PAM3012
Digital Image Processing for Radiographers

Image Enhancement in the Spatial Domain
(Part III)
Spatial Filtering

In this lecture

- ★Recap: Spatial Enhancement
- ★Spatial Filtering
- ★Smoothing Filters
- ★Sharpening Filters

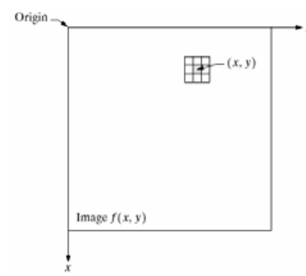
Background

- Procedures that operate directly on the aggregate of pixels composing an image

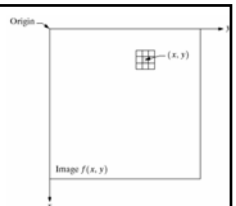
$$g(x,y) = T[f(x,y)]$$

Background

- A neighborhood about (x,y) is defined by using a square subimage area centered at (x,y).
- Operator T is applied to each location



Background

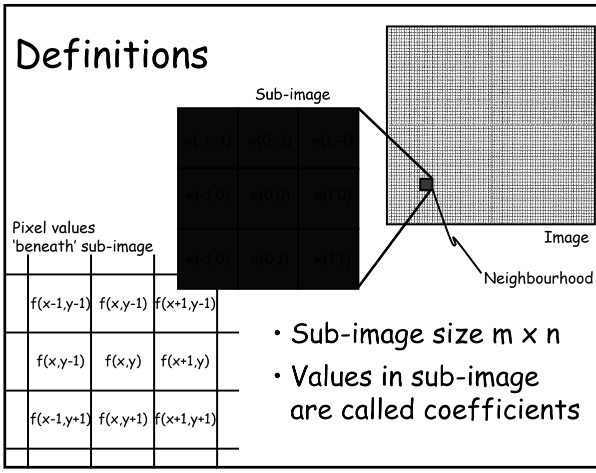


- If neighborhood is greater than 1 X 1
- Values of *f* in a predefined neighborhood of (x,y) determine the value of *g* at (x,y).
- Values of surrounding pixels (mask) determine nature of process in each pixel
- Called *Mask processing* or *filtering*

Spatial Filtering

Modifying brightness of pixels depending on brightness of surrounding pixels & predefined sub-image

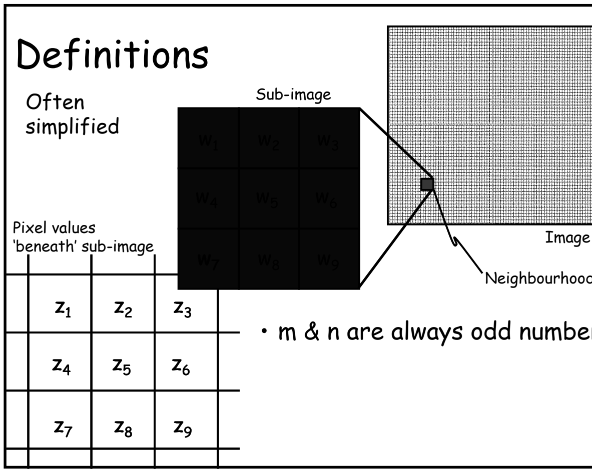
Definitions



- Sub-image size m x n
- Values in sub-image are called coefficients

Definitions

Often simplified



- m & n are always odd numbers

Basic Concepts

- Move mask from point to point
- At each point (x, y), response of filter is calculated using predefined relationship

Example: Linear Spatial Filter

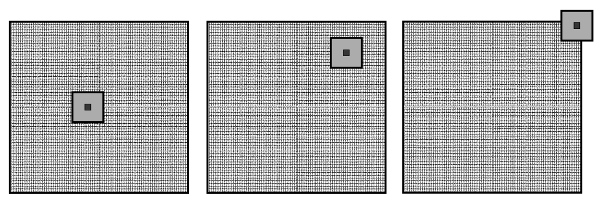
$$\text{Response, } R = w_1 z_1 + w_2 z_2 + w_3 z_3 + \ldots w_{nm} z_{nm}$$

$$or$$

$$= \sum_{i=0}^{nm} w_i z_i$$

Basic Concepts

- What happens when centre of filter approaches edge of image ?



Smoothing Spatial Filters

Smoothing Spatial Filters

- Used for smoothing (blurring) and noise deduction

Common Types

1. Smoothing Linear Filters
2. Order-Statistic Filters

Smoothing Linear Filters

- Output (response) is average of pixels in neighbourhood of filter mask
  - Replace value of every pixel with average gray-level value of surrounding pixels
  - Reduces 'sharp' transitions in gray-level

Smoothing Linear Filters

Mean or Box Filter

- All coefficients are equal

$\frac{1}{9}$ X [redacted]

$$R = \frac{1}{mn}\left(z_1 + z_2 + z_3 + \ldots z_{nm}\right)$$

or

$$= \frac{1}{mn}\sum_{i=0}^{nm} z_i$$

Smoothing Linear Filters

Weighted Average Filter

- Pixels in neighbourhood are multiplied by different coefficients before averaging

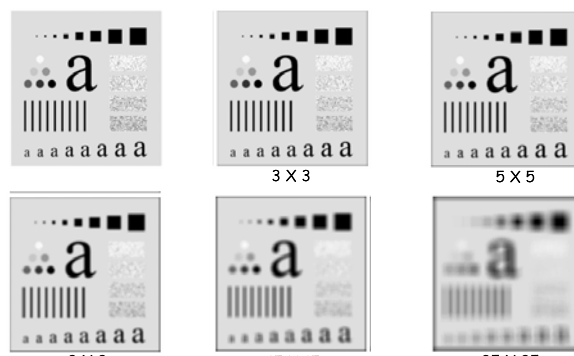
$\frac{1}{16}$ X [redacted]

$$R = \frac{\left(w_1 z_1 + w_2 z_2 + w_3 z_3 + \ldots w_{mn} z_{mn}\right)}{\left(w_1 + w_2 + w_3 + \ldots z_{mn}\right)}$$

or

$$= \frac{\sum_{i=0}^{nm} w_i z_i}{\sum_{i=0}^{nm} w_i}$$

Smoothing Linear Filters



3 X 3, 5 X 5, 9 X 9, 15 X 15, 35 X 35

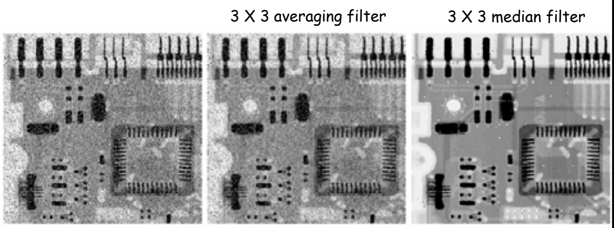
Order-Statistic Filters

- Non-linear spatial filters
- Response based on order (ranking) of pixel gray-levels within mask
- Centre value (x, y) replaced with this value

Order-Statistic Filters

- Example: Median Filter
- Replaces value of x, y with median gray-level in mask
- Used for removing certain types of noise

Order-Statistic Filters



Sharpening Spatial Filters

Sharpening Spatial Filters

- Used to highlight fine detail or enhance detail that has been blurred
- Smoothing - Averaging
- Sharpening - Opposite to averaging ?

Sharpening Spatial Filters

- Enhances regions with high rate of change in gray-scale
  - High intensity gradient (edges)
- De-emphasise areas with slowly varying gray-levels
  - Low intensity gradient (constant intensity)

Derivative Filters

- Averaging is analogous to integration and causes blurring
- Differentiation is expected to have opposite results and sharpen an image.

Derivatives

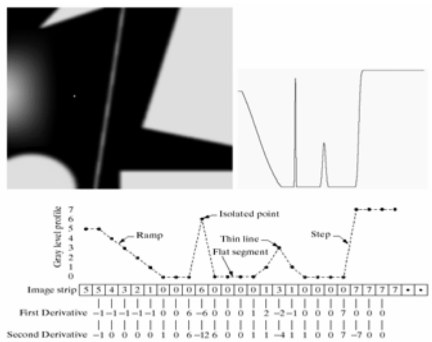
- First derivative

$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

- Second derivative

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x)$$

Derivatives



Digital Function Derivatives

- First derivative:
  - 0 in constant gray segments
  - Non-zero at the onset of steps or ramps
  - Non-zero along ramps
- Second derivative:
  - 0 in constant gray segments
  - Non-zero at the onset and end of steps or ramps
  - 0 along ramps of constant slope.

Observations

- 1st order derivatives produce thicker edges in an image
- 2nd order derivatives have stronger response to fine detail
- 1st order derivatives have stronger response to a gray lever step
- 2nd order derivatives produce a double response at step changes in gray level
- 2nd order derivatives have stronger response to a line than to a step and to a point than to a line

Derivative Filters

- Many different types of sharpening filters
- Example: Gradient Filter

Sharpening Filters

- The filter should have positive coefficients near the center and negative in the outer periphery:

$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

$\frac{1}{9} \times$

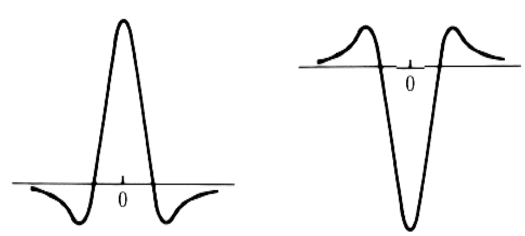
−1	−1	−1
−1	8	−1
−1	−1	−1

$\frac{1}{9} \times$

□1	□1	□1
□1	−8	□1
□1	□1	□1

Sharpening Filters

- Cross section of sharpening filter:



Sharpening Filters

- The sum of the coefficients is 0
  - When the filter is passed over regions of constant gray level, the output of the mask is 0.
- Some scaling and/or clipping is involved (compensates for negative gray-levels)

Gradient Enhancement

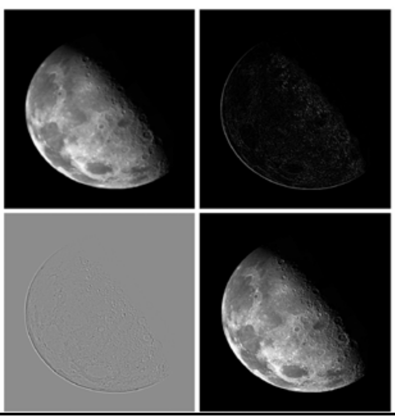
- Highlight gray-level discontinuities
- Deemphasise regions with slowly varying gray
- Produce images with greyish lines on a dark, featureless background
- Background can be recovered while preserving sharpening effect by adding original to derivative image

$$g(x,y) = f(x,y) + \nabla f(x.y)$$

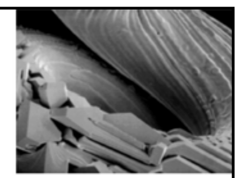
$$g(x,y) = f(x,y) - \nabla f(x.y)$$

Example

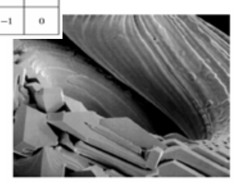
$g(x,y) = f(x,y) + \nabla f(x.y)$



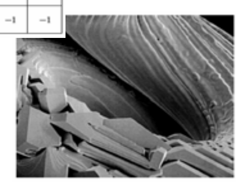
Example



0	−1	0
−1	5	−1
0	−1	0



−1	−1	−1
−1	9	−1
−1	−1	−1



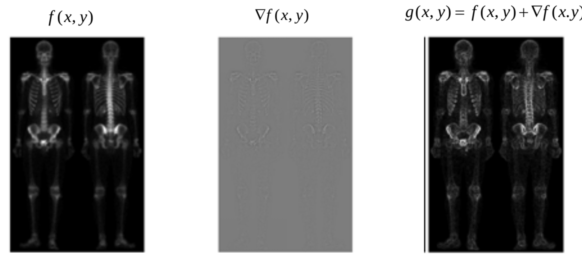
Combing Spatial Enhancement Methods

- Enhancement usually requires application of several complementary techniques

Example

- Nuclear whole body bone scan
  - Detect disease, infection & tumours
- Objective:
  - Bring out more skeletal detail

Example



Summary

★Recap: Spatial Enhancement
★Spatial Filtering
★Smoothing Filters
★Sharpening Filters