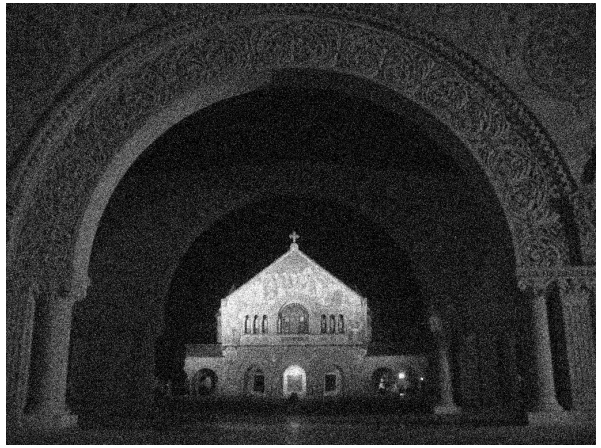
Point operations for combining images

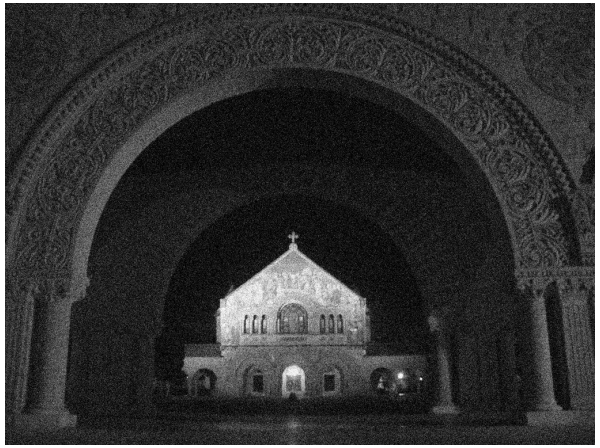
- Image averaging for noise reduction
- Combination of different exposures for high-dynamic range imaging
- Image subtraction for change detection
- Need for accurate alignment
- Displacement estimation

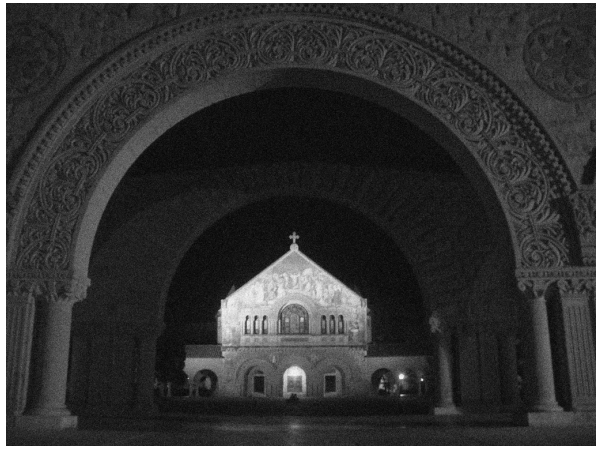
Image averaging for noise reduction

1 image

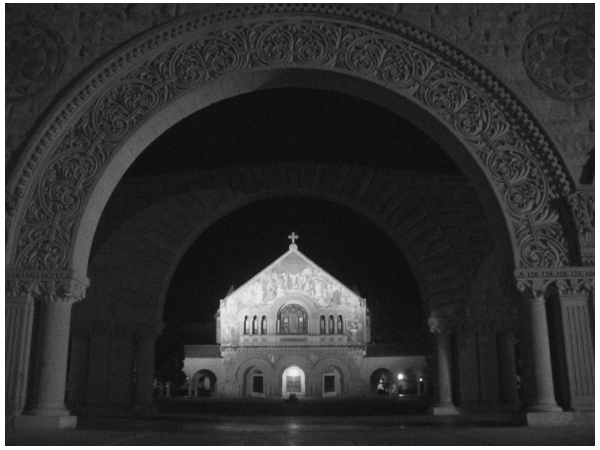


2 images





8 images



32 images

High-dynamic range imaging


-8 f-stops


-2 f-stops


+2 f-stops

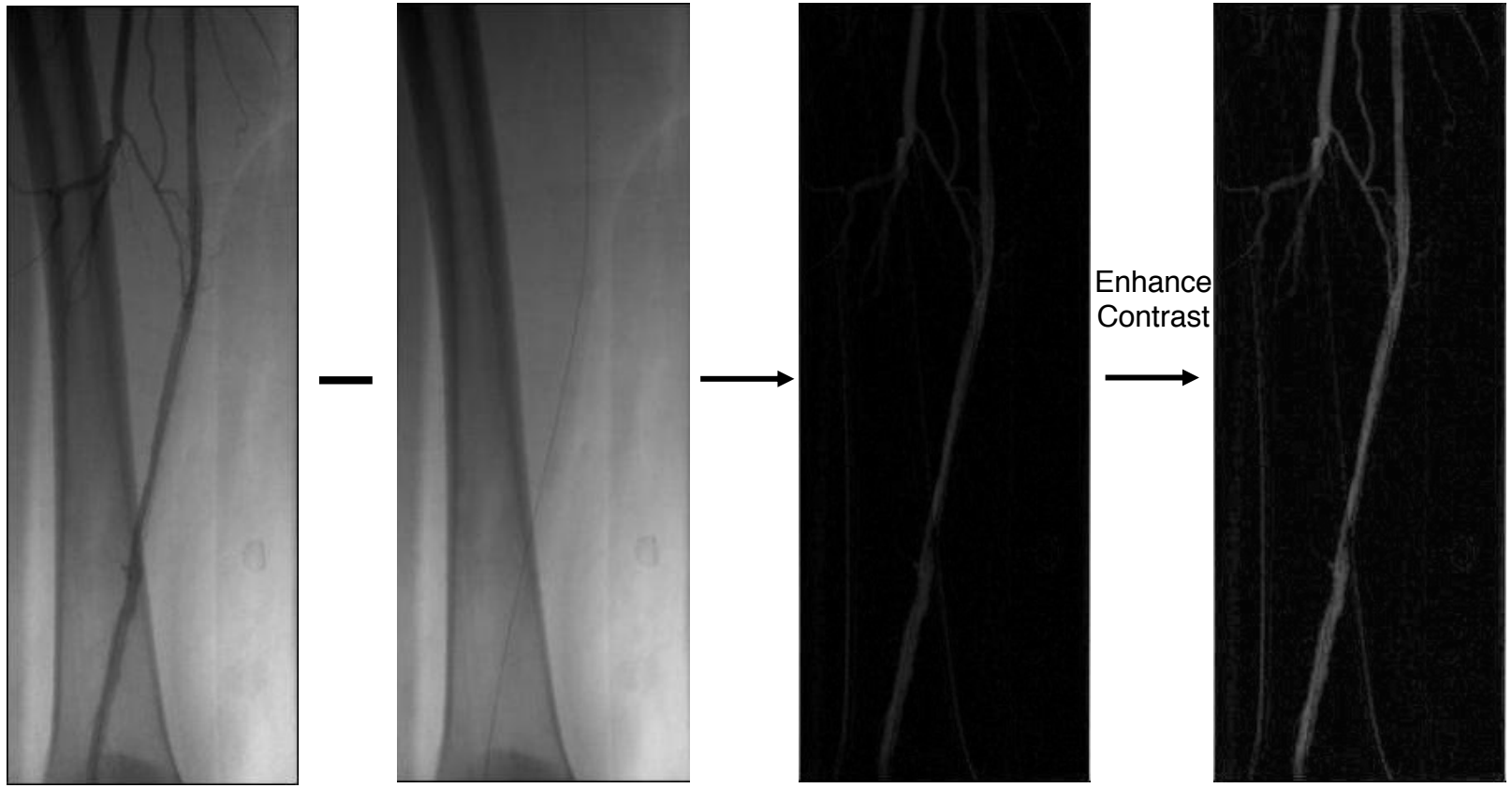

+4 f-stops

Blended image from Exposure Fusion

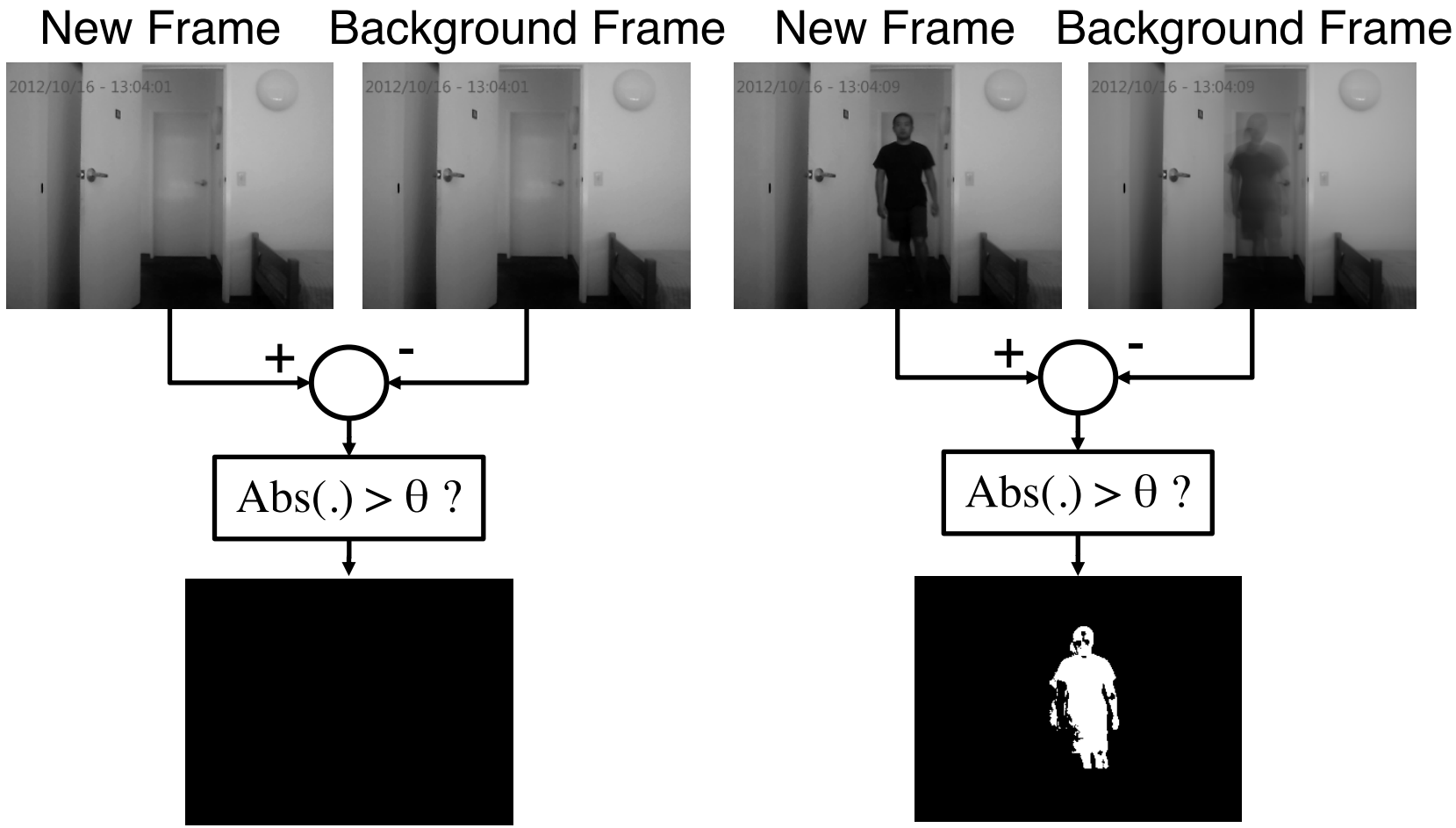
[Tom Mertens et al. 2007]

Image subtraction

- Find differences/changes between 2 mostly identical images
- Example: digital subtraction angiography



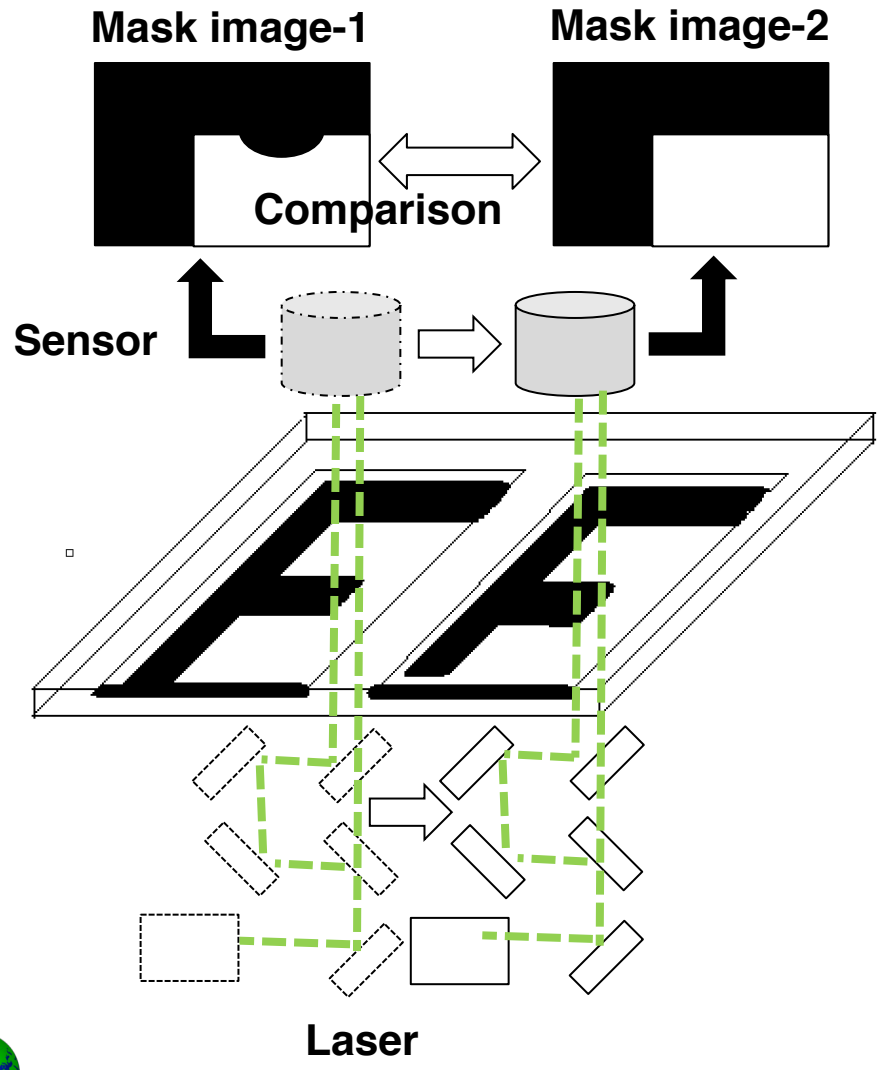
Video background subtraction

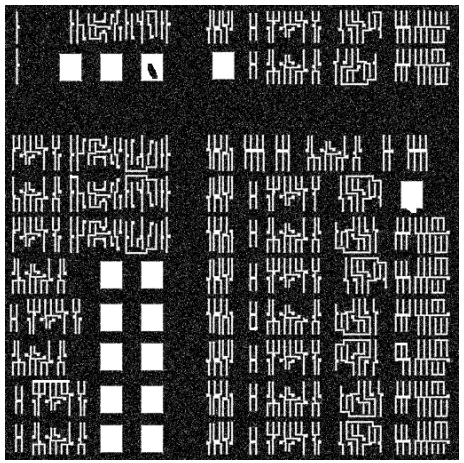


Update:

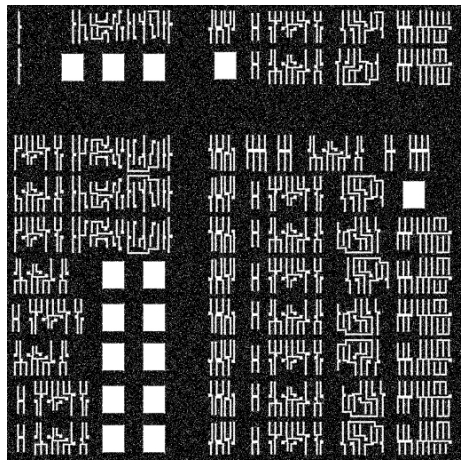
Background[t] := α Background[t-1] + (1- α) New[t]

Image subtraction in IC manufacturing: inspection of photomasks





Mask image-1



Mask image-2

Difference image

Where is the defect?

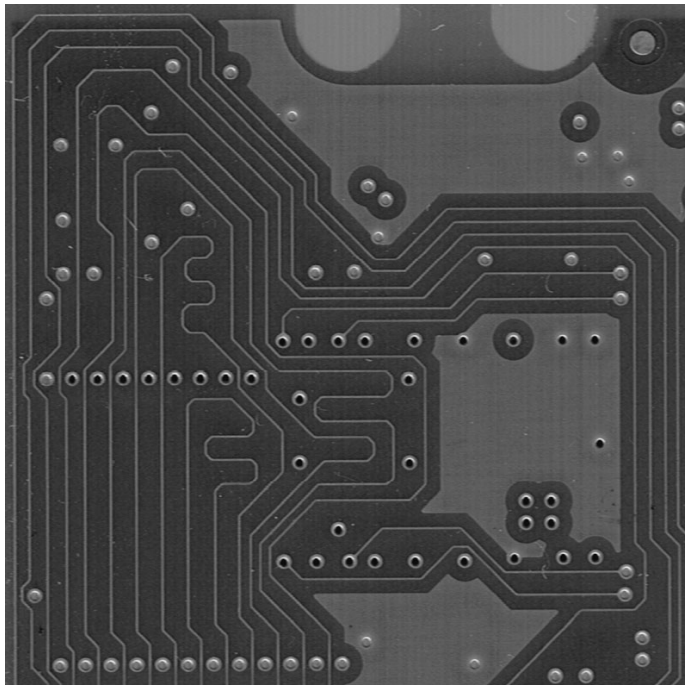


Image $g[x,y]$ (no defect)

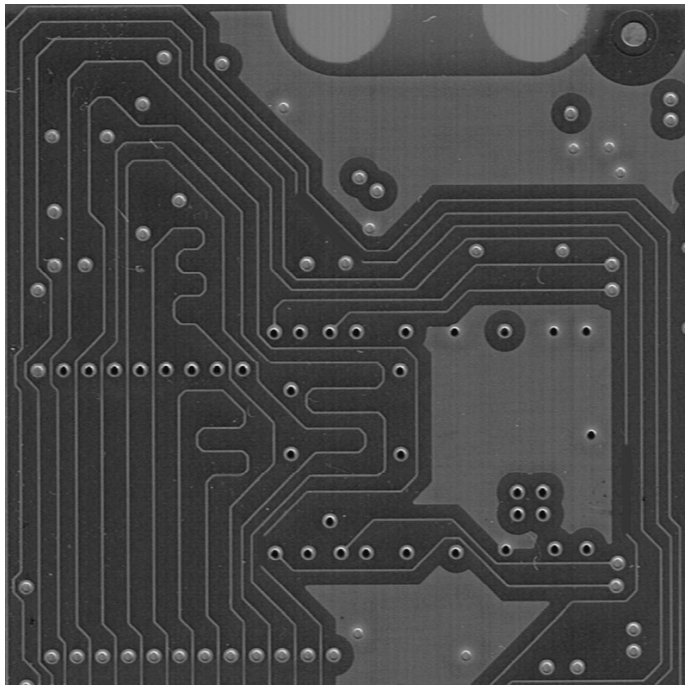
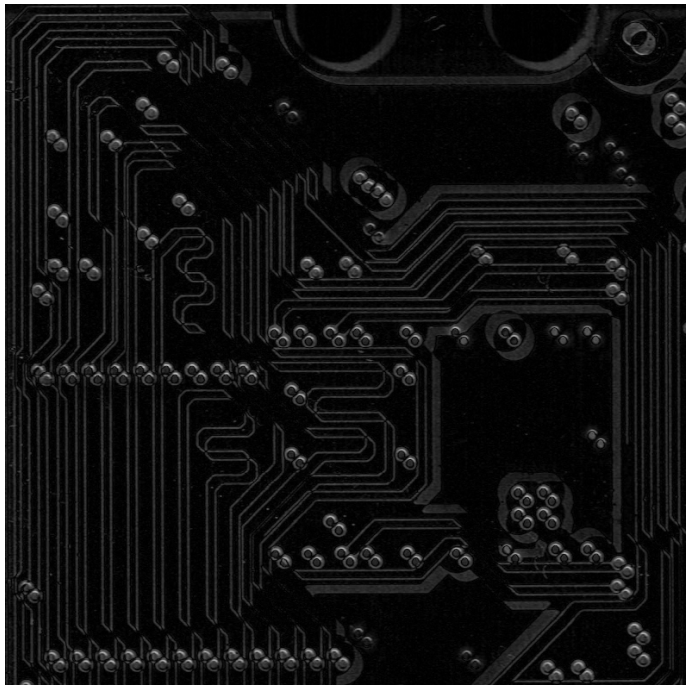
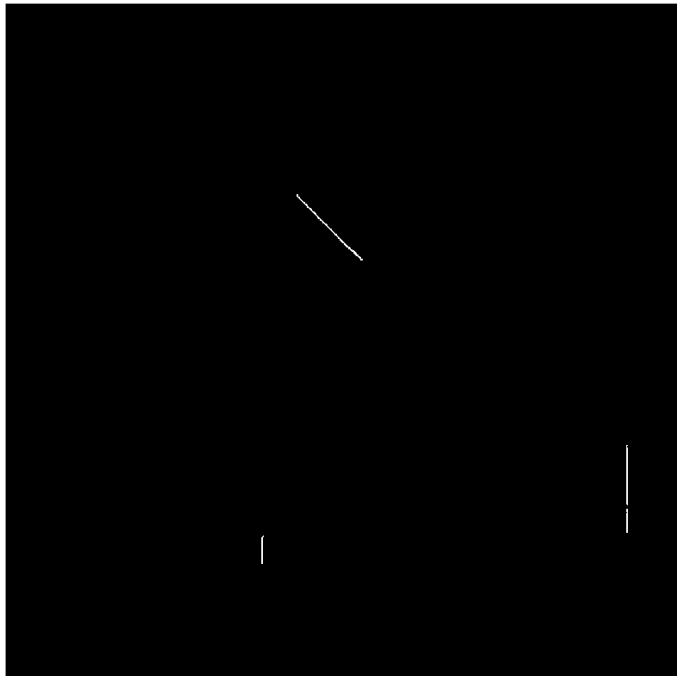


Image $f[x,y]$ (w/ defect)

Absolute difference between two images



$|f\text{-}g|$ w/o alignment



$|f\text{-}g|$ w/ alignment

Displacement estimation by block matching

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

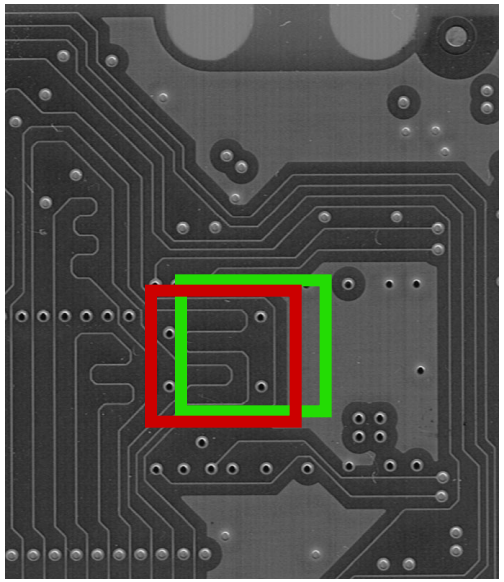


Image $g[x,y]$

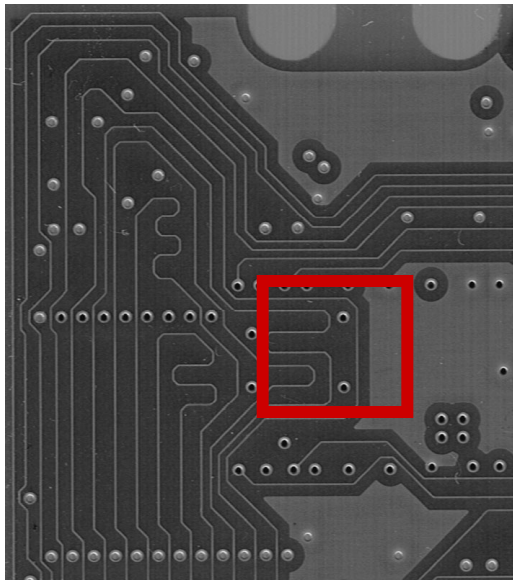


Image $f[x,y]$

Rectangular array of pixels is selected as a measurement window

Displacement estimation by block matching

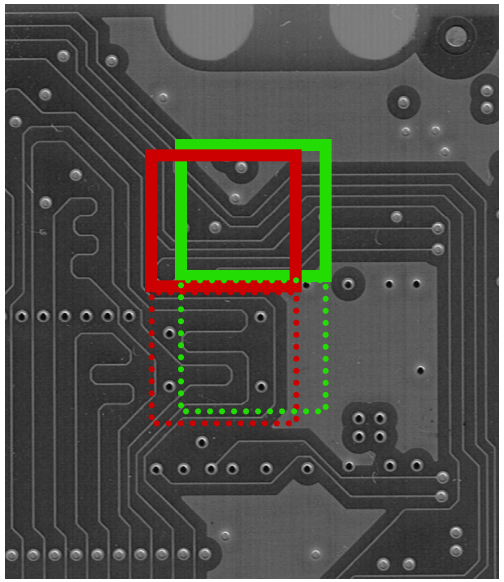


Image $g[x,y]$

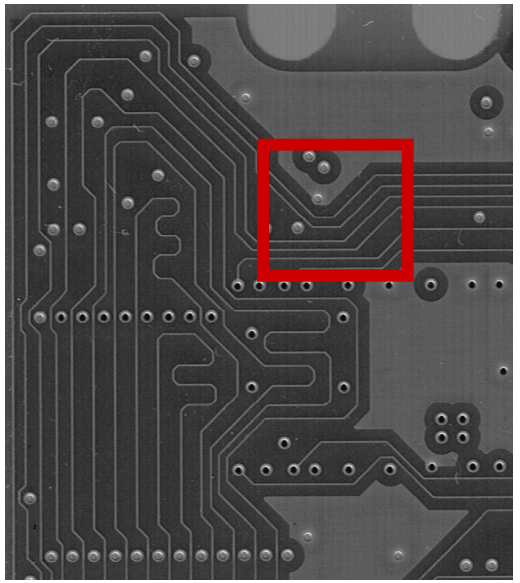


Image $f[x,y]$

. . . process repeated for another measurement window position.

Integer pixel shifts

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

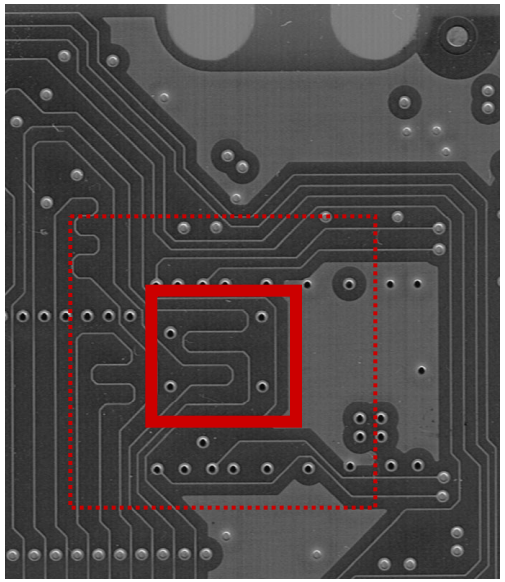


Image $g[x,y]$

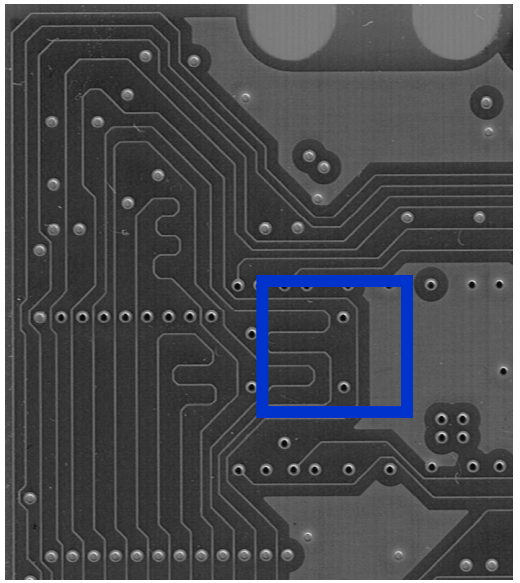
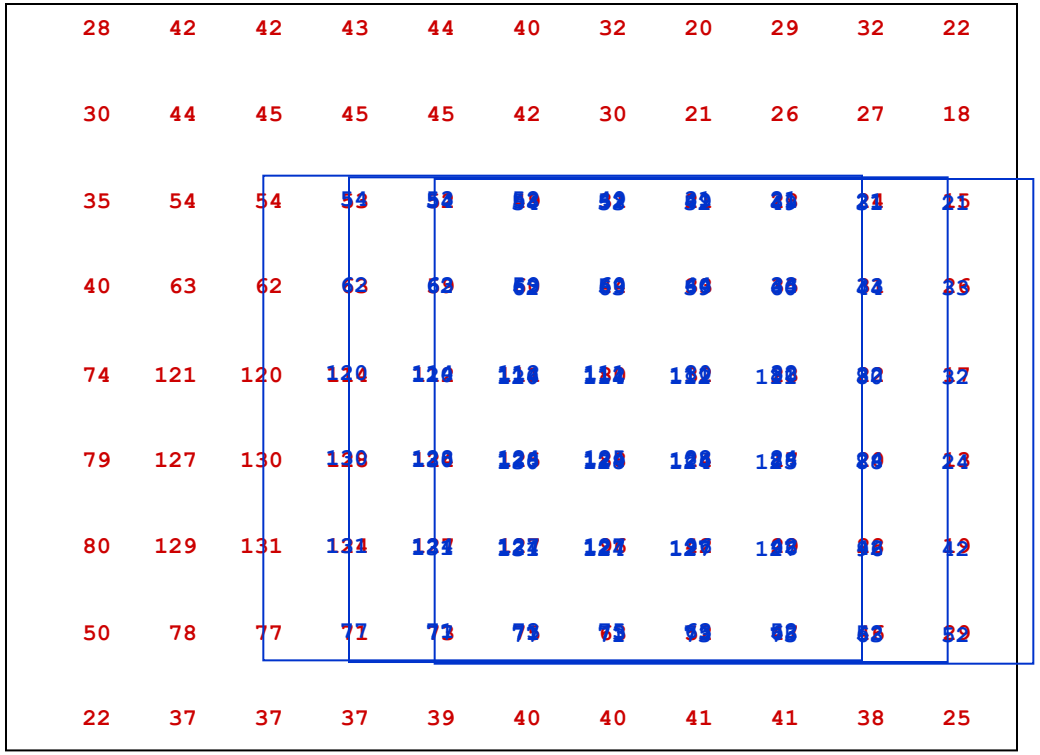


Image $f[x,y]$

Rectangular array of pixels is selected as a measurement window

Integer pixel shifts



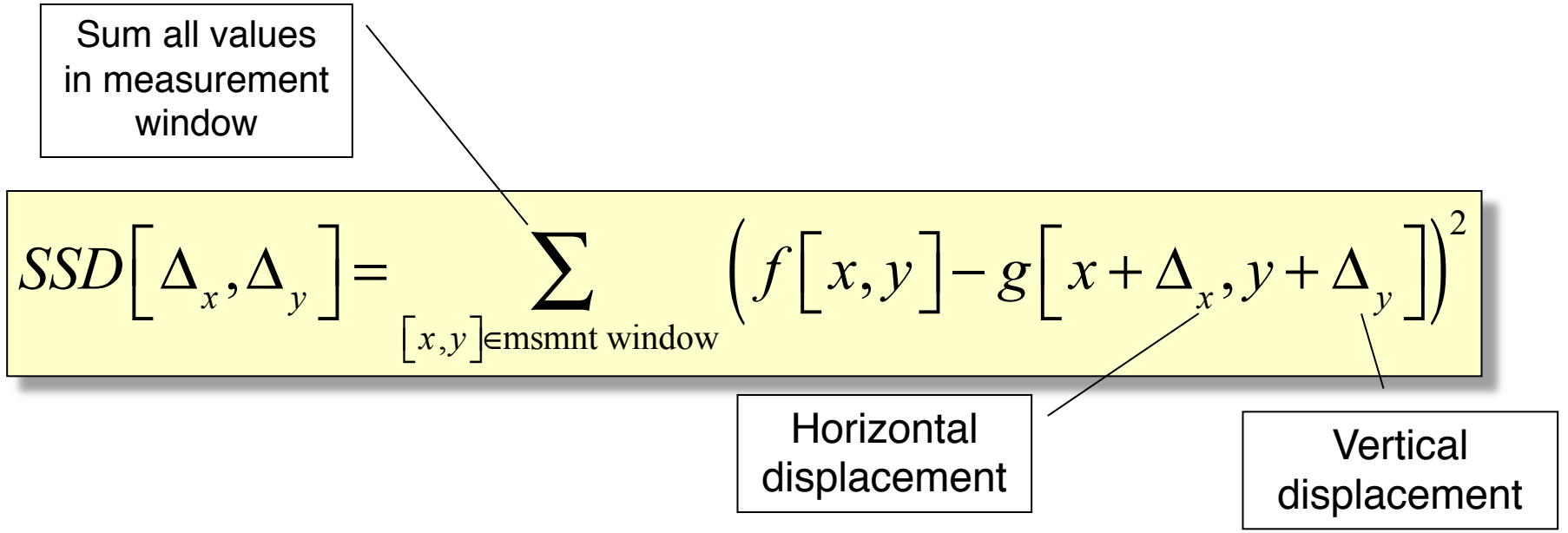
Measurement window is compared with a shifted array of pixels in the other image, to determine the best match

54	53	52	49	31	21
62	63	59	60	44	33
120	114	112	111	80	32
130	128	124	125	88	24
131	124	127	127	96	42
77	71	73	75	63	52

Rectangular array of pixels is selected as a measurement window

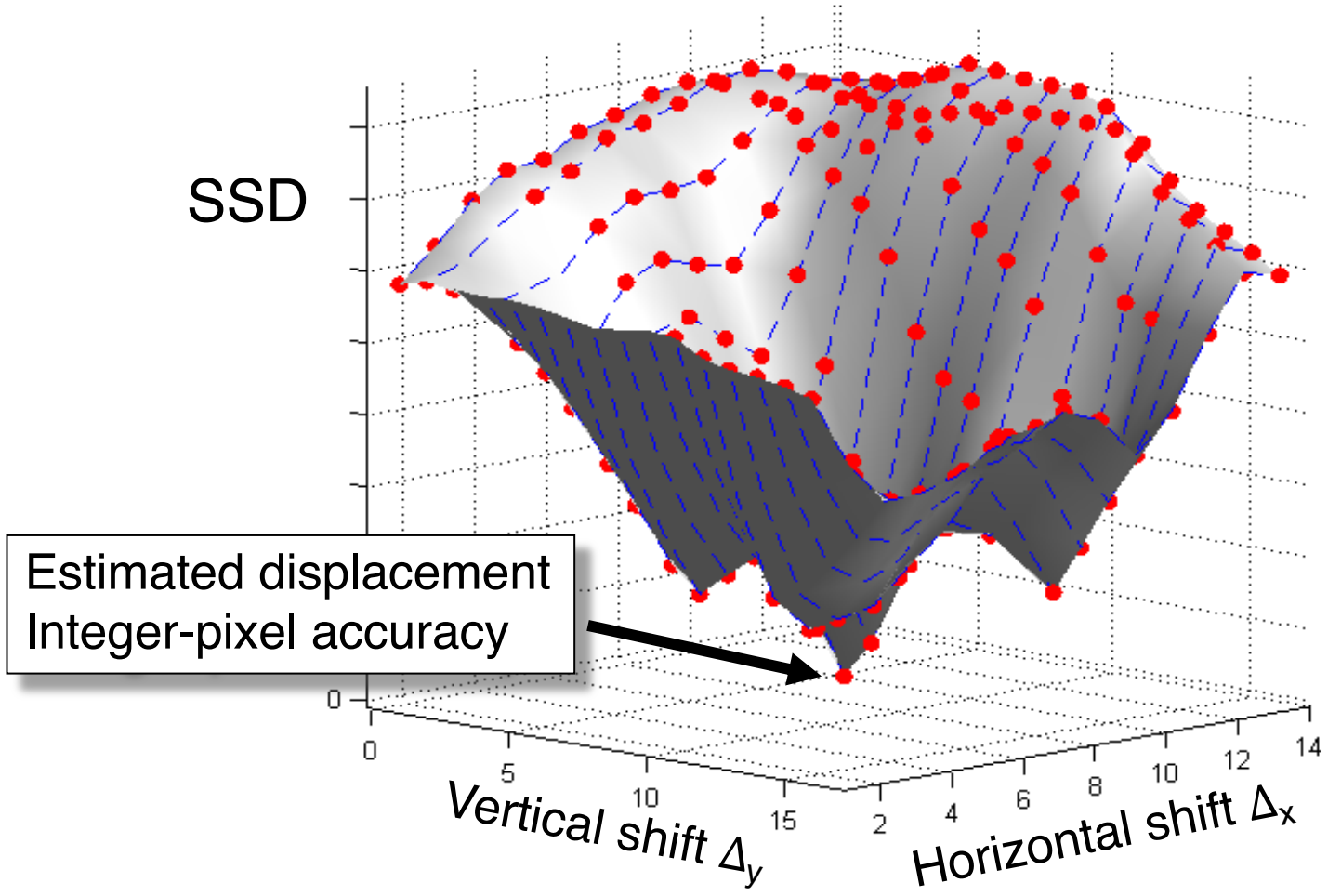
Error metric

- *Sum of Squared Differences*



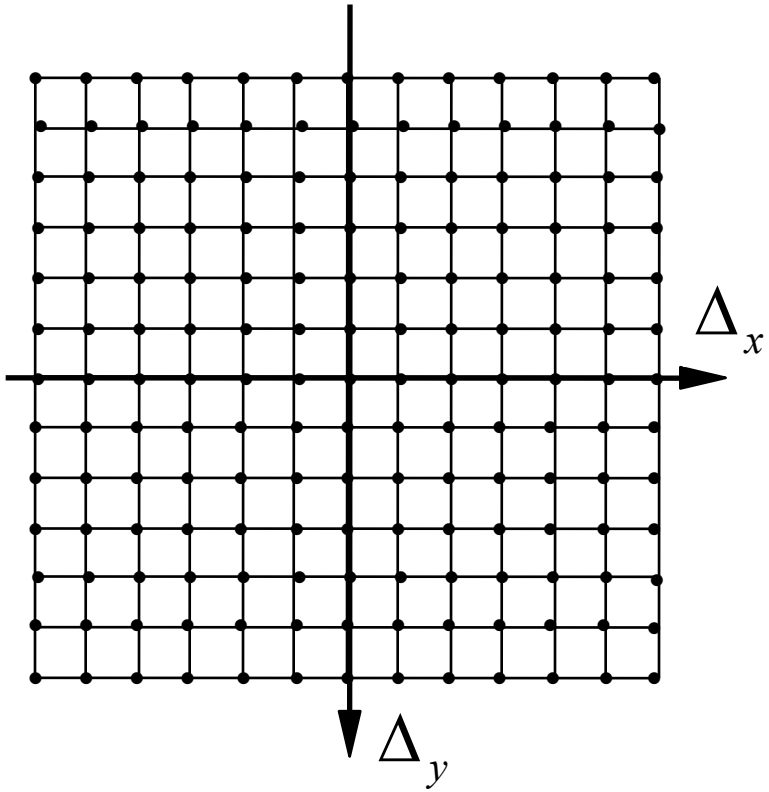
- Alternatives: SAD (*Sum of Absolute Differences*), cross correlation, mutual information . . .
- Robustness against outliers: sum of saturated squared differences, median of squared differences . . .

SSD values resulting from block matching



Block matching: search strategies

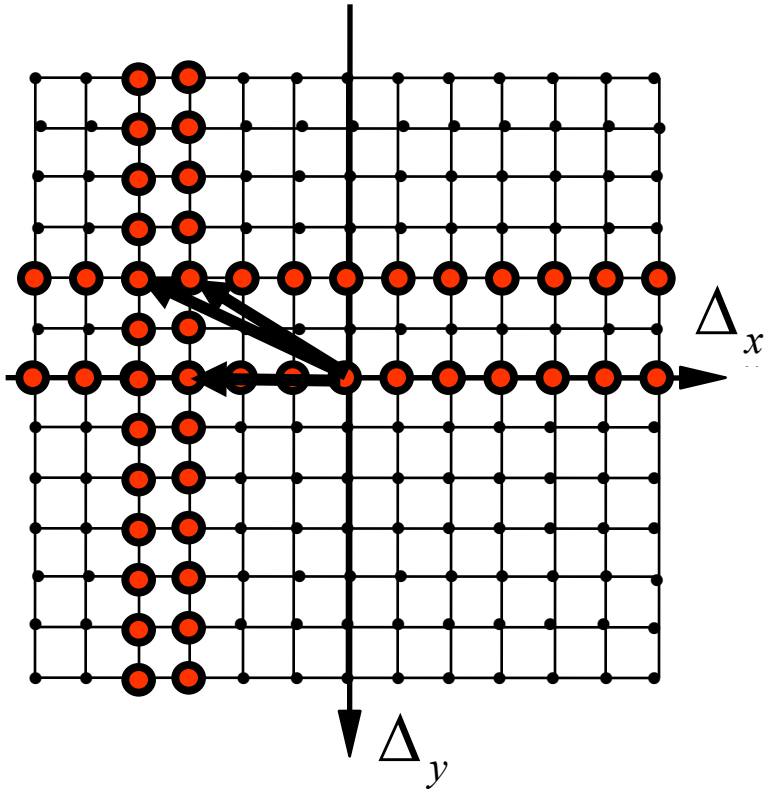
Full search



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

Block matching: search strategies

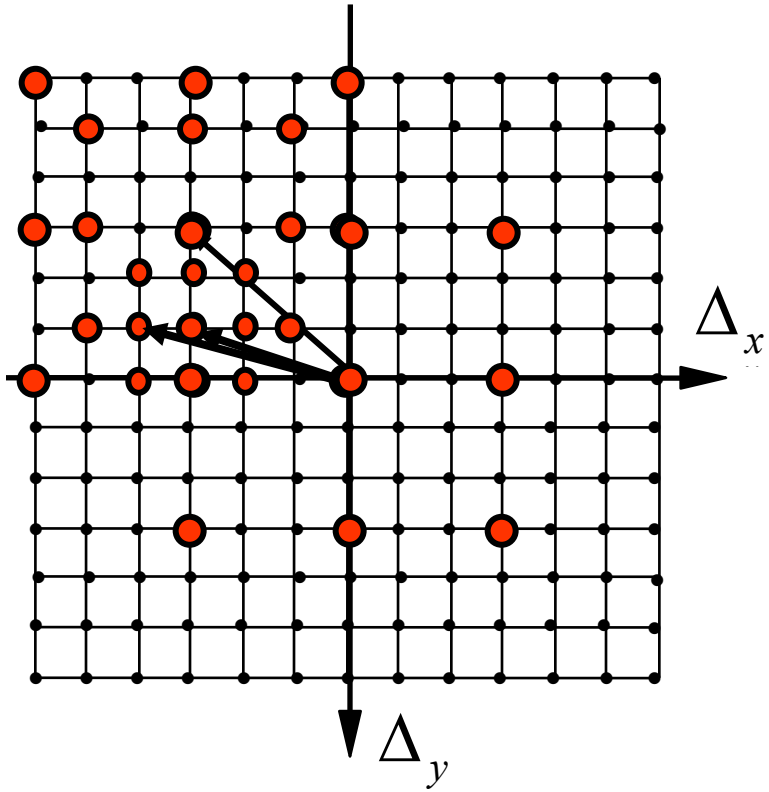
Conjugate direction search



- Alternate search in x and y directions
- Stop when there is no further improvement

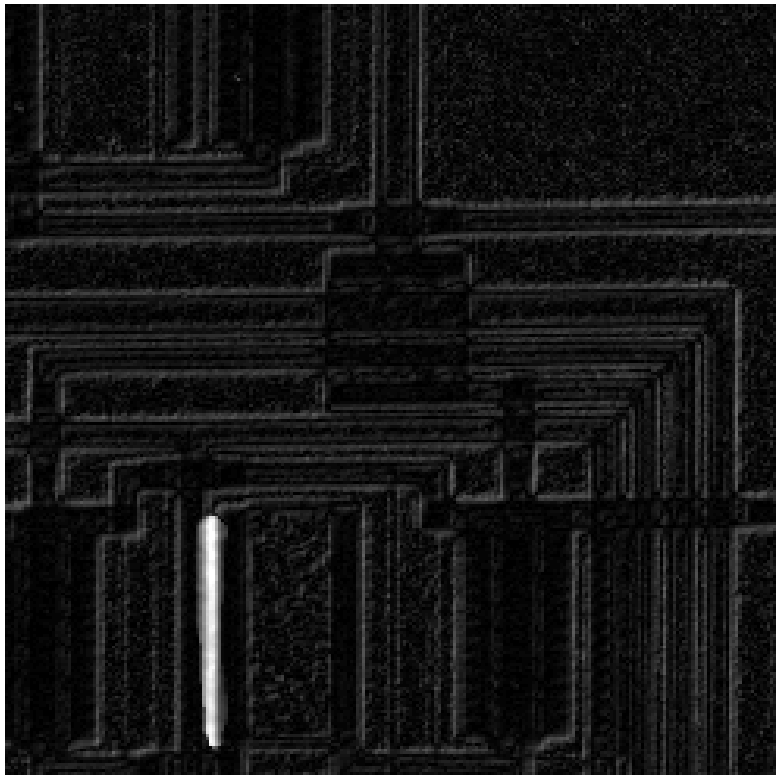
Block matching: search strategies

Coarse-to-fine

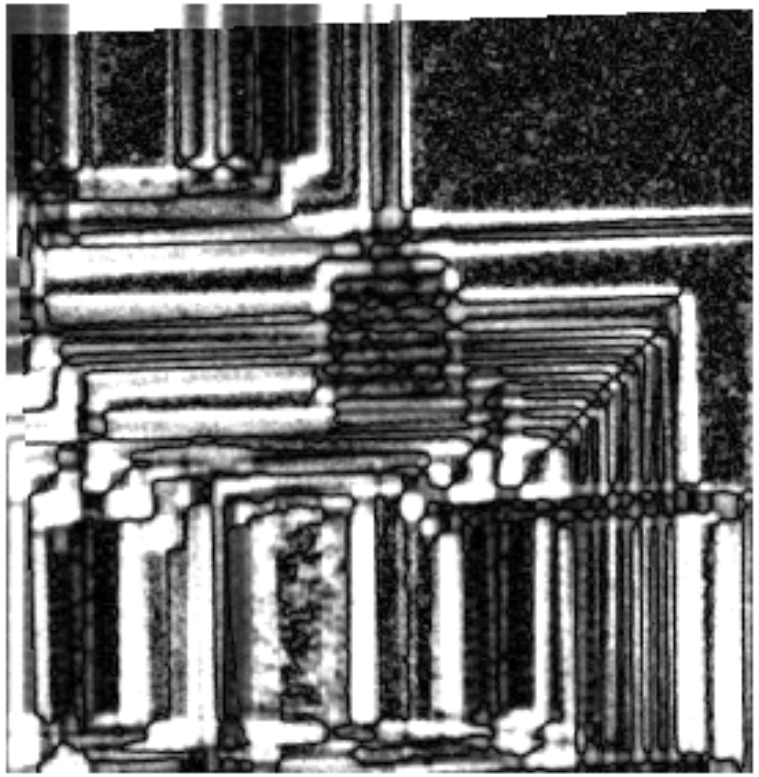


- Start with coarsely spaced candidate displacements
- Smaller pattern when best match is in the middle
- Stop when desired displacement accuracy is reached

Absolute difference between images

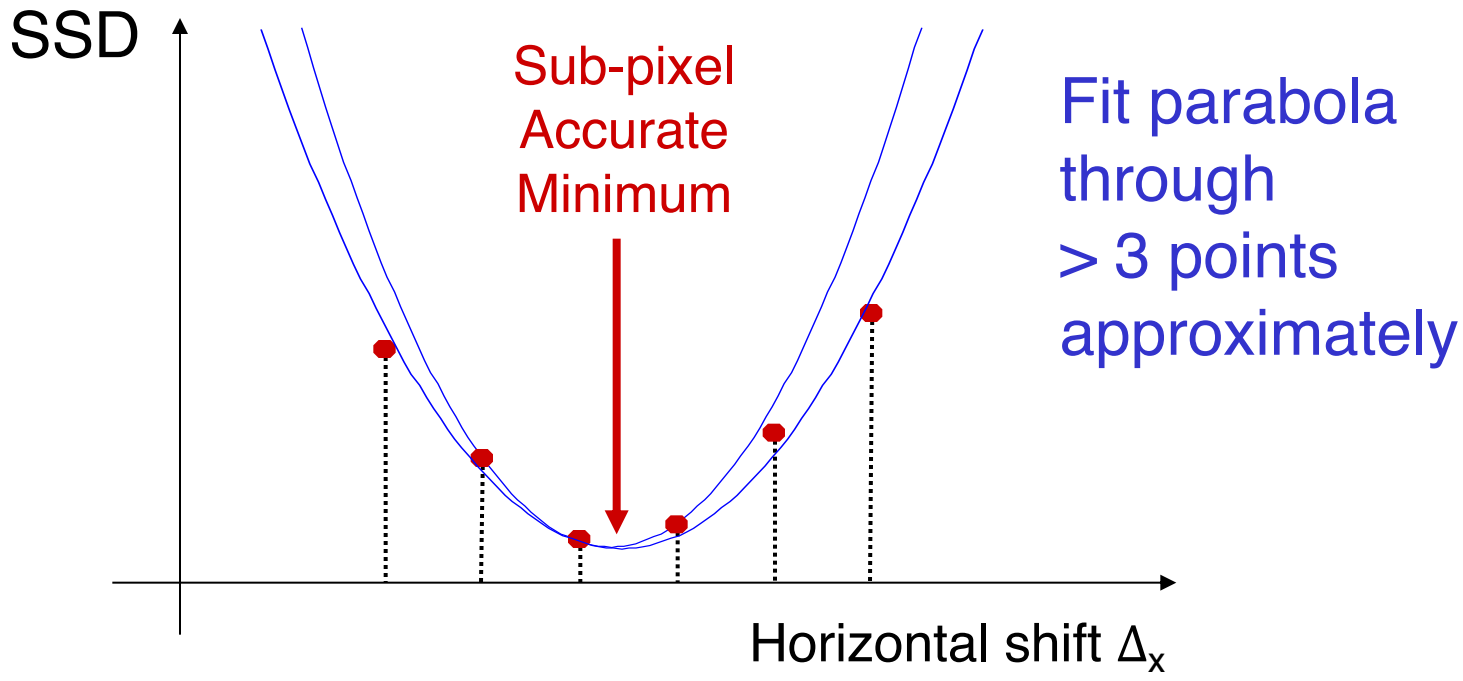


w/ integer-pixel alignment



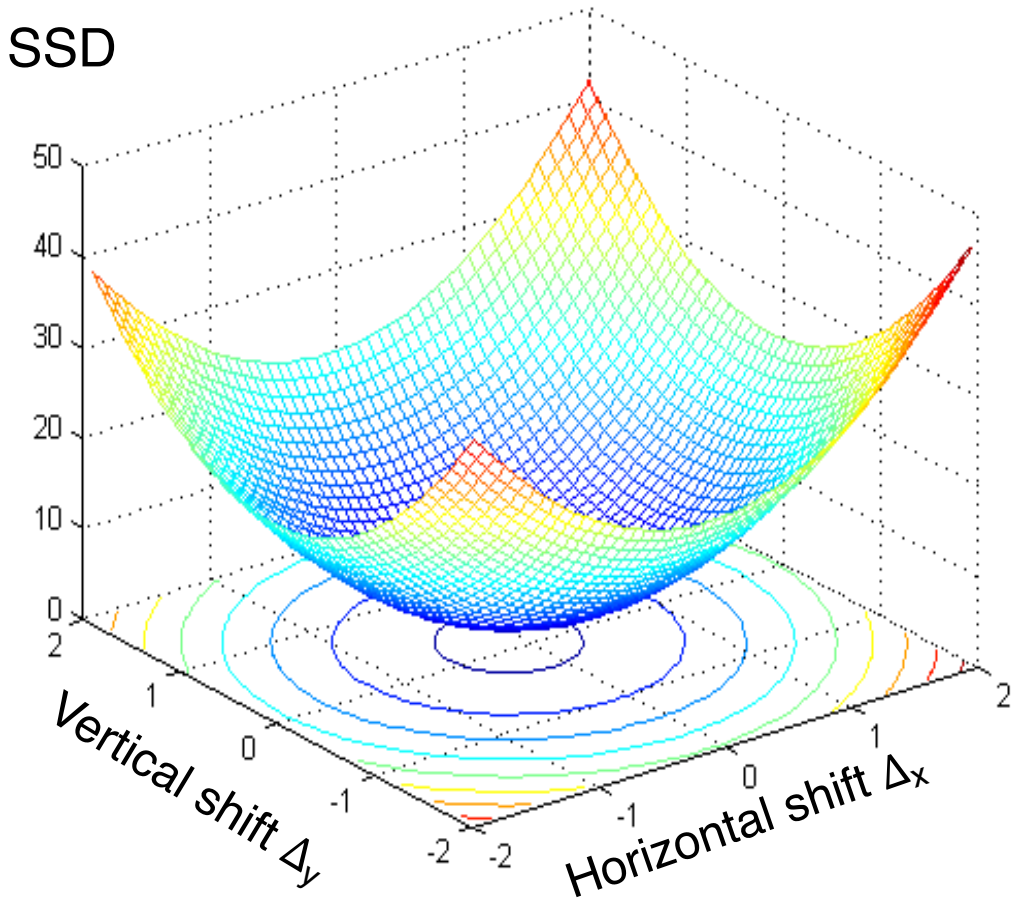
w/o alignment

Interpolation of the SSD Minimum



Fit parabola through > 3 points approximately

2-d Interpolation of SSD Minimum

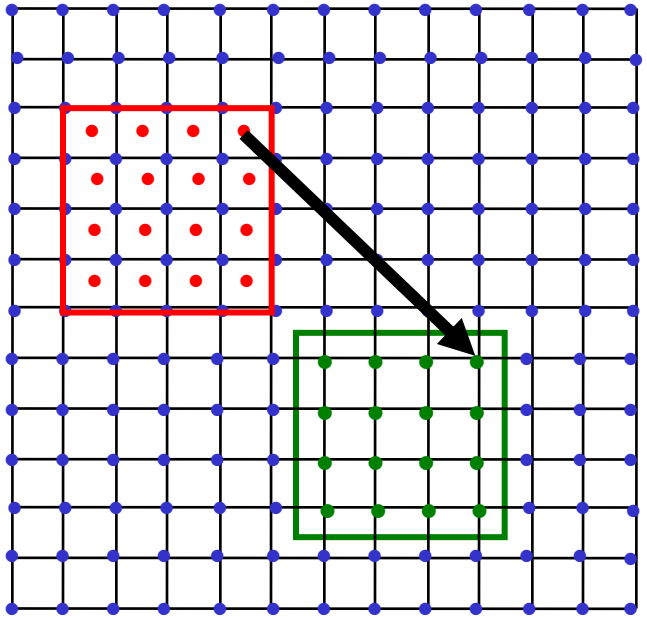


Paraboloid

- Perfect fit through 6 points
- Approximate fit through > 6 points

Sub-pixel accuracy

- Interpolate pixel raster of the reference image to desired sub-pixel accuracy (e.g., by bi-linear or bi-cubic interpolation)
- Straightforward extension of displacement vector search to fractional accuracy
- Example: half-pixel accurate displacements



$$\begin{pmatrix} \Delta_x \\ \Delta_y \end{pmatrix} = \begin{pmatrix} 4.5 \\ 4.5 \end{pmatrix}$$