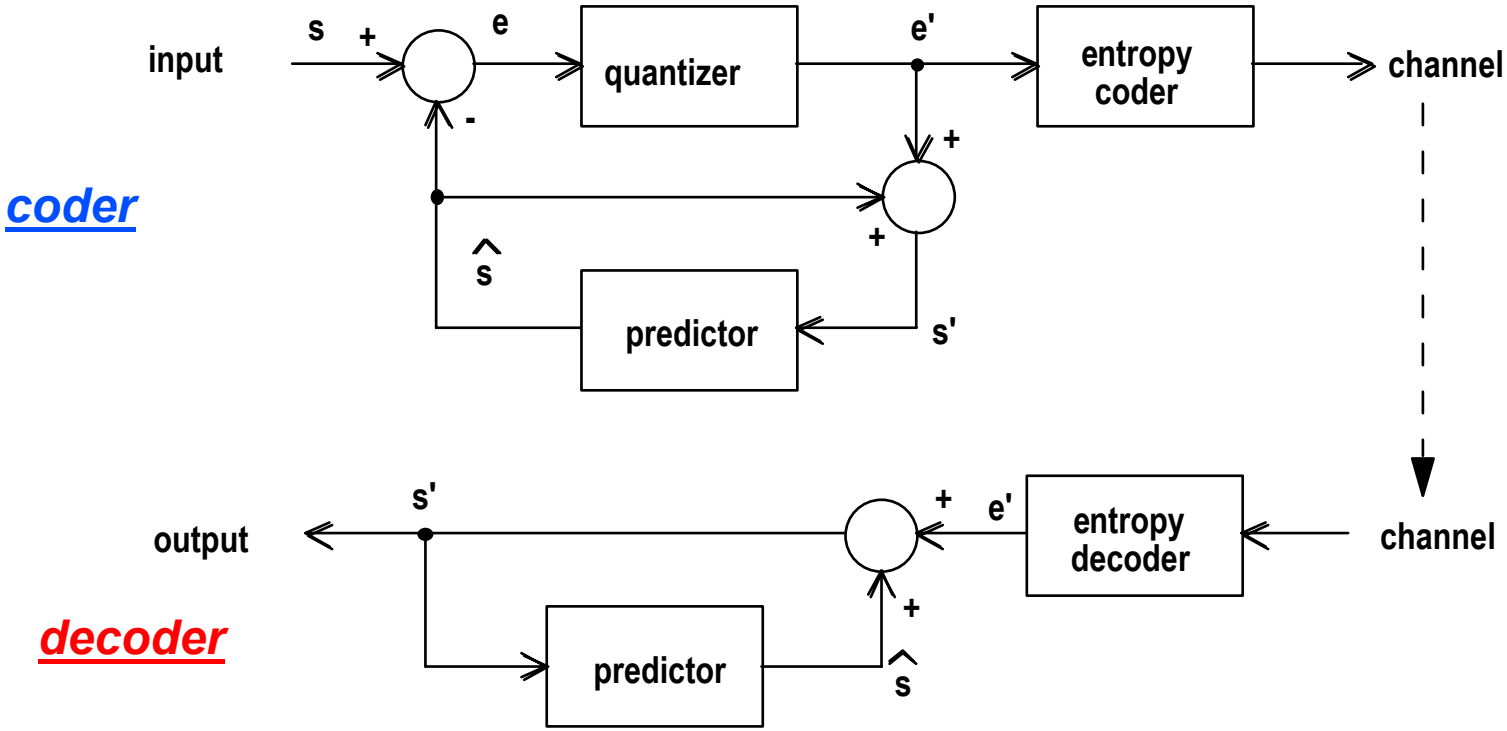
DPCM - Overview

- Principle of Differential Pulse Code Modulation (DPCM)
- Characteristics of DPCM quantization errors
- Predictive coding gain
- Adaptive intra-interframe DPCM
- Conditional Replenishment

Principle of DPCM



Prediction error

$$e = s - \hat{s}$$

Reconstruction

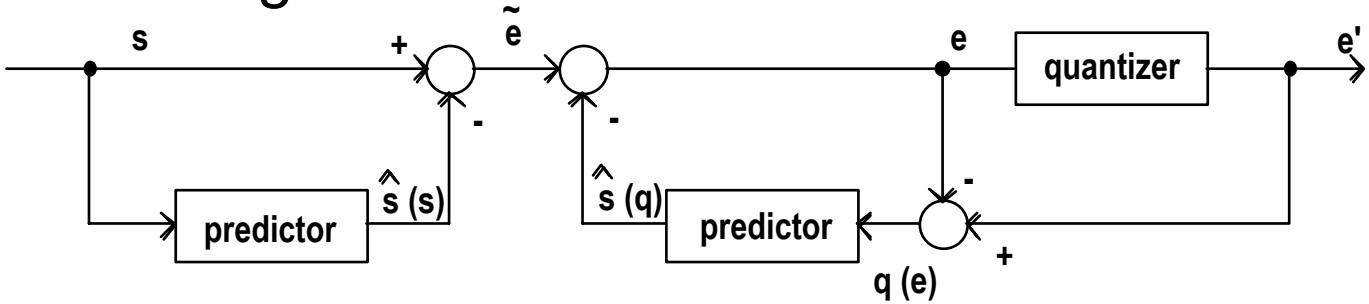
$$s' = e' + \hat{s}$$

Reconstruction error = quantization error

$$s' - s = e' - e = q$$

Quantization error feedback in the DPCM coder

- Assuming a linear predictor, the DPCM coder is equivalent to the following structure:



- Transfer function of the prefilter:

$$\tilde{E}(\Omega) = [1 - P(\Omega)]S(\Omega)$$

Ω - abbreviation for frequency vector, e.g., (ω_x, ω_y)

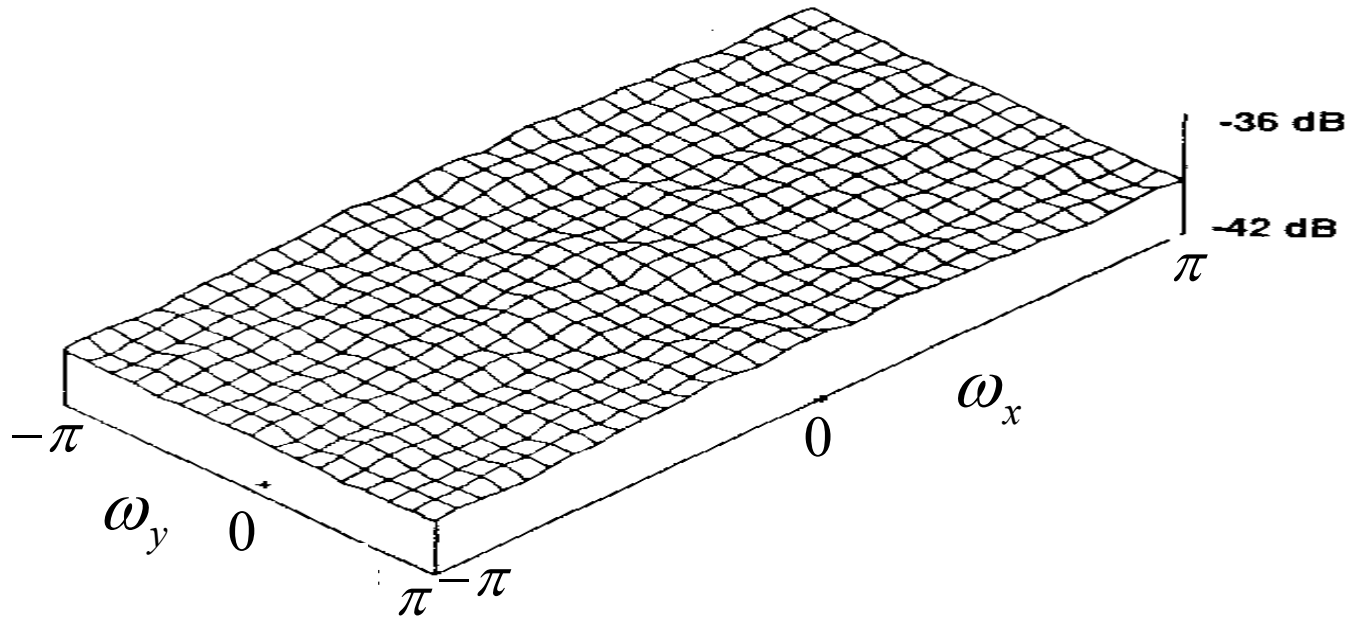
transfer function of the predictor

- Transfer function of quantization error feedback:

$$E'(\Omega) = \tilde{E}(\Omega) + [1 - P(\Omega)]Q(\Omega)$$

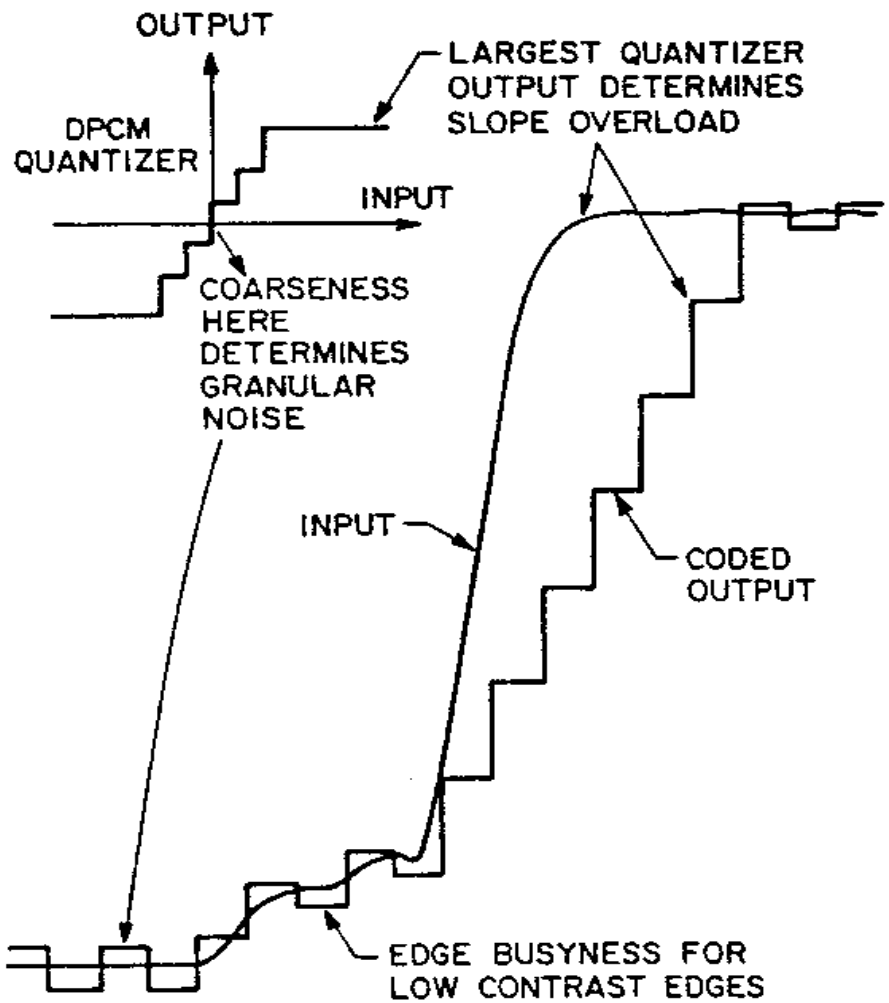
Power spectrum of the DPCM quantization error

- Power spectral density of the quantization error q measured for intraframe DPCM with a 16 level quantizer

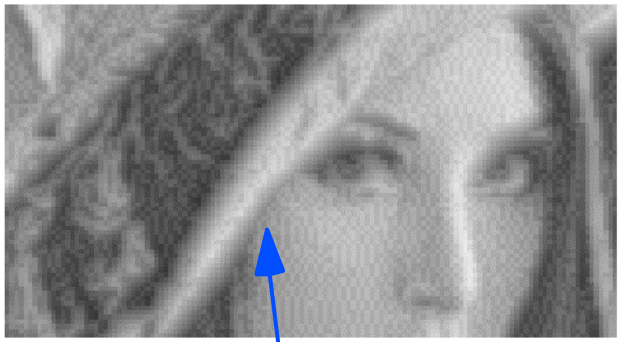


Signal distortions due to intraframe DPCM coding

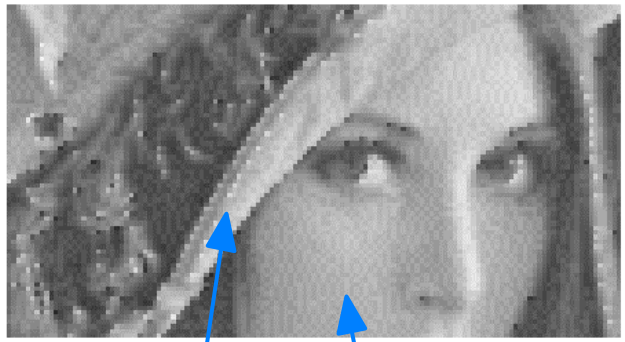
- Granular noise: random noise in flat areas of the picture
- Edge busyness: jittery appearance of edges (for video)
- Slope overload: blur of high-contrast edges, Moire patterns in periodic structures.



Example of intraframe DPCM coding



1 bit/pixel
prediction error coding



2 bit/pixel

3 bit/pixel

edge busyness

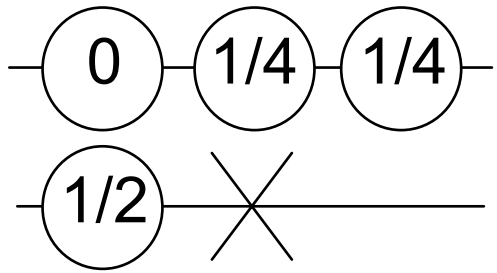
slope overload

granular noise

4 bit/pixel

original

- Linear predictor:



- Lloyd-Max quantizers
- Fixed-length coding

Recall from EE398A: High-rate performance of scalar quantizers

- High-rate distortion-rate function

$$d(R) \cong \varepsilon^2 \sigma_X^2 2^{-2R}$$

- Scaling factor ε^2

	Shannon LowBd	Lloyd-Max	Entropy-coded
Uniform	$\frac{6}{\pi e} \cong 0.703$	1	1
Laplacian	$\frac{e}{\pi} \cong 0.865$	$\frac{9}{2} = 4.5$	$\frac{e^2}{6} \cong 1.232$
Gaussian	1	$\frac{\sqrt{3}\pi}{2} \cong 2.721$	$\frac{\pi e}{6} \cong 1.423$

Predictive coding gain

- Distortion-rate function with DPCM

$$d_{DPCM}(R) \cong \varepsilon_e^2 \sigma_e^2 2^{-2R}$$

Variance of prediction error

- Prediction gain

$$G_{DPCM} = \frac{\varepsilon_s^2 \sigma_s^2}{\varepsilon_e^2 \sigma_e^2}$$

- Smallest achievable prediction error variance for N-dimensional signal determined by *spectral flatness*

$$\sigma_e^2 = \exp\left(\frac{1}{(2\pi)^N} \int_{\Omega} \ln\left(\Phi_{xx}(\Omega)\right) d\Omega \right)$$

Predictive coding gain (cont.)

- Consider 1-D Gaussian Markov-1 process with correlation coefficient ρ
- Autocorrelation function $E\left[S_n S_{n-k}\right] = \sigma_s^2 \left|\rho\right|^k$

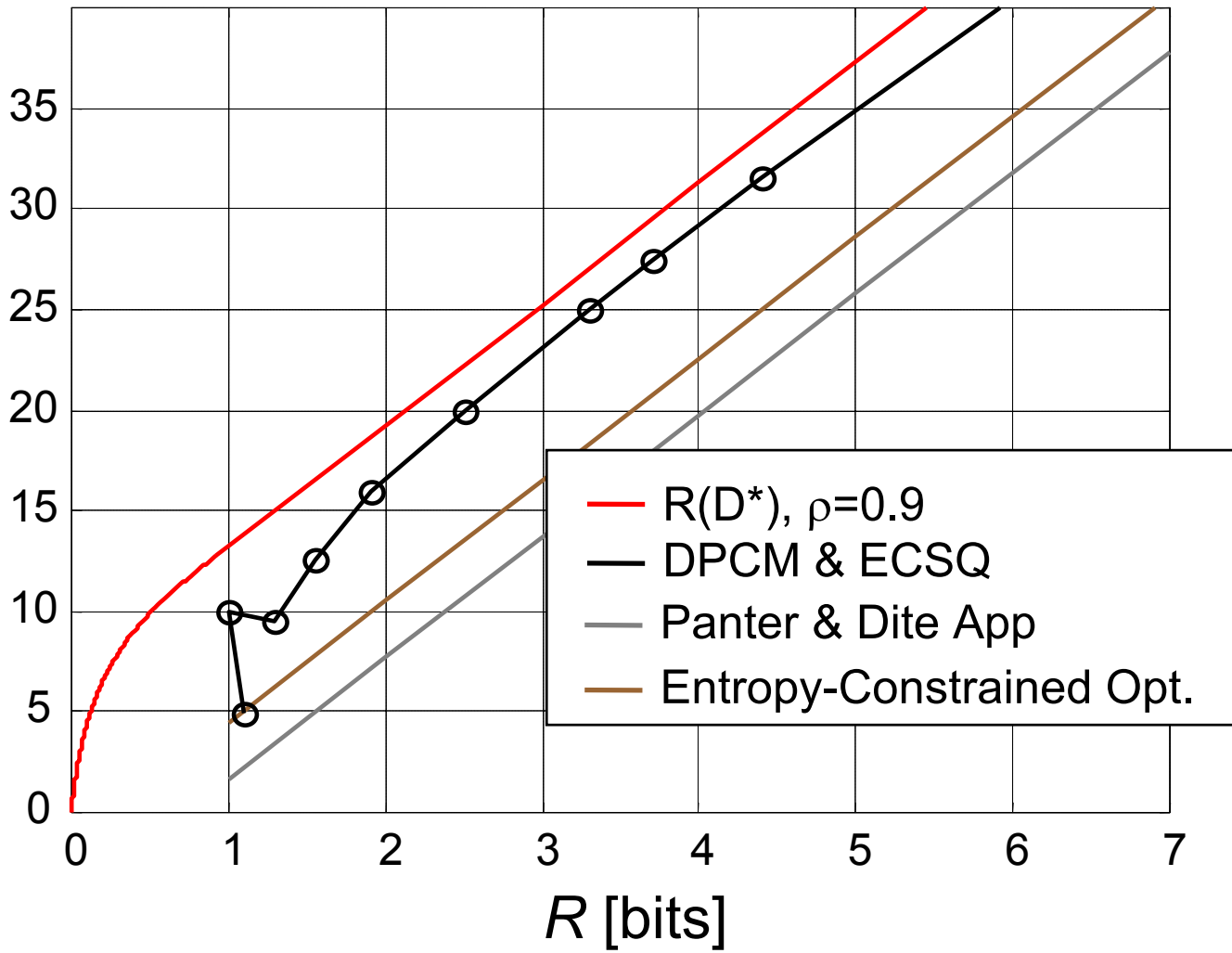
- Prediction gain

$$G_{DPCM} = \frac{1}{1-\rho^2}$$

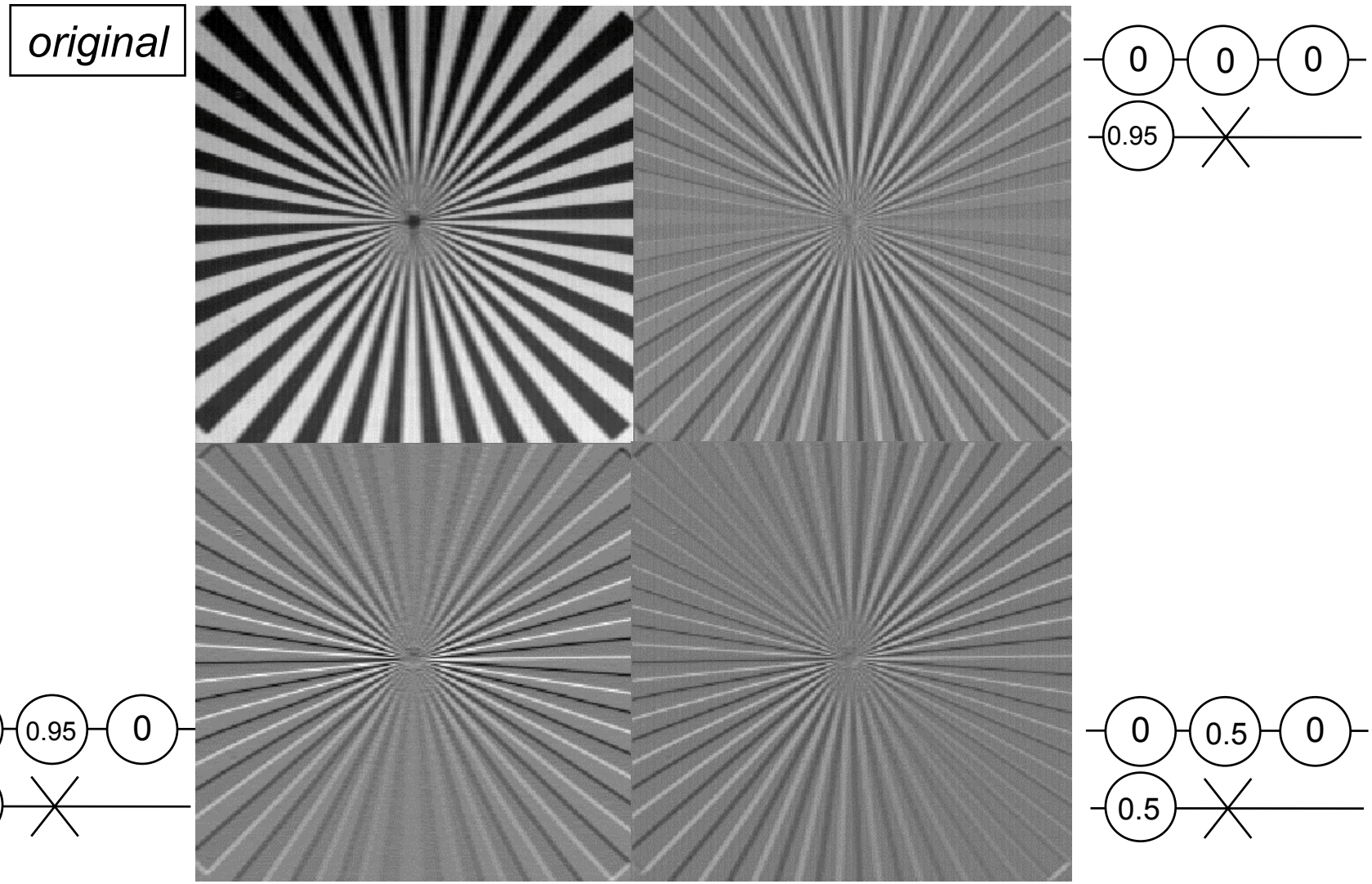
R-D curves for Gauss-Markov-1 source

$$\text{SNR [dB]} = 10\log_{10}\frac{\sigma^2}{D}$$

- Linear predictor order $N=1$, $a=0.9$
- Entropy-Constrained Scalar Quantizer with Huffman VLC
- Iterative design algorithm applied

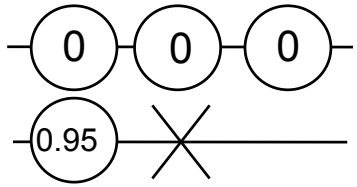


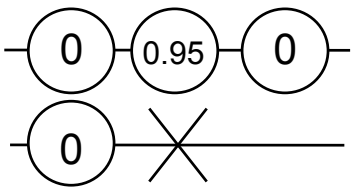
Prediction example: test pattern

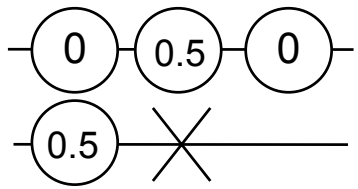


Prediction example: Cameraman

original

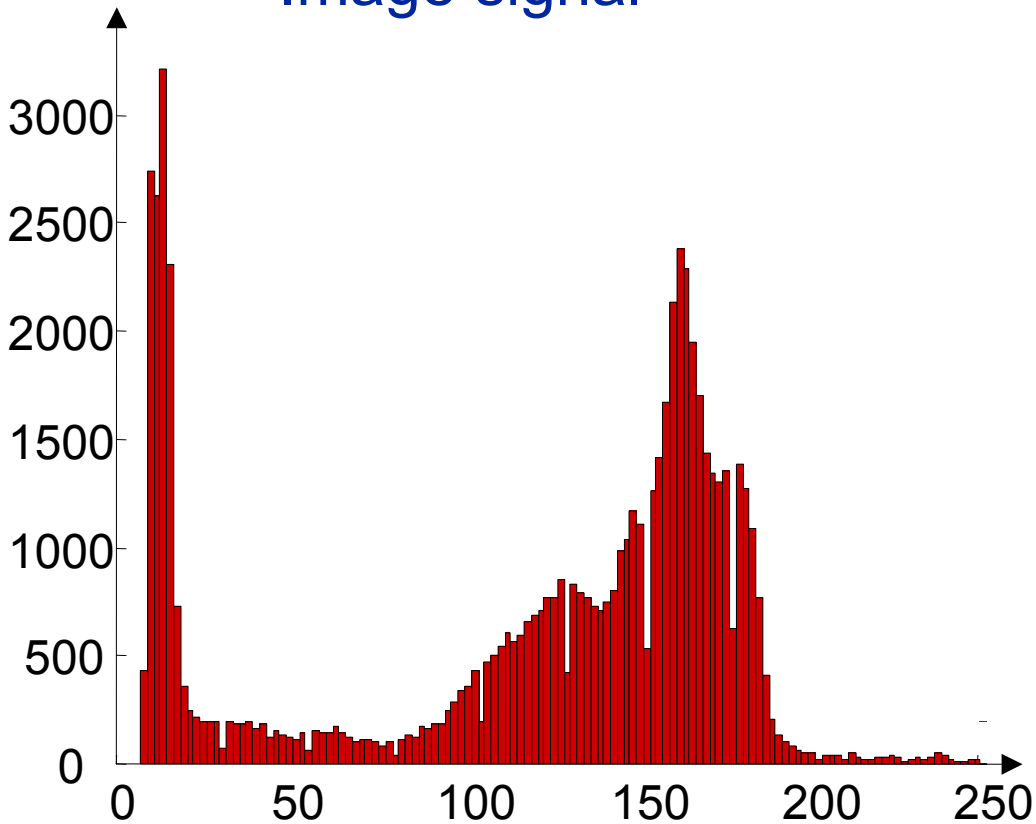




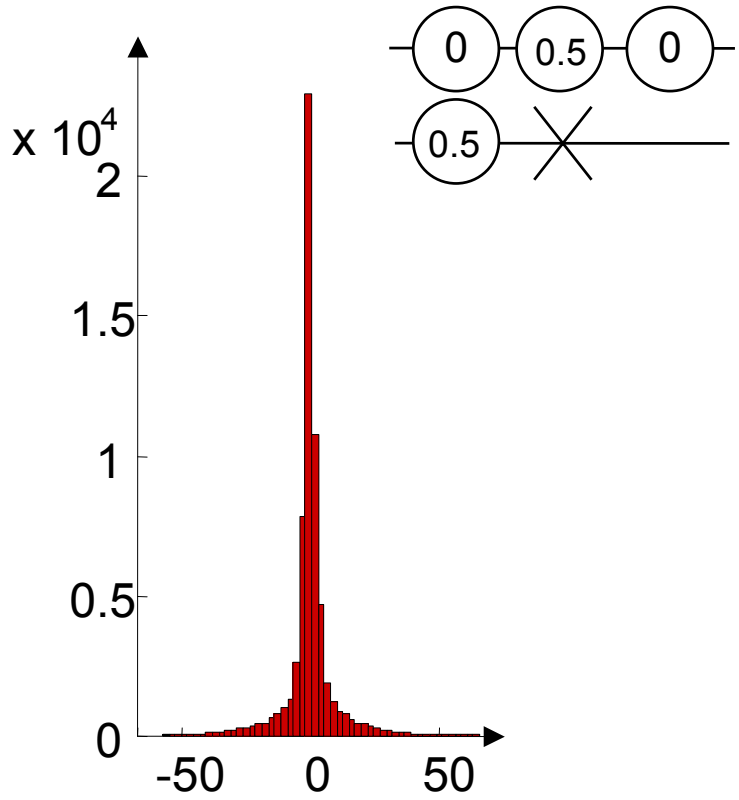


Histograms: Cameraman

Image signal



Prediction error



DPCM with entropy-constrained quantization

K=511, *H*=4.79 *bpp* *K*=15, *H*=1.98 *bpp* *K*=3, *H*=0.88 *bpp*

K...number of reconstruction levels, *H*...entropy

[J. R. Ohm]

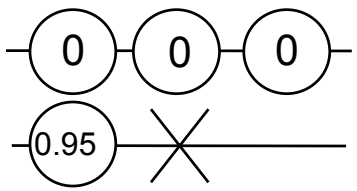
Transmission errors in a DPCM system

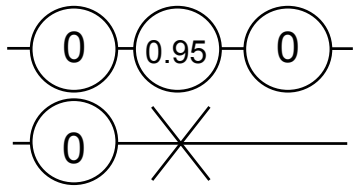
- For a linear DPCM decoder, the transmission error response is superimposed to the reconstructed signal S'
- For a stable DPCM decoder, the transmission error response decays
- For variable length coding, loss of synchronization can lead to errors in many prediction error samples after a single bit-error

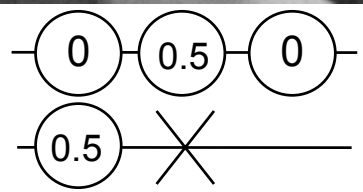
Transmission errors in a DPCM system (cont.)

Example: Lena, 3 *bpp* (fixed code word length)

Error rate: $p=10^{-3}$







[J. R. Ohm]

Interframe coding of video signals

- Interframe coding exploits similarity of temporally successive pictures
- Important interframe coding methods:
  - Adaptive intra-interframe coding
  - Conditional replenishment
  - Motion-compensated prediction

[Second Edition.]

PATENT SPECIFICATION

Convention Date (United States): April 25, 1929. **341,811**

Application Date (in United Kingdom): April 25, 1930. No. 12,805 / 30.

Complete Specification Accepted: Jan. 22, 1931.

COMPLETE SPECIFICATION.

Improvements relating to Electric Picture Transmission Systems.

We, THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, a British Company, having its registered office at Crown House, Aldwych, London, W.C. 2, (Assignees of RAY DAVIS KELL, of 111, Sanders Avenue, Scotia, County of Schenectady, State of New York, United States of America, a citizen of the United States of America), do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following

fineness of detail is limited only by the speed of the action to be transmitted.

The invention will be better understood from the following description when considered in connection with the accompanying drawings in which Fig. 1 illustrates a picture transmitting apparatus wherein the invention has been embodied; and Figs. 2 to 5 illustrate various details of an apparatus which may be utilised to receive the difference between the successive images of a picture or moving object.

"It has been customary in the past to transmit successive complete images of the transmitted picture."

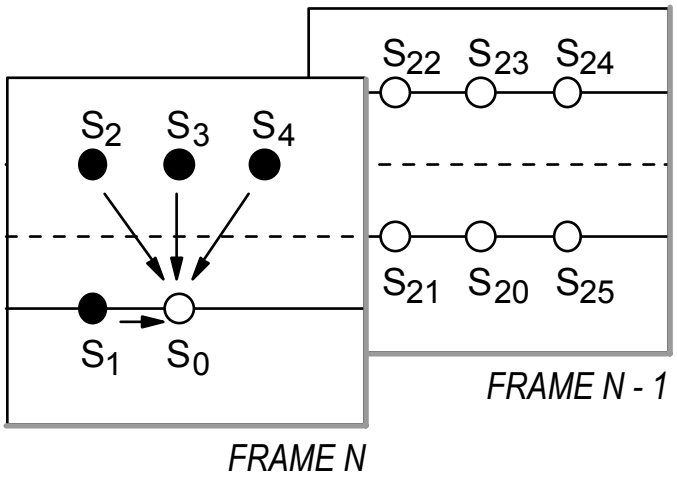
[...]

"In accordance with this invention, this difficulty is avoided by transmitting only the difference between successive images of the object."

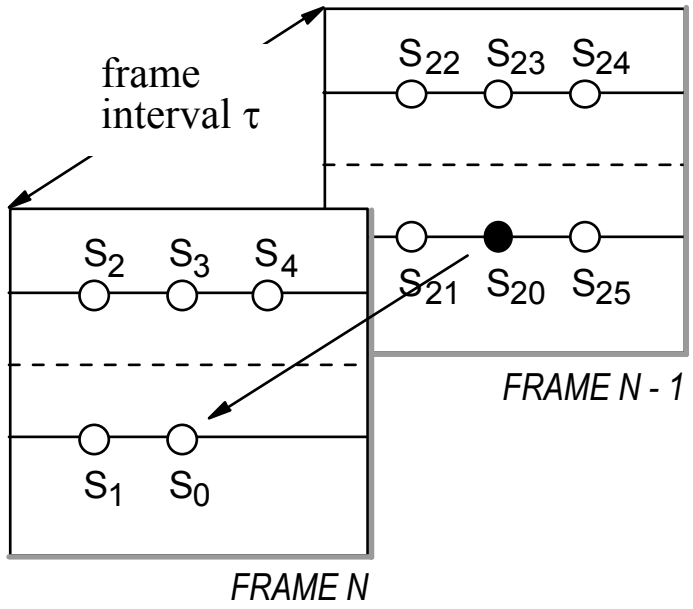
Principle of adaptive intra-interframe DPCM

- Predictor is switched between two states:

A: Intraframe prediction for moving or changed areas.



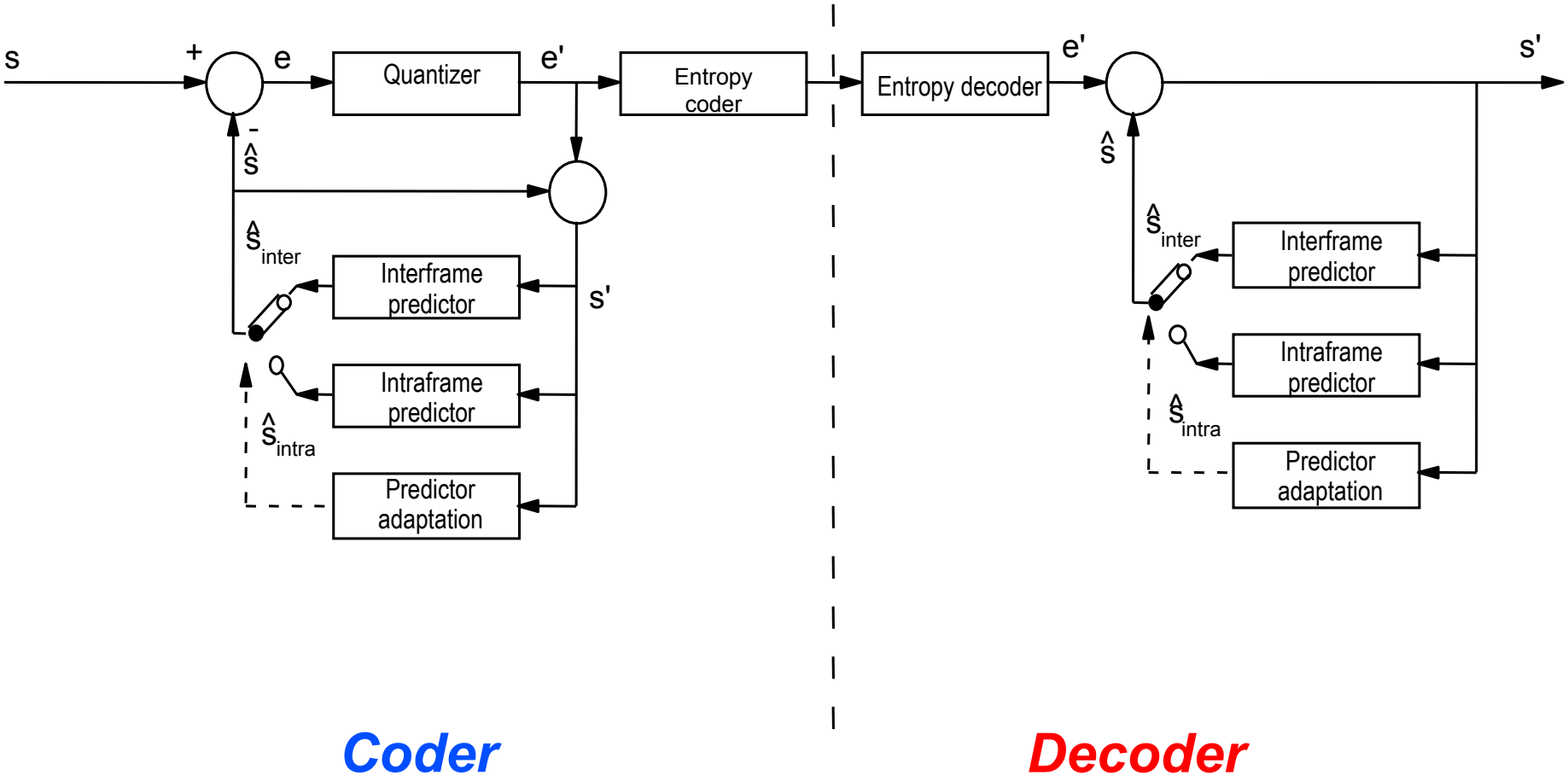
B: Interframe prediction (previous frame prediction) for still areas of the picture.



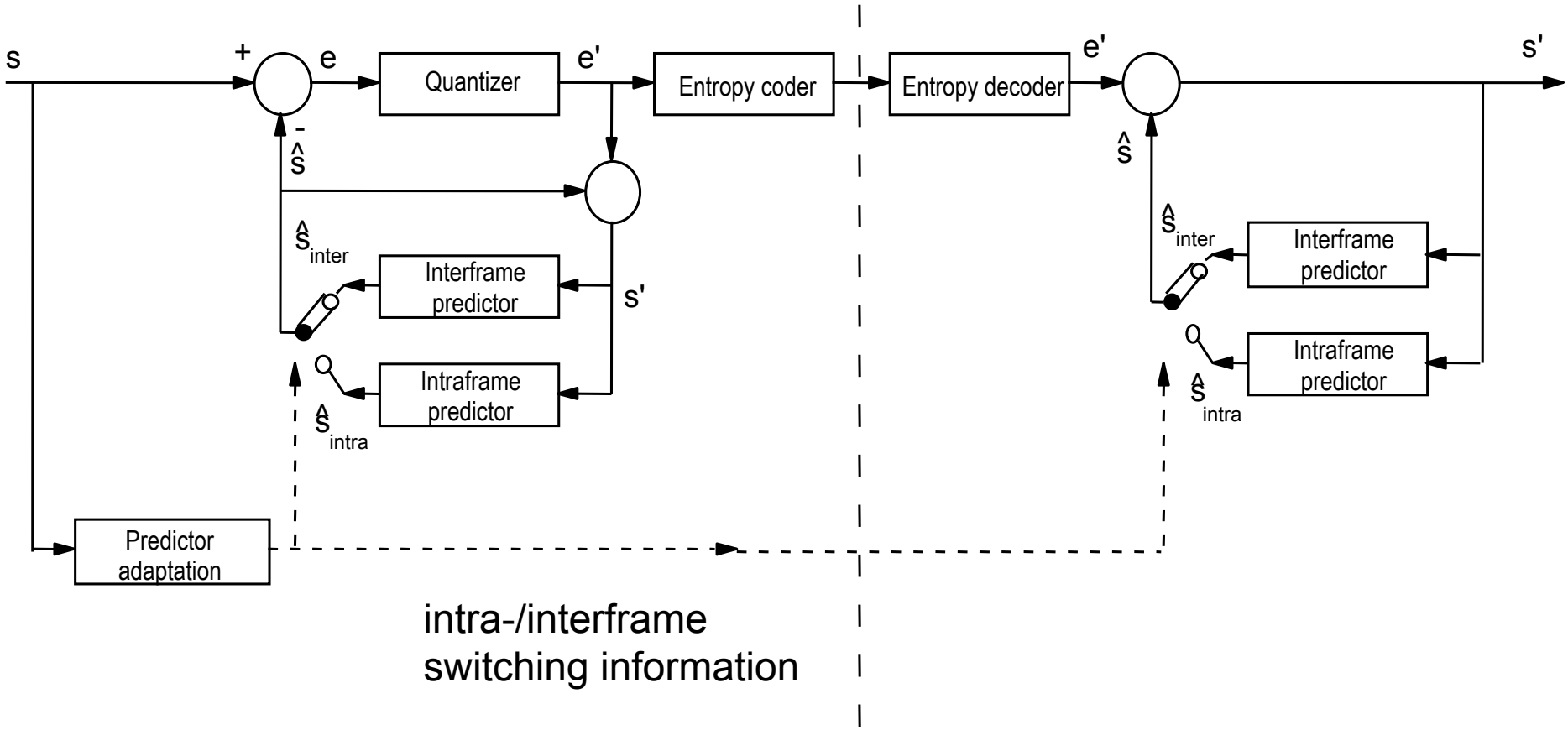
$$\hat{S}_{\text{intra}} = a_1 S_1 + a_2 S_2 + a_3 S_3 + a_4 S_4$$

$$\hat{S}_{\text{inter}} = S_{20}$$

Intra-interframe DPCM: feedback adaptation

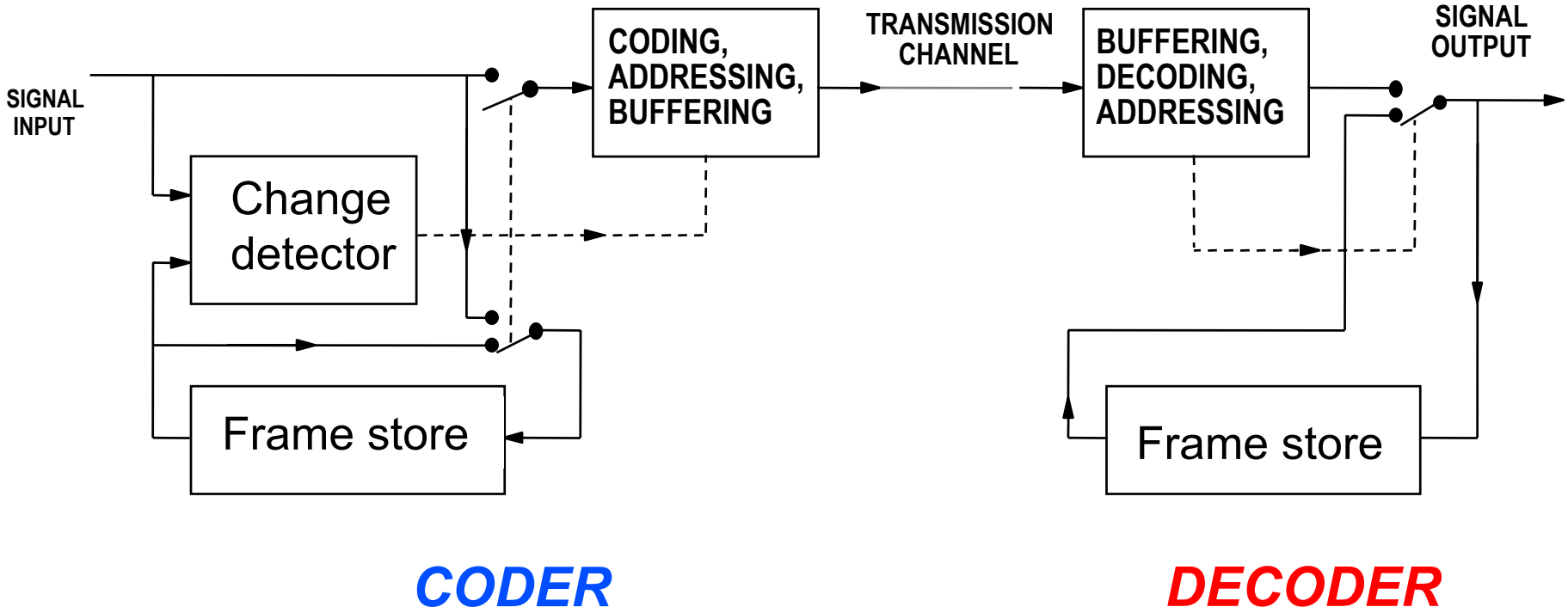


Intra-interframe DPCM: feedforward adaptation



Coder ***Decoder***

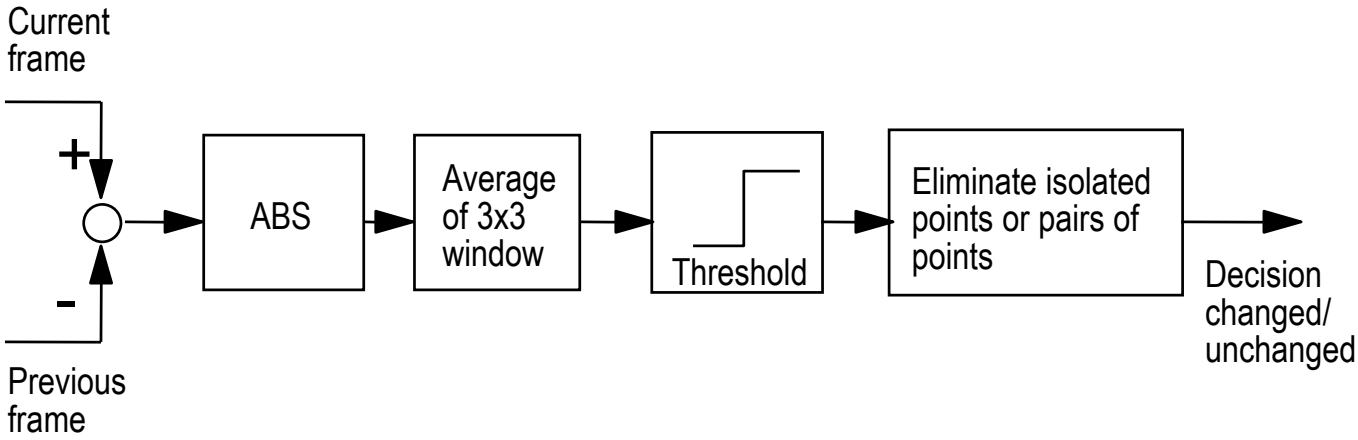
Conditional replenishment

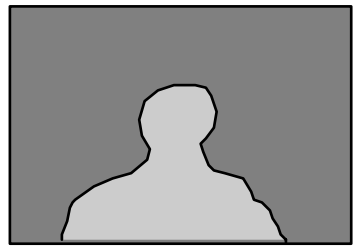


- Still areas: repeat from frame store
- Moving areas: encode and transmit address and waveform

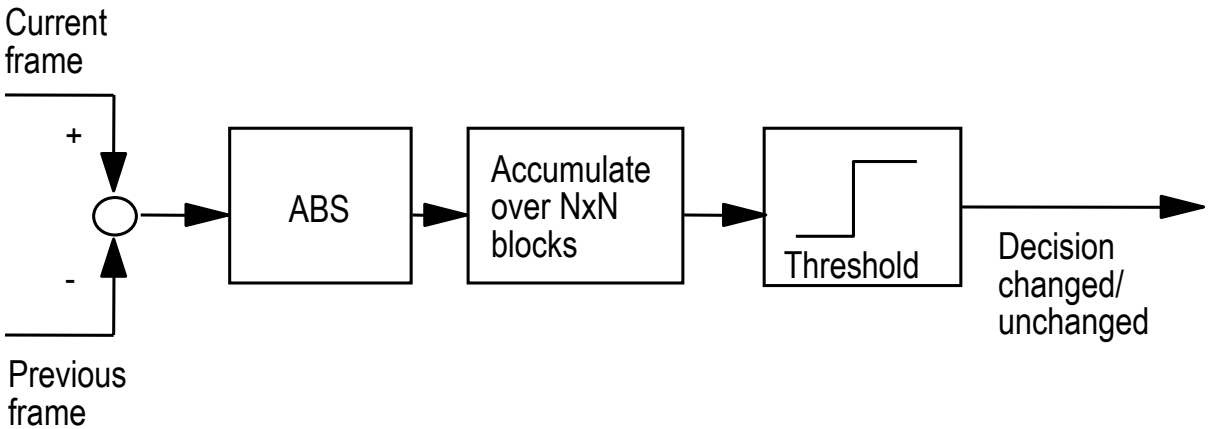
Change detection

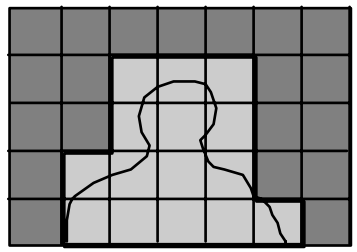
- Example of a pixel-wise change detector





- Example of a block-wise change detector





Rate-distortion optimized mode selection

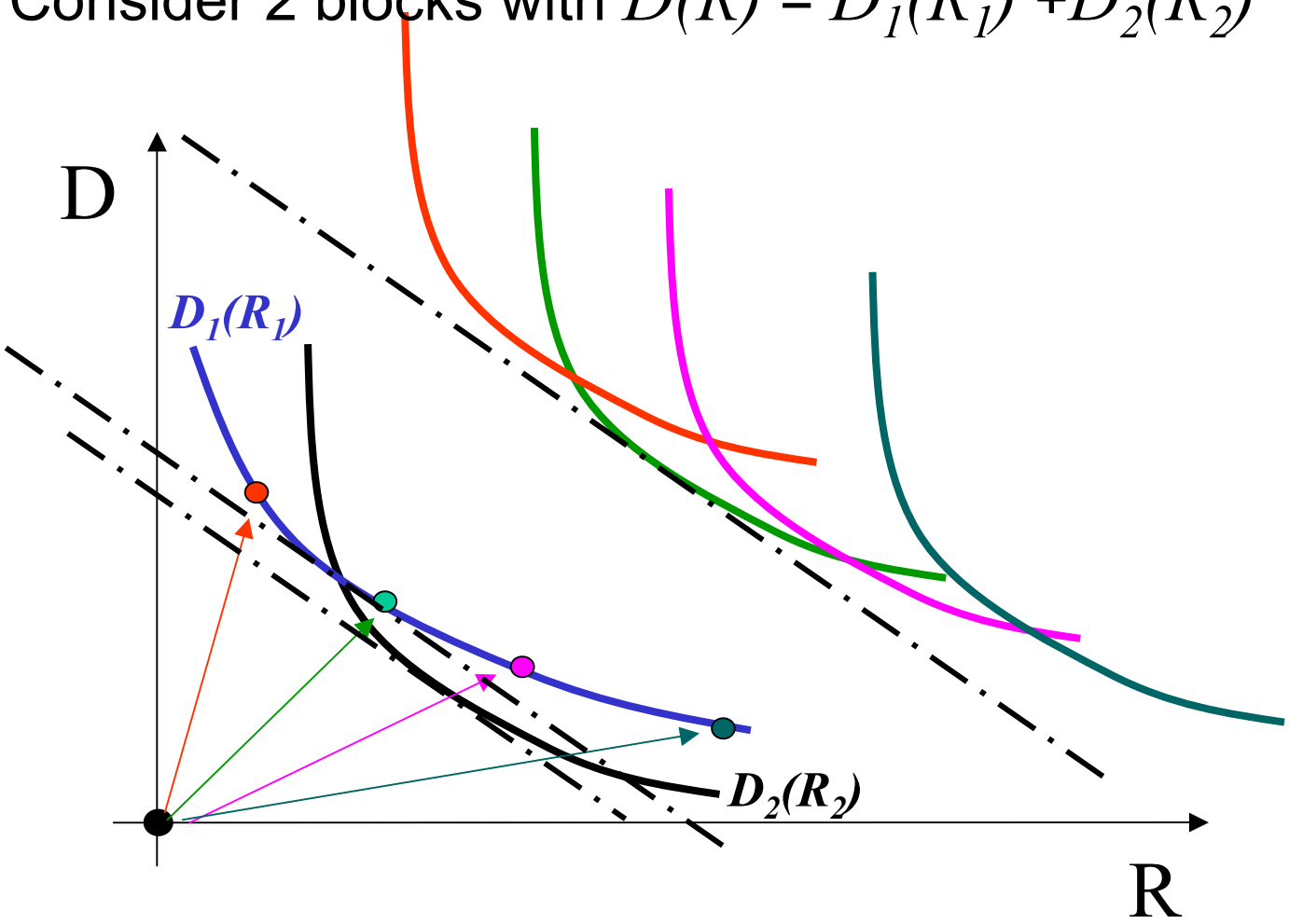
- How to choose the decision threshold, if distortion D shall be minimized for a given rate R?
- Assumptions
  - Blockwise mode selection, block index i
  - Additive overall distortion $D = \sum_i D_i$ and rate $R = \sum_i R_i$
- Lagrangian cost function

$$J = D + \lambda R = \sum_i D_i + \lambda R_i = \sum_i J_i$$

- Strategy: minimize J_i for each block i separately, using a common Lagrange multiplier λ

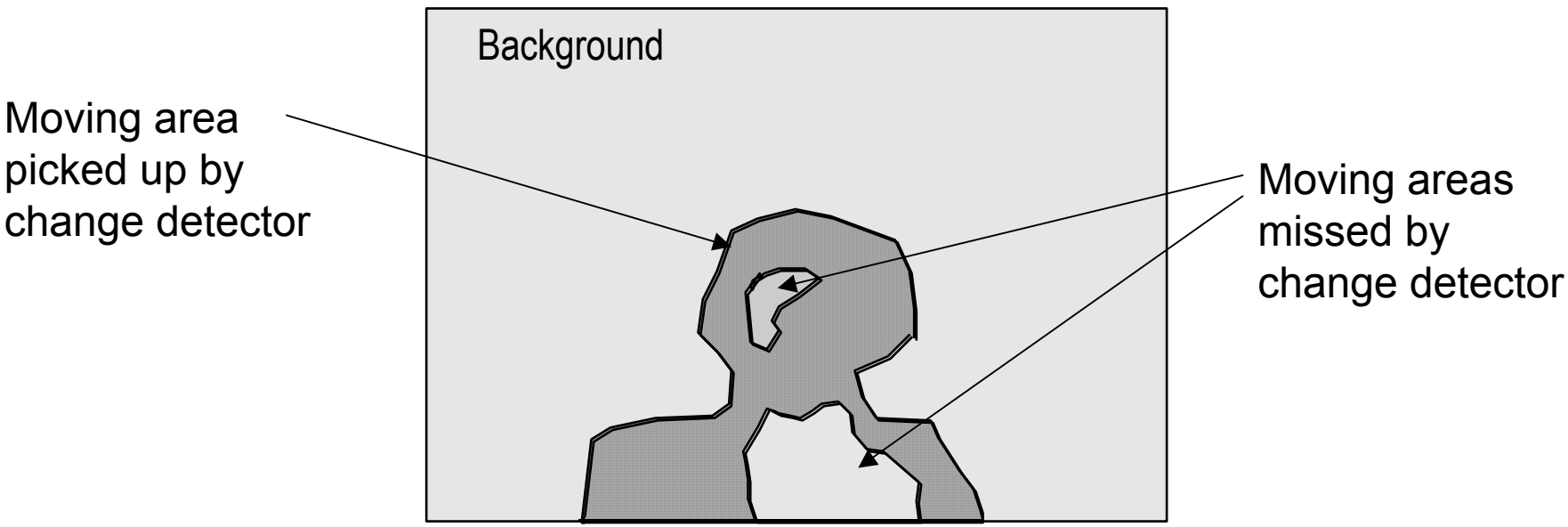
Rate-distortion optimized mode selection (cont.)

Consider 2 blocks with $D(R) = D_1(R_1) + D_2(R_2)$

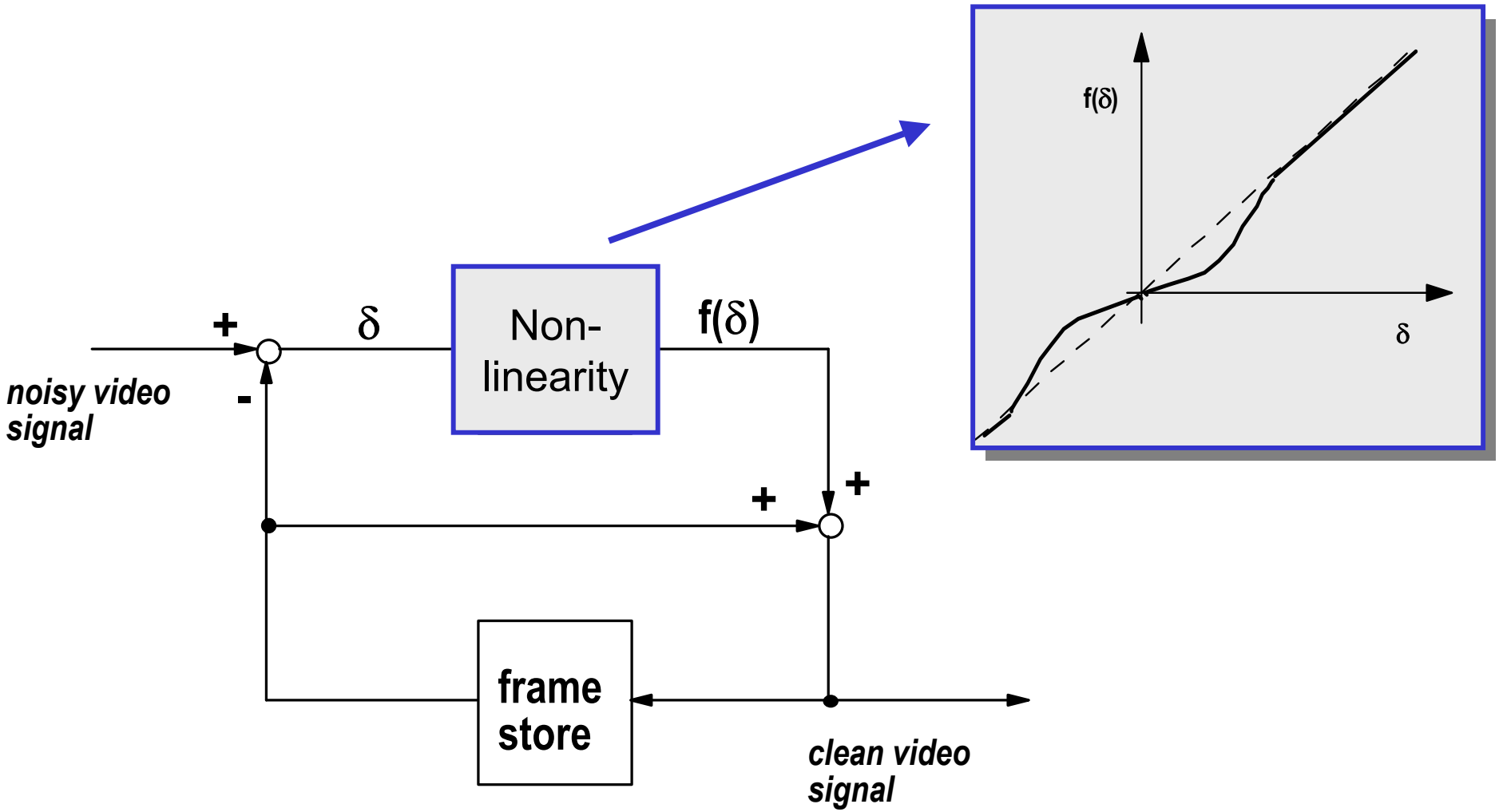


The “Dirty Window” effect

- Conditional replenishment scheme with change detection threshold set too high leads to the subjective impression of looking through a dirty window.



Crawford noise reduction filter



DPCM - Summary

- DPCM: Prediction from previously coded/transmitted samples (known at transmitter and receiver)
- Typical signal distortions for intraframe DPCM: granular noise, edge busyness, slope overload
- Prediction gain depends on spectral flatness
- Adaptive Intra-Interframe-DPCM: forward adaptation vs. backward adaptation
- Conditional replenishment: only transmit frame-to-frame changes
- Temporal noise reduction by nonlinear, recursive frame differencing