Digital Image Processing Lecture 4

Muhammad Usman Ghani Khan

Department of Computer Science & Engineering
UET, Lahore

Spring Semester

Outline

Outline

Sharpening Spatial Filters

Goal: highlight or enhance details in images

- Sharpening spatial filters seek to highlight fine detail
- Remove blurring from images
- Highlight edges

Procedure

- Sharpening filters are based on spatial differentiation. (why?)

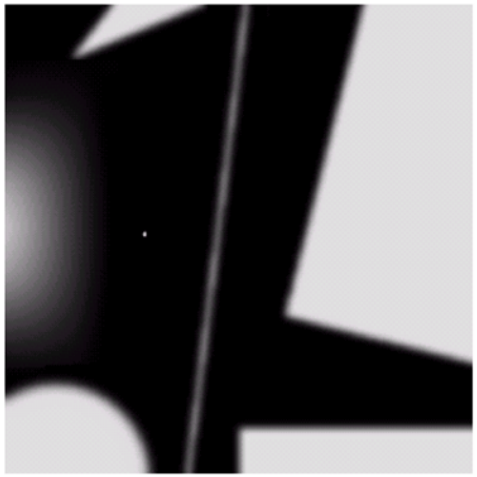
Some Applications

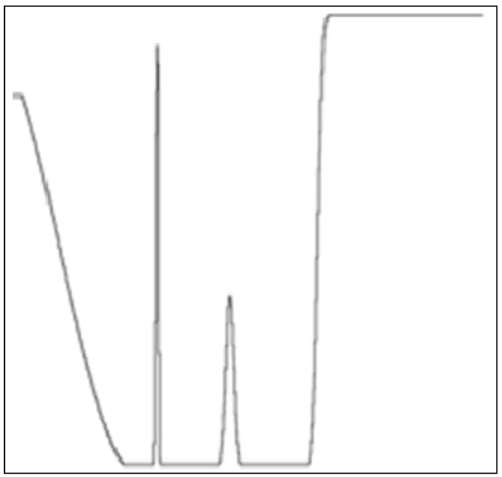
- Photo enhancement
- Medical image visualization
- Industrial defect detection

Outline

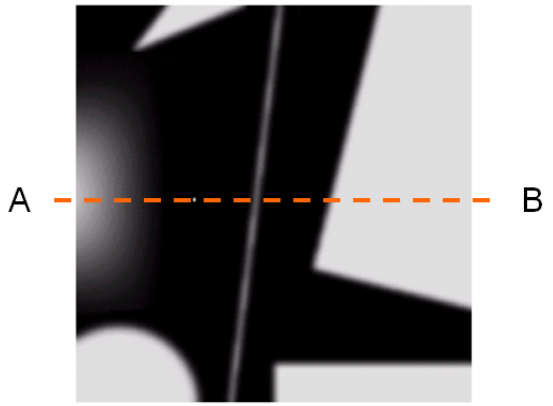
Spatial Differentiation

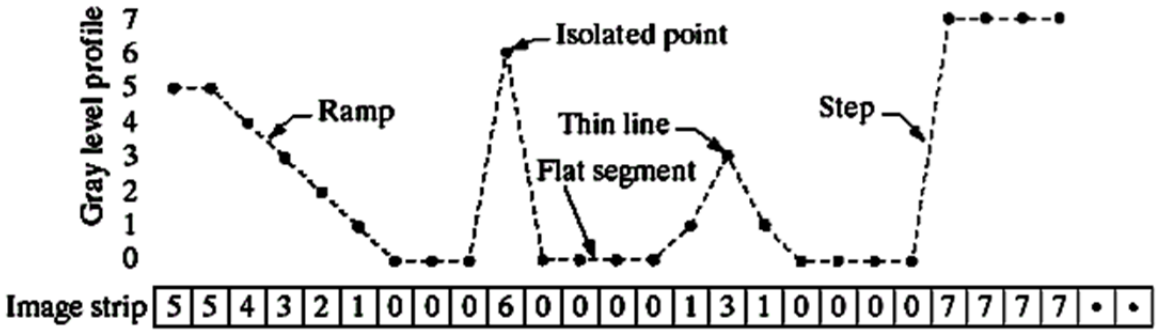
- Differentiation measures the rate of change of a function
- Let's consider a simple 1 dimensional example





Spatial Differentiation





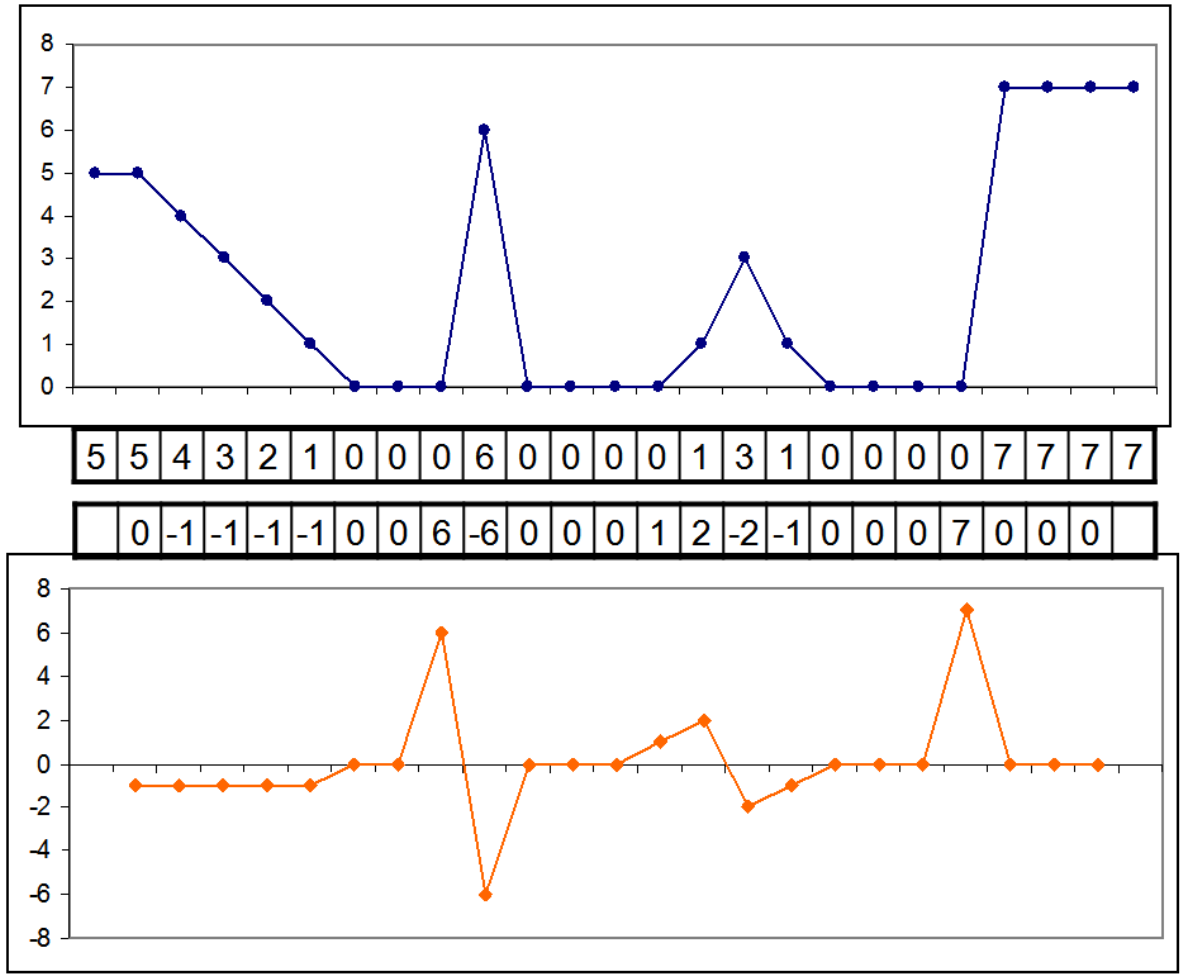
1^{st} Derivative

The formula for the 1^{st} derivative of a function is as follows:

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

It's just the difference between subsequent values and measures the rate of change of the function

1st Derivative



1^{st} Derivative

1. must be zero in flat segments(area of constant gray levels)
2. must be non-zero at the onset of a gray level step or ramp
3. must be non zero along ramps

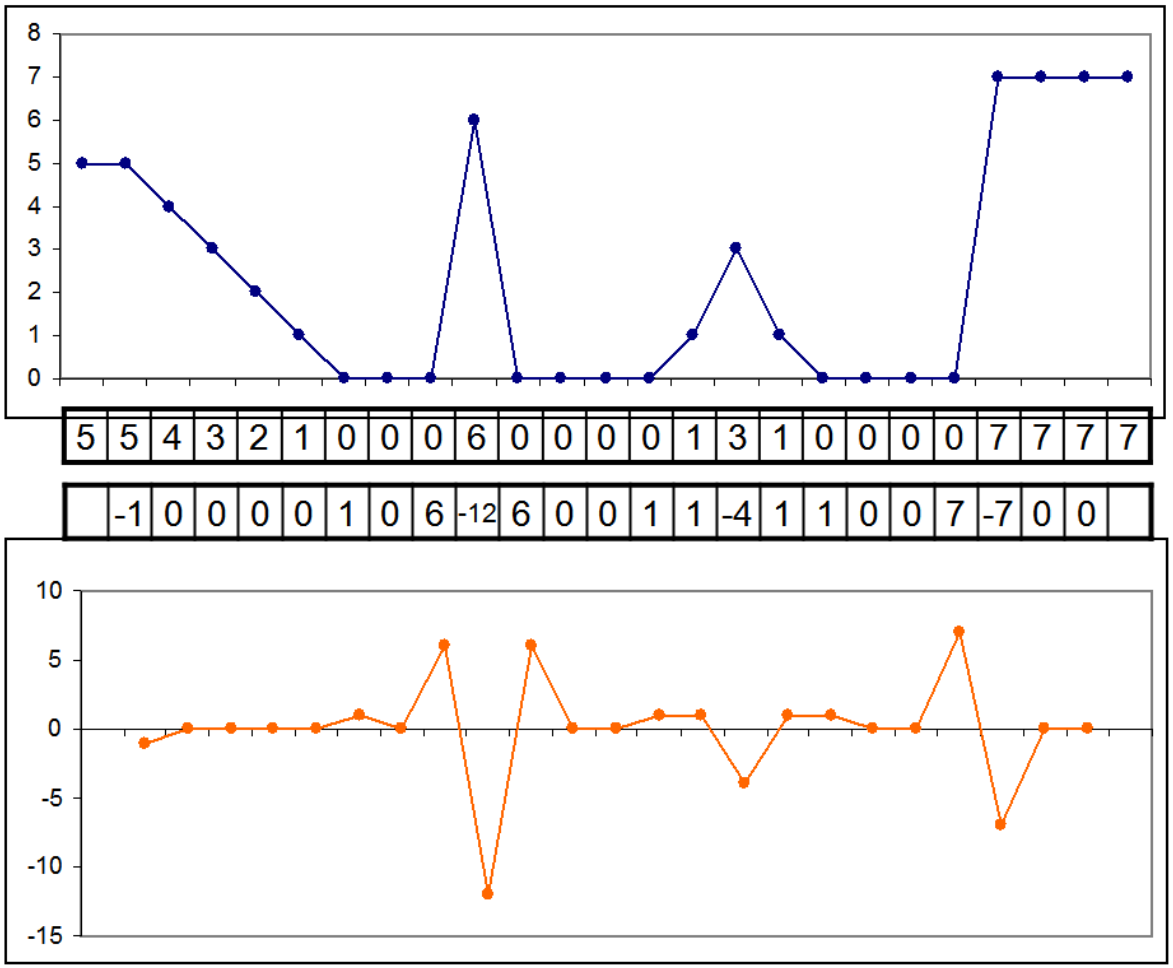
2^{nd} Derivative

The formula for the 2^{nd} derivative of a function is as follows:

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

Simply takes into account the values both before and after the current value

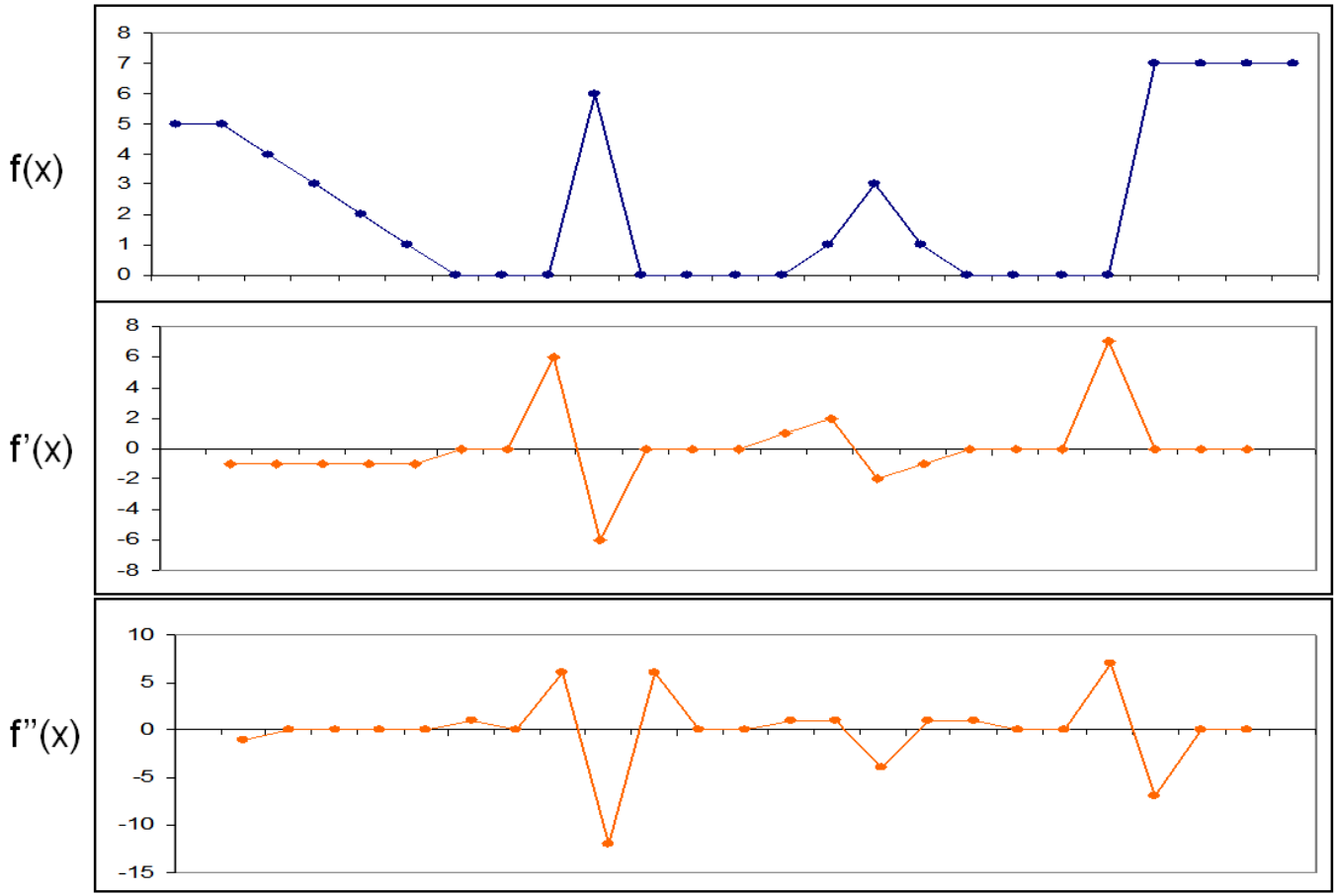
2nd Derivative



2nd Derivative

1. must be zero in flat segments
2. must be non-zero at the onset and end of a gray level step or ramp
3. must be non zero along ramps of constant slope

1st and 2nd Derivatives



Using Second Derivatives For Image Enhancement

- The 2nd derivative is more useful for image enhancement than the 1st derivative
  - Stronger response to fine detail
  - Simpler implementation

Outline

The Laplacian

The Laplacian is defined as follows:

$$\nabla^2 f = \frac{\partial^2 f}{\partial^2 x} + \frac{\partial^2 f}{\partial^2 y} \tag{3}$$

where partial 1^{st} Derivative in the x direction is defined as follows:

$$\frac{\partial^2 f}{\partial^2 x} = f(x+1, y) + f(x-1, y) - 2f(x, y) \tag{4}$$

and in the y direction as follows:

$$\frac{\partial^2 f}{\partial^2 y} = f(x, y+1) + f(x, y-1) - 2f(x, y) \tag{5}$$

The Laplacian

So, the Laplacian can be built as:

$$\bigtriangledown^2 f = [f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)]-4f(x,y) \quad (6)$$

We can easily build a filter based on this

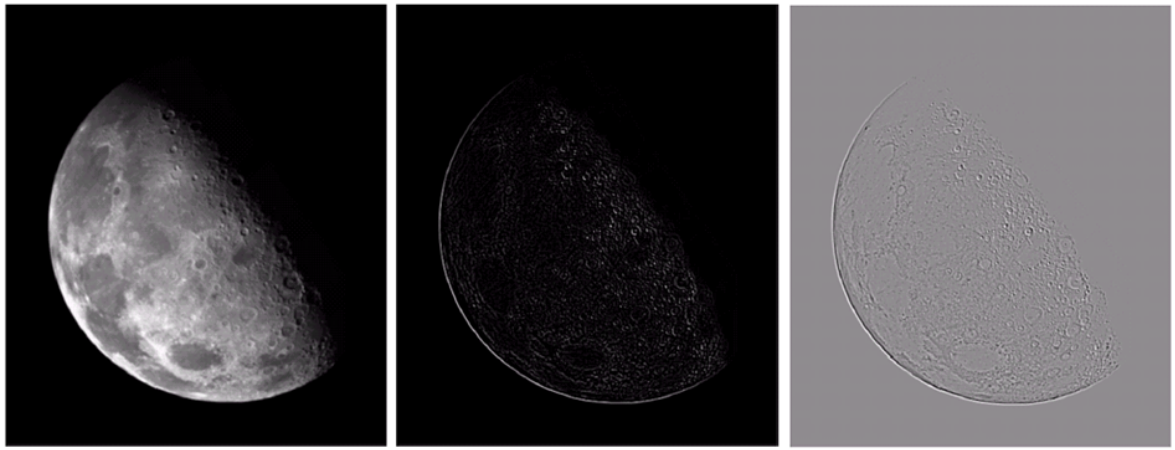
0	1	0
1	-4	1
0	1	0

The Laplacian – Different Filters

0	1	0	1	1	1
1	−4	1	1	−8	1
0	1	0	1	1	1
0	−1	0	−1	−1	−1
−1	4	−1	−1	8	−1
0	−1	0	−1	−1	−1

The Laplacian Example

Applying the Laplacian to an image we get a new image that highlights edges and other discontinuities



Original Image | Laplacian Filtered Image | Laplacian Filtered Image Scaled for Display

But That Is Not Very Enhanced!

- The result of a Laplacian filtering is not an enhanced image
- We have to do more work in order to get our final image
- Subtract the Laplacian result from the original image to generate our final sharpened enhanced image

$$g(x, y) = f(x, y) - \nabla^2 f \qquad (7)$$

Laplacian
Filtered Image
Scaled for Display

The Laplacian Example

Original Image | Laplacian Filtered Image | Sharpened Image

In the final sharpened image edges and fine detail are much more obvious

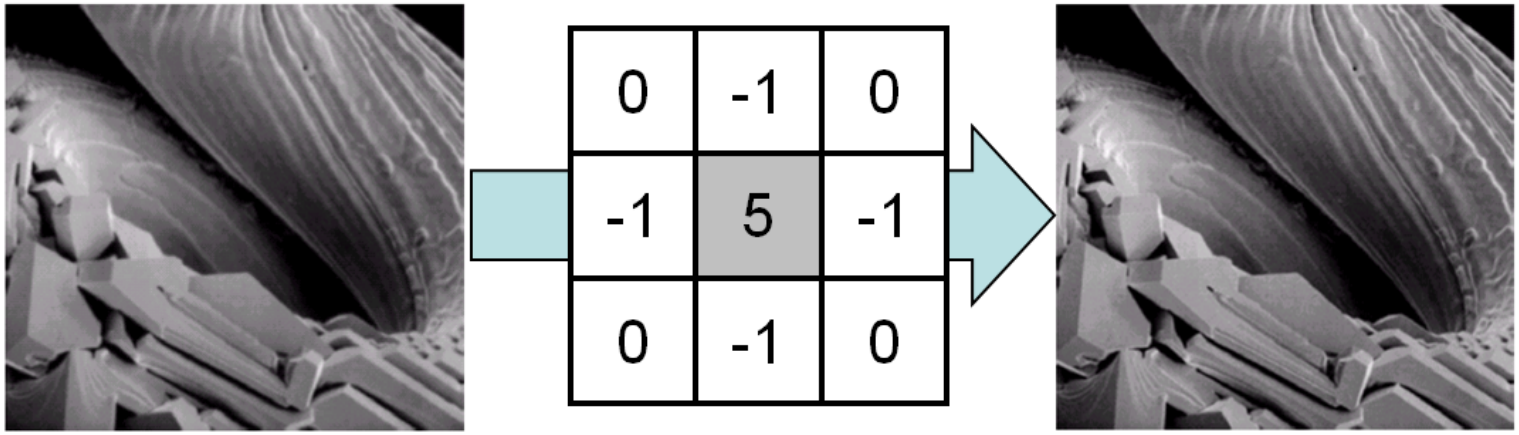
Simplified Image Enhancement

The entire enhancement can be combined into a single filtering operation

$$
\begin{aligned}
g(x,y) &= f(x,y) - \nabla^2 f \\
&= f(x,y) - [f(x+1,y) + f(x-1,y) \\
&\qquad + f(x,y+1) + f(x,y-1) \\
&\qquad - 4f(x,y)] \\
&= 5f(x,y) - f(x+1,y) - f(x-1,y) \\
&\qquad - f(x,y+1) - f(x,y-1)
\end{aligned}
$$

Simplified Image Enhancement

This gives us a new filter which does the whole job for us in one step



Variants On The Simple Laplacian

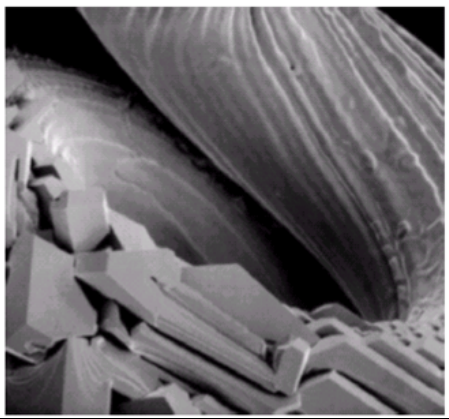
There are lots of slightly different versions of the Laplacian that can be used:

0	1	0
1	-4	1
0	1	0

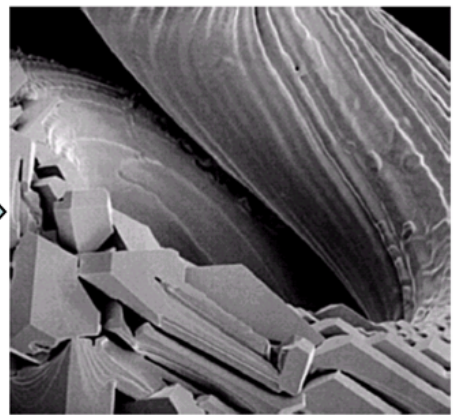
Simple Laplacian

1	1	1
1	-8	1
1	1	1

Variant of Laplacian



-1	-1	-1
-1	9	-1
-1	-1	-1



Unsharp Mask & Highboost Filtering

Using sequence of linear spatial filters in order to get Sharpening effect.

1. Blur
2. Subtract from original image
3. add resulting mask to original image

Sharpening using Unsharp Masking

Subtract blurred version of image from the image itself to produce sharp image

$$g(x, y) = f(x, y) - \bar{f}(x, y) \tag{8}$$

Sharpening using Highboost Filtering

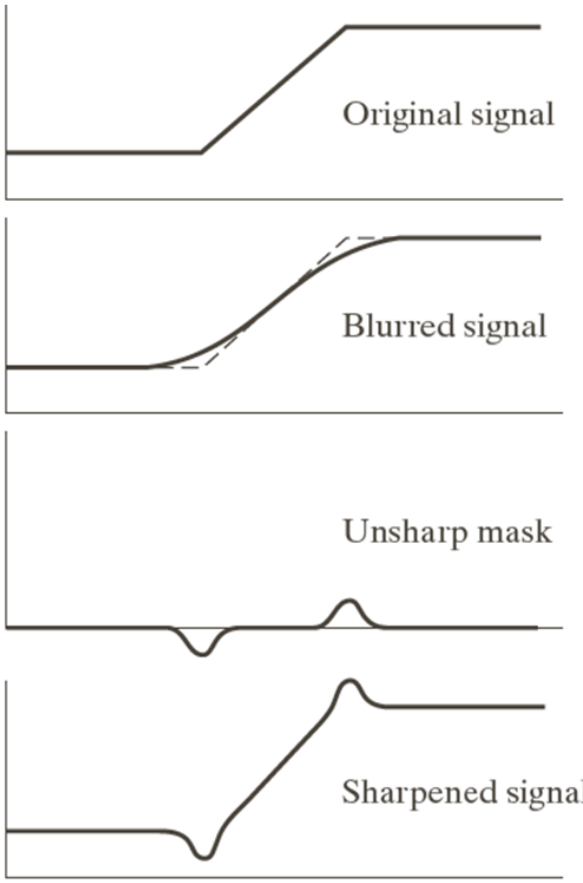
Generalization of unsharp masking

$$g(x, y) = Af(x, y) - \bar{f}(x, y) \tag{9}$$

As A increases, contribution of sharpening decreases

0	−1	0	−1	−1	−1
−1	$A + 4$	−1	−1	$A + 8$	−1
0	−1	0	−1	−1	−1

Highboost Filtering



a
b
c
d

FIGURE 3.39 1-D illustration of the mechanics of unsharp masking. (a) Original signal. (b) Blurred signal with original shown dashed for reference. (c) Unsharp mask. (d) Sharpened signal, obtained by adding (c) to (a).

a
b
c
d
e

FIGURE 3.40 (a) Original image. (b) Result of blurring with a Gaussian filter. (c) Unsharp mask. (d) Result of using unsharp masking. (e) Result of using highboost filtering.

Outline

1st Derivative Filtering

- Implementing 1st derivative filters is difficult in practice
- For a function $f(x, y)$ the gradient of f at coordinates (x, y) is given as the column vector:

$$\nabla \mathrm{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

1st Derivative Filtering

The magnitude of this vector is given by:

$$\begin{aligned}\nabla f &= mag(\nabla \mathrm{f}) \\ &= \left[G_x^2 + G_y^2\right]^{1/2} \\ &= \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2\right]^{1/2}\end{aligned}$$

For practical reasons this can be simplified as:

$$\nabla f \approx |G_x| + |G_y|$$

1st Derivative Filtering

There is some debate as to how best to calculate these gradients but we will use:

$$\nabla f \approx \left|(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)\right| + \left|(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)\right|$$

which is based on these coordinates

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

Sobel Operators

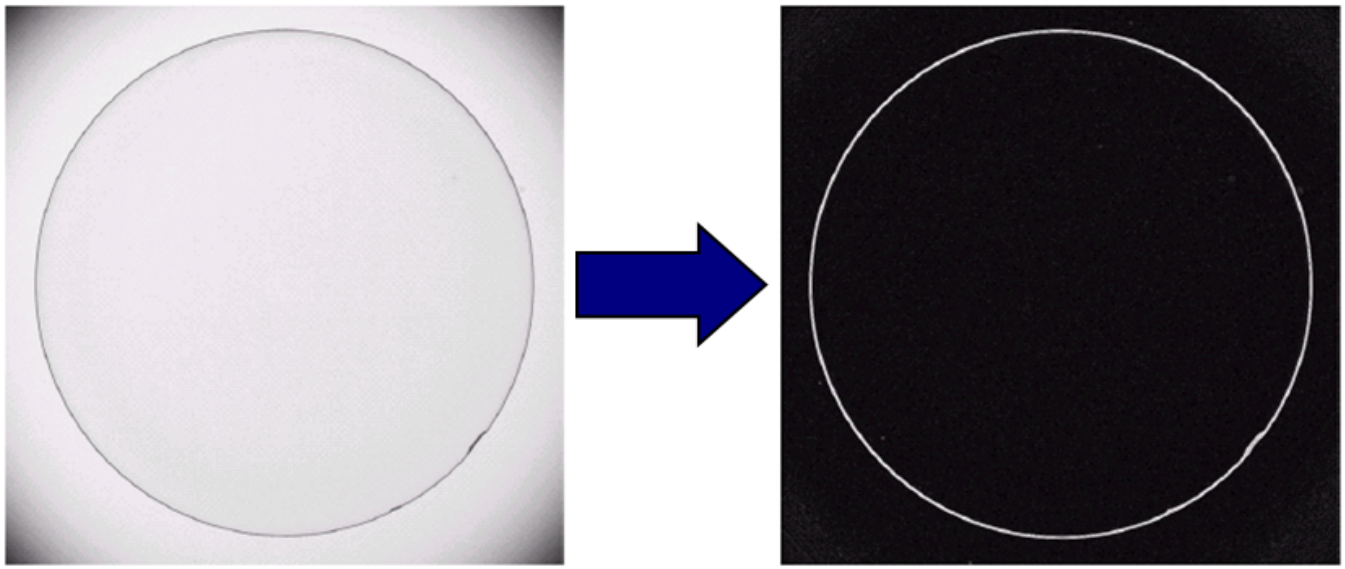
Based on the previous equations we can derive the Sobel Operators

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

To filter an image it is filtered using both operators the results of which are added together

Sobel Operators: Industrial Inspection



Outline

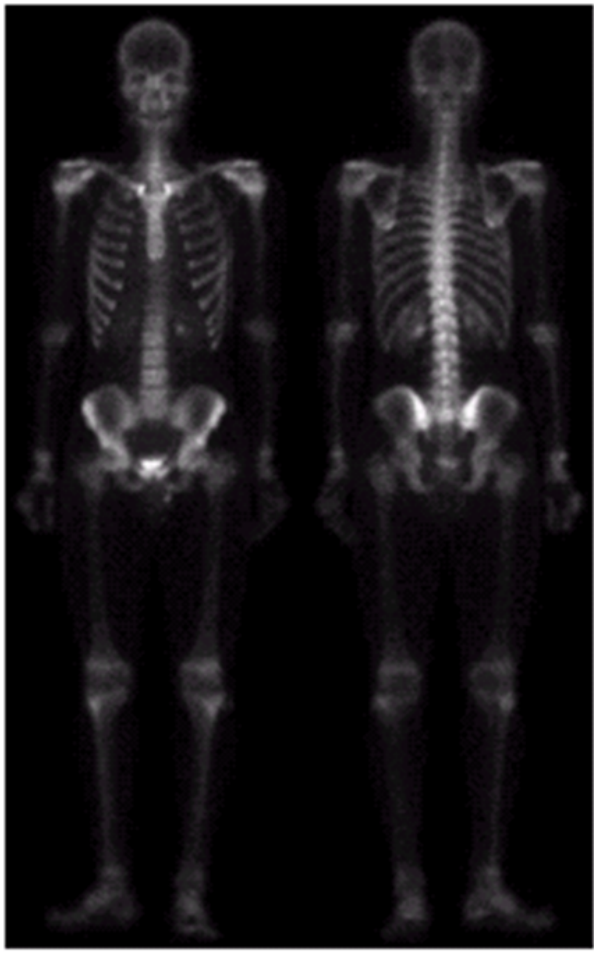
1st and 2nd Derivative Comparison

Comparing the 1st and 2nd derivatives we can conclude the following:

1. 1st order derivatives generally produce thicker edges
2. 2nd order derivatives have a stronger response to fine detail *e.g.*, thin lines
3. 1st order derivatives have stronger response to grey level step
4. 2nd order derivatives produce a double response at step changes in grey level

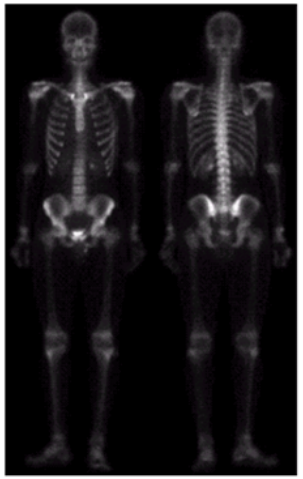
Outline

Combining Spatial Enhancement Methods



- Successful image enhancement is typically not achieved using a single operation
- Rather we combine a range of techniques in order to achieve a final result
- This example will focus on enhancing the bone scan to the right

Combining Spatial Enhancement Methods

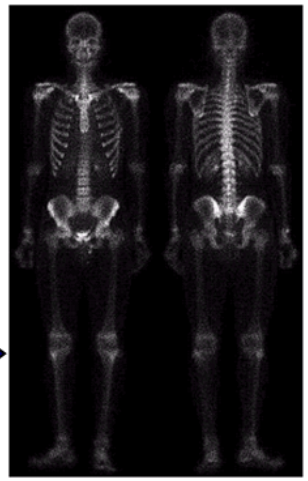


(a)

Laplacian filter of bone scan (a)

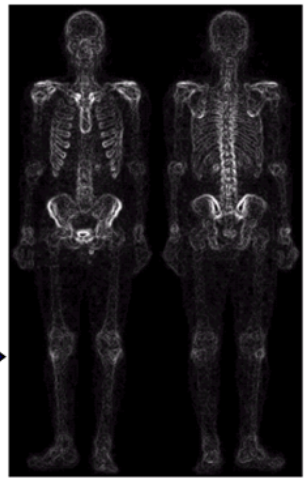
(b)

Sharpened version of bone scan achieved by subtracting (a) and (b)



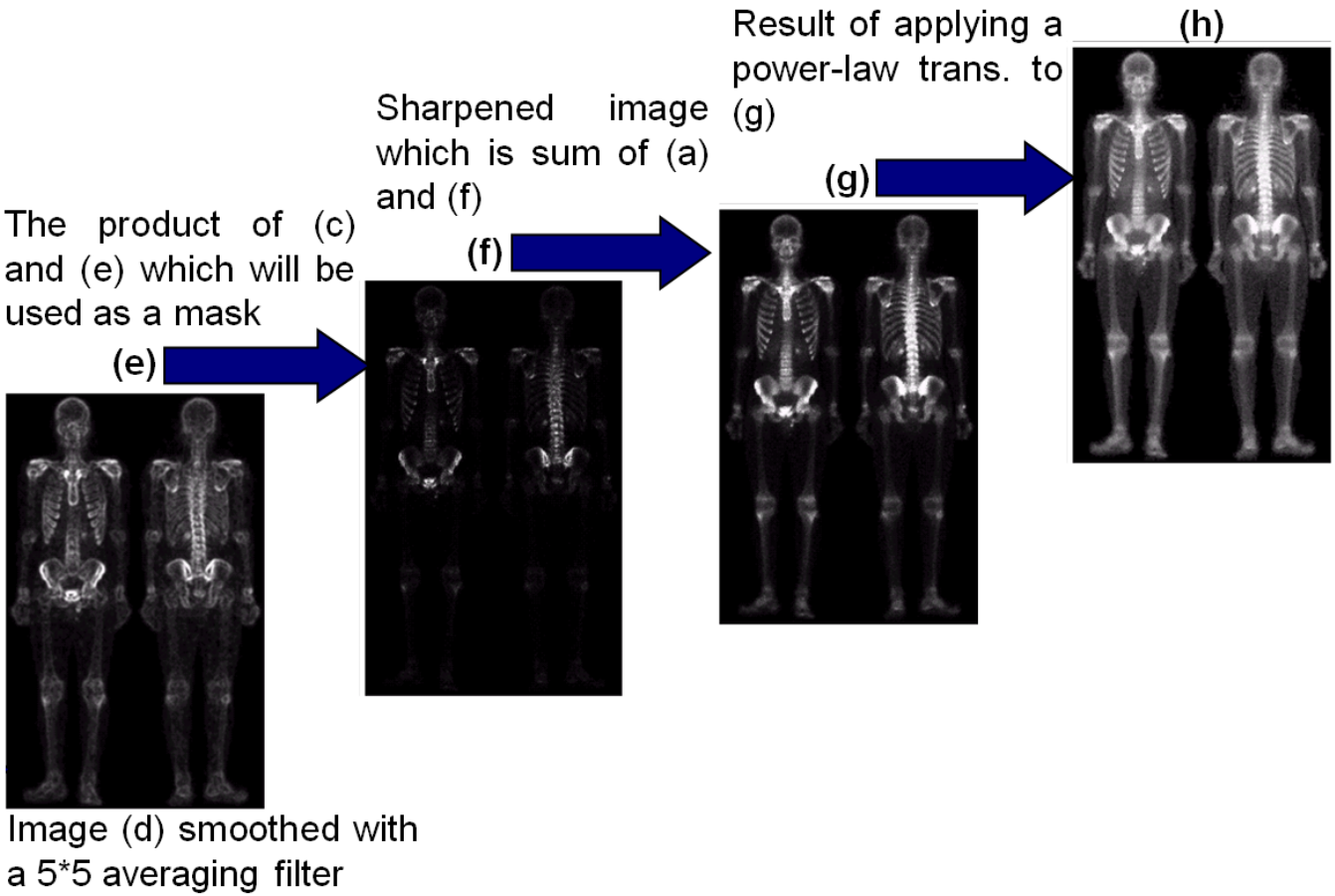
(c)

Sobel filter of bone scan (a)



(d)

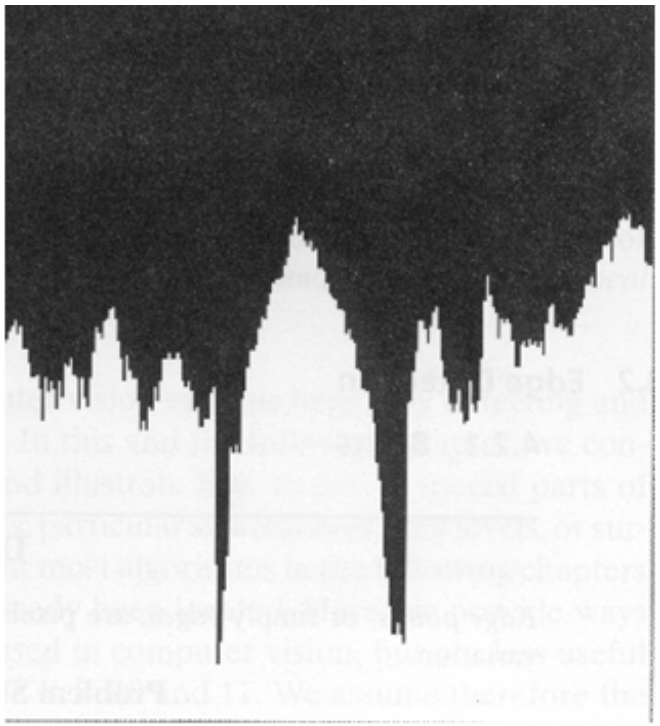
Combining Spatial Enhancement Methods



Combining Spatial Enhancement Methods

Definition of Edges

Edges are significant local changes of intensity in an image.



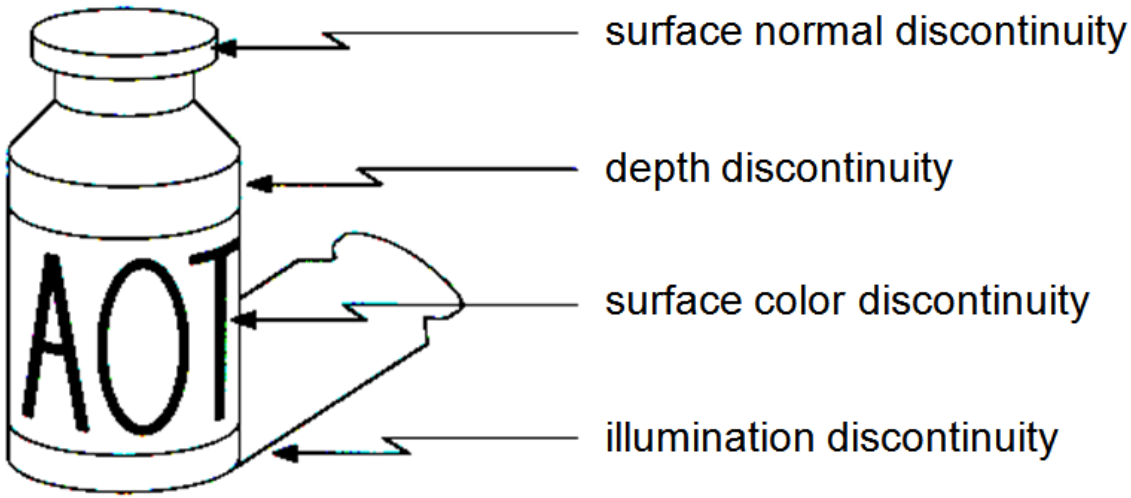
Importance of Edges

- Goal: Identify sudden changes (discontinuities) in an image
  - Intuitively, most semantic and shape information from the image can be encoded in the edges
  - More compact than pixels
- Ideal: artist's line drawing (but artist is also using object-level knowledge)

$$g(x, y) = f(x, y) - \bigtriangledown^2 f \qquad (10)$$

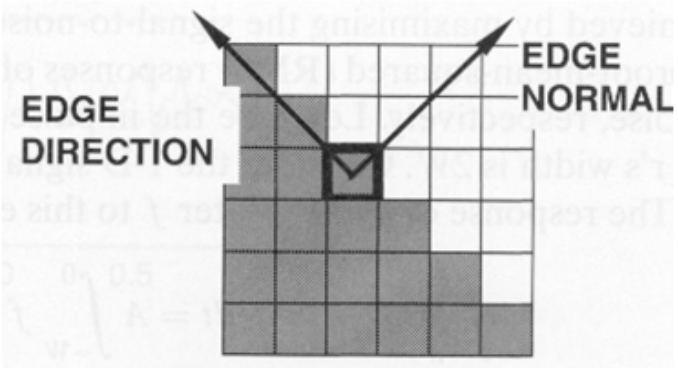
Origin of Edges

Edges are caused by a variety of factors



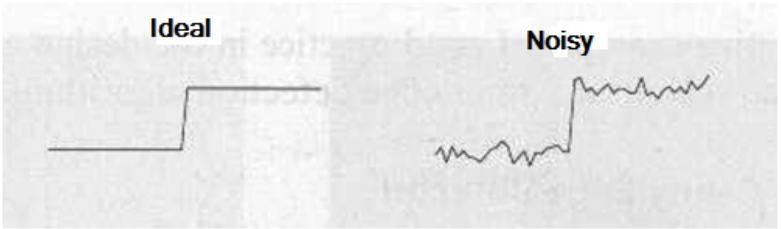
Edge Descriptors

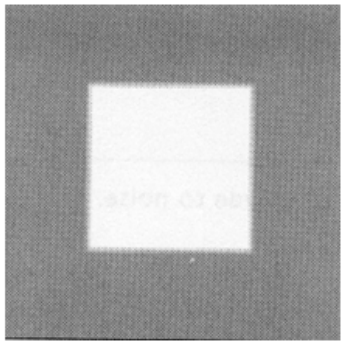
- Edge direction: perpendicular to the direction of maximum intensity change (i.e., edge normal)
- Edge strength: related to the local image contrast along the normal.
- Edge position: the image position at which the edge is located.



Modeling Intensity Changes - Edge Types

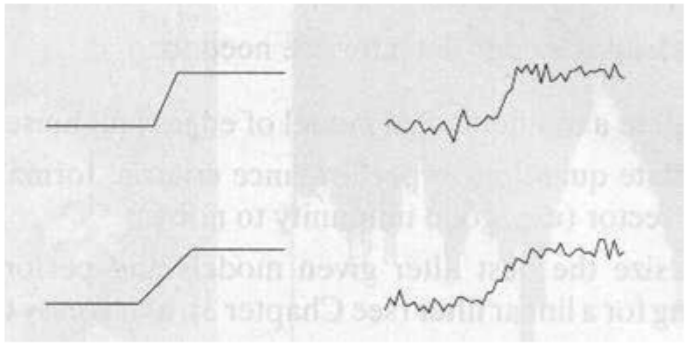
Step edge: the image intensity abruptly changes from one value on one side of the discontinuity to a different value on the opposite side.

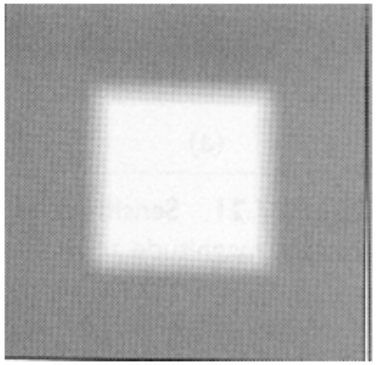




Modeling Intensity Changes - Edge Types

Ramp edge: a step edge where the intensity change is not instantaneous but occur over a finite distance.



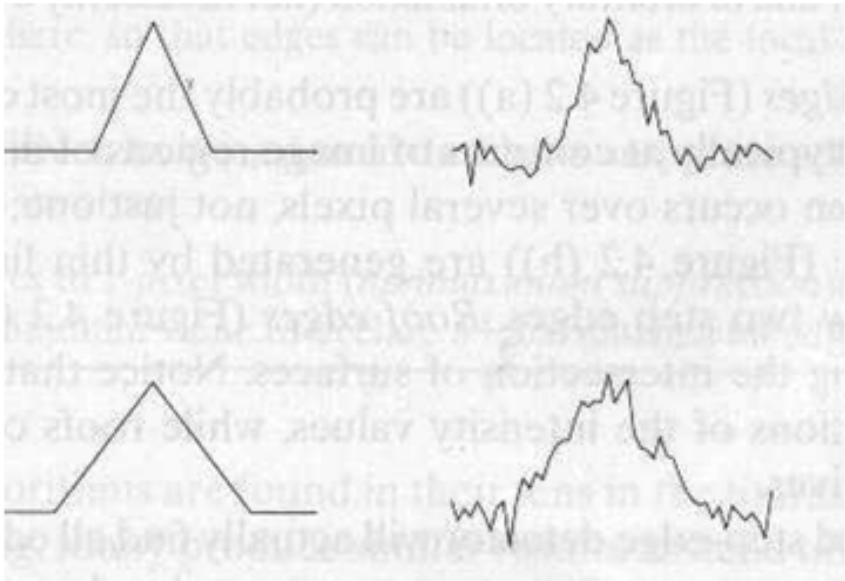


Modeling Intensity Changes - Edge Types

Ridge edge: the image intensity abruptly changes value but then returns to the starting value within some short distance (*i.e.*, usually generated by lines).

Modeling Intensity Changes - Edge Types

Roof edge: a ridge edge where the intensity change is not instantaneous but occur over a finite distance (*i.e.*, usually generated by the intersection of two surfaces).



Main Steps in Edge Detection

1. Smoothing: suppress as much noise as possible, without destroying true edges.
2. Enhancement: apply differentiation to enhance the quality of edges (*i.e.*sharpening).
3. Thresholding: determine which edge pixels should be discarded as noise and which should be retained (*i.e.*, threshold edge magnitude).
4. Localization: determine the exact edge location.
   - Sub-pixel resolution might be required for some applications to estimate the location of an edge to better than the spacing between pixels