

Image Enhancement (Spatial Filtering)

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In this lecture we will look at spatial filtering techniques:

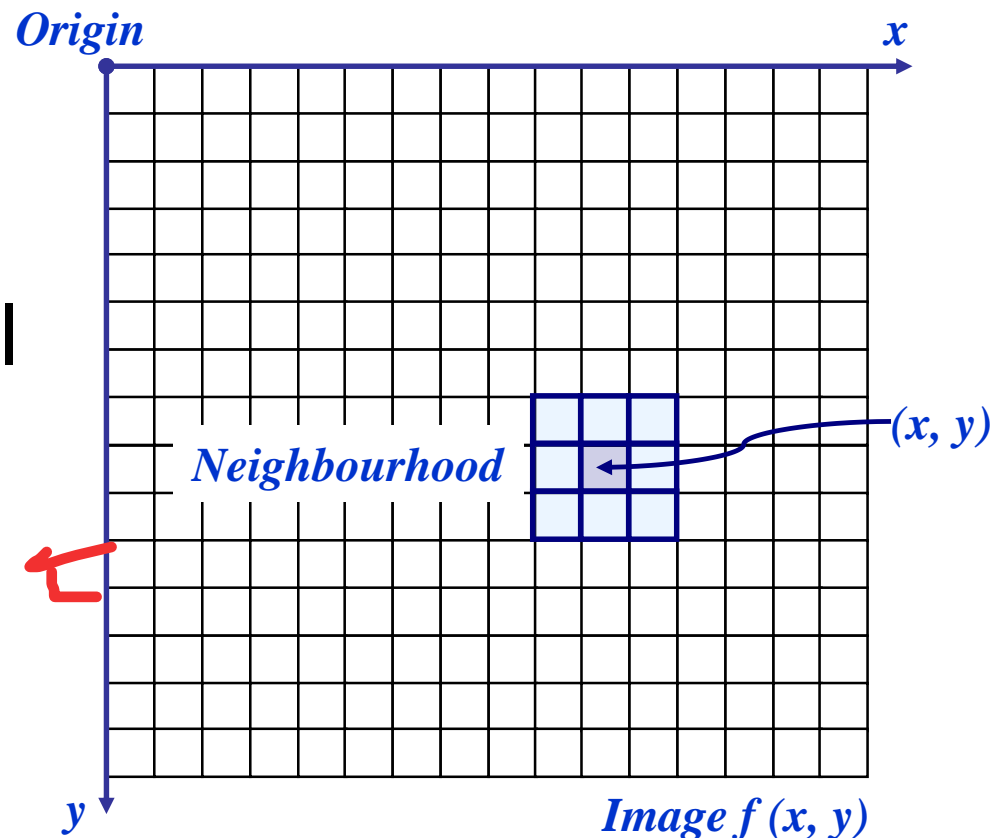
- Neighbourhood operations
- What is spatial filtering?
- Smoothing operations
- What happens at the edges?
- Correlation and convolution

Neighbourhood Operations

Neighbourhood operations simply operate on a larger neighbourhood of pixels than point operations

Neighbourhoods are mostly a rectangle around a central pixel

Any size rectangle and any shape filter are possible




Simple Neighbourhood Operations

Some simple neighbourhood operations include:

- **Min:** Set the pixel value to the minimum in the neighbourhood
- **Max:** Set the pixel value to the maximum in the neighbourhood
- **Median:** The median value of a set of numbers is the midpoint value in that set (e.g. from the set [1, 7, 15, 18, 24] 15 is the median). Sometimes the median works better than the average

Simple Neighbourhood Operations Example

Original Image



123	127	128	119	115	130	...
140	145	148	153	167	172	
133	154	183	192	194	191	
194	199	207	210	198	195	
164	170	175	162	173	151	
...						

x

y

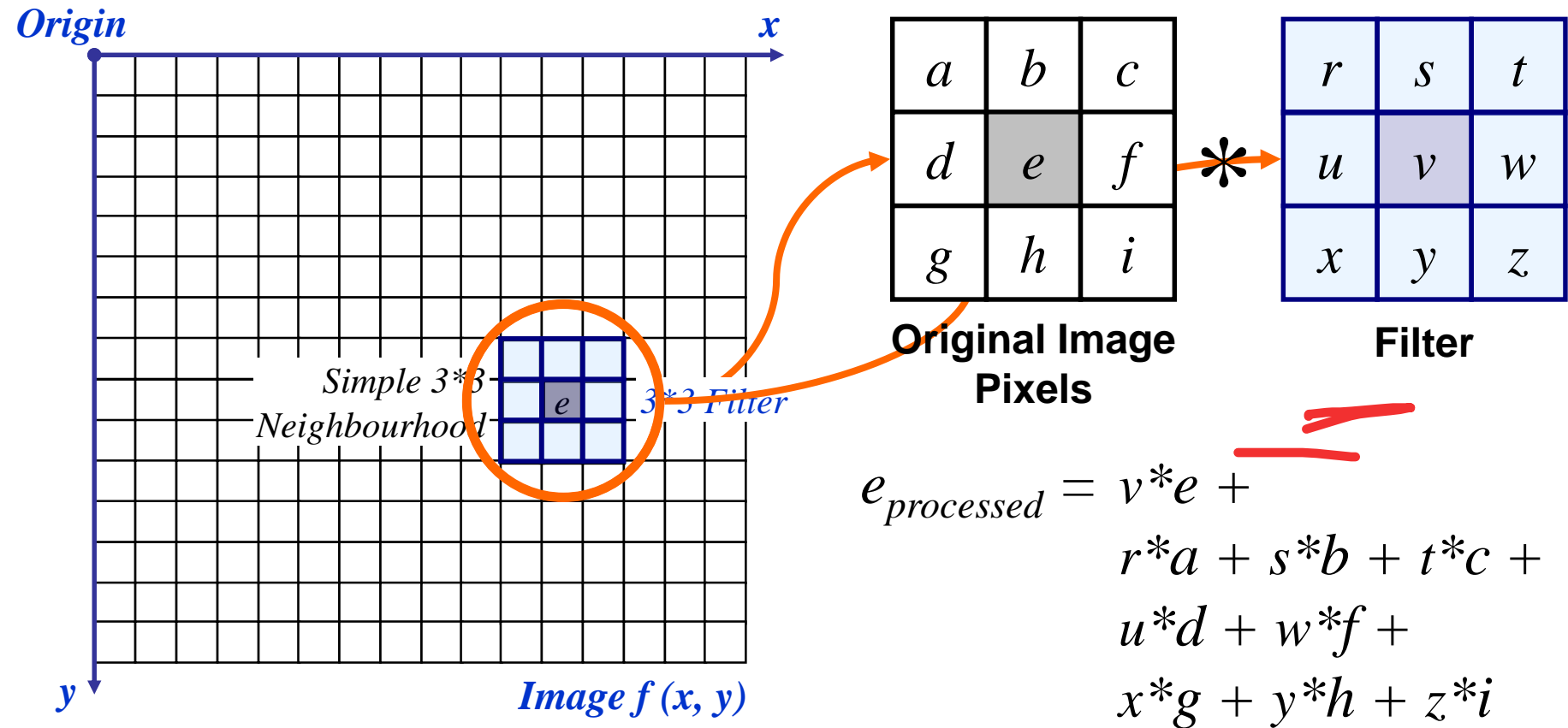
Enhanced Image

						...
...						

x

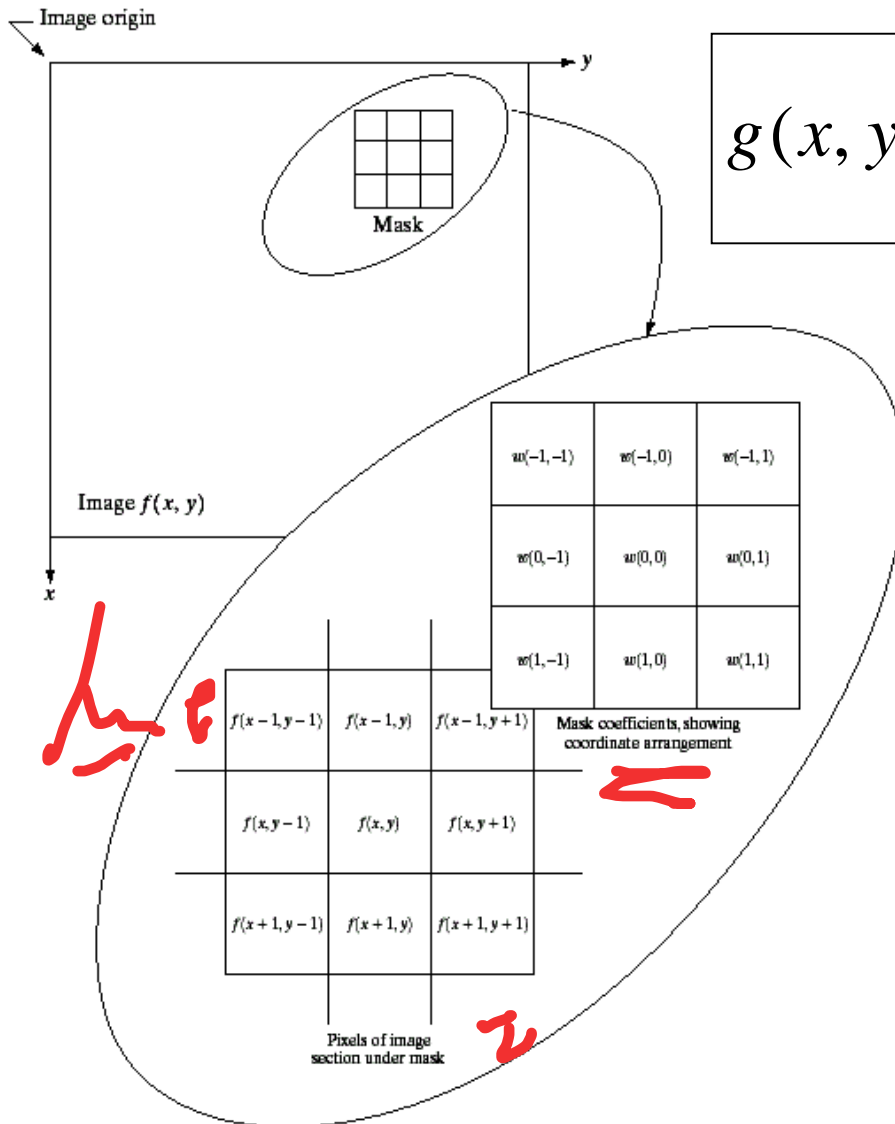
y

The Spatial Filtering Process



The above is repeated for every pixel in the original image to generate the filtered image

Spatial Filtering: Equation Form



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

Filtering can be given in equation form as shown above

Notations are based on the image shown to the left

Smoothing Spatial Filters

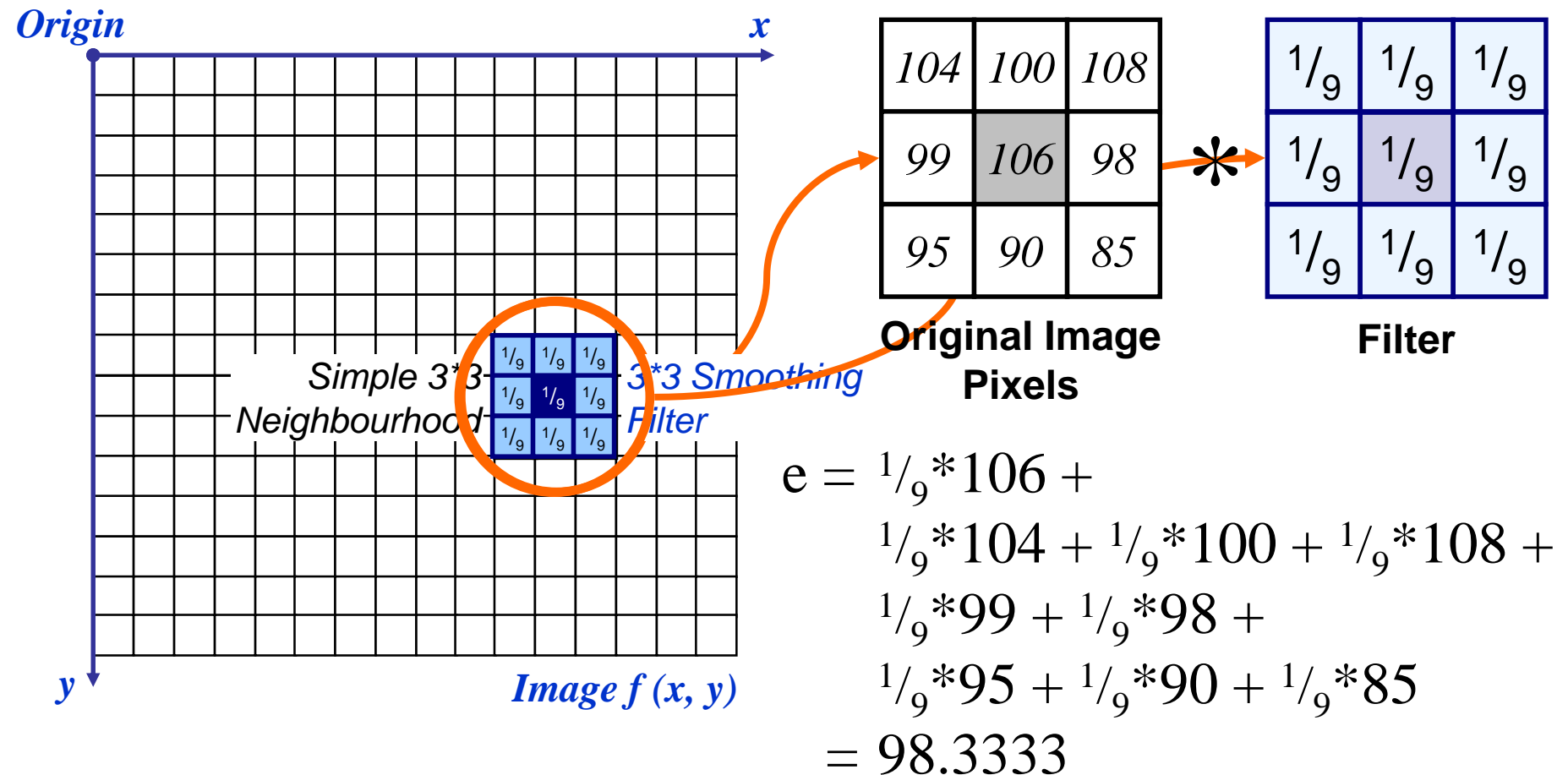
One of the simplest spatial filtering operations we can perform is a smoothing operation

- Simply average all of the pixels in a neighbourhood around a central value
- Especially useful in removing noise from images
- Also useful for highlighting gross detail

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

Simple
averaging
filter

Smoothing Spatial Filtering



The above is repeated for every pixel in the original image to generate the smoothed image

Image Smoothing Example

The image at the top left is an original image of size 500*500 pixels

The subsequent images show the image after filtering with an averaging filter of increasing sizes

– 3, 5, 9, 15 and 35

Notice how detail begins to disappear

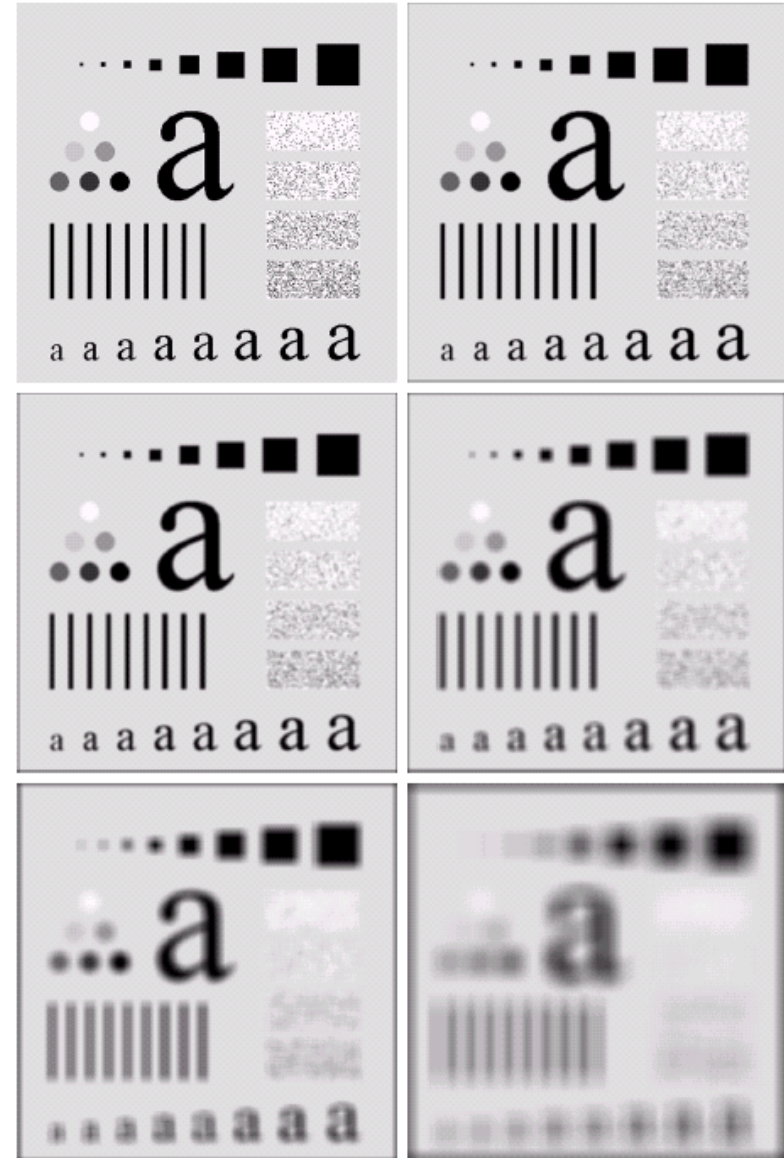


Image Smoothing Example

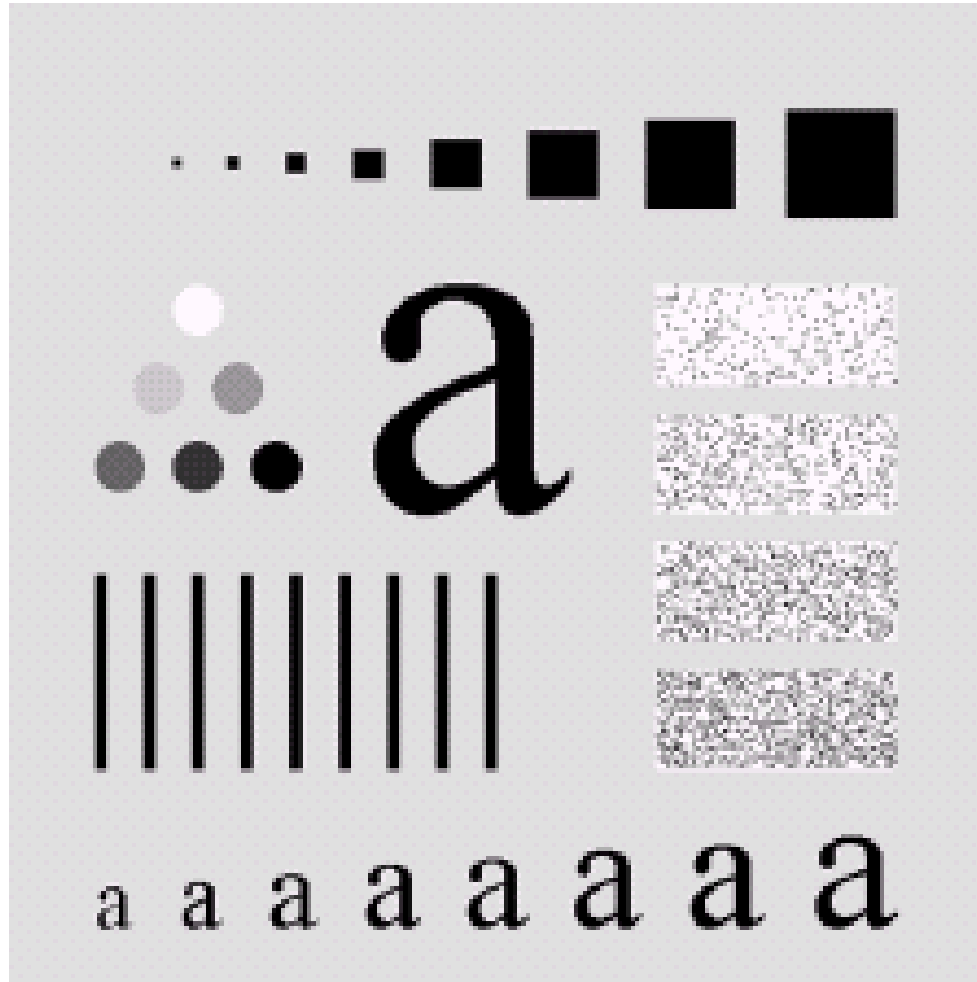


Image Smoothing Example



Image Smoothing Example

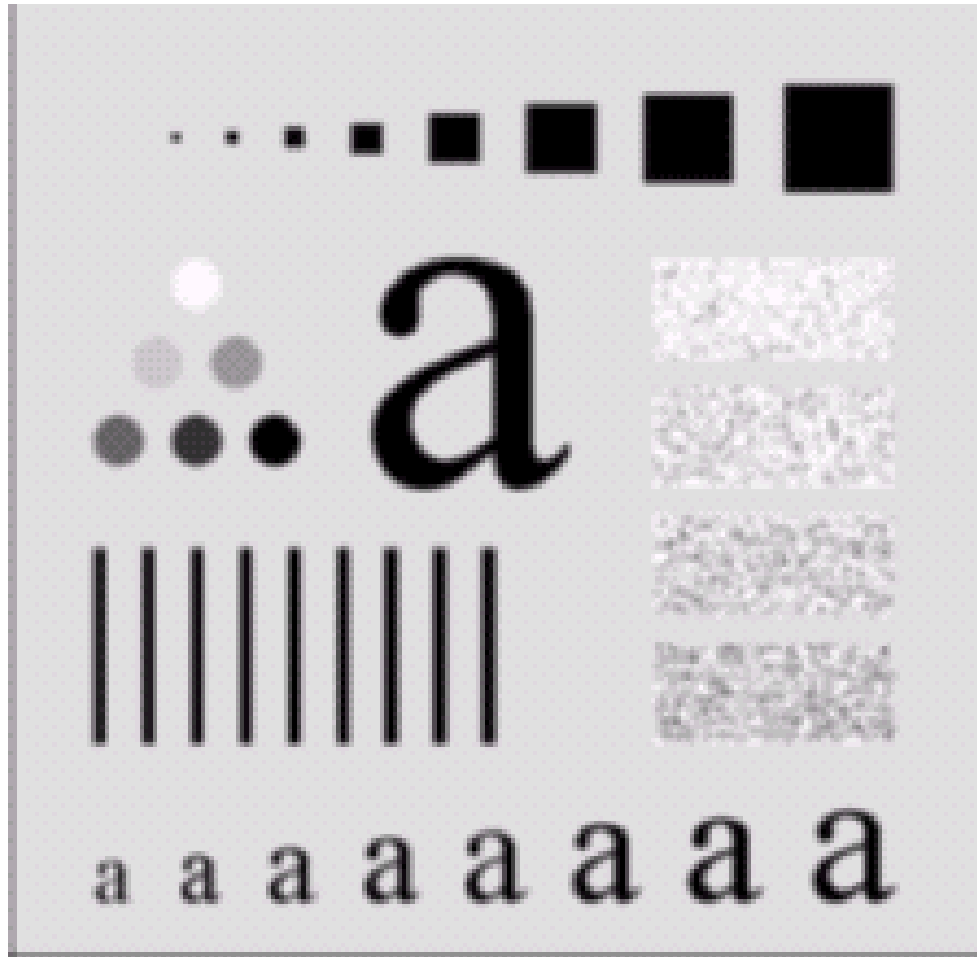


Image Smoothing Example

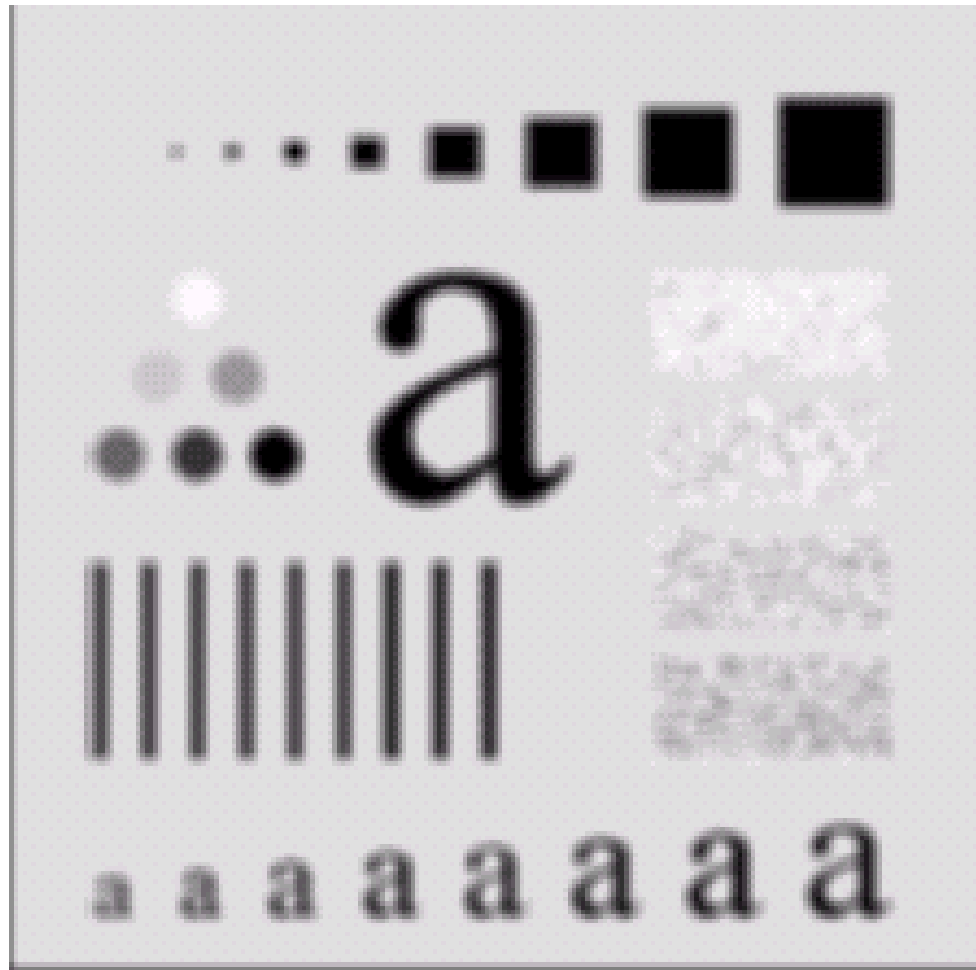


Image Smoothing Example

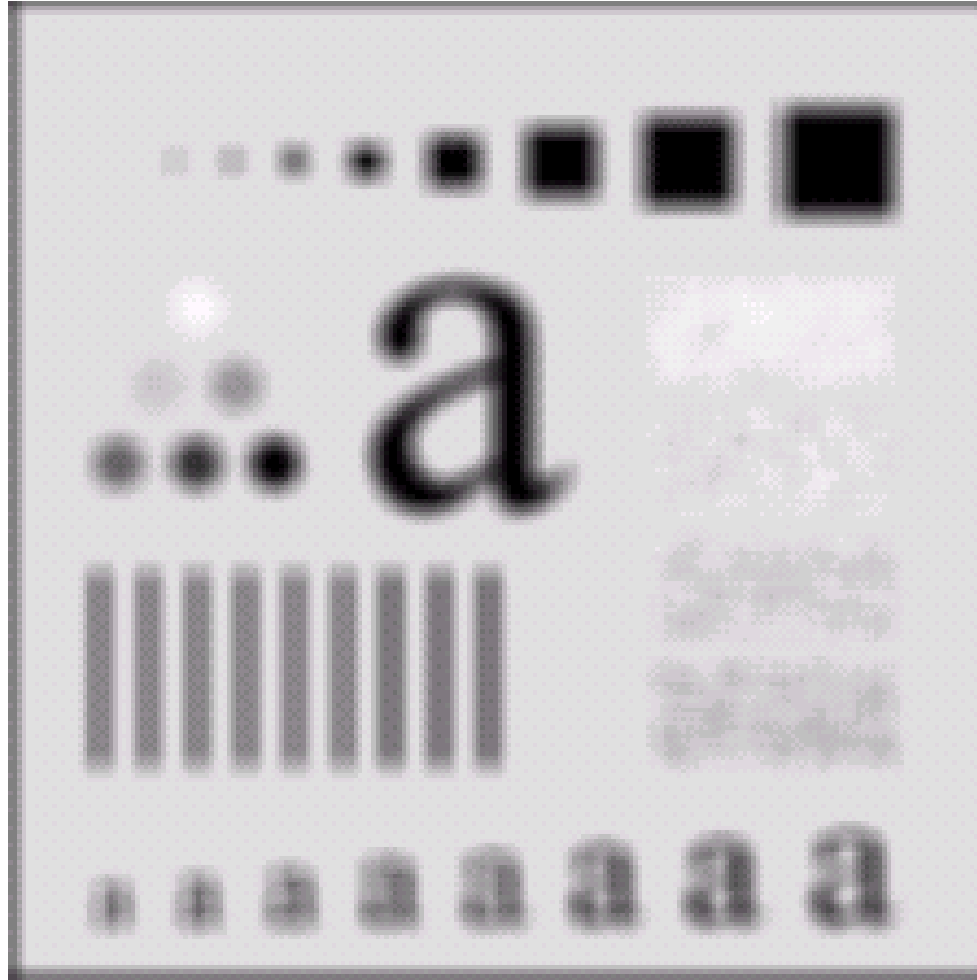
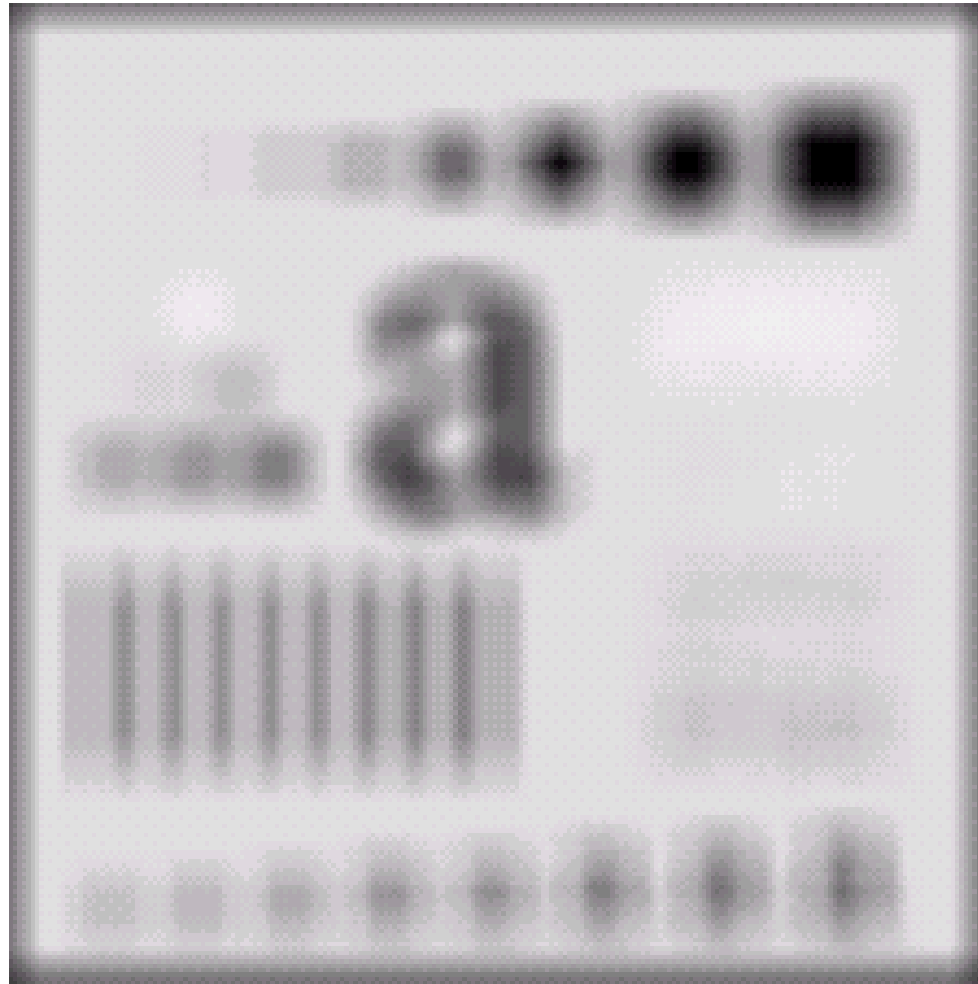


Image Smoothing Example



Weighted Smoothing Filters

More effective smoothing filters can be generated by allowing different pixels in the neighbourhood different weights in the averaging function

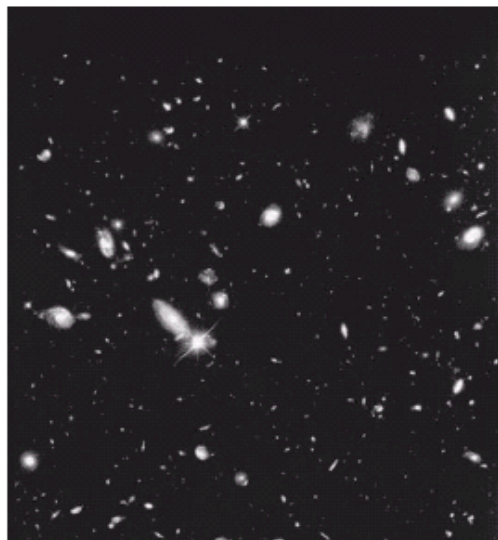
- Pixels closer to the central pixel are more important
- Often referred to as a weighted averaging

$1/16$	$2/16$	$1/16$
$2/16$	$4/16$	$2/16$
$1/16$	$2/16$	$1/16$

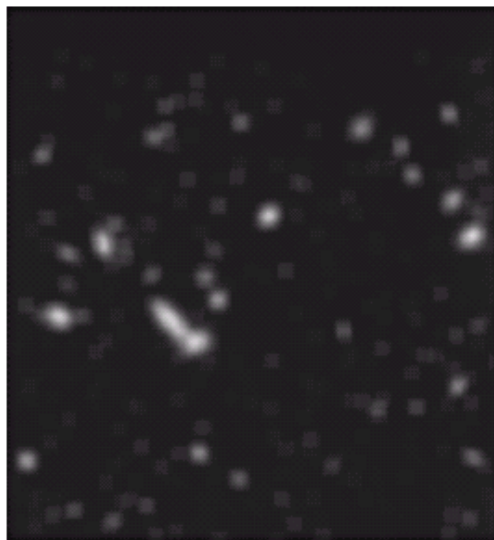
Weighted
averaging filter

✓✓✓✓ Another Smoothing Example

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



Original Image

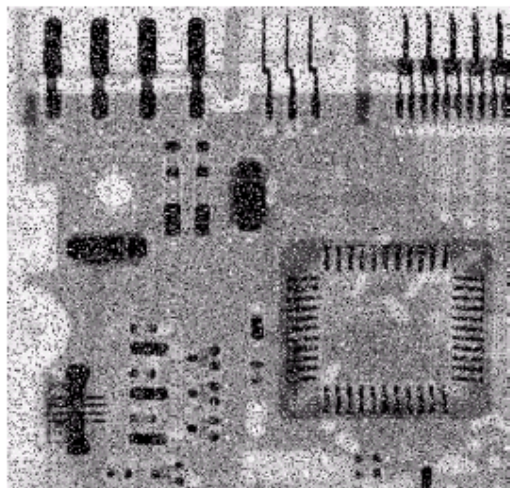


Smoothed Image

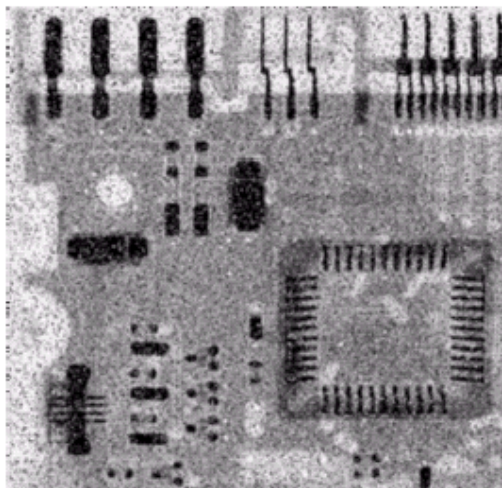


Thresholded Image

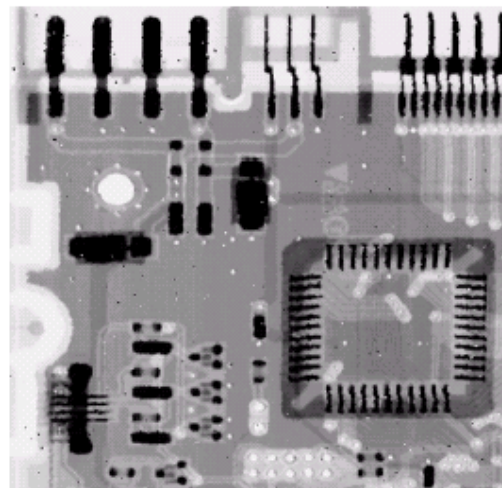
Averaging Filter Vs. Median Filter Example



**Original Image
With Noise**



**Image After
Averaging Filter**

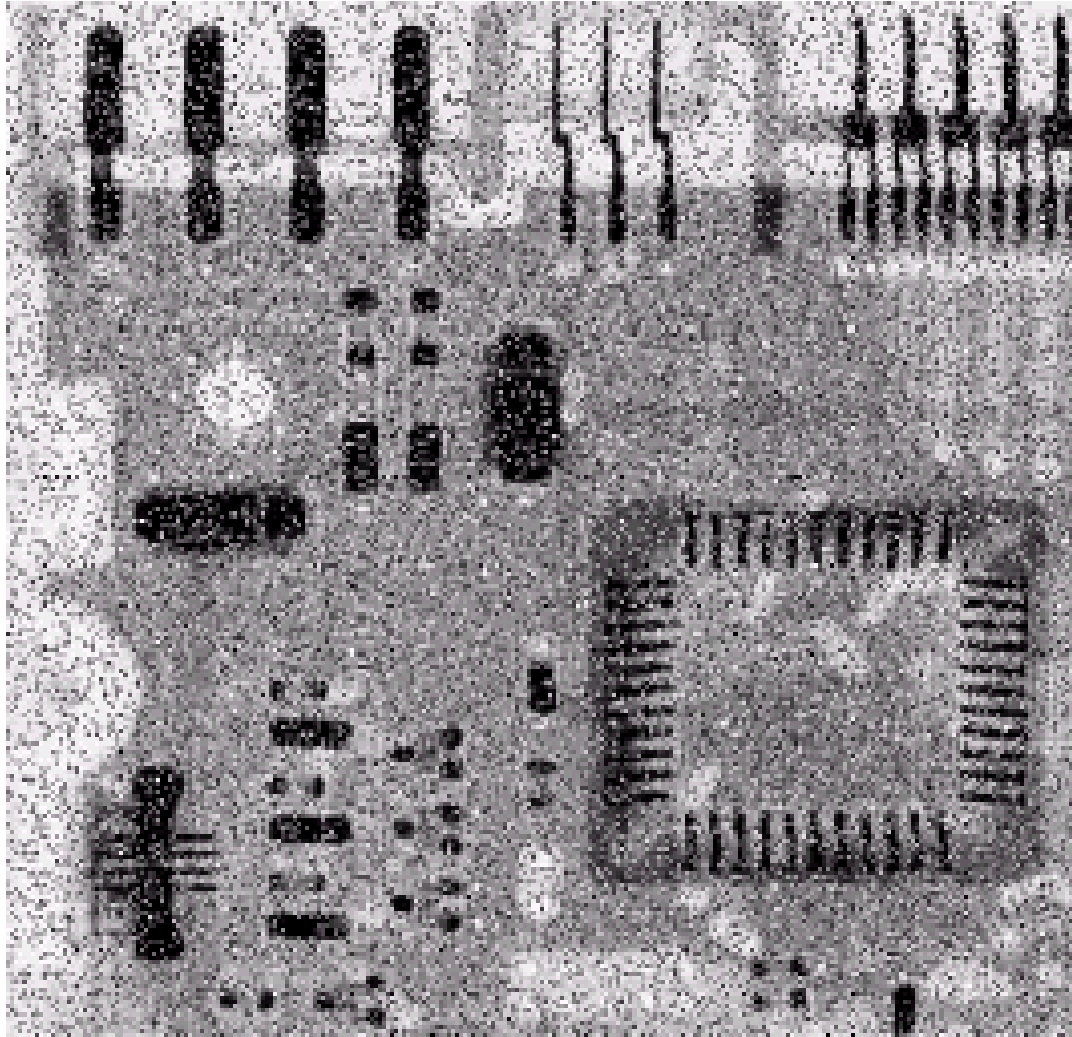


**Image After
Median Filter**

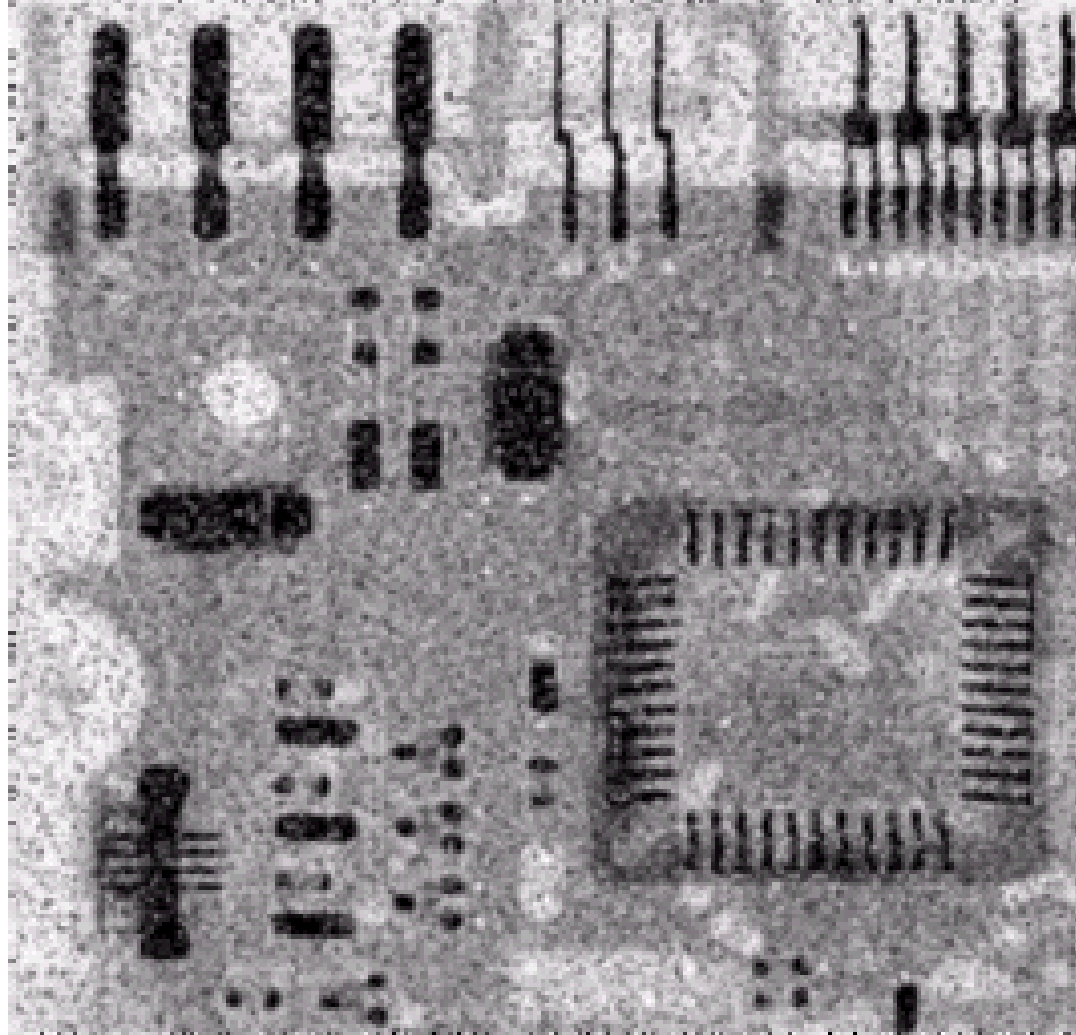
Filtering is often used to remove noise from images

Sometimes a median filter works better than an averaging filter

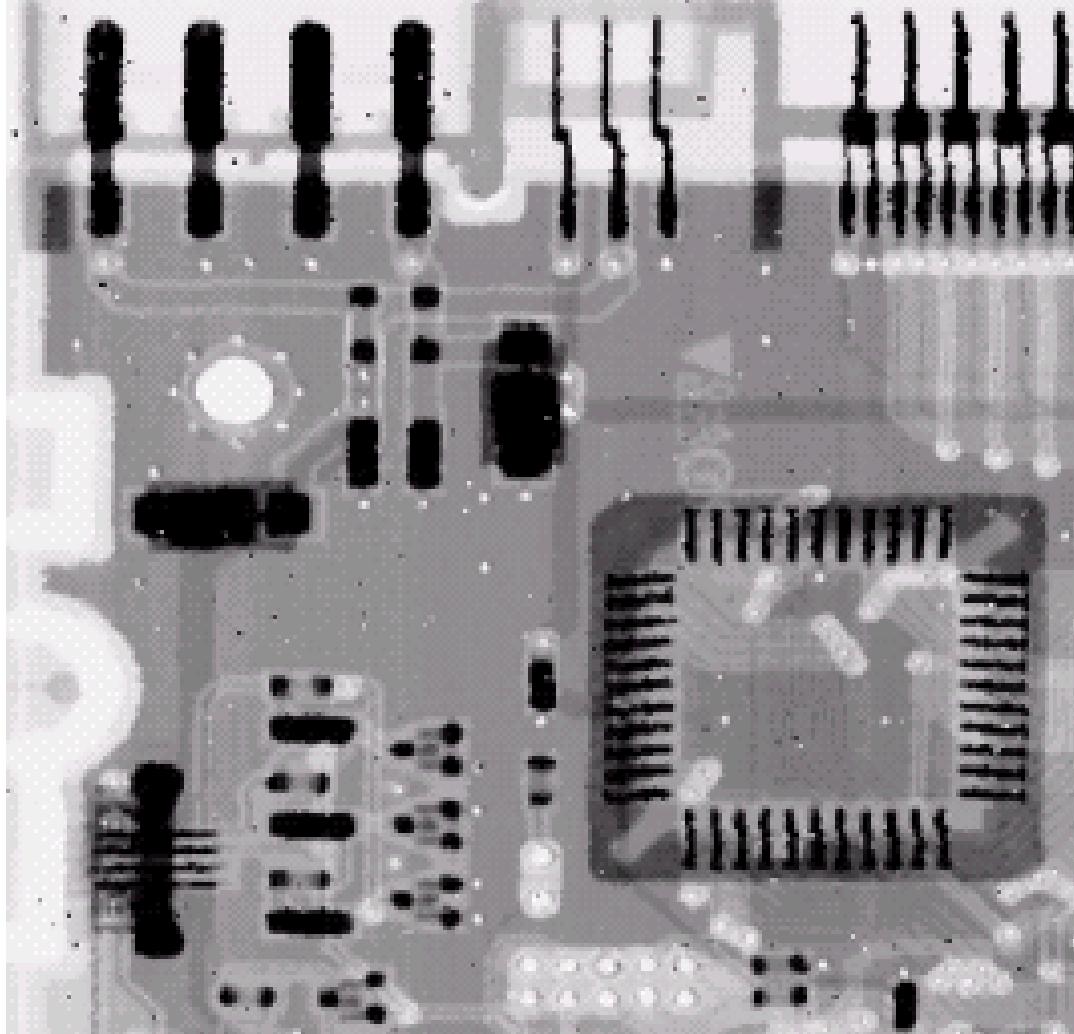
Averaging Filter Vs. Median Filter Example



Averaging Filter Vs. Median Filter Example



Averaging Filter Vs. Median Filter Example



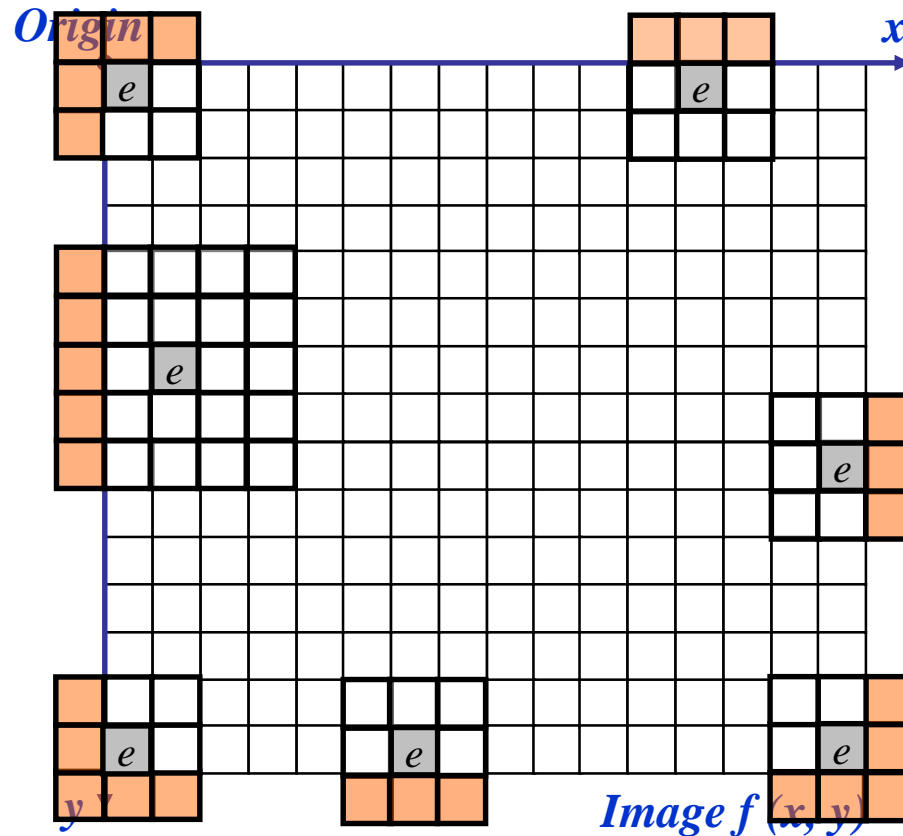
Simple Neighbourhood Operations

Example

123	127	128	119	115	130	
140	145	148	153	167	172	
133	154	183	192	194	191	• • •
194	199	207	210	198	195	
164	170	175	162	173	151	
		• • •				

Strange Things Happen At The Edges!

At the edges of an image we are missing pixels to form a neighbourhood



Strange Things Happen At The Edges!

(cont...)

There are a few approaches to dealing with missing edge pixels:

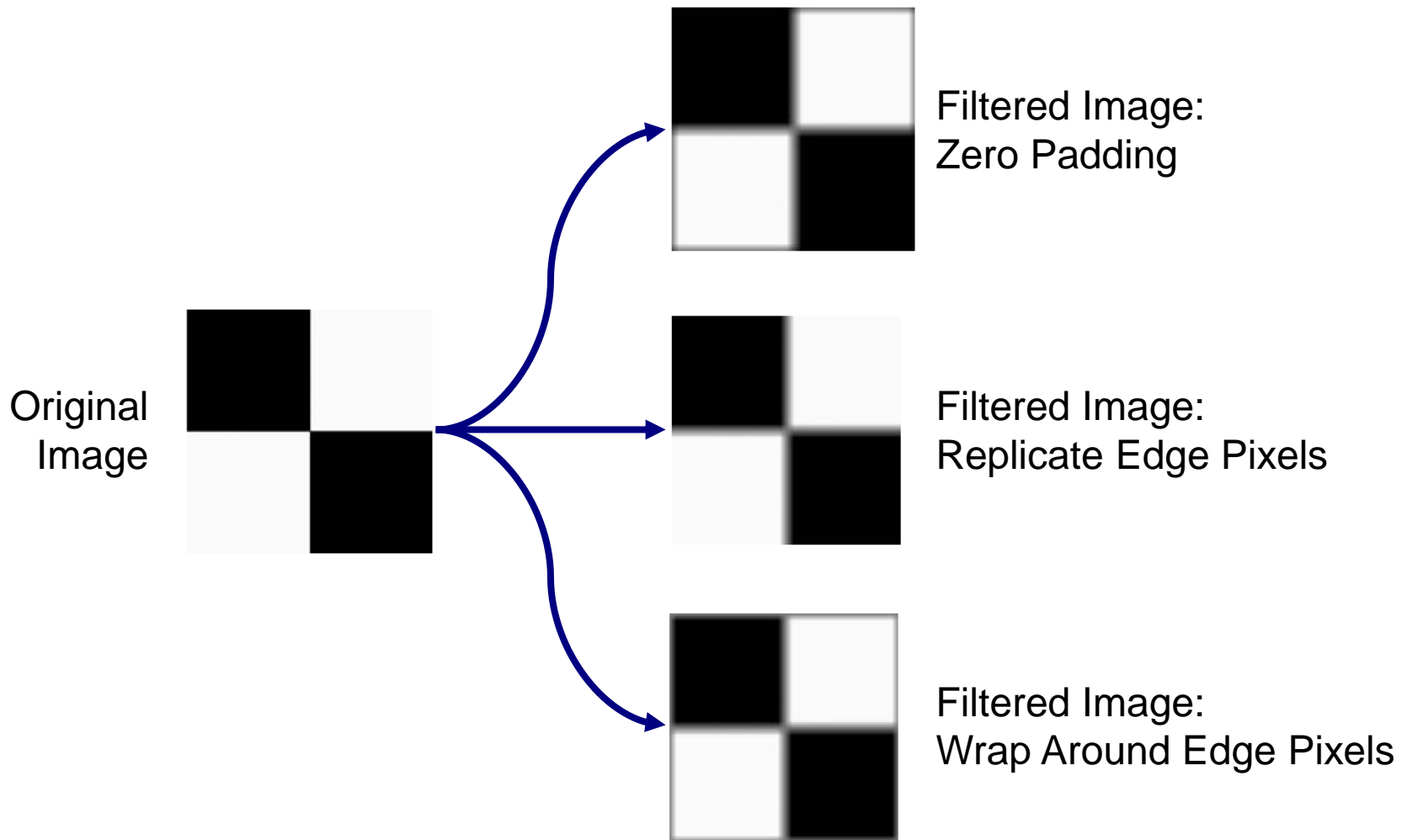
- Omit missing pixels
 - Only works with some filters
 - Can add extra code and slow down processing
- Pad the image
 - Typically with either all white or all black pixels
- Replicate border pixels
- Truncate the image
- Allow pixels *wrap around* the image
 - Can cause some strange image artefacts

Simple Neighbourhood Operations

Example

123	127	128	119	115	130	
140	145	148	153	167	172	
133	154	183	192	194	191	• • •
194	199	207	210	198	195	
164	170	175	162	173	151	
		•				
		•				
		•				

Strange Things Happen At The Edges! (cont...)



Strange Things Happen At The Edges! (cont...)



Strange Things Happen At The Edges! (cont...)



Strange Things Happen At The Edges! (cont...)



Correlation & Convolution

The filtering we have been talking about so far is referred to as *correlation* with the filter itself referred to as the *correlation kernel*

Convolution is a similar operation, with just one subtle difference

a	b	c
d	e	e
f	g	h

Original Image
Pixels

$*$

r	s	t
u	v	w
x	y	z

Filter

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

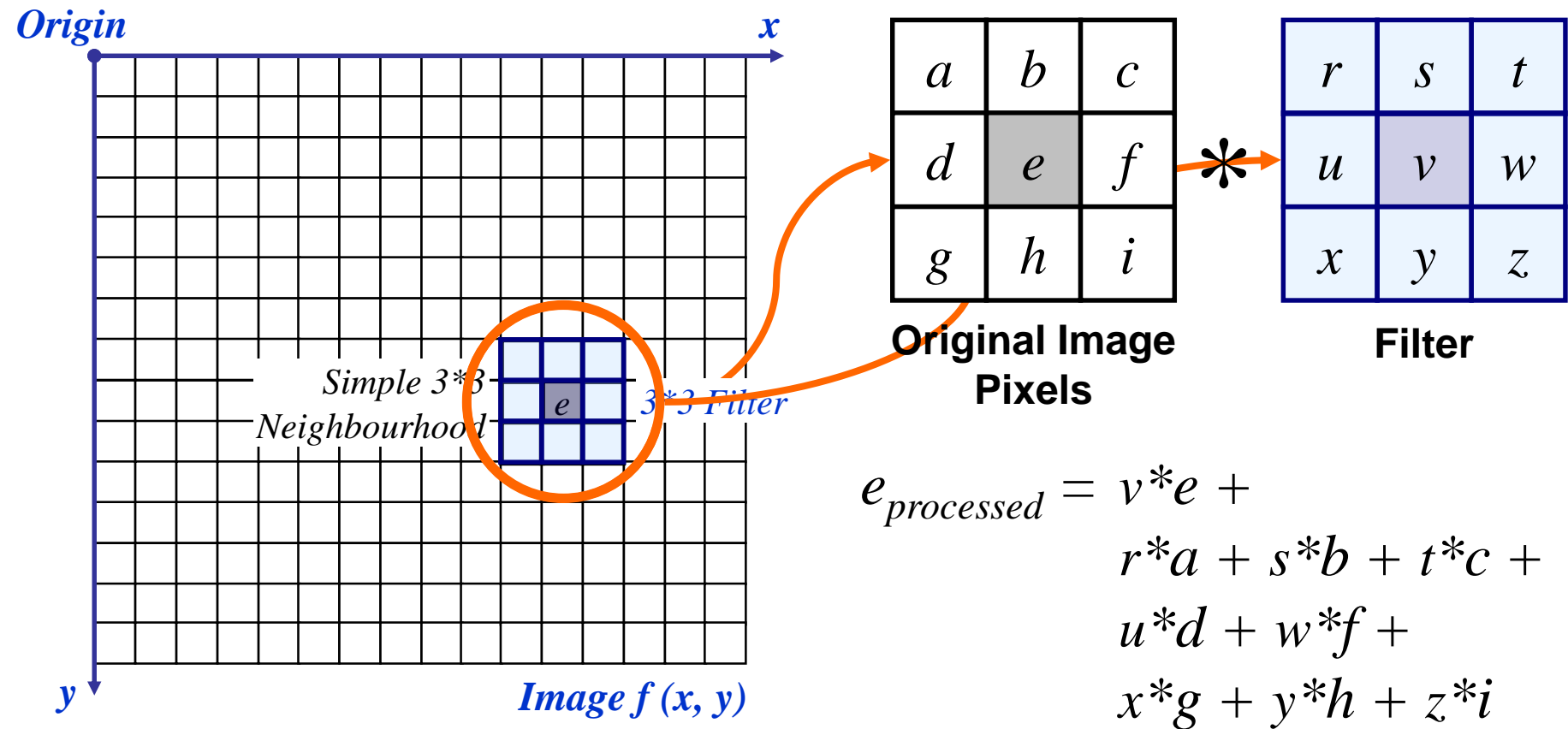
For symmetric filters it makes no difference

In this lecture we have looked at the idea of spatial filtering and in particular:

- Neighbourhood operations
- The filtering process
- Smoothing filters
- Dealing with problems at image edges when using filtering
- Correlation and convolution

Next time we will looking at sharpening filters and more on filtering and image enhancement

Spatial Filtering Refresher



The above is repeated for every pixel in the original image to generate the smoothed image

Sharpening Spatial Filters

Previously we have looked at smoothing filters which remove fine detail

Sharpening spatial filters seek to highlight fine detail

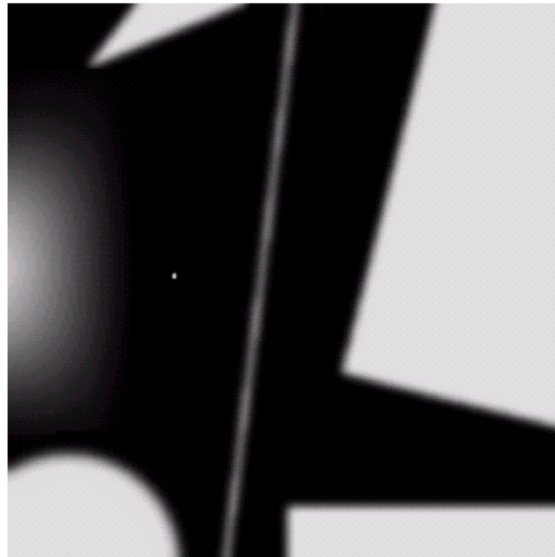
- Remove blurring from images
- Highlight edges

Sharpening filters are based on *spatial differentiation*

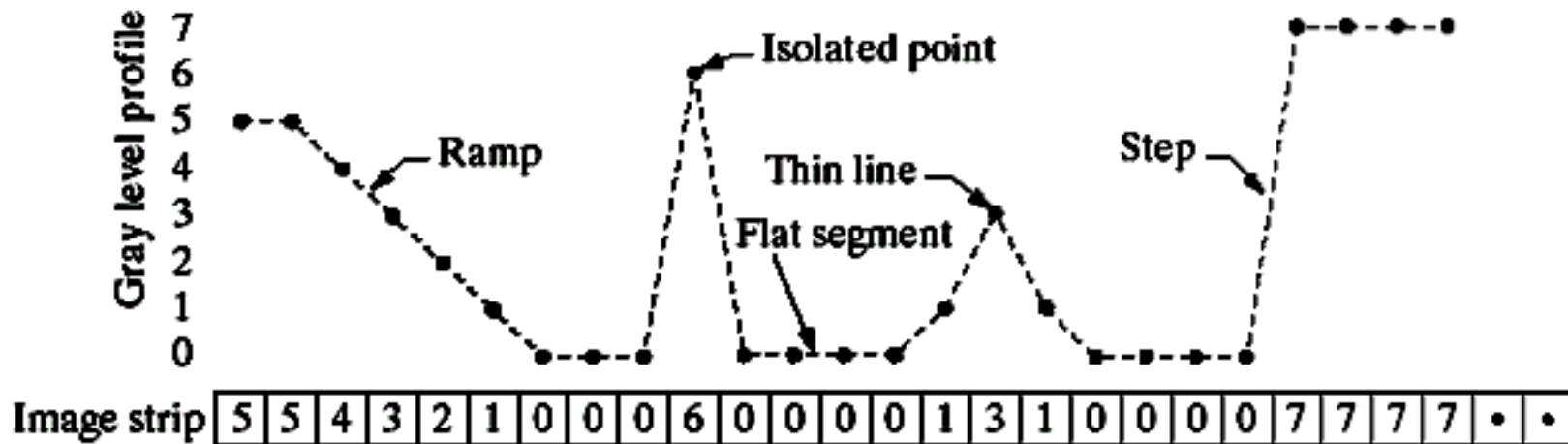
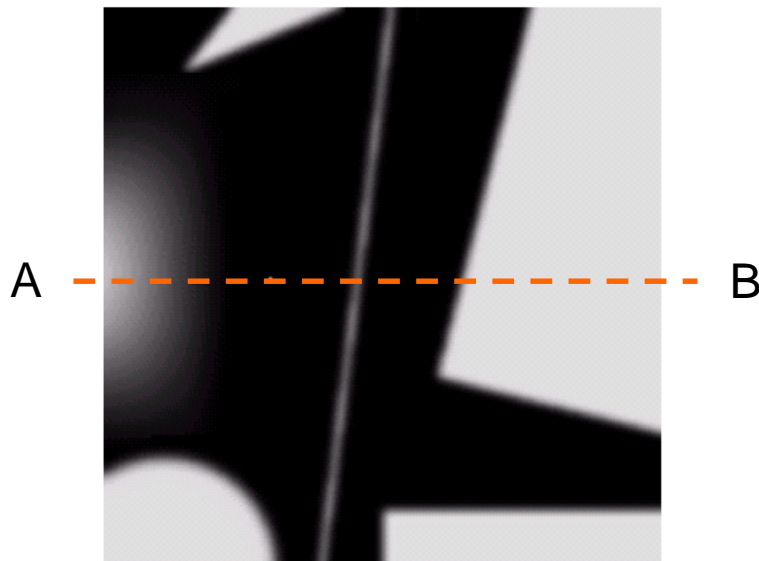
Spatial Differentiation

Differentiation measures the *rate of change* of a function

Let's consider a simple 1 dimensional example



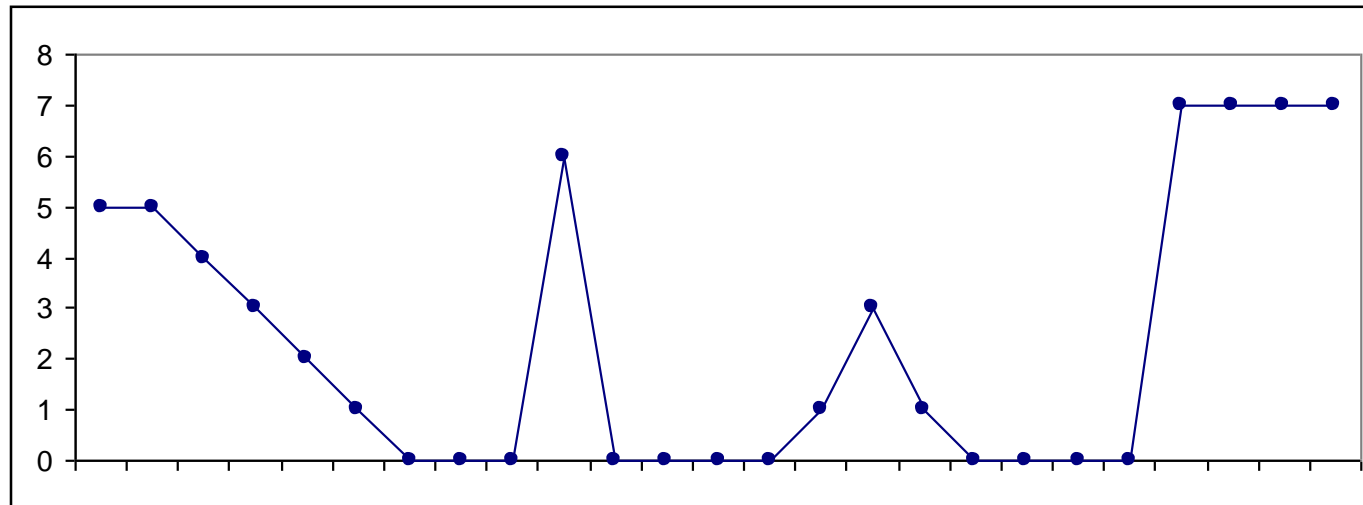
Spatial Differentiation



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

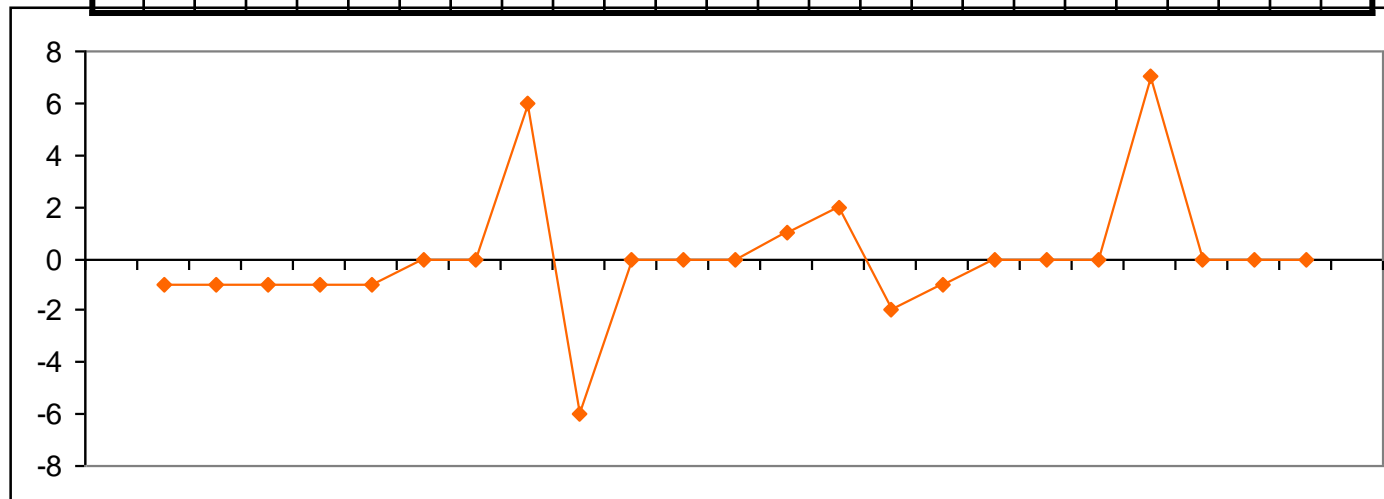
$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

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

1st Derivative (cont...)

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
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

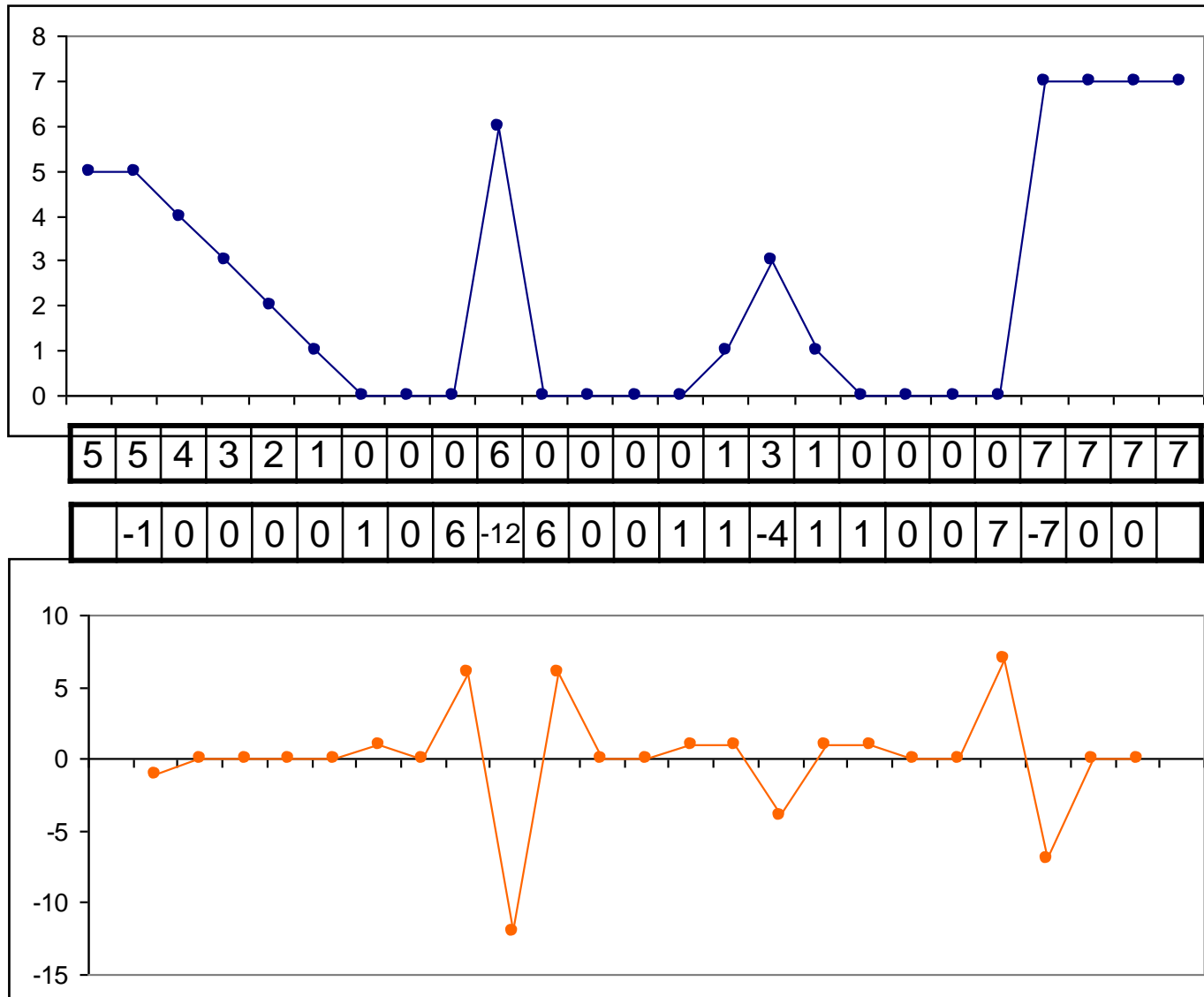
	0	-1	-1	-1	-1	0	0	6	-6	0	0	0	1	2	-2	-1	0	0	0	7	0	0	0	
--	---	----	----	----	----	---	---	---	----	---	---	---	---	---	----	----	---	---	---	---	---	---	---	--



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

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

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

2nd Derivative (cont...)

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
- We will come back to the 1st order derivative later on

The first sharpening filter we will look at is the *Laplacian*

- Isotropic
- One of the simplest sharpening filters
- We will look at a digital implementation

The Laplacian (cont...)

So, the Laplacian can be given as follows:

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

We can easily build a filter based on this

0	1	0
1	-4	1
0	1	0

The Laplacian is defined as follows:

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

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

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

and in the y direction as follows:

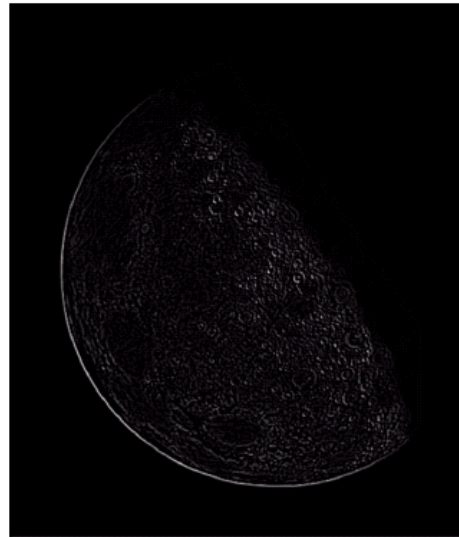
$$\frac{\partial^2 f}{\partial y^2} = f(x, y+1) + f(x, y-1) - 2f(x, y)$$

The Laplacian (cont...)

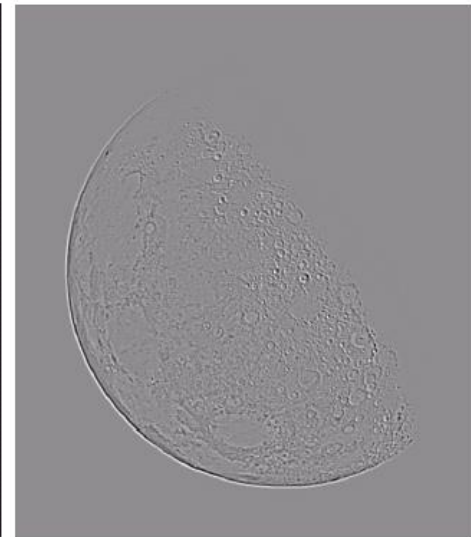
Applying the Laplacian to an image we get a new image that highlights edges and other discontinuities



Original
Image



Laplacian
Filtered Image



Laplacian
Filtered Image
Scaled for Display

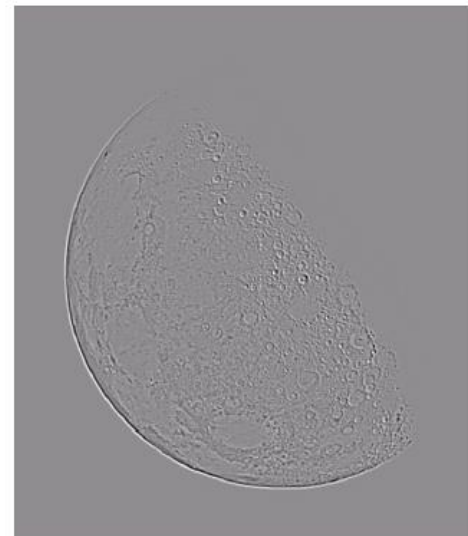
But That Is Not Very Enhanced!

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

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



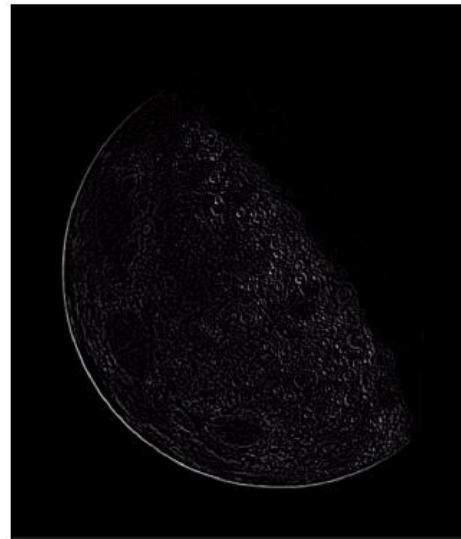
Laplacian
Filtered Image
Scaled for Display

Laplacian Image Enhancement



Original
Image

-



Laplacian
Filtered Image

=



Sharpened
Image

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

Laplacian Image Enhancement



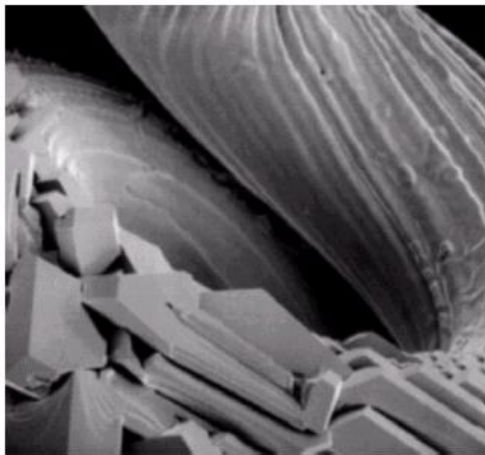
Simplified Image Enhancement

The entire enhancement can be combined into a single filtering operation

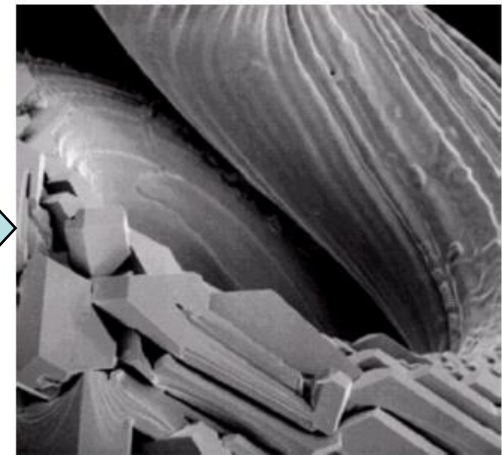
$$\begin{aligned} g(x, y) &= f(x, y) - \nabla^2 f \\ &= f(x, y) - [f(x+1, y) + f(x-1, y) \\ &\quad + f(x, y+1) + f(x, y-1) \\ &\quad - 4f(x, y)] \\ &= 5f(x, y) - f(x+1, y) - f(x-1, y) \\ &\quad - f(x, y+1) - f(x, y-1) \end{aligned}$$

Simplified Image Enhancement (cont...)

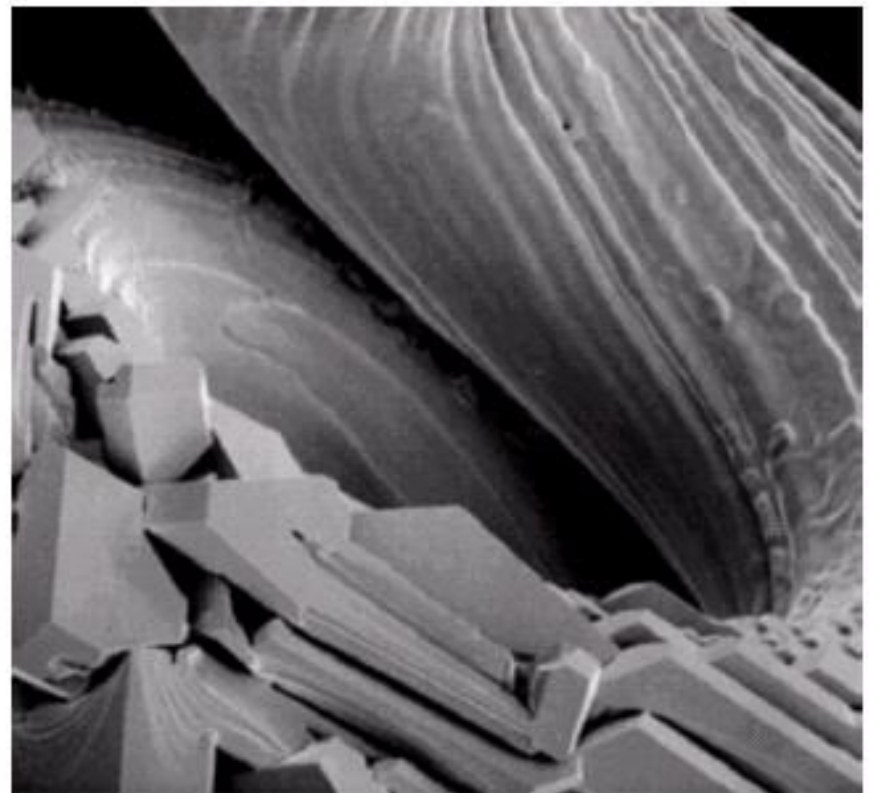
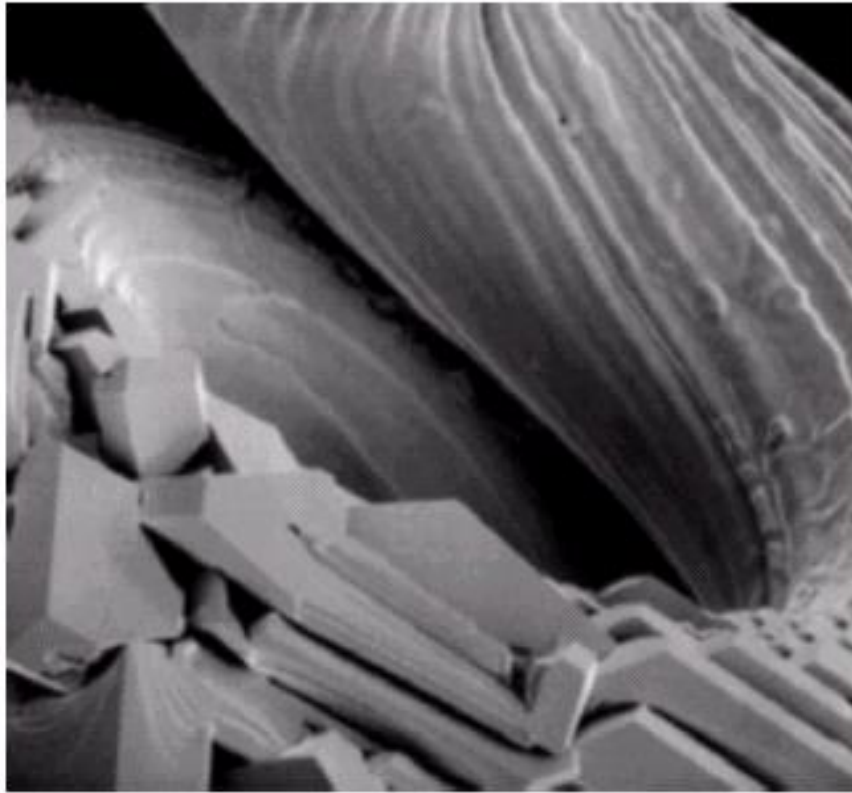
This gives us a new filter which does the whole job for us in one step



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



Simplified Image Enhancement (cont...)



Variants On The Simple Laplacian

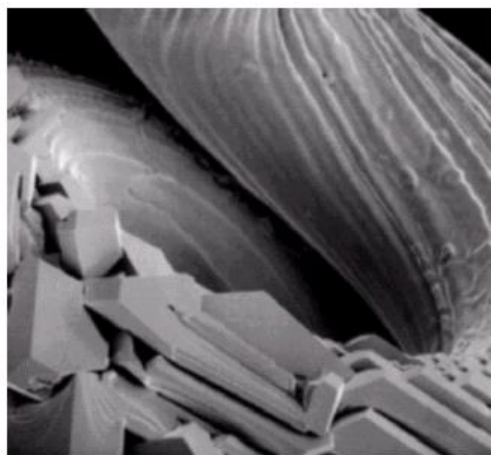
There are lots of slightly different versions of the Laplacian that can be used:

0	1	0
1	-4	1
0	1	0

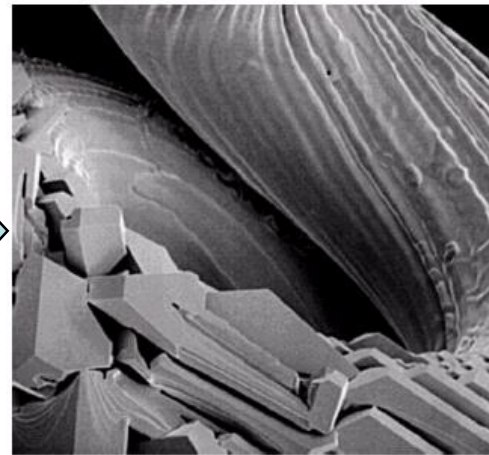
Simple
Laplacian

1	1	1
1	-8	1
1	1	1

Variant of
Laplacian



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



Unsharp masking and high-boost filtering

- *unsharp masking*

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

- *high-boost filtering*

$$f_{hb}(x, y) = Af(x, y) - \bar{f}(x, y)$$

Blurred image



0	-1	0	-1	-1	-1
-1	$A + 4$	-1	-1	$A + 8$	-1
0	-1	0	-1	-1	-1

a b

FIGURE 3.42 The high-boost filtering technique can be implemented with either one of these masks, with $A \geq 1$.

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:

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

1st Derivative Filtering (cont...)

The magnitude of this vector is given by:

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

For practical reasons this can be simplified as:

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

1st Derivative Filtering (cont...)

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

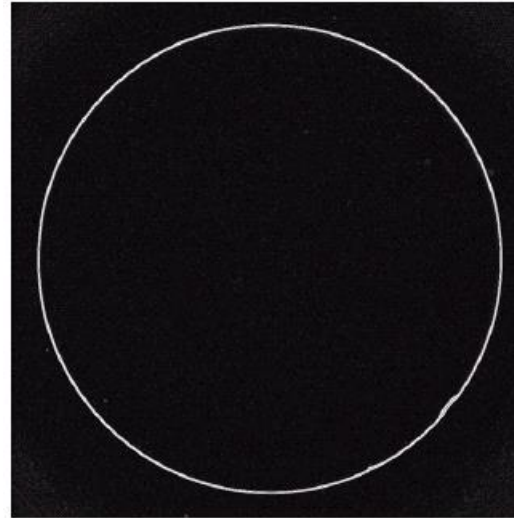
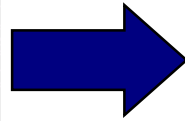
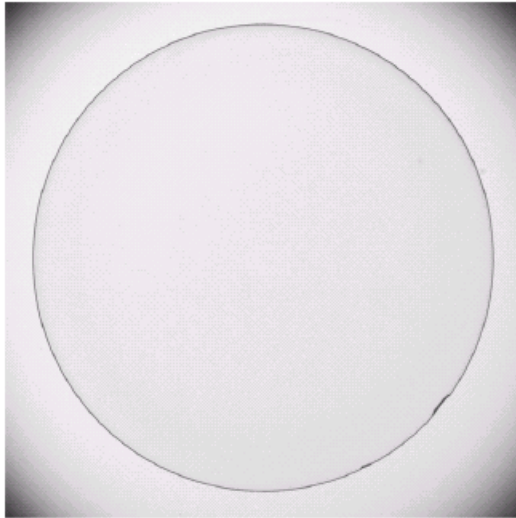
Based on the previous equations we can derive the *Sobel Operators*

-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 Example



An image of a contact lens which is enhanced in order to make defects (at four and five o'clock in the image) more obvious

Sobel filters are typically used for edge detection

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

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

In this lecture we looked at:

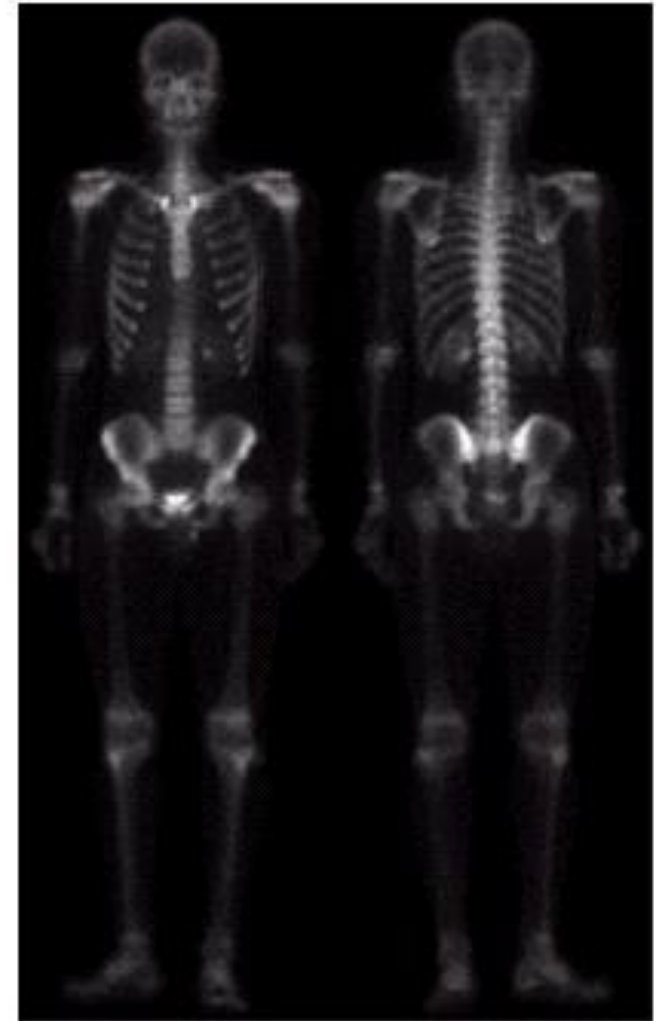
- Sharpening filters
 - 1st derivative filters
 - 2nd derivative filters
- Combining filtering techniques

Combining Spatial Enhancement Methods

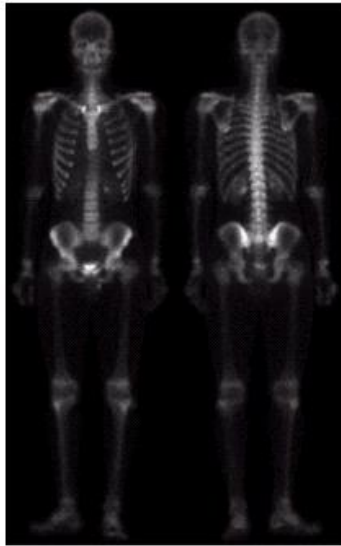
Successful image enhancement is typically not achieved using a single operation

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

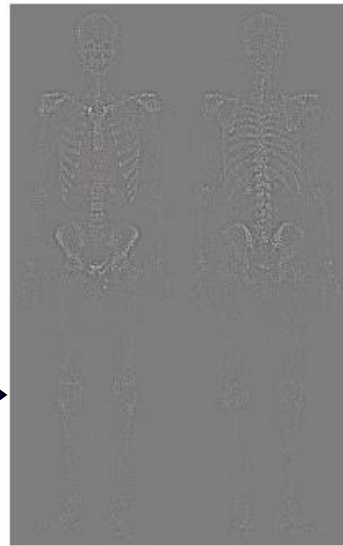


Combining Spatial Enhancement Methods (cont...)



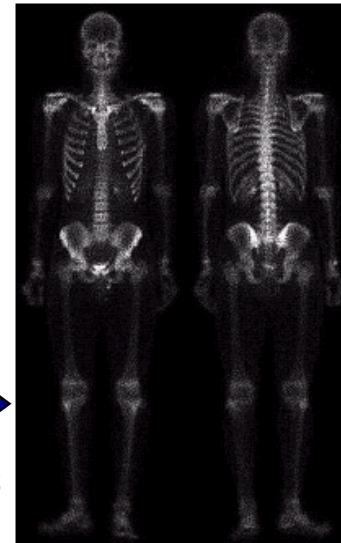
(a)

Laplacian filter of
bone scan (a)



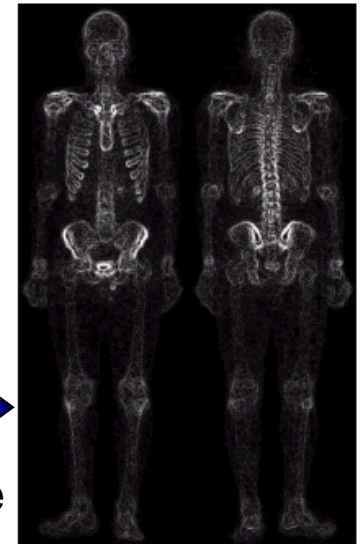
(b)

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



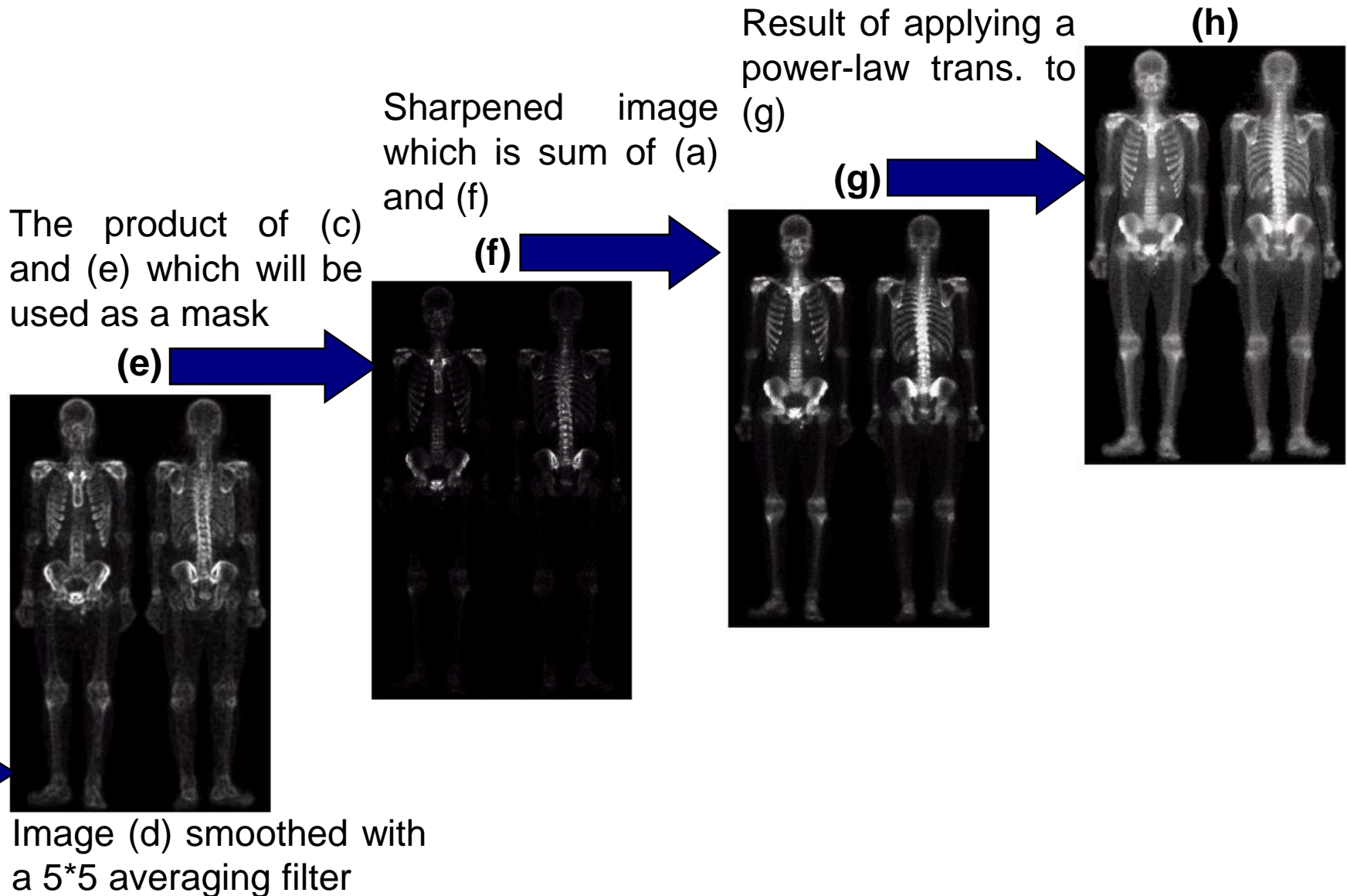
(c)

Sobel filter of bone
scan (a)



(d)

Combining Spatial Enhancement Methods (cont...)



Combining Spatial Enhancement Methods (cont...)

Compare the original and final images

