EE 4211 Computer Vision

Lecture 2B: Image enhancement (Spatial)

Semester A, 2020-2021

Spatial Domain Topics

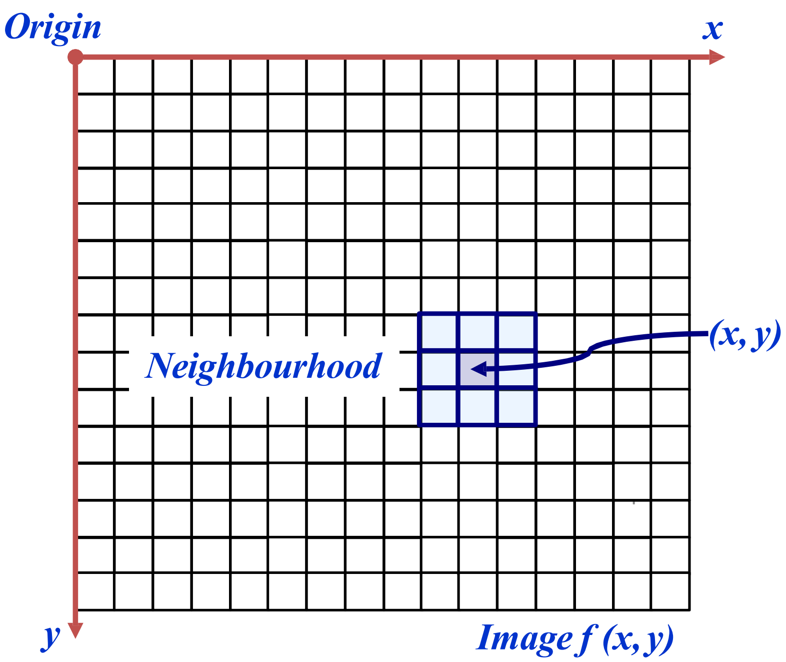
- Point processing – Gray values change without any knowledge of its surroundings (Part I)
  - Log, power-law, piecewise linear
  - Histogram Equalization
- Neighborhood processing (filtering) – Gray values change depending on the gray values in a small neighborhood of pixels around the given pixel (Part I)
  - Smoothing filters
  - Median filters
  - Sharpening

Spatial Filtering

- Basics of Spatial Filtering
- Smoothing Spatial Filters
  - Averaging filters, Order-Statistics filters
- Sharpening Spatial Filters
  - Laplacian filters, Sobel filter
- Combining Spatial Enhancement Methods

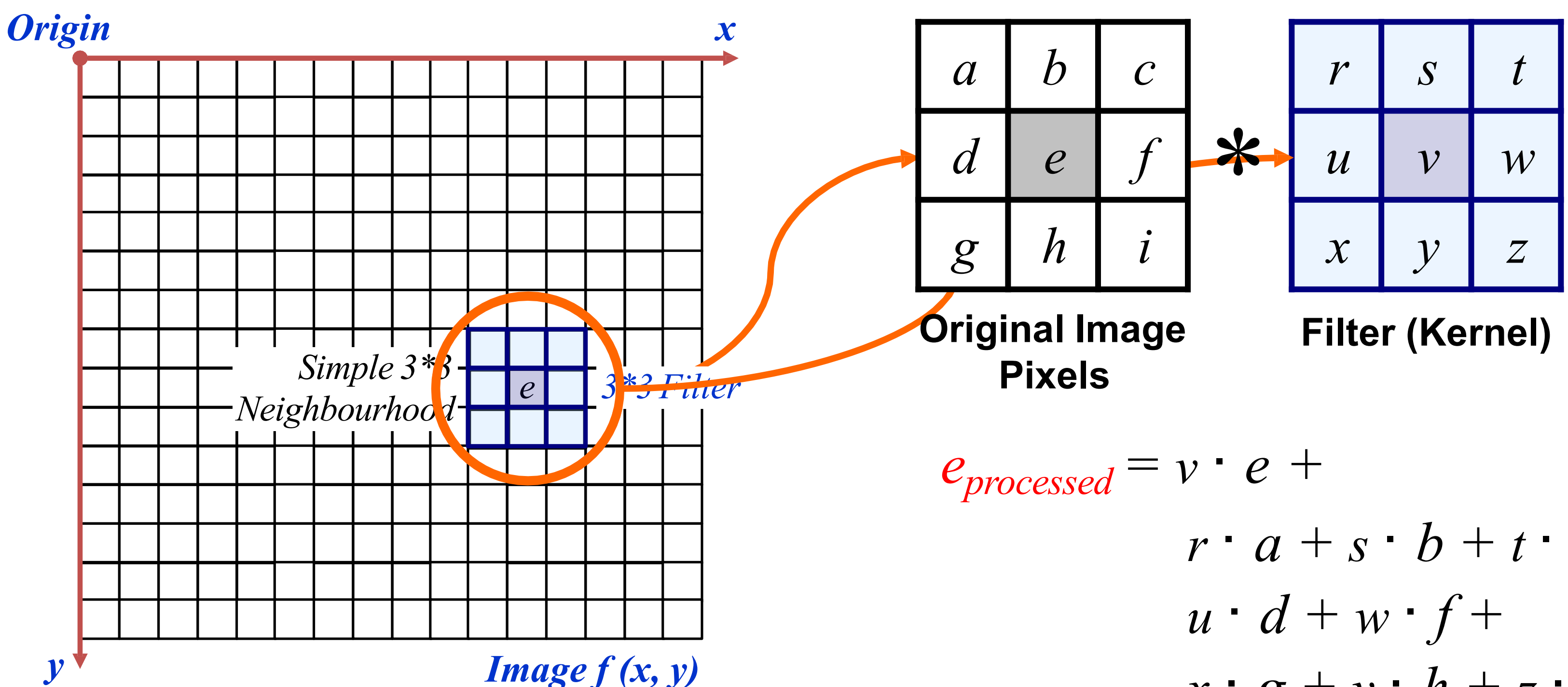
Linear Spatial Filtering

- g(x,y) = T[f(x,y)]
  - f(x,y): input image
  - g(x,y): output image
  - T: an operator on f defined over some neighborhood of (x,y)
- A spatial filter consists of
  - a neighborhood, and
  - a predefined operation



The Spatial Filtering Process

- Repeated for every pixel in the original image to generate the filtered image

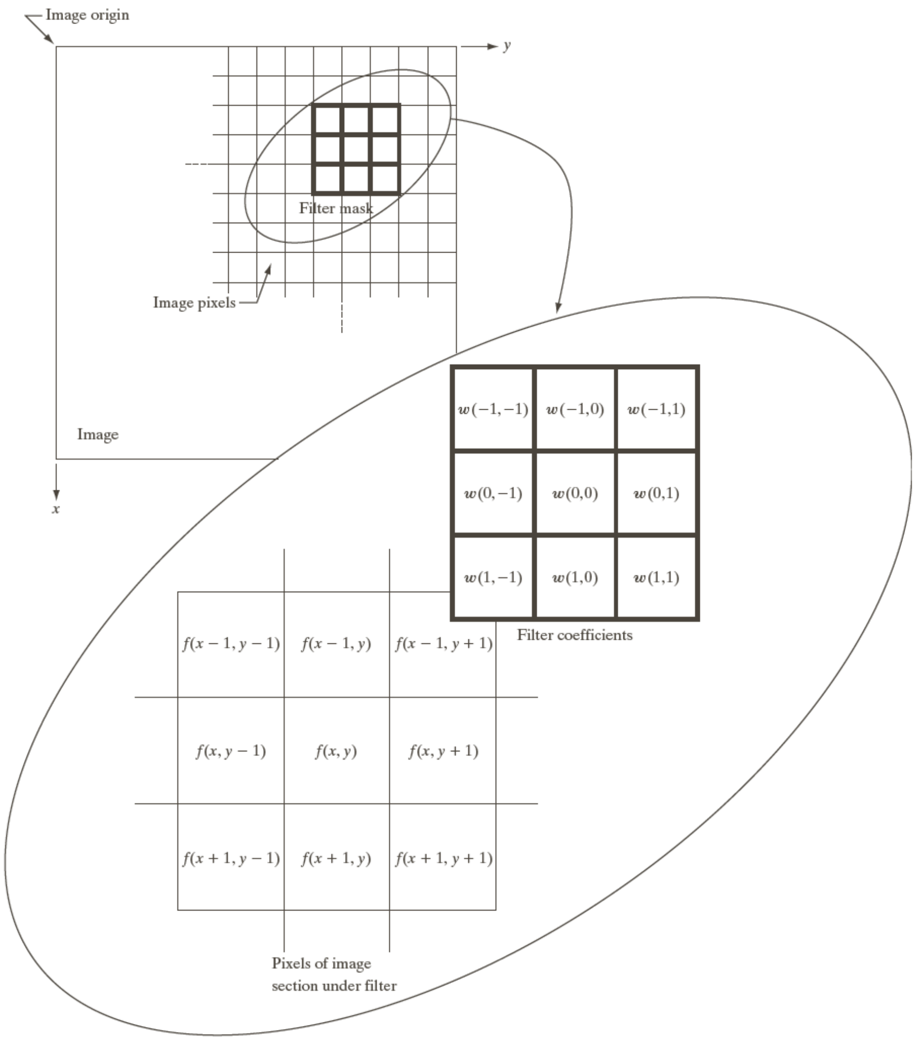


$$e_{processed} = v \cdot e + r \cdot a + s \cdot b + t \cdot c + u \cdot d + w \cdot f + x \cdot g + y \cdot h + z \cdot i$$

Spatial Filtering: Equation Form

- Filtering can be given in equation form by

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



Spatial Filtering

- Basics of Spatial Filtering
- Smoothing Spatial Filters
  - Averaging filters, Order-Statistics filters
- Sharpening Spatial Filters
  - Laplacian filters, High-boost filters
- Combining Spatial Enhancement Methods

Smoothing Spatial Filters

- Smoothing filters are used for blurring and for noise reduction
- Blurring is used in preprocessing steps, such as
  - Removal of small details from an image prior to object extraction
  - Bridging of small gaps in lines or curves
- Noise Reduction can be accomplished by blurring with linear or non-linear filters

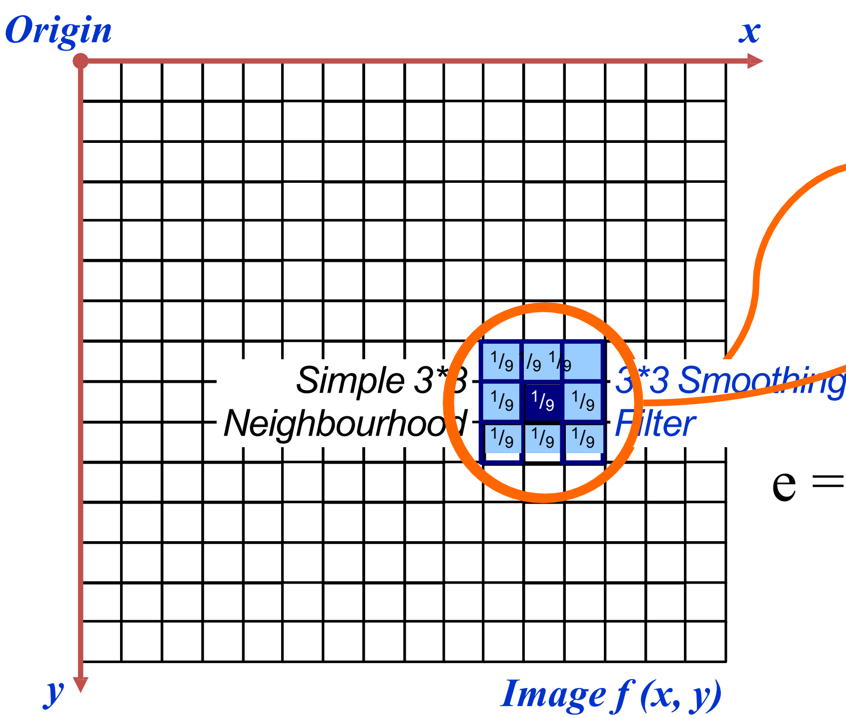
Spatial Smoothing Linear Filters

- Smoothing : One of the simplest spatial filtering operations
- Replace each pixel by the average of pixels in a square window surrounding this pixel
  - Especially useful in removing noise from images
  - Also useful for highlighting gross information

$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$

Simple Averaging Filter

Average Filtering Process



104	100	108
99	106	98
95	90	85

Original Image Pixels

*

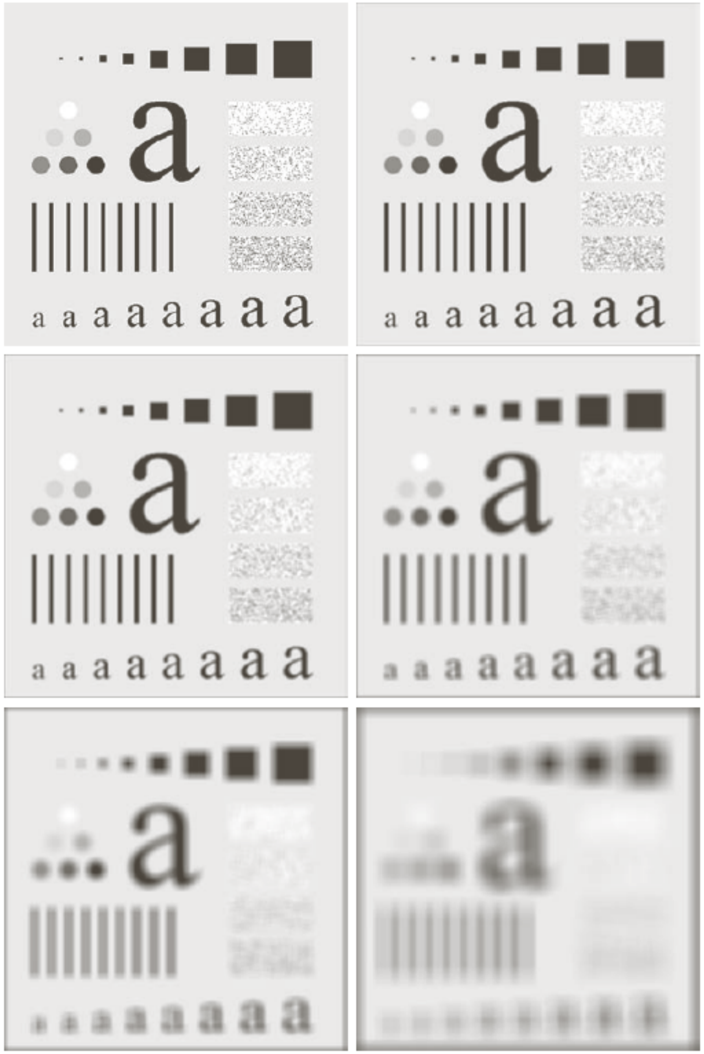
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$

Filter

$$
\begin{aligned}
e = {} & {}^1/_9 \cdot 106 + \\
& {}^1/_9 \cdot 104 + {}^1/_9 \cdot 100 + {}^1/_9 \cdot 108 + \\
& {}^1/_9 \cdot 99 + {}^1/_9 \cdot 98 + \\
& {}^1/_9 \cdot 95 + {}^1/_9 \cdot 90 + {}^1/_9 \cdot 85
\end{aligned}
$$

Examples

- Original image size 500x500 pixels
- Results of smoothing with averaging filter masks of size n=3, 5, 9, 15, 35, respectively

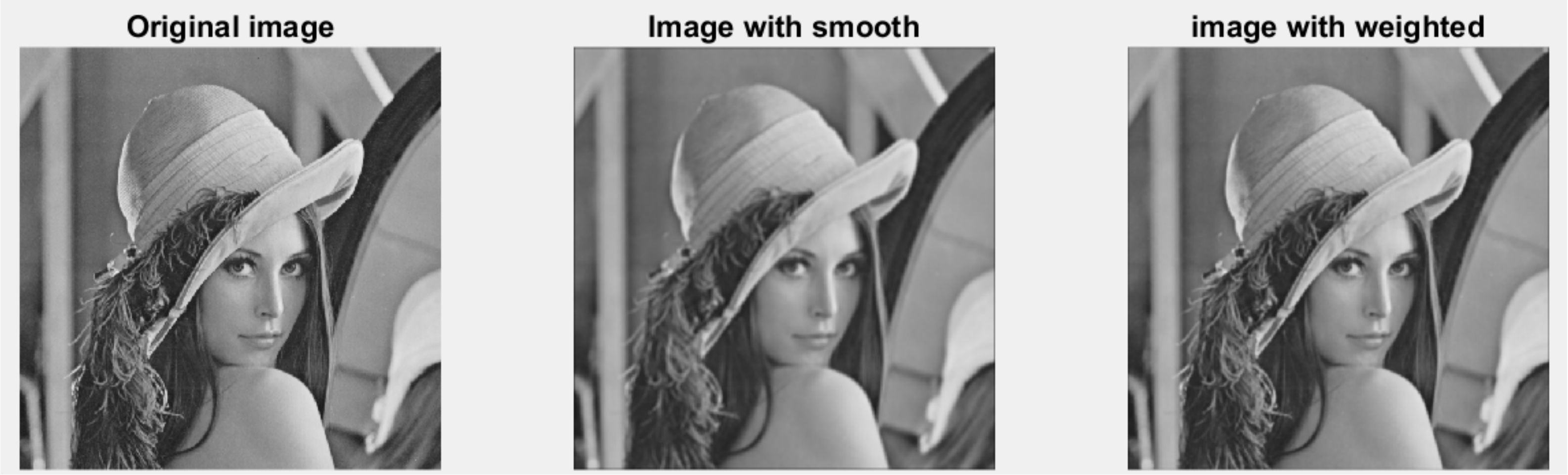


Weighted Smoothing Filters

- Instead of averaging all the pixel values in the window, this filter gives the closer-by pixels higher weighting, and far-away pixels lower weighting.
- Reduce value of coefficients as a function of increasing distance from the origin
- An attempt to reduce blurring in the smoothing process

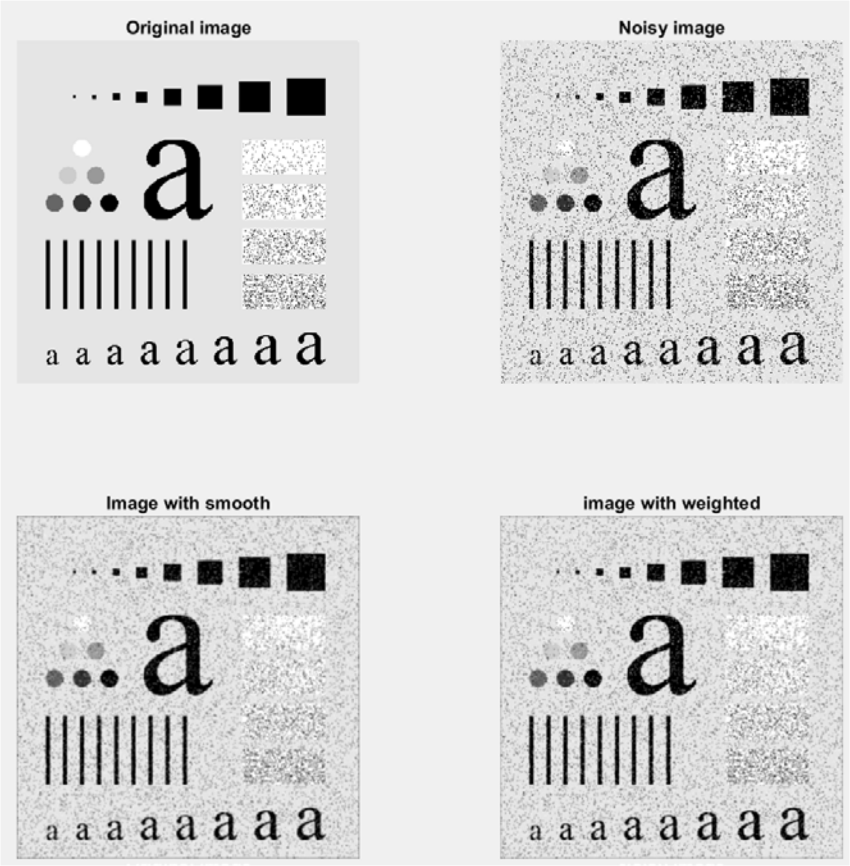
$^1/_{16}$	$^2/_{16}$	$^1/_{16}$
$^2/_{16}$	$^4/_{16}$	$^2/_{16}$
$^1/_{16}$	$^2/_{16}$	$^1/_{16}$

Examples to blur



Examples to remove noise

- By smoothing the original image, we get rid of lots of the finer detail which leaves only the gross features for thresholding



Order-Statistics Filters

- Non-linear filters
- Response is based on ordering (ranking) the pixels contained in the image area encompassed by the filter
- Example:
  - median filter, max filter, min filter

Median Filters

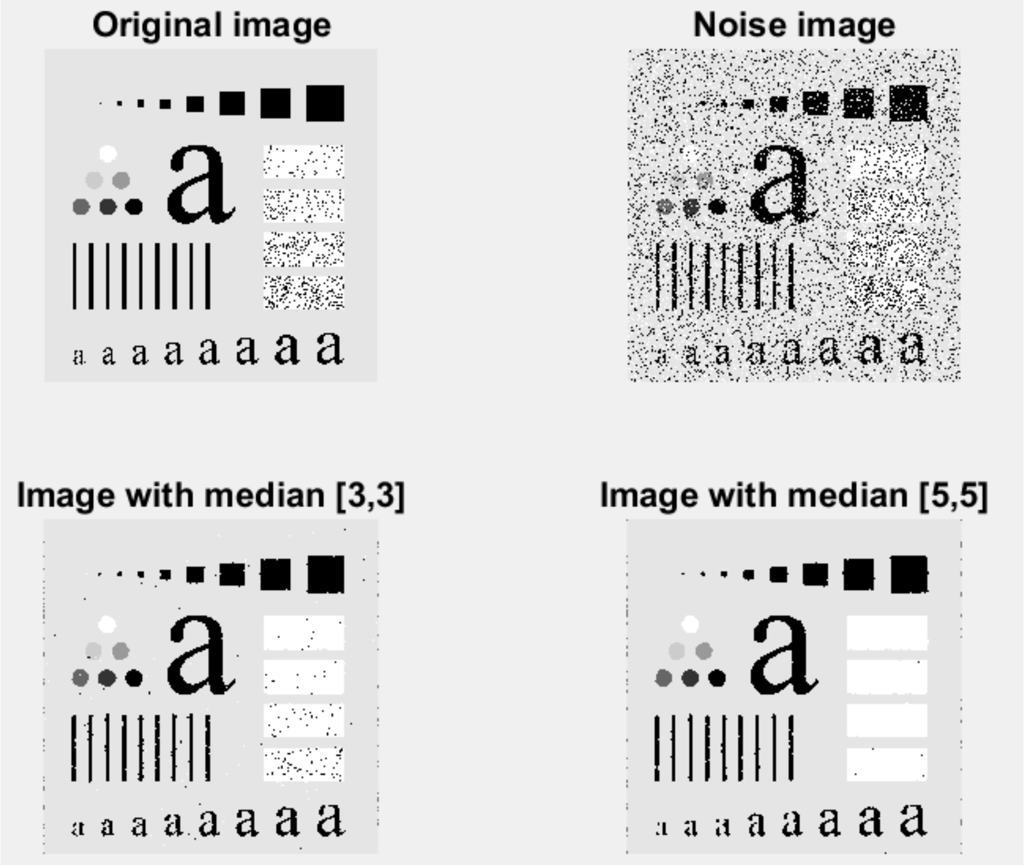
- Obtained by **sorting** all pixels in the analysis window in increasing or decreasing order of amplitudes and **picking the middle value** if the number of pixels is odd, or the average of the two values in middle if the number of pixels is even.

$$g(x,y) = median\{f(x-n, y-m), (n,m) \in N\}$$

- Popularly used for certain types of random noise (impulse noise, salt and pepper noise)
  - Excellent noise-reduction capabilities
  - Less blurring effect that linear smoothing filters of similar size

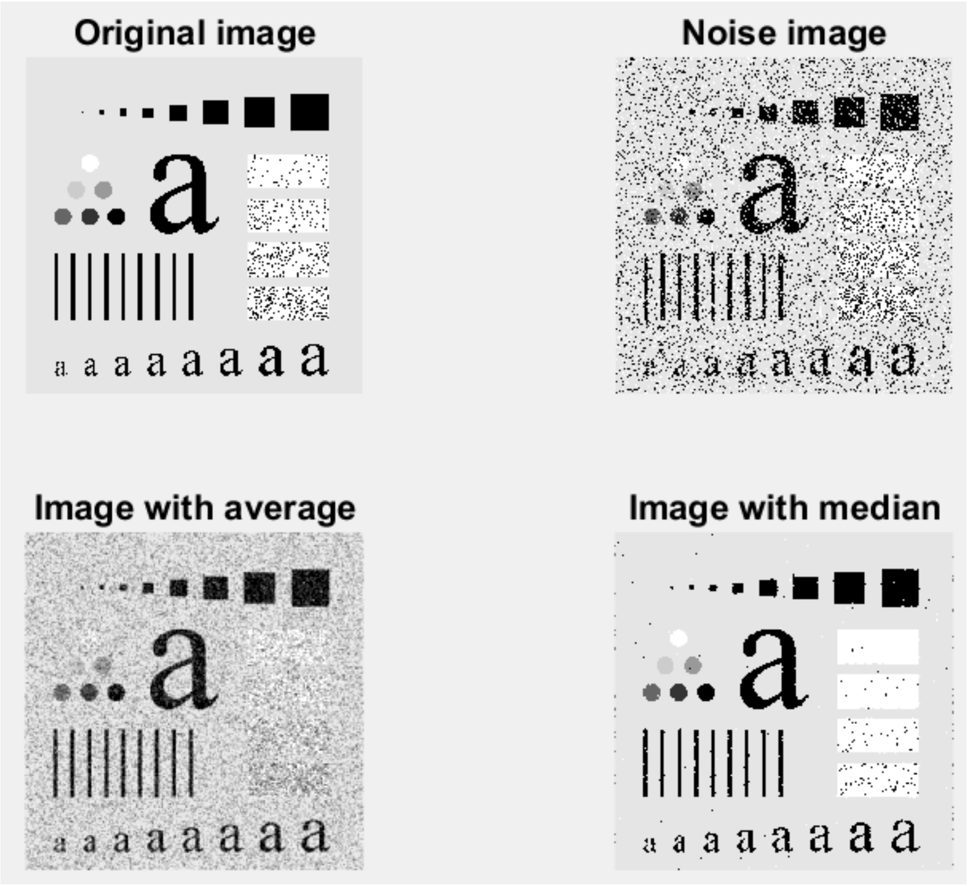
2D Median Filtering Example

- Filtering is often used to remove noise from images



Averaging Filter vs. Median Filter Example

- Filtering is often used to remove noise from images
- Sometimes a median filter works better than an averaging filter



Spatial Filtering

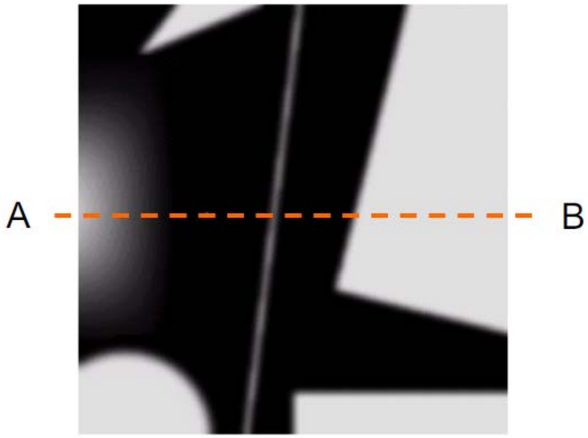
- Basics of Spatial Filtering
- Smoothing Spatial Filters
  - Averaging filters, Order-Statistics filters
- Sharpening Spatial Filters
  - Laplacian filters, Sobel filter
- Combining Spatial Enhancement Methods

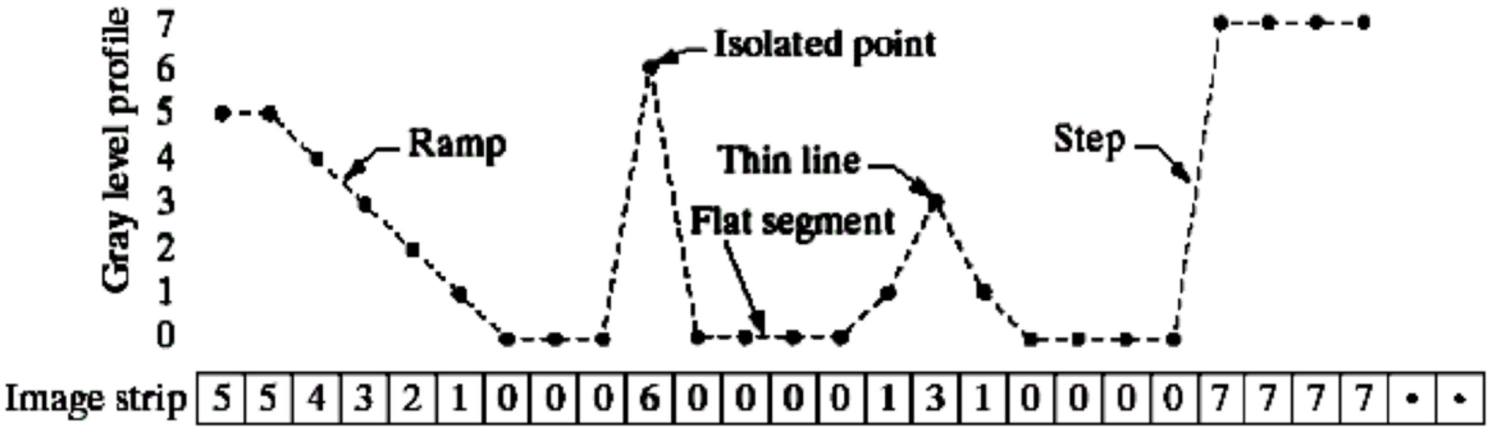
Sharpening Spatial Filters

- Smoothing filters remove fine detail
- Sharpening spatial filters seek to highlight fine detail
  - Remove blurring from images
  - Highlight edges
- Sharpening filters are based on spatial differentiation

Spatial Differentiation

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





1st Derivative

- The formula for the 1st derivative of a function is as follows:

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

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

5	5	4	3	2	1	0	0	0	6	0	0	0	0	1	3	1	0	0	0	0	7	7	7	7

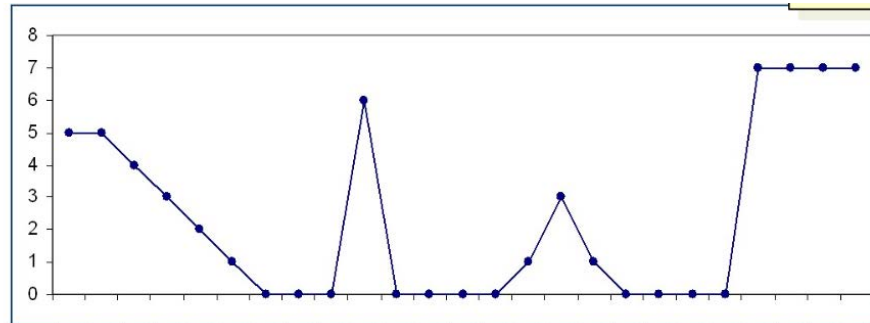
	-1	-1	-1	-1	-1	0	0	6	-6	0	0	0	1	2	-2	-1	0	0	0	7	0	0	0	
	4-5	3-4	2-3	1-2	0-1																			

2nd Derivative

- The derivatives of a function is as follows:

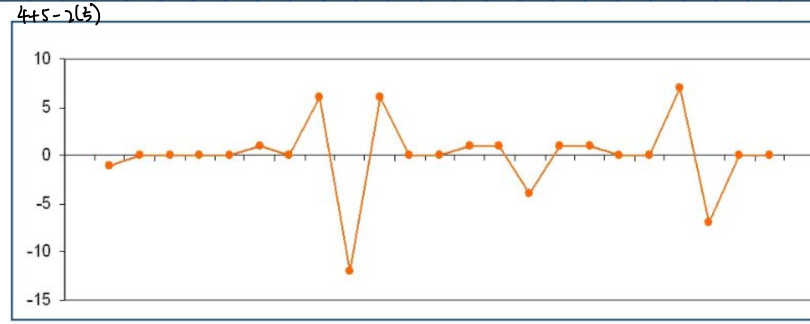
$$\frac{\partial^2 f}{\partial^2 x} = f(x+1) + f(x-1) - 2f(x)$$

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



5	5	4	3	2	1	0	0	0	6	0	0	0	0	1	3	1	0	0	0	0	7	7	7	7
	-1	-1	-1	-1	-1	0	0	6	-6	0	0	0	1	2	-2	-1	0	0	0	7	0	0	0	
	-1	0	0	0	0	1	0	6	-12	6	0	0	1	1	-4	1	1	0	0	7	-7	0	0	

4+5-2(5)



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
- The first sharpening filter we will look at is the Laplacian
  - Isotropic
  - One of the simplest sharpening filters

The Laplacian

- The Laplacian is defined as follows:

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

- where the partial 2nd order derivative in the *x* direction is defined as follows:

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

- and in the *y* direction as follows:

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

The Laplacian Operator

- So, the Laplacian can be given as follows:
  - $$\nabla^2 f = [f(x+1, y) + f(x-1, y) + f(x, y+1) + f(x, y-1) - 4f(x, y)$$
- We can easily build a filter based on this

0	1	0
1	-4	1
0	1	0

Laplacian Mask

- This Laplacian mask is implemented differently by incorporating the diagonal directions. The center value is now -8.

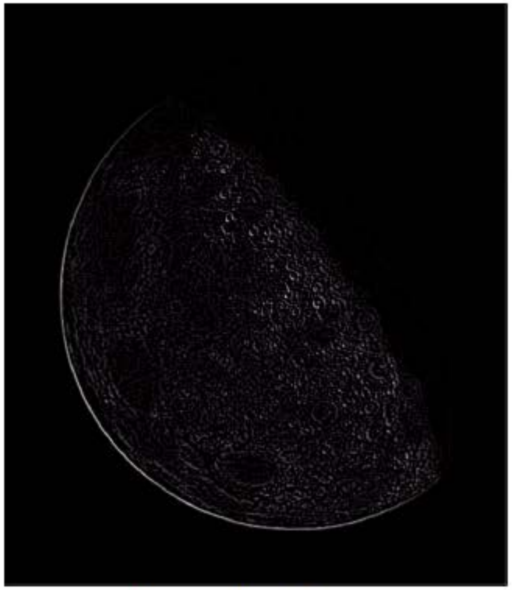
0	1	0
1	-4	1
0	1	0

1	1	1
1	−8	1
1	1	1

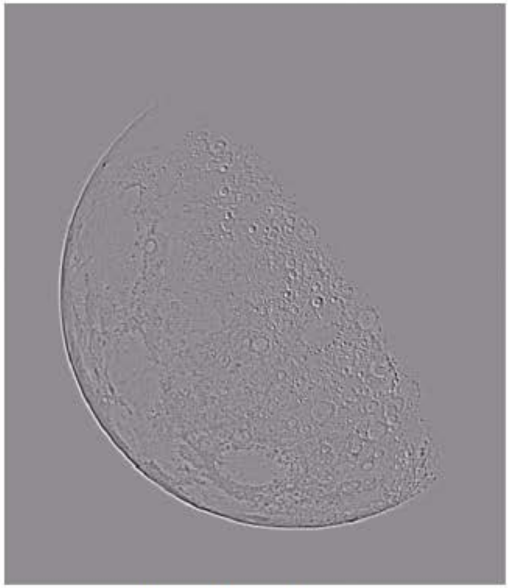
The Laplacian Filter Example

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

Original Image



Laplacian Filtered Image

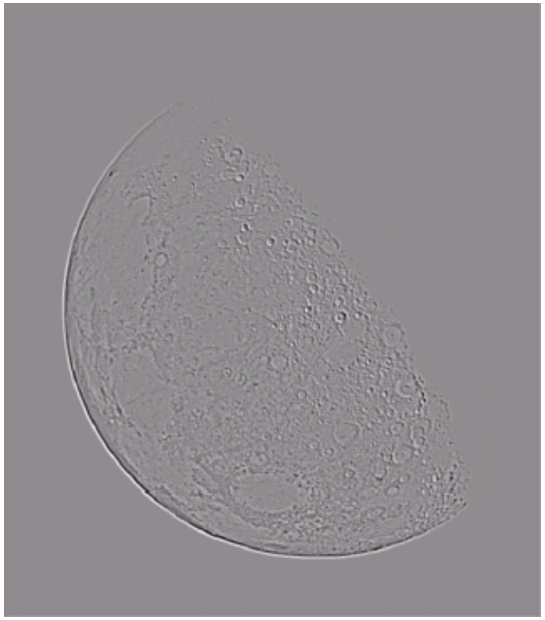


Laplacian Filtered Image Scaled for Display

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

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



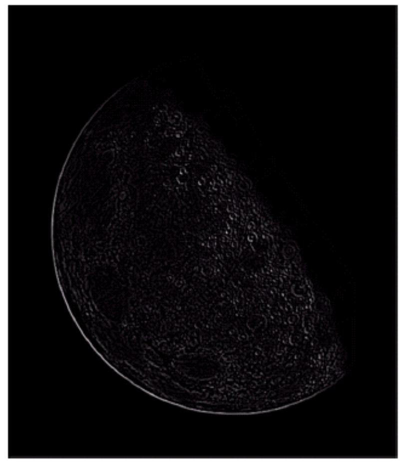
Laplacian Filtered Image
Scaled for Display

Laplacian Image Enhancement

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

Original Image

-



Laplacian Filtered Image

=

Sharpened Image

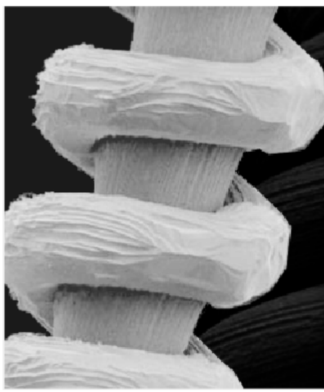
Simplified Image Enhancement

- The entire enhancement can be combined into a single filtering operation

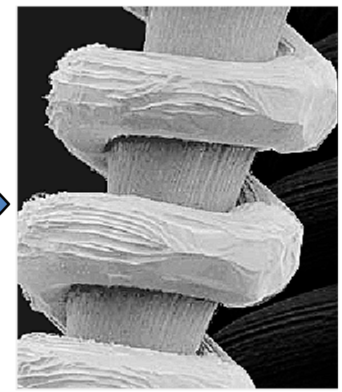
$$
\begin{aligned}
g(x, y) &= f(x, y) - \nabla^2 f \\
&= f(x, y) - [f(x+1, y) + f(x-1, y) + f(x, y+1) \\
&\quad + f(x, y-1) - 4f(x, y) \\
&= 5f(x, y) - f(x+1, y) - f(x-1, y) \\
&\quad - f(x, y+1) - f(x, y-1)
\end{aligned}
$$

Simplified Image Enhancement

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



0	-1	0
-1	5	-1
0	-1	0



Variants On The Simple Laplacian

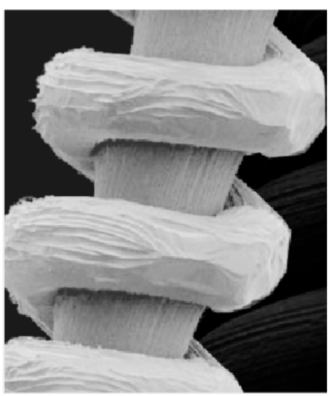
- There are lots of slightly different versions of the Laplacian that can be used:

0	1	0
1	-4	1
0	1	0

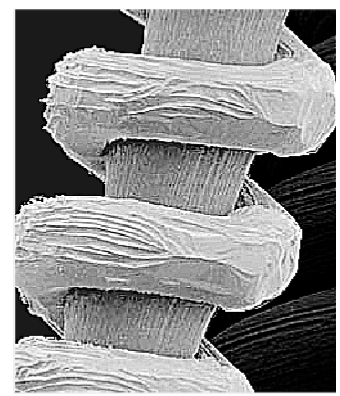
Simple Laplacian

1	1	1
1	-8	1
1	1	1

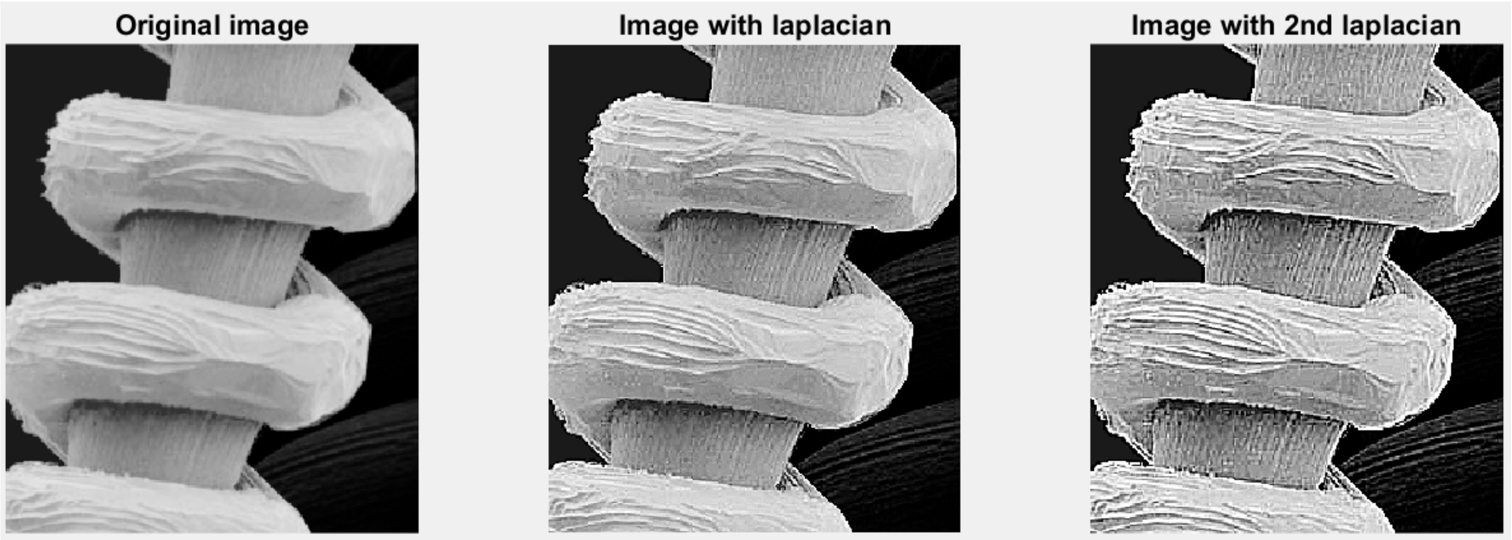
Variant of Laplacian



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



Comparison of Two Laplacians



First Derivatives: Gradient Operator

- First derivatives are implemented using the magnitude of the gradient

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

$$\nabla f = mag(\nabla \mathrm{f}) = [G_x^2 + G_y^2]^{1/2}$$

$$= \left[\left(\frac{\partial f}{\partial x} \right)^2 + \left(\frac{\partial f}{\partial y} \right)^2 \right]^{1/2}$$

Approximation:

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

Gradient Mask

- On the basis of a first-order derivative of a 2-D function f(x,y), the simplest approximation of the gradient mask: 2x2

$$G_x = (z_8 - z_5) \quad \text{and} \quad G_y = (z_6 - z_5)$$

$$\nabla f = [G_x^2 + G_y^2]^{1/2} = [(z_8 - z_5)^2 + (z_6 - z_5)^2]^{1/2}$$

$$\nabla f \approx |z_8 - z_5| + |z_6 - z_5|$$

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

Gradient Mask

- Roberts 2x2 cross-gradient operators [1965]

$$G_x = (z_9 - z_5) \quad \text{and} \quad G_y = (z_8 - z_6)$$

$$\nabla f = [G_x^2 + G_y^2]^{1/2} = [(z_9 - z_5)^2 + (z_8 - z_6)^2]^{1/2}$$

$$\nabla f \approx |z_9 - |z_5| + |z_8 - z_6|$$

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

−1	0
0	1

0	−1
1	0

Gradient Mask

- Sobel operators, 3x3

$$G_x = (z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)$$

$$G_y = (z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)$$

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

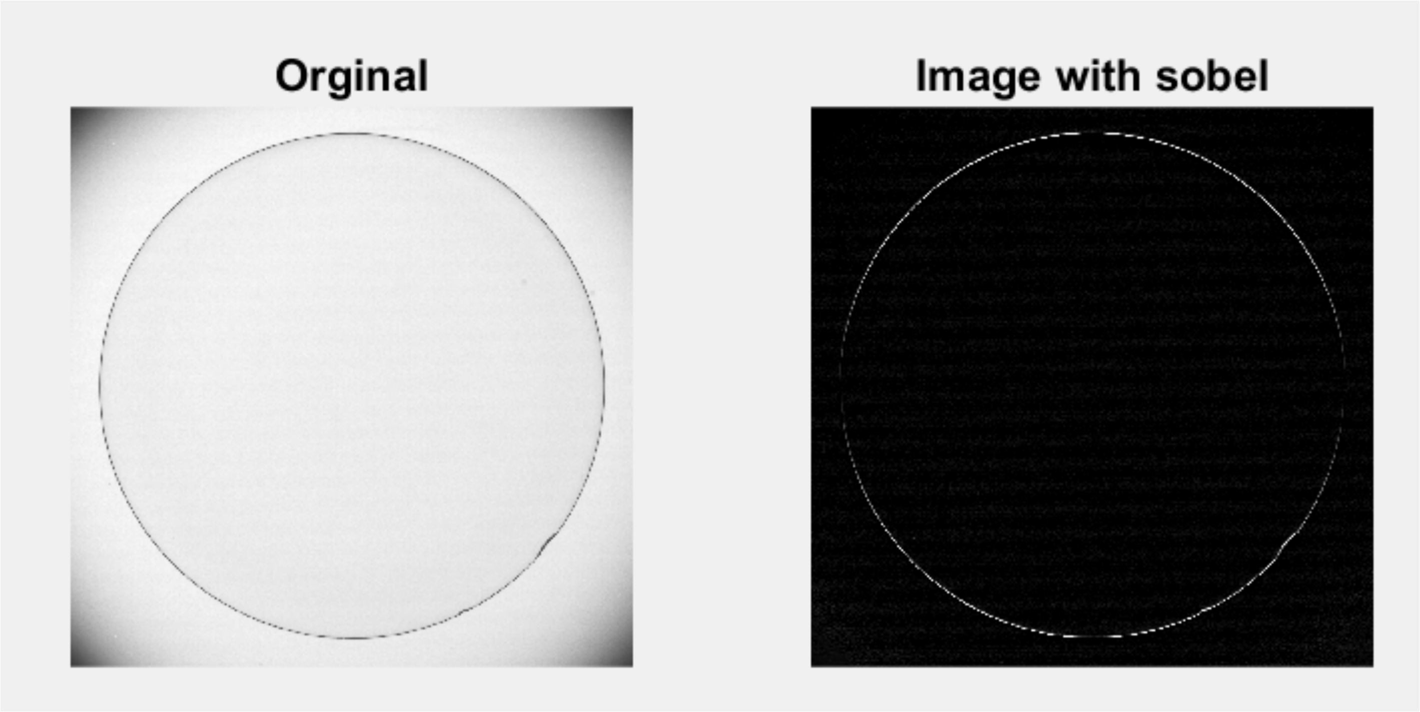
z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

The weight value 2 is to achieve smoothing by giving more important to the center point

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Example



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

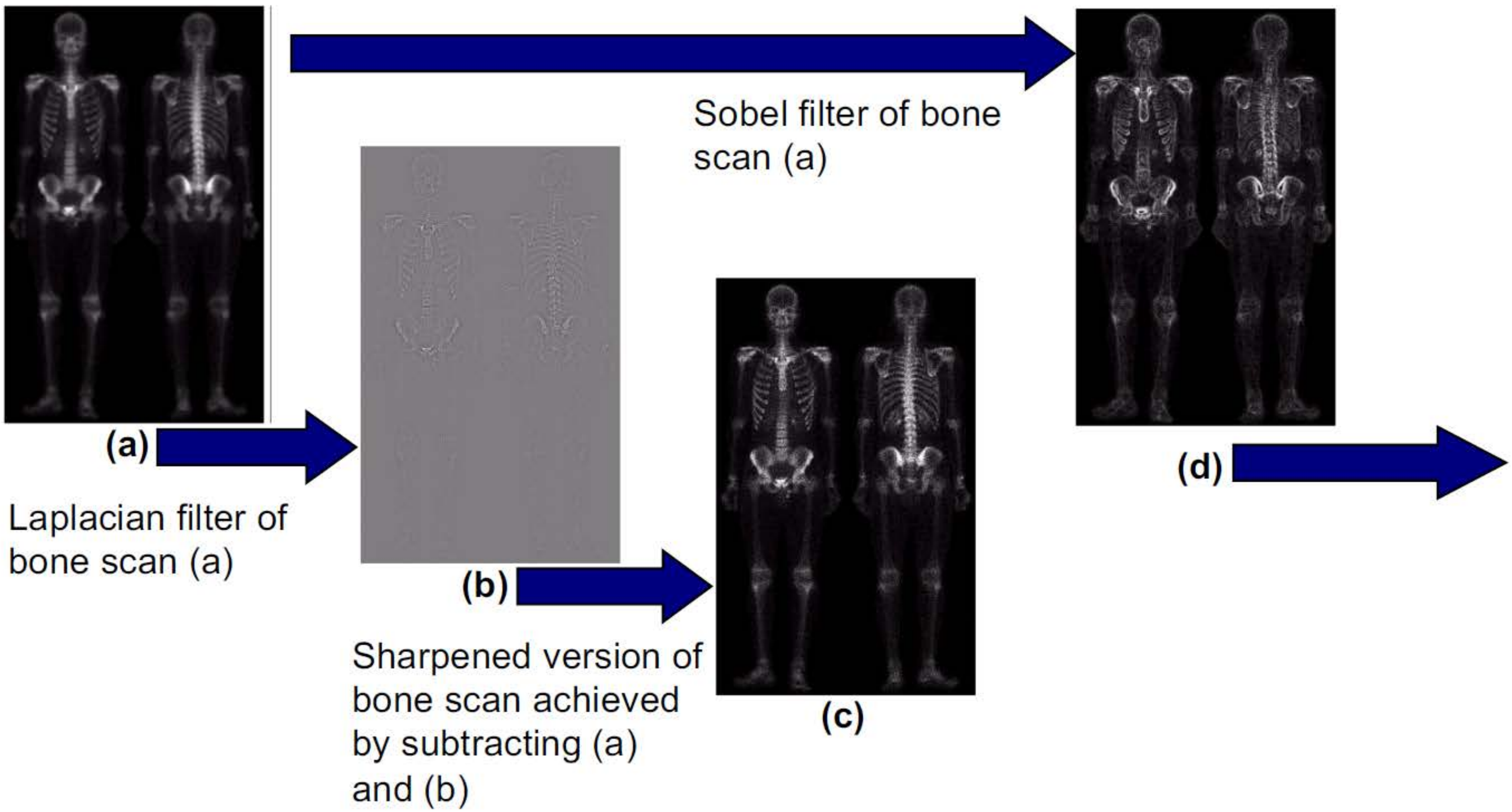
Example: Combining Spatial Enhancement Methods

- Target: To sharpen the original image and bring out more skeletal detail
- Problems:
  - Narrow dynamic range of gray level
  - High noise content makes image difficult to enhance

Example: Combining Spatial Enhancement Methods

- Solution:
  - Laplacian to highlight fine details
  - Gradient to enhance prominent edges
  - Gray level transformation to increase the dynamic range of gray levels

Combining Spatial Enhancement Methods I



Combining Spatial Enhancement Methods II