

Multimedia Video Coding & Architectures (5LSE0), Module 08

Intraframe DCT Coding, Standards JPEG and DV

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Module 08 Intraframe Coding Standards



5LSE0 - Mod 08 Part 1 JPEG Still image compression standard



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Introduction to JPEG

- * **International standardization in 1988 - 1992 led to ISO and ITU-Telecommunications standard for still picture coding**
 - Referred to as *ISO/IEC IS 10918*
- * **JPEG: Joint Photographic Experts Group**
- * **Rationales**
 - *Comparable* requirements for *many* applications
 - Possible exchange of compressed data
 - Hardware/software reduction (>10 years ago!)
 - DCT had become very popular
- * **JPEG is a strongly prescriptive standard**



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JPEG Requirements

- * **Usability:**
 - Wide range of bit rates and qualities
 - Moderate complexity
 - Encoder/decoder of comparable complexity
 - Sequential image build up (top-left to bottom-right)
- * **Quality guidelines:**
 - 0.25-0.50 bit/color pixel: Moderate to good quality
 - 0.50-0.75 bit/color pixel: Good to very good quality
 - 0.75-1.50 bit/color pixel: Excellent quality
 - >1.50 bit/color pixel: Indistinguishable from original



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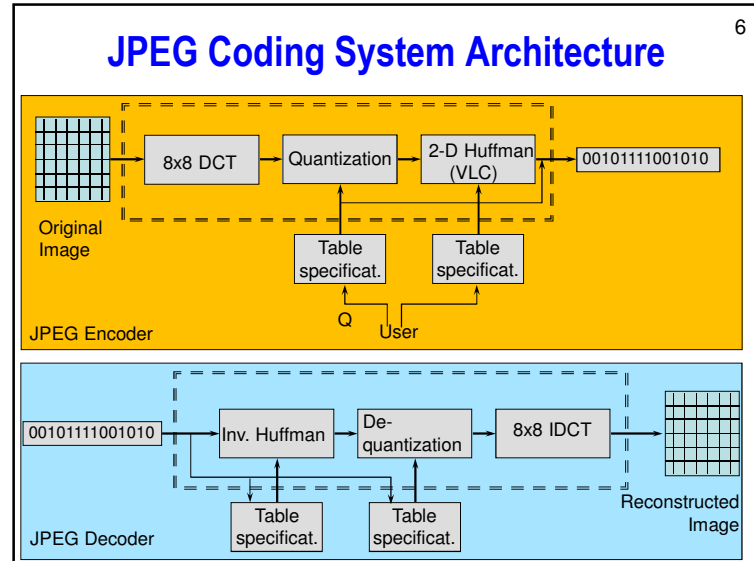


JPEG Coding Modes

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- * **Baseline JPEG (“sequential mode”)**
 - 8x8 DCT based compression
 - Quantization: normalization (=weight) matrix and rounding
 - DC coefficients are DPCM coded (lossless)
 - AC coefficients are {zero run, amplitude} Huffman coded
 - Up to 4 color components and 4 different normalization matrices
 - Bit stream can store normalization matrices and VLC table
 - No explicit bit rate control
- * **Progressive mode (currently: *Internet pictures*)**
- * **Hierarchical mode**
- * **Lossless compression mode: JPEG-LS**

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JPEG DCT Weighting & Quantization

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- * **Quantization:**

$$\hat{y}(u, v) = Q[y(u, v)] = \text{round} \left(\frac{y(u, v)}{QW(u, v)} \right)$$
- * **Recommended JPEG normalization matrix**

$$N(u, v) = W(u, v) = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

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JPEG User Controllable Quality

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- * **User has control over a “quality parameter” that runs from 100 (“perfect”) to 0 (“extremely poor”)**

The graph shows the relationship between the quality parameter Q (x-axis, 0 to 100) and the parameter used to scale the normalization matrix Q' (y-axis, 0 to 6). The curve shows that as Q increases (better quality), Q' decreases. The x-axis is labeled 'Increasing quality'.

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JPEG VLC Coding Example – (3)

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- * **The event series**

{1,-2} {0,-1} {0,-1} {0,-1} {2,-1} EOB

now becomes as bit string

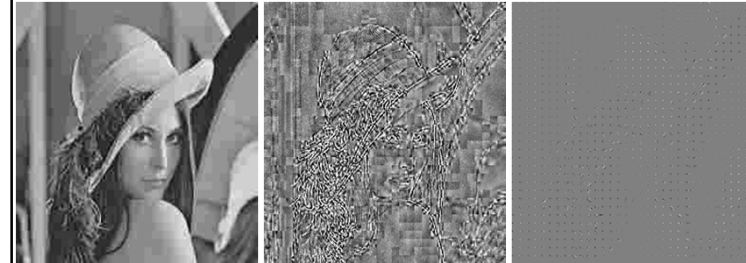
111001 01 / 00 0 / 00 0 / 00 0 / 11011 0 / 1010

- * **Bit rate for AC coefficients in this DCT block**

27 bits/64 pixels = 0.42 bit/pixel

JPEG VLC Coding Example – (4)

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Coded at Q=10

Quantization errors

Coded DCT block

JPEG Customization

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- * **Design of the normalization matrix $N(u,v)=W(u,v)$**

- * **Design of the Huffman tables**

- Usually done by quantization of all picture data,
- Followed by a histogram analysis of the (zero run-length, amplitude) combinations

- * **Rate-control mechanism (trial and error)**

- * **No possibility to vary Δ over DCT blocks (global Q)**

- * **Suboptimal alternative is to locally discard non-zero quantized DCT coefficients if they “cost” too much**

- Long zero run followed by small non-zero amplitude

JPEG follow-up: JPEG 2000

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- * **Recent update of existing standard**

- * **Advanced wavelet coding technique**

- Wavelet analysis of picture with filter banks
- Wavelet functions for suited for scalable video

- * **Special band-coding algorithms**

- Parent-children coding technique of (non-)zeros
- Special quantization and VLC

- * **Standard is accepted in digital Cinema, prof. imaging**

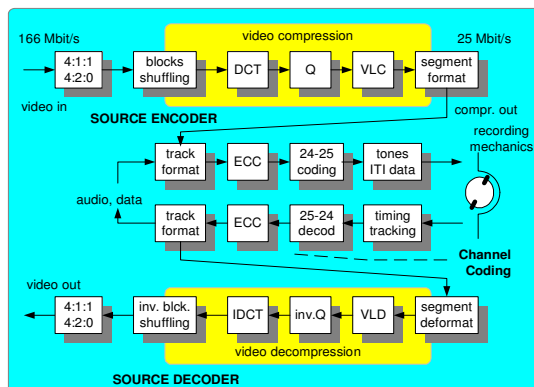
5LSE0 - Mod 08 Part 2 Intraframe DCT compression for digital video camcording: DV standard

Design considerations of DV compression

Contents

- * **System constraints**
- * **Cassette size and tape**
- * **Video mapping on sync blocks**
- * **Video compression**
- * **Data shuffling for trick play**
- * **Conclusions**

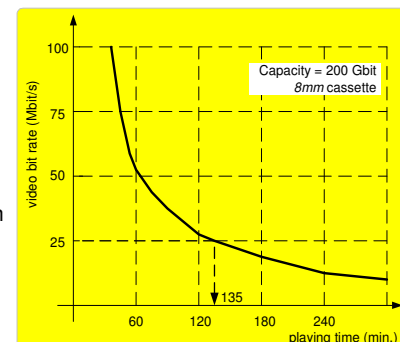
System constraints / DV architecture



System / Cassette size vs. playing time

Assumptions

- ME tape
- track width 10 μm
- bit length 0.25 μm
- 60% of data video
- video compression
- 25 Mbit/s



System / Cassette system outline – (1)

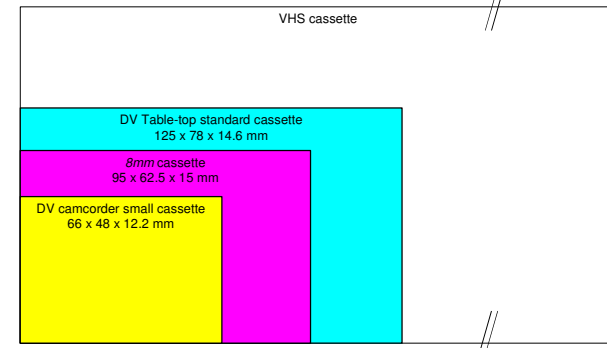
21

- * **Pocketable Camcorders**
 - more compact than analogue 8mm
 - playing time less important
- * **Home recording of HDTV**
 - minimum playing time 135 min. for movies
- * **Home recording of Standard Definition TV**
 - ratio HDTV to SDTV of 2:1
 - minimum playing time 270 min. for SDTV
- * **One-cassette system**

System / Cassette system outline – (2)

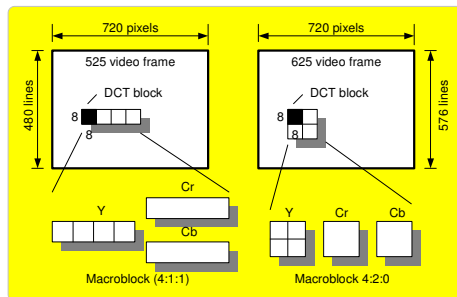
22

* Dual cassette system



System / Video Mapping Sync Blocks – (1)

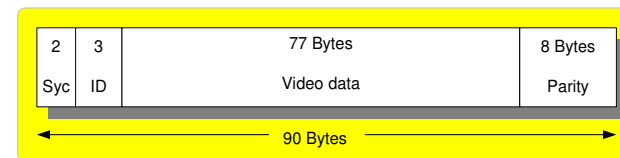
23



- * **1350 / 1620 Macroblocks per frame: map on 10 / 12 tracks / frame and 70 - 140 Sync Blocks / track**

System / Mapping Sync Blocks – (2)

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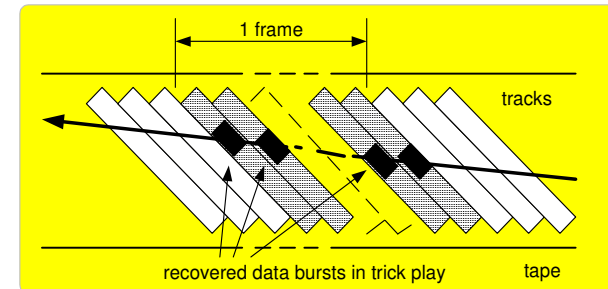


- * **Sync block is data packet in recording channel**
- * **Relatively short length of 90 Bytes**
- * **System aspects: robustness, search speed**

System / Recording system constraints - (1) ²⁵

- * Editing: preferably on picture basis
- * Repeated (de-)compression: robust for dubbing
- * Multitrack format: set of multiple tracks for 1 frame
- * Forward and backward search
 - picture recovery from small data bursts
- * Robustness: under all circumstances
- * High picture quality: beyond analog formats

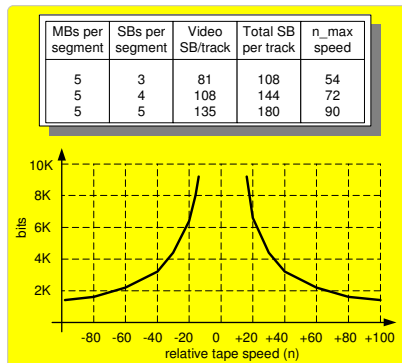
System / Recording system constr'ts – (2) ²⁶



- * Segmented recording and recovery

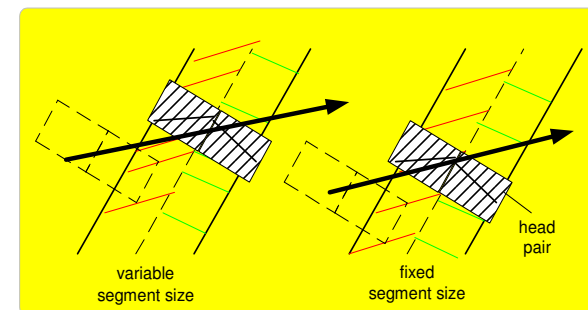
System / Mapping Sync Blocks – (3) ²⁷

- * 10 / 12 tracks per video frame (one channel rate)
- * 135 Macroblocks per track
- * 5 Macroblocks / video segment: division of 27



System / Fixed or variable segments ²⁸

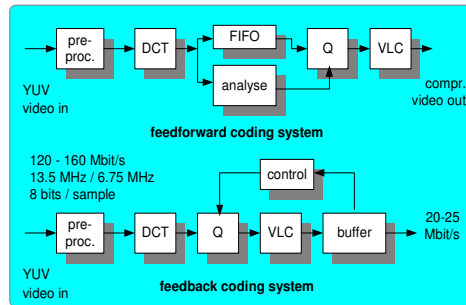
Note the predictive position of heads at specific tape speeds



System / Feedback or feedforward system

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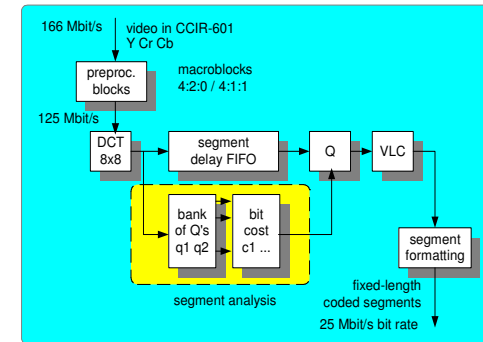
- * MPEG is feedback system
- * Fixed segment size coding requires other architecture



Video compression / Feedforward coding system

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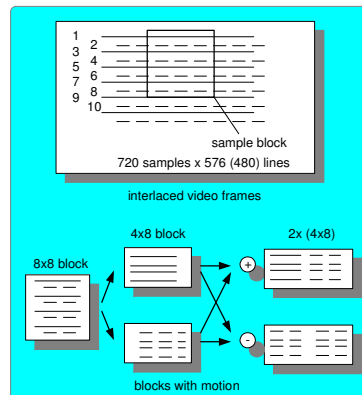
- * Independent coding of segments
- * Fixed-length compression for segments
- * Results in small accessible units



Video coding / Motion-adaptive DCT – (1)

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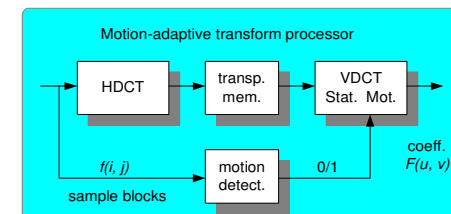
- * Video field interlacing in normal mode
- * Unequal time sampling
- * Sort block data by same time instant in case of motion
- * Separate LF and HF temp data



Video coding / Motion-adaptive DCT – (2)

32

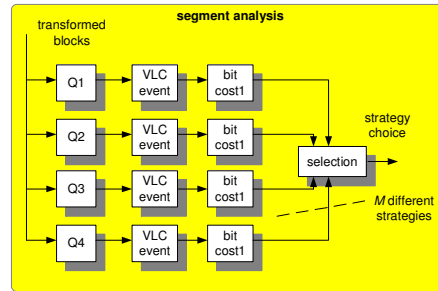
- * Motion detection for *a-priori* decision
- * Split horizontal and vertical proc. of transform
- * Vertical DCT should be 8-point (static) or 2x4-point (motion)



Video compr. / Segment analysis – (1)

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- * All K blocks of segment are analysed upfront
- * In hardware: various quantizers in parallel
- * Preliminary quantization and event coding for bit cost computation



Video compr. / Segment analysis – (2)

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Problem statement

- * For all blocks k with $0 \leq k \leq K-1$ do
- * Determine for strategy m and k -th block the bit cost

$$C_{m,k} = Cc_{m,k} \sum_{u,v} [Q_{m,k}(F_k(u,v))]$$

- * Perform all m quantizer strategies for $1 \leq m \leq M$

$$R_m = \sum_{k=0}^{K-1} C_{m,k} / KN^2$$

- * Select best strategy m_{opt} with $0 \leq m_{opt} \leq M-1$ such that the deviation of the desired rate is minimal, thus

$$|R_m - R_d| \cong 0$$

Video compr. / Quantization – (1)

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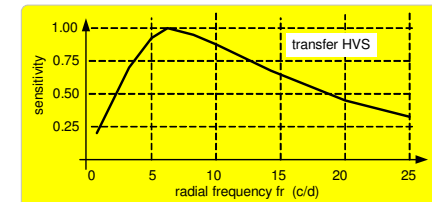
Quantization of $N \times N$ DCT blocks

- (1). Frequency-dependent: weighting
- (2). Adaptive to local image statistics
- (3). Uniform block quantization

Video compr. / Quantization – (2)

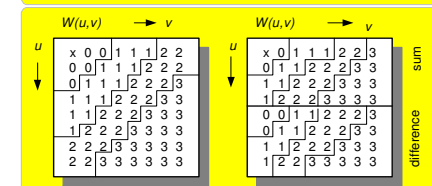
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- Weighting is frequency-dependent



- Relates to Human Visual System

- DV has strongly discretized weighting (only 4 weights)



Video compr. / Quantization – (3)

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- * **Local adaptivity**
 - 4 classes sufficient
 - any metric allowed, e.g. $\text{SUM } F^2(u, v)$
- * **Uniform quantization**
 - division by step size S
 - combine $W(u, v) / S$ into powers of 2

Q class number				W area number			
0	1	2	3	0	1	2	3
15							
14							
13							
12	15						
11	14						
10	13						
09	12	15	14				
08	11	14	13	1	1	1	1
07	10	13	12	1	1	1	2
06	09	12	11				
05	08	11	10	1	2	2	4
04	07	10	09				
03	06	09	08	2	2	4	4
02	05	08	07				
01	04	07	06	2	4	4	8
00	03	06	05				
	02	05	04	4	4	8	8
	01	04	03				
	00	03	02	4	8	8	16
		02	01				
		01	00	8	8	16	16
		00					

Video compr. / Var.-Length coding – (1)

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Algorithm: Coding {runlength, amplitude} combinations

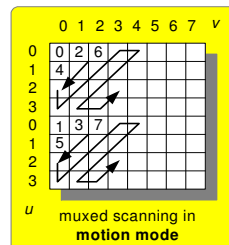
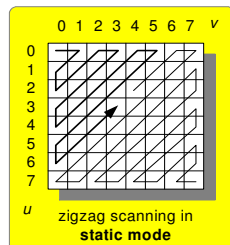
- (1). Count zeros until non-zero coefficient occurs = runlength
- (2). Combine actual runlength with non-zero coefficient into one statistical event
- (3). Apply one single codeword for the event

Example: DC +34 0 -16 +11 0 0 +2 -1 0 0 0 0 ..., becomes DC (0,+34) (1,-16) (0,+11) (2,+2) (0,-1) EOB

Video compr. / Var.-Length coding – (2)

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- * **Algorithm Step 1: Scanning of coefficients**
 - purpose is zero clustering
 - start with relevant info and conclude with EOB
 - Adaptive to motion mode (2 x (4x8) subblocks)



Video compr. / Var.-Length coding – (3)

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- * Algorithm Step 2: Runlength count and events
- * Algorithm Step 3: Coding of {runlength, amplitudes} events
 - 2-Dimensional coding table (words + wordlengths)
 - Entries are runlength and non-zero amplitude
 - Exceptions: concatenation of existing codewords, e.g. (5,+7) = (4,0) + (0,+7)

Video compr. / Var.-length coding – (4)

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* Two-dimensional coding table of wordlengths

zero run	amplitude →																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	11	2	3	4	4	5	5	6	6	6	7	7	7	8	8	8	8	8	9	9	14
1	12	4	6	7	7	8	9	9	10	10	10	11	11	12	12	12	12	12	12	12	12
2	12	5	7	9	10	10	11	12	12	13											
3	12	6	8	10	12	12	13														
4	12	6	9	11	12																
5	12	7	10	11	12																
6	13	7	10	12																	
7	13	8	12	12																	
8	13	8	12																		EOB = 4
9	13	9	12																		
10	13	9	13																		Example of wordlength table

Video compr. / Var.-Length coding – (5)

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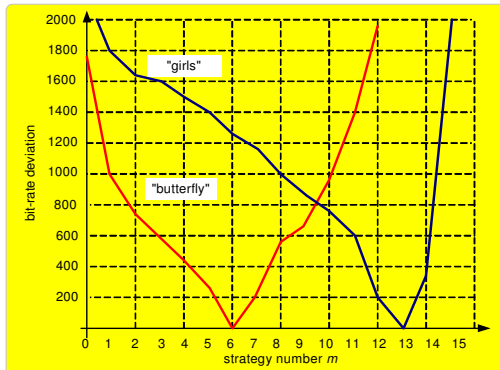
* Two-dimensional table of codewords

code	runlength	amplitude	code	runlength	amplitude	code	runlength	amplitude
0110		EOB	11100 000s	7	1	11110 0100s	5	2
00s	0	1	11100 001s	8	1	11110 0101s	6	2
010s	0	2	11100 010s	9	1	11110 0110s	3	3
0111s	1	1	11100 011s	10	1	11110 0111s	4	3
1000s	0	3	11100 100s	3	2	11110 1000s	2	4
1001s	0	4	11100 101s	4	2	11110 1001s	2	5
1010 0s	2	1	11100 110s	2	3	11110 1010s	1	8
1010 1s	1	2	11100 111s	1	5	11110 1011s	0	18
1011 0s	0	5	11101 000s	1	6	11110 1100s	0	19
1011 1s	0	6	11101 001s	1	7	11110 1101s	0	20
1100 00s	3	1	11101 010s	0	12	11110 1110s	0	21
1100 01s	4	1	11101 011s	0	13	11110 1111s	0	22
1100 10s	0	7	11101 100s	0	14	1111 1000 00s	5	3
1100 11s	0	8	11101 101s	0	15	1111 1000 01s	3	4
1101 000s	5	1	11101 101s	0	15	1111 1000 10s	3	5
1101 001s	6	1	11101 110s	0	16	1111 1000 11s	2	6
1101 010s	2	2	11101 111s	0	17	1111 1001 00s	1	9
1101 011s	1	3	11110 0000s	11	1	1111 1001 01s	1	10
1101 100s	1	4	11110 0001s	12	1	1111 1001 10s	1	11
1101 101s	0	9	11110 0010s	13	1	1111 1001 110		esc (0,0)
1101 110s	0	10	11110 0011s	14	1	1111 1001 111		esc (1,0)
1101 111s	0	11				1111 1010 1100		esc (2,0)

Video compr. / System optimization – (1)

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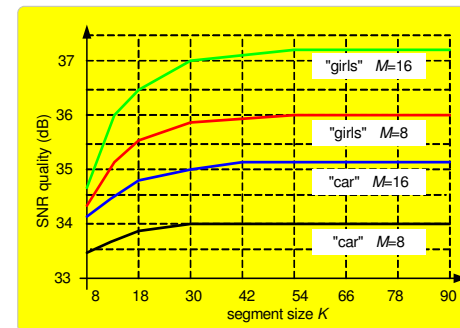
* Strategy vs. bit rate
 – 16 different strategies
 – Variable picture material



Video compr. / System optimization – (2)

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* Segment size in DCT blocks
 – Optimal choice segment size K
 – Number of strategies M
 – CCIR-601, 4:2:0, 25 Mbit/s bit rate
 – Result: $K = 30$, $M=16$



Video compr. / Robust MB format – (1) ⁴⁵

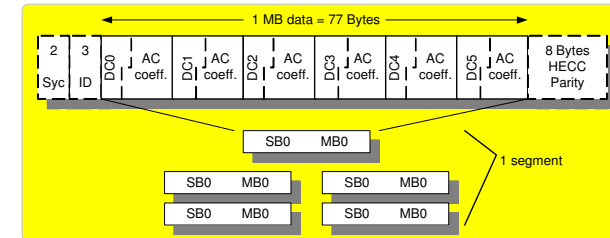
Ultra-Robust segment and MB format

- * Format for *compressed* data
- * Enables high search speeds
- * Robust for residual errors, because of partial ECC
- * Key aspect for portable equipment

Video compr. / Robust MB format – (2) ⁴⁶

Principal elements of format

- (1). Fixed-length coded segments
- (2). One MB (macroblock) per sync block
- (3). Special low-freq. part of DCT blocks on fixed positions



5LSE0 - Mod 08 Part 3 ⁴⁷

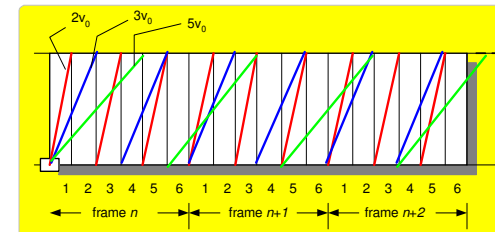
Intraframe DCT compression for digital video camcording: Fast Searching in the DV standard

(Addendum to Part 2)

Video compr. / Searching at speed ⁴⁸

Picture search at different speeds

- (1). Aim at full-image periodic refresh
- (2). Not every tape speed is allowed
- (3). Not a divisor or multiple of track count per frame

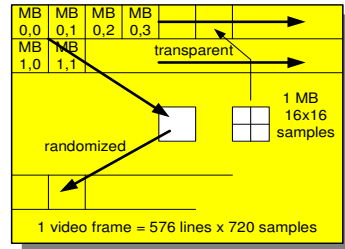


Video compr. / Video shuffling – (1)

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Video shuffling to support picture search

- (1). Transparent (process as received): minimum memory
- (2). Randomized: spreads moving and non-moving areas



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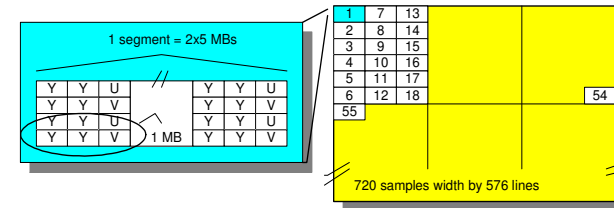


Video compr. / Video shuffling – (2)

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(3). Super MacroBlock Construction (SMBC):

- * Image divided in nearly square super blocks
- * Super blocks segmented into smaller super blocks
- * Coinciding super blocks fit as a fraction to tape speeds



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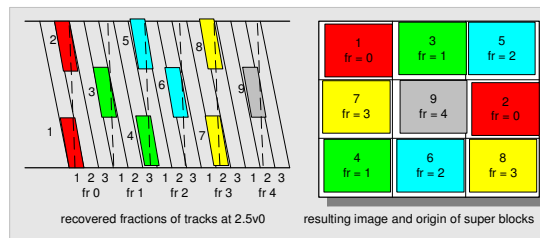


Video compr. / Video shuffling – (3)

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(3). Super MacroBlock Construction (SMBC):

- * rely on recovered fraction $1/(2(n-1))$ of track at nv_0 speed
- * construct larger blocks of smaller blocks fitting with fractions (consider example at $2.5 v_0$ with 3 double tracks per frame)



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Video compr. / Video shuffling – (4)

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(1). Transparent (Example at $2.5 v_0$ with 3 double tracks per frame)



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Video compr. / Video shuffling – (5) 53

(2). Randomized (Example $2.5 v_0$ with 3 double tracks per frame)





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Video compr. / Video shuffling – (6) 54

(3). SMBC (Example $2.5 v_0$ with 3 double tracks per frame)





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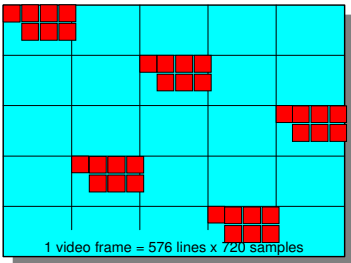


Video compr. / Video shuffling – (7) 55


Finally adopted frame-based shuffling

- * compromise on randomized (global) and SMBC (local)

- ❖ Gradual filling of image area in clusters of MBs
- ❖ Affects both coding efficiency and picture search quality




1 video frame = 576 lines x 720 samples



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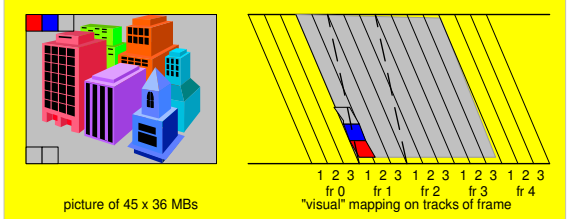
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Video compr. / Video shuffling – (8) 56

Additional shuffling step for trick play


- * Performed after compression: no influence on normal PQ
- * Lower speeds require larger adjacent areas
- * Coherent mapping of image required



picture of 45 x 36 MBs


1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
fr 0 fr 1 fr 2 fr 3 fr 4

"visual" mapping on tracks of frame



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DV Video Coding / Conclusions – (1)

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- * **(1) Cassette size and tape**
 - Minimized for camcording
 - ME tape and 2.5 sq.micron / bit density
 - Intraframe DCT Video compression to 25 Mbit/s
 - Sufficient playing time
- * **(2) Small segment feedforward video coding**
 - Independent compression of each segment
 - Motion-adaptive for interlace
 - Low-cost intraframe coding
 - High accessibility for editing
 - High robustness

DV Video Coding / Conclusions - (2)

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- * **(3) Special formatting and shuffling**
 - Distributed MBs for optimal compression
 - Coherent image areas on tape
 - Small segment size for high-speed search
 - Very robust inner segment format (even without ECC)

DV is a clear technological and market success, the compression has been adopted even for Hi8, and professional applications!

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