18-899 Special Topics in Signal Processing

Multimedia Communications:
Coding, Systems, and Networking

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Lecture 7

MPEG-2

MPEG-2

- Outline
  - Applications and history
  - Requirements
  - New features
  - Test Model 5
  - Bitstream syntax
  - Profiles and Levels
  - Scalability

MPEG-2 Video

- ISO/IEC 13818-2 (or ITU-T H.262)
- Broadcast TV, cable/satellite TV, HDTV, video services on networks (e.g., ATM)
- 4~9 Mbits/s, interlaced video, and scalable coding
- History
  - Late 1990: started
  - Nov 1991: competitive tests of video
  - Collaborative phase
  - Nov 1993: Committee Draft for video

Parts of MPEG-2

- Parts:
  - ISO/IEC 13818-1: Systems
  - ISO/IEC 13818-2: Video
  - ISO/IEC 13818-3: Audio
  - ISO/IEC 13818-4: Compliance Testing
  - ISO/IEC 13818-5: Software
  - ISO/IEC 13818-6: DSM-CC
  - ISO/IEC 13818-7: NBC Audio
  - ISO/IEC 13818-8: 10-Bit Video (dropped!)
  - ISO/IEC 13818-9: Real-Time Interface
  - ISO/IEC 13818-10: DSM-CC Conformance

Requirements

- ITU-R 601 interlaced video with high quality at 4~9 Mbits/s
- Random access/channel switching, seek and play in FF/FR using access points
- Allow video coding higher chroma resolution formats, e.g., 4:2:2 and 4:4:4
- Scalable video coding for multi-quality video applications
- System supporting audio-visual synchronized play/access for multiple streams
- Subset of the standard implementable as practical decoders

Additional Requirements

- Maximum interoperability/compatibility with MPEG-1
- Support coding of non-interlaced and interlaced formats of many frame rates
- Support video formats of various aspect ratios
- Low overhead syntax while supporting above requirements for overall efficiency
- Subset of the standard permits real-time encoder of reasonable complexity

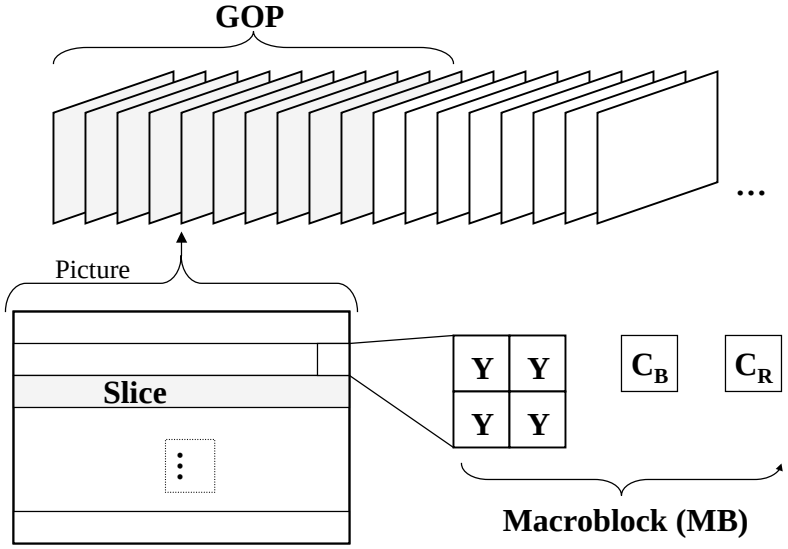
New Features

- Allows 4:2:2 and 4:4:4 formats
- Frame-pictures and field-pictures
- Frame/field adaptive DCT
- Frame/field/dual-prime adaptive motion compensation
- Alternate scan for DCT coefficients
- New VLC table for DCT coefficients
- Profiles and levels
- Nonlinear quantization table
  - Increased accuracy for small values

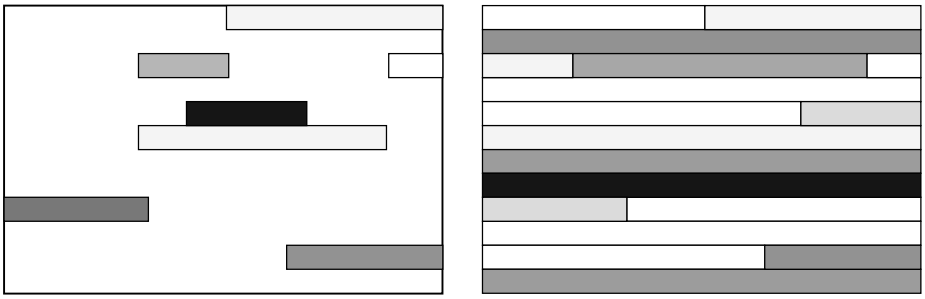
Additional New Features

- Chrominance samples horizontally co-sited as luminance samples
- Slices always start and end at the same row of macroblocks
- Concealment motion vectors for intra macroblocks
- Motion vectors always coded in half-pel units
- Display aspect ratio specified in bitstream
  - Pel aspect ratio derived from it
- IDCT mismatch control
- Coefficient VLC table escape format not allowed if use of shorter VLC possible

Slice and Macroblock



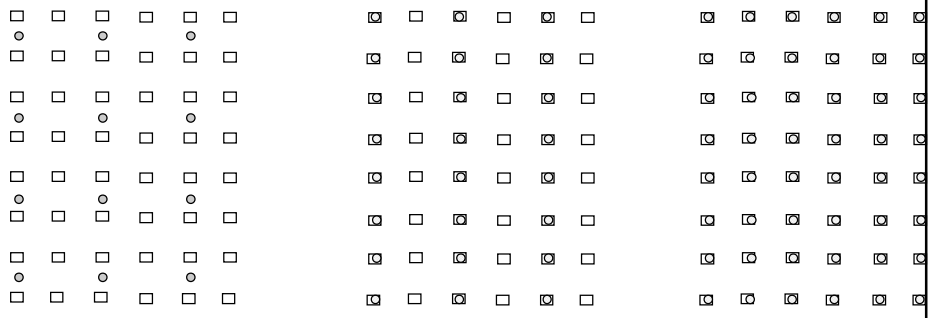
Slice Structure



general

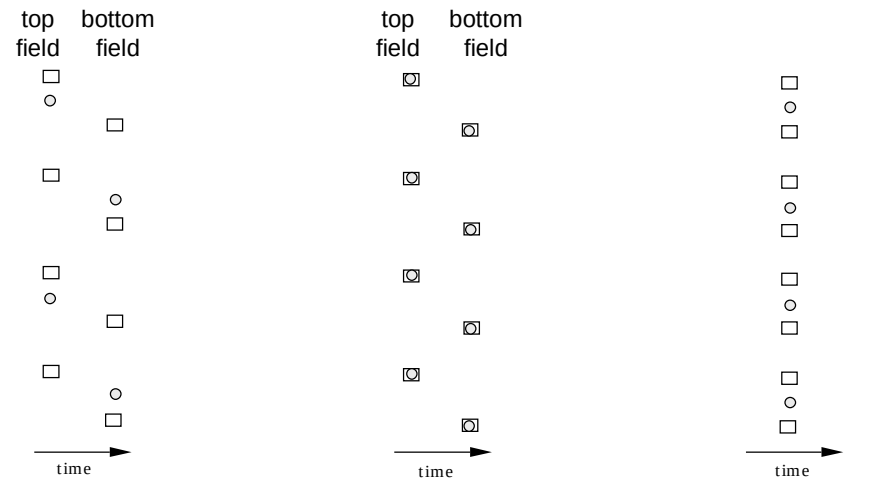
restricted

Chrominance Sampling



4:2:0 **4:2:2** **4:4:4**

Chrominance Sampling (cont.)

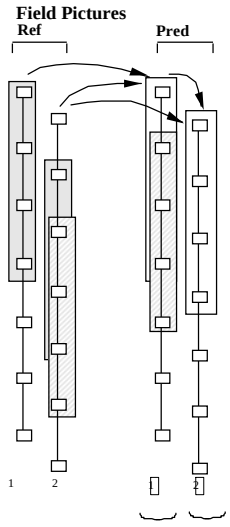


interlaced 4:2:0 interlaced 4:2:2/4:4:4 progressive

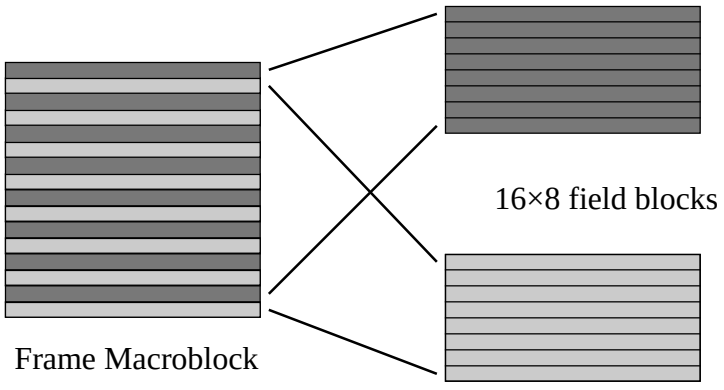
Coding of Interlaced Video

- Frame-pictures and field-pictures
- Motion compensation
  - Frame prediction for frame-pictures
    - Same as MPEG-1
  - Field prediction for field-pictures
  - Field prediction for frame-pictures
  - Dual-prime for P-pictures
    - field-pictures or frame-pictures
  - 16×8 MC for field pictures

Field Prediction for Field-Pictures

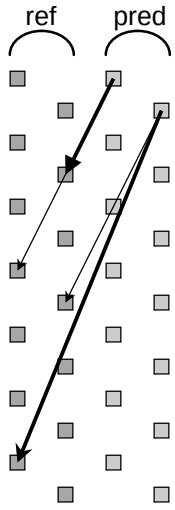


Field Prediction for Frame-Pictures



- 16×8 ME & MC
- Prediction from either field of the previous frame
- Good for fast motion

Dual-Prime Prediction



Performance

- PSNR at 4 Mbits/s
  - Frame-pictures, M=1

Sequence	Frame MC	Field MC	Frame/Field MC	Dualp MC	Frame/Field Dualp MC
Flowergarden	27.72	28.06 (+0.34)	28.22 (+0.50)	28.39 (+0.67)	29.38 (+1.66)
Mobile & Cal	25.69	25.86 (+0.17)	26.04 (+0.35)	25.51 (-0.18)	25.63 (-0.94)
Football	34.20	35.60 (+1.40)	35.69 (+1.49)	35.69 (+1.49)	36.04 (+1.84)
Bus	28.99	30.28 (+1.29)	30.43 (+1.44)	30.70 (+1.71)	31.31 (+2.32)
Carousel	28.67	29.97 (+1.30)	30.07 (+1.40)	29.99 (+1.32)	30.53 (+1.86)

  - Frame-pictures, M=3

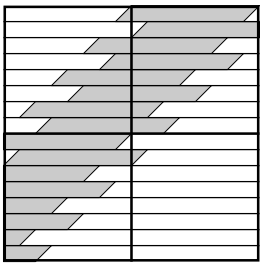
Sequence	Frame MC	Field MC	Frame/Field MC
Flowergarden	29.07	29.20 (+0.13)	29.63 (+0.56)
Mobile & Cal	28.11	27.86 (-0.25)	28.27 (+0.16)
Football	34.58	35.01 (+0.42)	35.12 (+0.53)
Bus	30.79	31.32 (+0.53)	31.60 (+0.81)
Carousel	29.82	29.54 (+0.32)	29.73 (+0.51)

  - Field-pictures, M=1

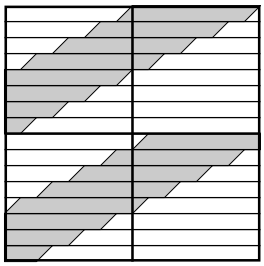
Sequence	Field MC	16x8 MC	Field/16x8 MC
Flowergarden	26.99	25.94 (-1.05)	27.18 (+0.19)
Mobile & Cal	25.02	23.61 (-1.41)	25.21 (+0.19)
Football	36.07	35.07 (-1.00)	35.89 (-0.18)
Bus	29.63	28.76 (-0.87)	29.83 (+0.20)
Carousel	29.37	28.54 (-1.01)	29.29 (+0.12)

Frame/Field Adaptive DCT

- Organize 16x16 block as frame blocks or filed blocks
- Compute correlation in vertical direction in each case
- Choose the case that has higher correlation



Frame blocks



Field blocks

Performance

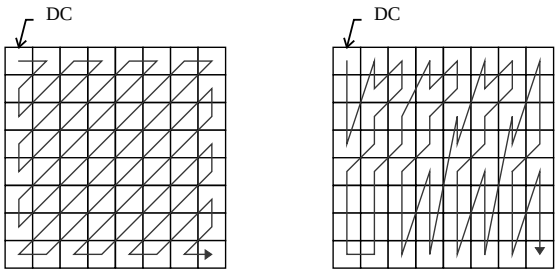
- PSNR at 4 Mbits/s
  - M=1

Sequence	Frame DCT	Field DCT	Frame/Field DCT
Flowergarden	29.36	29.04 (-0.32)	29.38 (+0.02)
Mobile & Cal	26.66	25.87 (-0.79)	26.63 (-0.03)
Football	35.54	35.95 (+0.41)	36.04 (+0.50)
Bus	31.05	31.00 (-0.05)	31.31 (+0.26)
Carousel	29.68	30.36 (+0.68)	30.53 (+0.85)

  - M=3

Sequence	Frame DCT	Field DCT	Frame/Field DCT
Flowergarden	29.61	29.46 (-0.15)	29.63 (+0.02)
Mobile & Cal	28.34	27.74 (-0.60)	28.27 (-0.07)
Football	34.67	35.04 (+0.37)	35.12 (+0.45)
Bus	31.34	31.41 (+0.07)	31.60 (+0.26)
Carousel	29.04	29.59 (+0.55)	29.73 (+0.69)

DCT Coefficients Scan



Zigzag scan inter DCT

Alternate scan intra DCT

Sequence	Zigzag Scan	Alternate Scan
Flowergarden	29.36	29.61 (+0.25)
Mobile & Cal	28.20	28.24 (+0.04)
Football	34.77	35.07 (+0.30)
Bus	31.35	31.57 (+0.22)
Carousel	29.57	29.68 (+0.11)

2D VLC (Inter)

2D VLC (Intra)

2D VLC (cont.)

- FLC table for runs and levels
  - Following the escape code of a VLC

FLC codeword	run
0000 00	0
0000 01	1
0000 10	2
…	…
…	…
…	…
…	…
…	…
1111 11	63

FLC codeword	signed_level
1000 0000 0000	reserved
1000 0000 0001	-2047
1000 0000 0010	-2046
…	…
1111 1111 1111	-1
0000 0000 0000	not allowed
0000 0000 0001	+1
…	…
0111 1111 1111	+2047

VLC for Differential DC

Range of Differential DC (DIFFs)	SIZE	SIZE VLC Luminance	SIZE VLC Chrominance	VLIs
-2047 to -1024	11	9*1	9*1 1	9*0 00 to 0 9*1 1
-1023 to -512	10	8*1 0	9*1 0	9*0 0 to 0 9*1
-511 to -256	9	7*1 0	8*1 0	9*0 to 0 8*1
-255 to -128	8	6*1 0	7*1 0	8*0 to 0 7*1
-127 to -64	7	5*1 0	6*1 0	7*0 to 0 6*1
-63 to -32	6	4*1 0	5*1 0	6*0to 0 5*1
-31 to -16	5	1110	4*1 0	5*0 to 0 4*1
-15 to -8	4	110	1110	4*0 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 4*1
16 to 31	5	1110	4*1 0	1 4*0 to 5*1
32 to 63	6	4*1 0	5*1 0	1 5*0 to 6*1
64 to 127	7	5*1 0	6*1 0	1 6*0 to 7*1
128 to 255	8	6*1 0	7*1 0	1 7*0 to 8*1
256 to 511	9	7*1 0	8*1 0	1 8*0 to 9*1
512 to 1023	10	8*1 0	9*1 0	1 9*0 to 9*1 1
1024 to 2048	11	9*1	9*1 1	1 9*0 0 to 9*1 11

Range larger then MPEG1

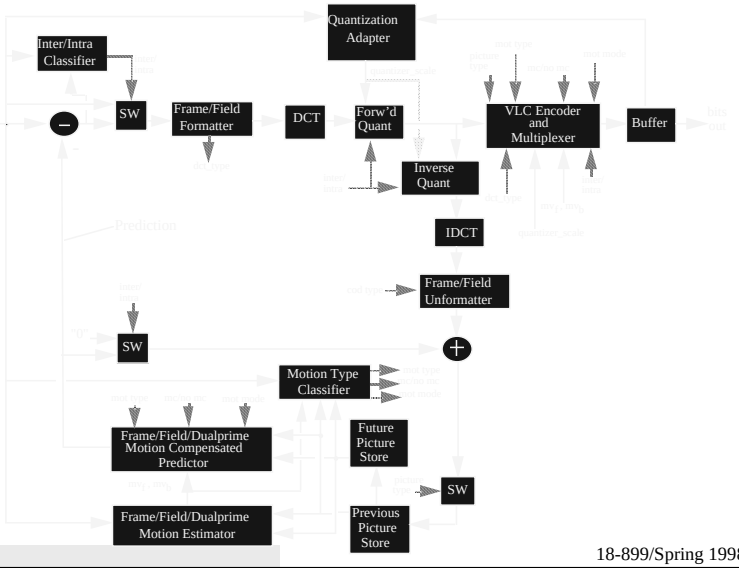
Test Model (TM) 5

- GOP with M=1 and 3
- Motion estimation
  - Frame/field/dual prime
  - Integer-pel full search followed by half-pel update
- Mode decision: MC/no MC, inter/intra
- Zigzag scan for inter; alternate scan for intra
- Quantization adaptation and rate control

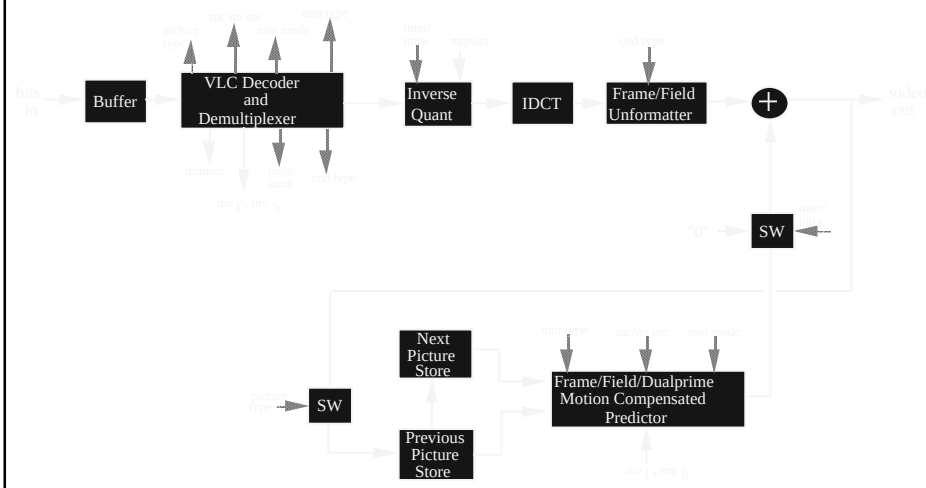
Motion Estimation

- Motion estimation on 16×16 luminance blocks
- Chrominance motion vectors by dividing luminance motion vectors and truncating
- Half-pel update on integer motion vectors
- –2048 to +2047.5 pels for half-pel motion vectors
- Depending on motion modes and types:
  - Frame motion vectors
  - Field motion vectors
  - Motion vectors in forward direction
  - Motion vectors in backward direction

Encoder

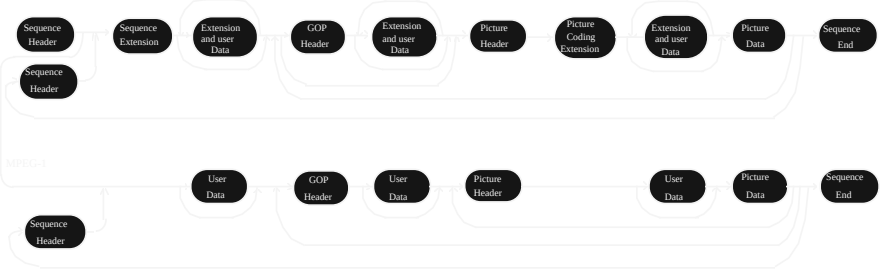


Decoder

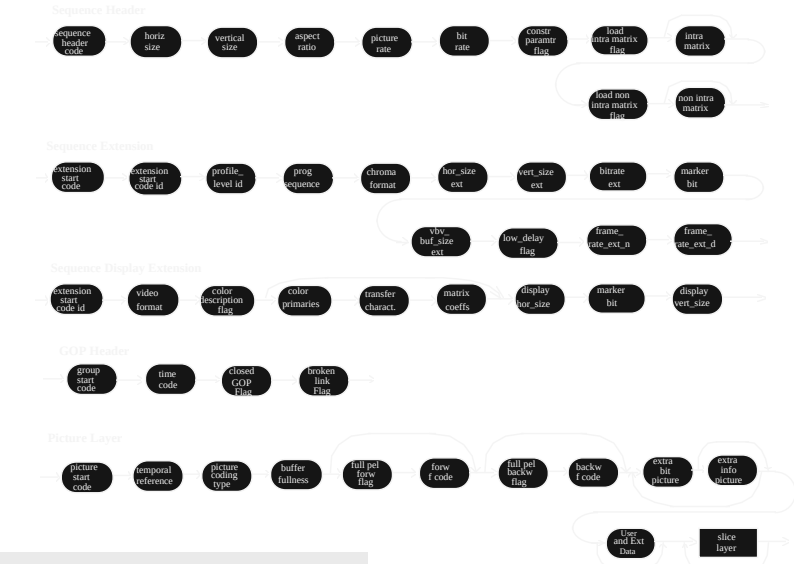


Syntax

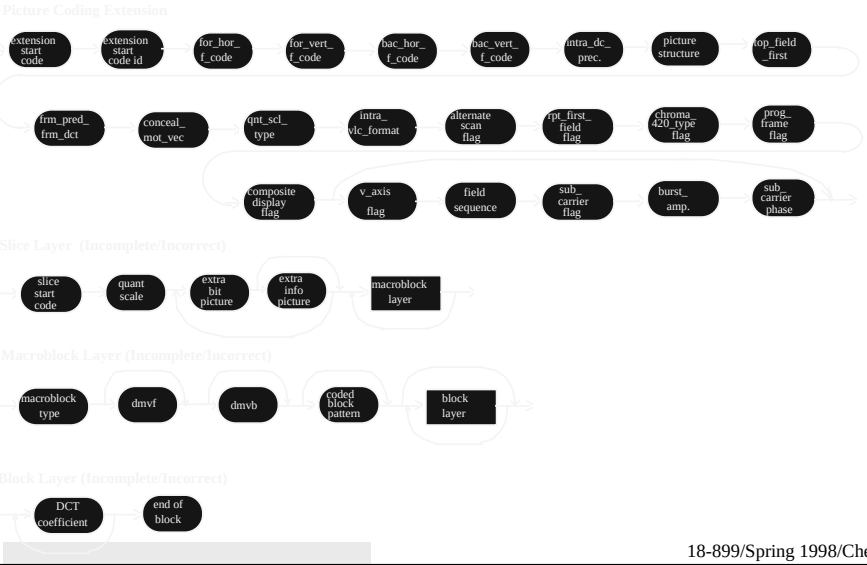
Syntax Header	Functionality
Sequence	Definition of Entire Video Sequence
Group of Pictures	Enables Random Access in Video Stream
Picture	Primary Coding Unit
Slice	Resyncrnization, Refresh and Errror Recovery
Macroblock	Motion Compensation Unit
Block	Transform and Compression Unit



Syntax (cont.)



Syntax (cont.)



Profiles and Levels

Level	SIMPLE	MAIN	SNR	SPATIAL	HIGH
HIGH		1920 pels/line 1152 lines/frame 60 frames/s 62.7 Msamples/s 80 Mbit/s			1920 pels/line 1152 lines/frame 60 frames/s 62.7 Msamples/s @ 83.5 Msamples/s * 100 Mbit/s for 3 layers
HIGH-1440		1440 pels/line 1152 lines/frame 60 frames/s 47.0 Msamples/s 60 Mbit/s		1440 pels/line 1152 lines/frame 60 frames/s 47.0 Msamples/s 60 Mbit/s for 3 layers	1440 pels/line 1152 lines/frame 60 frames/s 47.0 Msamples/s @ 62.7 Msamples/s * 80 Mbit/s for 3 layers
MAIN	720 pels/line 576 lines/frame 30 frames/s 10.4 Msample/s 15 Mbit/s	720 pels/line 576 lines/frame 30 frames/s 10.4 Msample/s 15 Mbit/s	720 pels/line 576 lines/frame 30 frames/s 10.4 Msample/s 15 Mbit/s for 2 layers		720 pels/line 576 lines/frame 30 frames/s 11.06 Msamples/s @ 14.75 Msamples/s * 20 Mbit/s for3 layers
LOW		352 pels/line 288 lines/frame 30 frames/s 3.04 Msamples/s 4 Mbit/s	352 pels/line 288 lines/frame 30 frames/s 3.04 Msamples/s 4 Mbit/s for 2 layers		
	nonscalable 4:2:0 (no B- pictures)	nonscalable 4:2:0	scalable 4:2:0	scalable 4:2:0	nonscalable 4:2:2 scalable 4:2:0/4:2:2 * refers to 4:2:0 @ refers to 4:2:2

Profile

Scalability Types

- Data Partitioning
- SNR Scalability
- Spatial Scalability
- Temporal Scalability
- Hybrid Scalability

Temporal Scalability

- Example 1
  - Picture structure for base layer with 2 B-frames. Enhancement layer uses either simple prediction or bi-directional prediction from the base layer.
  - Stereoscopic scalability
    - The base layer is the video for one eye. The enhancement layer is the video for the other eye
- Example 2
  - The base layer is a normal TV signal having 30 fps
  - The enhancement layer provides a compatible upgrade to 60 fps. Both progressive and interlaced 60 fps are possible

MPEG Average Quality

Bit Rate (Mbits/sec)	SIF-30 ~CVGA	CCIR 601 29.97 FPS ~VGA	HDTV 29.97 FPS	HDTV 60 FPS ~SVGA
1.1 Mbs	good	poor		
4.0 Mbs	excellent	good		
9.0 Mbs	excellent++	excellent		
18.0 Mbs		excellent++	good	good
28.0 Mbs			excellent	excellent

	SIF-30 ~CGA	CCIR 601 29.97 FPS ~VGA	HDTV 29.97 FPS	HDTV 60 FPS ~SVGA
Pels	352	704	1920	1280
Lines	240	480	1080	720
Uncompressed Bit Rates (Mbps)	30.4	121.5	745.7	663.6

References

- Joan L. Mitchell et al., *MPEG Video: Compression Standard*, Chapman & Hall, New York, NY
- Barry G. Haskell, Atul Puri, Arun N. Netravali, Sec 17.1, *Digital Video : An Introduction to MPEG-2*, Chapman & Hall, New York, NY