Differential Pulse Code Modulation
DPCM

- Introduction
- General block diagram
- Bi-dimensional prediction
- DPCM distortions
- Examples
- Lossless coding scheme
- Application to motion estimation (introduction)

Thanks for material provided

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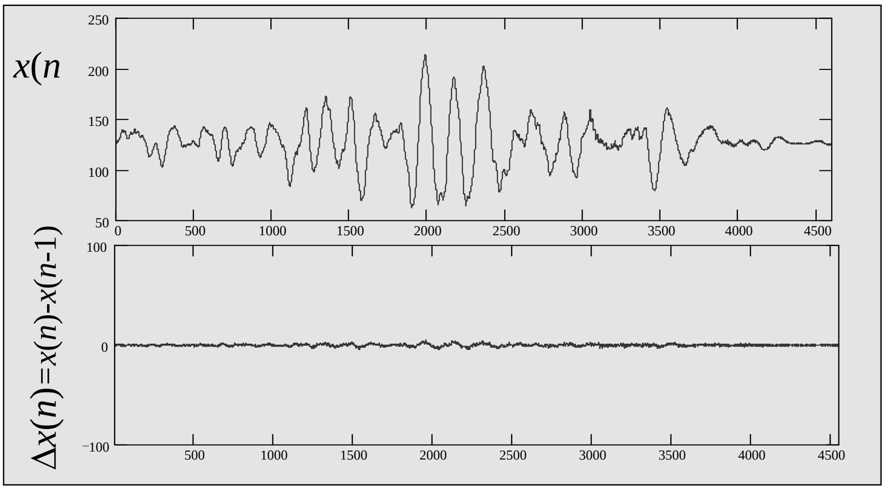
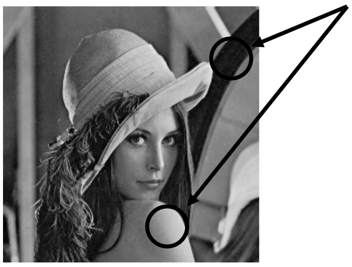
Thomas Wiegand, Heinrich-Hertz-Institut

Introduction DPCM (1)

- First technique of image coding (~1952)



Introduction DPCM (2)



The pixel's value can be predicted from its neighbors's value.

Sequences of pixels with similar value, will be found along a row of the image

Introduction DPCM (3)

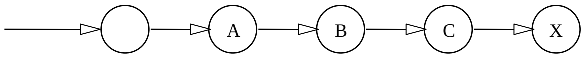
					?
150	156	154	148	152	[redacted]

To predict the value of a pixel from the previous values of the same row

- We predict that (for example) [redacted]
- We make an error doing the prediction!
- If the actual value is (for example) [redacted] the error is

[redacted] ← Information transmitted

Mathematical formulation



$$\hat{x} = f(A, B, C,)$$

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

Ideal prediction $\longrightarrow$ $\hat{x}(n) = E\left[x(n) \middle| x(n-1), x(n-2), \ldots, x(n-N)\right]$

Linear prediction $\longrightarrow$ $\hat{x}(n) = \sum_{j=1}^{N} h_j x(n-j)$

Prediction error must depend on the quantized signal !

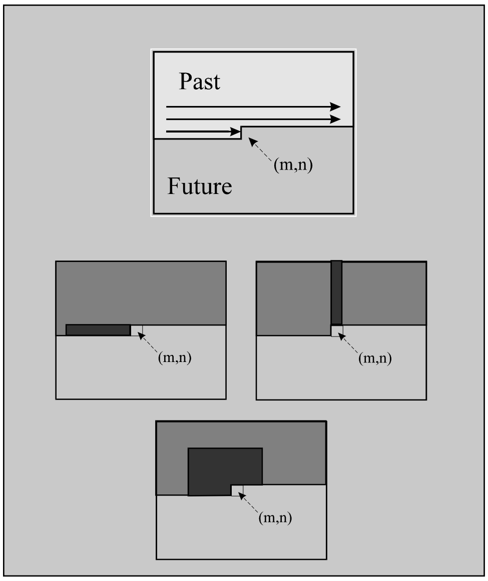
MSE optimal solution

$$\begin{bmatrix} R_x(1) \\ R_x(2) \\ \\ R_x(N) \end{bmatrix} = \begin{bmatrix} R_x(0) & R_x(1) & \cdots & R_x(N-1) \\ R_x(1) & R_x(0) & & R_x(N-2) \\ \vdots & & \ddots & \vdots \\ R_x(N-1) & R_x(N-2) & \cdots & R_x(0) \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ \\ h_N \end{bmatrix}$$

- From this set of equations the *N* linear prediction coefficients can be computed (Yule – Walker equations)
- Need to know $R_x(k)$: Autocorrelation function of $x(n)$

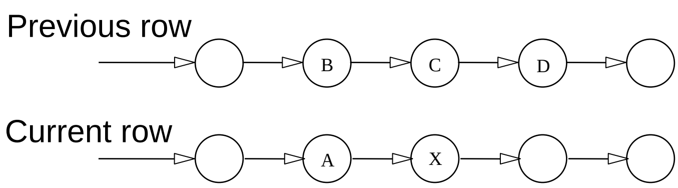
DPCM on images

- Same principle as 1-D
- Definition of “Past” and “Future” in images:



- Predictions:
  – horizontal (scan line)
  – vertical (column)
  – 2-dimensional

Bi-dimensional prediction



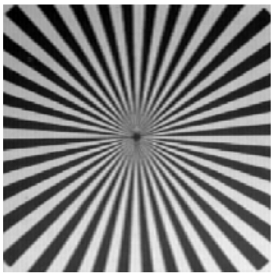
Bi-dimensional DPCM system

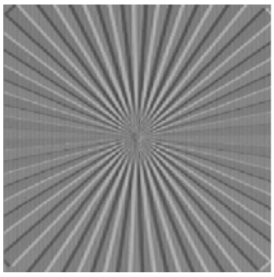
$X = \rho_h A - \rho_h \rho_v B + \rho_v C$	ρ: Correlation
$X = 0.97A$	1st-order, predictor 1-D
$X = 0.50A + 0.50C$	2n-order, predictor 2-D
$X = 0.90A - 0.81B + 0.90C$	3th-order, predictor 2-D
$X = 0.75A - 0.50B + 0.75C$	3th-order, predictor 2-D
$X = A - B + C$	3th-order, predictor 2-D

Yule walker equations need to be extended to 2D

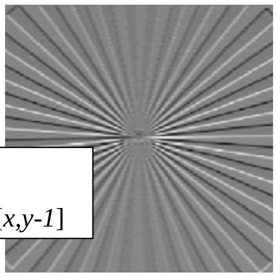
Prediction example: test pattern

$s[x,y]$



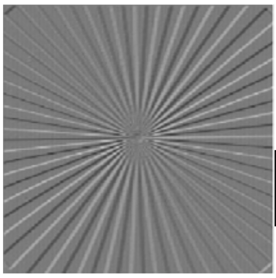


$u_H[x,y]=$
$s[x,y]-0.95\ s[x-1,y]$



$u_V[x,y]=$

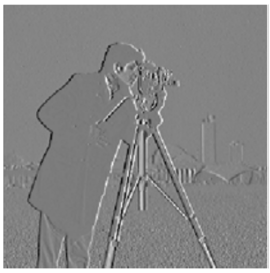
$s[x,y]-0.95\ s[x,y-1]$



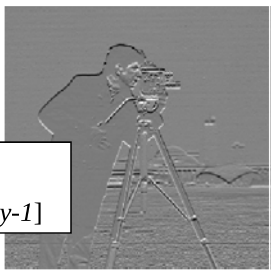
$u_D[x,y]=s[x,y]-$
$0.5(s[x,y-1]+ s[x-1,y])$

Prediction example: cameraman

$s[x,y]$



$u_H[x,y]=$
$s[x,y]-0.95\ s[x-1,y]$

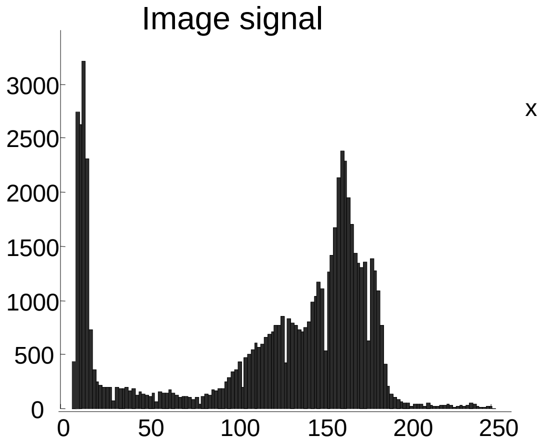


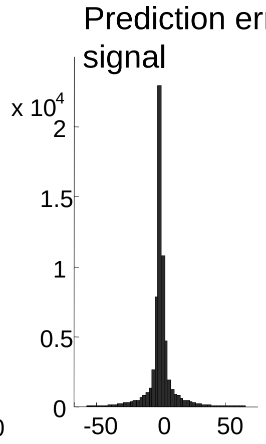
$u_V[x,y]=$

$s[x,y]-0.95\ s[x,y-1]$

$u_D[x,y]=s[x,y]-$
$0.5(s[x,y-1]+ s[x-1,y])$

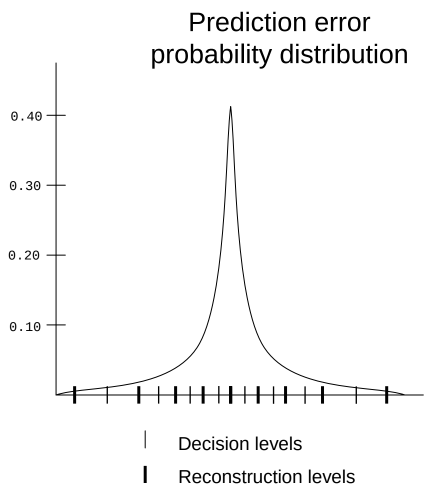
Prediction error

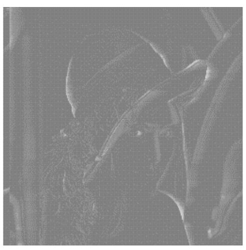




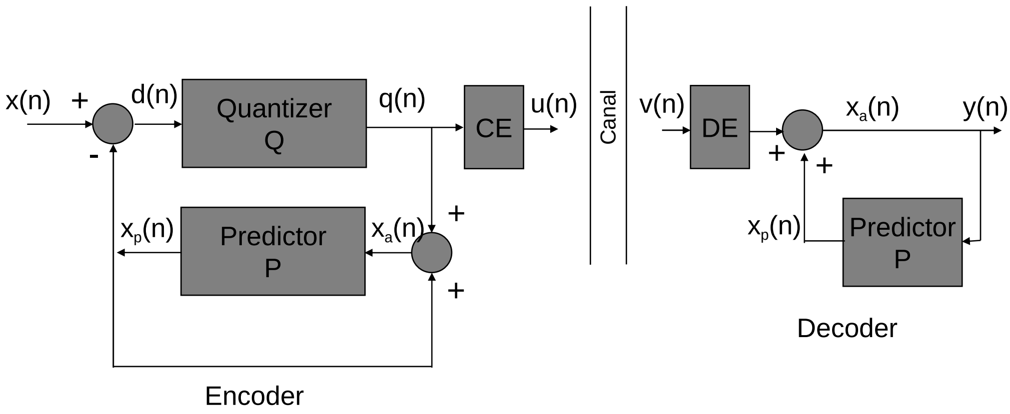
Can we use prediction for compression ?
Yes, if we reproduce the prediction signal at the decoder

Prediction error - Lenna

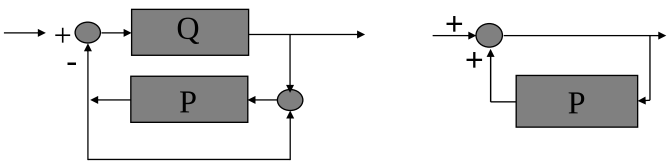




DPCM systems (1)



DPCM systems (2)

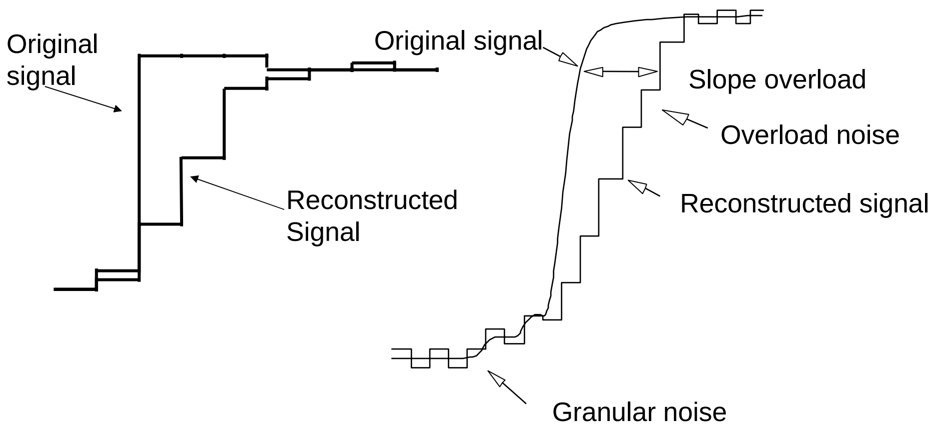


Reconstruction error = quantization error

- The compression is produced in the quantizer
- The predictor affects the design of the quantizer

⇨ Good prediction → - bits
Bad prediction → + bits

Distortions in DPCM systems



DPCM – granular noise

Original image Reconstructed image Prediction error

DPCM – overload noise

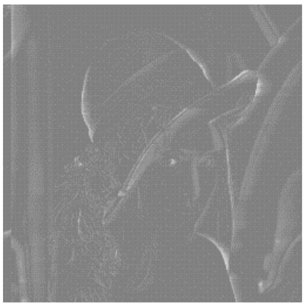
Original image Reconstructed image Prediction error

DPCM - examples (1)

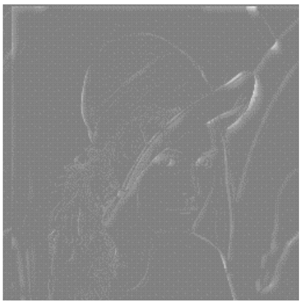
Original image

Coded image
2 bits/pixel

DPCM - examples (2)



Prediction error
1 bits/pixel



Prediction error
2 bit/pixel

DPCM - examples (3)
Entropy-Constrained Scalar Quantization

Example: Lena - 8 bits/pixel

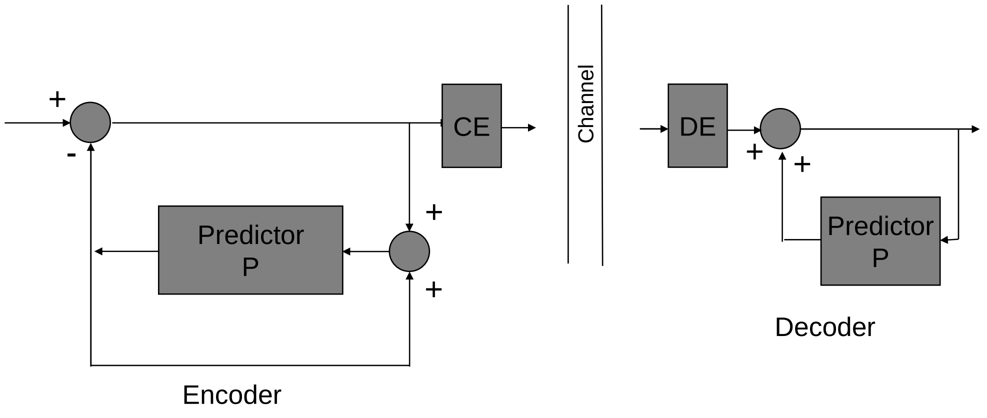
K=511 - H=4.79 b/p

K=15 - H=1.98 b/p

K=3 - H=0.88 b/p

K: number of reconstruction levels
H: entropy

Lossless predictive systems



Predictive systems applications

- Lossless JPEG Standard
- Video coding with motion estimation