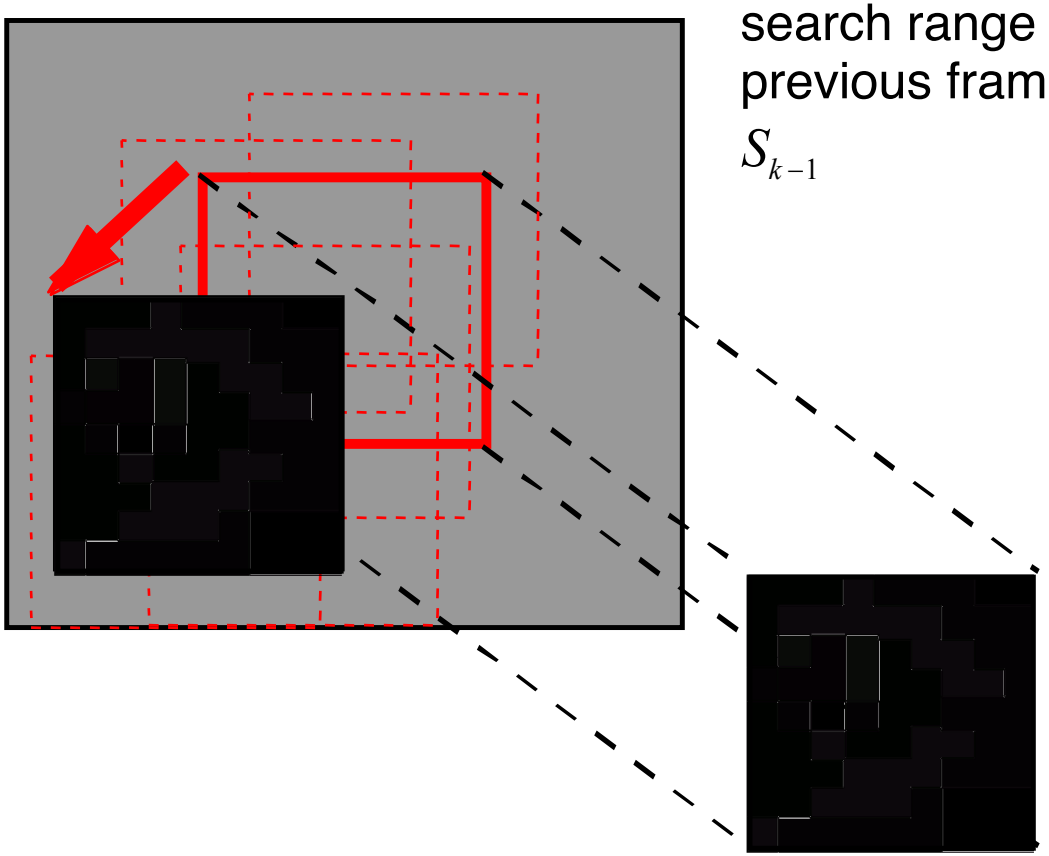
Motion-Compensated Coding

- Motion estimation
  - Blockmatching
  - Matching criterion for blockmatching
  - Sub-pixel accurate motion
- Motion-compensated coding
  - Motion-compensated prediction error
  - Prediction error coding
- Standard video codec architecture
- Video compression standards

Block-Matching Algorithm



search range in previous frame S_{k-1}

block of current frame S_k

- Subdivide every image into square blocks.
- Find one displacement vector for each block.
- Within a search range, find a best „match“ that minimizes an error measure.
- Intelligent search strategies can reduce computation.

Block-Matching Algorithm

Measurement window is compared with a shifted array of pixels in the other image, to determine the best match

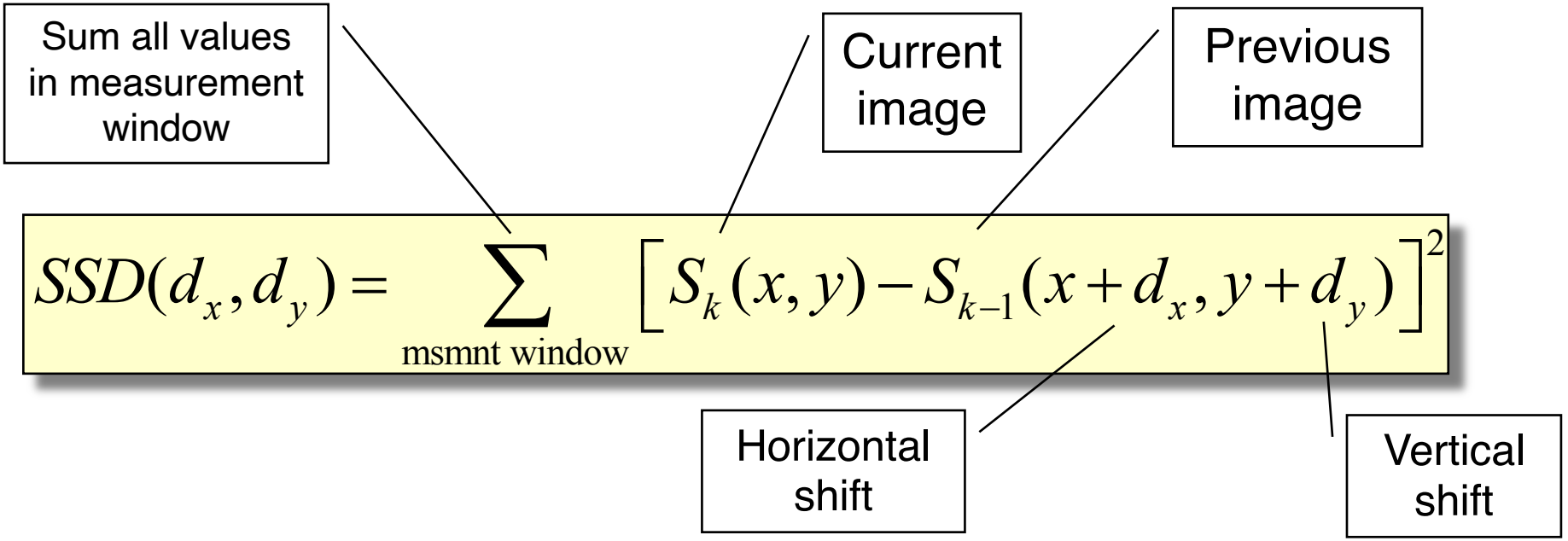
Rectangular array of pixels is selected as a measurement window

Block-Matching Algorithm

. . . process repeated for another measurement window position.

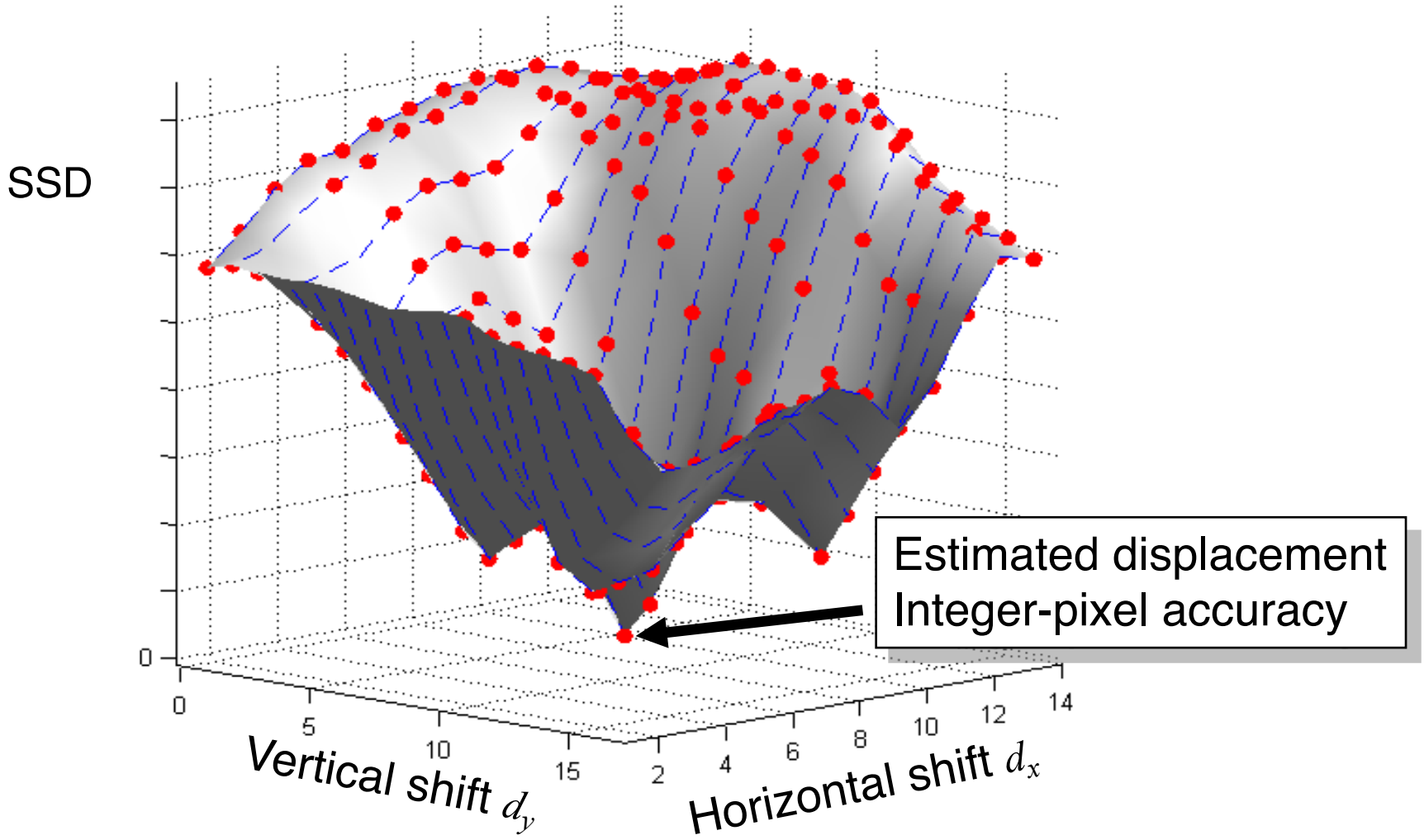
Blockmatching: Matching Criterion

- *Sum of Squared Differences* to determine similarity



- Alternative matching criteria: SAD (*Sum of Absolute Differences*), cross correlation, . . .

SSD Values Resulting from Blockmatching

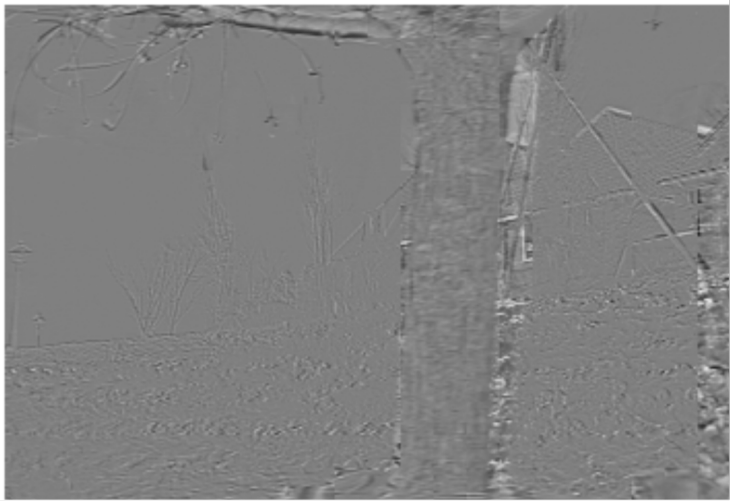


Motion-Compensated Prediction: Example

Previous frame

Current frame

Prediction with displacement vectors

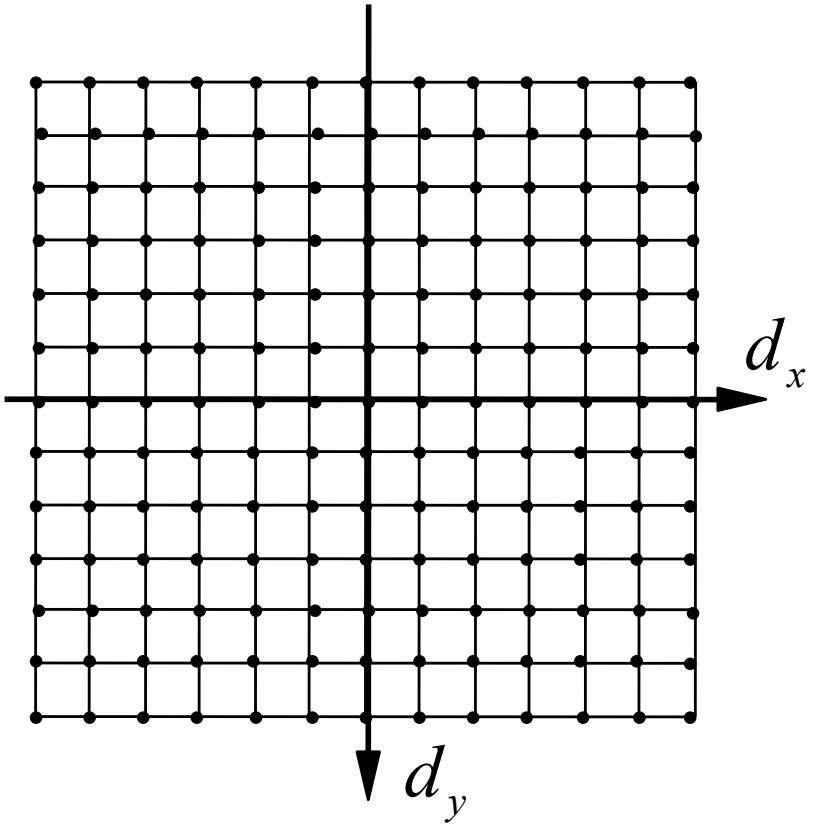


Motion-compensated prediction error

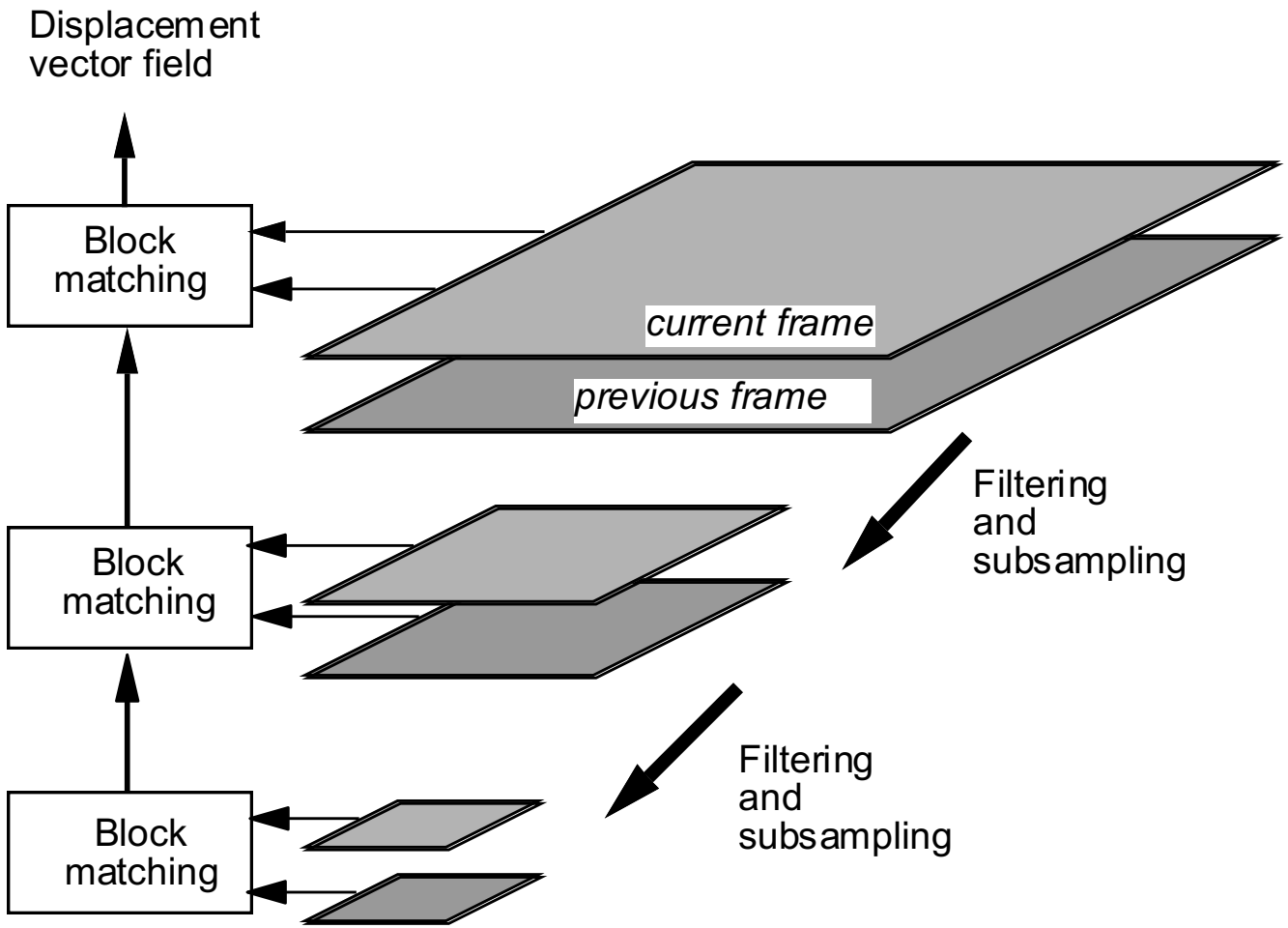
Blockmatching: Search Strategies

Full search

- All possible displacements within the search range are compared.
- Computationally expensive
- Highly regular, parallelizable

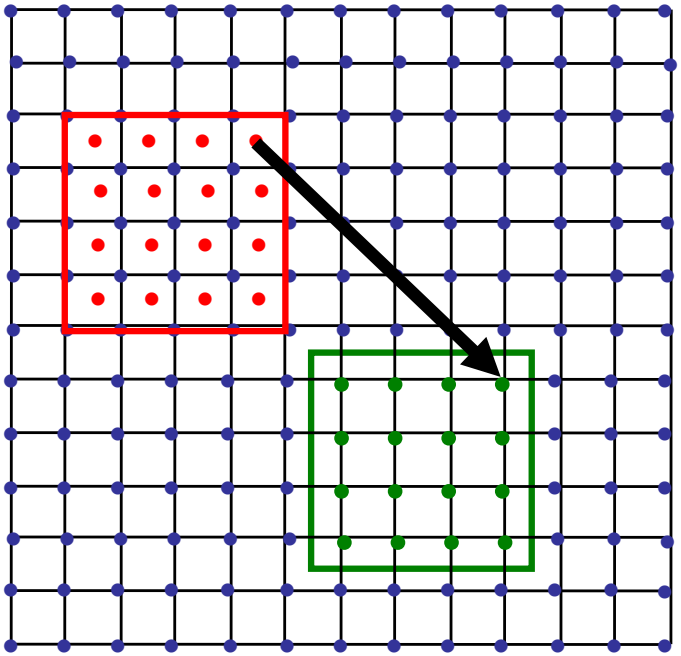


Hierarchical Blockmatching



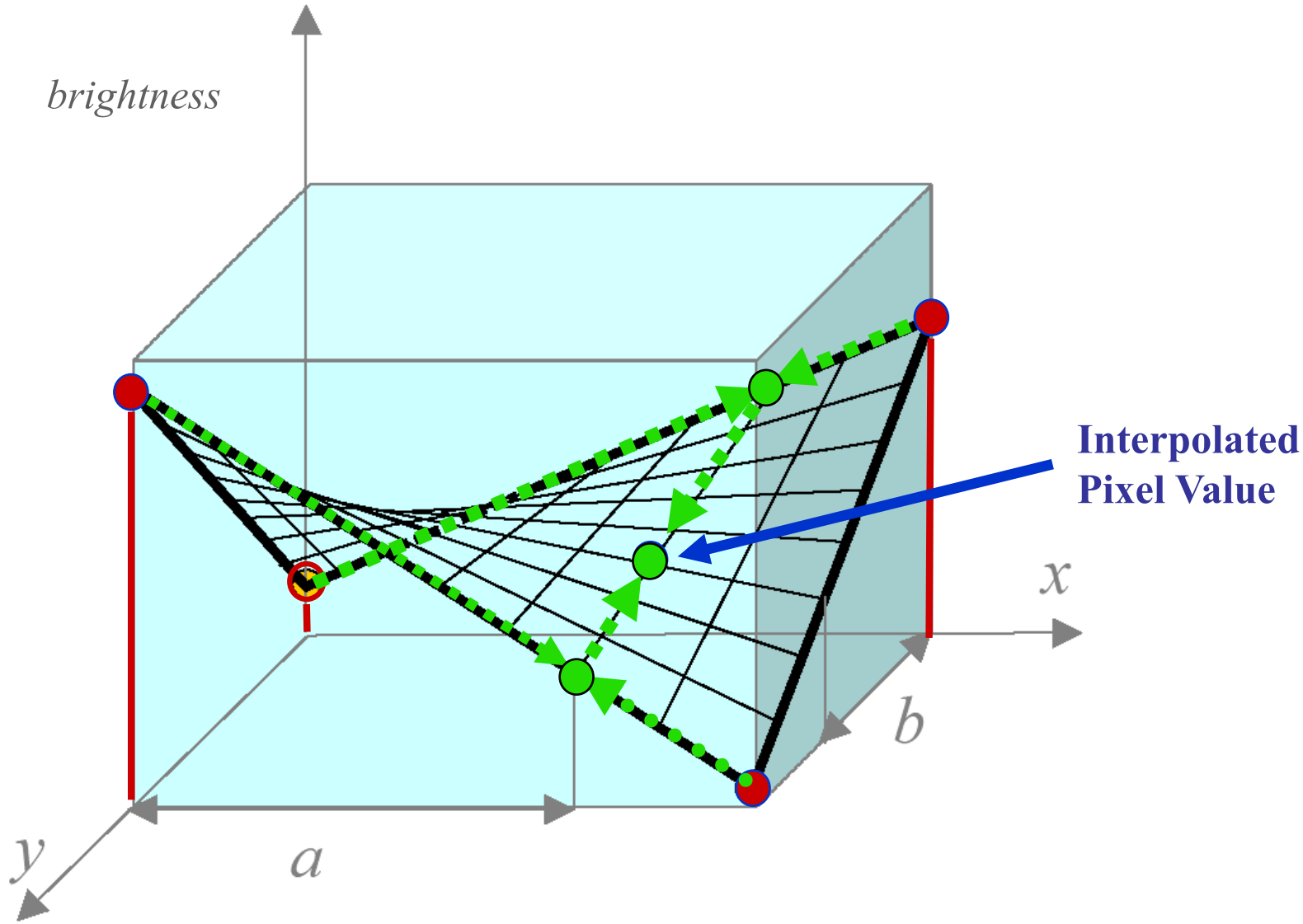
Sub-Pixel Accuracy

- Interpolate pixel raster of the reference image to desired sub-pixel accuracy (for example by bi-linear interpolation)
- Straightforward extension of displacement vector search to fractional accuracy
- Example: half-pixel accurate displacements

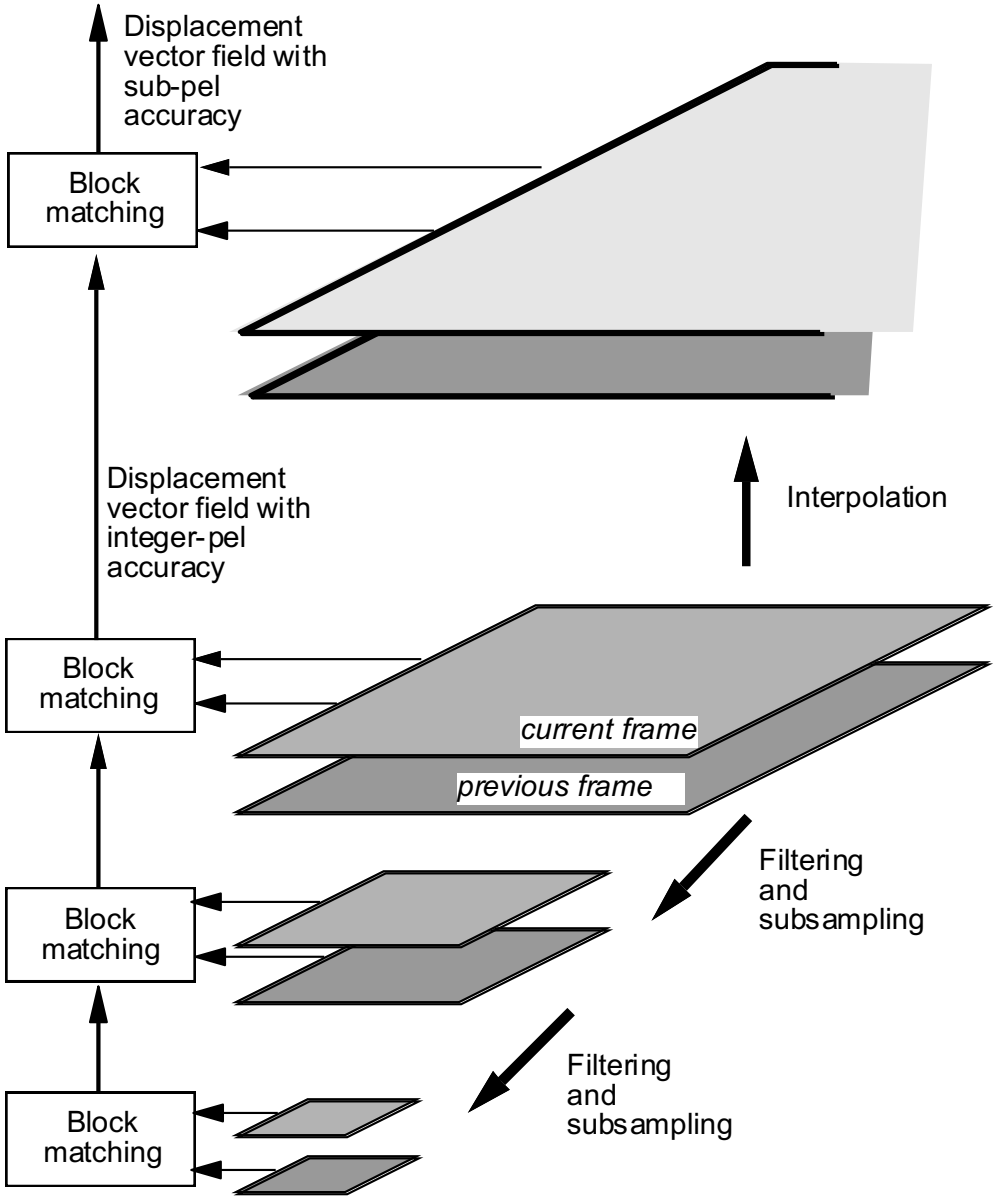


$$\begin{pmatrix} d_x \\ d_y \end{pmatrix} = \begin{pmatrix} 4.5 \\ 4.5 \end{pmatrix}$$

Bi-Linear Interpolation



Sub-Pixel Accuracy with Resolution Pyramid

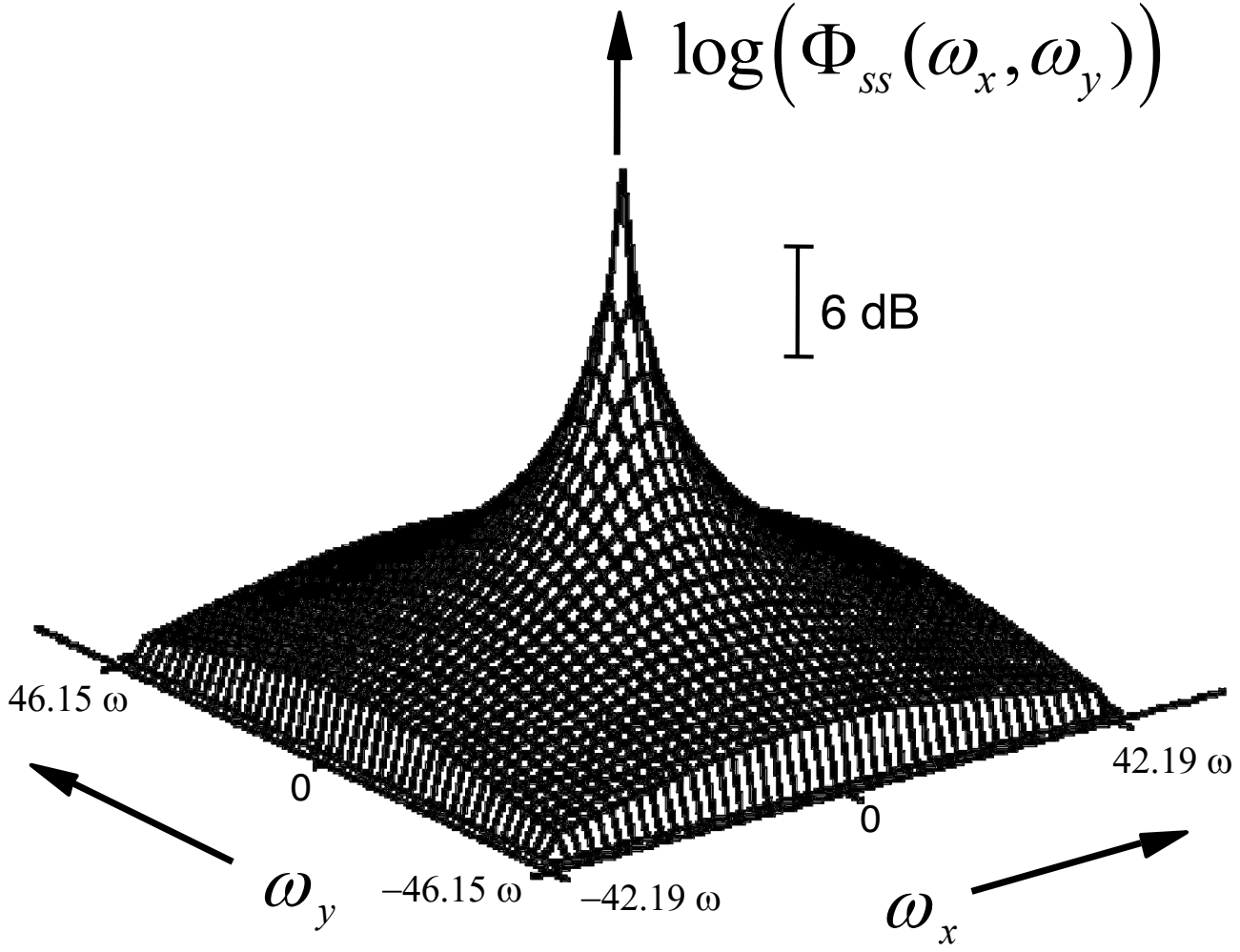


Motion-Compensated Coding

Motion-compensated prediction + intraframe coding

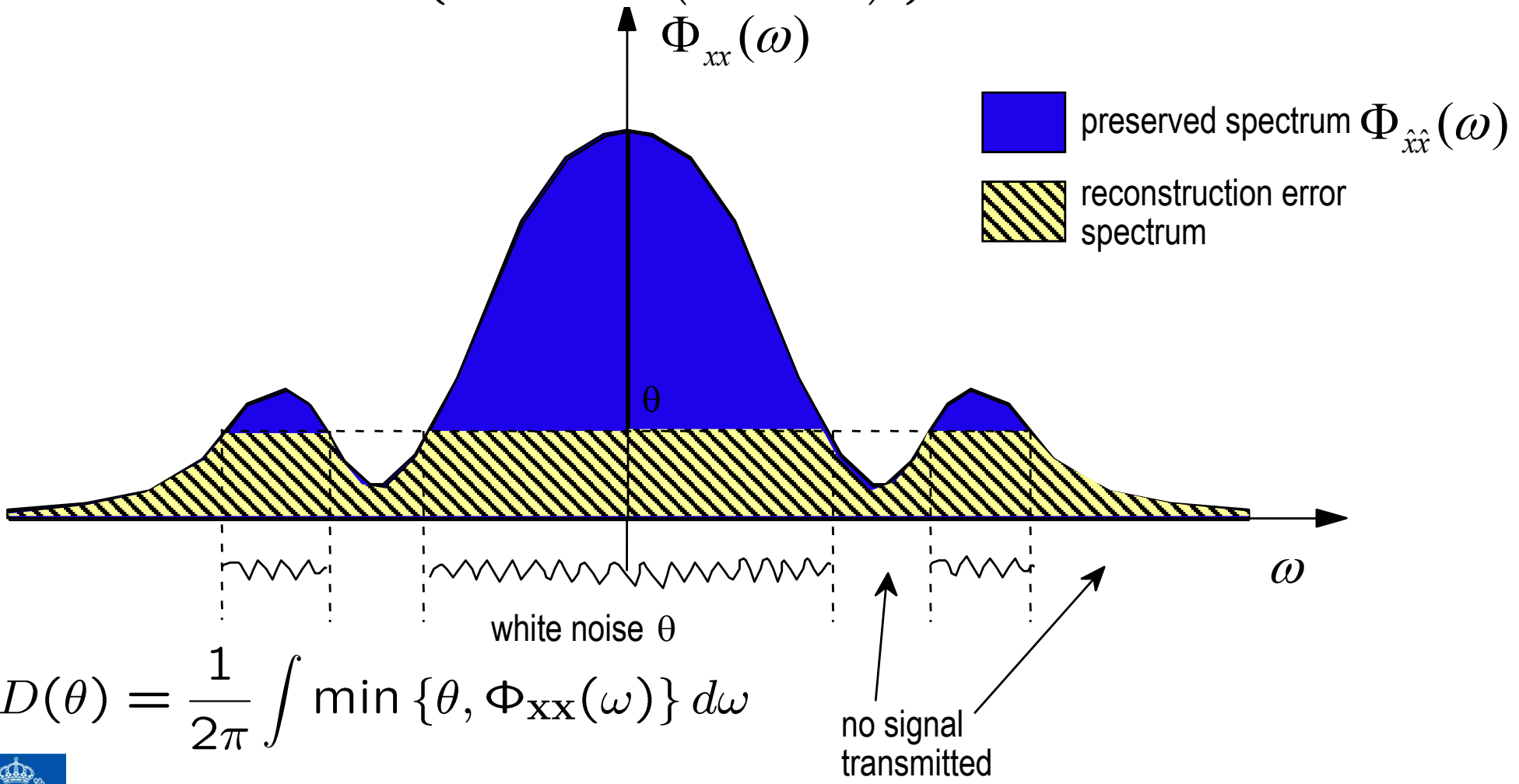
- Intraframe coding
- Motion-compensated prediction error
- Prediction error coding

PSD of Typical Intraframe



Intraframe Coding of Gaussian Image

$$R(\theta) = \frac{1}{2\pi} \int \max\left\{0, \frac{1}{2}\log_2\left(\frac{\Phi_{xx}(\omega)}{\theta}\right)\right\} d\omega$$



$$D(\theta) = \frac{1}{2\pi} \int \min\left\{\theta, \Phi_{xx}(\omega)\right\} d\omega$$

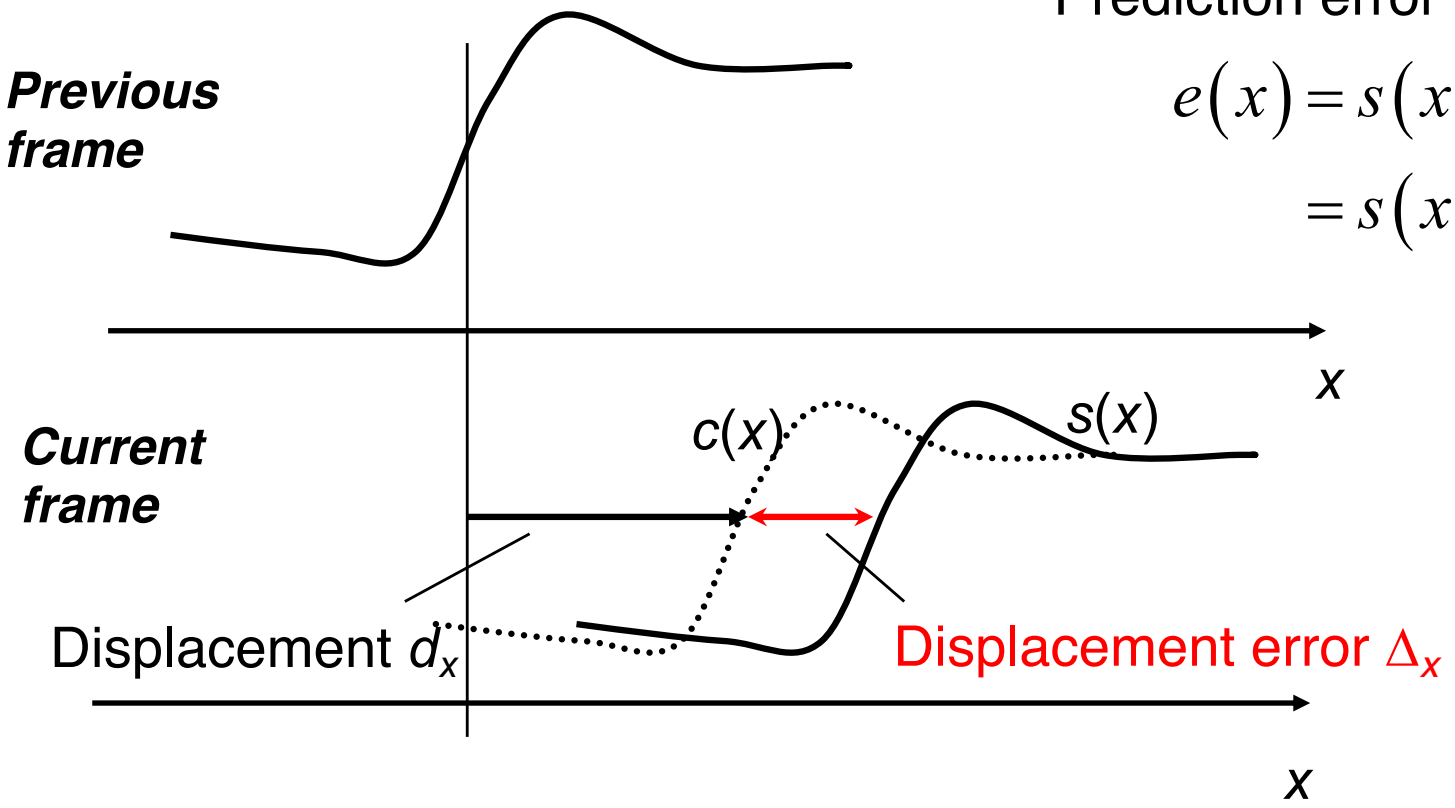
Motion-Compensated Prediction Error

Motion-compensated signal

$$c(x) = s(x - \Delta_x) - n(x)$$

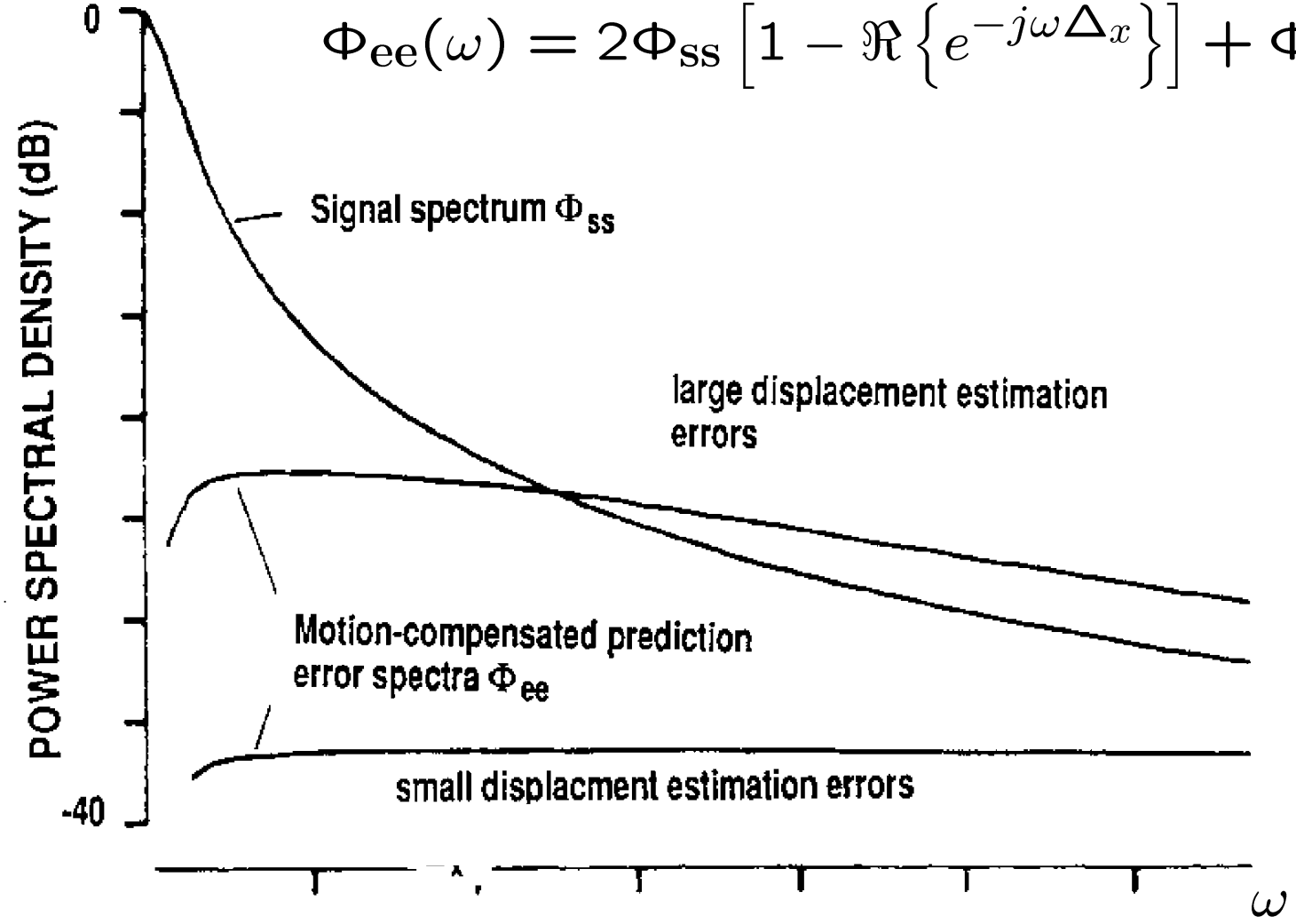
Prediction error

$$e(x) = s(x) - c(x)$$
$$= s(x) - s(x - \Delta_x) + n(x)$$

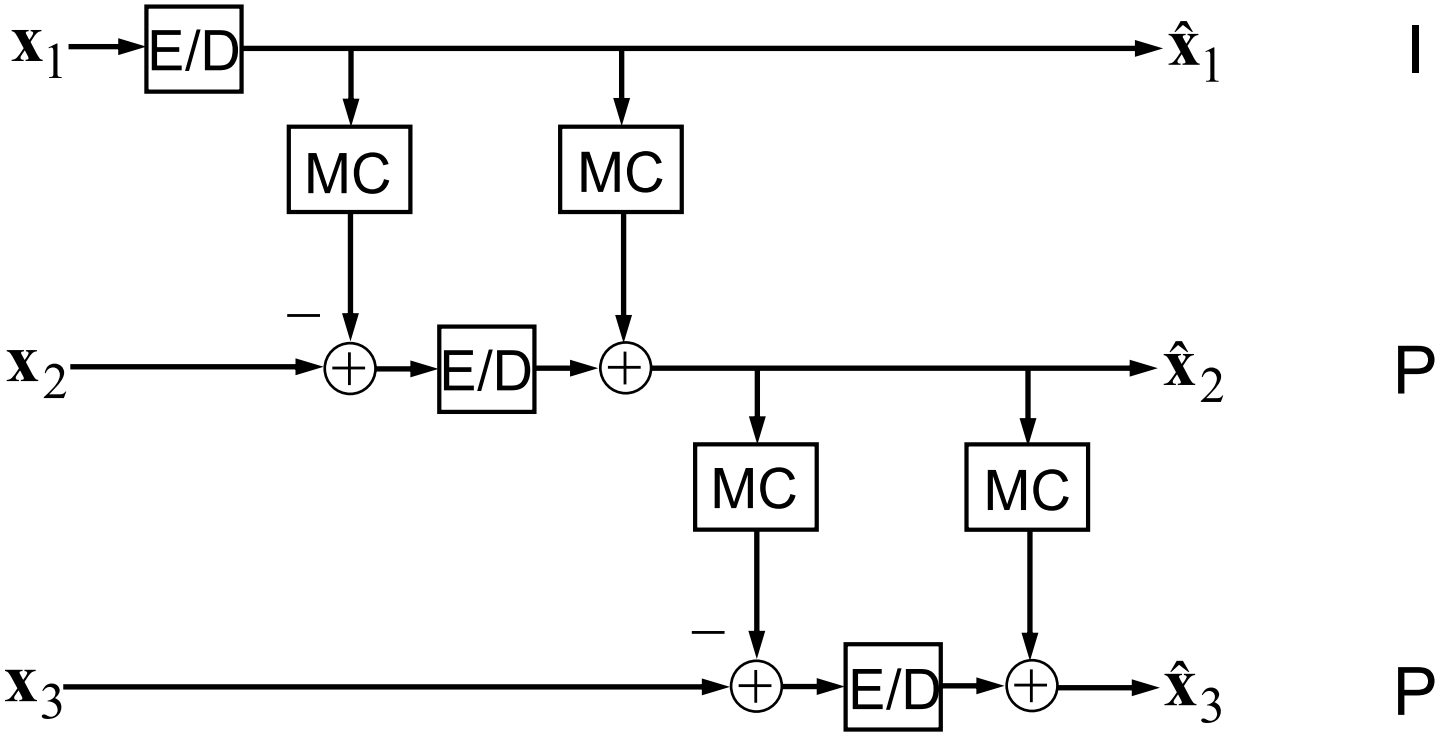


PSD of Motion-Compensated Prediction Error

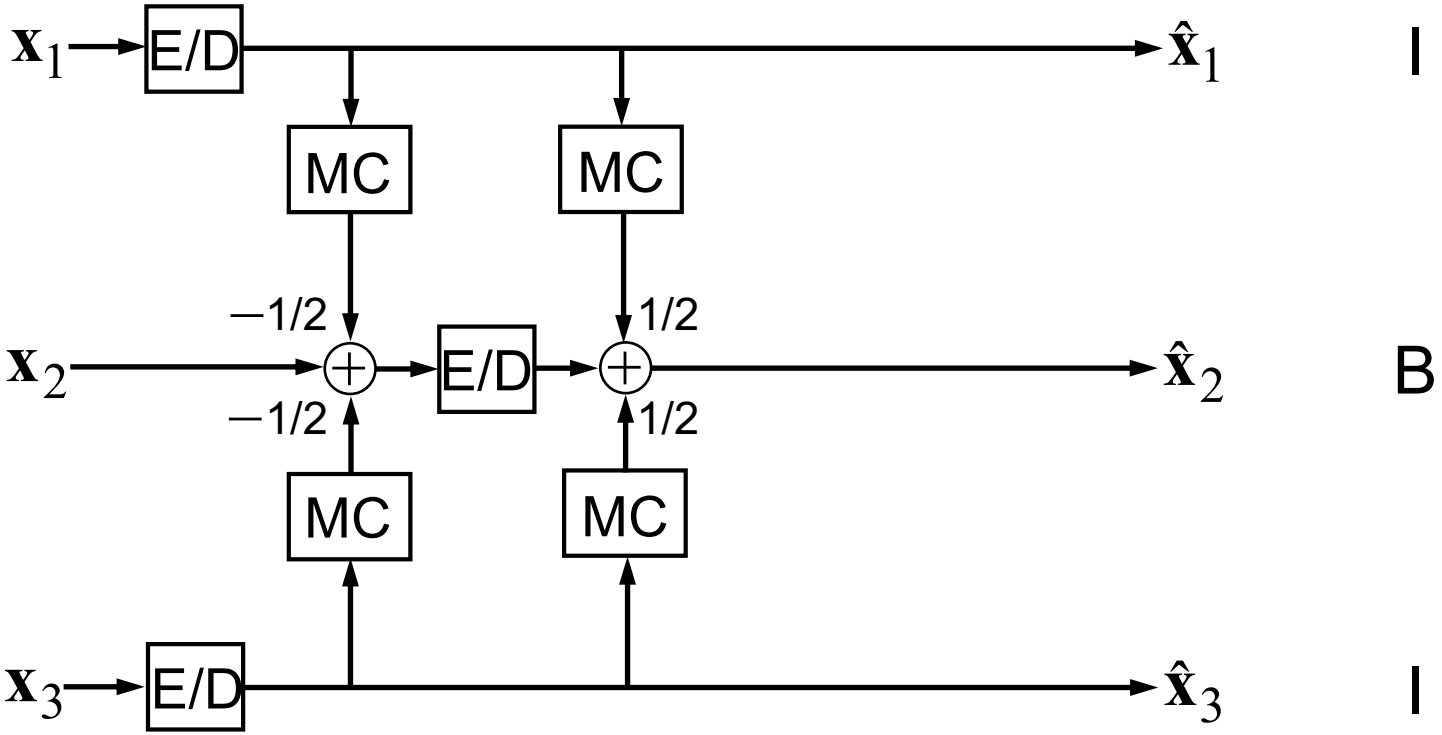
$$\Phi_{ee}(\omega) = 2\Phi_{ss}\left[1 - \Re\left\{e^{-j\omega\Delta_x}\right\}\right] + \Phi_{nn}(\omega)$$



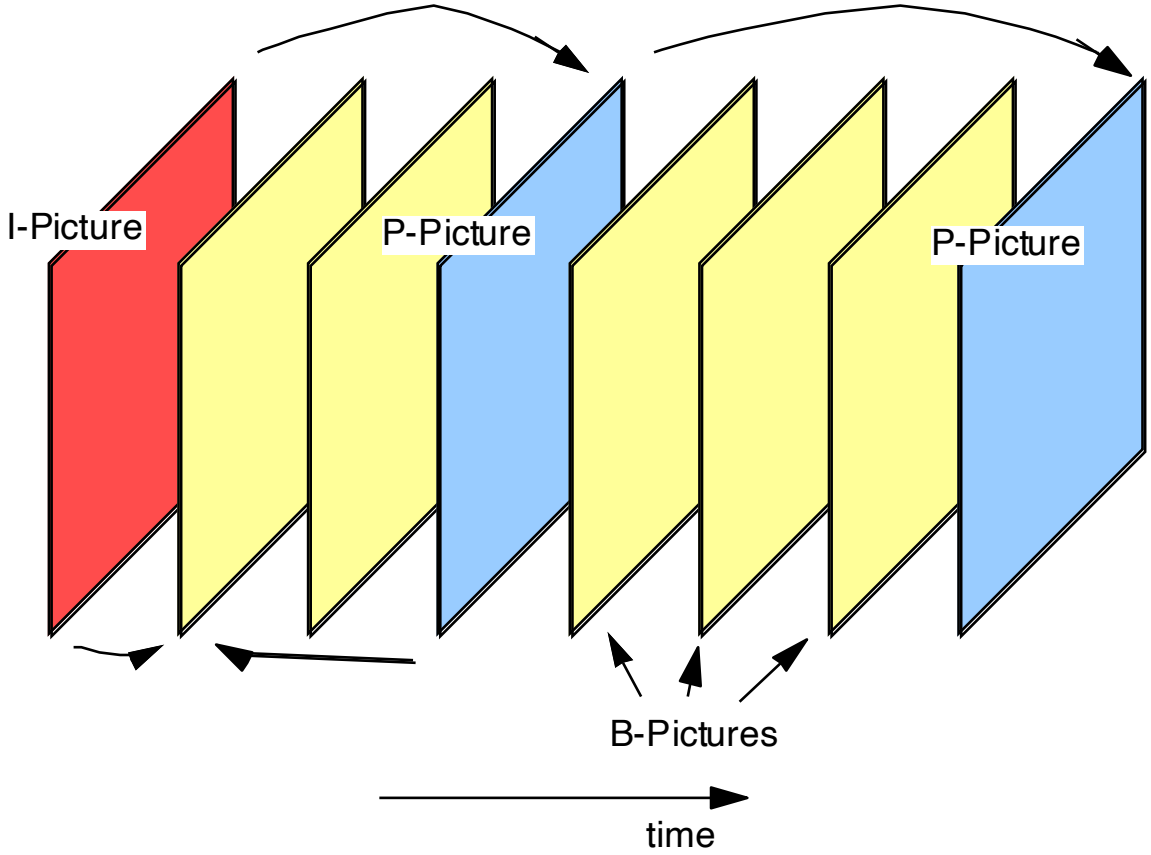
P Picture


$\mathbf{x}_1$
E/D
$\hat{\mathbf{x}}_1$
I
MC
MC
$\mathbf{x}_2$
E/D
$\hat{\mathbf{x}}_2$
P
MC
MC
$\mathbf{x}_3$
E/D
$\hat{\mathbf{x}}_3$
P

B Picture

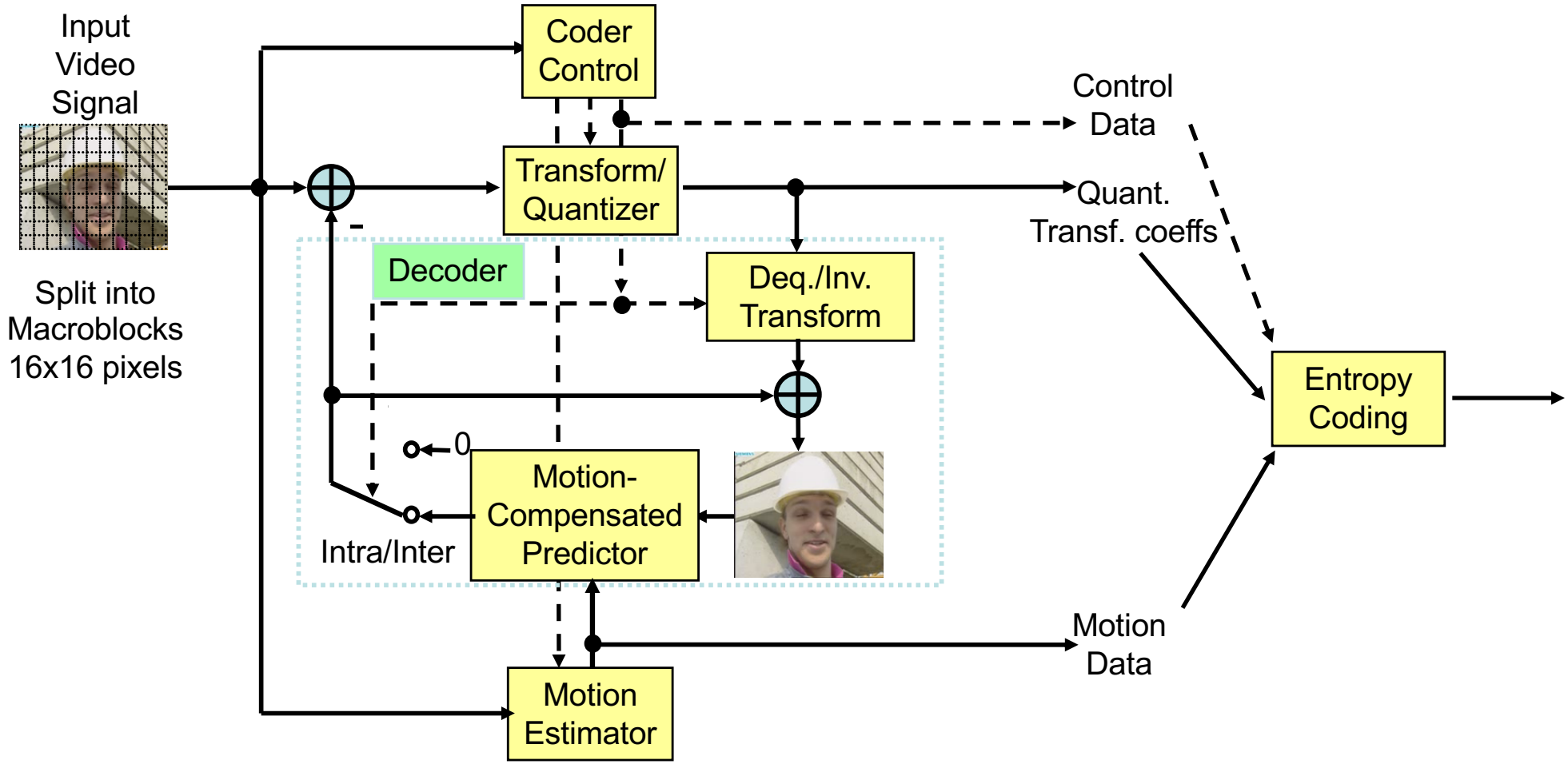

$\mathbf{x}_1$
E/D
$\hat{\mathbf{x}}_1$
I
MC
MC
−1/2
1/2
$\mathbf{x}_2$
E/D
$\hat{\mathbf{x}}_2$
B
−1/2
1/2
MC
MC
$\mathbf{x}_3$
E/D
$\hat{\mathbf{x}}_3$
I

GOP Structure Example



- Each I picture starts a **Group of Pictures** (GOP) that can be decoded independently.
- Encoder can flexibly choose I picture, P pictures and B pictures.

Standard Video Codec Architecture



Video Compression Standards

Intraframe coding: only spatial correlation exploited

➔ DCT [Ahmed, Natarajan, Rao 1974], JPEG [1992]

Conditional replenishment, DPCM, scalar quantization

➔ H.120 [1984]

Motion compensation: integer-pel accurate displacements

➔ H.261 [1991]

Half-pel accurate motion compensation

➔ MPEG-1 [1993], MPEG-2/H.262 [1994]

Variable block-size motion compensation

➔ H.263 [1996], MPEG-4 [1999]

Multi-frame motion compensation

➔ H.264/MPEG-4 AVC [2003]

Many improvements for higher rate-distortion efficiency

➔ H.265/MPEG-H HEVC [2013]

Complexity increases