Error Control

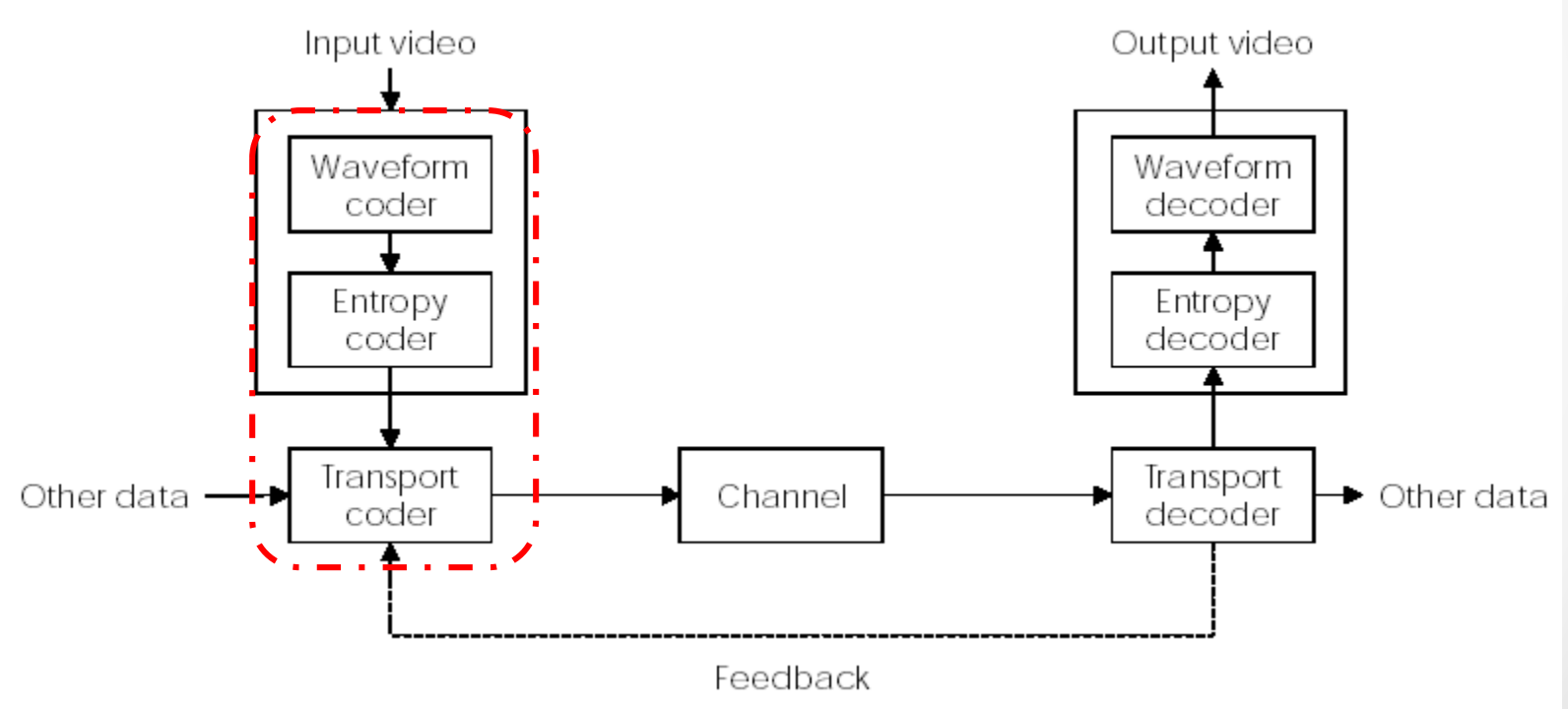
- Overview
- Forward Error Concealment at the Encoder
- Error Concealment by Post-Processing at the Decoder
- Encoder & Decoder Interactive Error Concealment
- Error Resilience at MPEG-4

Data Communication & Video Communication

- Data Communication
  - Lossless transmission
  - Focused on channel coding technique, e.g. forward error correction, error control coding and automatic retransmission request, is used.
- Video Communication
  - Focused on both source coding and channel coding.
  - Loss of video data is less critical than data communication, since human perception can accept some distortion.
  - A single bit error may cause considerable effects on compressed stream.

Video Communication System

- A functional block diagram for a video communication



Roles of each block

- Source encoder
  - Compress the video to the desired bit rate.
- Transport layer
  - Packetizes various data for multiplexing.
  - Inserts a time stamp for decoding at the correct time instance.
  - Inserts the redundancy (e.g. error correction code)
- Channel
  - Physical network for communication.
- Feedback
  - Signal path to provide information in the decoder

Error Rates

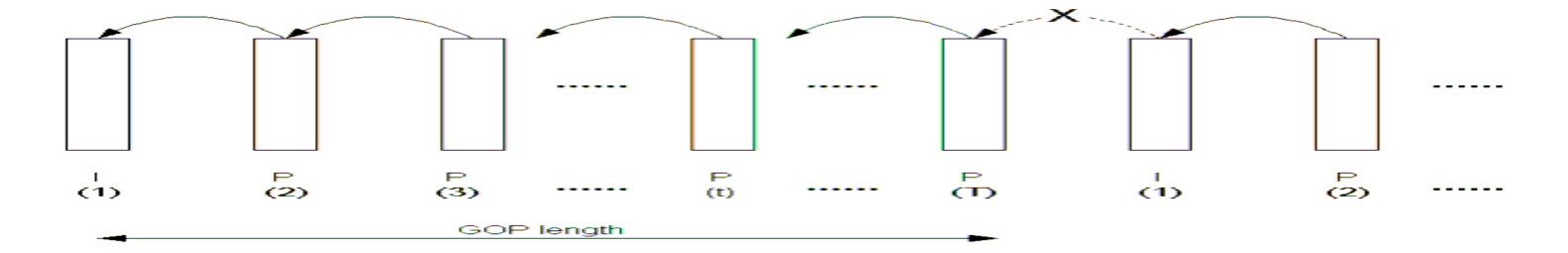
- Error rates: error rate are the measures of the behavior of the network with respect to alternation, loss, duplication or out of order delivery of data.
  - Data alternation
    - When the data received are different from the data emitted, i.e. inversion of bits, or loss of trailing or heading parts in data blocks or packets.
  - Data loss
    - Internal network congestion affecting nodes or transmission lines.
  - Data duplication
    - The same data are received unexpectedly more than once by the receiver.

Error Rates

- Out-of-order delivery of data
  - Because of alternate routes between two end-systems.
  - In internet, when failures or congestion occur, alternate routes may be involved, and route oscillations may happen. As not all routes have the same transit delay, packets may be delivered in a different order than they were emitted.
- Metrics for error rates
  - Bit error rate (BER):The BER is the frequency of residual erroneous bits, after transmission and possible correction internal to the network. BER are 10^{-11} to 10^{-12} for optical fiber.
  - Packet error rate (PER): The frequency of lost, duplicated or out-of-order packets or cells.

Challenges in video communications

Compressed bit-stream is fairly vulnerable to transmission error



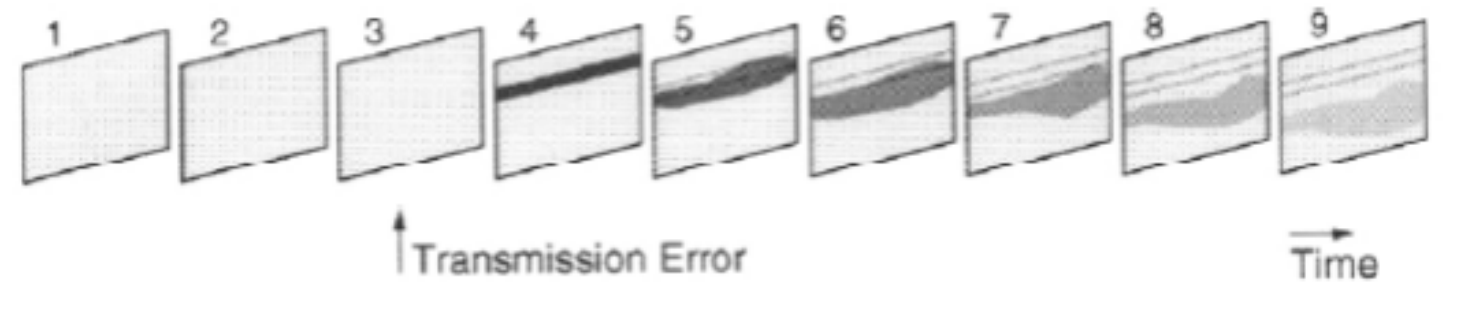


Illustration of spatiotemporal error propagation

Effect of transmission error

No loss

3%

5%

10%

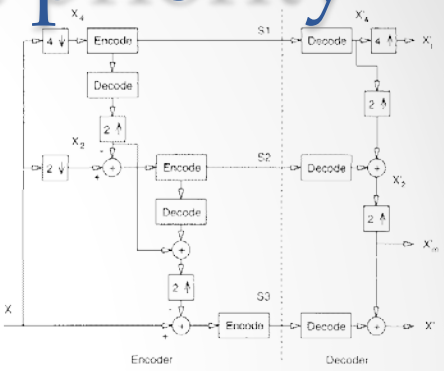
Reconstructed video frames from a H.263 coded bitstream, subject to packet losses (cited from Reference [1])

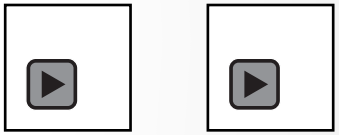
Forward Error Concealment at the Encoder

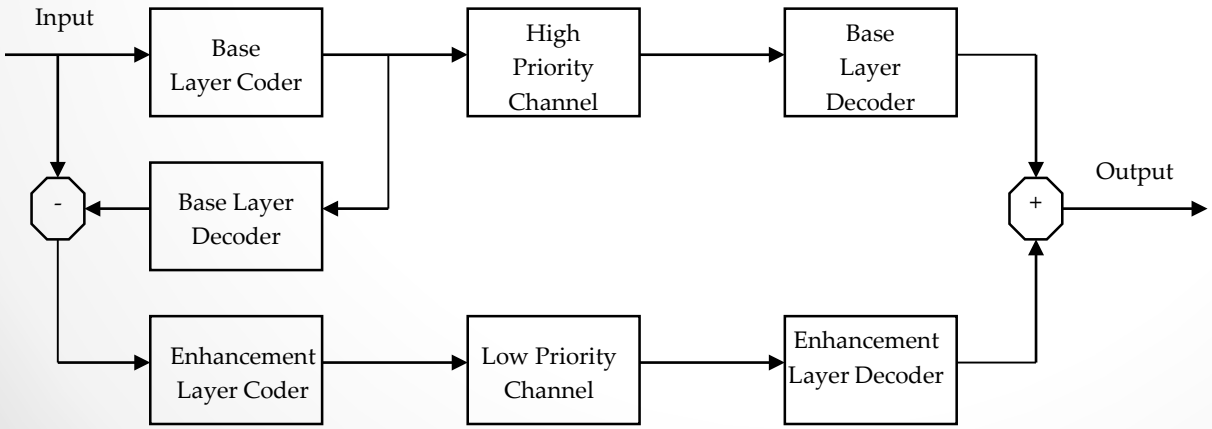
- All the methods add a controlled amount of redundancy in either the source coder or the transport coder.
  - Layered coding with transport priority
  - Multiple reference frames
  - Multiple description coding
  - Forward error correction
  - Joint source and channel coding
  - Robust waveform coding
  - Robust entropy coding
  - Transport level control

Layered coding with transport priority

- Partition into more than one layer.
- Base layer contains essential information to generate an output video with acceptable quality. Enhancement layer enhance video quality.
- In case of error transmission channel, base layer transmit with high degree of error protect.
- Base layer may transmit with high priority and enhancement layer transmit with low priority. (How about audio data compare with video data?)

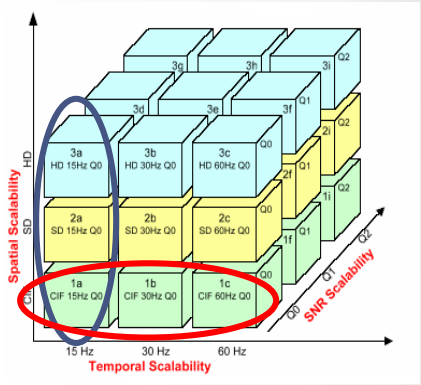






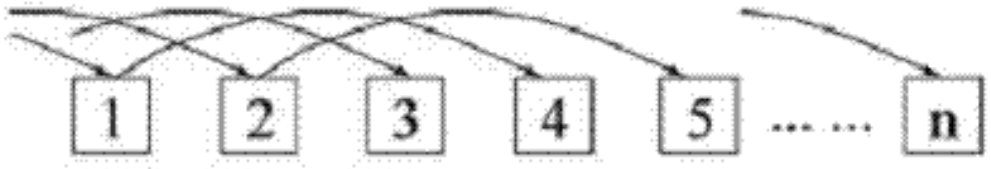
Layered coding with transport priority

- Temporal domain
  - Base layer bit stream with low frame rate, enhancement layer contain incremental information output with high frame rate.
- Spatial domain
  - Base layer contain sub-sampled video, enhancement layer contain extra information obtaining high resolution.
- Frequency domain (quality/snr scalability)
  - Base layer contain low frequency coefficient, high frequency carried by enhancement layer.
- In video coding, coding mode and motion vector are put in base layer as the information are more important.



Multiple Reference Frames

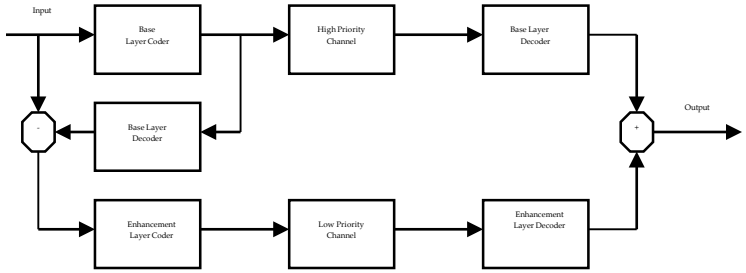
- Available in H.264 standard
- The current P frame can refer to any of the previous P frame.
- Distortion can be reduced.
- Coding efficiency will be affected.



- Figure shows that each P frame uses the third previous frame as a reference.

Multiple Description Coding (MDC)

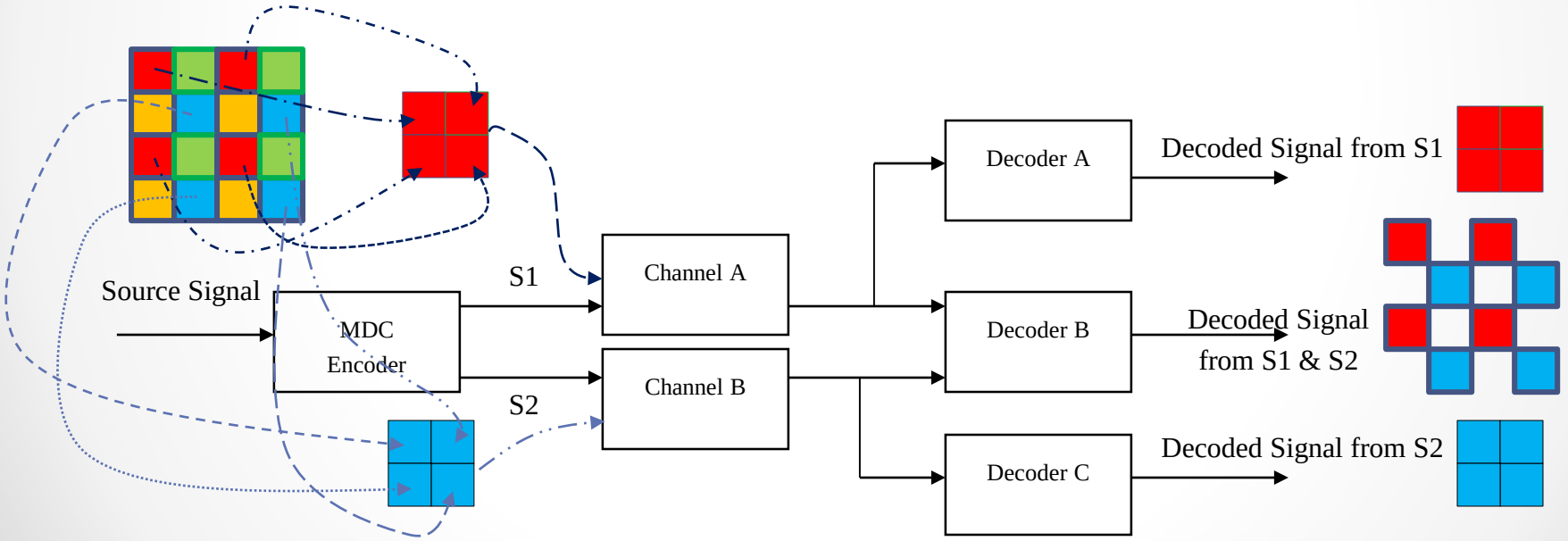
- In layered coding, we assume that the base layer is transmitted in error free channel with the helping of FEC or retransmission. It may not be guarantee in many cases.



- With MDC, several bit stream are generated and transmitted over separate channel.
- The MDC coder and decoder are designed such that the quality of the reconstructed signal is acceptable with any one description (bit stream) and that incremental improvement is achievable with more descriptions.

Multiple Description Coding and Decoding

- Each description must carry sufficient information for independent decoding.
- Reduce the coding efficiency compared to conventional signal description coder.
- E.g. splitting adjacent samples among several channels, then code the sub-image accordingly. Very low coding efficiency, since the coder cannot make use of the correlation among adjacent samples.

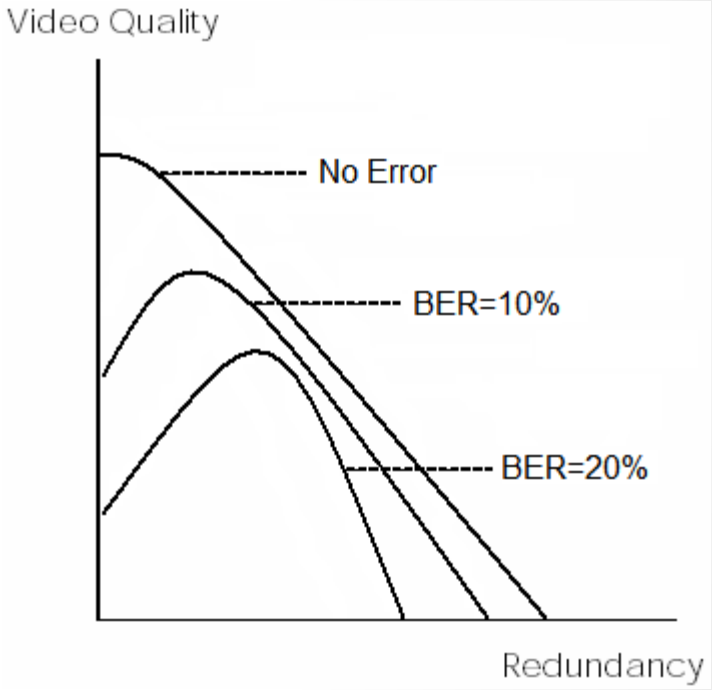


Forward Error Correction (FEC)

- FEC has the effect to increase transmission overhead and decrease usable bandwidth for the payload data.
- In H.261, an 18 bits error correction code is optionally computed and appended to 493 video bits for detection and correction of 2 random bit errors.

Video Quality and Redundancy

- To help error detection and concealment at the decoder, a certain amount of redundancy needs to be added at the waveform, entropy and transport coder.
- Assume that the total bit rate used for source and channel coding is fixed.

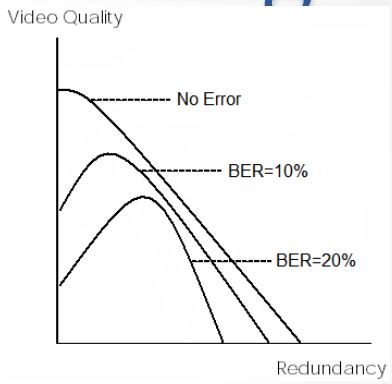


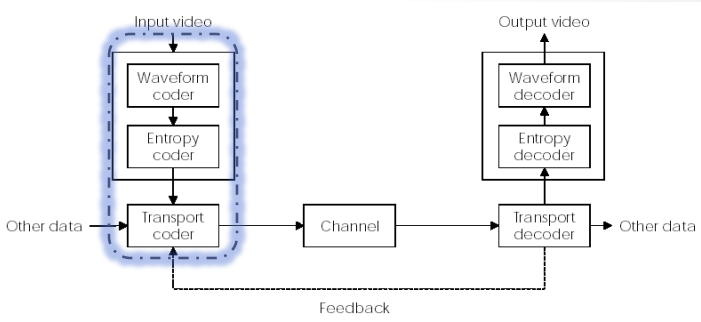
FEC bits

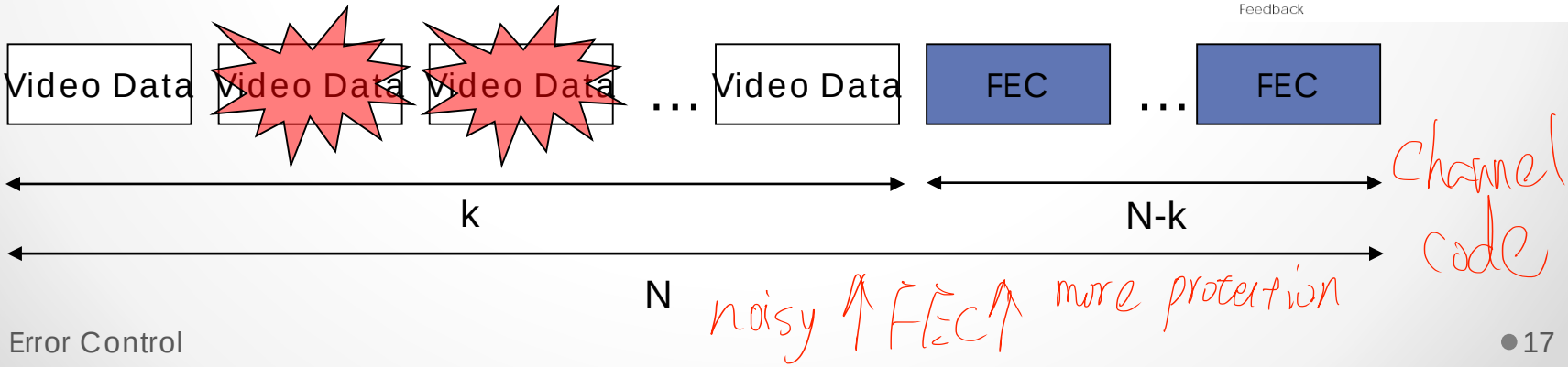
N is fix

Joint Source and Channel Coding

- In layered coding, the source coder produce bit stream and assume that the transmission channel guarantee to delivery the base layer.
- In MDC, the source coder assume the transmission channel treat all bits equally and all bits are subject to loss.
- Joint source and channel coding is achieved by designing the quantizer and entropy coder for given channel error characteristics to minimize the effect of transmission errors.
- E.g., when channel becomes very noisy, a coarse quantizer instead of a fine quantizer in the source coding stage.





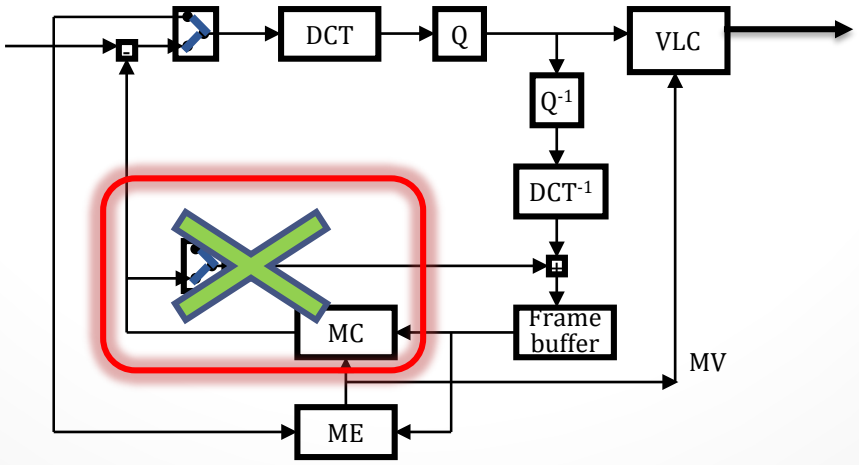


Robust Waveform Coding

- Source coder is to eliminate both the statistical and the visual redundancy of the signal as much as possible to achieve the best compression gain.
- It makes error concealment very difficult.
- Keep some redundancy in the source coding stage such that better error concealment can be performed at the decoder.

Robust Waveform Coding by Motion-Compensated Temporal Prediction

- Replace a damaged macroblock with the spatially corresponding macroblock in the previous frame.
- MPEG-2 coder has the option of sending motion vectors for macroblocks in I-frame, when certain macroblocks in I-frame are damaged, motion vector can be used to retrieve the missing details if they are damaged during transmission.

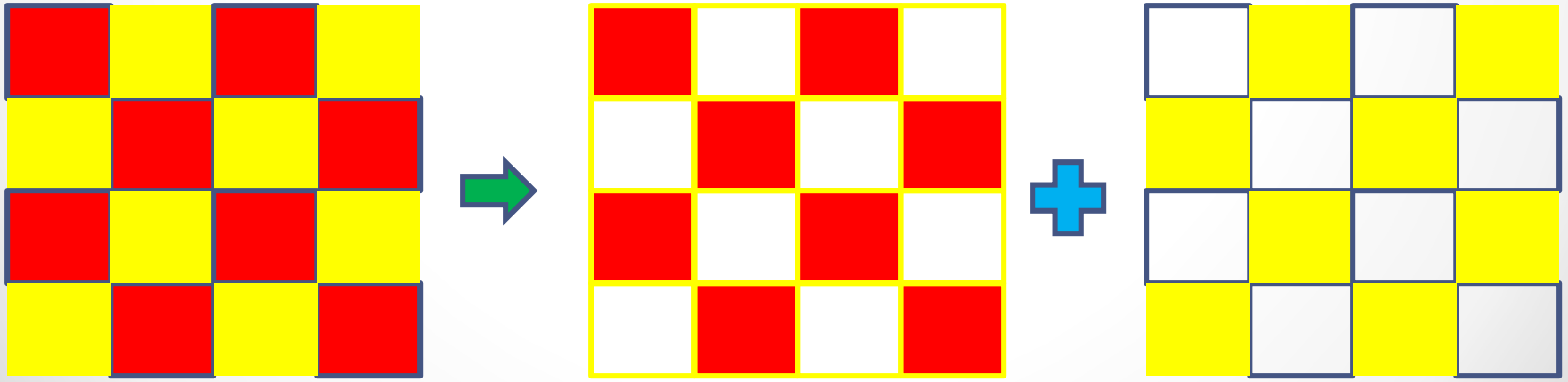


Robust Entropy Coding

- Add redundancy in the entropy coding stage to help detect bit errors and/or prevent error propagation.
- In variable length coding (VLC), a single bit error can lead to the loss of synchronization.
- When bit error happen, decoder can recognizes that an error, but it may not know which bit is in error, so cannot decode subsequent bits.
- Insert a unit synchronization code word in the bit stream, decoder will regain synchronization when the decoder captures the code word.

Transport Level Control

- The header and coding mode information is embedded into all packets. So when one packet loss, other packet can still be useful.
- A packet contains data from several blocks, successive blocks are put into non-adjacent packet.
- A packet will affect blocks in an interleaved order, which will ease the error concealment performed at the decoder, since the damaged block is surrounded by undamaged blocks.



Error Concealment by Post-Processing at the Decoder

- All the post-processing techniques make use of the correlation between a damaged macroblock and its adjacent macroblocks in the same frame and/or the previous frame.
  - Maximally smooth recovery
  - Projection onto Convex Sets (POCS)
  - Recovery of motion vectors and coding mode

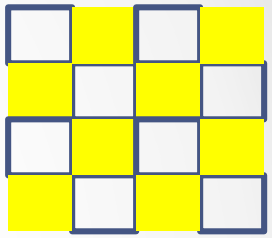
Maximally Smooth Recovery

- Make use of the smoothness property of most image and video signals.
- The method minimizes a measure of spatial and temporal variation between adjacent pixels in the block and its spatially and temporally neighboring blocks, so that resulting estimated video signal is as smooth as possible.

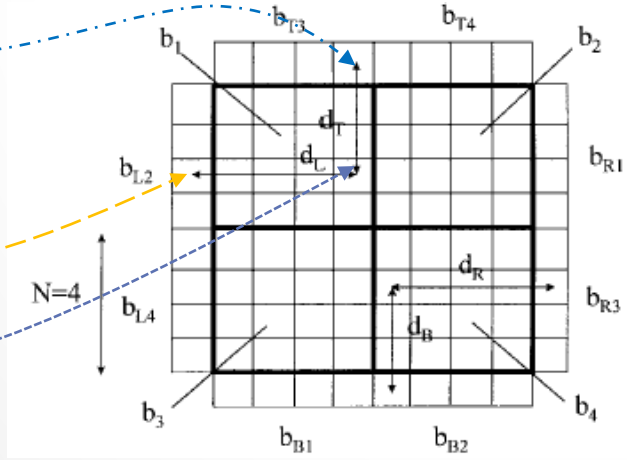
Maximally Smooth Recovery -- Spatial Domain

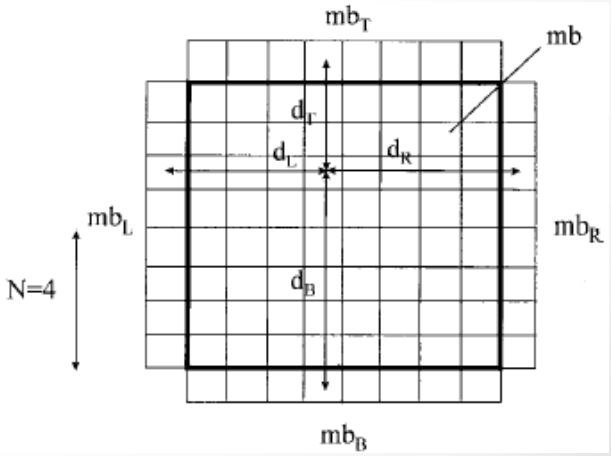
Interpolation

- Two methods to improve the estimation accuracy.
  - A pixel is interpolated from two pixels in its two nearest boundaries.
  - A pixel in the macroblock is interpolated from the pixels in all four boundary.



$$c = a \times \frac{\frac{1}{d_L}}{\frac{1}{d_L}+\frac{1}{d_T}} + b \times \frac{\frac{1}{d_T}}{\frac{1}{d_L}+\frac{1}{d_T}} = a \times \frac{d_T}{d_T+d_L} + b \times \frac{d_L}{d_T+d_L}$$

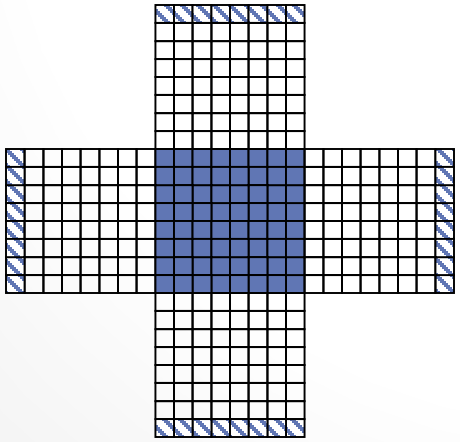




Maximally Smooth Recovery -- Frequency Domain

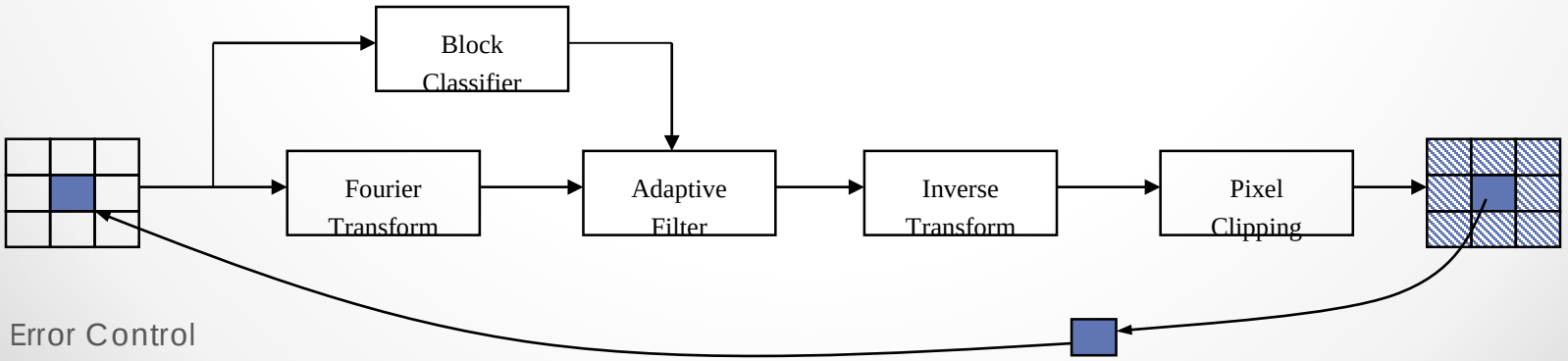
Interpolation

- Coefficient in a damaged block is likely to be close to the corresponding coefficients in spatially adjacent blocks.
- Frequency domain interpolation is equivalent to interpolating each pixel in the damaged block from the corresponding pixels in four adjacent blocks rather than the nearest pixels.
- The pixels used for interpolation are eight pixels away in four different directions, the correlation between these pixels and the missing pixel is likely to be small.



Projection onto Convex Sets (POCS)

- Sobel operator is used to test the edge existence of the combined block.
- The block is classified as either a monotone block or an edge block.
- The edge orientation is quantized to one of the eight directions with equal space from 0-180^{o}.
- First projection is depend on the edge classified output
  - Monotone block: the block is subject to isotropic low-pass filter.
  - Edge block: band-pass filter is applied along that direction.
- The above filtering is applied in the Fourier transform domain.
- Second projection: truncates the output pixel values to the range [0,255], and eight surrounding blocks values remain to original values.
- Two projection operations are applied until the block does not change anymore.



Symmetric

Projection onto Convex Sets (POCS)

222	222	222	222	222	222	222	222
0	222	222	222	222	222	222	222
0	0	222	222	222	222	222	222
0	0	0	222	222	222	222	222
0	0	0	0	222	222	222	222
0	0	0	0	0	222	222	222
0	0	0	0	0	0	222	222
0	0	0	0	0	0	0	222

999.0000	-505.6505	0.0000	-52.8587	0	-15.7686	-0.0000	-3.9796
505.6505	111.0000	-231.9944	-0.0000	-41.6617	0.0000	-12.7719	0.0000
0	231.9944	111.0000	-131.4143	0	-26.1399	0.0000	-6.1333
52.8587	-0.0000	131.4143	111.0000	-85.2677	0.0000	-16.2045	-0.0000
0	41.6617	0	85.2677	111.0000	-56.9741	0	-8.2870
15.7686	-0.0000	26.1399	0.0000	56.9741	111.0000	-36.3714	0.0000
0	12.7719	0	16.2045	0	36.3714	111.0000	-19.1145
3.9796	0.0000	6.1333	-0.0000	8.2870	0.0000	19.1145	111.0000

222	222	222	222	222	222	222	222
222	222	222	222	222	222	222	0
222	222	222	222	222	222	0	0
222	222	222	222	222	0	0	0
222	222	222	222	0	0	0	0
222	222	222	0	0	0	0	0
222	222	0	0	0	0	0	0
222	0	0	0	0	0	0	0

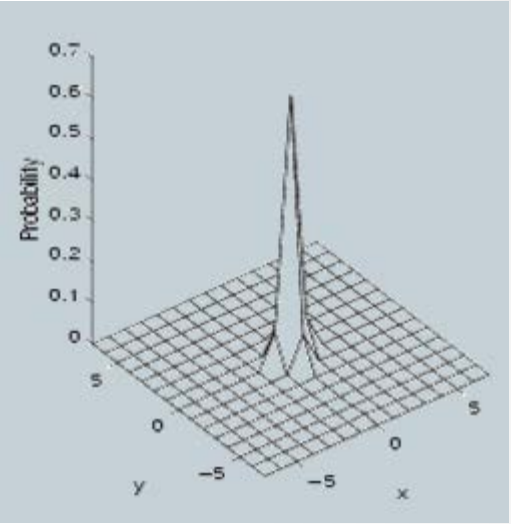
999.0000	505.6505	0.0000	52.8587	0	15.7686	-0.0000	3.9796
505.6505	-111.0000	-231.9944	0.0000	-41.6617	-0.0000	-12.7719	-0.0000
0	-231.9944	111.0000	131.4143	0	26.1399	0.0000	6.1333
52.8587	0.0000	131.4143	-111.0000	-85.2677	-0.0000	-16.2045	0.0000
0	-41.6617	0	-85.2677	111.0000	56.9741	0	8.2870
15.7686	0.0000	26.1399	-0.0000	56.9741	-111.0000	-36.3714	-0.0000
0	-12.7719	0	-16.2045	0	-36.3714	111.0000	19.1145
3.9796	-0.0000	6.1333	0.0000	8.2870	-0.0000	19.1145	-111.0000

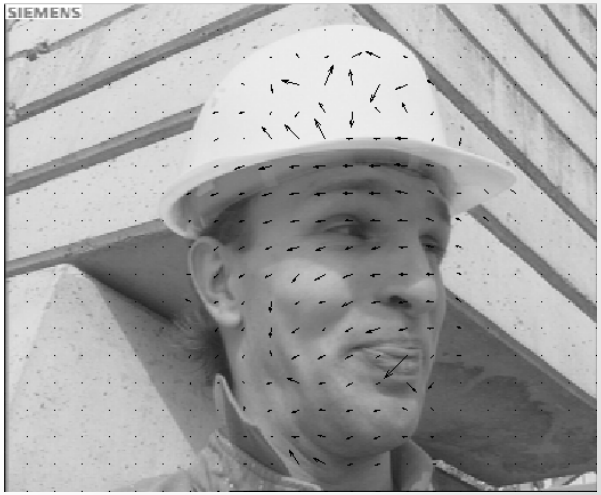
222	222	222	222	222	0	0	0
222	222	222	222	222	0	0	0
222	222	222	222	222	0	0	0
222	222	222	222	222	0	0	0
222	222	222	222	222	0	0	0
222	222	222	222	222	0	0	0
222	222	222	222	222	0	0	0
222	222	222	222	222	0	0	0

222	222	222	222	222	222	222	222
222	222	222	222	222	222	222	222
222	222	222	222	222	222	222	222
222	222	222	222	222	222	222	222
222	222	222	222	222	222	222	222
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Recovery of Motion Vectors

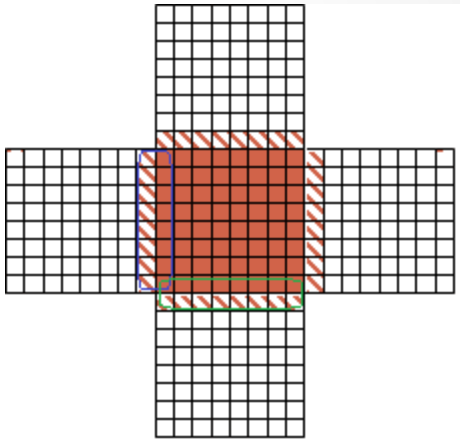
- Assuming that picture is spatial and temporal smoothness, motion vectors can be interpolated from the adjacent blocks.
- There are four methods
  - Simply setting the motion vectors to zeros, which works well for video sequences with relatively small motion.
  - Using the motion vectors of the corresponding block in the previous frame.
  - Using the average of the motion vectors from spatially adjacent blocks.
  - Using the median of motion vectors from the spatially adjacent blocks.





Recovery of Motion Vectors

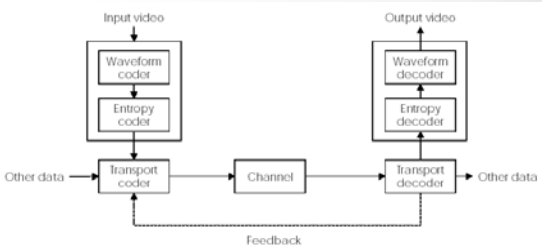
- Select among four methods, depending on which one yields the least boundary matching error.
- The error defined as the sum of variations along the one pixel wide boundary between the recovered macroblock with residue coefficients and the one on above, below, left and right respectively.
- If the residue coefficients are also lost, we assume that the residue coefficients of the damaged block are zero.
- The combination of the motion vector and residue coefficients that obtains the smallest boundary matching error is the final estimation solution.

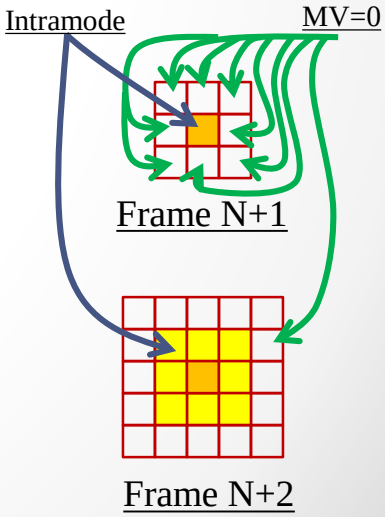


Encoder and Decoder Interactive Error

Concealment

- Better performance can be achieved if the encoder and decoder cooperate in the process of error concealment.
- Re-transmission leads to decoding delays that may be unacceptable for real-time applications.
- One technique is whenever the decoder detects an error, it sends a request to the encoder so that the next video frame is coded in intramode. Error propagation will hence stop, after a round trip delay.
- To reduce the bit rate increase due to the intra mode request, only part of the image need to intra code with a correct estimation of the motion vector range. E.g. MV range is [+15, -15] in frame number N, if the encoder receive the intra mode request before frame N+2, the affected range is [+30, -30]. Eight adjacent macroblock and the missing macroblock may need to be resent.





Error Resilience in MPEG-4

- Error resilience tools in MPEG-4
  - Resynchronization marker
  - Motion maker (Data partitioning)
  - Reversible Variable Length Codes (RVLC)
  - Adaptive Intra Refresh (AIR) method

Resynchronization Marker

- Resynchronization marker is used to distinguish the start of a new video packet.
- Uniquely identifiable from all possible VLC code words as well as the VOP start code.
- All predictively encoded information must be restricted within a video packet so as to prevent the propagation of errors.
- Start with the macroblock number and quantization parameter.

17 bits

Resynchronization Marker

- The length of the video packets are not based on the number of macroblocks, but instead on the number of bits contained in that packet.
- If the number of bits contained in the current video packet exceeds a predetermined threshold, then a new video packet is created at the start of the next macroblock.

Resync Marker	macroblock _number	quant_ scale	HEC	Macroblock Data	Resync Marker

** Resynchronization marker is a binary string of at least 16 zero's followed by a one "0 0000 0000 0000 0001".

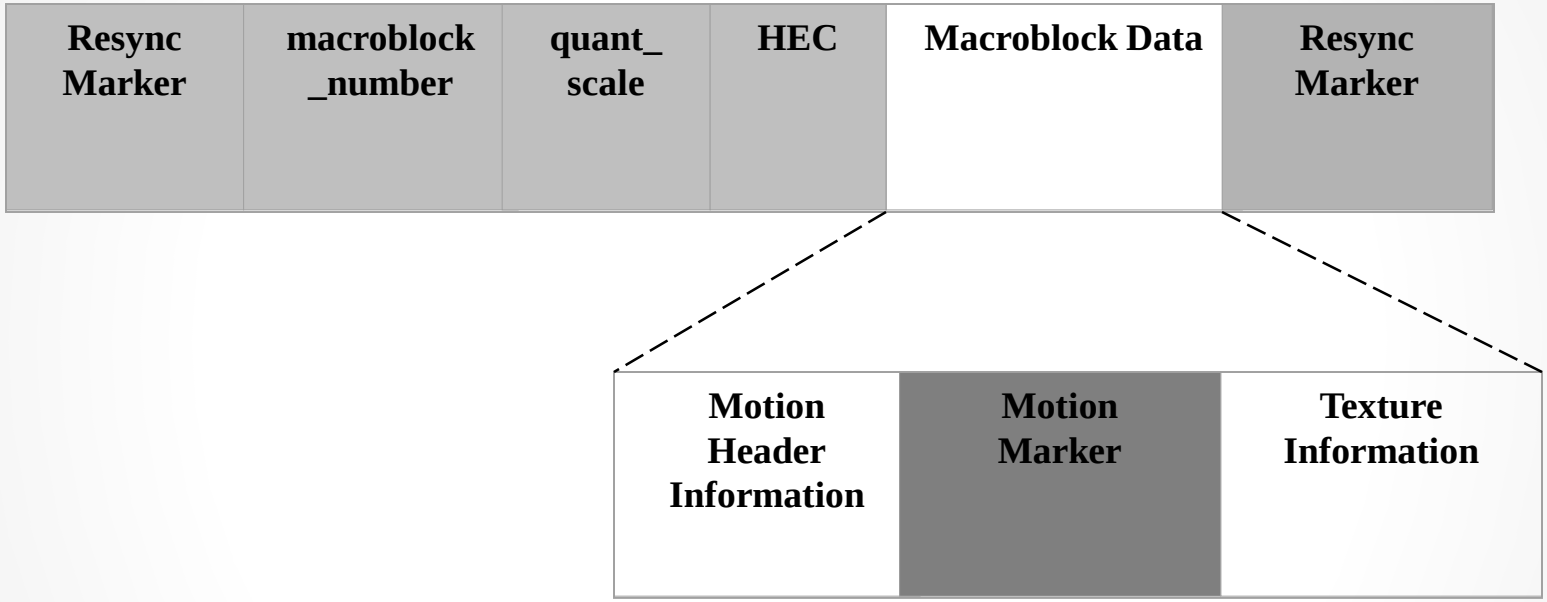
MVs + Motion marker + DCT

Motion marker (Data partitioning)

- The grouped MVs and DCT coefficients are separated by a boundary marker. Since motion is more important than DCT coefficients.
- The boundary marker signals the end of the MV and the beginning of the DCT coefficient.
- Advantages
  - errors can be localized to data of a certain type, and the unaffected data can be employed for video reconstruction.
  - if undetected errors occur in a video packet, the received data can be considered invalid if the boundary marker is not detected.

motion

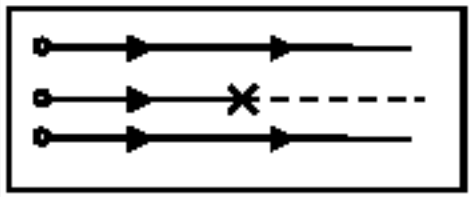
Motion marker (Data partitioning)



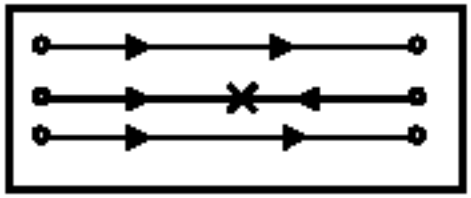
** Motion Marker is a 17-bit binary string ‘1 1111 0000 0000 0001’.

Reversible Variable Length Codes (RVLC)

- Errors are present in the following cases:
  - An illegal RVLC is found
  - More than 64 DCT coefficients are decoded in a block.
- Bi-directionally decodable
- The bit stream is decoded in the forward direction first.
- If no errors are detected, the bit stream is assumed to be valid and the decoding process is finished for that video packet.
- If an error is detected however, two-way decoding is applied.



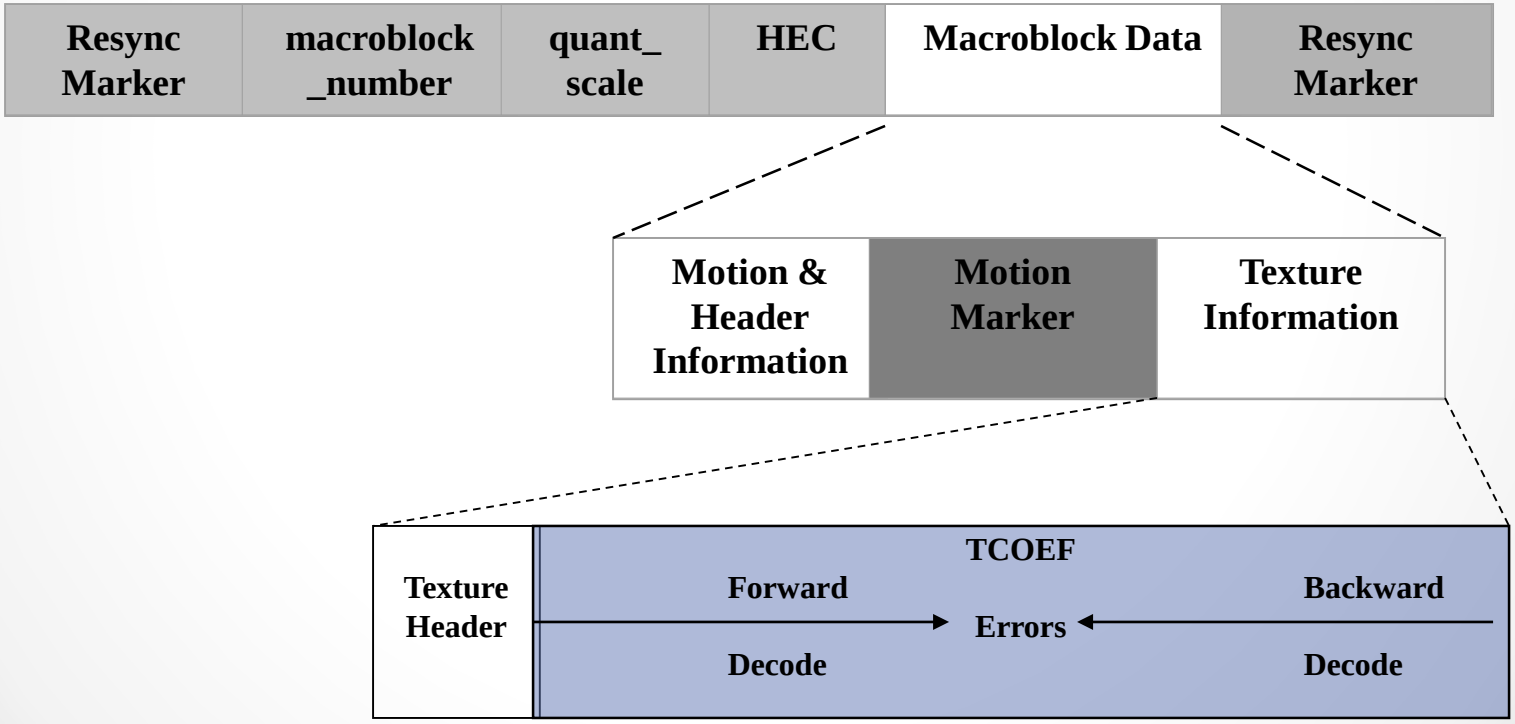
Forward decoding only



Forward and backward decoding

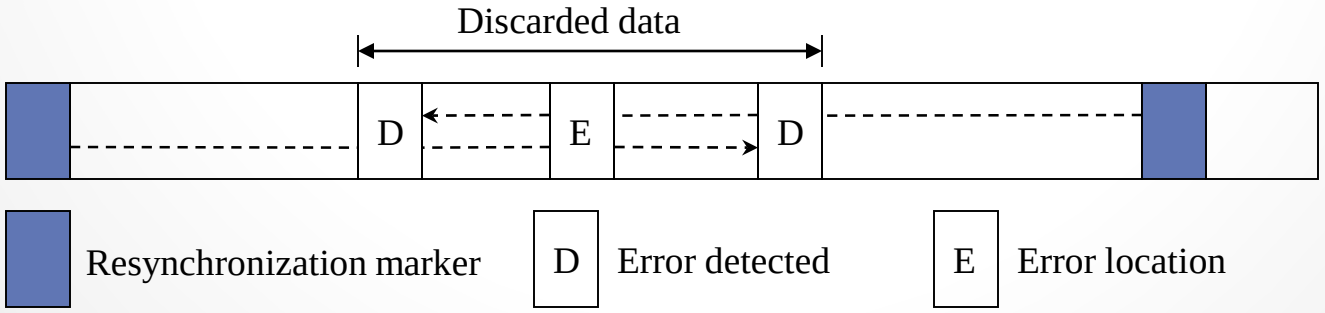
Reversible Variable Length Codes

- Compare the results from both forward decoder and backward decoder and take necessary steps to reduce error effects.



Reversible Variable Length Codes

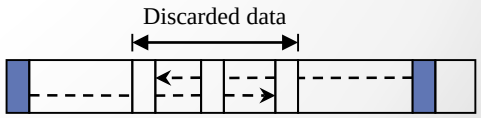
- Only DCT coefficients can have RVLC.
- VLCs that have the prefix property in the forward and reverse directions => uniquely decodable in both directions
- Can be constructed to be symmetric or asymmetric
- Asymmetrical RVLCs provide better compression efficiency than symmetrical RVLCs
- Disadvantage: reduces the compression efficiency
- Usually employed with data partitioning



Symmetric and Asymmetric RVLC

	Probability	Length	Codeword	Length	Codeword
E	0.14878570	3	010	3	000
T	0.09354149	3	101	3	111
A	0.08833733	4	0110	4	0101
O	0.07245796	4	1001	4	1010
R	0.06872164	4	0000	4	0110
N	0.06498532	4	1111	4	1001
H	0.05831331	5	01110	4	0011
I	0.05644515	5	10001	4	1100
S	0.05537763	5	00100	5	00100
D	0.04376834	5	11011	5	11011
L	0.04123298	6	011110	5	01110
U	0.02762209	6	100001	5	10001
P	0.02575393	6	001100	6	010010
F	0.02455297	6	110011	6	101101
M	0.02361889	7	0111110	6	011110
C	0.02081665	7	1000001	6	100001
W	0.01868161	7	0011100	6	001011
G	0.01521216	7	1100011	6	110100
Y	0.01521216	7	0001000	7	0100010
B	0.01267680	7	1110111	7	1011101
V	0.01160928	8	01111110	7	0010100
K	0.00867360	8	10000001	7	1101011
X	0.00146784	8	00111100	8	10111101
J	0.00080064	9	011111110	9	010000010
Q	0.00080064	10	0111111110	10	0100000010
Z	0.00053376	10	1000000001	10	1011111101
Average length		4.46463681		4.18734808	

- try this example: ETAO: 010101011001001
- symmetric codeword one bit error 010001011001001
- which bits to be discarded?
- what is the decoded codeword?



Use MB to update I

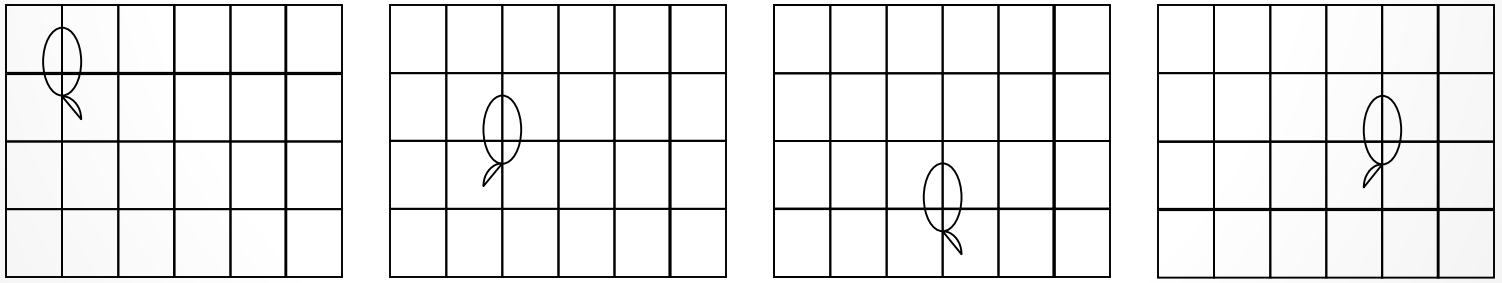
Adaptive Intra Refresh (AIR) Method

- AIR is the technique of the intra refresh method for the error resilience.
- The technique is to extract the motion area from the rectangular VOP at the encoder and encode it in intra mode.
- The estimation of motion is performed by the comparison between SAD and SAD_th. SAD is the Sum of the Absolute Differential value between the current MB and the MB in same location of the previous VOP.
- If SAD greater than SAD_th, the MB is considered as a motion MB, the corresponding location in the Refresh Map need to be set and wait for intra encoding.
- The quality of this area that is corrupted by the transmission error can be recovered quickly.
- The number of Intra MBs to be refreshed in a VOP is fixed and pre-determined. It depends on bitrates and frame rate.

Low activity

Adaptive Intra Refresh (AIR) Method

- The processing of the "AIR"
- The fixed number of the Intra MB to be refreshed in a VOP is set to "2" as an example.

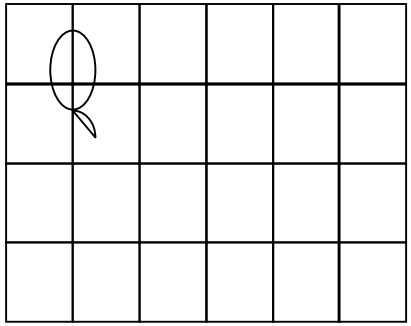


1st VOP 2nd VOP 3rd VOP 4th VOP

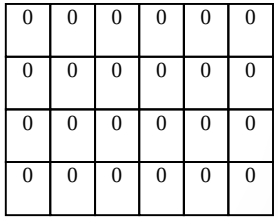
Adaptive Intra Refresh (AIR) Method

- 1st VOP ([a]~[b]): The all MBs in the 1st VOP are encoded in Intra mode [a]. The Refresh Map is set to “0”, because there is no previous VOP [b].

1st VOP



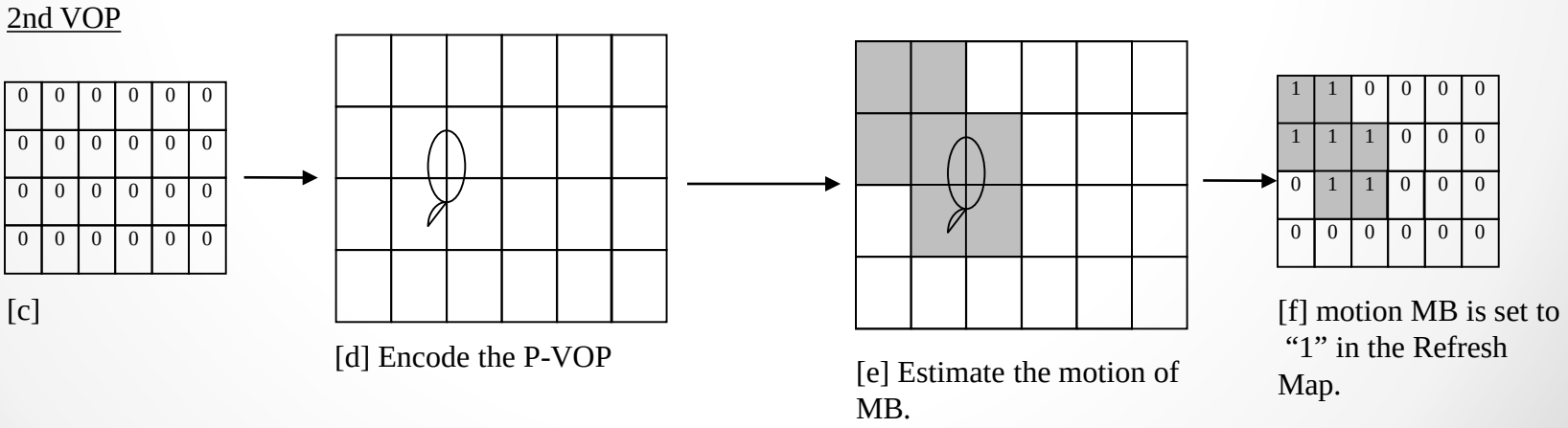
[a] Encode the I-VOP



[b] Refresh Map

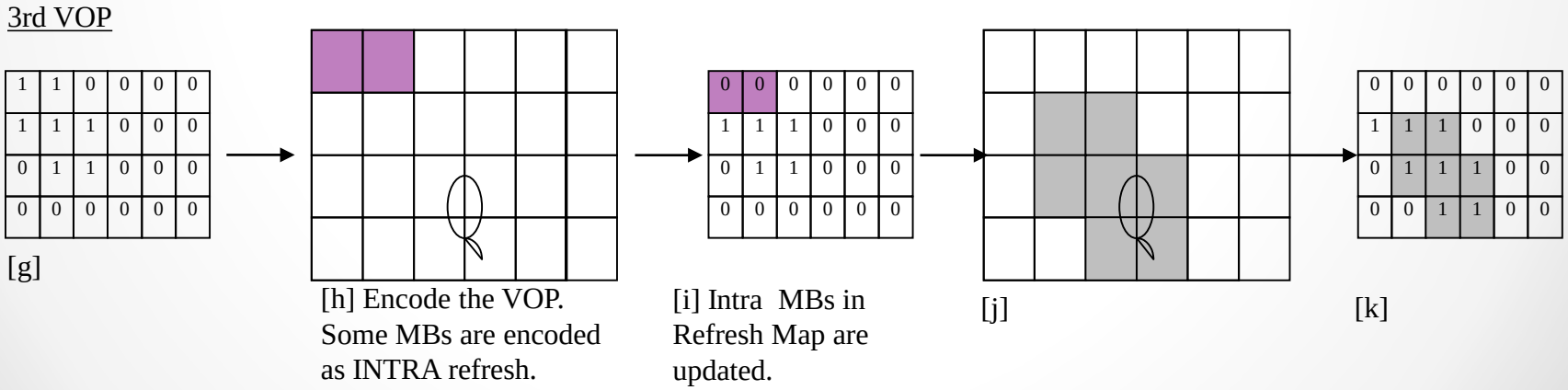
Adaptive Intra Refresh (AIR) Method

- 2nd VOP ([c] ~ [f]): The 2nd VOP is encoded as P-VOP. Intra refresh is not performed in this VOP, because all values in the Refresh Map is zero ([c] and [d]). The encoder estimates motion of each MB. If the SAD for current MB is larger than the SAD_th, it is regarded as motion area (hatched area in [e]). And the Refresh Map is updated [f].



Adaptive Intra Refresh (AIR) Method

- 3rd VOP ([g] ~ [k]): When the 3rd VOP is encoded, the encoder refers to the Refresh Map [g]. If the current MB is the target of the Intra refresh, it is encoded in Intra mode [h]. The value of the MB in Refresh Map is decreased by 1 [i]. If the decreased value is 0, this MB is not regarded as motion area. After this, the processing is as same as the 2nd VOP [j]~[k].



Adaptive Intra Refresh (AIR) Method

- 4th VOP ([l]~[p]): It is as same as 3rd VOP.