ITCT
Programming Homework III

MPEG-1 Tutorial Guide

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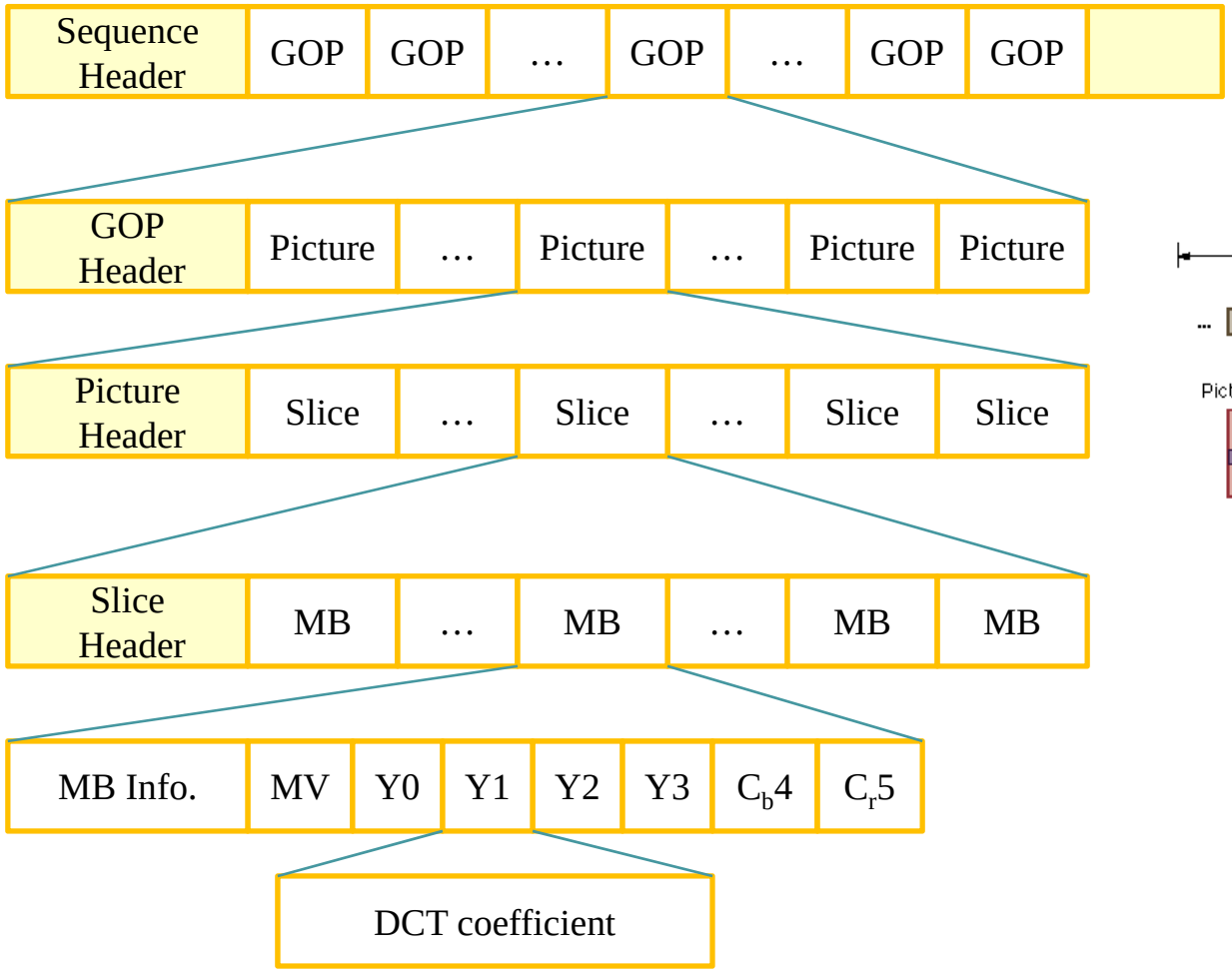
Introduction

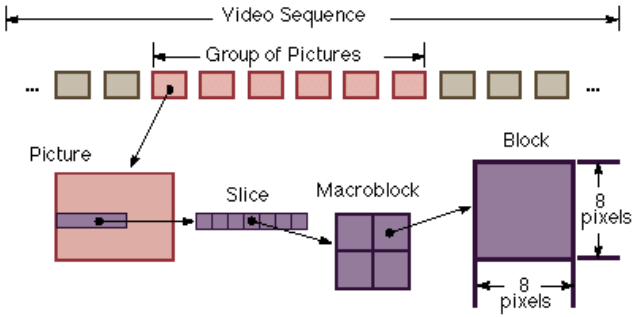
- **In 1988 the International Standards Organization (ISO) set up the Moving Picture Expert Group (MPEG) to standardize this compression.**
- **Its first standard, IS 11172 (known as MPEG-1) came in five parts:**
  - System (11172-1)
  - Video (11172-2)
  - Audio (11172-3)
  - Compliance testing (11172-4)
  - Software for MPEG-1 coding (11172-5)

About MPEG SPEC

- **Part1**
  - Brief Introduction and Overview
- **Part2**
  - Definition, Abbreviations and Symbols
- **Part3**
  - Video Bitstream Syntax
- **Part4**
  - The Video Decoding Process
- **Part5**
  - Annex for necessary table and codec detail

MPEG-1 Syntax Hierarchy



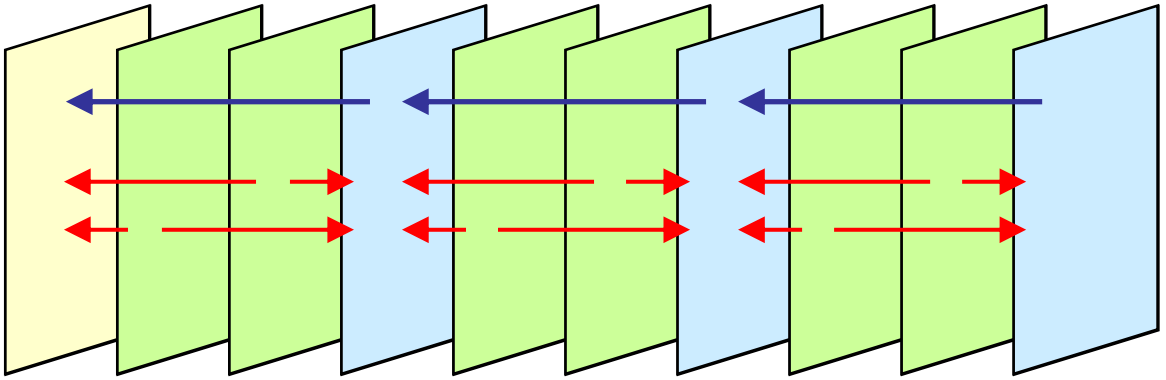


Pictures Types

- **I pictures (Intra-coded pictures)**
  - All macroblocks coded without prediction
- **P pictures (Predictive coded pictures)**
  - Coded with forward prediction from references made from previous I and P pictures
- **B pictures (Bi-directionally predicted pictures)**
  - Coded with interpolated prediction from past and future I or P references

GOP Layer

- **I, P, B three type of picture to consist a GOP (group of picture)**

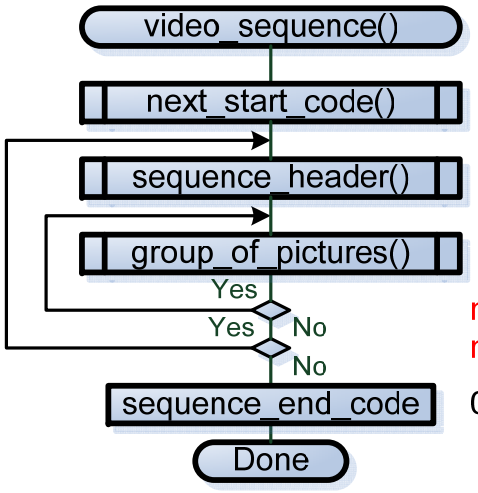


Temporal :	1	2	3	4	5	6	7	8	9	10
Coding seq. :	1	3	4	2	6	7	5	9	10	8
Picture type :	I	B	B	P	B	B	P	B	B	P

Video Bitstream Syntax

- **Function of each layer of the bit stream**
  - Video Sequence Layer
    - Random access unit: context
  - Group of Pictures (GOP) Layer
    - Random access unit: video
  - Picture Layer
    - Primary coding unit
  - Slice Layer
    - Resynchronization unit
  - Macroblock Layer
    - Motion compensation unit
  - Block Layer
    - DCT unit

Algorithms for Parsing Video Sequence



nextbits(32) = 0x 00 00 01 B8?
nextbits(32) = 0x 00 00 01 B3?

0x 00 00 01 B7

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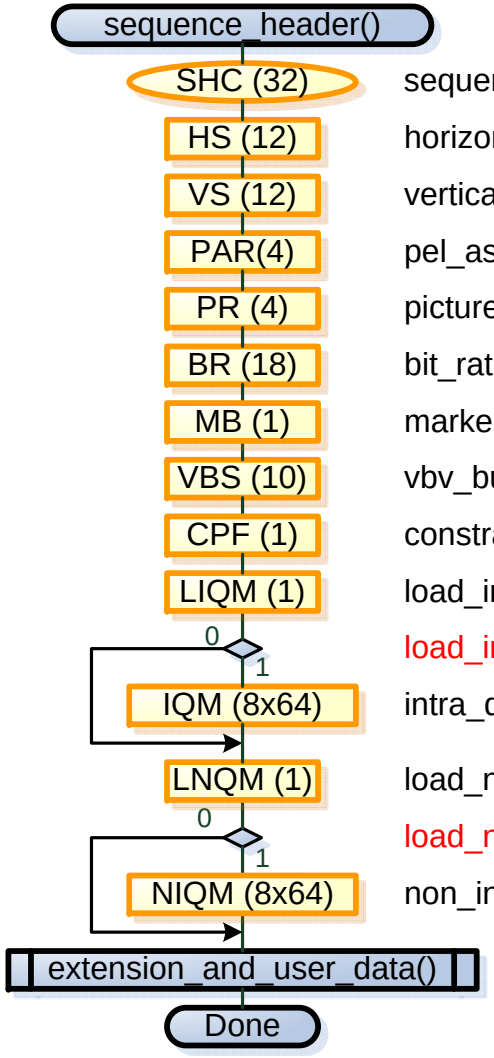
name	hexadecimal value
picture_start_code	00000100
slice_start_codes (including slice_vertical_positions	00000101 through 000001AF
reserved	000001B0
reserved	000001B1
user_data_start_code	000001B2
sequence_header_code	000001B3
sequence_error_code	000001B4
extension_start_code	000001B5
reserved	000001B6
sequence_end_code	000001B7
group_start_code	000001B8
system start codes (see note)	000001B9 through 000001FF
NOTE - system start codes are defined in Part 1 of tl	

p28

sequence_header()



sequence_header_code (0x 00 00 01 B3)

horizontal_size

vertical_size

pel_aspect_ratio

picture_rate

bit_rate

marker_bit

vbv_buffer_size

constrained_parameters_flag

load_intra_quantizer_matrix

load_intra_quantizer_matrix ?

intra_quantizer_matrix

load_non_intra_quantizer_matrix

load_non_intra_quantizer_matrix ?

non_intra_quantizer_matrix

p29

Default intra 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

p36

Default non-intra quantization matrix

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

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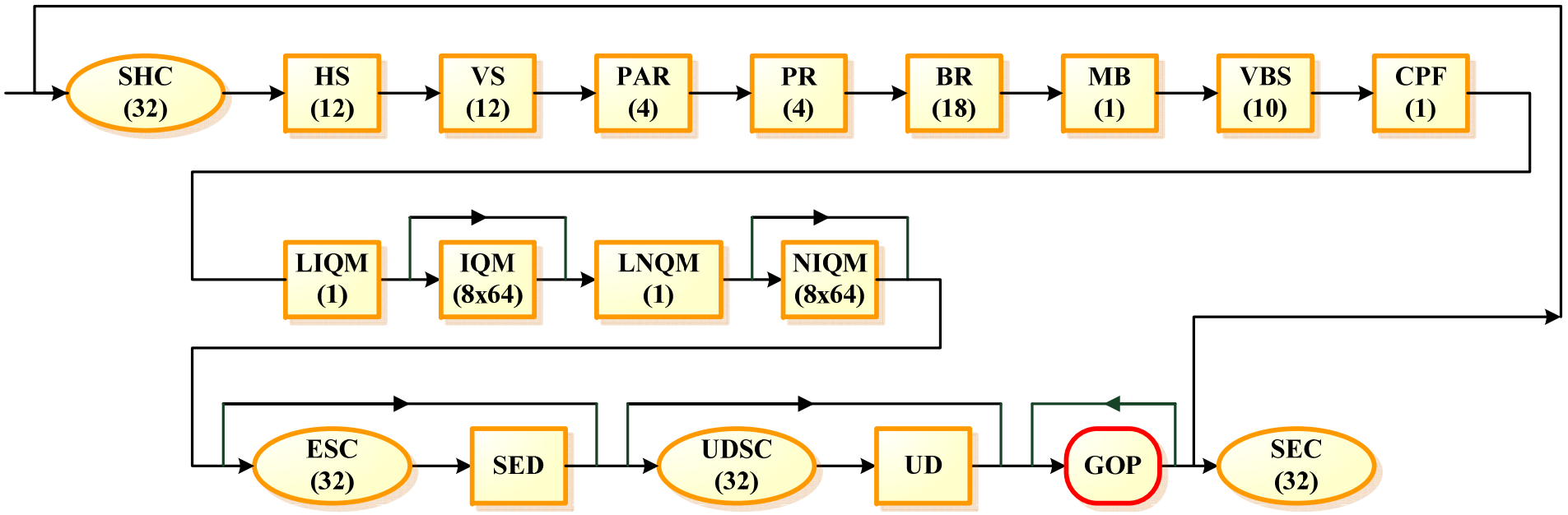
Video Sequence Layer



SHC: sequence_header_code
HS: horizontal_size
VS: vertical_size
PAR: pel_aspect_ratio
PR: picture_rate
BR: bit_rate
MB: marker_bit
VBS: vbv_buffer_size
CPF: constrained_parameters_flag

LIQM: load_intra_quantizer_matrix
IQM: intra_quantizer_matrix
LNQM: load_non_intra_quantizer_matrix
NIQM: non_intra_quantizer_matrix
ESC: extension_start_code
SED: sequence_extension_data
UDSC: user_data_start_code
UD: user_data
SEC: sequence_end_code

Lookup Tables

Ratio of height to width for the 16 pel_aspect_ratio codes

pel_aspect_ratio	height/width	example
0000	forbidden	
0001	1.0000	VGA etc.
0010	0.6735	
0011	0.7031	16:9, 625line
0100	0.7615	
0101	0.8055	
0110	0.8437	16:9, 525line
0111	0.8935	
1000	0.9375	CCIR601, 625line
1001	0.9815	
1010	1.0255	
1011	1.0695	
1100	1.1250	CCIR601, 525line
1101	1.1575	
1110	1.2015	
1111	reserved	

p35

Picture rate in pictures per second and typical applications

picture_rate	pictures per second
0000	forbidden
0001	23.976
0010	24
0011	25
0100	29.97
0101	30
0110	50
0111	59.94
1000	60
. . .	reserved
1111	reserved

p35

Constrained parameters bounds

horizontal_size <= 768 pels,
vertical_size <= 576 pels,
((horizontal_size+15)/16) *((vertical_size+15)/16) <= 396,
((horizontal_size+15)/16) *((vertical_size+15)/16))*picture_rate <= 396*25,
picture_rate <= 30 pictures per second.
forward_f_code <= 4 (forward_f <= 8)
backward_f_code <= 4 (backward_f <= 8)

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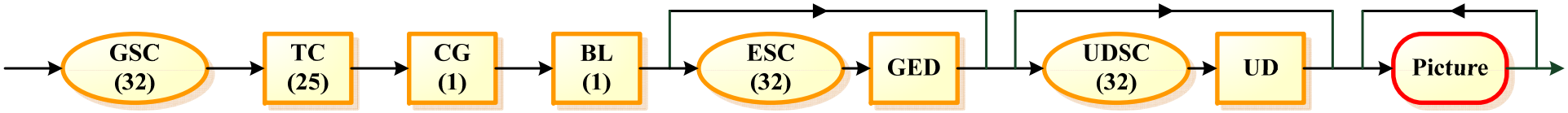
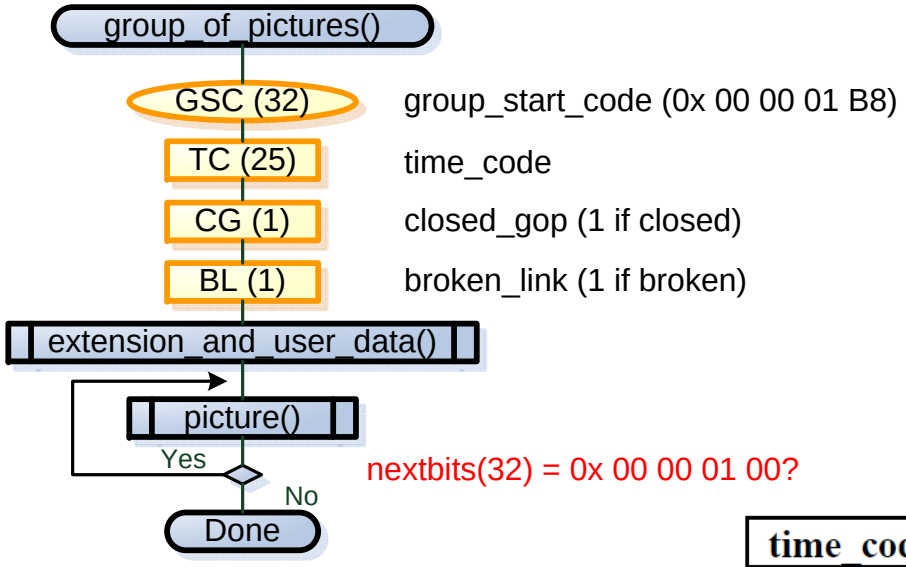
Group of Pictures Layer





nextbits(32) = 0x 00 00 01 00?

p30

GSC: group_start_code
TC: time_code
CG: closed_gop
BL: broken_link
ESC: extension_start_code
GED: group_extension_data
UDSC: user_data_start_code
UD: user_data

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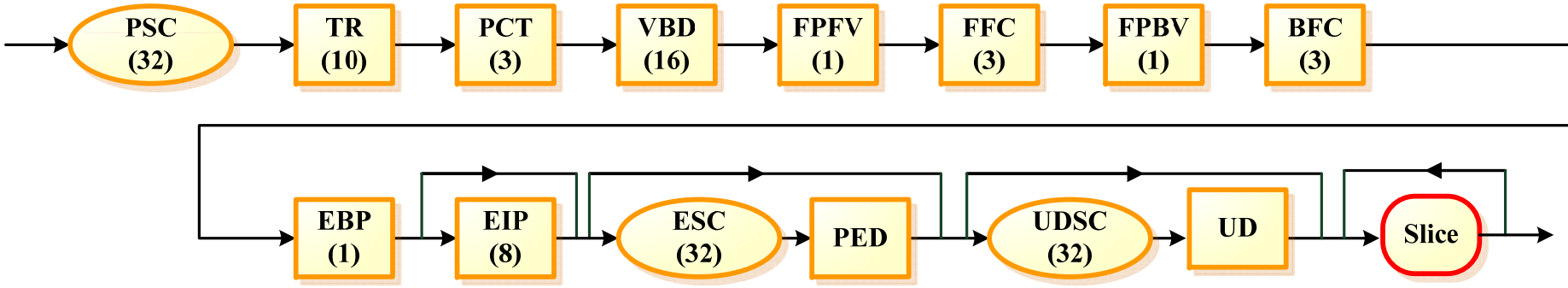
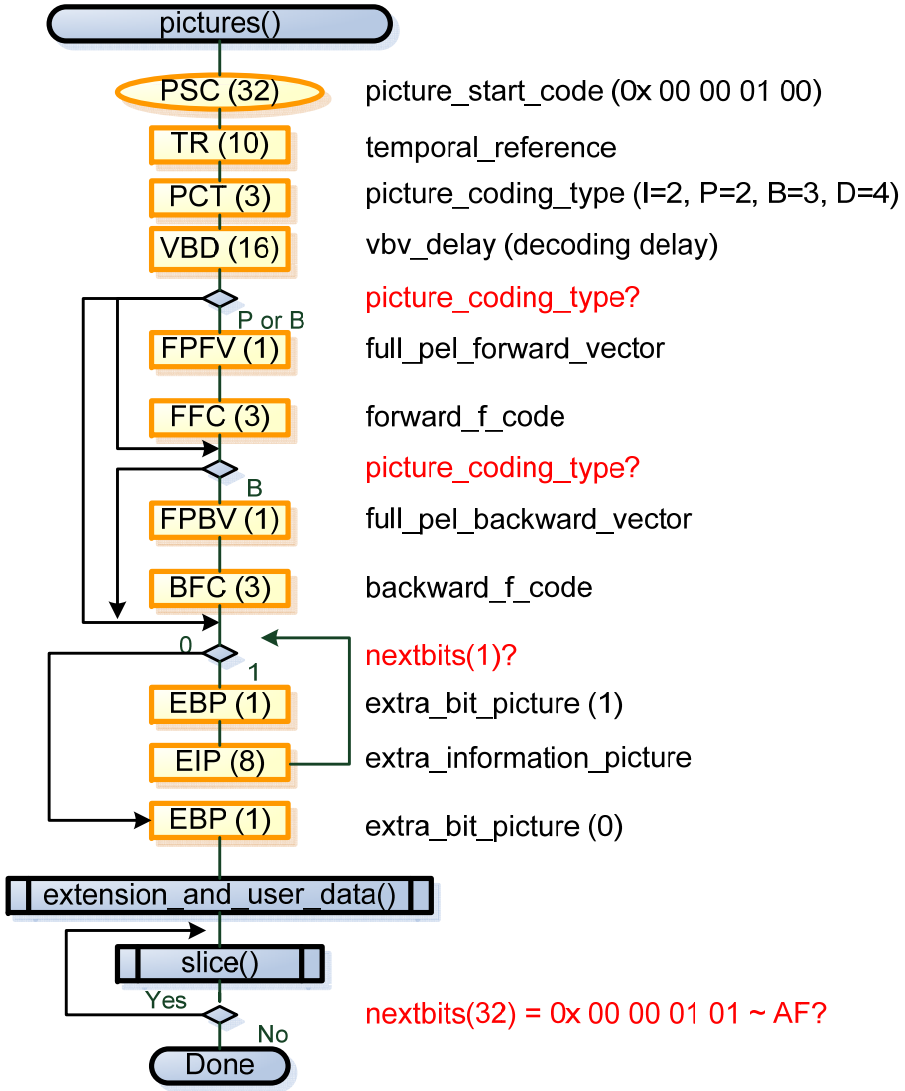
time_code	range of value	bits
drop_frame_flag		1
time_code_hours	0 - 23	5
time_code_minutes	0 - 59	6
marker_bit	1	1
time_code_seconds	0 - 59	6
time_code_pictures	0 - 59	6

Picture Layer



PSC: picture_start_code
TR: temporal_reference
PCT: picture_coding_type
VBD: vbv_delay
FPFV: full_pel_forward_vector
FFC: forward_f_code
FPBV: full_pel_backward_vector
BFC: backward_f_code
EBP: extra_bit_picture
EIP: extra_information_picture
ESC: extension_start_code
PED: picture_extension_data
UDSC: user_data_start_code
UD: user_data

Picture Layer



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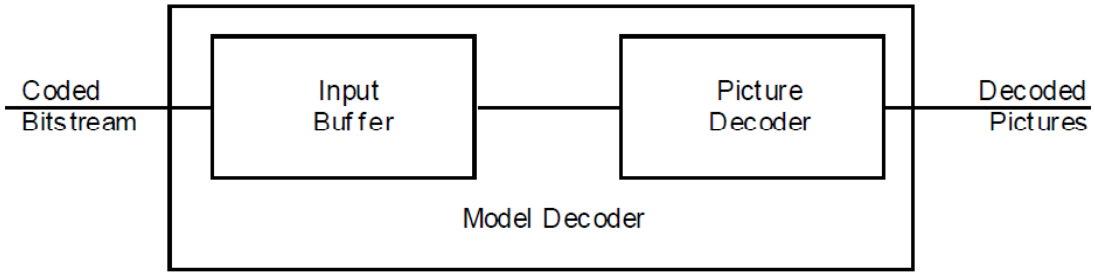
Picture type codes

Code	Picture type
000	forbidden
001	I-picture
010	P-picture
011	B-picture
100	D-picture
101	reserved
...	...
111	reserved

pD-24

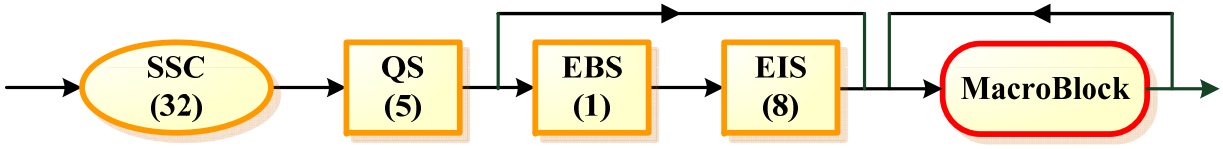
Buffer Size and Delay

- **vbv_delay**
  - This parameter defines the time needed to fill the Input Buffer from an empty state to the correct level immediately before the Picture Decoder removes all the bits for the picture.
  - This time is thus a delay and is measured in units of 1/90000 second.

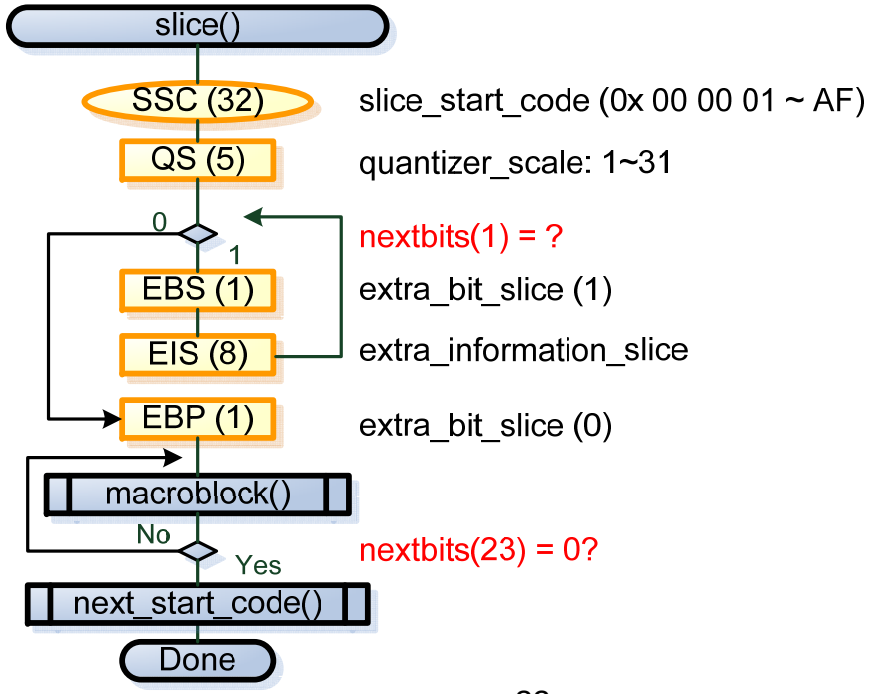


pD-13

Slice Layer

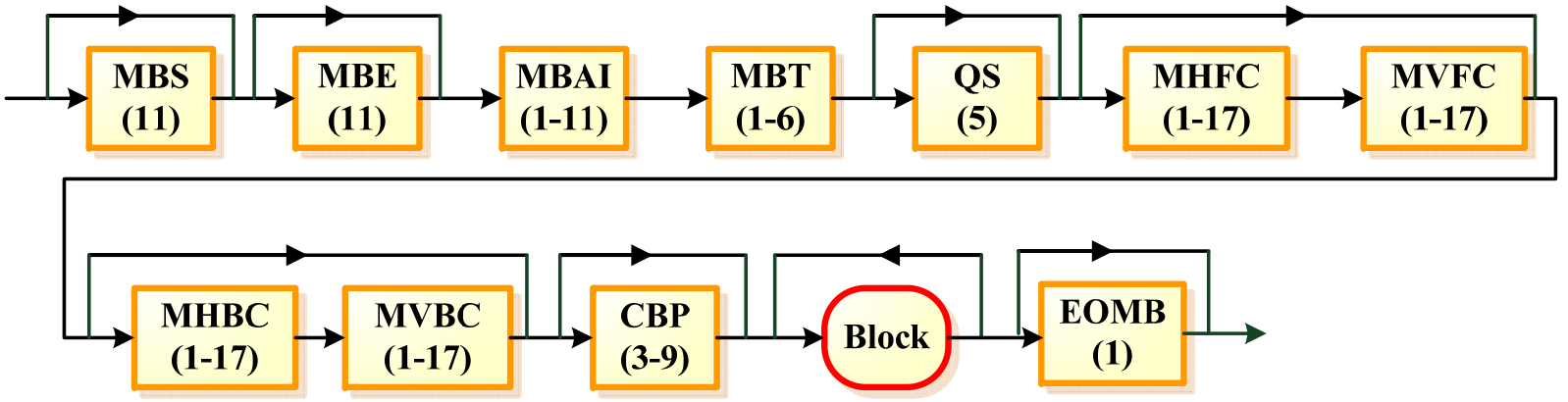


SSC: slice_start_code
QS: quantizer_scale
EBS: extra_bit_slice
EIS: extra_information_slice



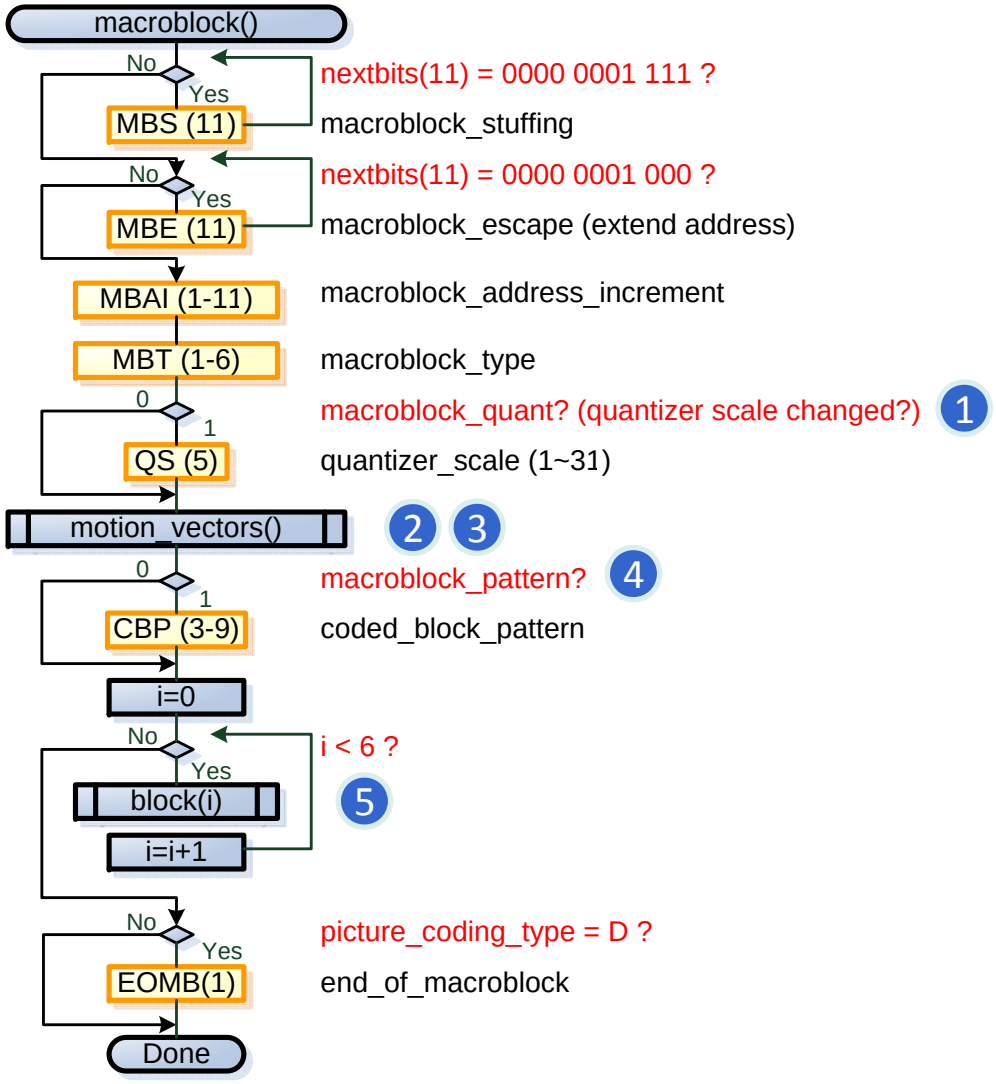
p32

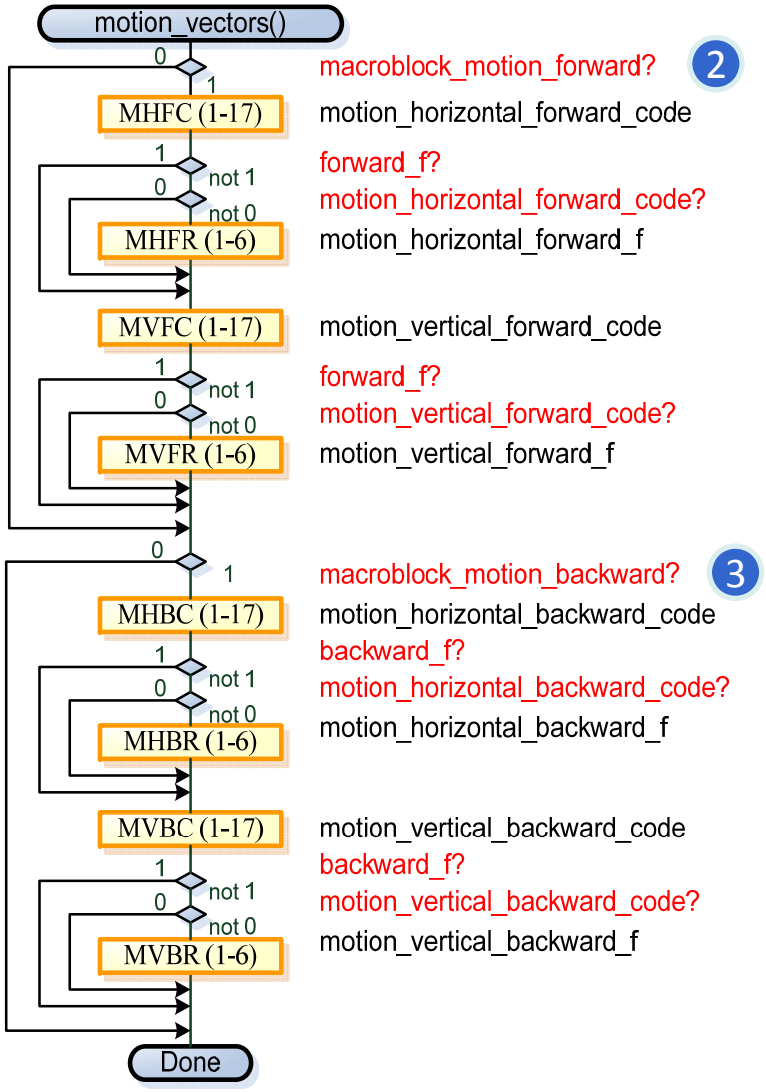
Macroblock Layer



MBS: macroblock_stuffing
MBE: macroblock_escape
MBAI: macroblock_address_increment
MBT: macroblock_type
QS: quantizer_scale
MHFC: motion_horizontal_forward_code
MVFC: motion_vertical_forward_code
MHBC: motion_horizontal_backward_code
MVBC: motion_vertical_backward_code
CBP: coded_block_pattern (pD-51~D-52)
EOMB: end_of_macroblock

Macroblock Layer





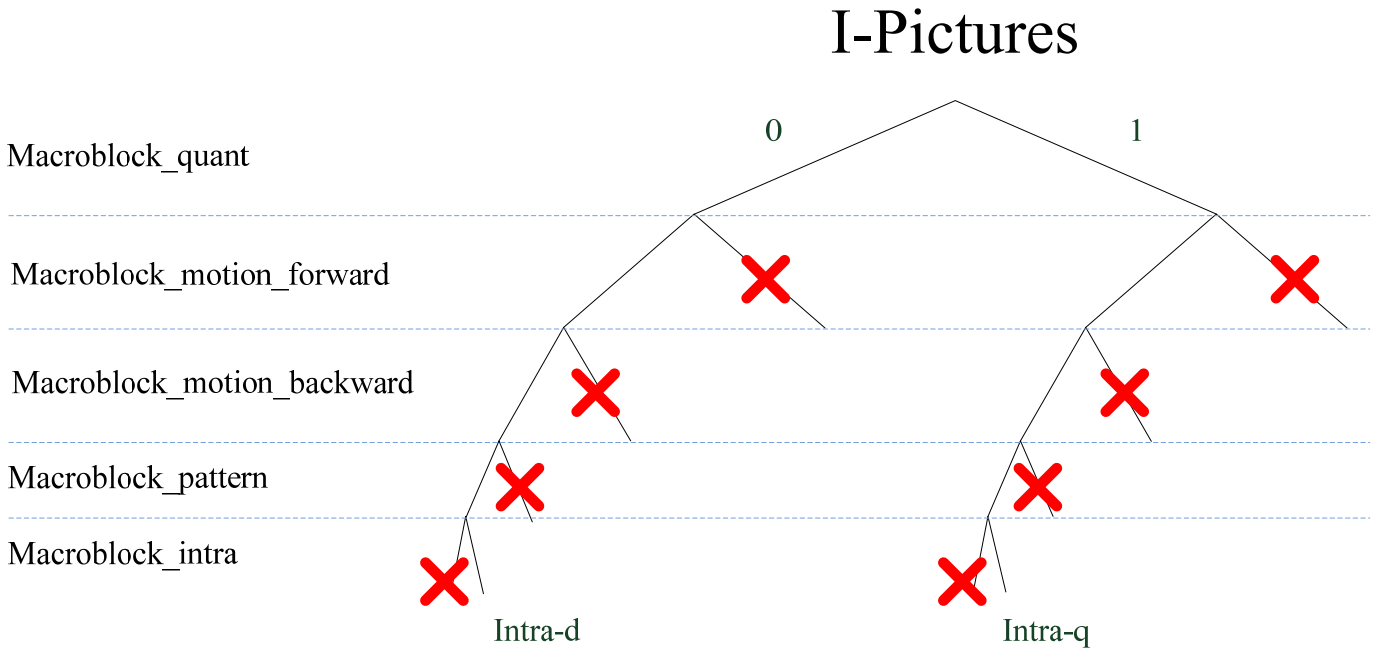
VLC for macroblock_type

	VLC code	macroblock_ quant	macroblock_ motion_ forward	macroblock motion_ backward	macroblock_ pattern	macroblock_ intra
I-pictures	1	0	0	0	0	1
	01	1	0	0	0	1
P-pictures	1	0	1	0	1	0
	01	0	0	0	1	0
	001	0	1	0	0	0
	00011	0	0	0	0	1
	00010	1	1	0	1	0
	00001	1	0	0	1	0
	000001	1	0	0	0	1
B-pictures	10	0	1	1	0	0
	11	0	1	1	1	0
	010	0	0	1	0	0
	011	0	0	1	1	0
	0010	0	1	0	0	0
	0011	0	1	0	1	0
	00011	0	0	0	0	1
	00010	1	1	1	1	0
	000011	1	1	0	1	0
	000010	1	0	1	1	0
	000001	1	0	0	0	1
D-pictures	1	0	0	0	0	1

1 2 3 4 5

pB-2

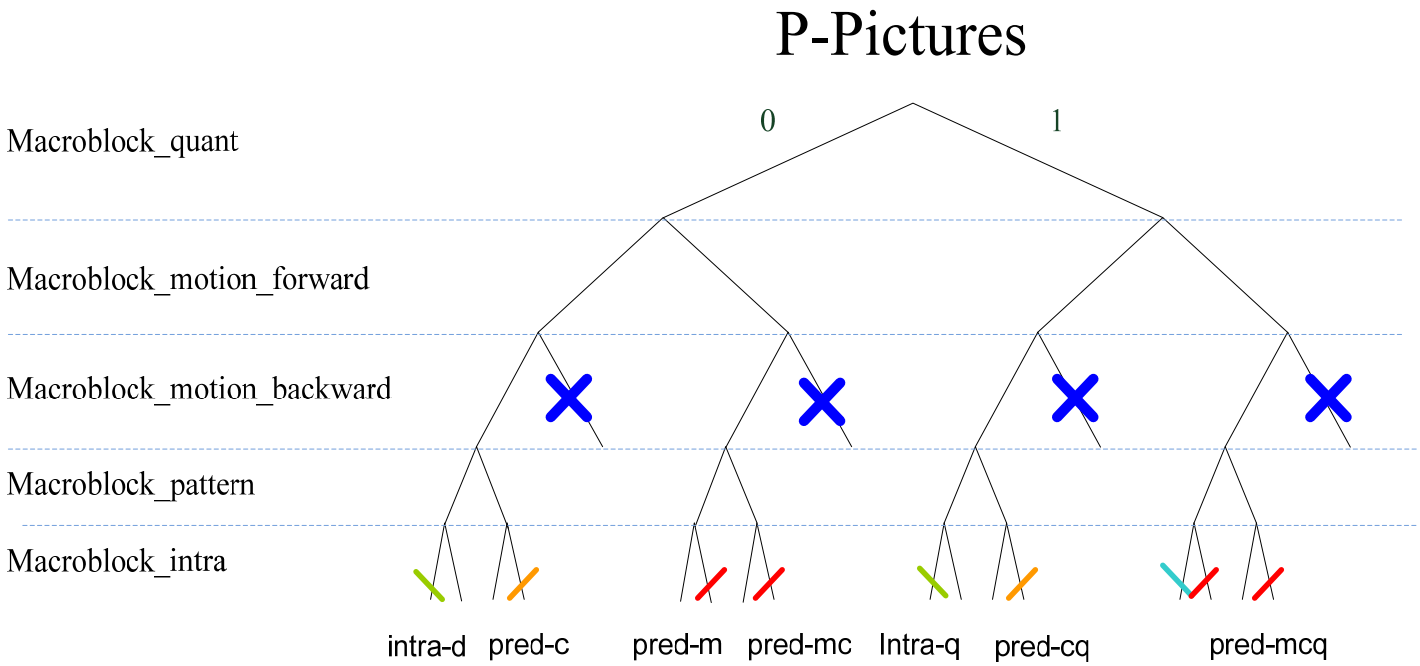
Macroblock Type in I-pictures



2 modes

Intra-d is the default type where the quantizer scale is not changed.
Intra-q sets the quantizer scale.

Macroblock Type in P-pictures

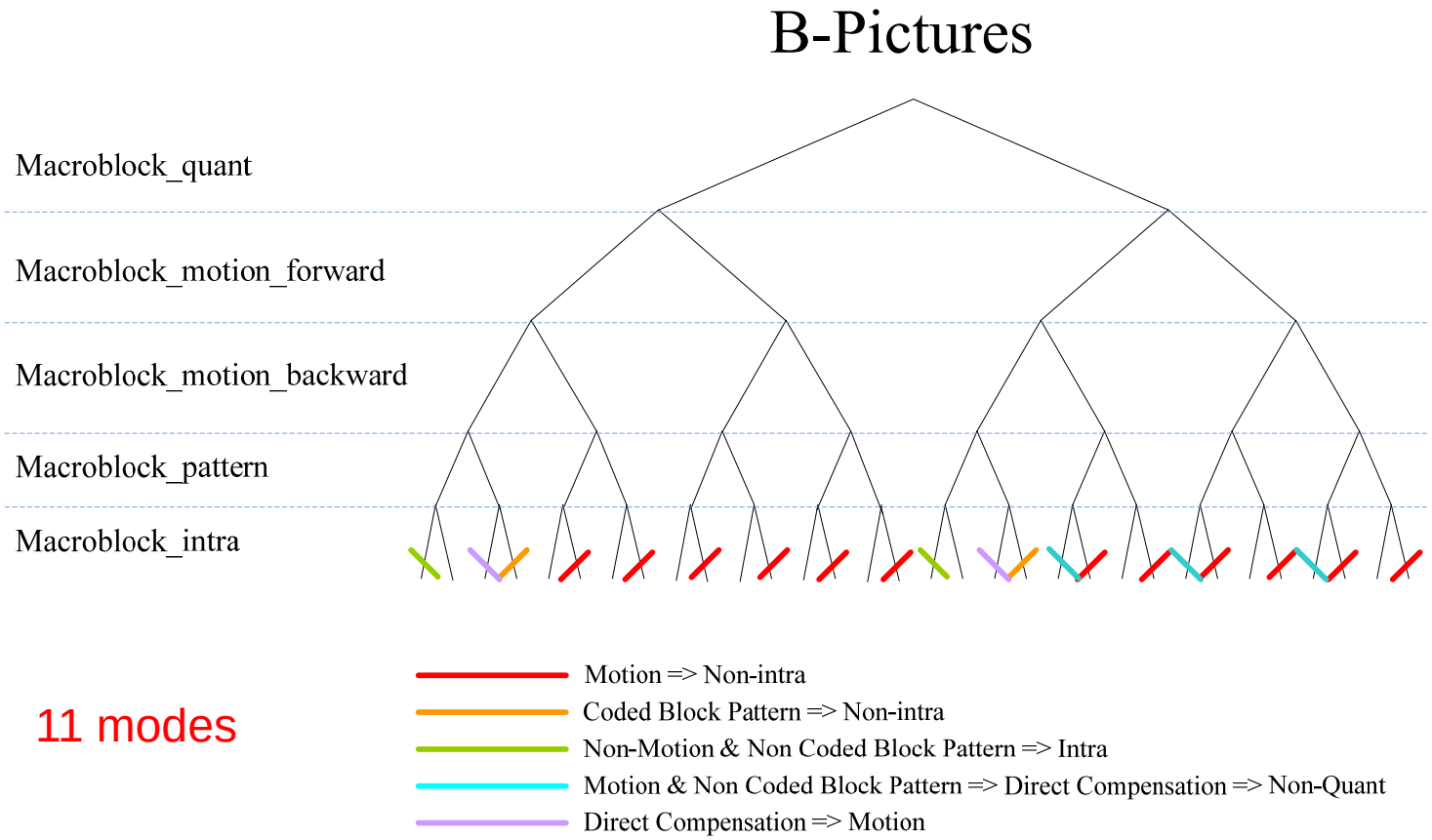


7 modes

- No Backward Motion
- Forward Motion => Non-intra
- Coded Block Pattern => Non-intra
- Non-Motion & Non Coded Block Pattern => Intra
- Motion & Non Coded Block Pattern => Direct Compensation => Non-Quant

pB-2

Macroblock Type in B-pictures



Macroblock Type in B-pictures

Type	VLC	Intra	M F	M B	Coded pattern	Quant
pred-i	10		1	1		
pred-ic	11		1	1	1	
pred-b	010			1		
pred-bc	011			1	1	
pred-f	0010		1			
pred-fc	0011		1		1	
intra-d	0001 1	1				
pred-icq	0001 0		1	1	1	1
pred-fcq	0000 11		1		1	1
pred-bcq	0000 10			1	1	1
intra-q	0000 01	1				1
skipped						

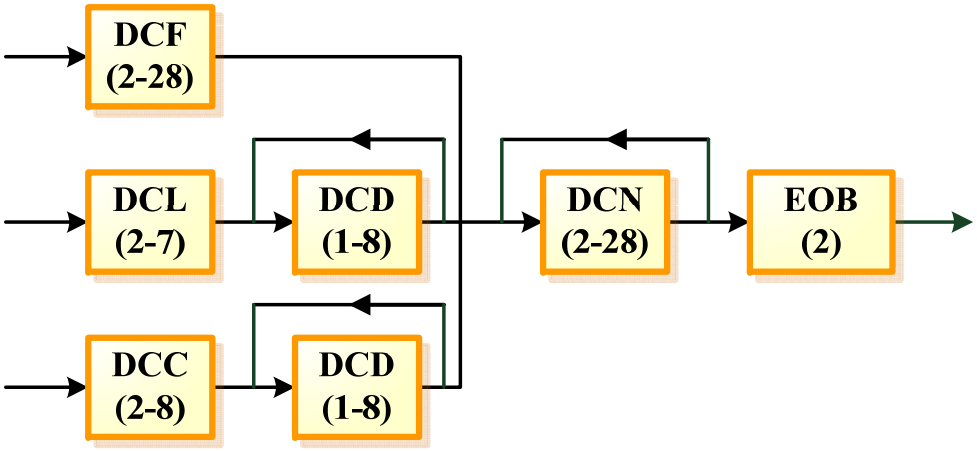
pD-58

- *VLC* - variable length code
- *M F* - motion forward
- *M B* - motion backward
- *pred* - predictive
- *m* - motion compensated
- *c* - at least one block in the macroblock is coded and transmitted
- *d* - default quantizer is used
- *q* - quantizer scale is changed
- *i* - interpolated. This is a combination of forward prediction and backward prediction.
- *b* - backward prediction
- *f* - forward prediction

Macroblock Skip

- In ***I-pictures***, all macroblocks are coded and there are no skipped macroblocks
- In ***P-pictures***, the skipped macroblock is defined to be a macroblock with a reconstructed motion vector equal to zero and no DCT coefficients.
- In ***B-pictures***, the skipped macroblock is defined to have the same macroblock type as the prior macroblock, differential motion vectors equal to zero (use the motion vector predictor as its motion vector), and no DCT coefficients.

Block Layer



DCF: dct_coeff_first
DCL: dct_dc_size_luminance
DCC: dct_dc_size_chrominance
DCD: dct_dc_differential
DCN: dct_coeff_next
EOB: end_of_block

Algorithm for Blocks Layer

```
block( i ) {  // from ISO 11172-2 2.4.2.8

    if ( pattern_code[i] ) {  // if i-th block coded
      if ( macroblock_intra ) {  // intra-coded macroblock in I, D, P or B
        if ( i<4 ) {  // luminance blocks
          dct_dc_size_luminance            // r/w VLC for Y size
          if(dct_dc_size_luminance != 0)   // if Y size not zero
            dct_dc_differential            // r/w size bits of diff. DC
          }
        else {  // chrominance blocks
          dct_dc_size_chrominance          // r/w VLC for Cb or Cr size
          if(dct_dc_size_chrominance !=0)  // if Cb or Cr size not zero
            dct_dc_differential            // r/w size bits of diff. DC
          }
        }
      else {  // inter-coded macroblock in P or B
        dct_coeff_first    // r/w VLC 1st run-level
        }
      if ( picture_coding_type != 4 ) {  // if not D-picture
        while ( nextbits() != '10')    // while not end-of-block
          dct_coeff_next    // r/w VLC next run-level → zigzag scan
        end_of_block        // r/w '01' EOB
        }
      }
  }  /* end block(i) function */
```

DC quantized coefficient coding

- **Example:**
  - Luminance DC change of 10 → 1101010

DIFFERENTIAL DC (absolute value)	SIZE	VLC CODE (luminance)	VLC CODE (chrominance)
0	0	100	00
1	1	00	01
2 to 3	2	01	10
4 to 7	3	101	110
8 to 15	4	110	1110
16 to 31	5	1110	1111 0
32 to 63	6	1111 0	1111 10
64 to 127	7	1111 10	1111 110
128 to 255	8	1111 110	1111 1110

Table 2-D.12. Differential DC size and VLC

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

Table 2-D.13. Differential DC additional code

8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

AC quantized coefficient coding

RUN-LENGTH	LEVEL
1	2
0	4
0	-3
3	-5
0	1
14	130
end	

RUN	VALUE	CODE	COMMENT
1	2	0001 100	
0	4	0000 1100	
0	-3	0010 11	
3	-5	0000 0100 0011 1111 1011	esc seq
0	1	110	
14	130	0000 0100 1110 0000 0000 1000 0010	esc seq
EOB		10	

Table 2-D.15

RUN	LEVEL	VLC CODE
EOB		10
0	1	1s IF FIRST COEFF
0	1	11s NOT FIRST COEFF
0	2	0100 s
0	3	0010 1s
0	4	0000 110s
0	5	0010 0110 s
0	6	0010 0001 s
0	7	0000 0010 10s
0	8	0000 0001 1101 s
0	9	0000 0001 1000 s
1	1	011s
1	2	0001 10s
1	3	0010 0101 s
1	4	0000 0011 00s
1	5	0000 0001 1011 s
1	6	0000 0000 1011 0s
30	1	0000 0000 0001 1100s
31	1	0000 0000 0001 1011s
ESCAPE	-	0000 01

Table 2-D.16

RUN-LENGTH	VLC CODE
0	0000 00
1	0000 01
2	0000 10
.	.
6	3 : 000011
63	1111 11

Table 2-D.17

LEVEL	VLC CODE
-256	FORBIDDEN
-255	1000 0000 0000 0001
-254	1000 0000 0000 0010
.	.
-129	1000 0000 0111 1111
-128	1000 0000 1000 0000
-127	1000 0001
-5 :	1111 1011
-1	1111 1111
0	FORBIDDEN
1	0000 0001
2	0000 0010
.	.
126	0111 1110
127	0111 1111
128	0000 0000 1000 0000
129	0000 0000 1000 0001
.	.
254	0000 0000 1111 1110
255	0000 0000 1111 1111

s = 0 for positive level
s = 1 for negative level

Motion Vector

- **Each macroblock has an associated motion vector.**
- **The vectors of adjacent macroblocks are highly correlated.**
  - The horizontal or vertical motion vector, MV, is predicted from the one of the preceding macroblock, PMV, in the slice. →only the difference, dMV, is coded.

$$dMV = MV - PMV$$

Motion Vector (cont.)

- **full_pel_forward_vector: 0,1**
- **forward_f_code: 1~7**
  - forward_r_size : 0~6

    forward_r_size = forward_f_code - 1
  - forward_f : 1, 2, 4, 8, 16, 32, 64.

    $forward\_f = 2^{forward\_r\_size} = 2^{forward\_f\_code - 1}$
- **motion_horizontal_forward_code: -16 ~ +16.**
- **motion_horizontal_forward_r**

dMV = motion_code x f – Sign(motion_code) x motion_r

$$Sign(\ ) \qquad Sign(x) \qquad \begin{matrix} = 1 & x > 0 \\ 0 & x == 0 \\ -1 & x < 0 \end{matrix}$$

Motion Vector Range

- **Range of motion_code: -16~16**

f_code	r_size	motion_r	f	Range [low, high]	
				full_pel=0	full_pel=1
1	0	0	1	[-8, 7.5]	[-16, 15]
2	1	0~1	2	[-16, 15.5]	[-32, 31]
3	2	0~3	4	[-32, 31.5]	[-64, 63]
4	3	0~7	8	[-64, 63.5]	[-128, 127]
5	4	0~15	16	[-128, 127.5]	[-256, 255]
6	5	0~31	32	[-256, 255.5]	[-512, 511]
7	6	0~63	64	[-512, 511.5]	[-1024, 1023]

pD-25, pD-37

Motion Vector Coding

- **Assume that a slice has the following vectors, expressed in the units set by the full pel flag**
  - 3 10 30 30 –14 –16 27 24
- **The initial prediction is zero, so the differential values are**
  - 3 7 20 0 –44 –2 43 –3
- **The differential values are reduced to the range –32 to 31 by adding or subtracting modulus 64 corresponding to the forward_f_code 2:**
  - 3 7 20 0 20 -2 -21 -3

forward_f_code	Modulus
1	32
2	64
3	128
4	256
5	512
6	1024
7	2048

pD-41

Motion Vector Coding (cont.)

dMV = motion_code x f – Sign(motion_code) x motion_r

3 = 2 x 2 - 1
7 = 4 x 2 - 1
20 = 10 x 2 - 0
0 = 0 x 2
- 2 = -1 x 2 + 0
-21 = -11 x 2 + 1
- 3 = -2 x 2 + 1

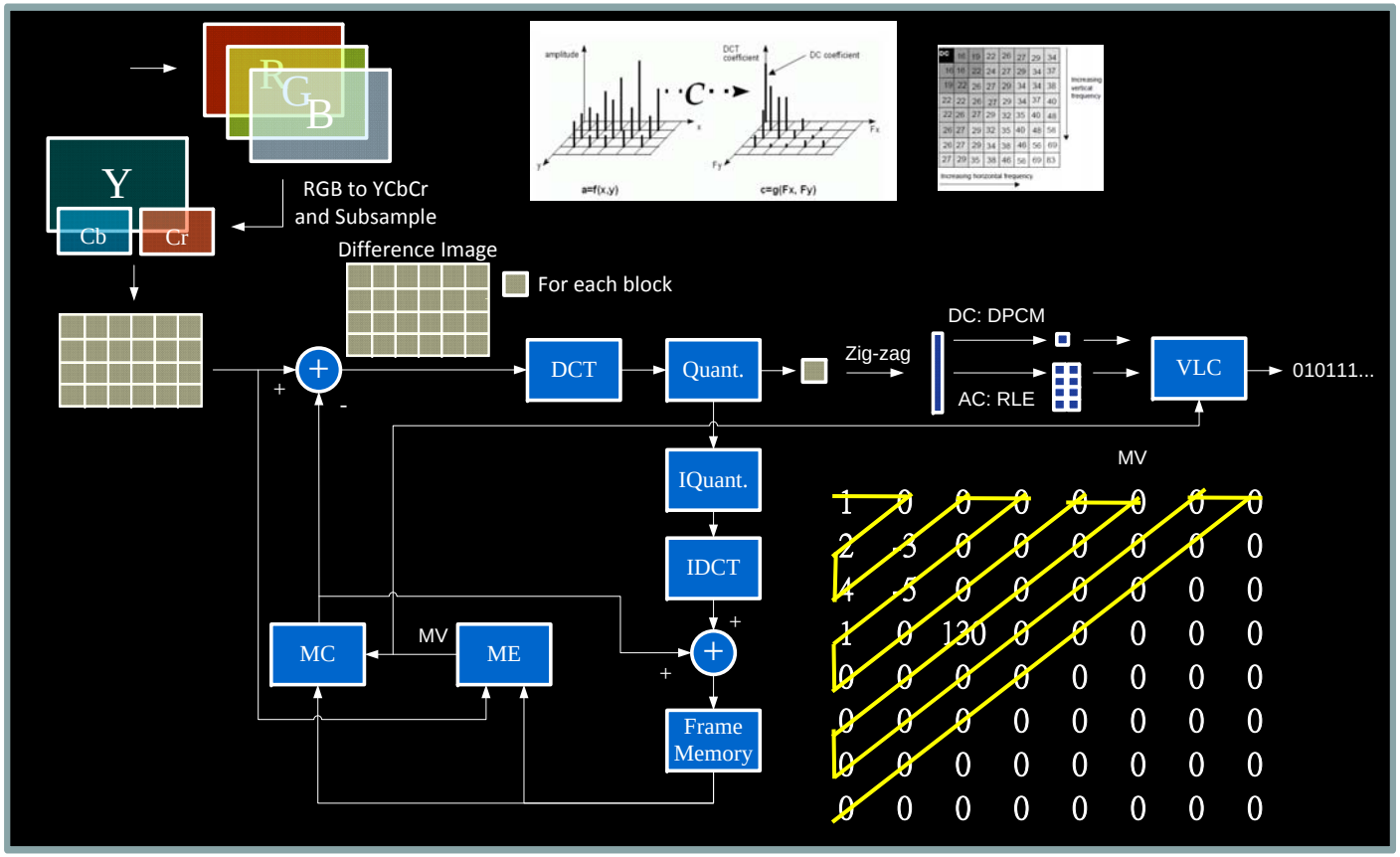
Value	VLC	Value	VLC
3	0010 0	20	0000 0100 101
7	0000 1100	-2	0111
20	0000 0100 101	-21	0000 0100 0110
0	1	-3	0011 0

code	VLC code
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

pD-40

s = 0 for positive value
s = 1 for negative value

Review of MPEG Compression



Predictive Coding:
Difference **P**ulse
Coded **M**odulation

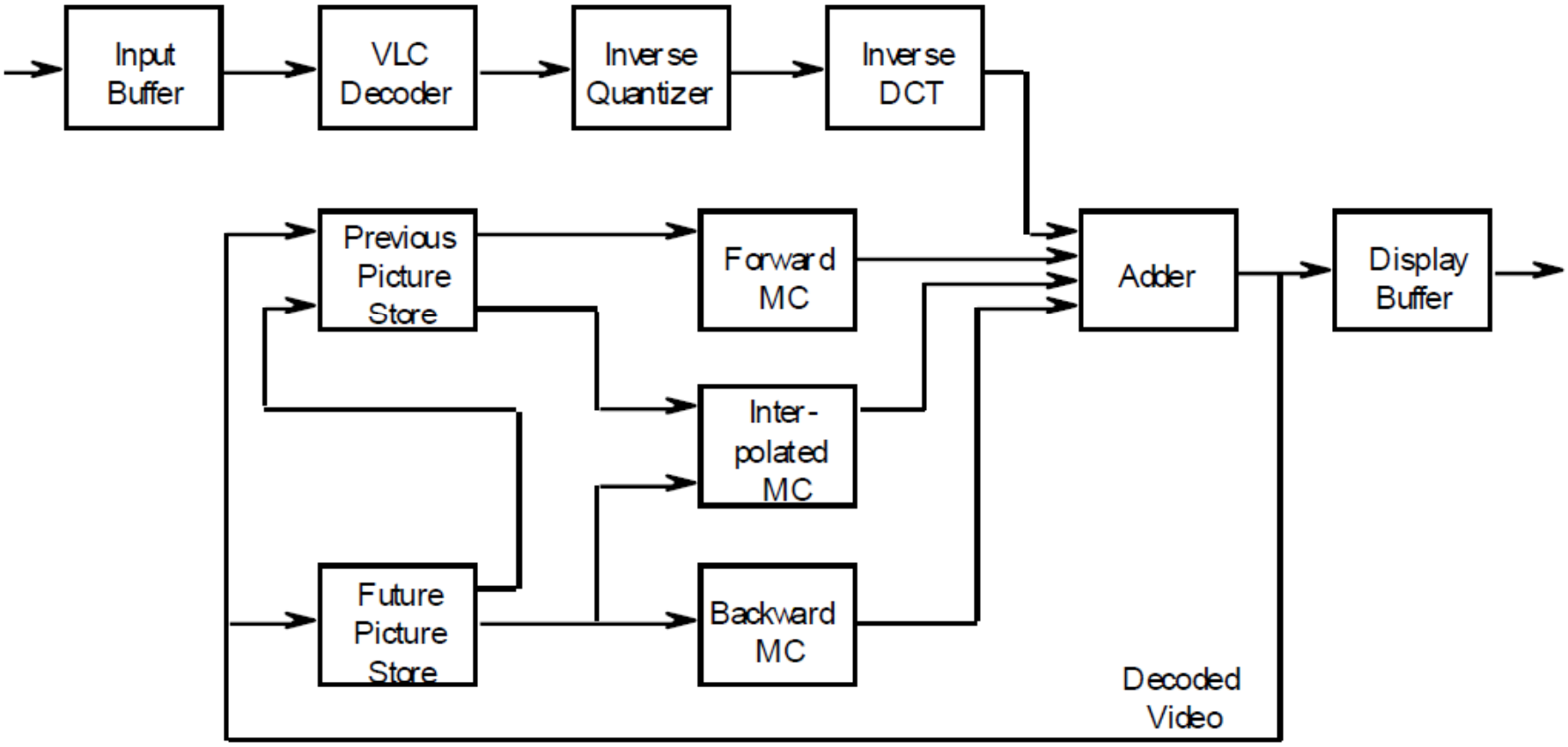
DC: 1,

AC: 0, 2, 4, -3, 0, 0, 0, -5, 1, 0,…, 0, 130, 0, …

(1,2) (0,4) (0,-3) (3,-5) (0,1) (14,130) EOB

Run Length Encoding

A block diagram of an MPEG-1 decoder



pD-7

Optimization

- **Optimization Issue**
  - InBitStream efficiency
  - VLC decoding efficiency
  - Fast IDCT
  - Efficient Motion Compensation
  - Use binary shift instead of *,/ operation.
  - YCbCr → RGB transform
- **You can use 3rd party codes, e.g., IDCT, to optimize your program.**

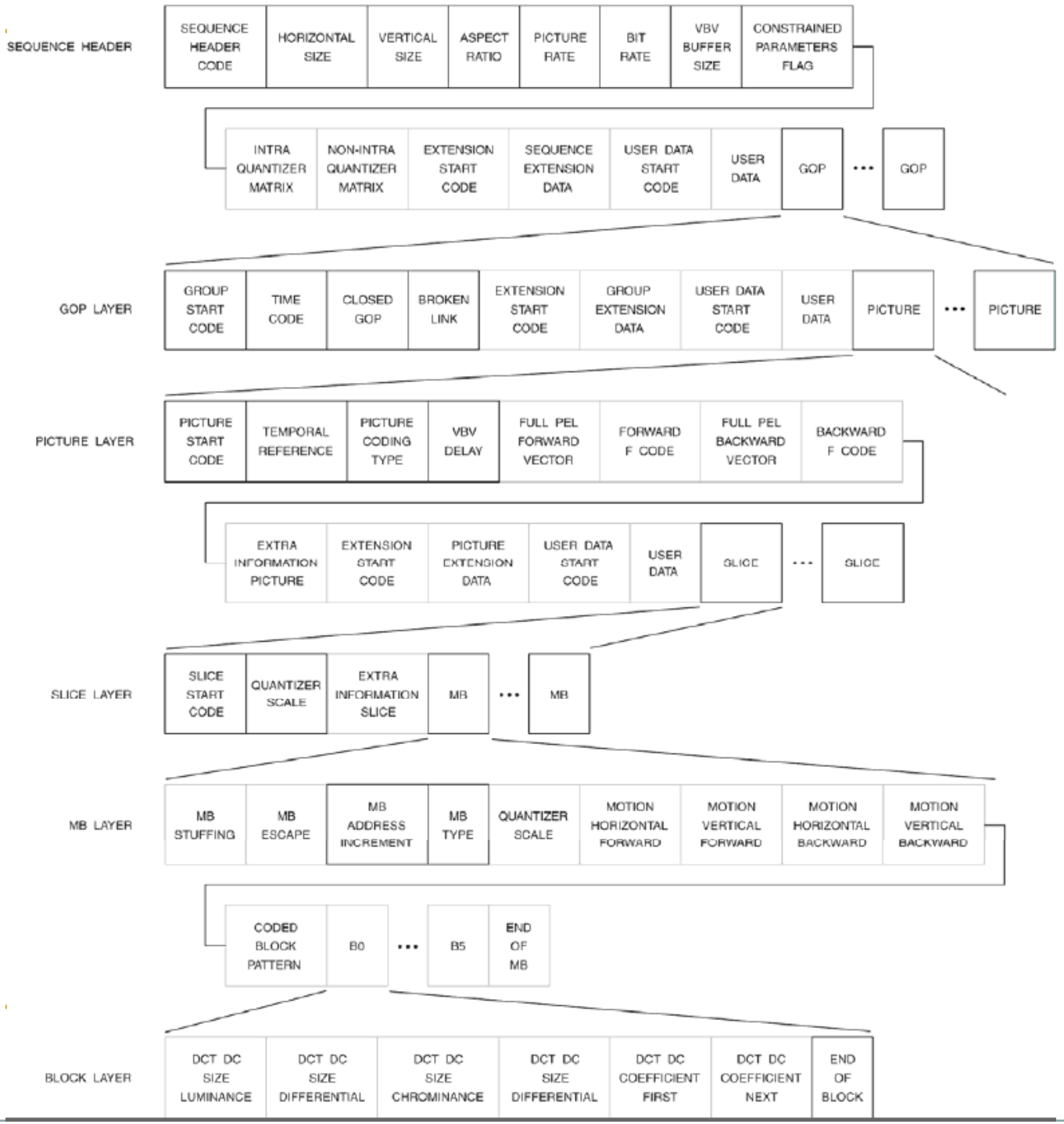
Summary

- **Step1:**
  - MPEG Syntax Parser
- **Step2:**
  - Basic MPEG-1 Decoder
- **Step3:**
  - Optimization

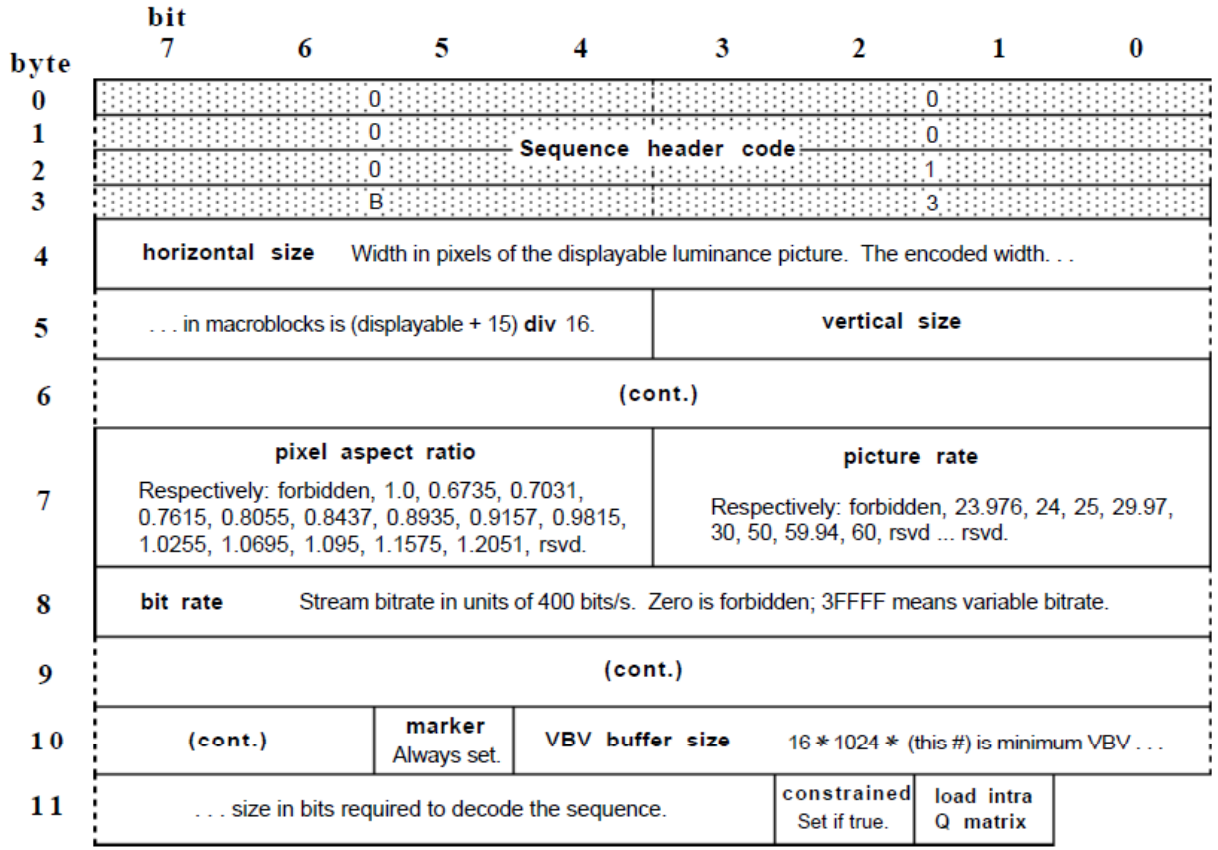
Grading

- **Basic requirement**
  - MPEG-1 I-Frame decoder with UI
- **P frame decodable / B frame decodable**
- **MPEG encoder**
- **Can read the file with audio/video and system mixed together (.mpg)**
- **VCR functionality**
  - random access, fast-forward/backward
- **Any practical improvement**

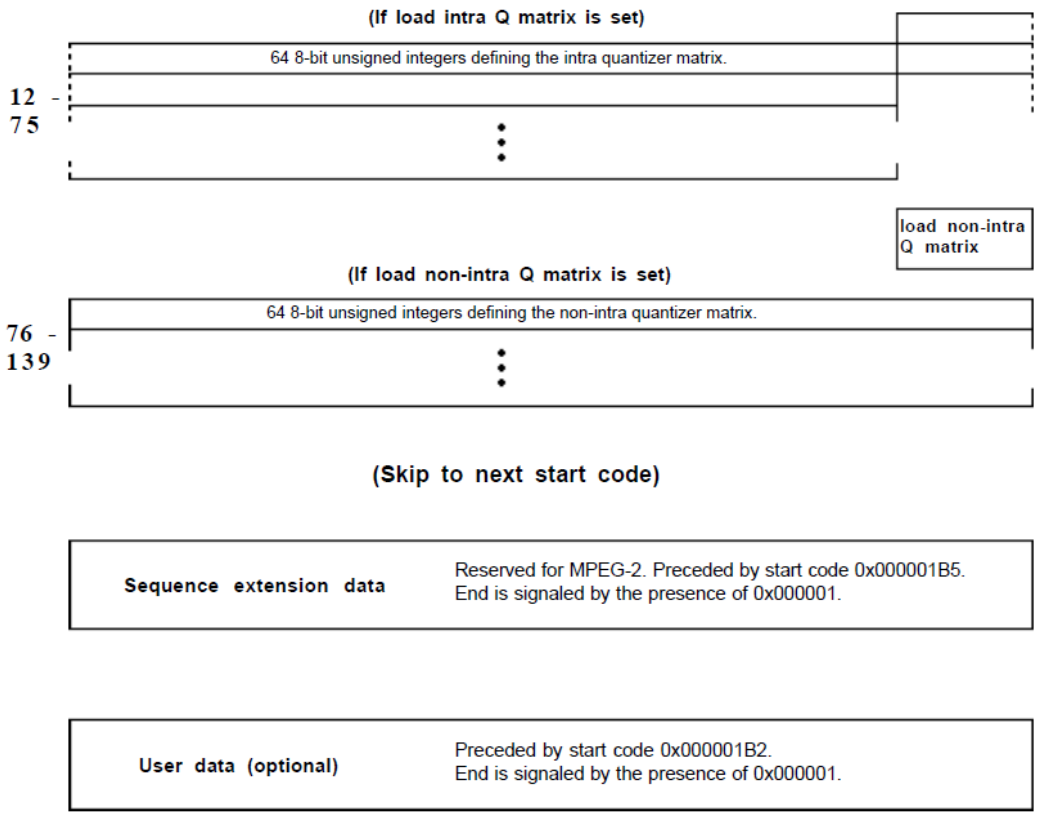
Some appendixes…


SEQUENCE HEADER
SEQUENCE HEADER CODE
HORIZONTAL SIZE
VERTICAL SIZE
ASPECT RATIO
PICTURE RATE
BIT RATE
VBV BUFFER SIZE
CONSTRAINED PARAMETERS FLAG
INTRA QUANTIZER MATRIX
NON-INTRA QUANTIZER MATRIX
EXTENSION START CODE
SEQUENCE EXTENSION DATA
USER DATA START CODE
USER DATA
GOP
GOP
GOP LAYER
GROUP START CODE
TIME CODE
CLOSED GOP
BROKEN LINK
EXTENSION START CODE
GROUP EXTENSION DATA
USER DATA START CODE
USER DATA
PICTURE
PICTURE
PICTURE LAYER
PICTURE START CODE
TEMPORAL REFERENCE
PICTURE CODING TYPE
VBV DELAY
FULL PEL FORWARD VECTOR
FORWARD F CODE
FULL PEL BACKWARD VECTOR
BACKWARD F CODE
EXTRA INFORMATION PICTURE
EXTENSION START CODE
PICTURE EXTENSION DATA
USER DATA START CODE
USER DATA
SLICE
SLICE
SLICE LAYER
SLICE START CODE
QUANTIZER SCALE
EXTRA INFORMATION SLICE
MB
MB
MB LAYER
MB STUFFING
MB ESCAPE
MB ADDRESS INCREMENT
MB TYPE
QUANTIZER SCALE
MOTION HORIZONTAL FORWARD
MOTION VERTICAL FORWARD
MOTION HORIZONTAL BACKWARD
MOTION VERTICAL BACKWARD
CODED BLOCK PATTERN
B0
B5
END OF MB
BLOCK LAYER
DCT DC SIZE LUMINANCE
DCT DC SIZE DIFFERENTIAL
DCT DC SIZE CHROMINANCE
DCT DC SIZE DIFFERENTIAL
DCT DC COEFFICIENT FIRST
DCT DC COEFFICIENT NEXT
END OF BLOCK

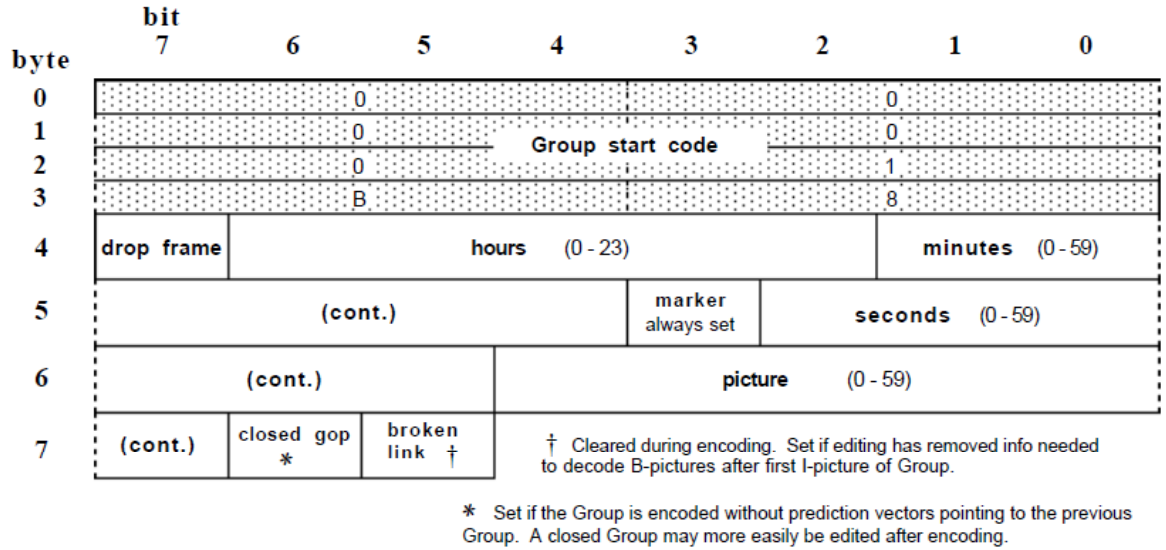
Video Sequence Header



Video Sequence Header (cont.)



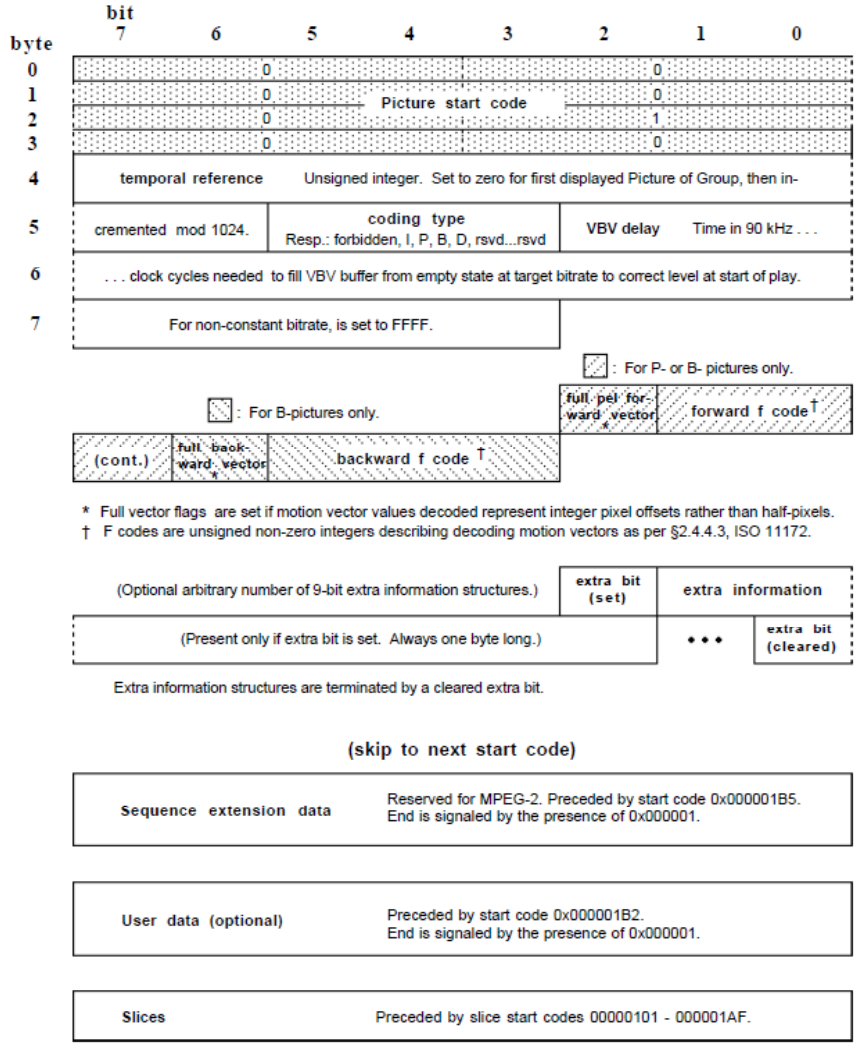
GOP Header



(skip to next start code)

Group extension data	Reserved for MPEG-2. Preceded by start code 0x000001B5. End is signaled by the presence of 0x000001.
User data (optional)	Preceded by start code 0x000001B2. End is signaled by the presence of 0x000001.
Pictures	Arbitrary number, preceded by Picture start code 0x00000100.

Picture Header



Slice Header