James Wang

Some notes are adapted from Prof. Lawrence A. Rowe's original slides at http://www.BMRC.Berkeley.EDU/~larry

Representations

- **Composite**
  - NTSC - 6MHz (4.2MHz video), 29.97 frames/second
  - PAL - 6-8MHz (4.2-6MHz video), 50 frames/second
- **Component**
  - Separation video (luma, chroma) - svhs, Hi8mm
  - RGB, YUV, YIQ, …
  - YC_BC_R - used for most compressed representations
- **Separation video called "s-video"**

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Analog Video Representations

- **NTSC**
  - Y = 0.299R + 0.587G + 0.114B
  - I = 0.596R - 0.275G - 0.321B
  - Q = 0.212R - 0.523G + 0.311B
  - composite = Y + I*cos*(Fsc t) + Q*sin*(Fsc t)
- **PAL**
  - Y = 0.299R + 0.587G + 0.114B
  - U = 0.492(B-Y)
  - V = 0.877(R-Y)
  - composite = Y + U*sin*(Fsc t) + V*cos*(Fsc t)

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Digitizing

- **Analog TV is a continuous signal**
- **Digital TV uses discrete numeric values**
  - Signal is sampled
  - Samples are quantized
  - Small, discrete regions are digitized
- **Image represented by pixel array**

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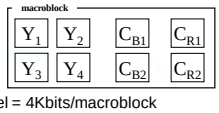
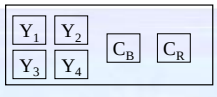
Digital Video Block Structure

- **4:2:2 YC_BC_R**
  - 16x16 macroblock
  - 8x8 pixel blocks
  - 8 bits/sample = 16 bits/pixel = 4Kbits/macroblock



- **4:1:1 YC_BC_R**
  - 3Kbits/macroblock
  - 12 bits/pixel



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What is Video Data Rate?

- **Digital**
  - 720x483 = 347,760 pixels/frame
  - 4:2:2 sampling gives 695,520 bytes/frame
  - 21 MB/sec (167 Mbs)
  - 4:4:4 sampling gives 250 Mbs
- **ATV (MPEG MP@ML)**
  - 1280x720 = 921,600 pixels/frame
  - 4:2:0 sampling gives 1,382,400 bytes/frame
  - 41 MB/sec (328 Mbs)

(Note: MPEG coded streams are 1.5-80 Mbs)

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What is Video Data Rate (cont.)?

- **ATSC (720P)**
  - 720x1280 = 921,600 pixels per frame
  - 4:2:2 sampling = 1,843,200 bytes per frame
  - 24 fps = 44,236,800 bytes per second
  - ➔ 44 MB/s = 354 Mbs
- **ATSC (studio 1080I)**
  - 1080x1920 = 2,073,600 pixels per frame
  - 4:4:4 sampling = 6,220,800 bytes per frame
  - 30 fps = 186,624,000 bytes per second
  - ➔187MB/s = 1.5 Gbs

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Human Perception

- **What is smooth motion**
  - Depends on source material
  - Most action is perceived as smooth at 24 fps
- **Human most sensitive**
  - Low frequencies
  - Changes in luminance and blue-orange axis
- **Vision emphasizes edge detection**
  - Strong bias to horizontal and vertical lines
- **Visual masking by large luminance changes**

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H. 261

- **Developed by CCITT (Consultative Committee for International Telephone and Telegraph) in 1988-1990**
- **Designed for videoconferencing, video-telephone applications over ISDN telephone lines. Bit-rate is *p* x 64 Kb/sec, where *p* ranges from 1 to 30.**

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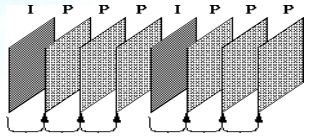
Overview of H. 261

- **Frame Sequence**



- **Frame types are CCIR 601 CIF (352 x 288) and QCIF (176 x 144) images with 4:2:0 sub-sampling.**
- **Two frame types: Intra-frames (*I-frames*) and Inter-frames (*P-frames*):**
- **I-frame provides an accessing point, it uses basically JPEG.**
- **P-frames use "pseudo-differences" from previous frame ("predicted"), so frames depend on each other.**

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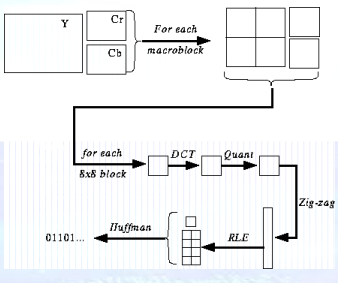
Intra-frame Coding



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Intra-frame Coding

- **Macroblocks are 16 x 16 pixel areas on Y plane of original image. A macroblock usually consists of 4 Y blocks, 1 Cr block, and 1 Cb block.**
- **Quantization is by constant value for all DCT coefficients (i.e., no quantization table as in JPEG).**

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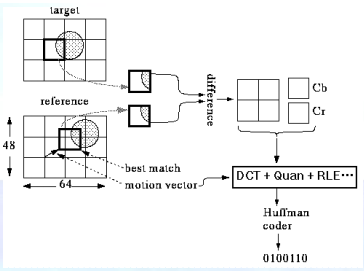
Inter-frame (P-frame) Coding



A Coding Example (P-frame)

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Inter-frame (P-frame) Coding

- **Previous image is called *reference image*, the image to encode is called *target image*.**
- **Points to emphasize:**
  1. The difference image (not the target image itself) is encoded.
  2. Need to use the decoded image as reference image, *not* the original.
  3. We're using "Mean Absolute Error" (MAE) to decide best block.
     Can also use "Mean Squared Error" (MSE) = sum(E*E)/N

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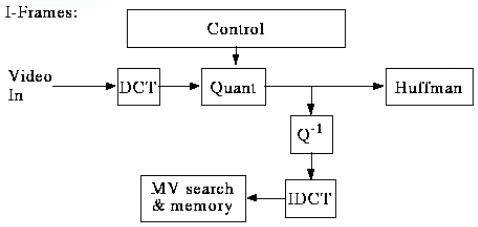
H. 261 Encoder



- Control" -- controlling the bit-rate. If the transmission buffer is too full, then bit-rate will be reduced by changing the quantization factors.
- "memory" -- used to store the reconstructed image (blocks) for the purpose of motion vector search for the next P-frame.

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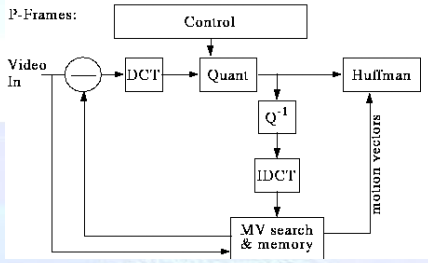
H. 261 Encoder



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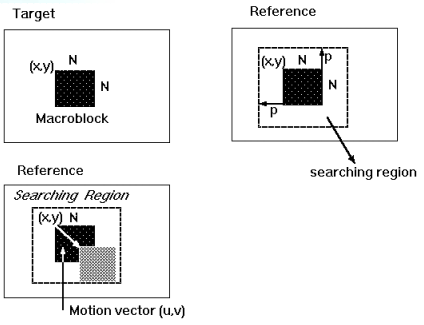
Methods for Motion Vector Searches



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Methods for Motion Vector Searches

- C(x + k, y + l) -- pixels in the macro block with upper left corner (x, y) in the Target frame.
- R(x + i + k, y + j + l) -- pixels in the macro block with upper left corner (x + i, y + j) in the Reference frame.
- Cost function is:

$$MAE(i,j) = \frac{1}{N^2}\sum_{k=0}^{N-1}\sum_{l=0}^{N-1}|C(x+k,y+l) - R(x+i+k,y+j+l)|$$

  where *MAE* stands for *Mean Absolute Error*.
- Goal is to find a vector (u, v) such that *MAE*(u, v) is minimum.

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Methods for Motion Vector Searches

Full Search Method

- Sequentially search the whole [-p, p] region --> very slow

Two-Dimensional Logarithmic Search

- Similar to binary search. MAE function is initially computed within a window of [-p/2, p/2] at nine locations as shown in the figure.
- Repeat until the size of the search region is one pixel wide:
  1. Find one of the nine locations that yields the minimum MAE
  2. Form a new searching region with half of the previous size and centred at the location found in step 1.

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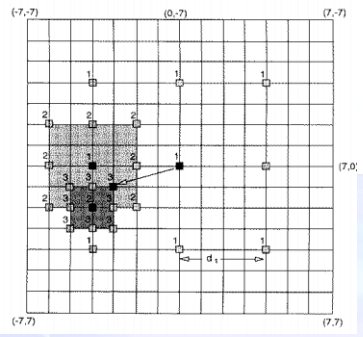
Methods for Motion Vector Searches



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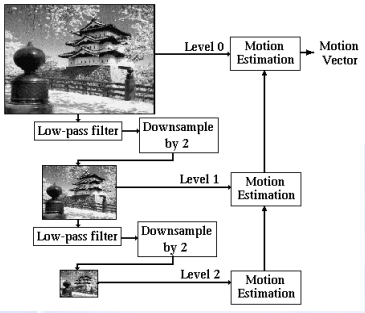
Methods for Motion Vector Searches

Hierarchical Motion Estimation



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Hierarchical Motion Estimation

1. **Form several low resolution version of the target and reference pictures**
2. **Find the best match motion vector in the lowest resolution version.**
3. **Modify the motion vector level by level when going up**

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Some Important Issues

- **Avoiding propagation of errors**
  1. Send an I-frame every once in a while
  2. Make sure you use decoded frame for comparison
- **Bit-rate control**
  - Simple feedback loop based on "buffer fullness"
  - If buffer is too full, increase the quantization scale factor to reduce the data.

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Details

How the Macroblock is Coded ?

Addr	Type	Quant	Vector	CBP	b0	b1	...	b5

- **Many macroblocks will be exact matches (or close enough). So send address of each block in image --> *Addr***
- **Sometimes no good match can be found, so send INTRA block --> *Type***
- **Will want to vary the quantization to fine tune compression, so send quantization value -->*Quant***
- ***Motion vector --> vector***
- ***Some blocks in macroblock will match well, others match poorly. So send bitmask indicating which blocks are present (Coded Block Pattern, or CBP).***
- ***Send the blocks (4 Y, 1 Cr, 1 Cb) as in JPEG.***

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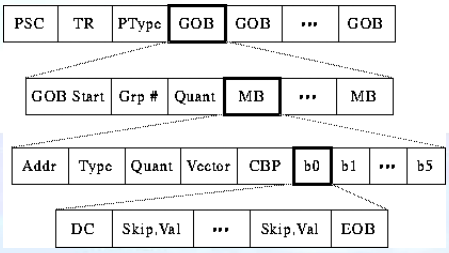
Details

H. 261 Bitstream Structure



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Details

- Need to delineate boundaries between pictures, so send Picture Start Code --> *PSC*
- Need timestamp for picture (used later for audio synchronization), so send Temporal Reference --> *TR*
- Is this a P-frame or an I-frame? Send Picture Type --> *PType*
- Picture is divided into regions of 11 x 3 macroblocks called Groups of Blocks --> *GOB*
- Might want to skip whole groups, so send Group Number (Grp #)
- Might want to use one quantization value for whole group, so send Group Quantization Value --> GQuant
- Generally, bitstream is designed so that we can skip data whenever possible and still remain unambiguous.

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H. 263

- H. 263 is an improved standard for low bit-rate video, adopted in March 1996.
- As H. 261, it uses the *transform coding* for intra-frames and predictive coding for inter-frames.
- Advanced Options:
  - Half-pixel precision in motion compensation
  - Unrestricted motion vectors
  - Syntax-based arithmetic coding
  - Advanced prediction and PB-frames
- In addition to CIF and QCIF, H. 263 could also support SQCIF, 4CIF, and 16CIF. The following page is a summary of video formats supported by H. 261 and H. 263:

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H. 263

Video Formats Supported

Video format	Luminance Image Resolution	Chrominance Image Resolution	H.261 support	H.263 support	Bit-rate (Mbit/s) (if uncompressed, 30 fps) B / W	Bit-rate (Mbit/s) (if uncompressed, 30 fps) Color	Max bits allowed per picture (BPPmax, Kb)
SQCIF	128 x 96	64 x 48	n/a	Required	3	4.4	64
QCIF	176 x 144	88 x 72	Required	Required	6.1	9.1	64
CIF	352 x 288	176 x 144	Optional	Optional	24.3	36.5	256
4CIF	704 x 576	352 x 288	n/a	Optional	97.3	146	512
16CIF	1408 x 1152	704 x 576	n/a	Optional	389.3	583.9	1024

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MPEG

What is MPEG ?

- "Motion Picture Coding Experts Group", established in 1988 to create standard for delivery of video and audio.
- MPEG-1 Target: VHS quality on a CD-ROM or Video CD (VCD) (352 x 240 + CD audio @ 1.5 Mbits/sec)
- Standard had three parts: Video, Audio, and System (control interleaving of streams)

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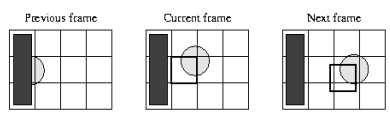
MPEG-1 Video

- Problem: some macroblocks need information not in the previous reference frame.

  Example: The darkened macroblock in Current frame does not have a good match from the Previous frame, but it will find a good match in the Next frame.



- MPEG solution: add third frame type: bidirectional frame, or *B-frame*
- In B-frames, search for matching macroblocks in both *past* and *future* frames.

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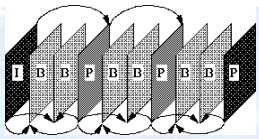
MPEG-1 Video

- Typical pattern is

  IBBPBBPBB IBBPBBPBB IBBPBBPBB

- Actual pattern is up to encoder, and need not be regular.



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Differences from H. 261

- Larger gaps between I and P frames, so need to expand motion vector search range.
- To get better encoding, allow motion vectors to be specified to fraction of a pixel (1/2 pixel).
- Bitstream syntax must allow random access, forward/backward play, etc.
- Added notion of *slice* for synchronization after loss/corrupt data. Example: picture with 7 slices:

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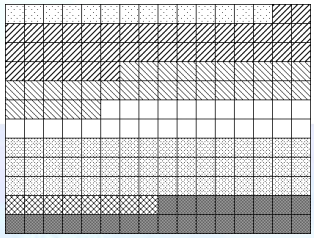
Differences from H. 261

- Example of 7 slices:



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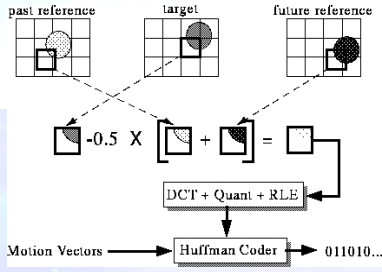
B Frame

- B frame macroblocks can specify *two* motion vectors (one to past and one to future), indicating result is to be averaged



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MPEG-1 Compression

Compression performance of MPEG 1

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

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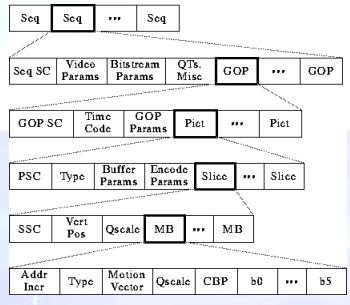
MPEG Video Bitstream

- Public domain tool such as mpeg_stat and mpeg_bits is able to analyze an MPEG bitstream.



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MPEG Video Bitstream

- **Sequence Information**
  1. *Video Params* include width, height, aspect ratio of pixels, picture rate.
  2. *Bitstream Params* are bit rate, buffer size, and constrained parameters flag (means bitstream can be decoded by most hardware)
  3. Two types of QTs: one for intra-coded blocks (I-frames) and one for inter-coded blocks (P-frames).
- **Group of Pictures (GOP) information**
  1. *Time code*: bit field with SMPTE time code (hours, minutes, seconds, frame).
  2. *GOP Params* are bits describing structure of GOP. Is GOP *closed*? Does it have a dangling pointer *broken*?
- **Picture Information**
  1. *Type*: I, P, or B-frame?
  2. *Buffer Params* indicate how full decoder's buffer should be before starting decode.
  3. *Encode Params* indicate whether half pixel motion vectors are used.

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MPEG Video Bitstream

- **Slice Information**
  1. *Vert Pos*: what line does this slice start on?
  2. *QScale*: How is the quantization table scaled in this slice?
- **Marcoblock (MB) Information**
  1. *Addr Incr*: number of MBs to skip.
  2. *Type*: Does this MB use a motion vector? What type?
  3. *QScale*: How is the quantization table scaled in this MB?
  4. *Coded Block Pattern (CBP)*: bitmap indicating which blocks are coded.

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Decoding MPEG Video in Software

- **Software Decoder goals: portable, multiple display types**
- **Breakdown of time**

Function	% Time
Parsing Bitstream	17.40%
IDCT	14.20%
Reconstruction	31.50%
Dithering	24.50%
Misc. Arith.	9.90%
Other	2.70%

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