Machine Vision

Wu Wei

Images Enhancement

01 Gray Level Transformations

02 Histogram Processing

03 Arithmetic/Logical Operation

04 Spatial Filtering

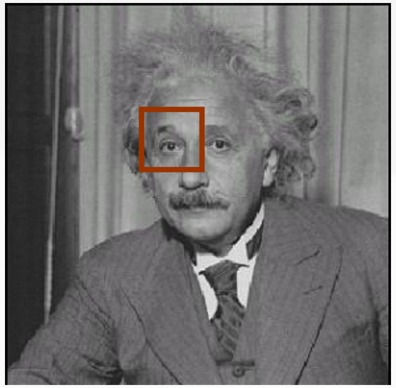
05 Frequency Filtering

Spatial Filtering

Smoothing

Original

0	0	0
0	1	0
0	0	0



Filtered (no change)

Spatial Filtering

Smoothing

Original

0	0	0
0	0	1
0	0	0

?

Spatial Filtering

Smoothing

Original

0	0	0
0	0	1
0	0	0

Shifted *left* By 1 pixel

Image Enhancement

Spatial Filtering

- Smoothing

Original

$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

?

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Image Enhancement

Spatial Filtering

- Smoothing

Original

$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Blur (with a box filter)

Spatial Filtering

Smoothing

Original

$$\begin{bmatrix}0&0&0\\0&2&0\\0&0&0\end{bmatrix} - \frac{1}{9}\begin{bmatrix}1&1&1\\1&1&1\\1&1&1\end{bmatrix} \quad ?$$

(Note that filter sums to 1)

Spatial Filtering

- Fundamentals (Kernel, convolution, filtering)
- Smoothing (Linear / non-linear filters)
- Sharpening (The Laplacian-2ndorder derivatives, the gradient -first order derivatives)
- Combing Spatial Enhancement Methods

Spatial Filtering

Sharpening

- Principle objective

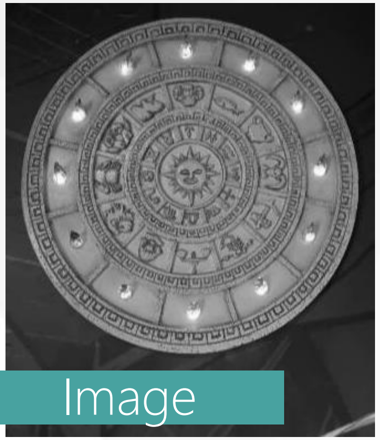
To **highlight fine detail** in an image or to **enhance detail** that has been blurred, either in error or as a natural effect of a particular method of image acquisition.

Image Enhancement

Spatial Filtering

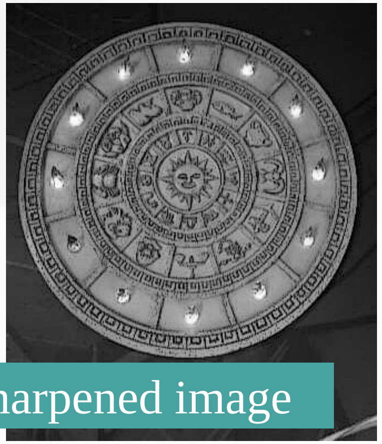
Sharpening

- Previously we have looked at smoothing filters which remove fine detail
- *Sharpening spatial filters* seek to highlight fine detail
  - Remove blurring from images
  - Highlight edges
- Sharpening filters are based on spatial differentiation



Image

$$\begin{bmatrix} -0.5 & 0 & -0.5 \\ 0 & 2 & 0 \\ -0.5 & 0 & -0.5 \end{bmatrix} \rightarrow$$



Sharpened image

Spatial Filtering

Sharpening

- Properties of 1st and 2nd-Order Derivatives
- Use of 2nd Derivatives for Enhancement- The Laplacian
- Use of 1st Derivatives for Enhancement - The Gradient

Spatial Filtering

Sharpening

- First order derivative for a discrete function

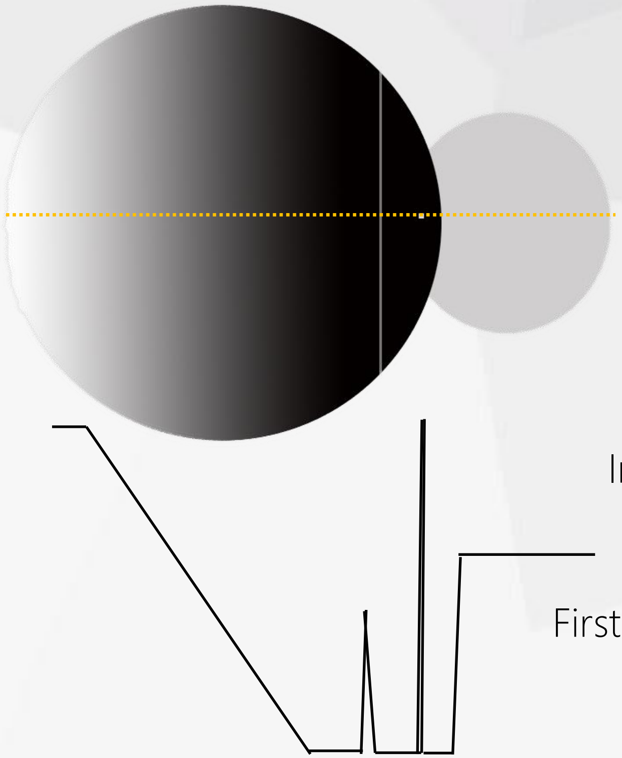
$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

- Second order derivative for a discrete function

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

Spatial Filtering

Sharpening



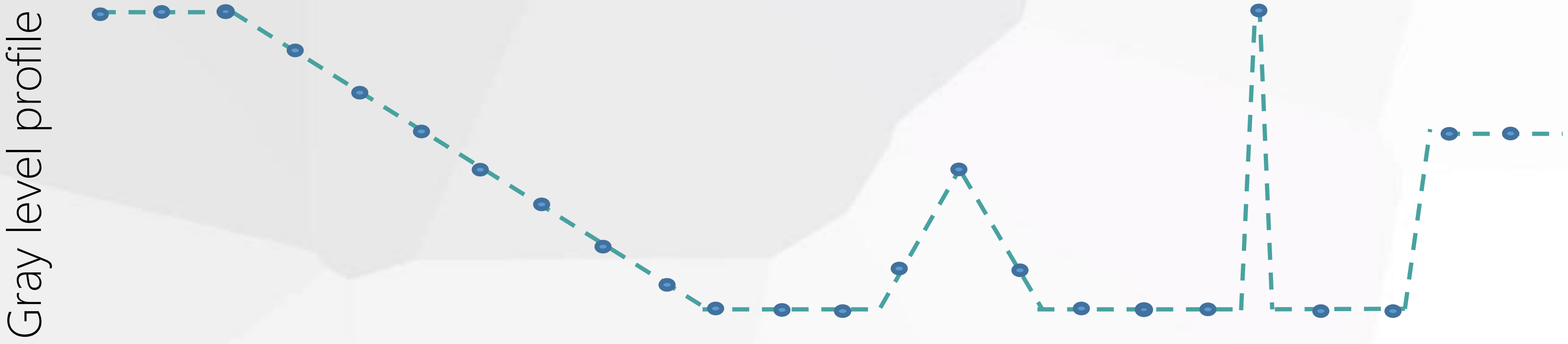


Image strip	8	8	8	7	6	5	4	3	2	1	0	0	0	1	4	1	0	0	0	9	0	0	5	5
First Derivative		0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	1	3	-3	-1	0	0	9	-9	0	5	0
Second Derivative		0	-1	0	0	0	0	0	0	0	1	0	1	2	-6	2	1	0	9	-18	9	5	-5	

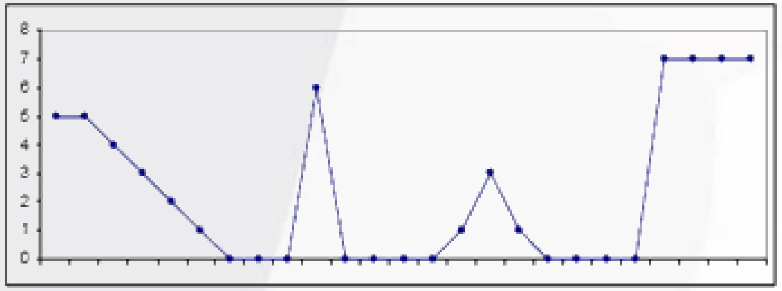
Spatial Filtering

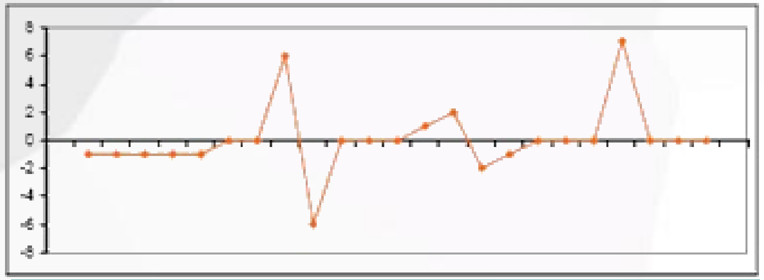
Sharpening

Definition:

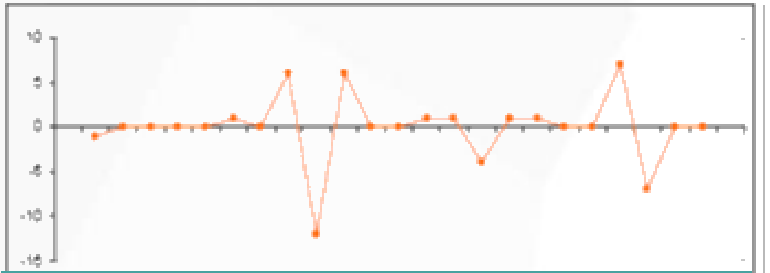
- First derivative filter output
  - Zero at constant intensities
  - Non zero at the onset of a step or ramp
  - Non zero along ramps

- Second derivative filter output
  - Zero at constant intensities
  - Non zero at the onset of a step or ramp
  - Zero along ramps





First derivative filter output



Second derivative filter output

Spatial Filtering

Sharpening

Conclusion:

- First-order derivatives generally produce thicker edges in an image.
- Second-order derivatives have a stronger response to fine detail, such as thin lines and isolated points.
- First order derivatives generally have a stronger response to a gray-level step.
- Second-order derivatives produce a double response at step changes in gray level.

Spatial Filtering

Sharpening

- Properties of 1st and 2nd-Order Derivatives
- Use of 2nd Derivatives for Enhancement- The Laplacian
- Use of 1st Derivatives for Enhancement - The Gradient

Spatial Filtering

Sharpening

- A common second derivative sharpening filter is the **Laplacian**
  - – Isotropic
    - • Rotation invariant: Rotating the image and applying the filter is the same as applying the filter and then rotating the image.
  - – One of the simplest sharpening filters

Spatial Filtering

Sharpening

- The **Laplacian**

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

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

0	1	0
1	-4	1
0	1	0

Spatial Filtering

Sharpening

- The **Laplacian**

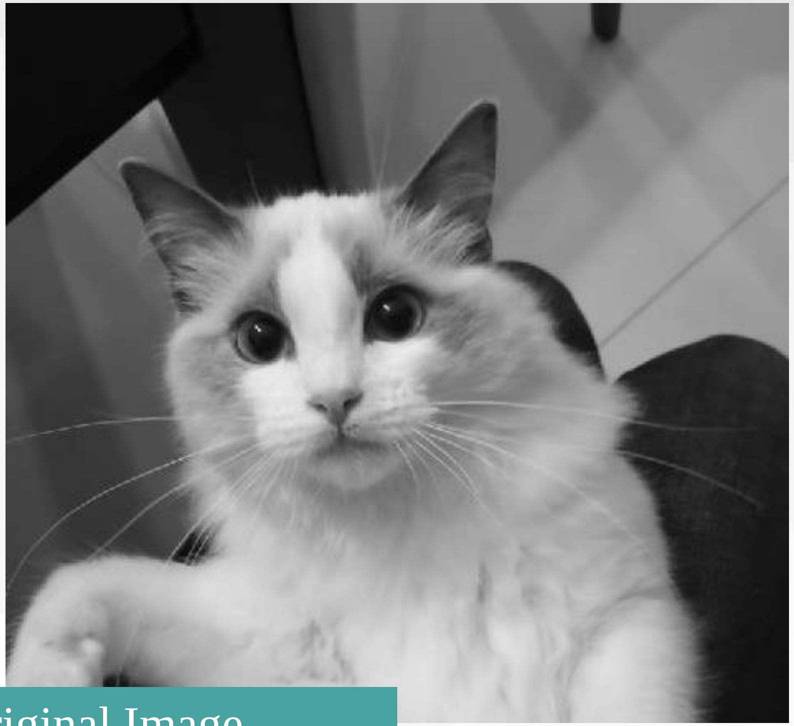
$$\begin{matrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{matrix} \qquad \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & -8 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} \qquad \begin{matrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{matrix} \qquad \begin{matrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{matrix}$$

Spatial Filtering

Sharpening

- The **Laplacian**

1	2	1
1	−10	1
1	2	1



Original Image

Laplacian Filtered Image

Spatial Filtering

Sharpening

- The **Laplacian**

The result of a Laplacian filtering is not an enhanced image

- We have to do more work
- Subtract the Laplacian result from the original image to Laplacian Filtered Image generate our final sharpened enhanced image

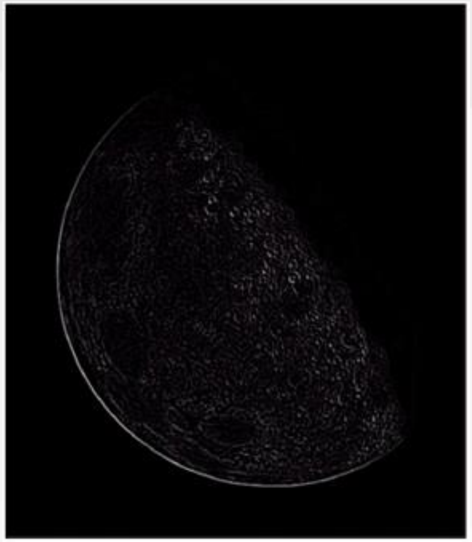
$$g(x,y) = f(x,y) - \nabla^2 f(x,y)$$

Spatial Filtering

Sharpening

- The **Laplacian**

-



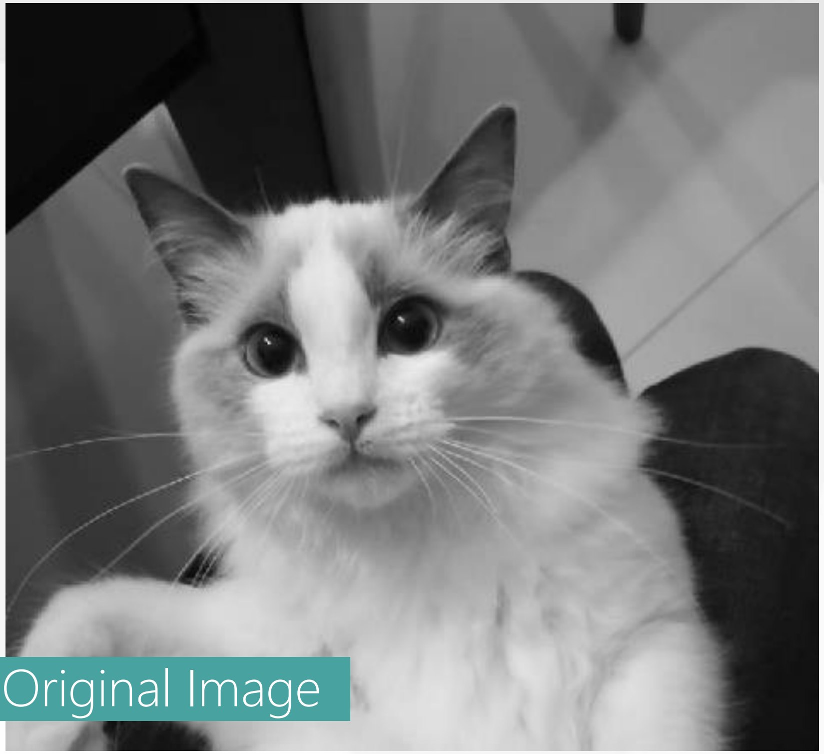
=

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

Spatial Filtering

Sharpening

- The **Laplacian**



Original Image

Enhanced Image

Spatial Filtering

Sharpening

- The **Laplacian**

Original Image

Enhanced Image

Image Enhancement

Spatial Filtering

Sharpening

- The **Laplacian**

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix} \quad \begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \quad \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

The composed *Laplacian* enhancement image is given by:

$$g(x,y) = \begin{cases} f(x,y) - \nabla^2 f(x,y) & \text{if the center coefficient of the Laplacian mask is negative} \\ f(x,y) + \nabla^2 f(x,y) & \text{if the center coefficient of the Laplacian mask is positive} \end{cases}$$

Spatial Filtering

Sharpening

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

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

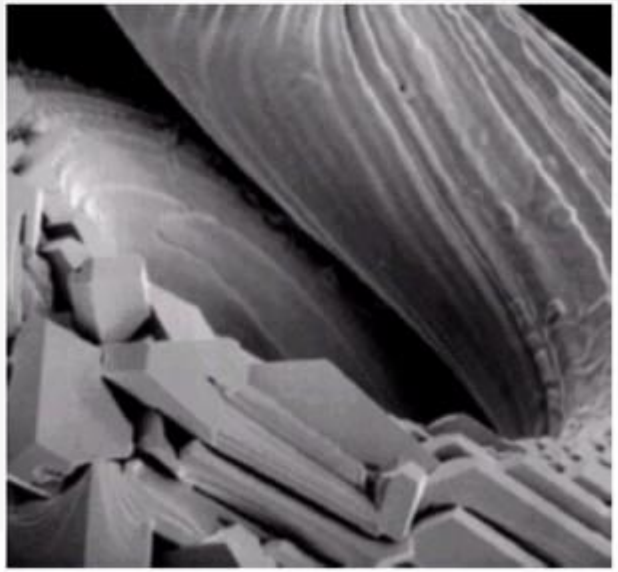
0	−1	0
−1	5	−1
0	−1	0

Spatial Filtering

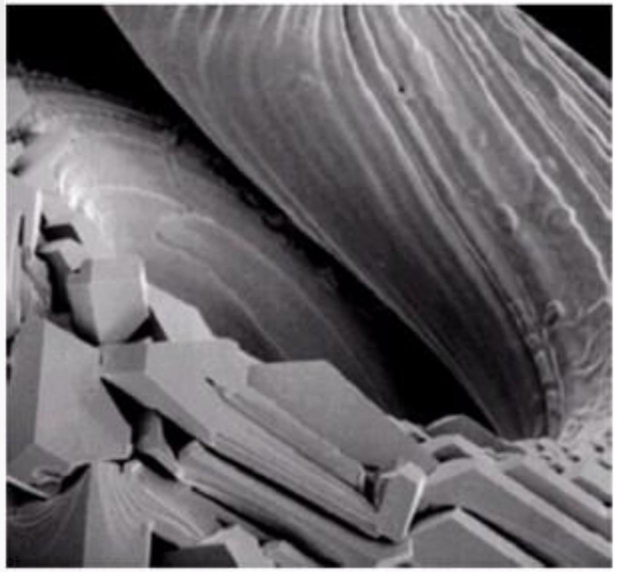
Sharpening

- The **Laplacian**

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



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

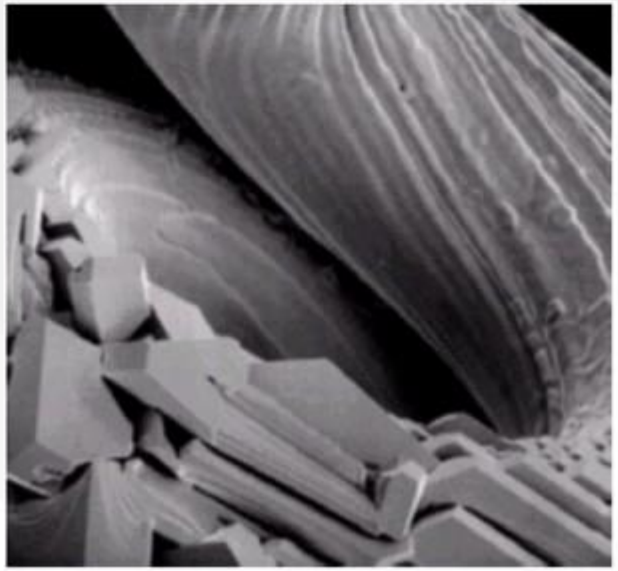


Spatial Filtering

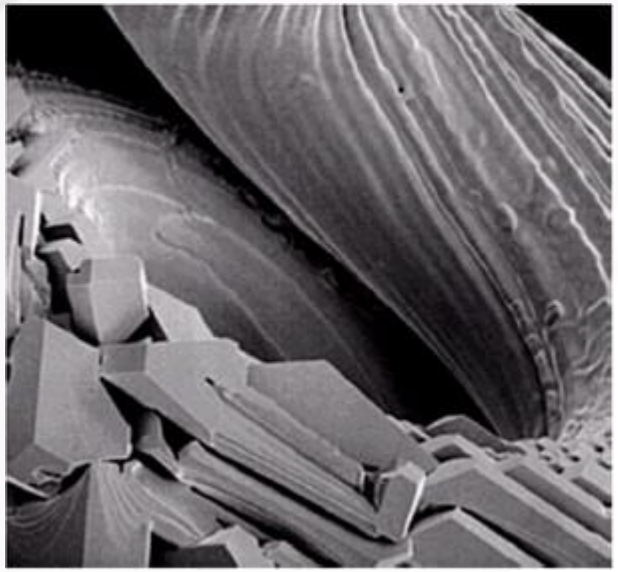
Sharpening

- The **Laplacian**

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



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



Spatial Filtering

Sharpening

- The **Laplacian**

Original

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

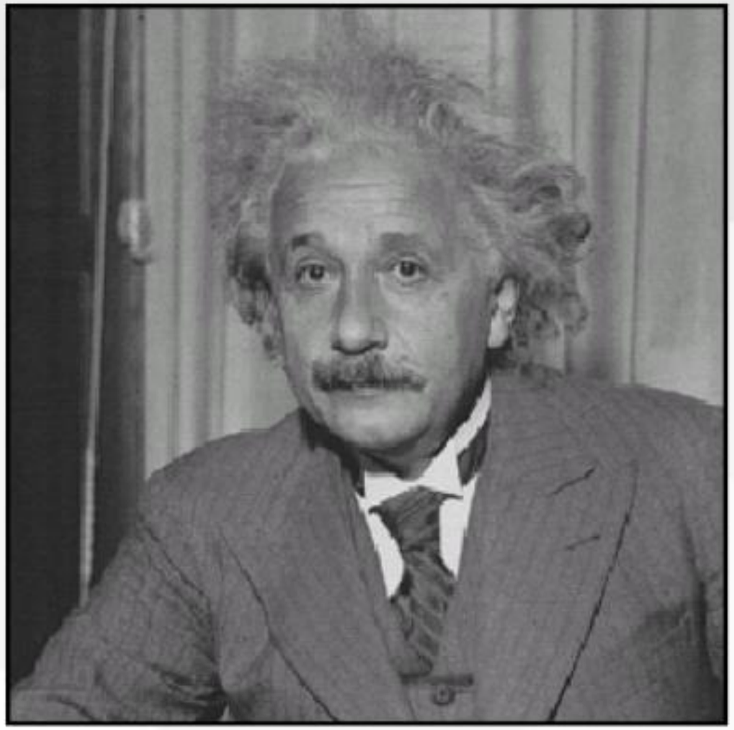
(Note that filter sums to 1)

Sharpening filter
- Accentuates differences with local average

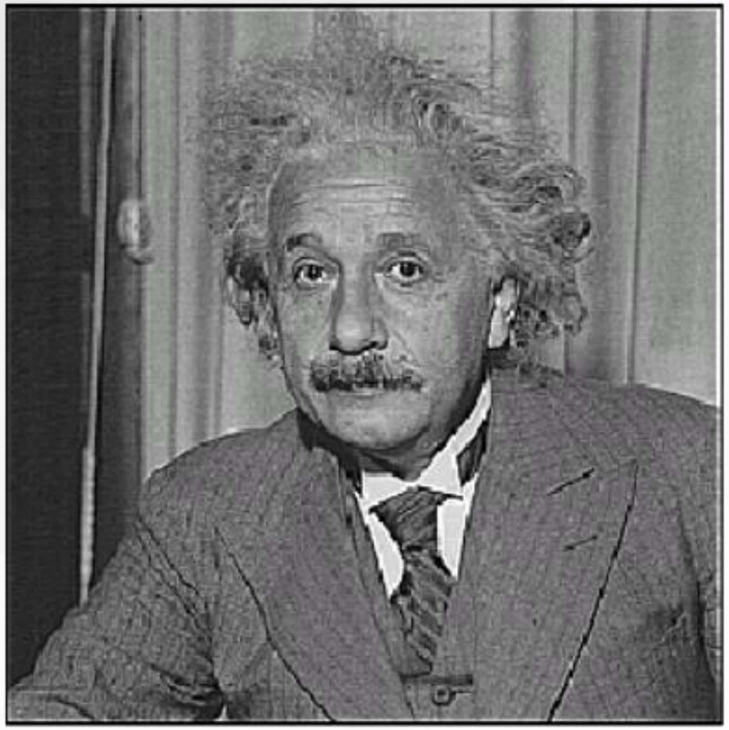
Spatial Filtering

Sharpening

- The **Laplacian**



Before



After

Spatial Filtering

Sharpening

- The **Laplacian**

Unsharp Masking and High-Boost Filtering

- *Unsharp masking* is expressed as

$$f_s(x,y) = f(x,y) - \overline{f}(x,y)$$

where $\overline{f}(x,y)$ is a blurred version of $f(x, y)$

- *high-boost filtering* ---- a slight further generalization of unsharp masking

$$f_{hb}(x,y) = kf(x,y) - \overline{f}(x,y) \qquad k > 1$$

Spatial Filtering

Sharpening

- Properties of 1st and 2nd-Order Derivatives
- Use of 2nd Derivatives for Enhancement- The Laplacian
- Use of 1st Derivatives for Enhancement - The Gradient

Spatial Filtering

Sharpening

- The Gradient -Use of 1st Derivatives for Enhancement

They are implemented using the magnitude of the gradient

–Gradient definition

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

–The magnitude of the Gradient

$$\nabla f = \text{mag}(\nabla \mathbf{f}) = \sqrt{G_x^2 + G_y^2}$$

$$= \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

– For computational consideration, in practice

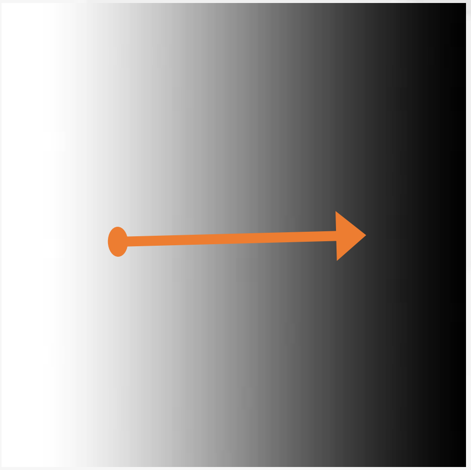
$$\nabla f \approx |G_x| + |G_y|$$

Image Enhancement

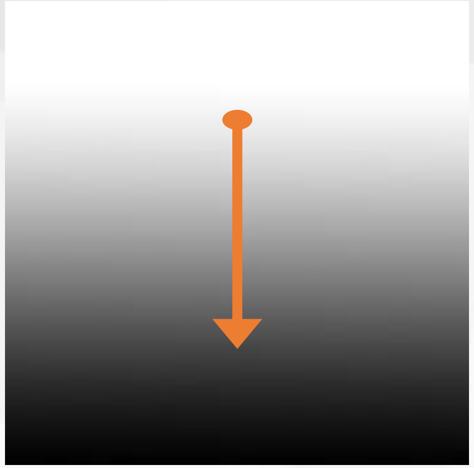
Spatial Filtering

Sharpening

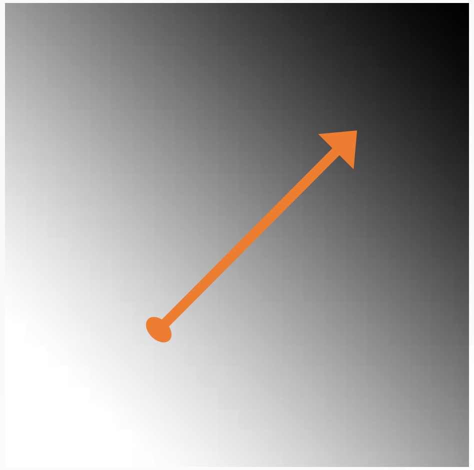
- The Gradient
  - The gradient points in the direction of most rapid increase in intensity.



$$\nabla f = \left[\frac{\partial f}{\partial x}, 0\right]$$



$$\nabla f = \left[0, \frac{\partial f}{\partial y}\right]$$



$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

Spatial Filtering

Sharpening

- The Gradient


Original Image


f_x


f_y

Which shows changes with respect to x?

Spatial Filtering

Sharpening

The Gradient

- Sobel operator (filter) is a popular discretization of the gradient

$$T_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix} \qquad T_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{pmatrix}$$

- – f_x is calculated using T_x, and f_y using T_y
  – The magnitude of the gradient is then given by:

$$\nabla f \approx |f_x| + |f_y|$$

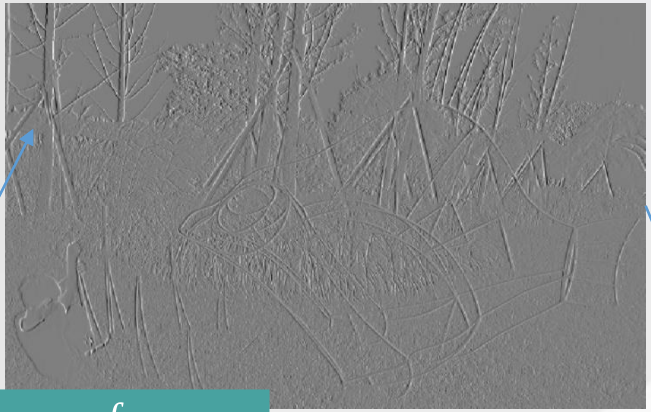
Spatial Filtering

Sharpening

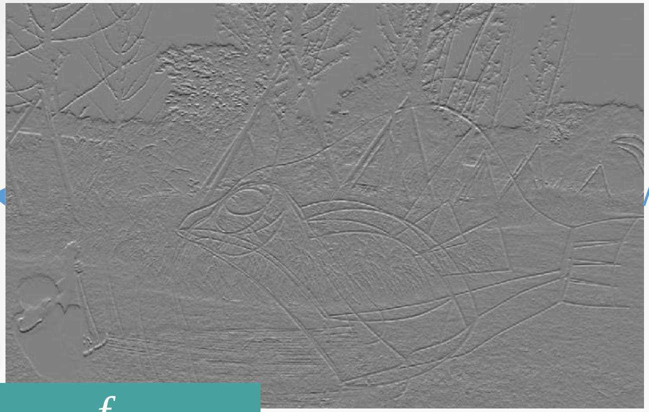
- The Gradient

$$T_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix}$$

Original Image



f_x



f_y

$$T_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{pmatrix}$$

Gradient Image

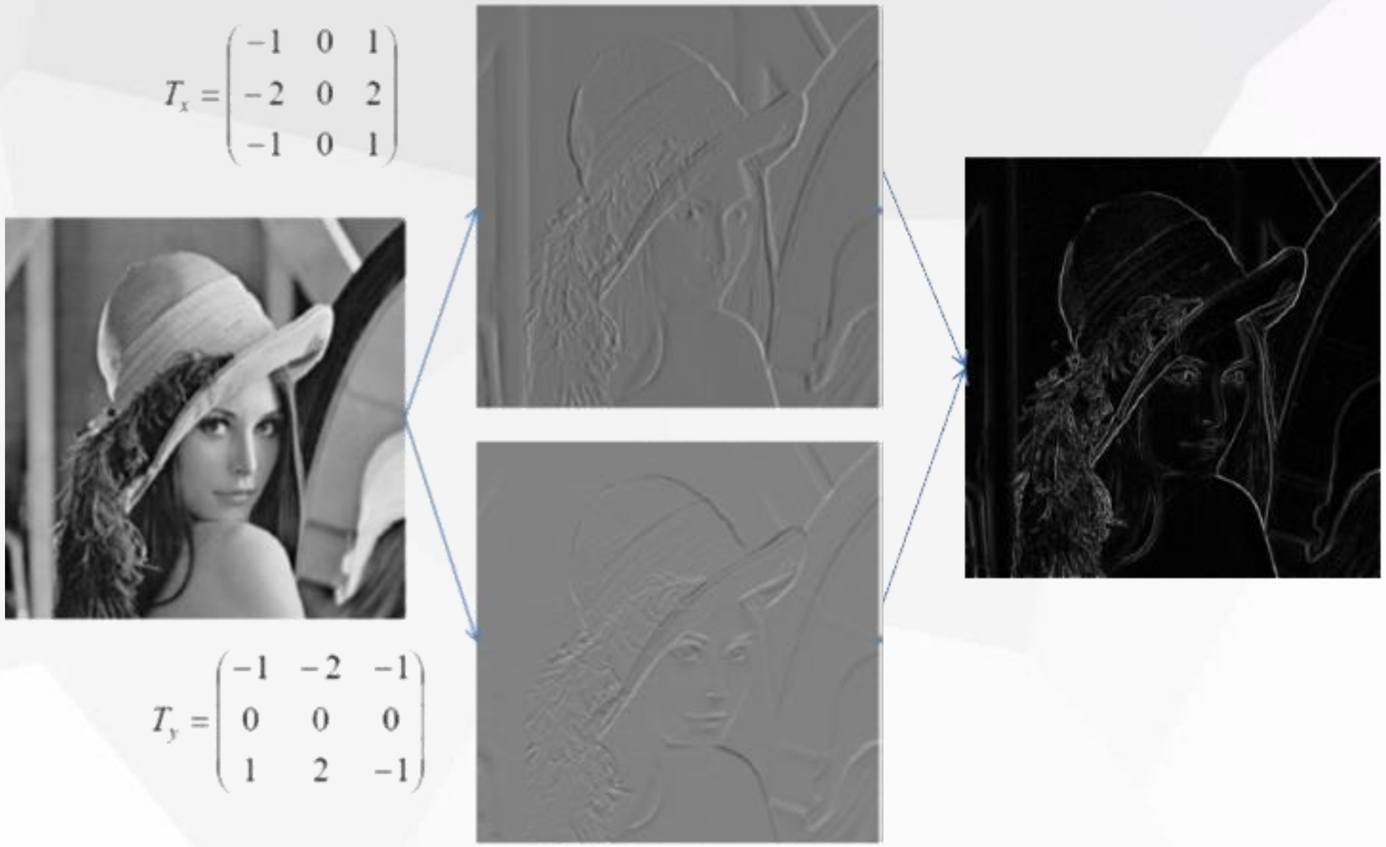
$$\nabla f \approx |f_x| + |f_y|$$

Spatial Filtering

Sharpening

- The Gradient

$$T_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix}$$



$$T_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & -1 \end{pmatrix}$$

Image Enhancement

Spatial Filtering

Sharpening

- The Gradient

Gradient Image

Sobel operator

$$\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Scharr operator

$$\begin{bmatrix} 3 & 0 & -3 \\ 10 & 0 & -10 \\ 3 & 0 & -3 \end{bmatrix} \begin{bmatrix} 3 & 10 & 3 \\ 0 & 0 & 0 \\ -3 & -10 & -3 \end{bmatrix}$$

Roberts Cross operator

$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

Prewitt operator

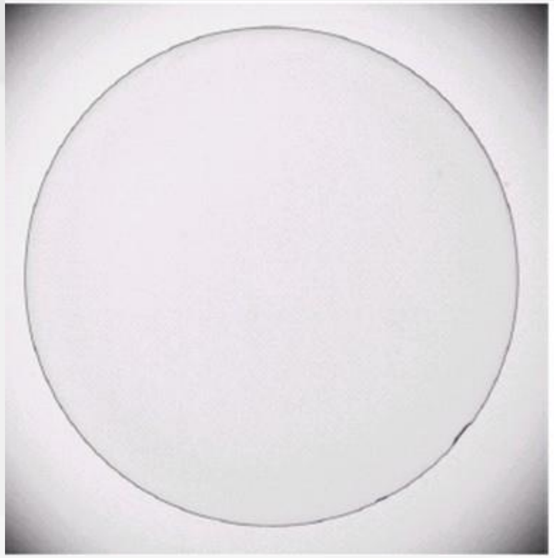
$$\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$$

Original Image

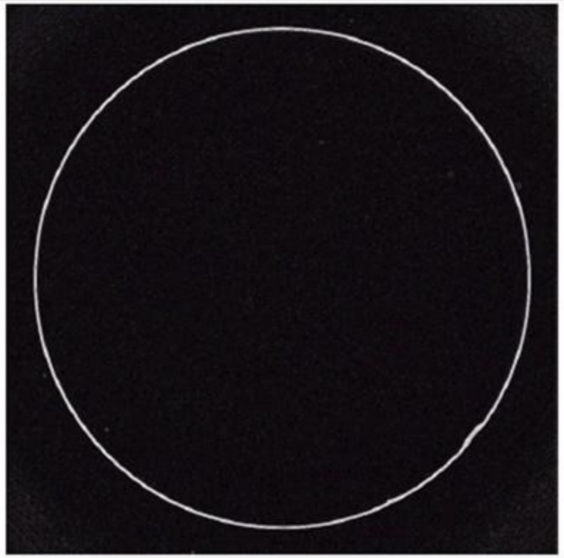
Spatial Filtering

Sharpening

The Gradient



Input image



Gradient magnitude

(at four and five o’clock in the image)

- Sobel gradient aids to eliminate constant or slowly varying shades of gray and assist automatic inspection.
- It also enhances small discontinuities in a flat gray filed.

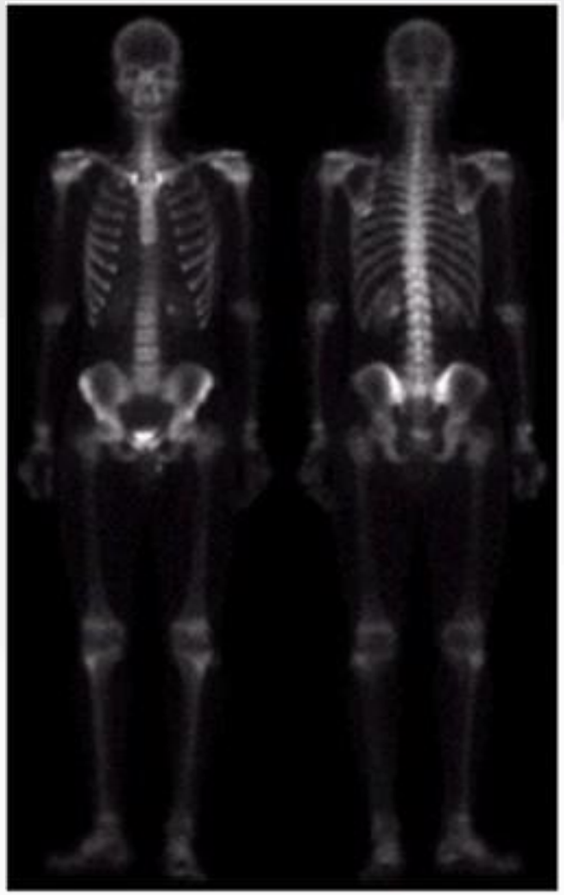
Spatial Filtering

- Fundamentals (Kernel, convolution, filtering)
- Smoothing (Linear / non-linear filters)
- Sharpening (The Laplacian-2ndorder derivatives, the gradient -first order derivatives)
- Combing Spatial Enhancement Methods

Spatial Filtering

Combing Spatial Enhancement

- 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
- The narrow dynamic range of the low gray levels and high noise content make this image difficult to enhance.



Spatial Filtering

Combing Spatial Enhancement

- Utilize the *Laplacian* to highlight fine detail
- Utilize the *gradient* to enhance prominent edges
- Combine *Laplacian* and smoothed *gradient* to get the detail-enhanced and noise-compressed image
- Increase the contrast of low gray levels by using a gray-level transformation.

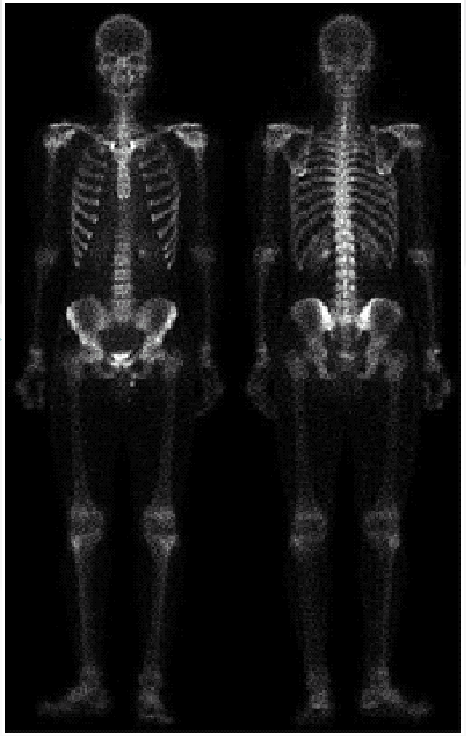
Spatial Filtering

Combing Spatial Enhancement

−1	−1	−1
−1	8	−1
−1	−1	−1

Laplace operator

$$f(x, y) + \nabla^2 f(x, y)$$



A rather noisy sharpened image is expected.

Original image

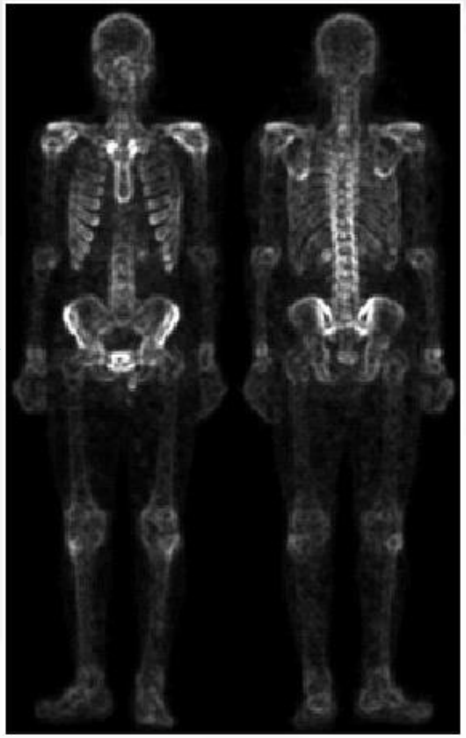
Spatial Filtering

Combing Spatial Enhancement

$$T_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix}$$

$$T_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{pmatrix}$$

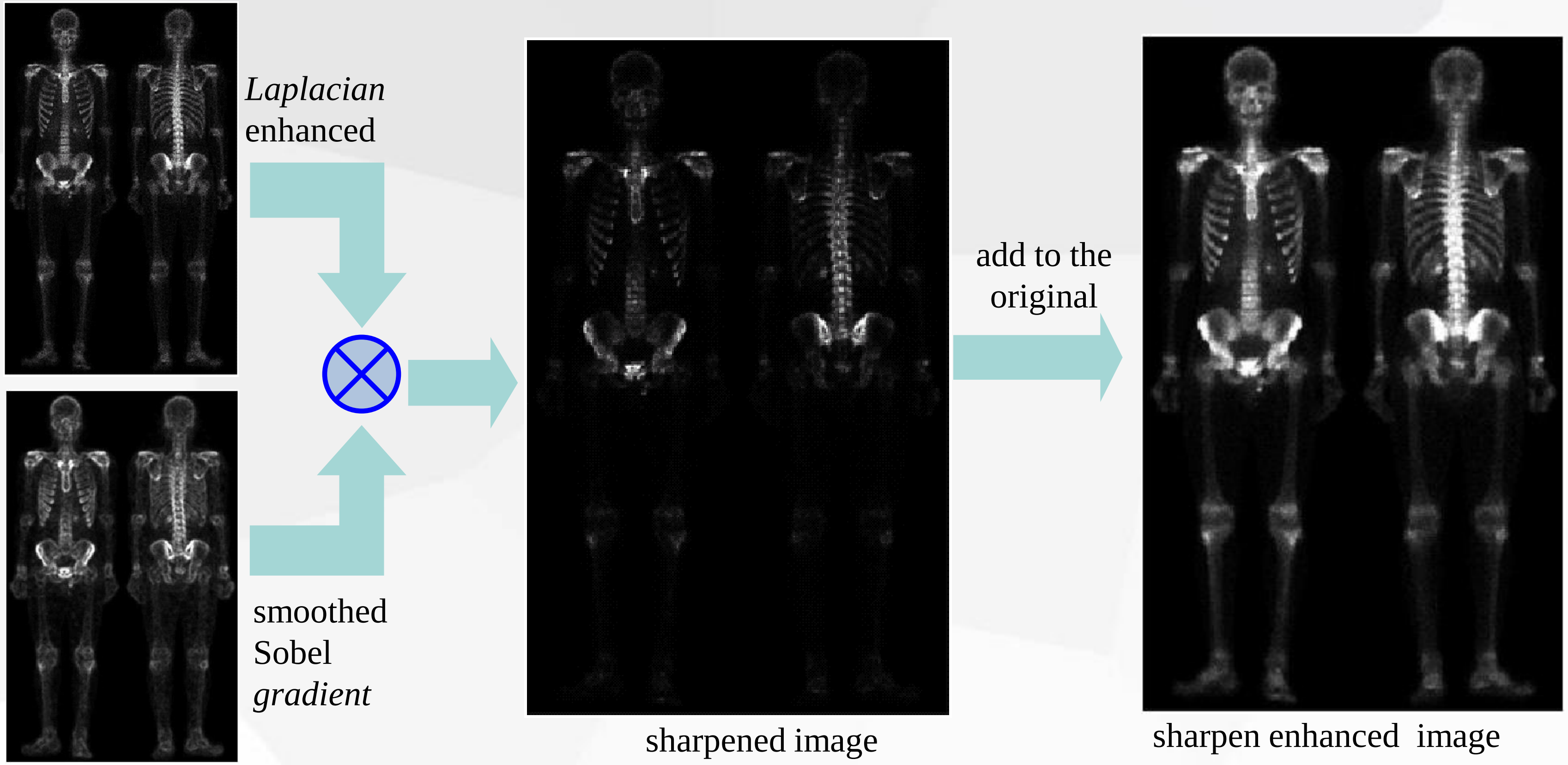
5 x 5 box smooth



mask image

Spatial Filtering

Combing Spatial Enhancement

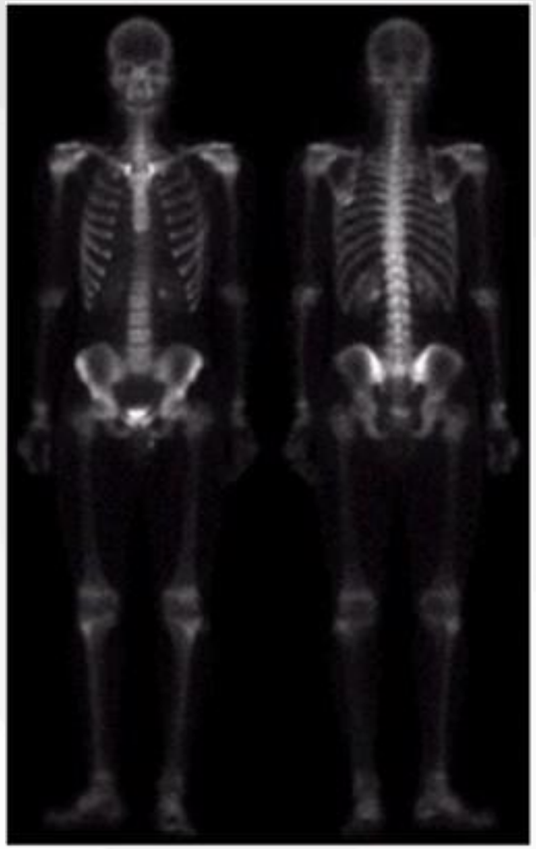


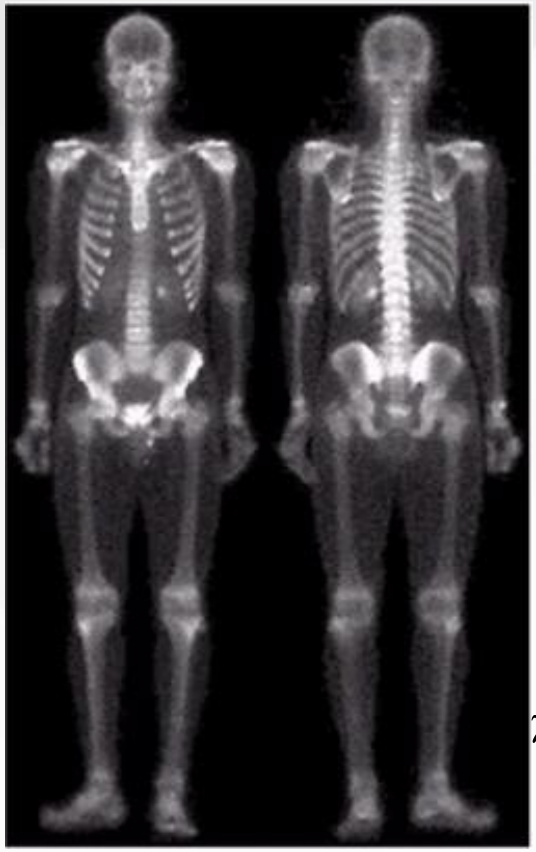
strong edges and the relative lack of visible noise

Spatial Filtering

Combing Spatial Enhancement

- Compare the original and final images





γ=0.5 c=1

Thanks