VIDEOTELEPHONY AND VIDEOCONFERENCE OVER ISDN

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Digital Video

Video versus Images

- **Still Image Services – No strong temporal requirements; no real-time notion.**
- **Video Services (moving images) – It is necessary to strictly follow critical delay requirements to provide a good illusion of motion; essential to provide real-time performance.**

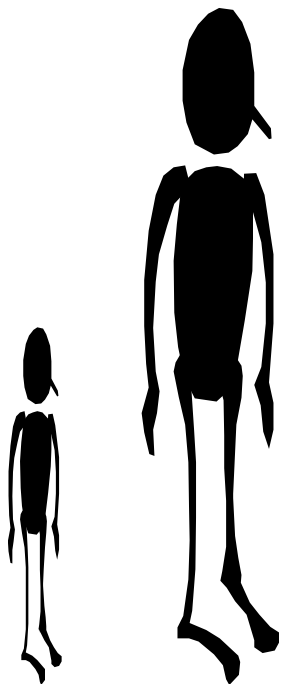
For each image and video service, it is possible to associate a quality target (quality of service); the first impact of this target is the selection of the right (PCM) spatial and temporal resolutions to use.

Why Does Video Information Have to be Compressed ?

A video sequence is created and consumed as a set of images, happening at a certain temporal rate (F), each of them with a spatial resolution of M×N luminance and chrominance samples and a certain number of bits per sample (L)

This means the total number of (PCM) bits

- and thus the required bandwidth and memory – necessary to digitally represent a video sequence is HUGE !!!



Videotelephony: Just an Example

- **Resolution: 10 images/s with 288×360 luminance samples and 144 × 188 samples (4:2:0) for each chrominance, with 8 bit/sample**

  $[(360 \times 288) + 2 \times (180 \times 144)] \times 8 \times 10 = 12.44$ Mbit/s

- **Reasonable bitrate: e.g. 64 kbit/s for an ISDN B channel**

=> Compression Factor: 12.44 Mbit/s/64 kbit/s ≈ 194

The usage or not of compression/source coding implies the possibility or not to deploy services and, thus, the existence or not of certain industries, e.g. DVD.

Digital Video: Why is it So Difficult ?

Service	Spatial resolution (lum, chrom)	Temporal resolution	Bit/sample	PCM bitrate
Full HD 1080p	1080 × 1920 1080 × 960	25 imagens/s progressivas	8 bit/amostra	830 Mbit/s
HD Ready 720p	720 × 1280 720 × 640	25 imagens/s progressivas	8 bit/amostra	370 Mbit/s
Standard TV, DVD	576 × 720 576 × 360	25 imagens/s entrelaçadas	8 bit/amostra	166 Mbit/s
Internet *streaming*	288 × 360 144 × 180	25 imagens/s progressivas	8 bit/amostra	31 Mbit/s
Mobile video	144 × 180 72 × 90	25 imagens/s progressivas	8 bit/amostra	7.8 Mbit/s
Music (stereo)	-	44000 amostras/s	16 bit/amostra	1.4 Mbit/s
Speech (GSM)	-	8000 amostras/s	8 bit/amostra	64 kbit/s

Video Coding/Compression: a Definition

Efficient representation (this means with a smaller than the PCM number of bits) of a periodic sequence of (correlated) images, satisfying the relevant requirements, e.g. minimum acceptable quality, low delay, error robustness, random access.

And the service requirements change with the services/applications and the corresponding funcionalities ...

How Big Has to be the Compression 'Hammer' ?

Service	Spatial resolution (lum, chrom)	Temporal resolution	Bit/sample	PCM bitrate	Compressed bitrate	Compression factor
Full HD 1080p	1080 × 1920 1080 × 960	25 imagens/s progressivas	8 bit/amostra	830 Mbit/s	8-10 Mbit/s	80-100
HD Ready 720p	720 × 1280 720 × 640	25 imagens/s progressivas	8 bit/amostra	370 Mbit/s	6-8 Mbit/s	60
Standard TV, DVD	576 × 720 576 × 360	25 imagens/s entrelaçadas	8 bit/amostra	166 Mbit/s	6 Mbit/s	27.5
Internet *streaming*	288 × 360 144 × 180	25 imagens/s progressivas	8 bit/amostra	31 Mbit/s	150 kbit/s	200
Mobile video	144 × 180 72 × 90	25 imagens/s progressivas	8 bit/amostra	7.8 Mbit/s	100 kbit/s	80
Music (stereo)	-	44000 amostras/s	16 bit/amostra	1.4 Mbit/s	100 kbit/s	14
Speech (GSM)	-	8000 amostras/s	8 bit/amostra	64 kbit/s	13 kbit/s	5

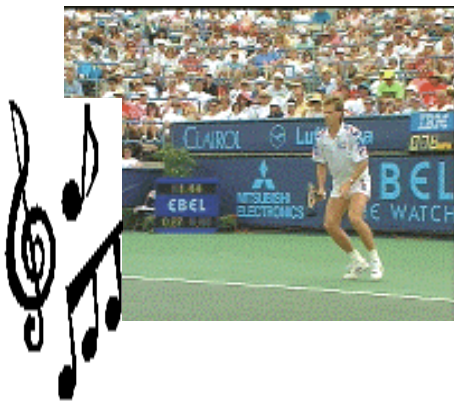
Interoperability as a Major Requirement: Standards to Assure that More is not Less ...

- **Compression is essential for digital audiovisual services where interoperability is a major requirement.**

- **Interoperability requires the specification and adoption of standards, notably audiovisual coding standards.**

- **To allow some evolution of the standards and some competition in the market between compatible products from different companies, standards must specify the minimum set of technology possible, typically the bitstream syntax and the decoding process (not the encoding process).**

Standards: a Trade-off between Fixing and Inovating

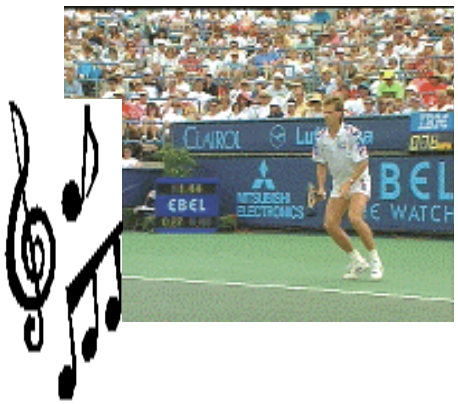


Normative !

Encoder

Bits !!!

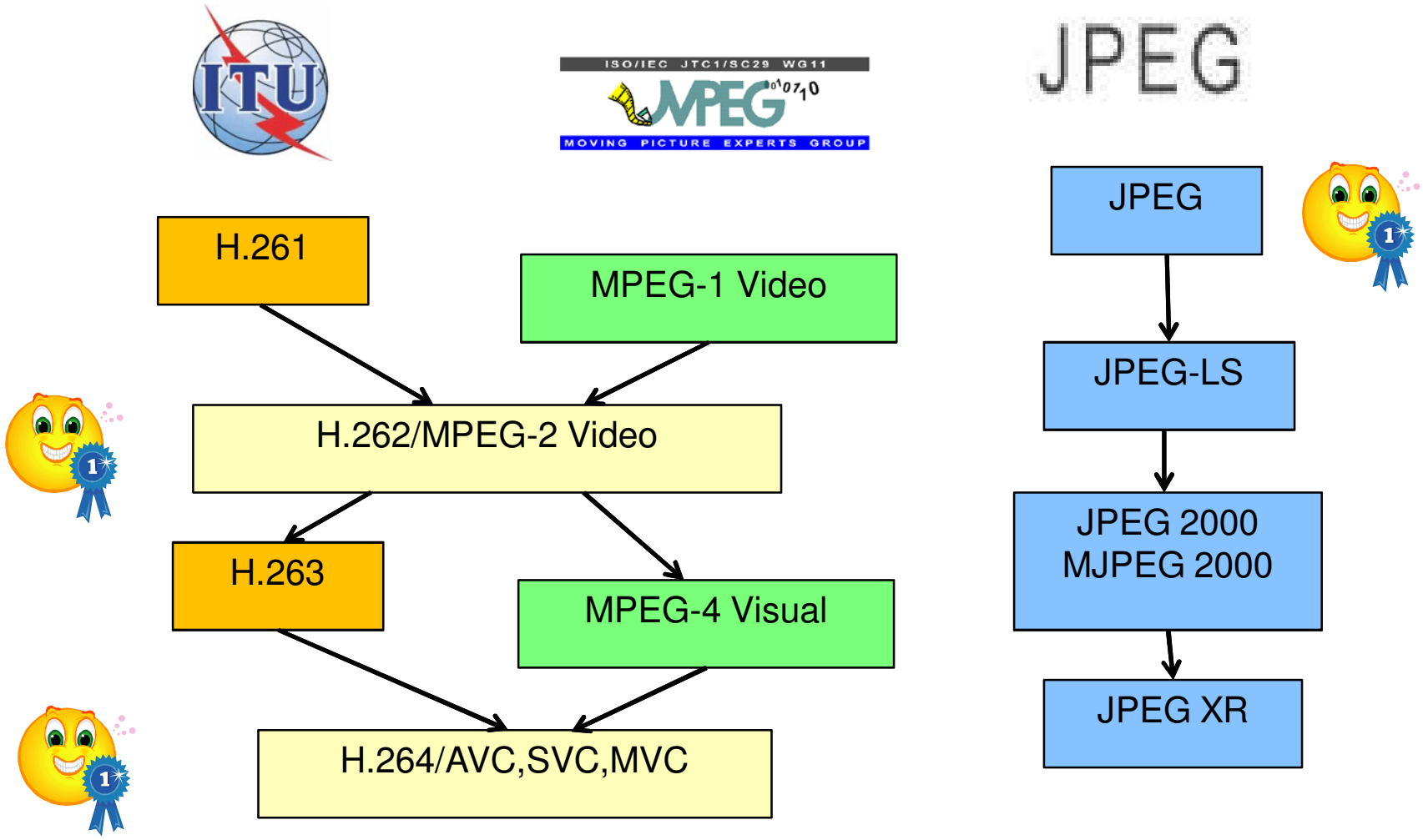
Decoder



Video Coding Standards …

- **ITU-T H.120 (1984) - Videoconference (1.5 - 2 Mbit/s)**
- **ITU-T H.261 (1988) – Audiovisual services (videotelephony and videoconference) at p×64kbit/s, p=1,…,30**
- **ISO/IEC MPEG-1 (1990)- CD-ROM Video**
- **ISO/IEC MPEG-2 also ITU-T H.262 (1993) – Digital TV**
- **ITU-T H.263 (1996) – PSTN and mobile video**
- **ISO/IEC MPEG-4 (1998) – Audiovisual objects, improved efficiency**
- **ISO/IEC MPEG-4 AVC also ITU-T H.264 (2003) – Improved efficiency**

The Video Coding Standardization Path …



ITU-T H.320 Terminals

Videotelephony and Videoconference

Videotelephony and Videoconference

Personal (bidirectional) communications in real-time ...





ITU-T H.320 Recommendation: Motivation

The starting of the work towards Rec. H.320 and H.261 goes back to 1984 when it was acknowledged that:

- **There was an increase in the demand for image-based services, notably videotelephony and videoconference.**
- **There was a growing availability of 64, 384 e 1536/1920 kbit/s digital lines as well as ISDN lines.**
- **There was a need to make available image-based services and terminals for the digital lines mentioned above.**
- **Rec. H.120, just issued at that time, for videoconference services, was already obsolete in terms of compression efficiency due to the fast development in the area of video compression.**

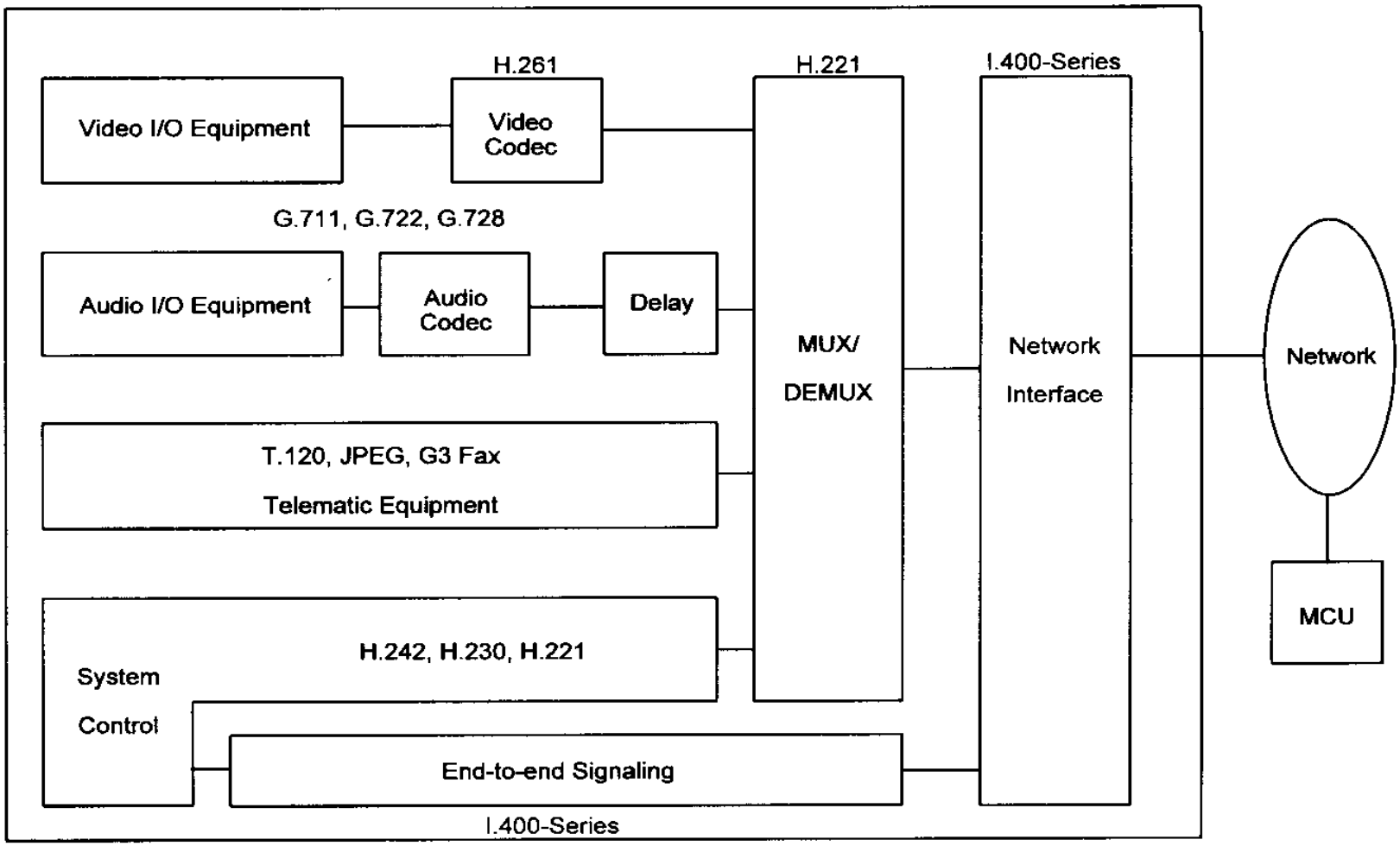
Basic ISDN Channels

- **B-Channel - 64 kbit/s – B-channel connections may be performed with circuit-switching, packet-switching or rented lines.**
- **D-Channel - 16 ou 64 kbit/s – D-channels have the main function to transport the signalling information associated to B-channels; in the idle periods, they may be used to transmit user data using packet-switching**
- **H-Channel - 384, 1536 ou 1920 kbit/s – Offer connections with higher bitrates.**

Videotelephony and Videoconference: Main Requirements/Features

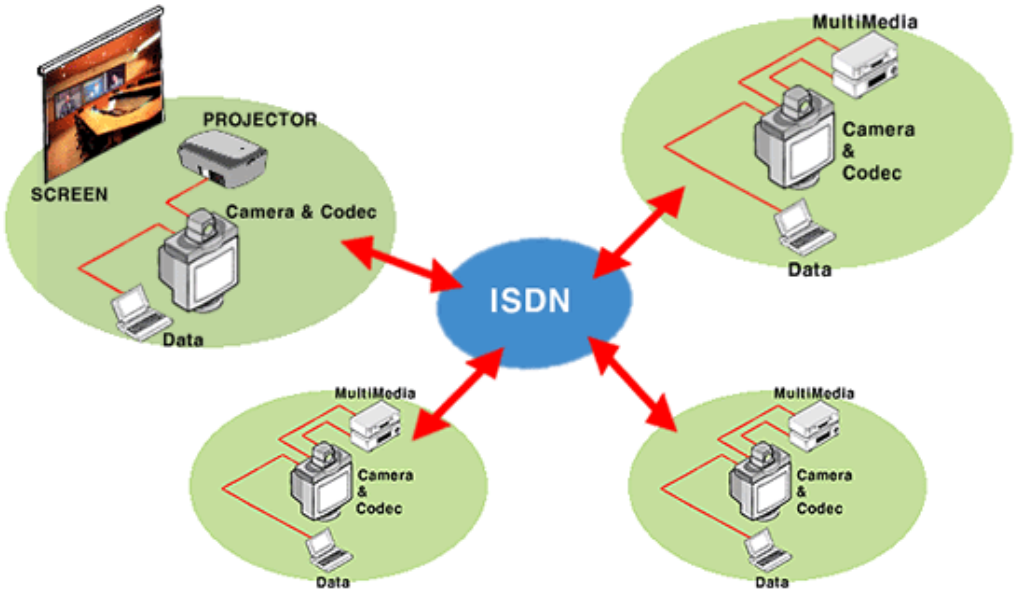
- Personal communications (point to point or multipoint to multipoint)
- Symmetric bidirectional communications (all nodes involved have the same similar features)
- Critical delay requirements
- Low or intermediate quality requirements
- Strong psychological and sociological impacts

Rec. H.320 Terminal



Video Coding: Rec. ITU-T H.261

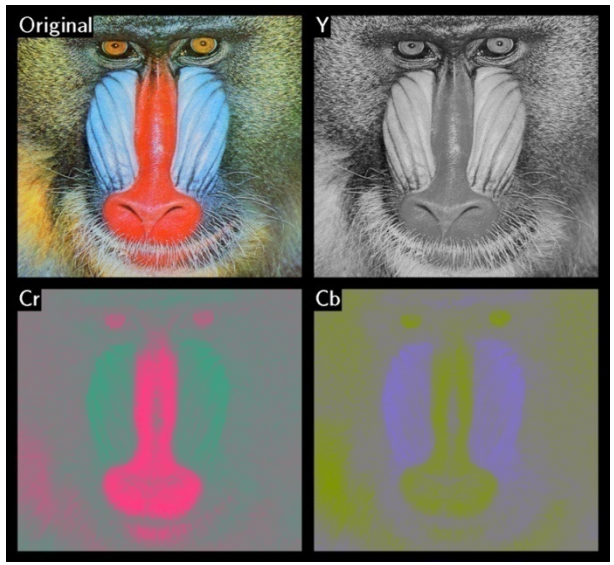
Recommendation H.261: Objectives



Efficient coding of videotelephony and videoconference sequences with a minimum acceptable quality using a bitrate from 40 kbit/s to 2 Mbit/s, targeting synchronous channels (ISDN) at p×64 kbit/s, with p=1,...,30.

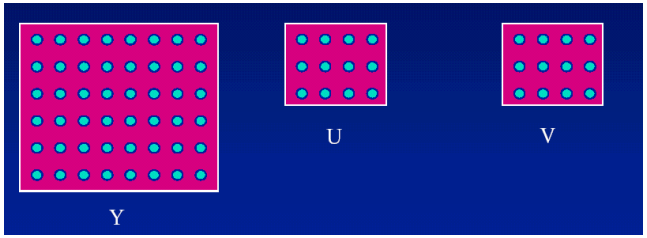
This is the first international video coding standard with relevant adoption, thus introducing the notion of backward compatibility in video coding standards.

H.261: Signals to Code



- The signals to code for each image are luminance (Y) and 2 chrominances, and C_R or U and V.
- The samples are quantized with 8 bits/sample, according to Rec. ITU-R BT-601:
  - Black = 16; White = 235; Null colour difference = 128
  - Peak colour difference (U,V) = 16 and 240
- The coding algorithm operates over progressive (non-interlaced) content at 29.97 image/s.
- The frame rate (temporal resolution) may be decreased by skipping 1, 2 or 3 images between each transmitted image.

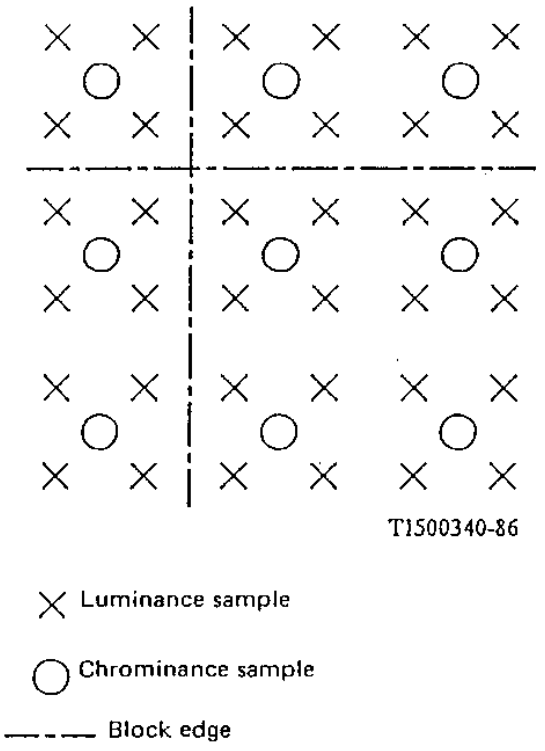
H.261: Image Format



Two spatial resolutions are possible:

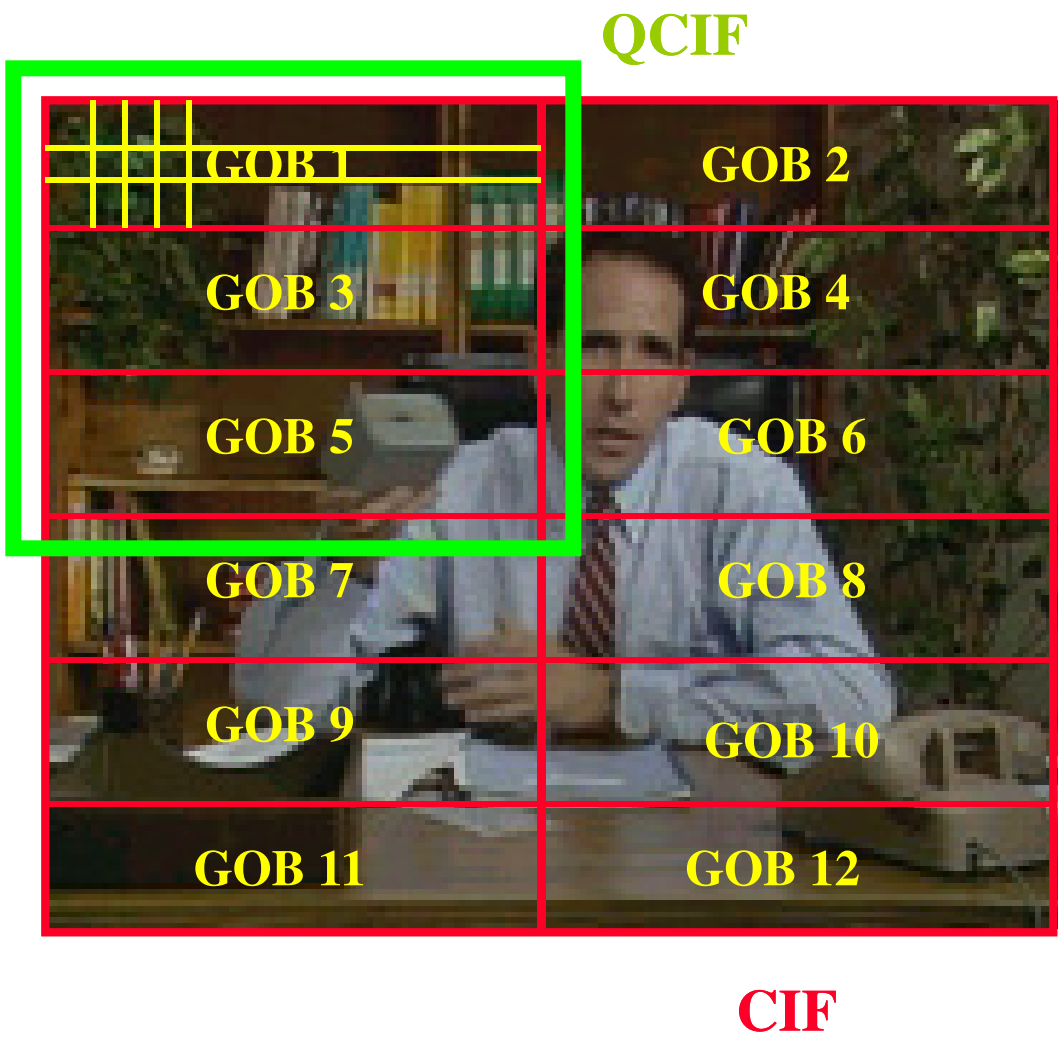
- **CIF (*Common Intermediate Format*) - 288 × 352 samples for luminance (Y) and 144 × 176 samples for each chrominance (U,V) this means a 4:2:0 subsampling format, with 'quincux' positioning, progressive, 30 frame/s with a 4/3 aspect ratio.**

- **QCIF (*Quarter CIF*) – Similar to CIF with half spatial resolution in both directions this means 144 × 176 samples for luminance and 72 × 88 samples for each chrominance.**



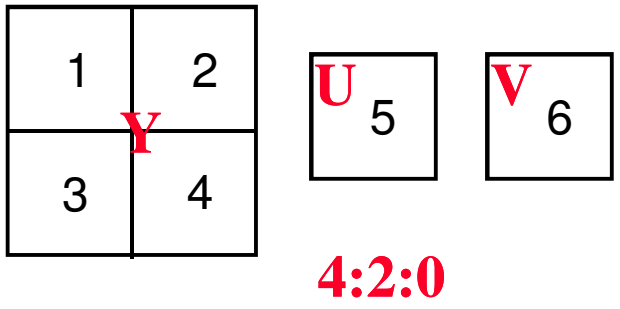
All H.261 codecs must work with QCIF and some may be able to work also with CIF (resolution is set after negotiation).

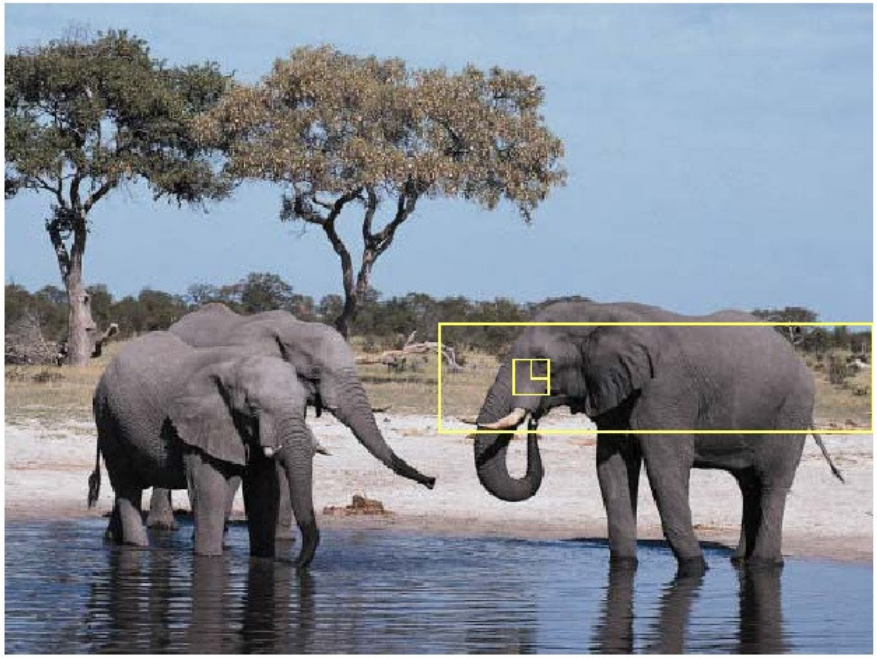
Images, Groups Of Blocks (GOBs), Macroblocks and Blocks



The video sequence is spatially organized according to a hierarchical structure with 4 levels:

- Images
- Group of Blocks (GOB)
- Macroblocks (MB)
- Blocks



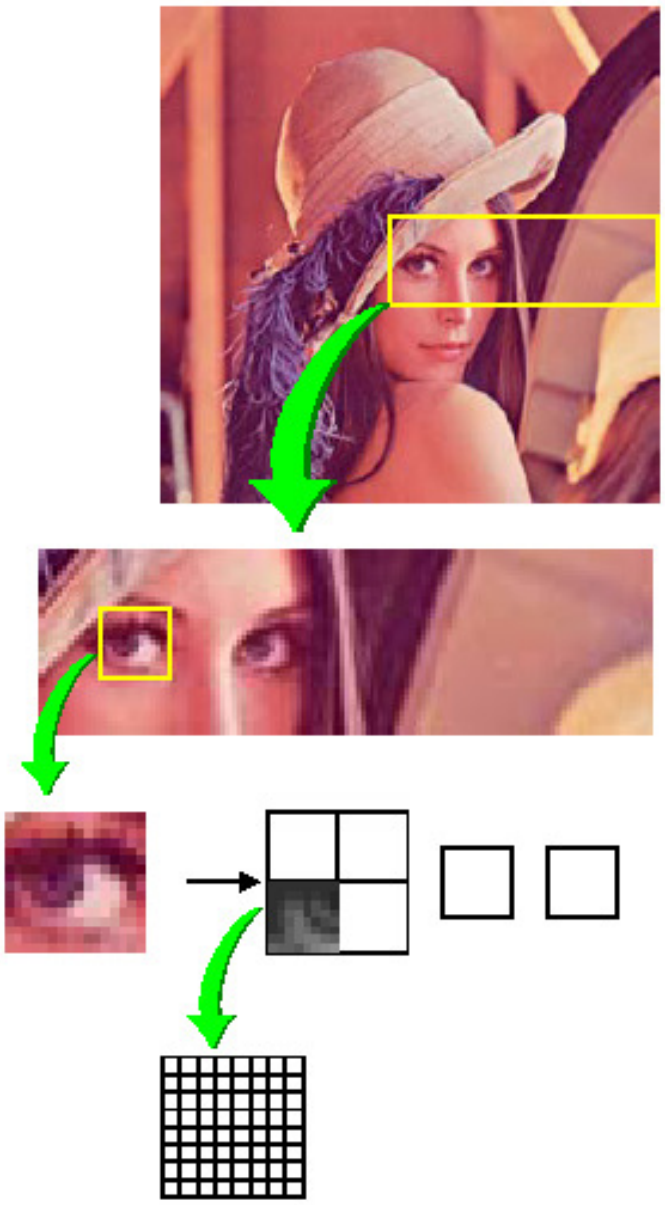


Picture

GOB

Macroblock

Block



H.261: Coding Tools

- **Temporal Redundancy**

  Predictive coding: temporal differences

  and differences after motion compensation

- **Spatial Redundancy**

  Transform coding (Discrete Cosine Transform, DCT)

- **Statistical Redundancy**

  Huffman entropy coding

- **Irrelevancy**

  Quantization of DCT coefficients

Exploiting

Temporal Redundancy

Temporal Prediction and Prediction Error

- **Temporal prediction is based on the principle that, locally, each image may be represented using as reference a part of some preceding image, typically the previous one.**
- **The prediction quality strongly determines the compression performance since it defines the amount of information to code and transmit, this means the energy of the error/difference signal called *prediction error*.**
- **The lower is the prediction error, the lower is the information/energy to transmit and thus**
  - Better quality may be achieved for a certain available bitrate
  - Lower bitrate is needed to achieve a certain video quality

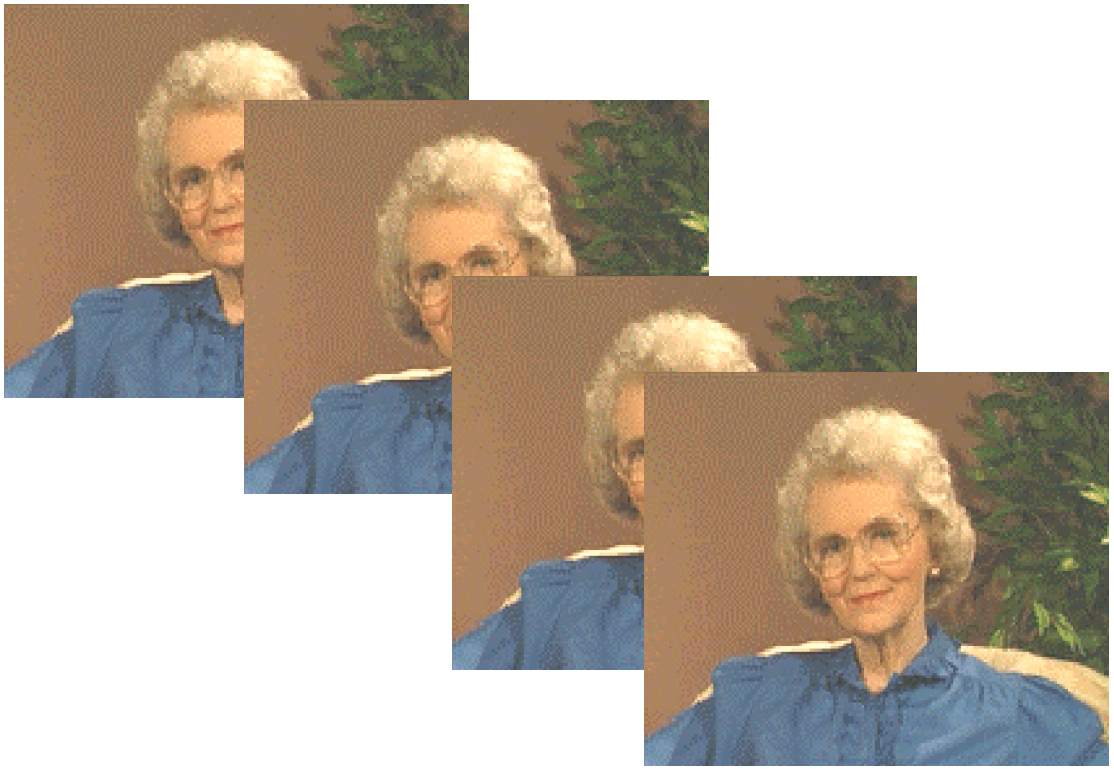
H.261 Temporal Prediction

Rec. H.261 includes 2 temporal prediction tools which have both the target to eliminate/reduce the temporal redundancy in the PCM video signal:

Temporal Differences

Differences after Motion Compensation

Temporal Redundancy: Sending the Differences

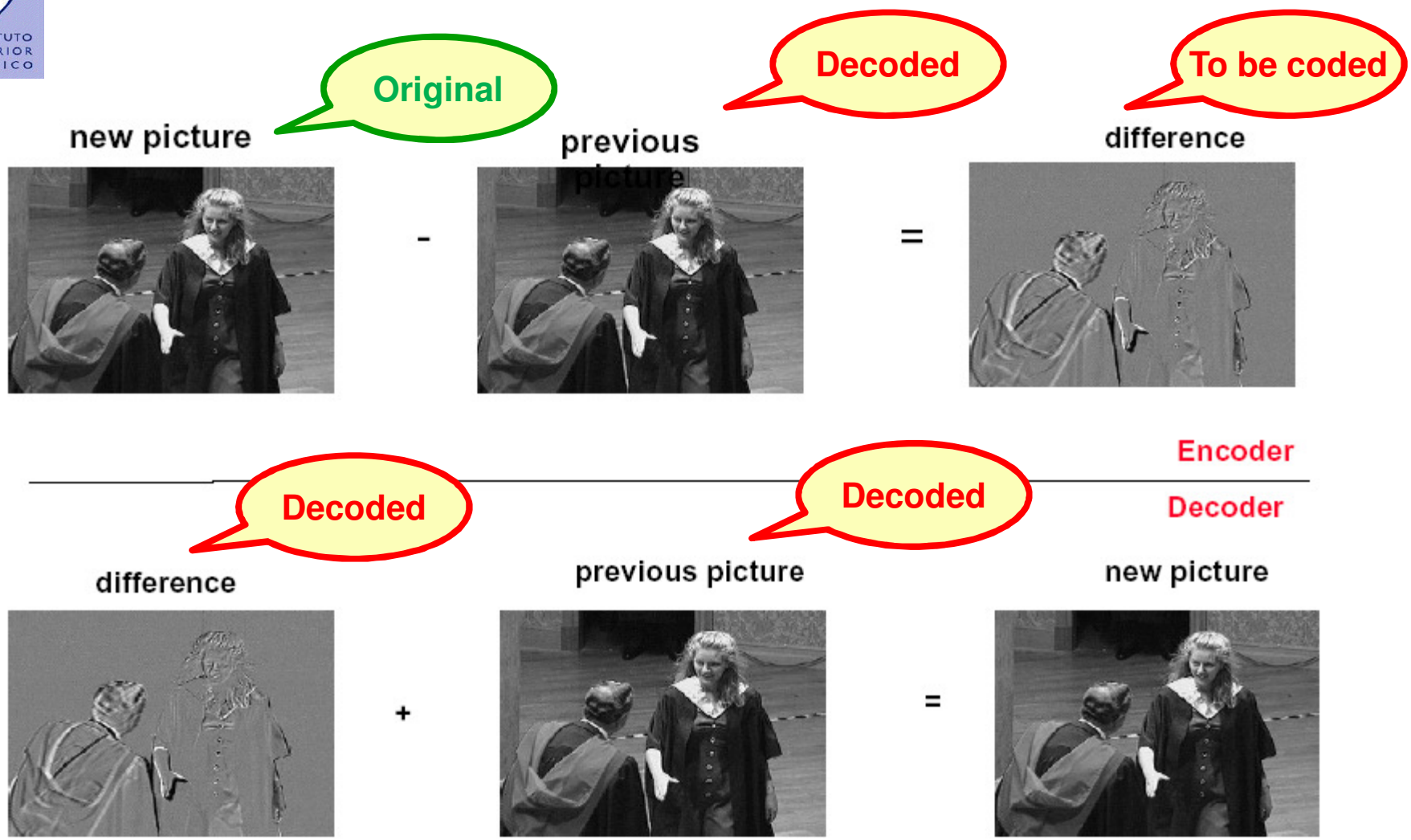


The idea is that only the new information in the new image (this means what changes from the previous image) is sent; the previous image works as a simple prediction of the current image.

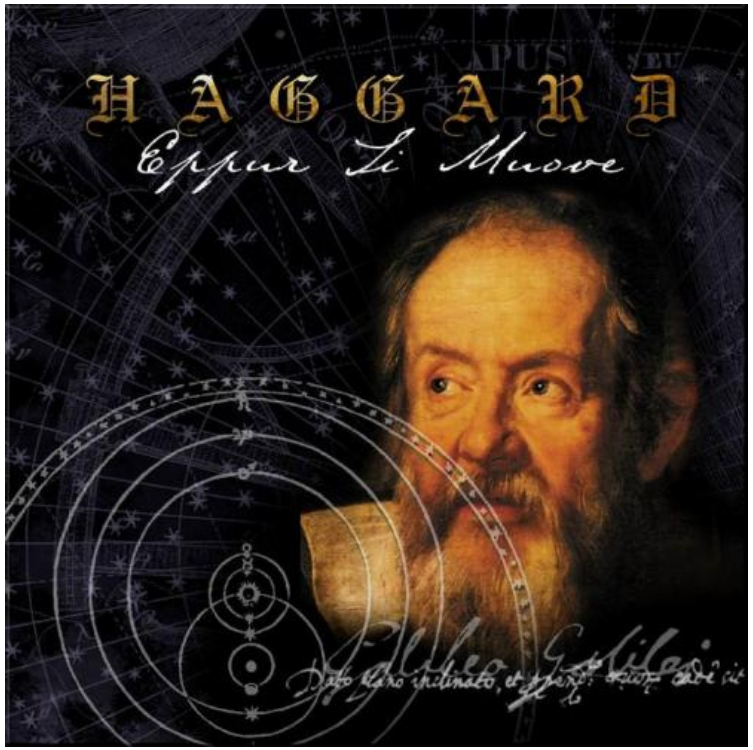
●●●

There are no losses !

Coding and Decoding ...



Eppur Si Muove …



Motion Estimation and Compensation

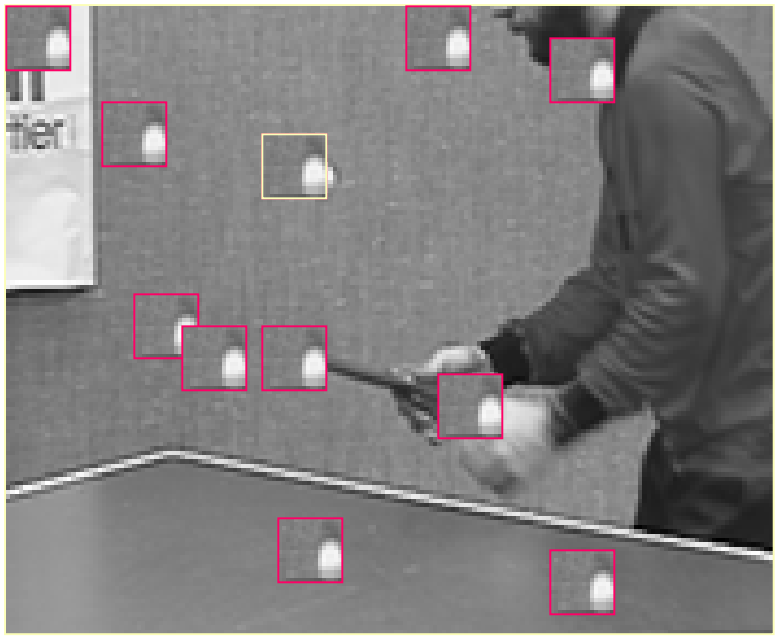
Motion estimation and compensation have the target to improve the temporal predictions for each image zone by detecting, estimating and compensating the motion in the image.

- **Motion estimation is not normative (it is part of the encoder) but the so-called *block matching* is the most used technique.**
- **In H.261, motion compensation is made at macroblock level. The usage of motion compensation for each MB is optional and decided by the encoder.**

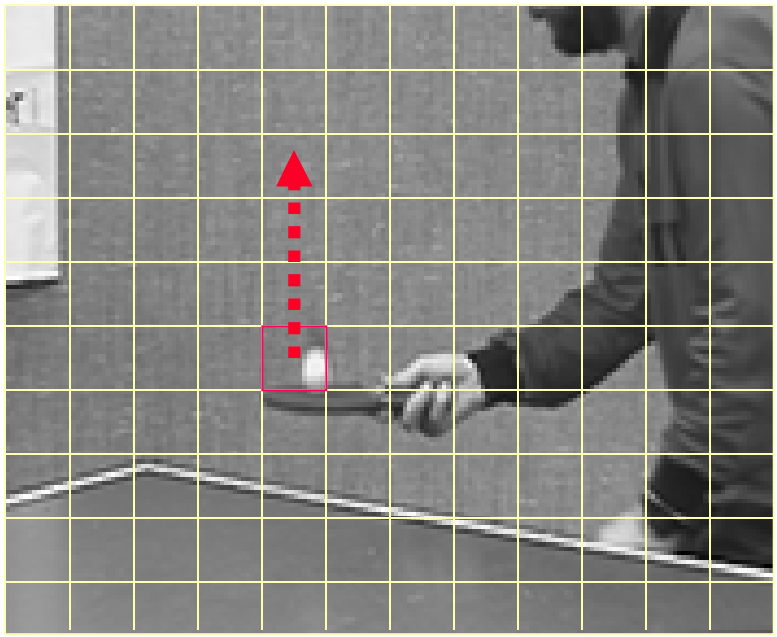
Motion estimation implies a very high computational effort. This justifies the usage of fast motion estimation methods which try to decrease the complexity compared to full search without much quality losses.

Temporal Redundancy: Motion Estimation

Frame i-1



Frame i



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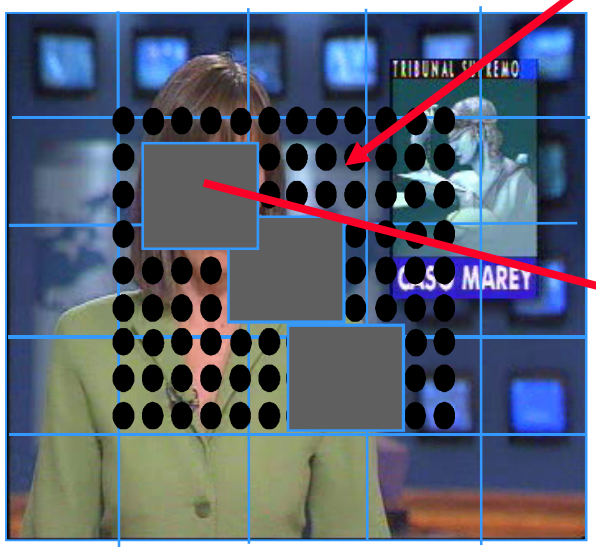
Motion Search: Where to be Worthwhile ?

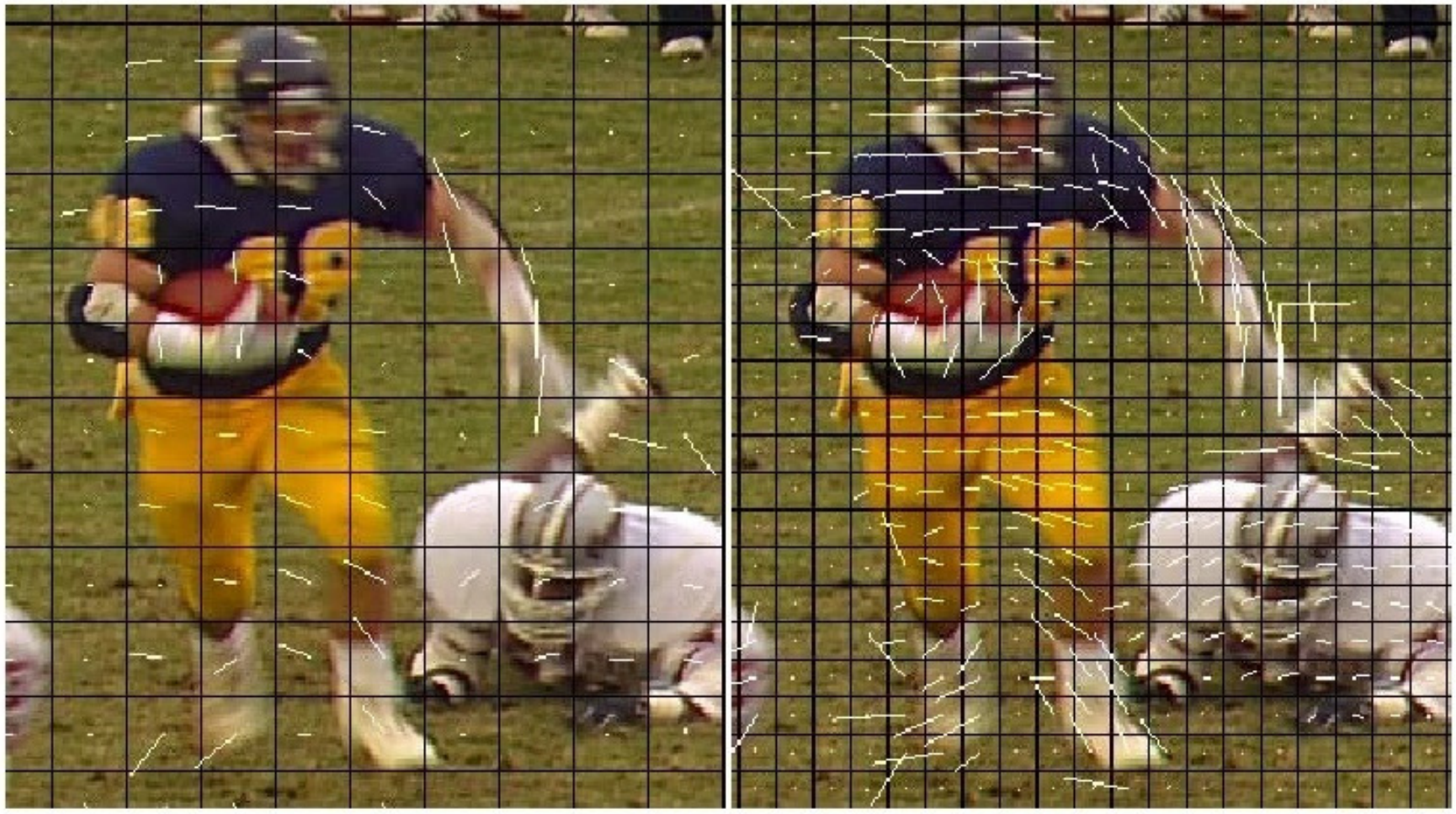
Searching area



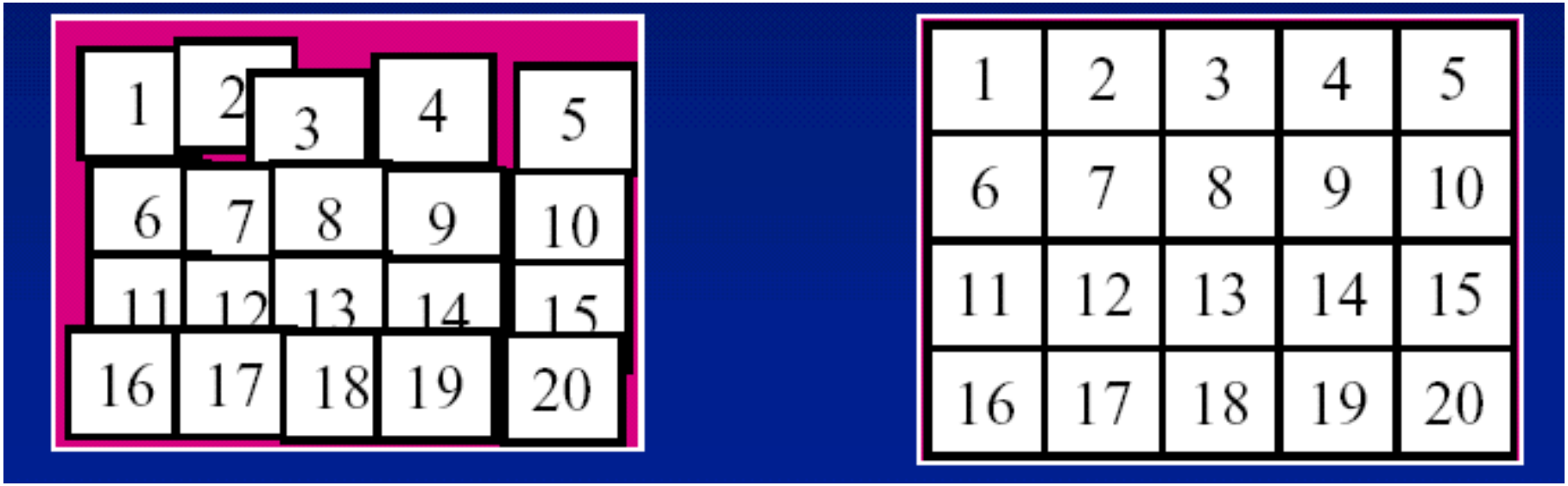
Previous image

Image to code

Motion Vectors at Different Spatial Resolutions



MBs to Code and Prediction MBs



Reference content (coded macroblocks)

Current image under coding

Motion Compensation: an Example

Image i

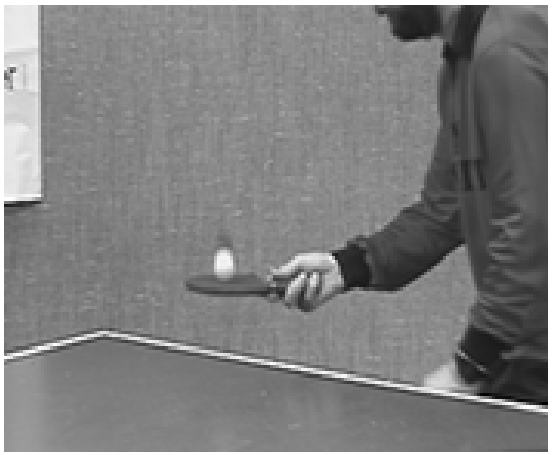
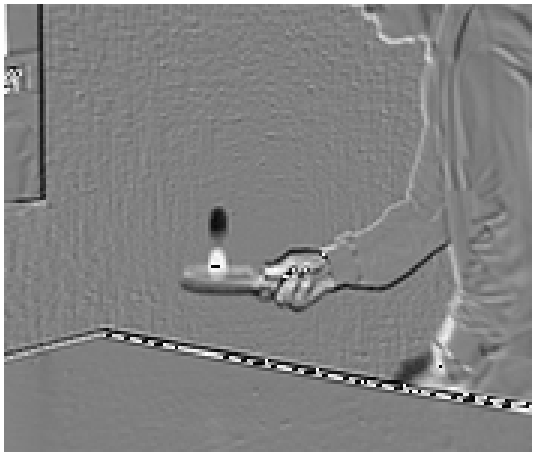
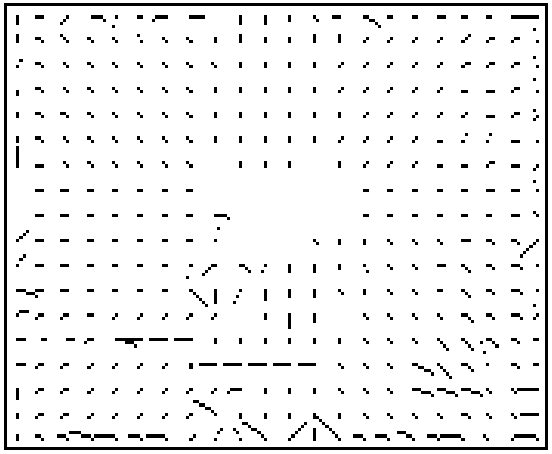


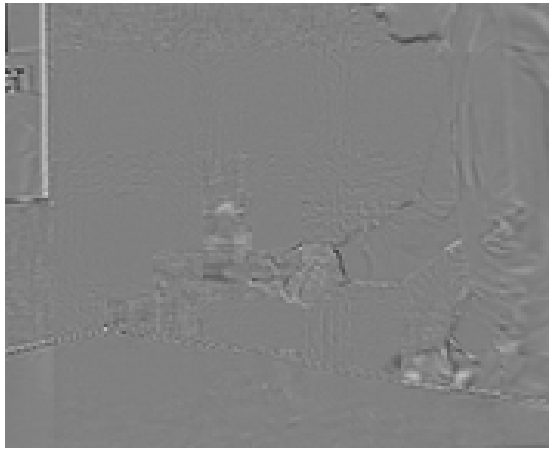
Image i-1



Diff. WITHOUT motion comp.



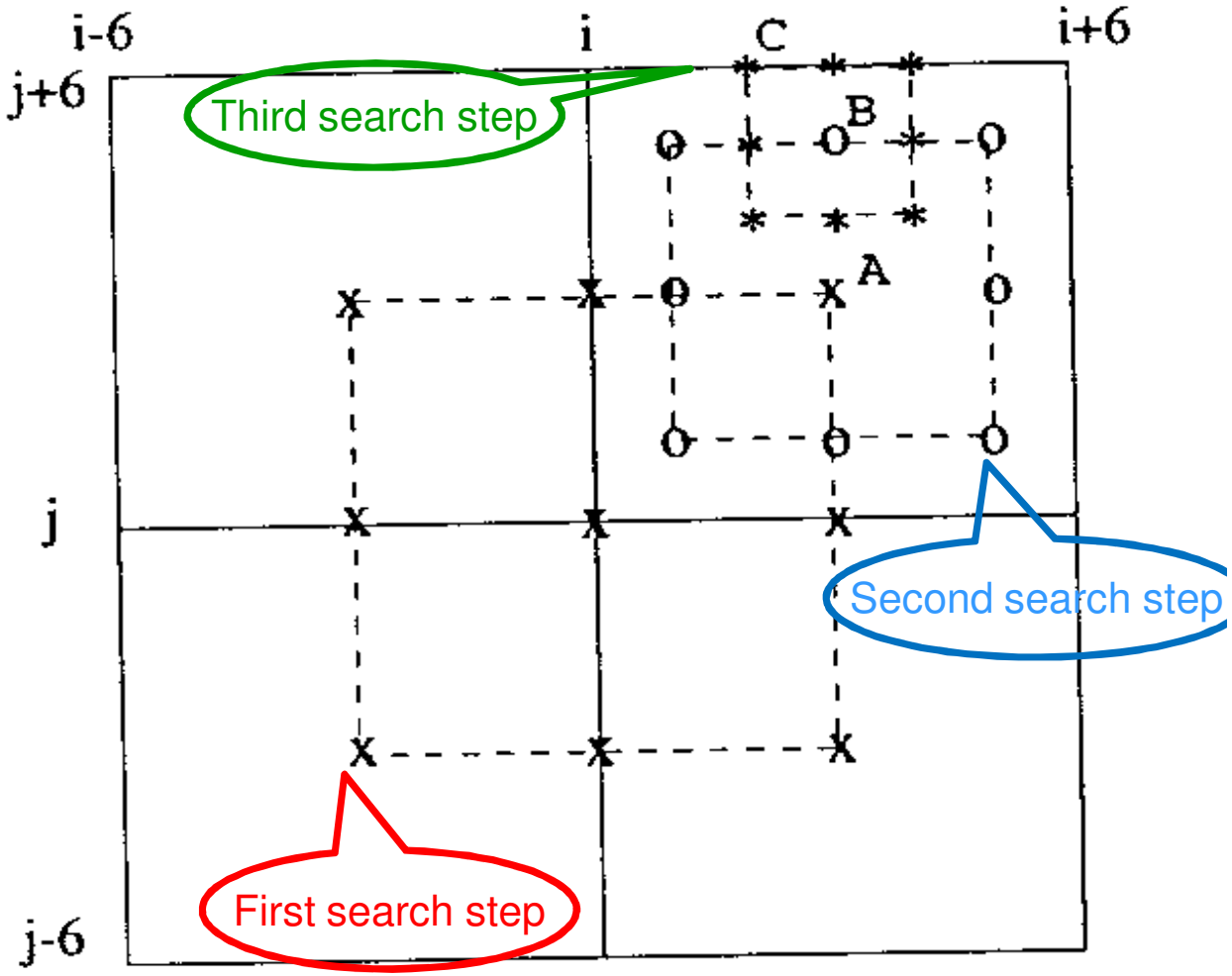
Motion vectors



Differences WITH motion comp.

Fast Motion Estimation: Three Steps Motion Estimation Algorithm

Fast motion estimation algorithms offer much lower complexity than full search at the cost of some small quality reduction since predictions are less optimal and thus the prediction error is higher !

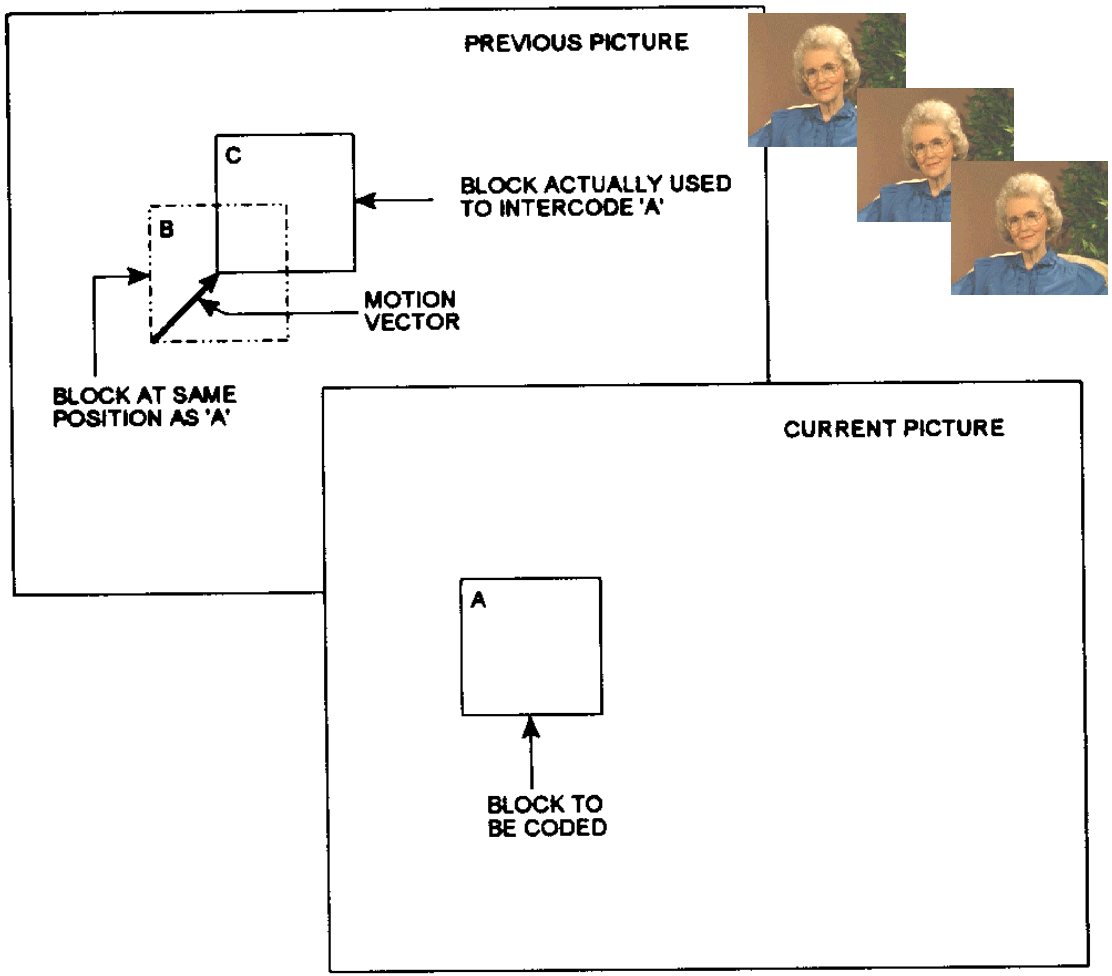


Predicting in Time … With or Without Motion

Two main temporal prediction coding modes are available for each MB:

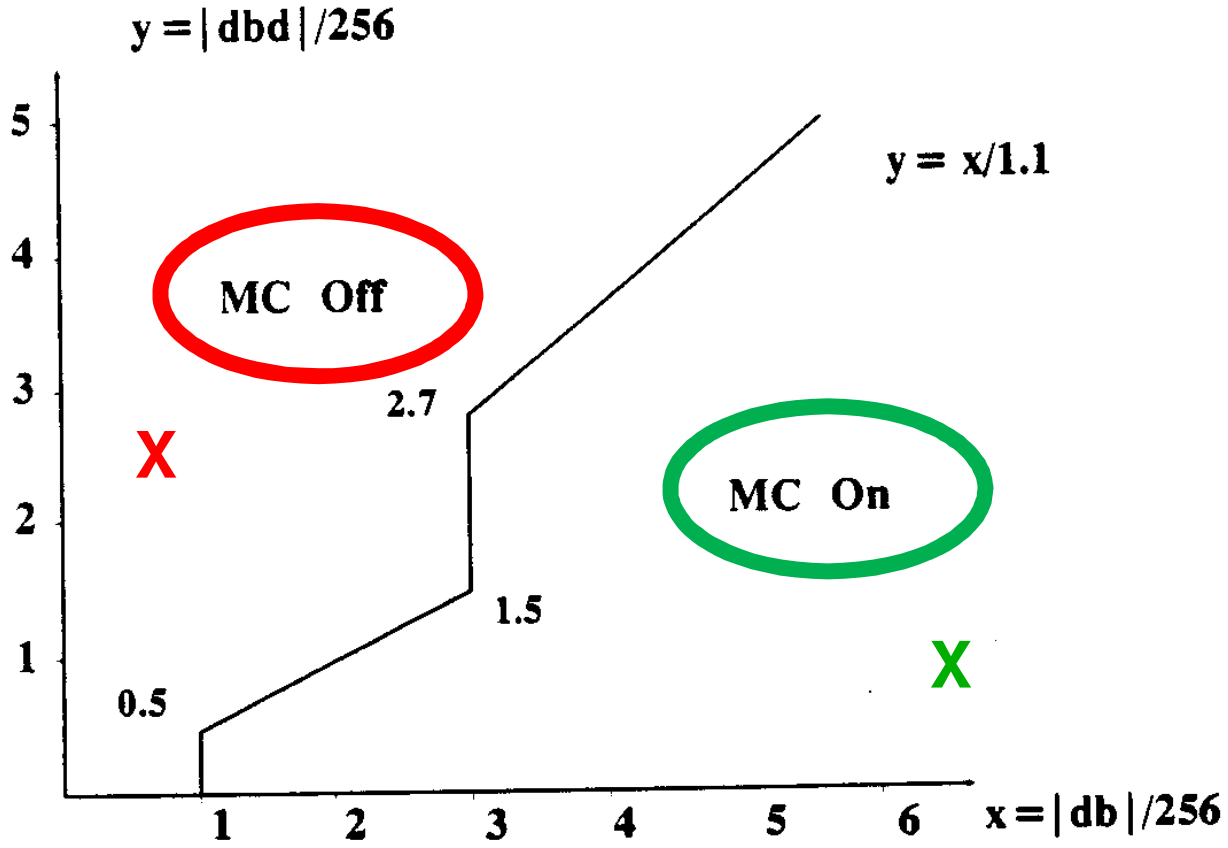
- **Prediction from the same position in the previous frame (no motion vector)**
- **Prediction from the previous frame using a motion vector**

The encoder has to choose the best deal using some (non-normative) criteria !

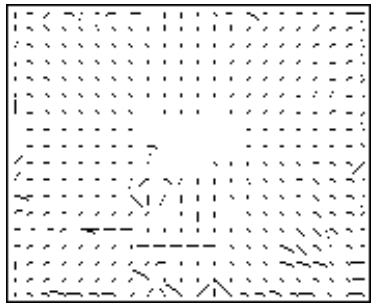


Motion Compensation Decision Characteristic Example (MB level)

db – ***difference block***
dbd – ***displaced block difference***



H.261 Motion Estimation Rules …



- **Number of MVs** - One motion vector may be transmitted for each macroblock (if the encoder so desires).
- **Range of MVs** - Motion vector components (x and y) may take values from -15 to + 15 pels, in the vertical and horizontal directions, only the integer values.
- **Referenced area** - Only motion vectors referencing areas within the reference (previously coded) image are valid.
- **Chrominance MVs** - The motion vector transmitted for each MB is used for the 4 luminance blocks in the MB. The chrominance motion vector is computed by dividing by 2 and truncating the luminance motion vector.
- **Semantics** - A positive value for the horizontal or vertical motion vector components means the prediction must be made using the samples in the previous image, spatially located to the right and below the samples to be predicted.

H.261 Motion Vectors Coding

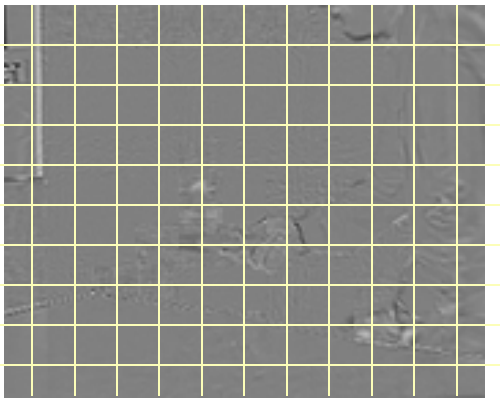
- To exploit the redundancy between the motion vectors of adjacent MBs, each motion vector is differentially coded as the difference between the motion vector of the actual MB and its prediction, this means the motion vector of the preceding MB.

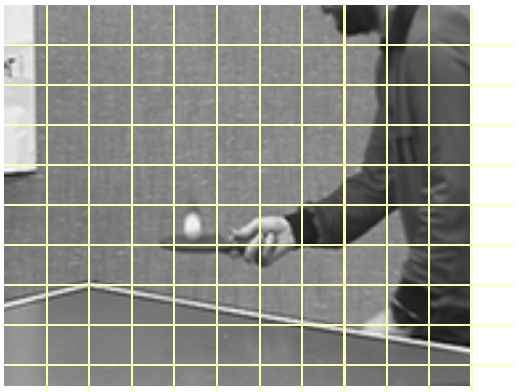
- The motion vector prediction is null when no redundancy is likely to be present, notably when:
  - The actual MB is number 1, 12 or 23
  - The last transmitted MB is not adjacent to the actual MB
  - The preceding and contiguous MB did not use motion compensation

Inter Versus Intra Coding

In H.261, the MBs are coded either in Inter or Intra coding modes:

- **INTER CODING – To be used when there is substantial temporal redundancy; may imply the usage or not of motion estimation.**
- **INTRA CODING – To be used when there is NO substantial temporal redundancy; no temporal predictive coding is used in this case ('absolute' coding like in JPEG is used).**





Exploiting Spatial Redundancy and Irrelevancy

After Temporal Redundancy, Spatial Redundancy

Original

Actual image

+

+

-

To be coded

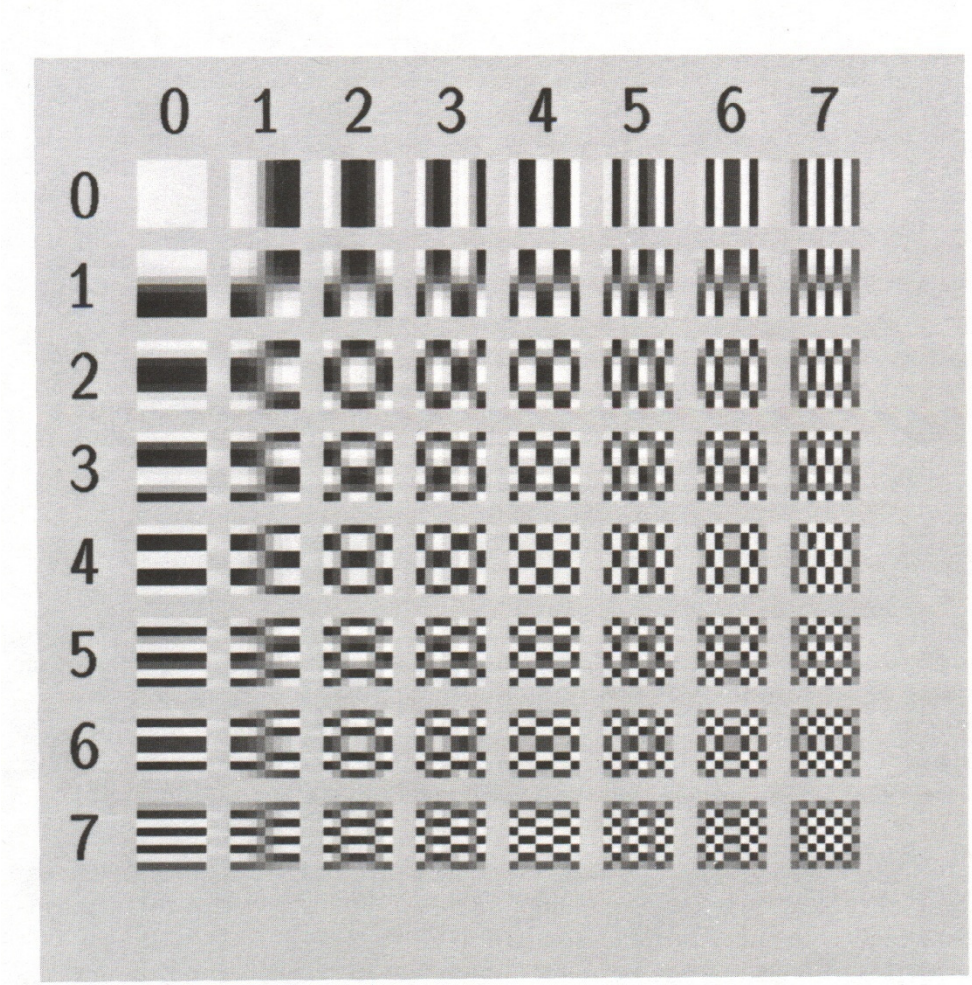
DCT
Transform

Prediction error

Decoded

Prediction image,
motion compensated

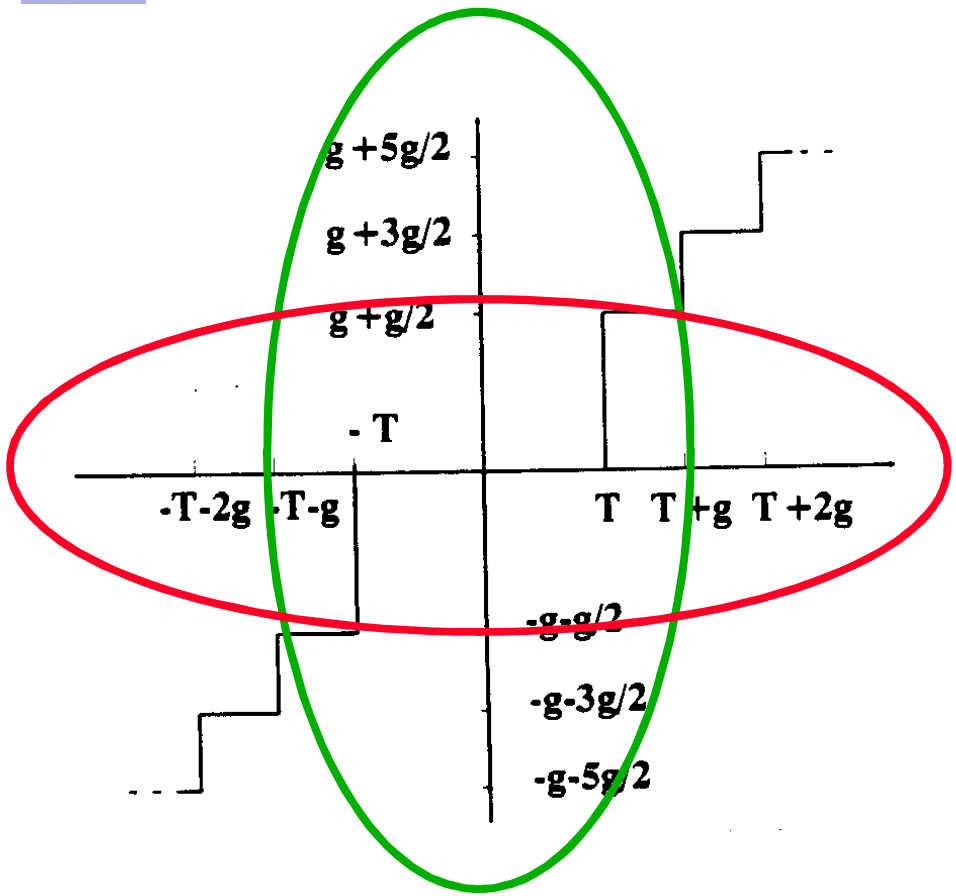
Bidimensional DCT Basis Functions (N=8)



The DCT Transform in H.261

- **Block size** - In H.261, the DCT is applied to blocks with 8×8 samples. This value results from a trade-off between the exploitation of the spatial redundancy and the computational complexity.
- **Coefficients selection** - The DCT coefficients to transmit are selected using non-normative thresholds allowing the consideration of psychovisual criteria in the coding process, targeting the maximization of the subjective quality.
- **Quantization** - To exploit the irrelevancy in the original signal, the DCT coefficients to transmit for each block are quantized.
- **Zig-Zag scanning** - Since the signal energy is compacted in the upper, left corner of the coefficients' matrix and the human visual system sensibility is different for the various frequencies, the quantized coefficients are zig-zag scanned to assure that more important coefficients are always transmitted before less important ones.

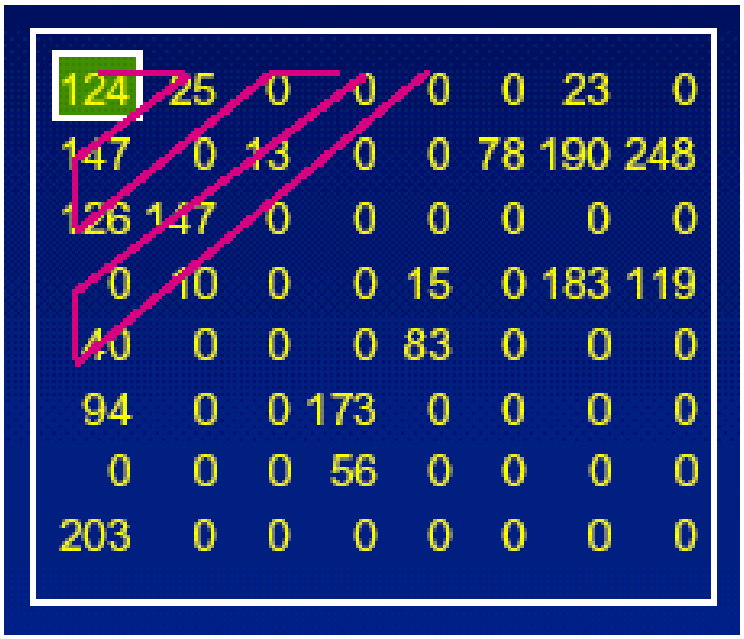
H.261 Quantization



Example quantization characteristic

- H.261 uses as quantization steps all even values between 2 and 62 (31 quantizers available).
- Within each MB, all DCT coefficients are quantized with the same quantization step with the exception of the DC coefficient for Intra MBs which are always quantized with step 8.
- H.261 normatively defines the regeneration values for the quantized coefficients but not the decision values which may be selected to implement different quantization characteristics, uniform or not.

Serializing the DCT Coefficients



- **The transmission of the quantized DCT coefficients requires to send the decoder two types of information about the coefficients: their position and quantization level (for the selected quantization step).**

- **For each DCT coefficient to transmit, its position and quantization level are represented using a bidimensional symbol**

(*run, level*)

where the *run* indicates the number of null coefficients before the coefficient under coding, and the *level* indicates the quantized level of the coefficient.

Exploiting Statistical Redundancy

Statistical Redundancy: Entropy Coding

Entropy coding

CONVERTS SYMBOLS IN BITS !

Using the statistics of the symbols to transmit to achieve additional (lossless) compression by allocating in a clever way bits to the input symbol stream.

- **A, B, C, D -> 00, 01, 10, 11**
- **A, B, C, D -> 0, 10, 110, 111**

Huffman Coding

Huffman coding is one of the entropy coding tools which allows to exploit the fact that the symbols produced by the encoder do not have equal probability.

- **To each generated symbol is attributed a codeword which size (in bits) is 'inversely' proportional to its probability.**
- **The usage of variable length codes implies the usage of an output buffer to 'smooth' the bitrate flow, if a synchronous channel is available.**
- **The increase in coding efficiency is 'paid' with an increase in the sensibility to channel errors.**

Combining the Tools ...

H.261: Coding Tools

- **Temporal Redundancy**

  Predictive coding: temporal differences

  and differences after motion compensation

- **Spatial Redundancy**

  Transform coding (Discrete Cosine Transform, DCT)

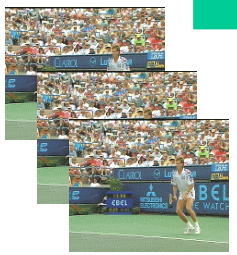
- **Statistical Redundancy**

  Huffman entropy coding

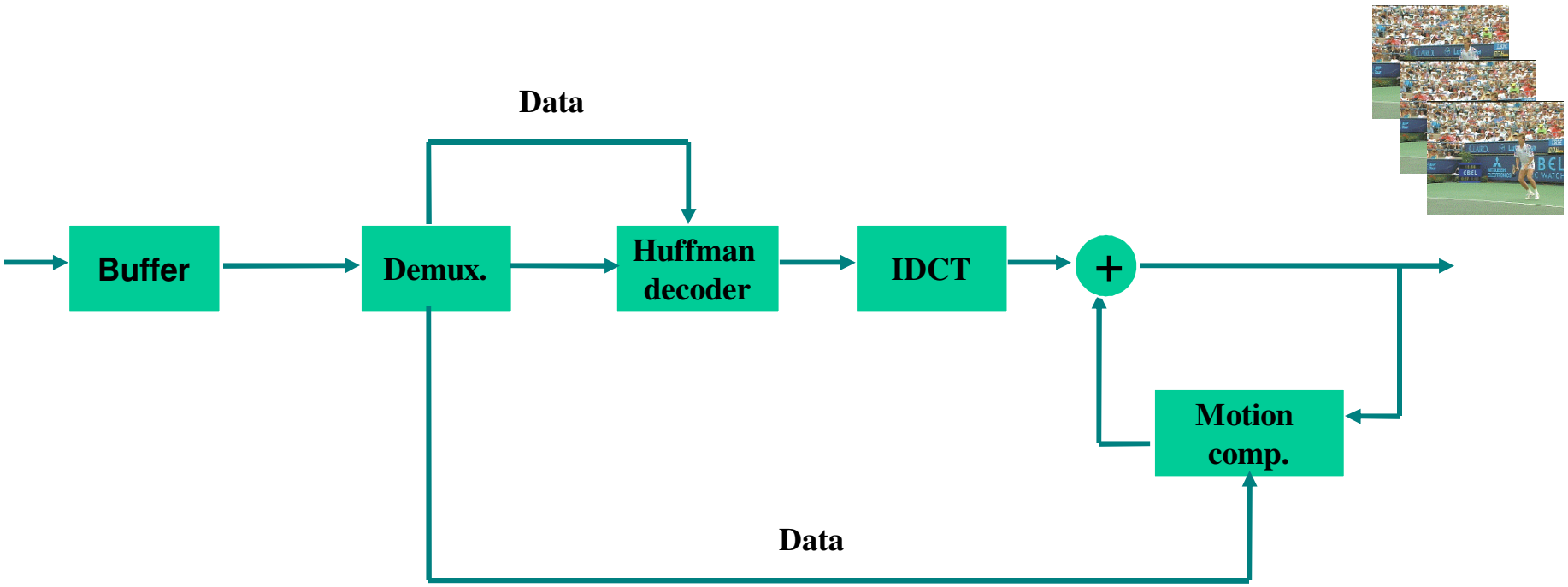
- **Irrelevancy**

  Quantization of DCT coefficients

Encoder: the Winning Cocktail !



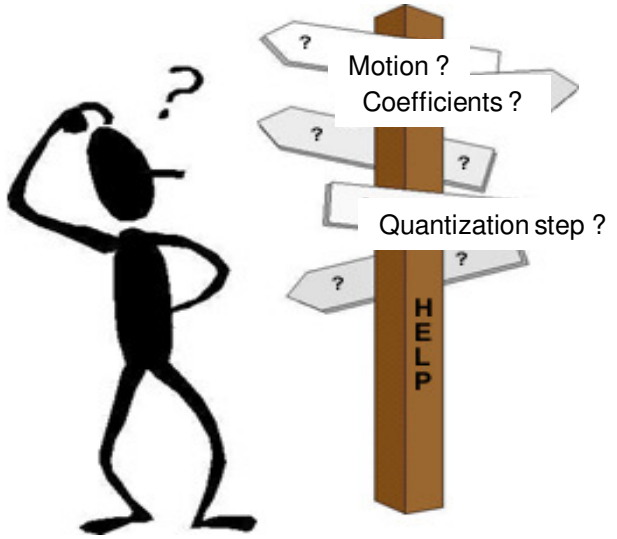
Decoder: the Slave !



The Importance of Well Choosing !

To well exploit the redundancy and irrelevancy in the video sequence, the encoder has to select:

- **Which coding tools are used for each MB, depending of its characteristics;**
- **Which set of symbols is the best to represent MB, e.g. motion vector and DCT coefficients.**



While the encoder has the mission to take important decisions and make critical choices, the decoder is a 'slave', limited to follow the 'orders' sent by the encoder; decoder intelligence is only shown for error concealment.

A Tool Box for Macroblock Classification

- **Macroblocks are the basic coding unit since it is at the macroblock level that the encoder selects the coding tools to use.**
- **Each coding tool is more or less adequate to a certain type of content and, thus, MB; it is important that, for each MB, the right coding tools are selected.**
- **Since Rec. H.261 includes several coding tools, it is the task of the encoder to select the best tools for each MB; MBs are thus classified following the tools used for their coding.**
- **When only spatial redundancy is exploited, MBs are INTRA coded; if also temporal redundancy is exploited, MBs are INTER coded.**

Macroblock Classification Table

VLC table for MTYPE

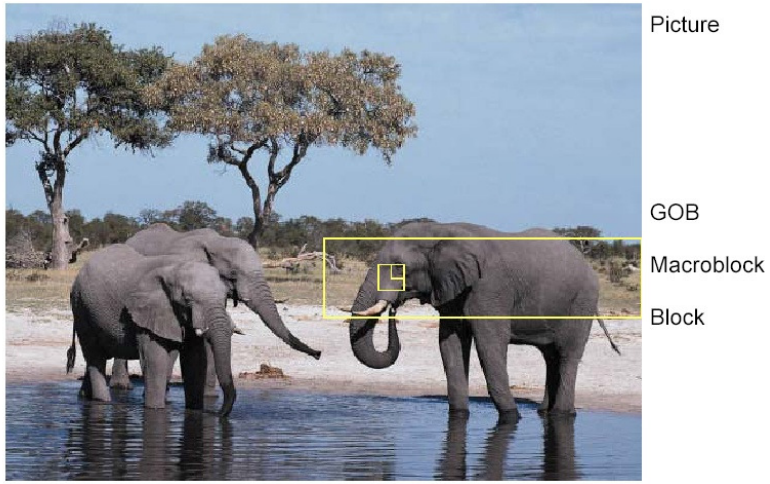
Prediction	MQUANT	MVD	CBP	TCOEFF	VLC
Intra				x	0001
Intra	x			x	0000 001
Inter			x	x	1
Inter	x		x	x	0000 1
Inter + MC		x			0000 0000 1
Inter + MC		x	x	x	0000 0001
Inter + MC	x	x	x	x	0000 0000 01
Inter + MC + FIL		x			001
Inter + MC + FIL		x	x	x	01
Inter + MC + FIL	x	x	x	x	0000 01

Note 1 – "x" means that the item is present in the macroblock.

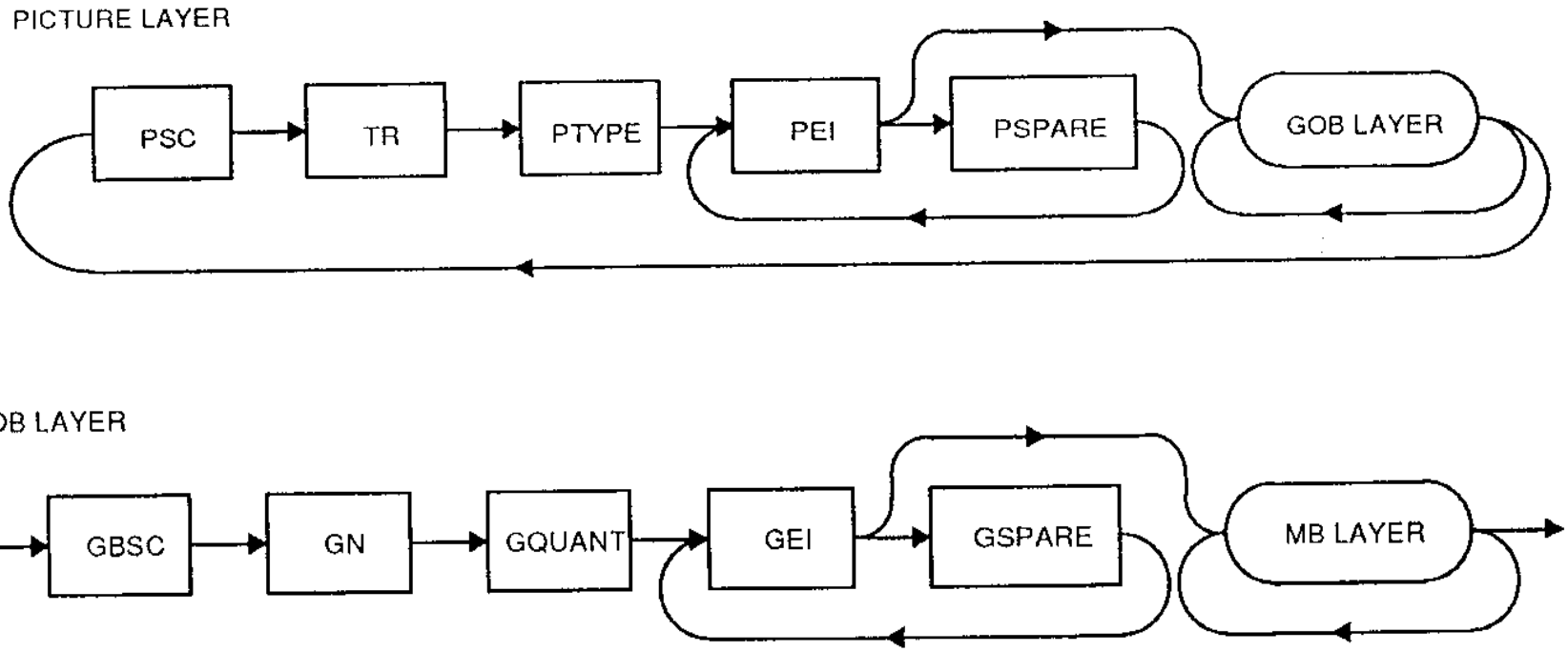
Note 2 – It is possible to apply the filter in a non-motion compensated macroblock by declaring it as MC + FIL but with a zero vector.

Hierarchical Information Structure Functions

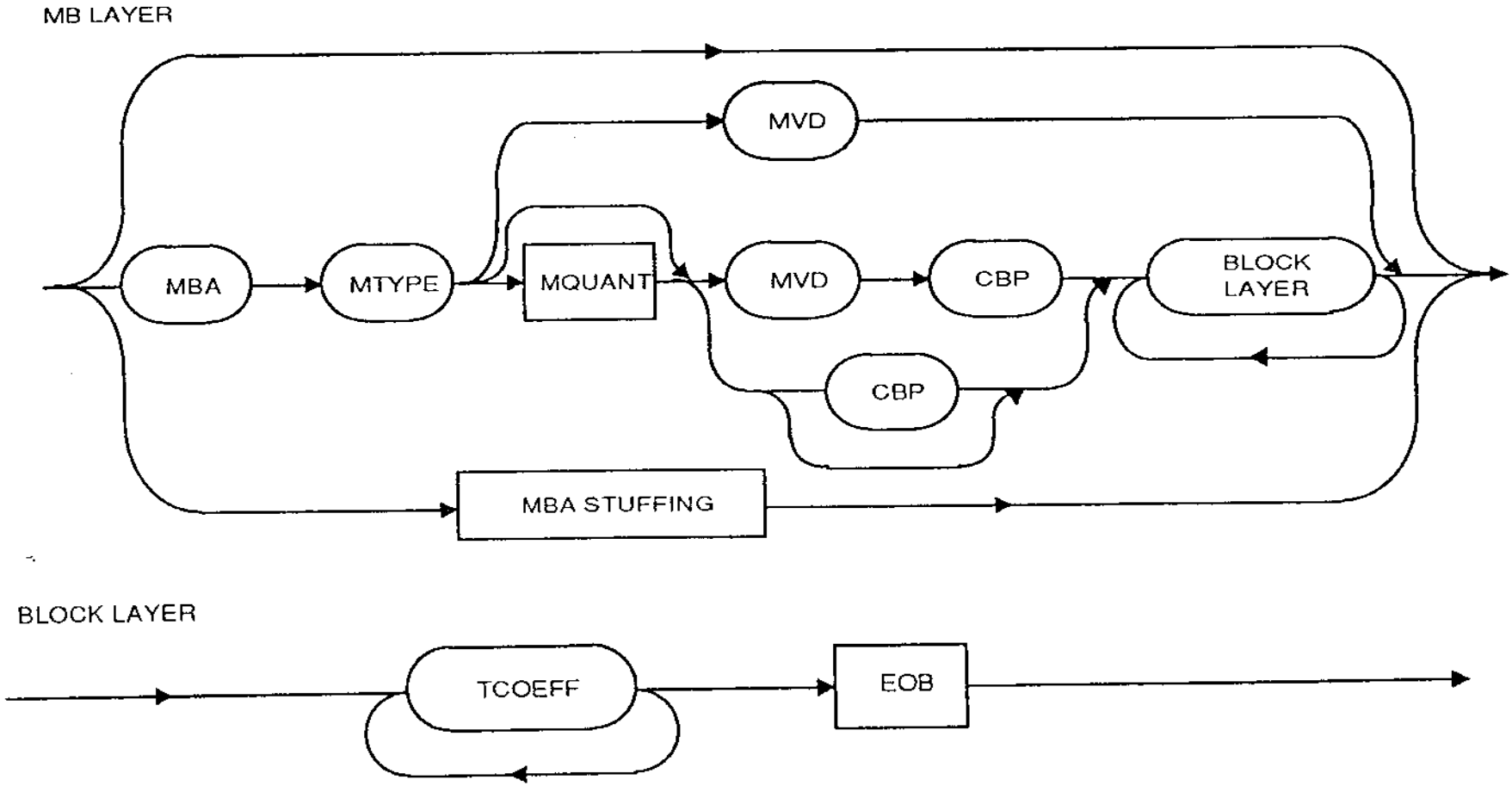
- **Image**
  - **Resynchronization (*Picture header*)**
  - **Temporal resolution control**
  - **Spatial resolution control**
- **Group of Blocks (GOB)**
  - **Resynchronization (*GOB header*)**
  - **Quantization step control (mandatory)**
- **Macroblock**
  - **Motion estimation and compensation**
  - **Quantization step control (optional)**
  - **Selection of coding tools (MB classification)**
- **Block**
  - **DCT**



Coding Syntax: Image and GOB Levels



Coding Syntax: MB and Block Levels



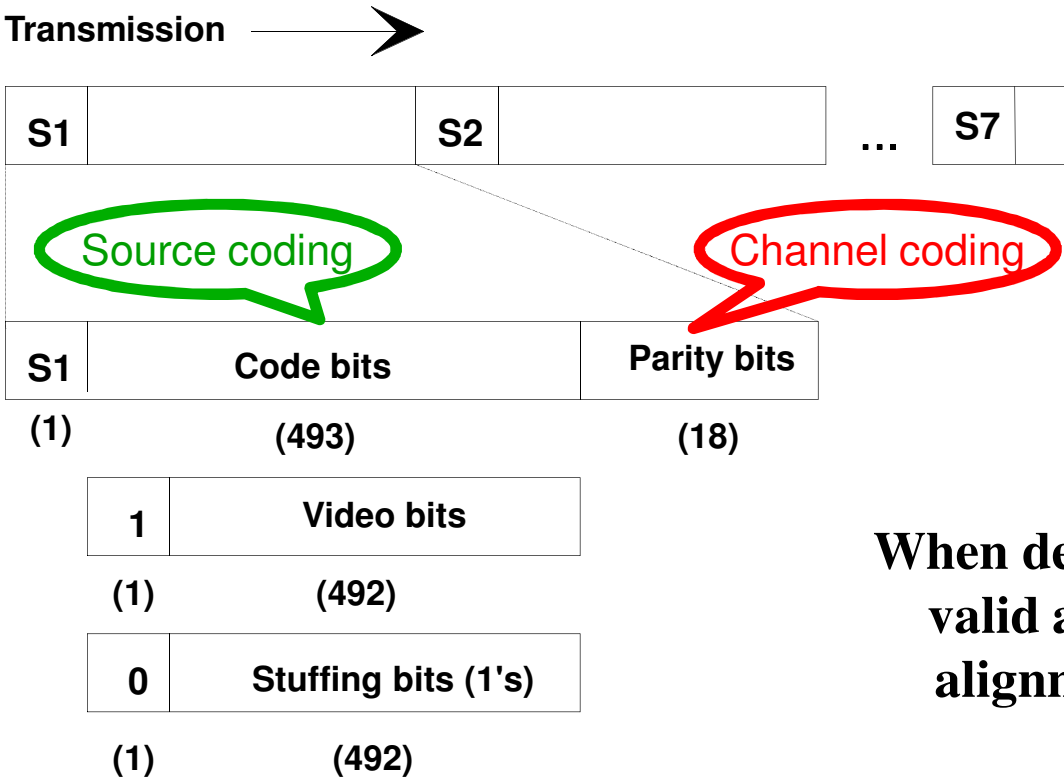
Error Protection for the H.261 Binary Flow

- **Error protection for the H.261 binary flow is implemented by using a BCH (511,493) - *Bose-Chaudhuri-Hocquenghem* – block code (channel coding).**
- **The usage of the channel coding bits (also parity bits) at the decoder is optional.**
- **The syndrome polynomial to generate the parity bits is**

$$g(x) = (x^9 + x^4 + x)(x^9 + x^6 + x^4 + x^3 + 1)$$

Error Protection for the H.261 Binary Flow

The final video signal stream structure (multiframe with 512×8 = 4096 bits) is:



S1S2S3S4S5...S8 – Alignment sequence

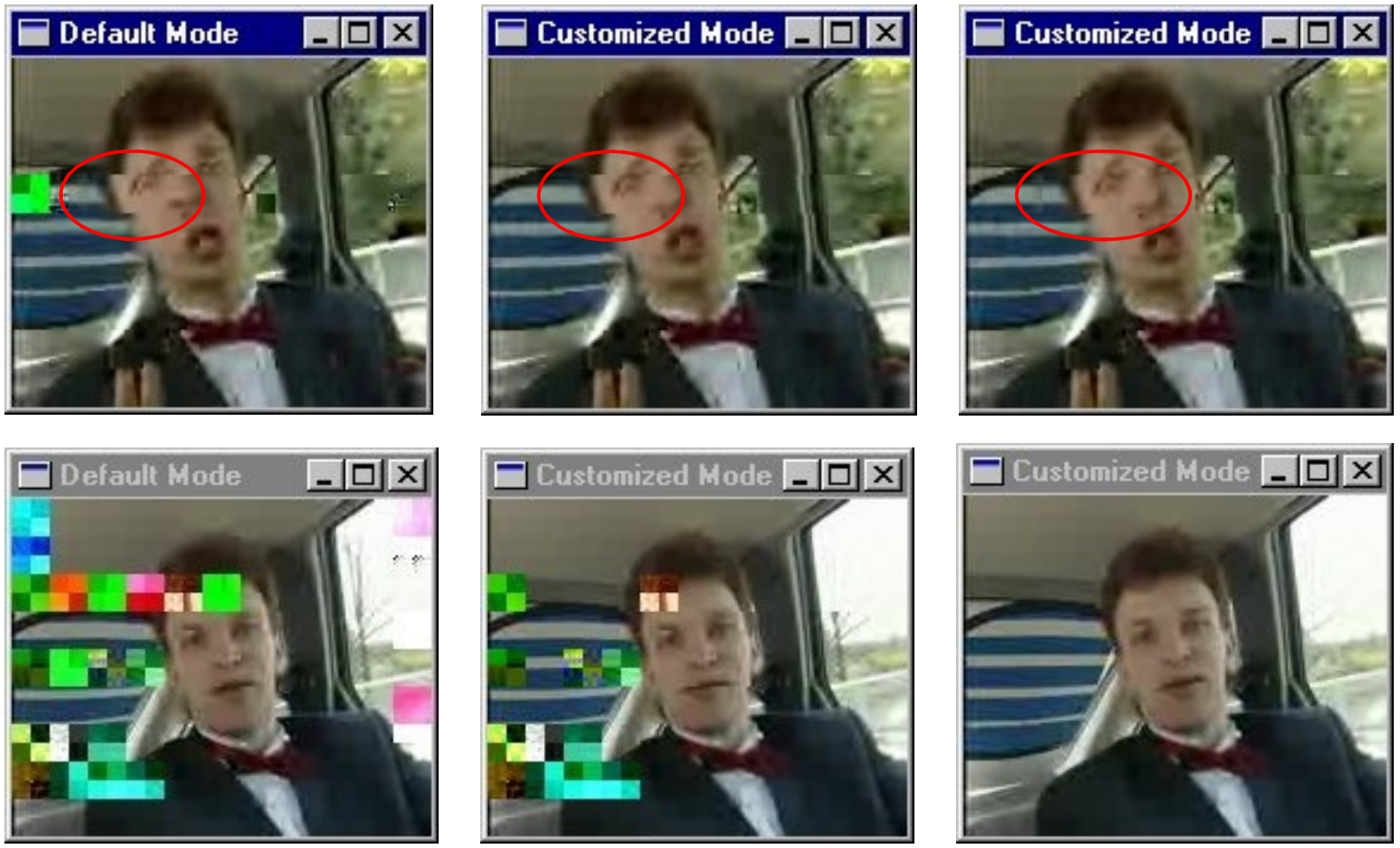
00011011

When decoding, realignment is only valid after the good reception of 3 alignment sequences (S1S2 ...S8).

Error Concealment

- Even when channel coding is used, some residual (transmission) errors may end at the source decoder.
- Residual errors may be detected at the source decoder due to syntactical and semantic inconsistencies.
- For digital video, the most basic error concealment techniques imply:
  - Repeating the co-located data from previous frame
  - Repeating data from previous frame after motion compensation
- Error concealment for non-detected errors may be performed through post-processing.

Error Concealment and Post-Processing Examples



Final Comments

- **Rec. H.261 has been the first video coding international standard with relevant adoption.**
- **As the first relevant video coding standard, Rec. H.261 has established legacy and backward compatibility requirements which have influenced the standards to come after, notably in terms of technology selected.**
- **Many products and services have been available based on Rec. H.261.**
- **However, Rec. H.261 does not represent anymore the state-of-the-art on video coding (remind this standard is from 1990).**

Bibliography

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