18-899 Special Topics in Signal Processing

Multimedia Communications:
Coding, Systems, and Networking

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Lecture 6

MPEG-1

Moving Picture Expert Group

- Moving Pictures Expert Group (MPEG)
  - ISO/IEC JTC1/SC29/WG11
  - Formed in Jan. 1988
- MPEG standards
  - MPEG-1
  - MPEG-2
  - MPEG-4 (ongoing)
  - MPEG-7 (ongoing)
- Specify only bitstream syntax and decoding

MPEG-1/2

- MPEG-1
  - Audio and video on storage media such as CD-ROM
    - 1x CD-ROM: 150 KB/s = 1.2 Mbits/s
  - Targeted at 1 to 1.5 Mbits/s
    - ~1.2 Mbits/s for video, ~250 kbits/s for audio
- MPEG-2
  - Digital TV: SDTV, HDTV
  - Wide range of bit rates 4 to 80 Mbits/s
  - Optimized around 4 Mbits/s
  - Supports interlaced video and scalable coding

MPEG-1

- Outline
  - Applications and history
  - Requirements
  - New features (w.r.t. H.261)
  - Simulation Model 3
  - Bitstream syntax
  - Video buffering verifier

MPEG-1

- Applications
  - Video on digital storage media
  - Computer and telecommunication networks

- History

Competition
- 1988: started
- Sep. 1989: Proposal registration
- Oct. 1989: Subjective tests

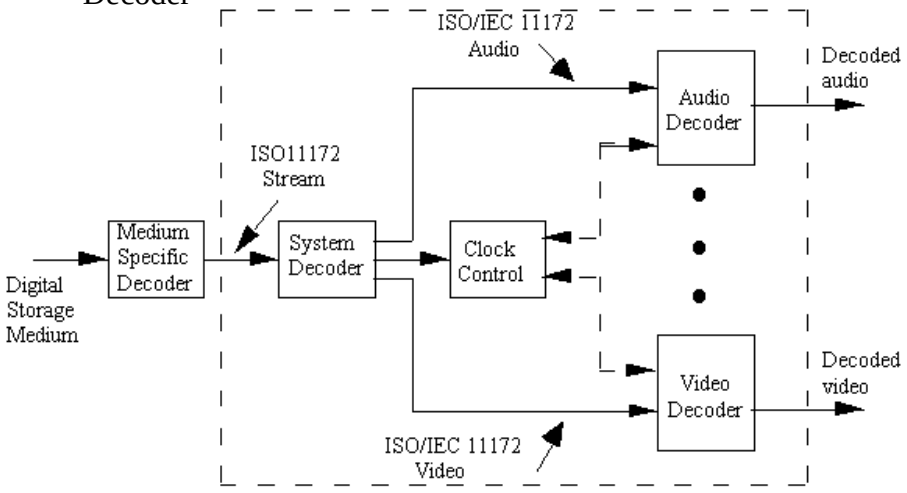
Convergence
- Mar. 1990: Definition of video algorithm (Simulation Model 1)
- Sep. 1990: Committee Draft for video

Parts of MPEG-1

- ISO/IEC 11172-1: Systems
- ISO/IEC 11172-2: Video
- ISO/IEC 11172-3: Audio
- ISO/IEC 11172-4: Conformance Testing
- ISO/IEC 11172-5: Software

MPEG-1 System

- Decoder



Requirements: Basic

- Coding of generic video with good quality (about VHS video) at 1 to 1.5 Mbits/s
- Random access to a frame in limited time
  - Frequent access points
- Fast forward/reverse
  - Seek and play in FF/FR using access points
- System supporting audio-visual synchronized play/access
- A practical/implementable decoder

Requirements: Additional

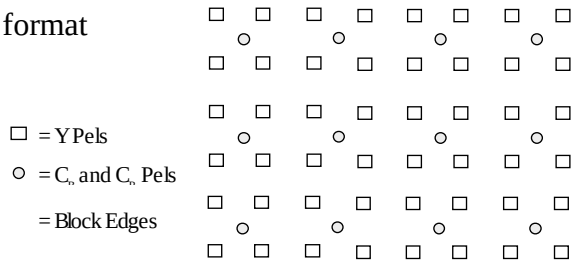
- Reverse playback
  - Access points and buffering
- Tradeoff quality with coding/decoding delay
  - Delay between 150 ms to 1 sec
- Source coding scheme and bits organization to be robust to errors
- Some flexibility in picture format to support variety of applications
- Real-time encoder at reasonable cost

New Features (w.r.t. H.261)

- Flexible picture sizes, picture rates, etc.
- Flexible slice structure instead of GOB
- Group of pictures (GOP)
- Bi-directional motion compensation
- Half-pel motion compensation
- Separate MB-type VLC tables for I, P, and B pictures
- Quantization tables
- VLC supports large range of DCT coefficients

Parameters

- Picture size up to 4096 × 4096 supported
  - Normally at 360 × 240
- Pel aspect ratio: 14 choices
- Picture rates: 23.976, 24 (movies), 25 (PAL), 29.97, 30, 50, 59.94, 60
- 4:2:0 format

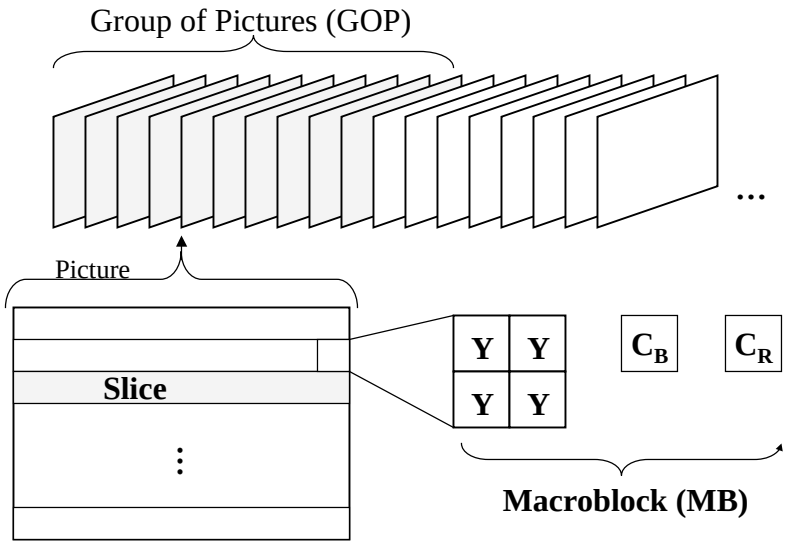


Constrained Parameters

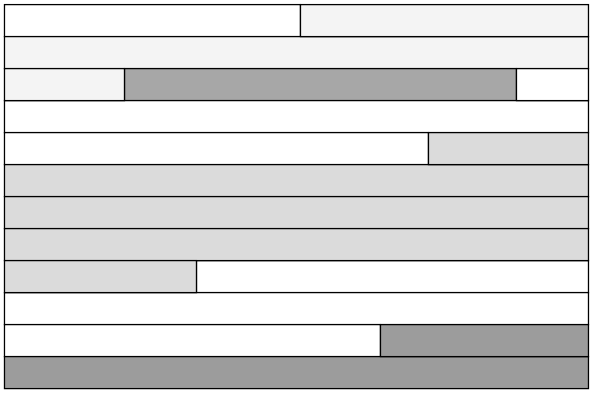
- To allow interoperability of MPEG-1 equipment, a subset of parameter space is defined
- All MPEG-1 conformant decoders shall decode constrained parameter bitstreams

Horizontal picture size	≤ 768 pels
Vertical picture size	≤ 576 lines
Picture area	≤ 396 macroblocks
Pel rate	≤ 396×25 macroblocks per second
Picture rate	≤ 30 Hz
Motion vector range	< –64 to +63.5 pels (using half-pel vectors), etc.
Input buffer size (in VBV model)	≤ to 327 680 bits
Bitrate	≤ 1 856 000 bits/second (constant bitrate)

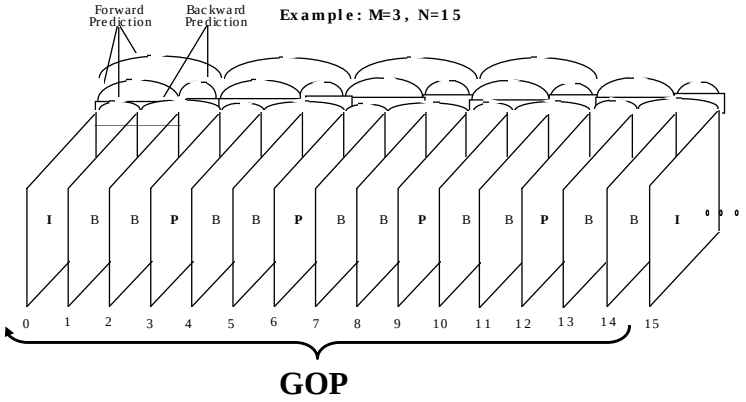
GOP, Slice and Macroblock



Possible Slice Arrangement



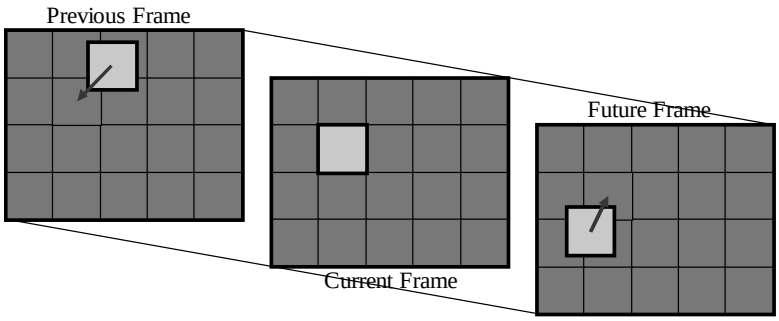
Group of Picture (GOP)



- N = number of pictures in a GOP
- M = prediction distance (M-1 in-between B-pictures)
- Tradeoff on M

Bi-Directional Prediction

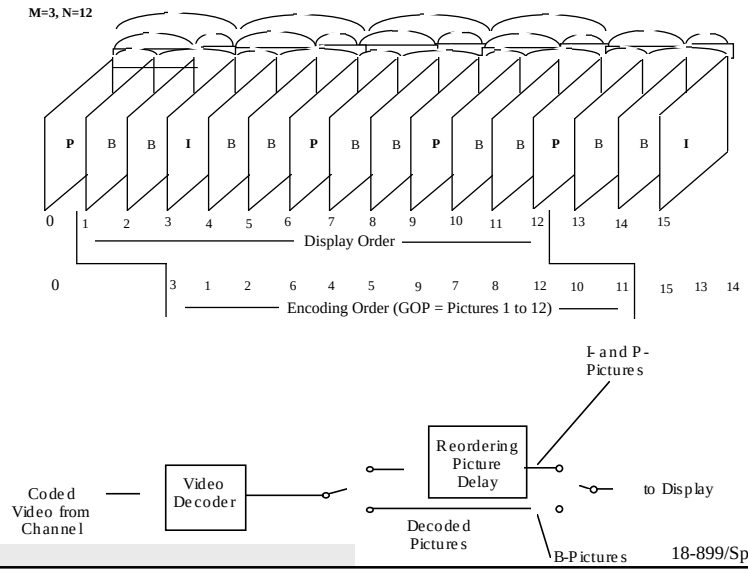
- Prediction from the previous frame, or the prediction from the future frame, or an average of both is used as the final prediction.
- The prediction error is then coded and transmitted



Bi-Directional Prediction (cont.)

- Advantages
  - Higher coding efficiency
  - No uncovered background problem
  - Increased frame rate with few extra bits
  - No error propagation
- Disadvantages
  - More frame storage is needed
  - More delay

Delay



Motion Compensation

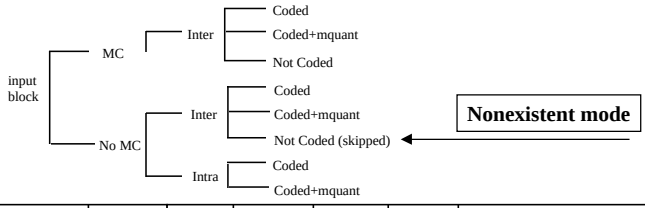
- Half-pel resolution for motion vectors
  - Bilinear interpolation
- Separate MB-type VLC tables for I, P, and B pictures
- Differential coding of motion vectors
- Motion compensation on 16×16 luminance blocks
  - Motion vectors divided by 2 for chrominance

MB Type

- For I-pictures

mb_type modes	mb_quant	mb_mot forward	mb_mot backward	mb_ pattern	mb_intra	VLC
Intra					y	1
Intra+mquant	y				y	01

- For P-pictures
  - MB Type

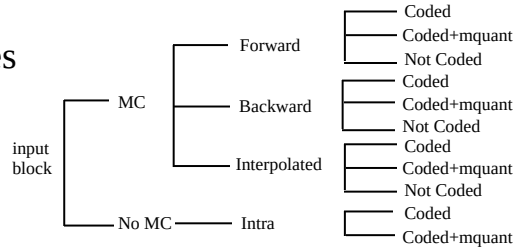


  - VLC Table

mb_type modes	mb_quant	mb_mot forward	mb_mot backward	mb_ pattern	mb_intra	VLC
MC, Coded		y		y		1
No MC, Coded				y		01
MC, Not Coded		y				001
Intra					y	00011
MC, Coded+mquant	y	y		y		00010
No MC, Coded+mquant	y			y		00001
Intra+mquant	y				y	000001

MB Type (cont.)

- For B-pictures
  - MB Types



  - VLC Table

mb_type modes	mb_quant	mb_mot forward	mb_mot backward	mb_ pattern	mb_intra	VLC
MC Interpolated, Not Coded		y	y			10
MC Interpolated, Coded		y	y	y		11
MC Backward, Not Coded			y			010
MC Backward, Coded			y	y		011
MC Forward, Not Coded		y				0010
MC Forward, Coded		y		y		0011
Intra					y	00011
MC Interpol., Coded+mquant	y	y	y	y		00010
MC Forward, Coded+mquant	y	y		y		000011
MC Backward, Coded+mquant	y		y	y		000010
Intra+mquant	y				y	000001

VLC for MV Difference

f=1,2,4,8,16,32,64

dMD=MD – PMD

motion_code=[dMD+Sign(dMD)×(f-1)]/f

r = | motion_code × f | – | dMD |

The residual r is sent with log(f) bits

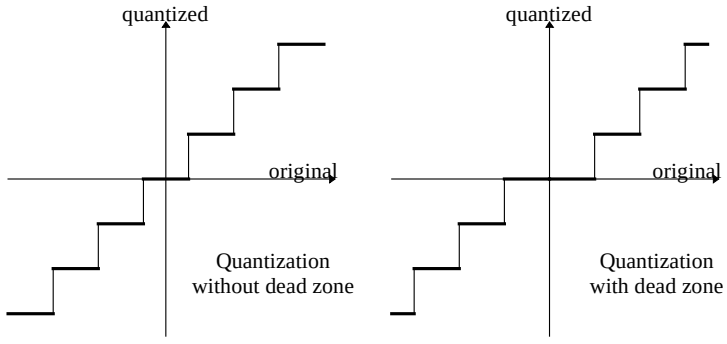
dMD = motion_code×f

– Sign(motion_code)×r

|motion_code|	VLC
0	1
1	01s
2	001s
3	0001 s
4	0000 11s
5	0000 101s
6	0000 100s
7	0000 011s
8	0000 0101 1s
9	0000 0101 0s
10	0000 0100 1s
11	0000 0100 01s
12	0000 0100 00s
13	0000 0011 11s
14	0000 0011 10s
15	0000 0011 01s
16	0000 0011 00s

- Range [–512, +511.5] for half-pel motion vectors
- Range [–1024, +1023] for full-pel motion vectors

Quantization



Intra

(nearest integer)

Nonintra

(rounded down)

Quantization

- Default quantizer matrices

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

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

inter

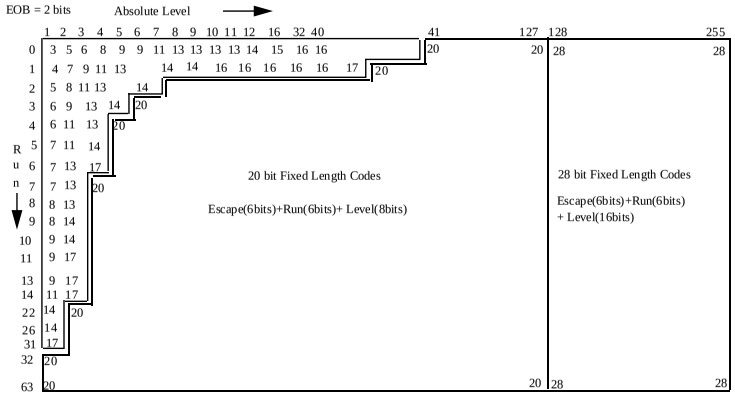
Coding for Intra DC

- VLC and VLI for Intra DC differential values

Differential DC	SIZE	VLC Luminance	VLC Chrominance	VLI
-255 to -128	8	1111 110	1111 1110	00000000 to 01111111
-127 to -64	7	1111 10	1111 110	0000000 to 0111111
-63 to -32	6	1111 0	1111 10	000000 to 011111
-31 to -16	5	1110	1111 0	00000 to 01111
-15 to -8	4	110	1110	0000 to 0111
-7 to -4	3	101	110	000 to 011
-3 to -2	2	01	10	00 to 01
-1	1	00	01	0
0	0	100	00	
1	1	00	01	1
2 to 3	2	01	10	10 to 11
4 to 7	3	101	110	100 to 111
8 to 15	4	110	1110	1000 to 1111
16 to 31	5	1110	1111 0	10000 to 11111
32 to 63	6	1111 0	1111 10	100000 to 111111
64 to 127	7	1111 10	1111 110	1000000 to 1111111
128 to 255	8	1111 110	1111 1110	10000000 to 11111111

2D VLC

- Similar to H.261
  - Most codes same, some codes shorter
  - Levels up to 255



2D VLC (cont.)

Run	Level	Code Word
0	1	1s (if first inter coefficient)
0	1	11s (otherwise)
0	2	0100 s
0	3	0010 1s
0	4	0000 110s
0	5	0010 0110s
0	6	0010 0001s
0	7	0000 0010 10s
0	8	0000 0001 1101s
0	9	0000 0001 1000s
0	10	0000 0001 0011s
0	11	0000 0001 0000s
0	12	0000 0000 1101s
0	13	0000 0000 1100s
0	14	0000 0000 1100s
0	15	0000 0000 1011s
1	1	011s
1	2	0001 10s
1	3	0010 0101s
1	4	0000 0011 00s
1	5	0000 0001 1011 s
1	6	0000 0000 1011 0s
1	7	0000 0000 1010 1s
2	1	0101 s
2	2	0000 100s
2	3	0000 0010 11s
2	4	0000 0001 0100s
2	5	0000 0000 1010 0s
3	1	0011 1s
3	2	0010 0100s
3	3	0000 0001 1100s
3	4	0000 0000 1001 1s
EOB		10
Escape		0000 01

Run	Level	Code Word
4	1	0011 0s
4	2	0000 0011 11s
4	3	0000 0001 0010s
5	1	0001 11s
5	2	0000 0010 01s
5	3	0000 0000 1001 0s
6	1	0001 01s
6	2	0000 0001 1110s
7	1	0001 00s
7	2	0000 0001 0101s
8	1	0000 0111s
8	2	0000 0001 0001s
9	1	0000 0101s
9	2	0000 0000 1000 1s
10	1	0010 0111 s
10	2	0000 1000 0s
11	1	0010 0011 s
12	1	0010 0010 s
13	1	0000 0011 10s
14	1	0000 0011 01s
15	1	0000 0010 00s
16	1	0000 0001 1111s
17	1	0000 0001 1010s
18	1	0000 0001 1001s
19	1	0000 0001 0111s
20	1	0000 0001 0110s
21	1	0000 0001 0100s
22	1	0000 0000 1111 1s
23	1	0000 0000 1111 0s
24	1	0000 0000 1110 1s
25	1	0000 0000 1110 0s
26	1	0000 0000 1101 1s

2D VLC (cont.)

Run	Level	Code Word
0	16	8*0 0111 11s
0	17	8*0 0111 10s
0	18	8*0 0111 01s
0	19	8*0 0111 00s
0	20	8*0 0110 11s
0	21	8*0 0110 10s
0	22	8*0 0110 01s
0	23	8*0 0110 00s
0	24	8*0 0101 11s
0	25	8*0 0101 10s
0	26	8*0 0101 01s
0	27	8*0 0101 00s
0	28	8*0 0100 11s
0	29	8*0 0100 10s
0	30	8*0 0100 01s
0	31	8*0 0100 00s
0	32	8*0 0011 000s
0	33	8*0 0010 111s
0	34	8*0 0010 110s
0	35	8*0 0010 101s
0	36	8*0 0010 100s
0	37	8*0 0010 011s
0	38	8*0 0010 010s
0	39	8*0 0010 001s
0	40	8*0 0010 000s

8*0 = 0000 0000

Run	Level	Code Word
1	8	8*0 0011 111s
1	9	8*0 0011 110s
1	10	8*0 0011 101s
1	11	8*0 0011 100s
1	12	8*0 0011 011s
1	13	8*0 0011 010s
1	14	8*0 0011 001s
1	15	8*0 0001 0011s
1	16	8*0 0001 0010s
1	17	8*0 0001 0001s
1	18	8*0 0001 0000s
6	3	8*0 0001 0100s
11	2	8*0 0001 1010s
12	2	8*0 0001 1001s
13	2	8*0 0001 1000s
14	2	8*0 0001 0111s
15	2	8*0 0001 0110s
16	2	8*0 0001 0101s
27	1	8*0 0001 1111s
28	1	8*0 0001 1110s
29	1	8*0 0001 1101s
30	1	8*0 0001 1100s
31	1	8*0 0001 1011s

2D VLC (cont.)

fixed length code	run
0000 00	0
0000 01	1
0000 10	2
...	...
...	...
...	...
...	...
...	...
...	...
1111 11	63

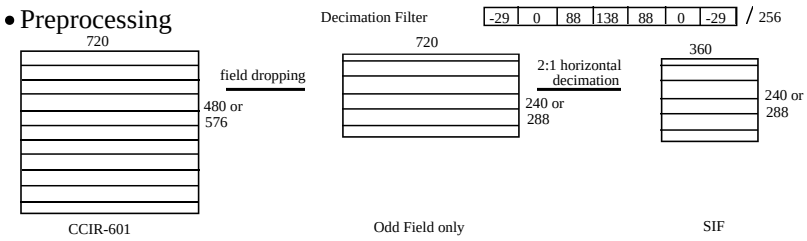
fixed length code	level
forbidden	-256
1000 0000 0000 0001	-255
1000 0000 0000 0010	-254
...	
1000 0000 0111 1111	-129
1000 0000 1000 0000	-128
1000 0001	-127
1000 0010	-126
...	...
1111 1110	-2
1111 1111	-1
forbidden	0
0000 0001	1
...	...
0111 1111	127
0000 0000 1000 0000	128
0000 0000 1000 0001	129
...	
0000 0000 1111 1111	255

Simulation Model (SM) 3

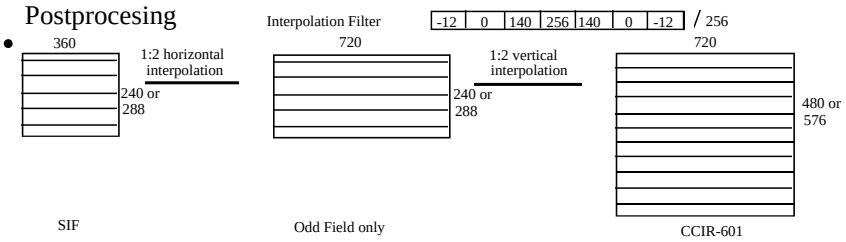
- Pre- and Post- processing
- Motion estimation/compensation
  - Telescopic search
  - Half-pel update
- Mode decision: MC/no MC inter/intra
- Quantization adaptation and rate control
- See Annex D of IS 11172-2

Pre- and Post- Processing

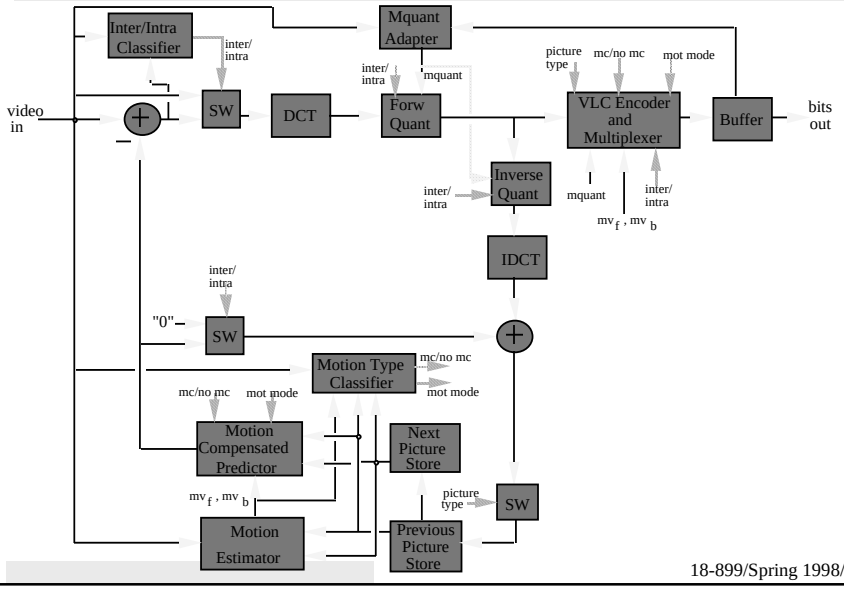
- Preprocessing



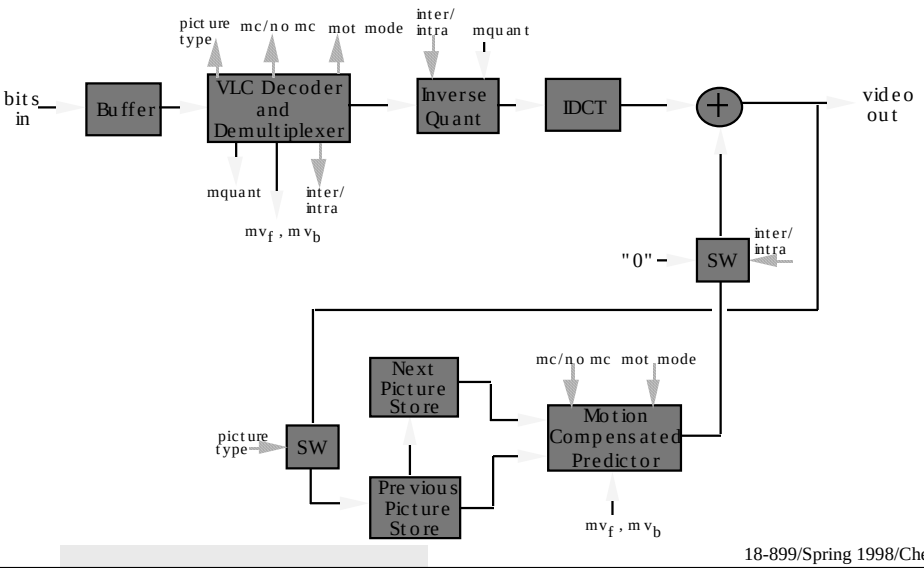
- Postprocesing



SM 3 Encoder

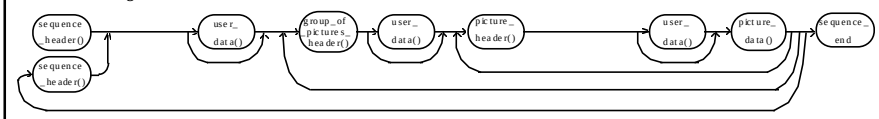


Decoder

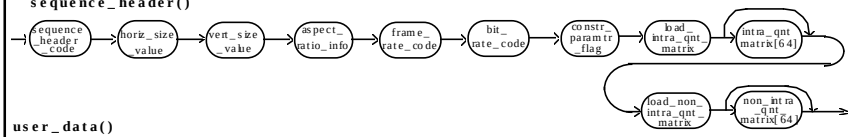


Bitstream Syntax

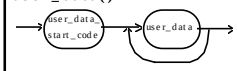
Bitstream Organization



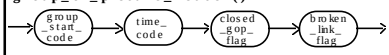
sequence_header()



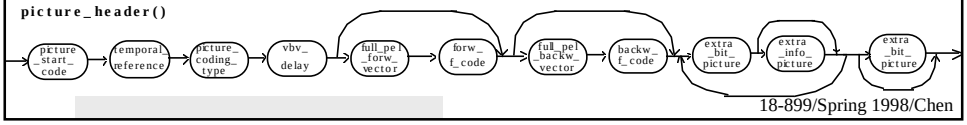
user_data()



group_of_picture_header()

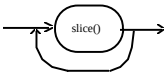


picture_header()

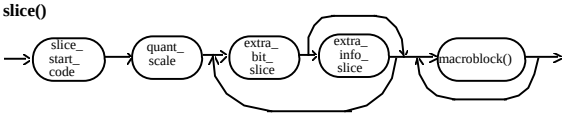


Bitstream Syntax (cont.)

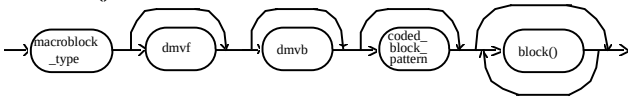
picture_data()



slice()

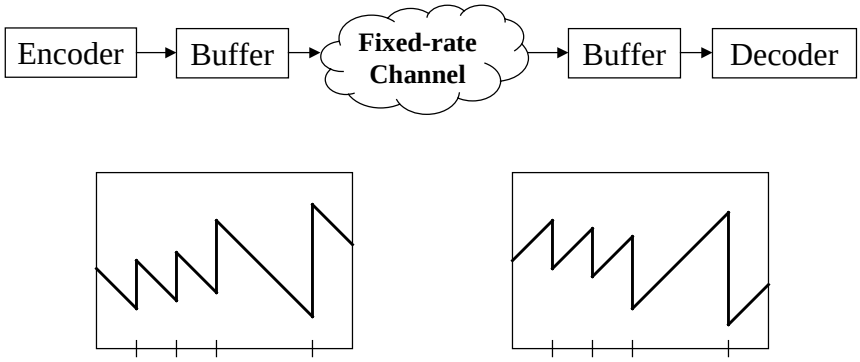


macroblock()



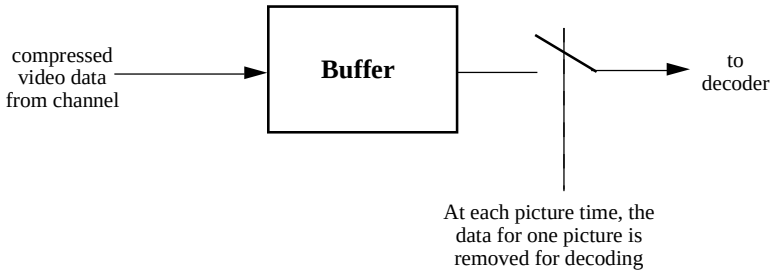
block()

Encoder and Decoder Buffers



Video Buffer Verifier

- Video Buffer Verifier (VBV)
  - Any MPEG-1 bit-stream is prohibited from over/under-flowing the buffer of this VBV
  - For constant bit-rate operation, this puts limitation on the variation of bits per picture



Reference

– Joan L. Mitchell et al., *MPEG Video: Compression Standard*, Chapman & Hall, New York, NY