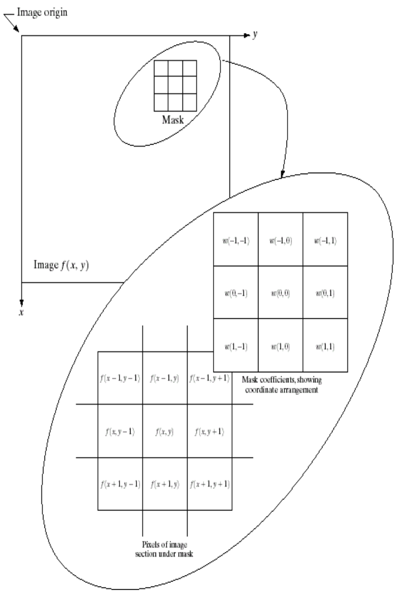
2.4 Spatial Filtering

- The output intensity value at (x,y) depends not only on the input intensity value at (x,y) but also on the specified number of neighboring intensity values around (x,y)
- Spatial masks (also called window, filter, kernel, template) are used and convolved over the entire image for local enhancement (spatial filtering)
- The size of the masks determines the number of neighboring pixels which influence the output value at (x,y)
- The values (coefficients) of the mask determine the nature and properties of enhancing technique.
- The mechanics of spatial filtering
- For an image of size *M* x *N* and a mask of size *m* x *n*
- The resulting output gray level for any coordinates x and y is given by

$$g(x, y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

where $a = (m-1)/2, \quad b = (n-1)/2$

$x = 0, 1, 2, ..., M-1, \quad y = 0, 1, 2, ..., N-1,$



Given the 3×3 mask with coefficients: w_1, w_2,…, w_9

The mask cover the pixels with gray levels: z_1, z_2,…, z_9

$$z_5 \leftarrow z = w_1 z_1 + w_2 z_2 + \cdots + w_9 z_9 = \sum_{i=1}^{9} w_i z_i$$

z gives the output intensity value for the processed image (to be stored in a new array) at the location of z_5 in the input image

Mask operation near the image border

Problem arises when part of the mask is located outside the image plane; to handle the problem:

- Discard the problem pixels (e.g. 512x512$_{input}$ 510x510$_{output}$ if mask size is 3x3)
- Zero padding: expand the input image by padding zeros (512x512$_{input}$ 514x514$_{output}$)
- Zero padding is not good - create artificial lines or edges on the border

- We normally use the gray levels of border pixels to fill up the expanded region (for 3x3 mask). For larger masks a border region equal to half of the mask size is mirrored on the expanded region.

Spatial Filtering for Smoothing

- For blurring/noise reduction;
- Smoothing/Blurring is usually used in preprocessing steps,

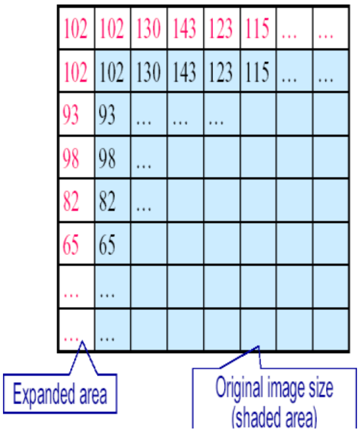
e.g., to remove small details from an image prior to object extraction, or to bridge small gaps in lines or curves

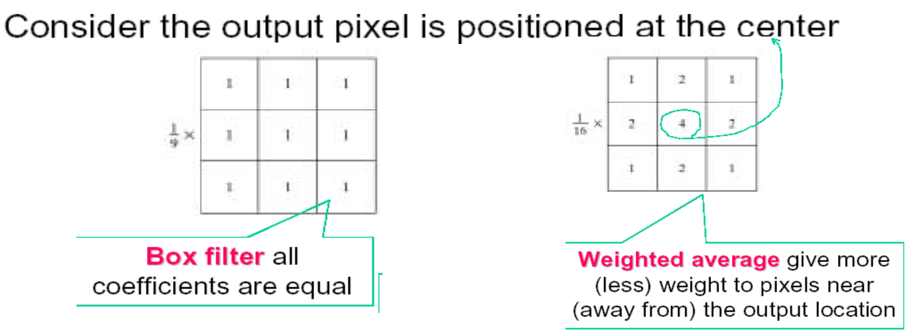
- Equivalent to Low-pass spatial filtering in frequency domain because smaller (high frequency) details are removed based on neighborhood averaging (averaging filters)

Implementation: The simplest form of the spatial filter for averaging is a square mask (assume $m \times m$ mask) with the same coefficients $1/m^2$ to preserve the gray levels (averaging).

Applications: Reduce noise; smooth false contours

Side effect: Edge blurring





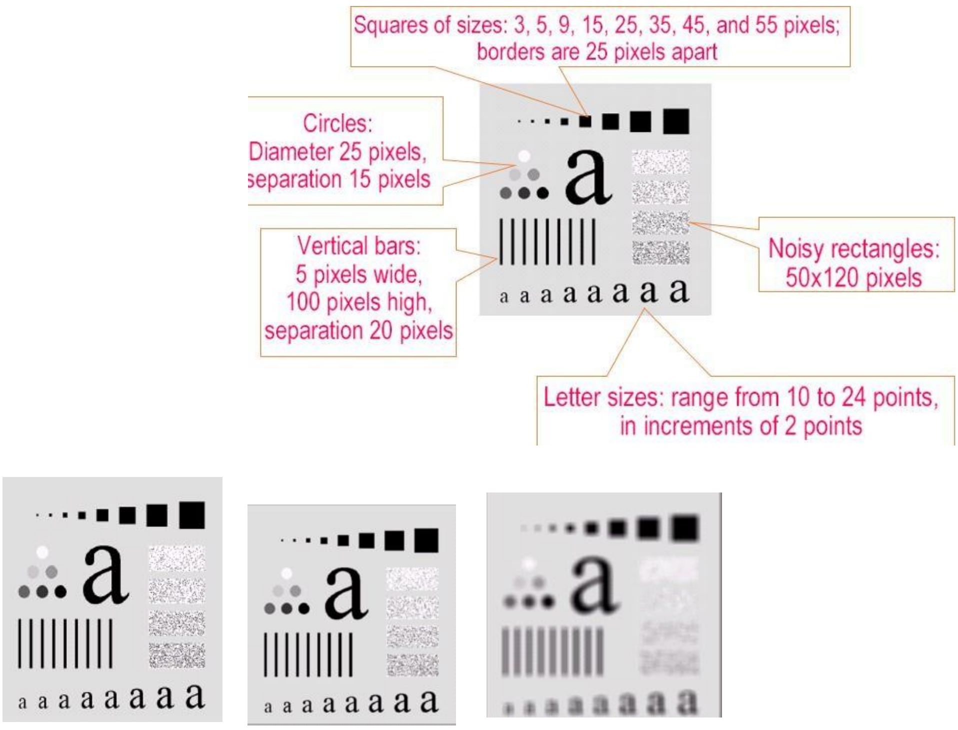


Fig. 2.17 Spatial filtering

Spatial Filtering for Sharpening

Background: to highlight fine detail in an image or to enhance blurred detail

Applications: electronic printing, medical imaging, industrial inspection, autonomous target detection (smart weapons)

Foundation:

- Blurring/smoothing is performed by spatial averaging (equivalent to integration)
- Sharpening is performed by noting only the gray level changes in the image that is the differentiation

Operation of Image Differentiation

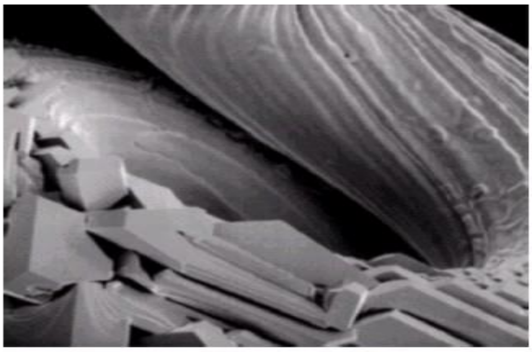
- Enhance edges and discontinuities (magnitude of output gray level >>0)
- De-emphasize areas with slowly varying gray-level values (output gray level: 0)

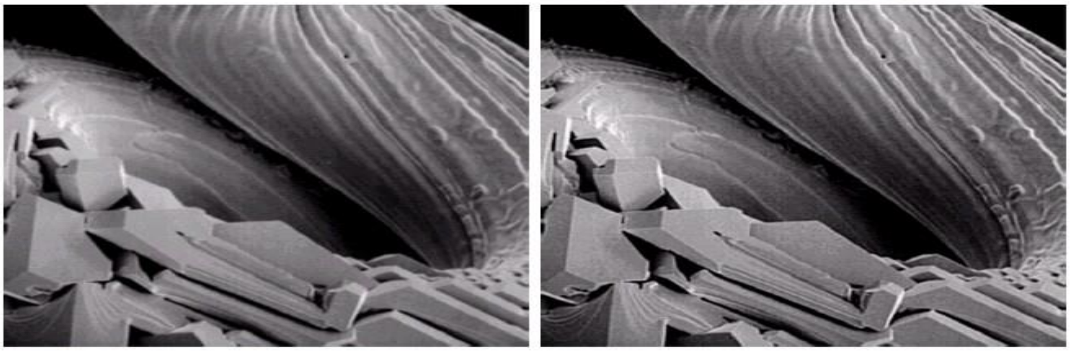
Mathematical Basis of Filtering for Image Sharpening

- First-order and second-order derivatives
- Approximation in discrete-space domain
- Implementation by mask filtering

0	−1	0
−1	5	−1
0	−1	0

−1	−1	−1
−1	9	−1
−1	−1	−1





a b c
d e

FIGURE 2.18 (a) Composite Laplacian mask. (b) A second composite mask. (c) Scanning electron microscope image. (d) and (e) Results of filtering with the masks in (a) and (b), respectively. Note how much sharper (e) is than (d). (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)