Digital Image Processing

Image Enhancement
(Spatial Filtering 1)

Contents

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

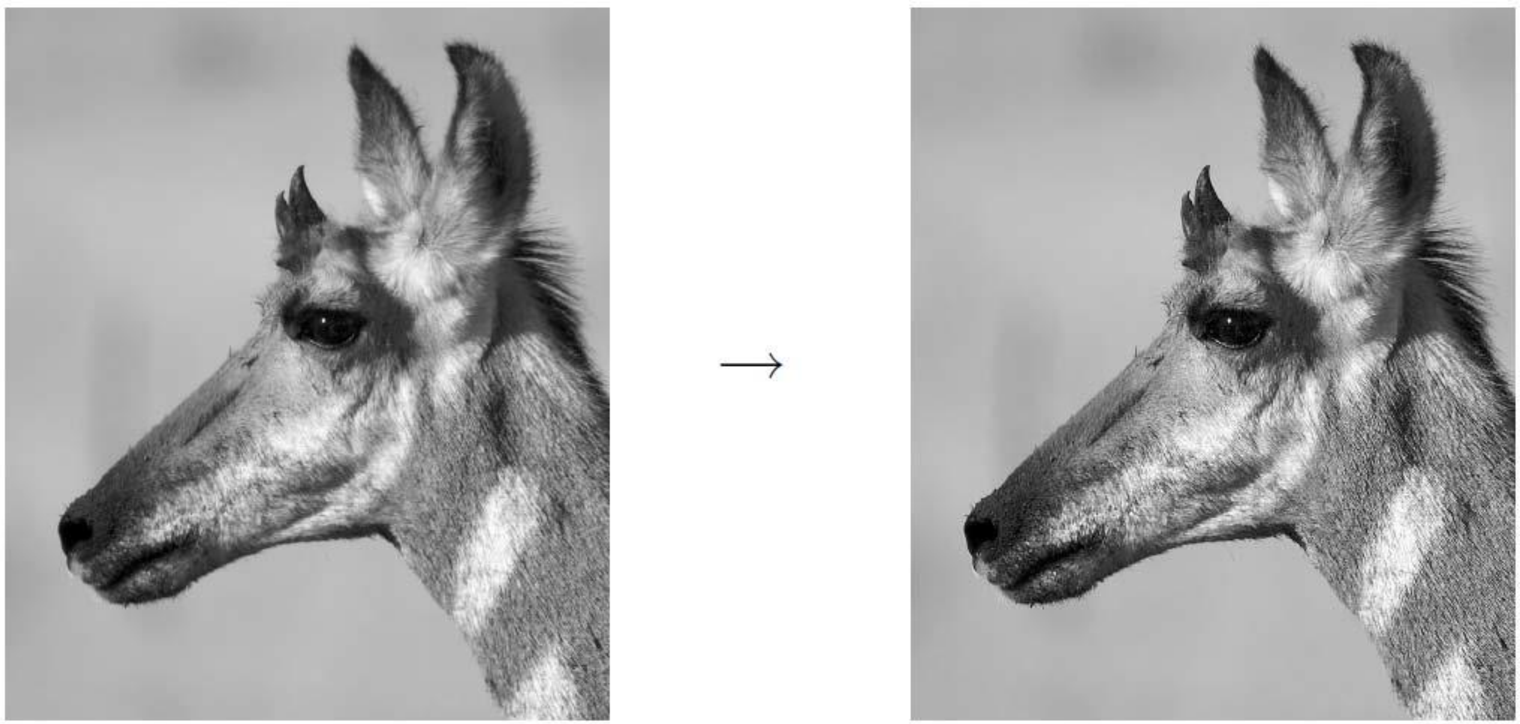
What is a Filter?

- Capabilities of point operations are limited
- **Filters:** combine **pixel's value + values of neighbours**
- **E.g. blurring:** Compute average intensity of block of pixelsCorrelation and convolution

- Combining multiple pixels needed for certain operations:
- Blurring, Smoothing
- Sharpening

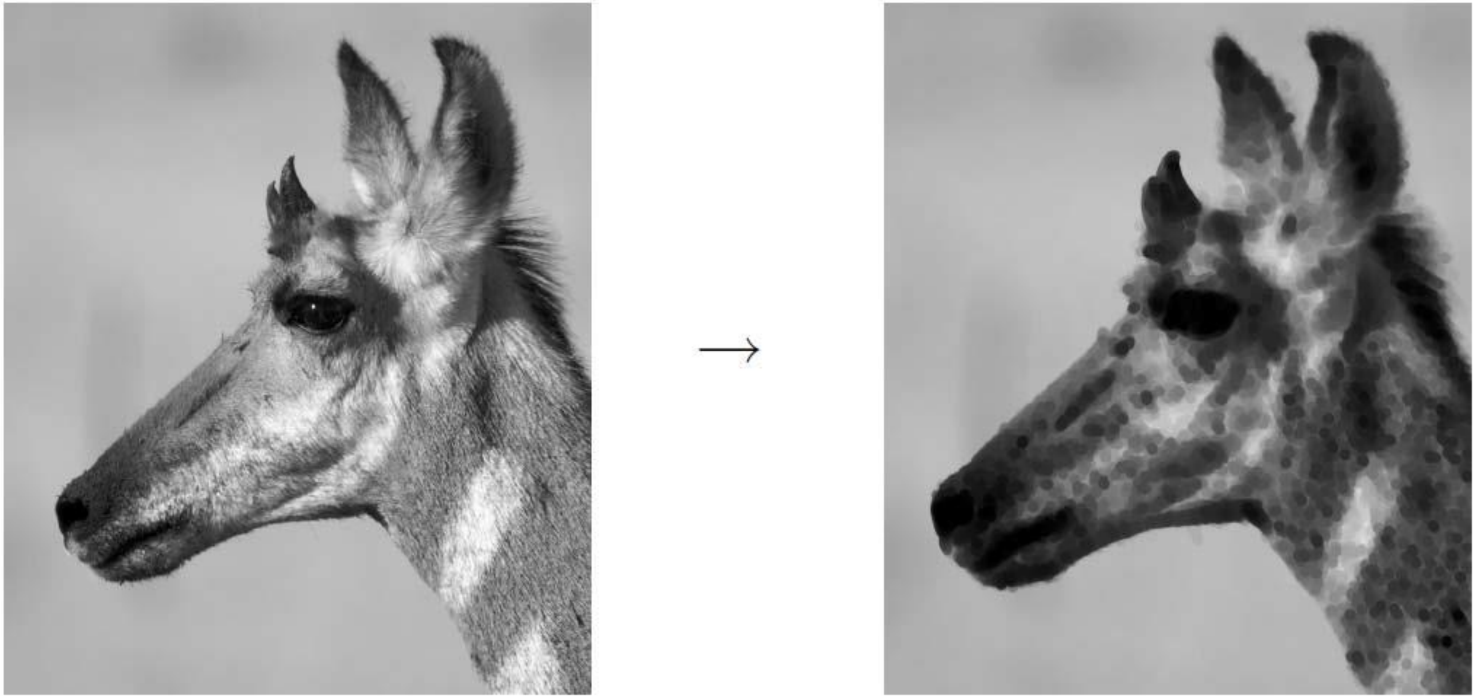
What Point Operations Can't Do

- Example: sharpening



What Point Operations Can't Do

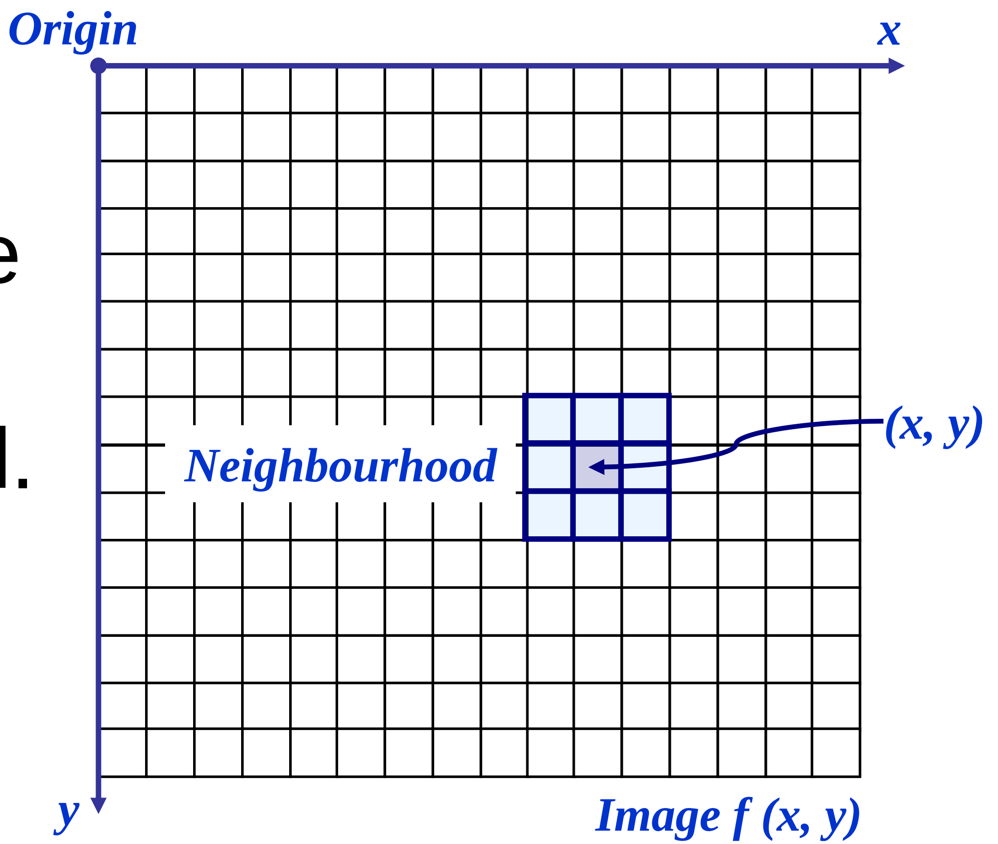
- Other cool artistic patterns by combining pixels



Neighbourhood Operations

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

- Neighbourhoods are mostly a rectangle around a central pixel.



Filter Parameters

- Many possible filter parameters (size, weights, function, etc)
- **Filter size (size of neighbourhood):**
  3x3, 5x5, 7x7, …,21x21,..
- **Filter shape:** not necessarily square. Can be rectangle, circle, etc
- **Filter weights:** May apply unequal weighting to different pixels
- **Filters function:** can be linear (a weighted summation) or nonlinear

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

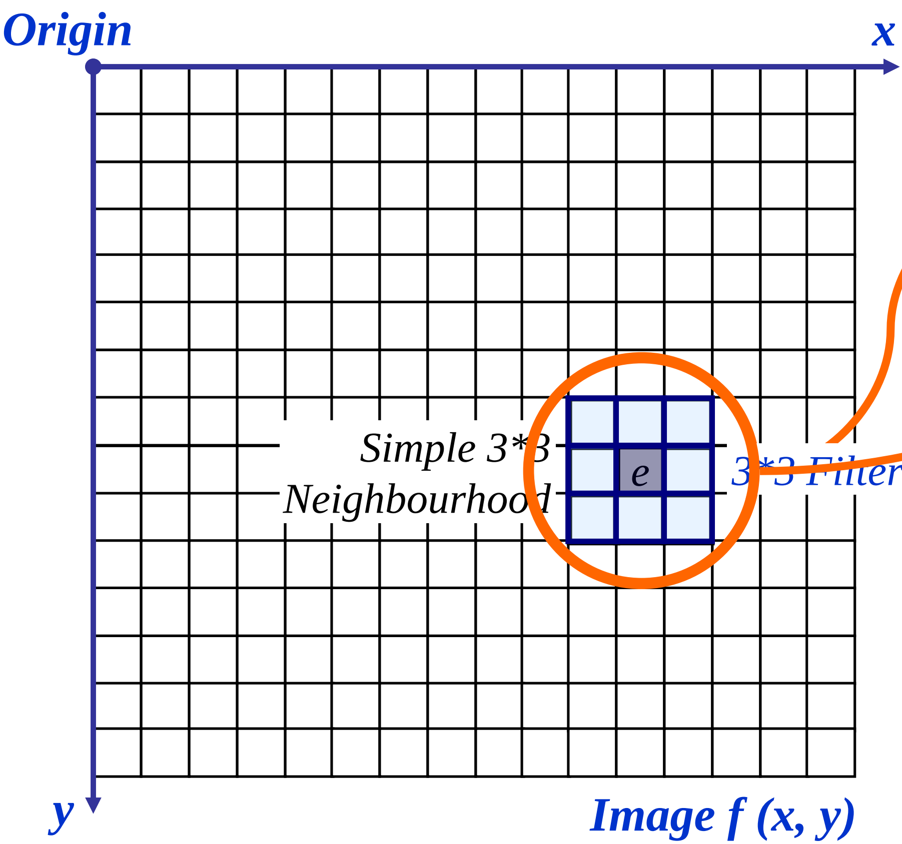
Simple Neighbourhood Operations Example

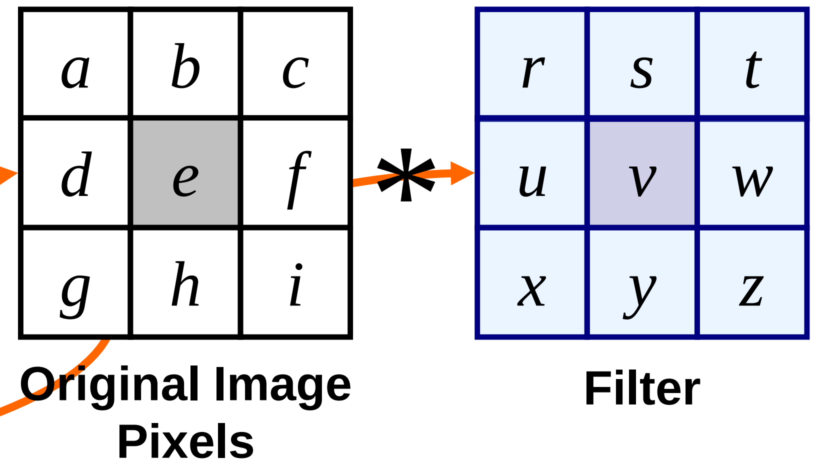
Original Image

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

Enhanced Image

The Spatial Filtering Process

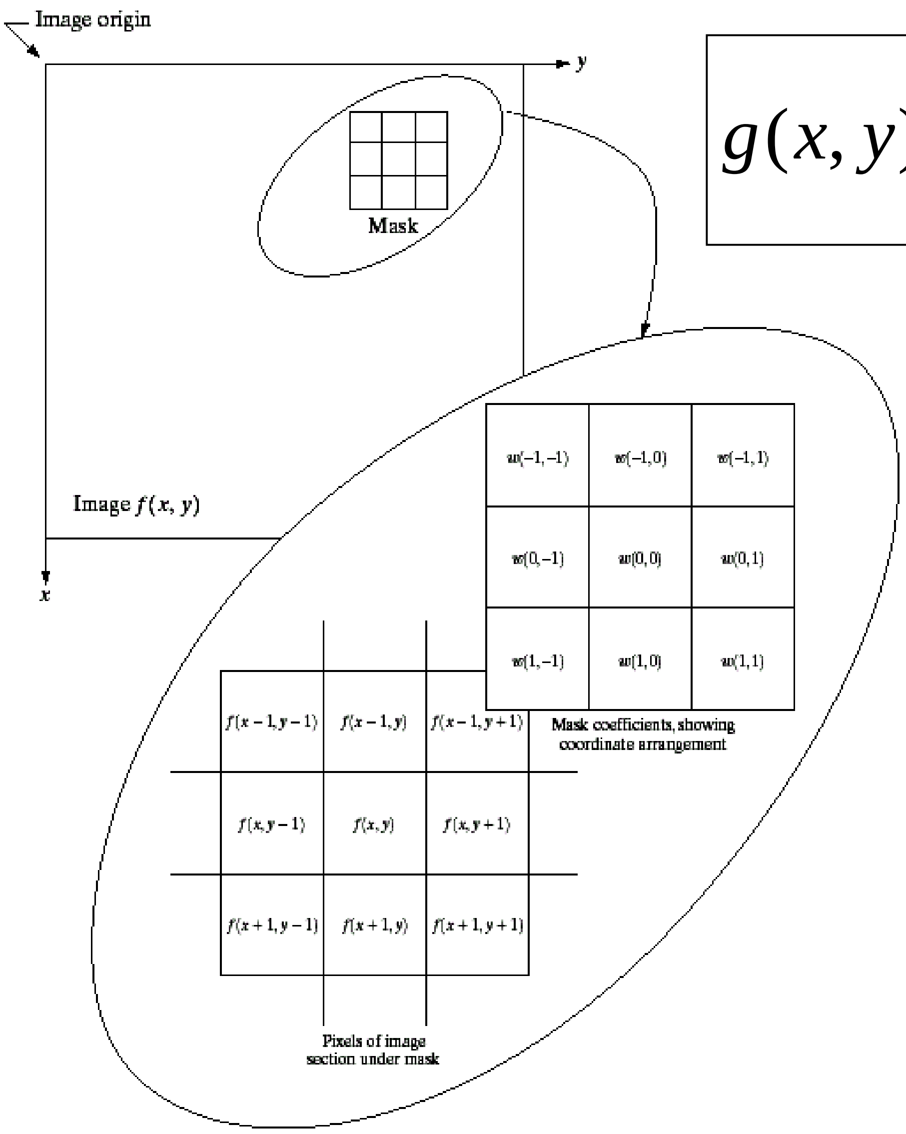




$$e_{processed} = v*e + r*a + s*b + t*c + u*d + w*f + x*g + y*h + z*i$$

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

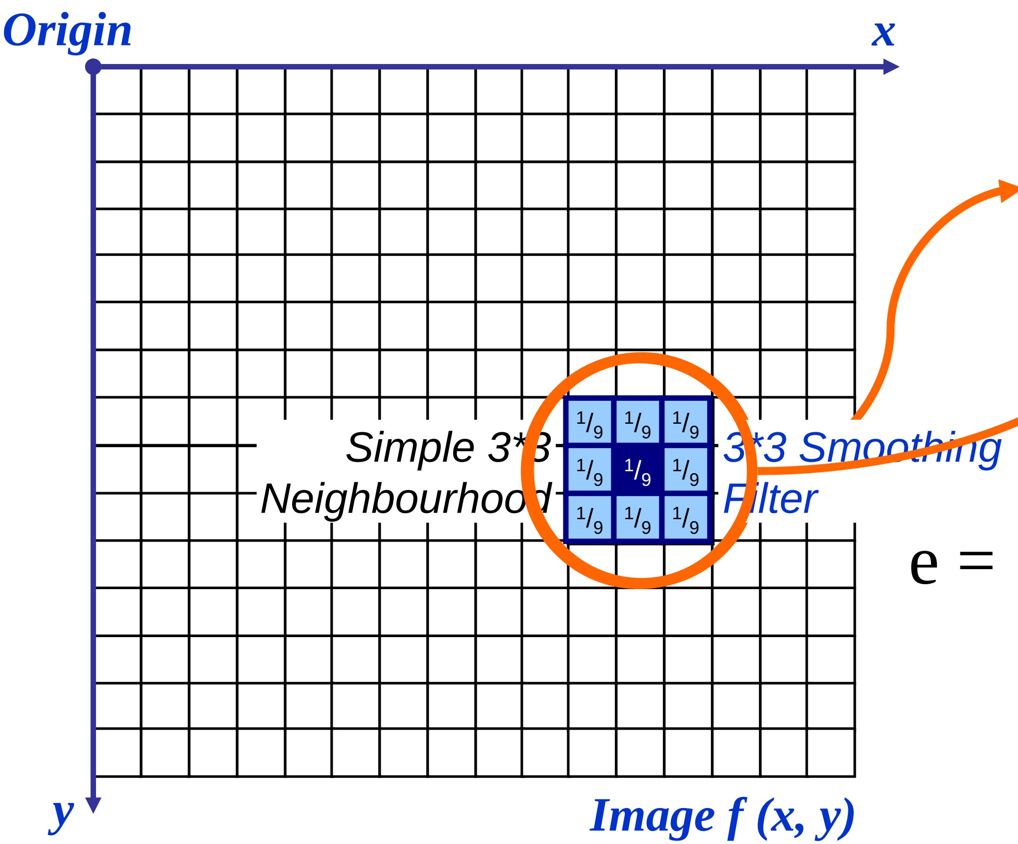
One of the simplest spatial filtering operations we can perform is a smoothing operation

- 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

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

Simple averaging filter

Smoothing Spatial Filtering



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

$$e = {}^1/_9*106 + {}^1/_9*104 + {}^1/_9*100 + {}^1/_9*108 + {}^1/_9*99 + {}^1/_9*98 + {}^1/_9*95 + {}^1/_9*90 + {}^1/_9*85 = 98.3333$$

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

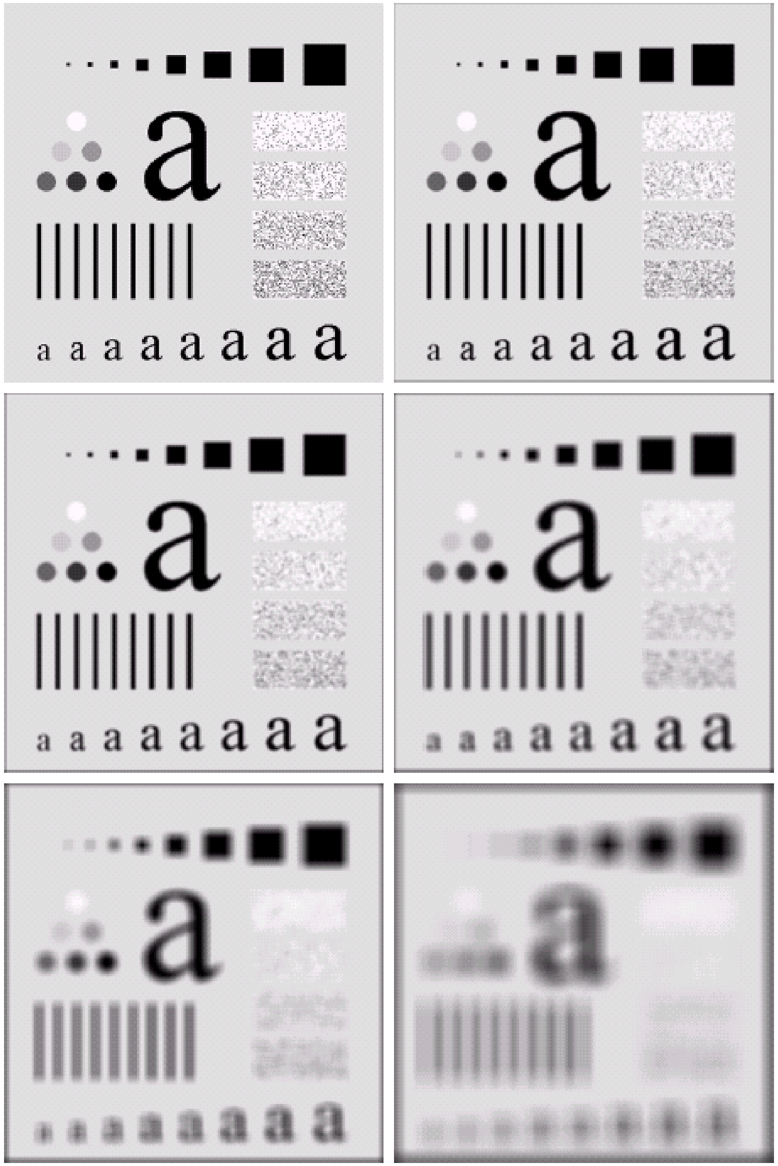


Image Smoothing Example

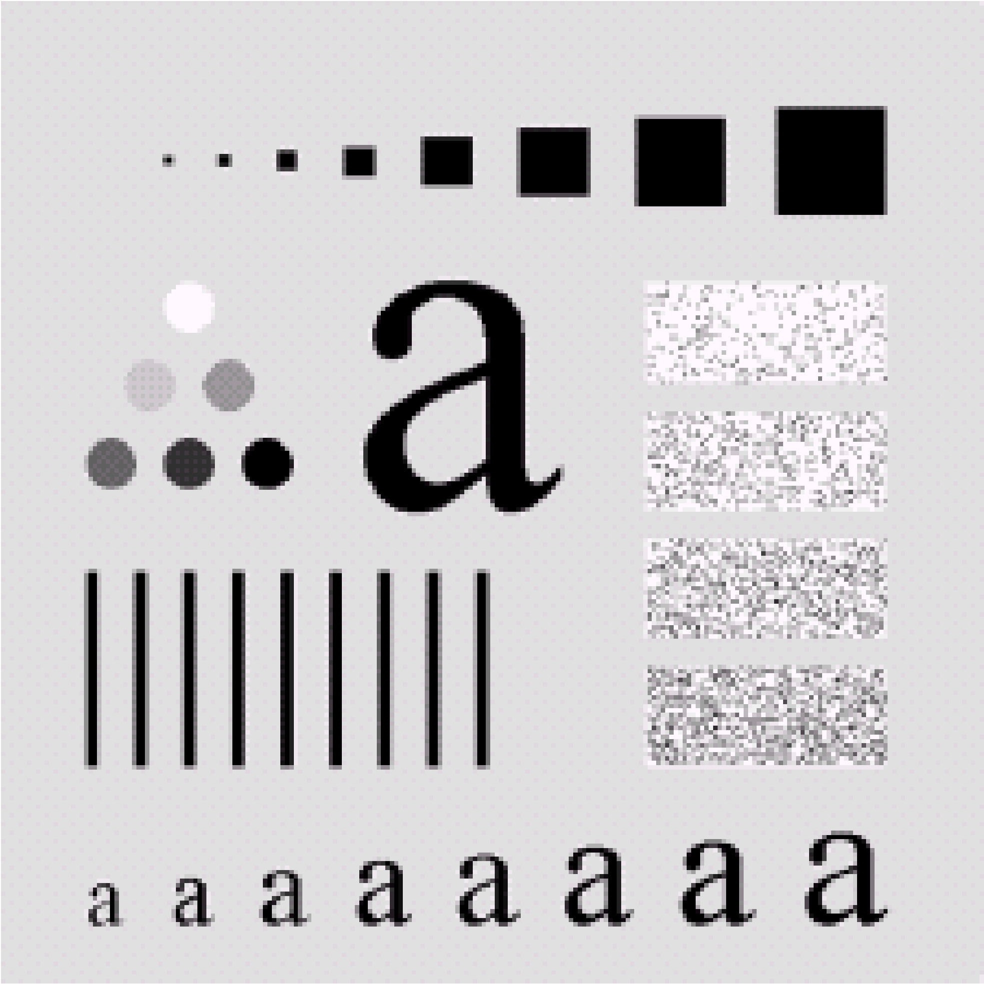


Image Smoothing Example

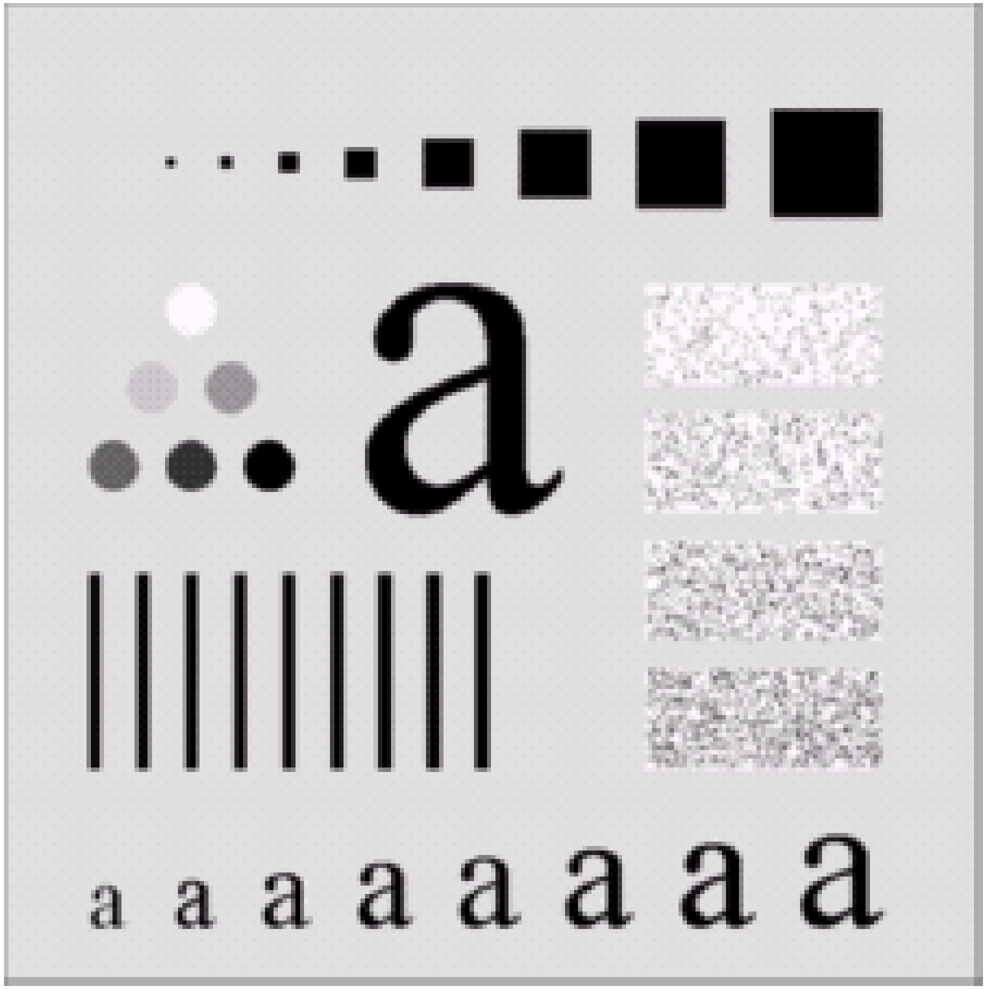


Image Smoothing Example

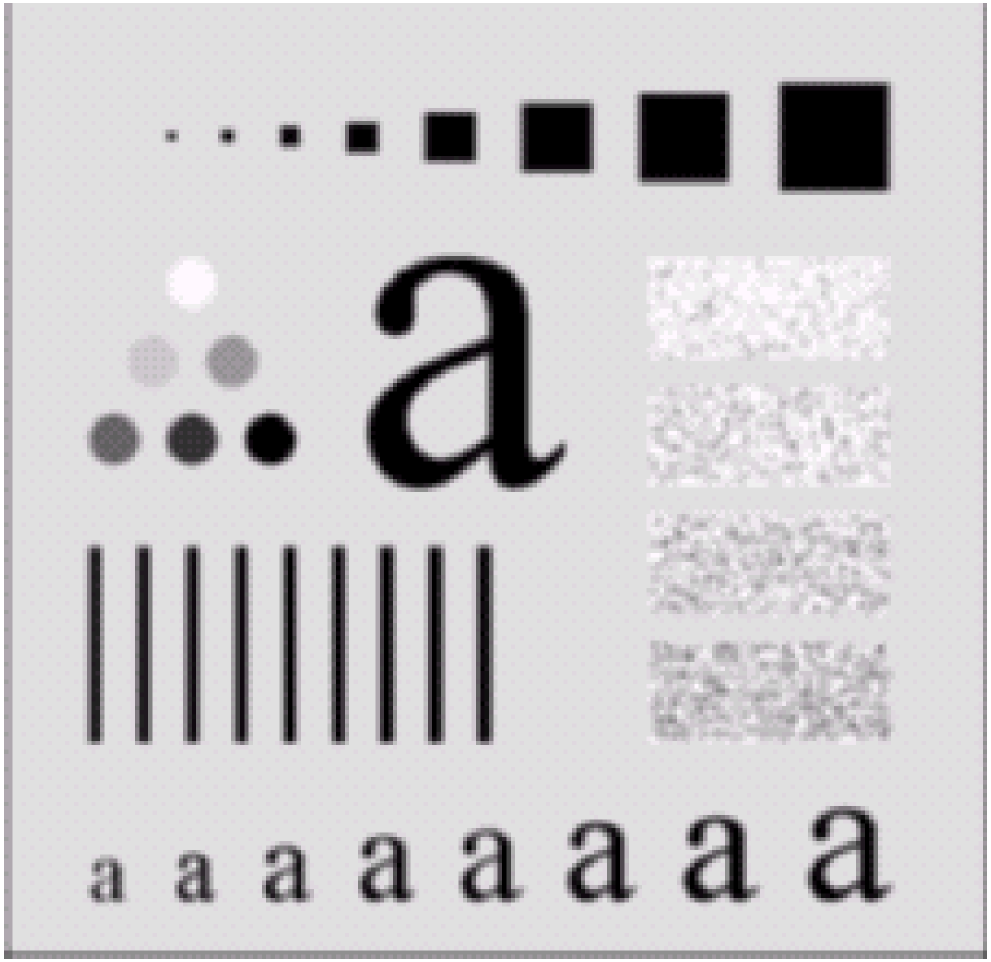


Image Smoothing Example

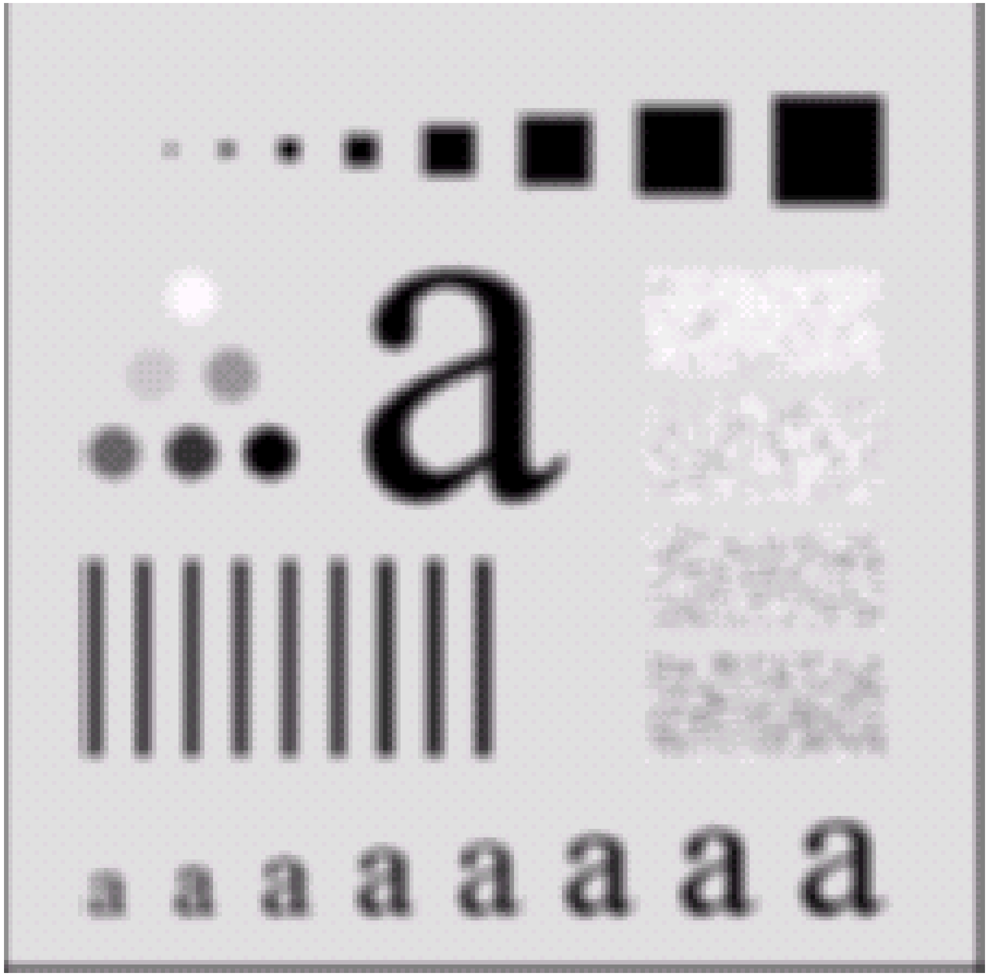


Image Smoothing Example

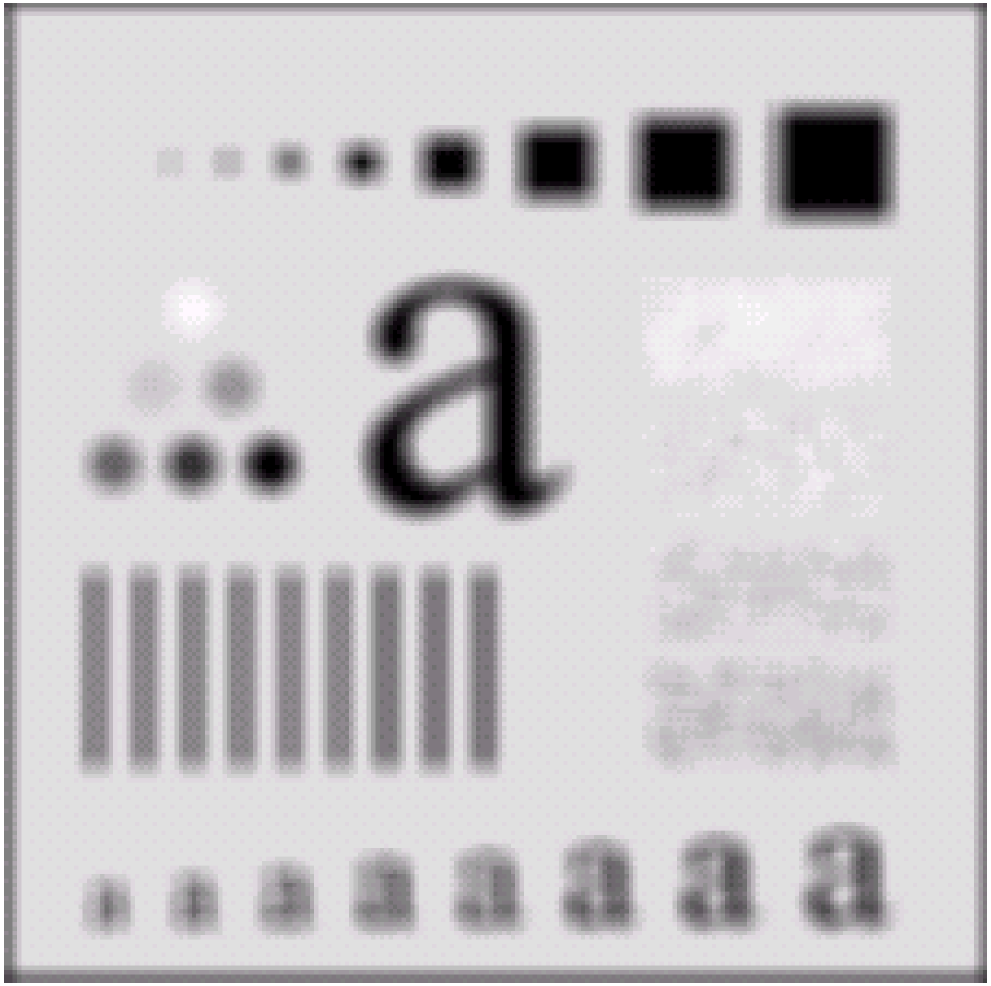


Image Smoothing Example

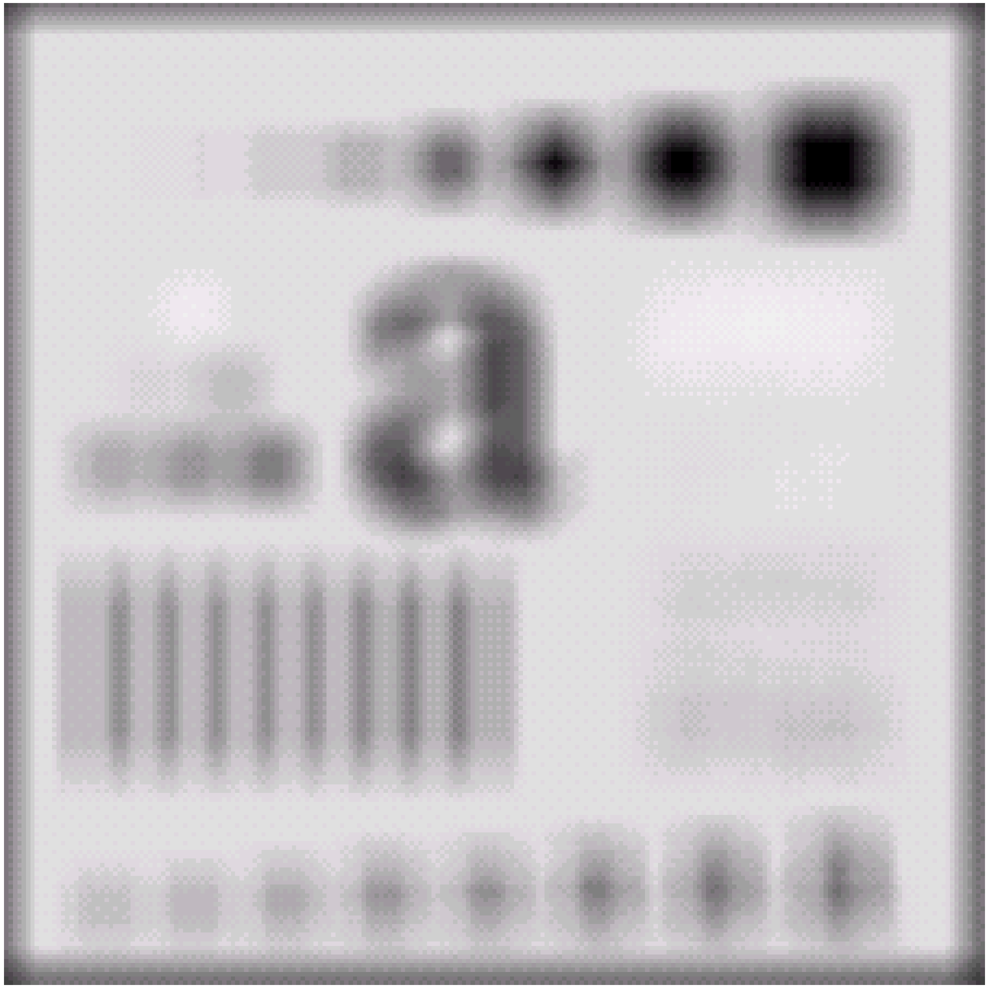
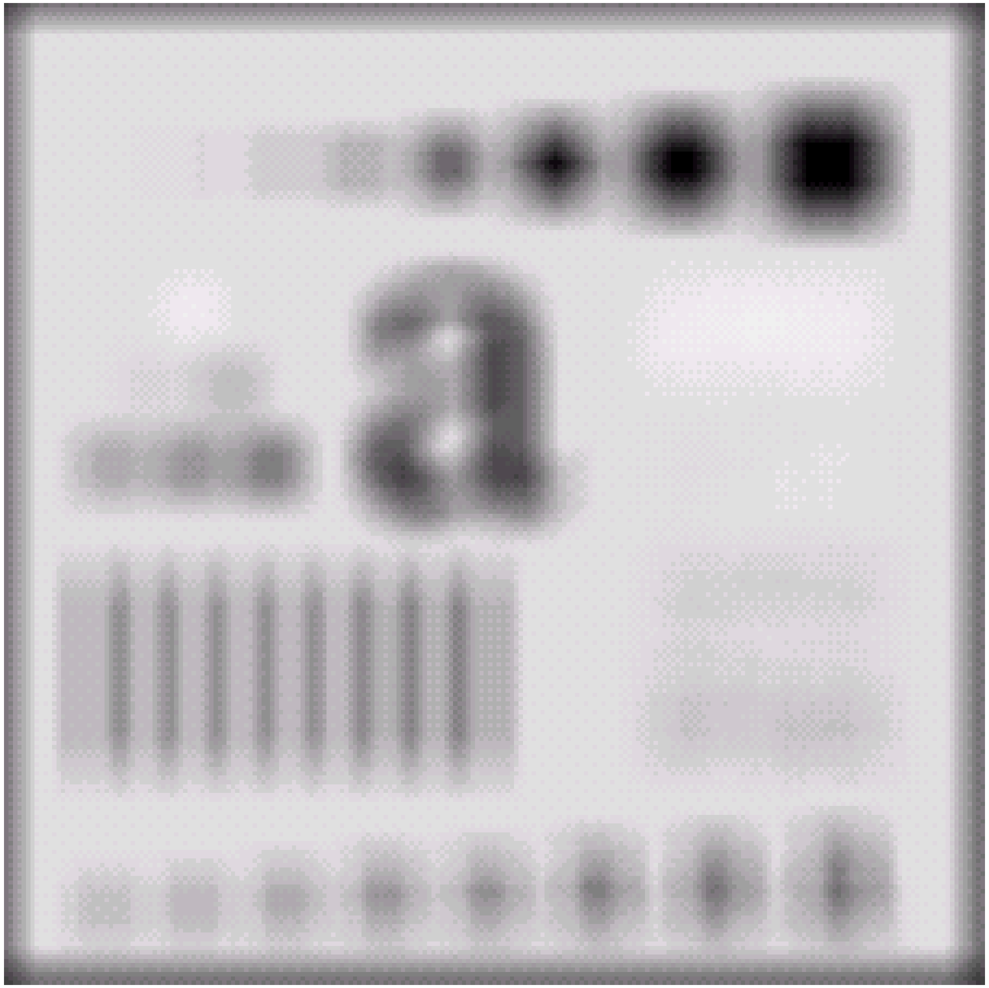


Image Smoothing Example



Weighted Smoothing Filters

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

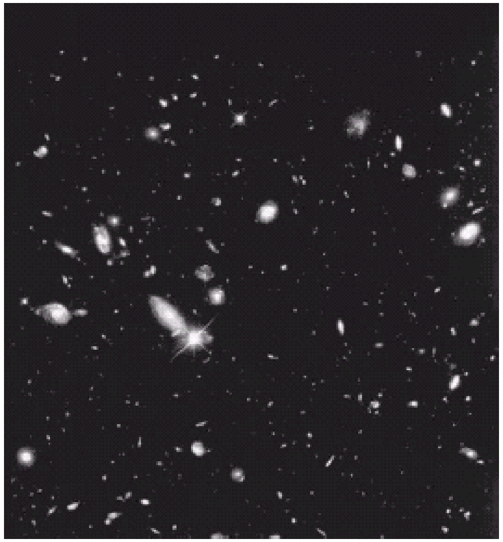
- Pixels closer to the central pixel are more important
- Often referred to as a *weighted averaging*

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

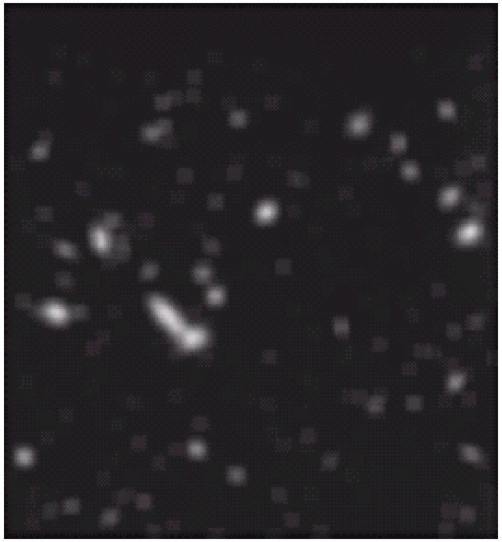
Weighted averaging filter

Another Smoothing Example

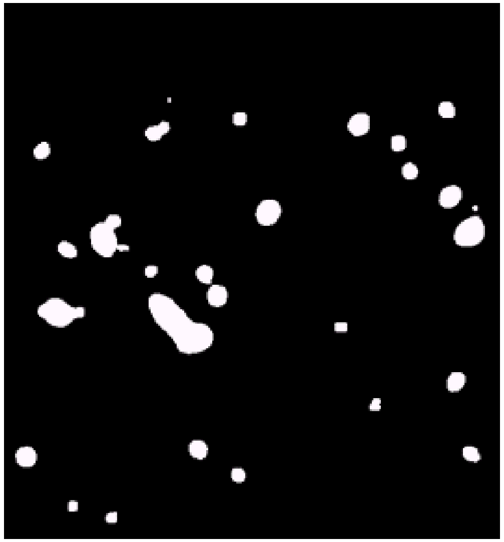
By smoothing the original image we get rid of lots of the finer detail which leaves only the gross features for thresholding



Original Image



Smoothed Image



Thresholded Image

The Filter Matrix

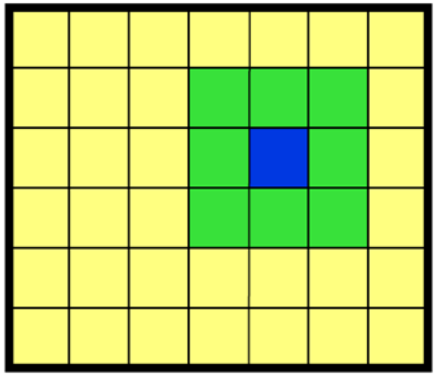
$$I'(u,v) \leftarrow \frac{p_0 + p_1 + p_2 + p_3 + p_4 + p_5 + p_6 + p_7 + p_8}{9}$$

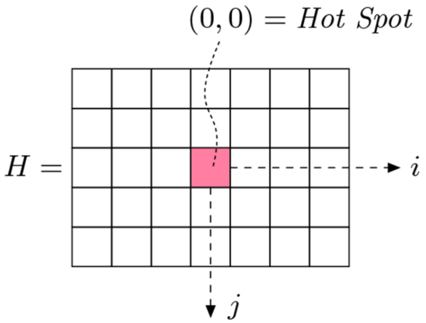
$$\begin{aligned} I'(u,v) \leftarrow \tfrac{1}{9} \cdot [\, & I(u-1,v-1) + I(u,v-1) + I(u+1,v-1) + \\ & I(u-1,v) + I(u,v) + I(u+1,v) + \\ & I(u-1,v+1) + I(u,v+1) + I(u+1,v+1) \,] \end{aligned}$$

$$H(i,j) = \begin{bmatrix} 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

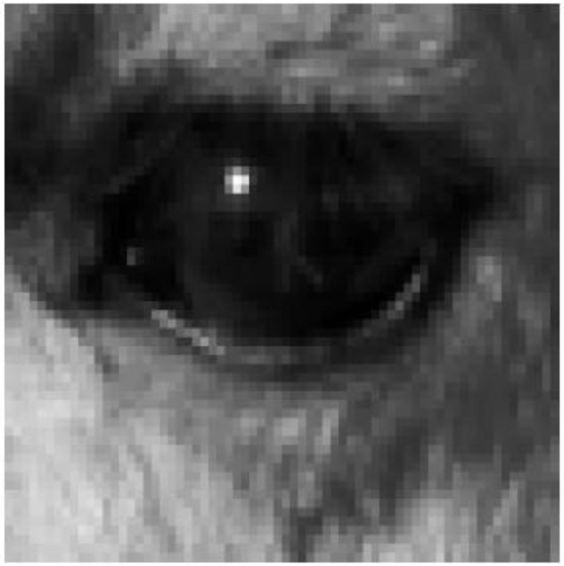
Filter operation can be expressed as a matrix
Example: averaging filter

Filter matrix also called
filter mask ***H(i,j)***

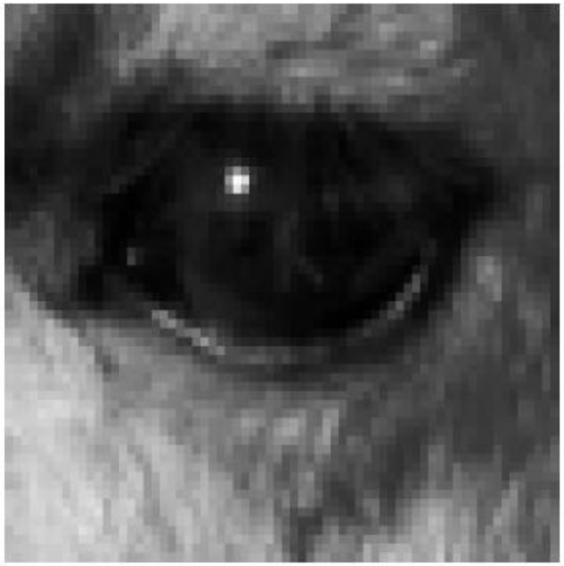




Example: What does this Filter Do?

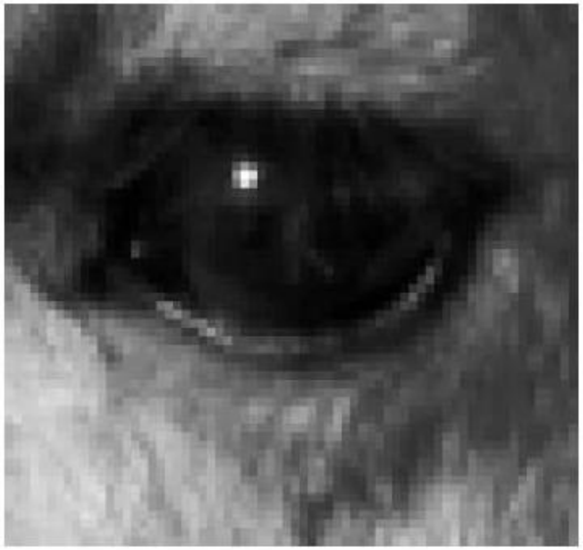


0	0	0
0	1	0
0	0	0

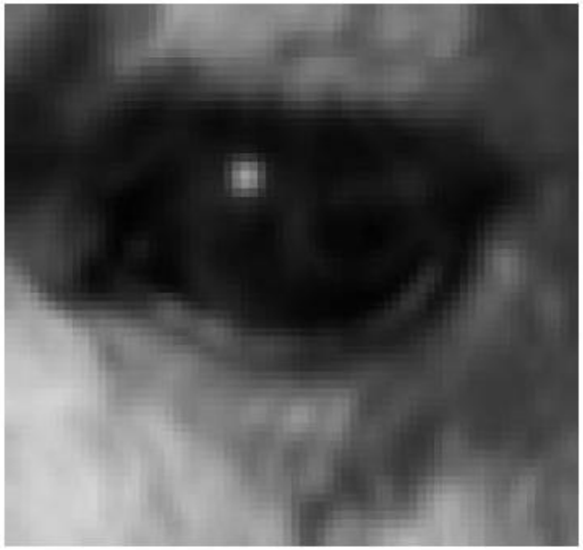


Identity function (leaves image alone)

Example: What does this Filter Do?



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



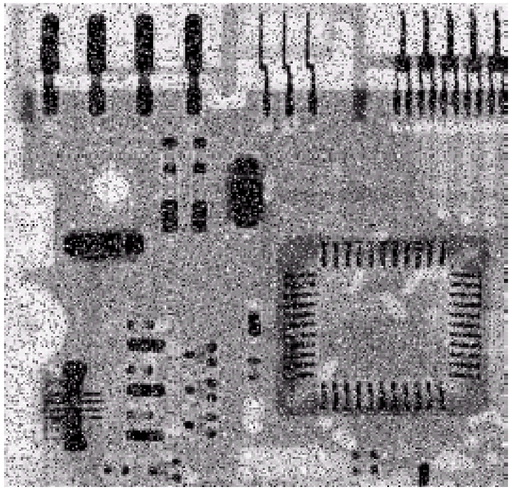
Mean (averages neighbourhood)

Mean Filters: Effect of Filter Size




Original 7×7 15×15 41×41

Averaging Filter Vs. Median Filter Example



Original Image With Noise

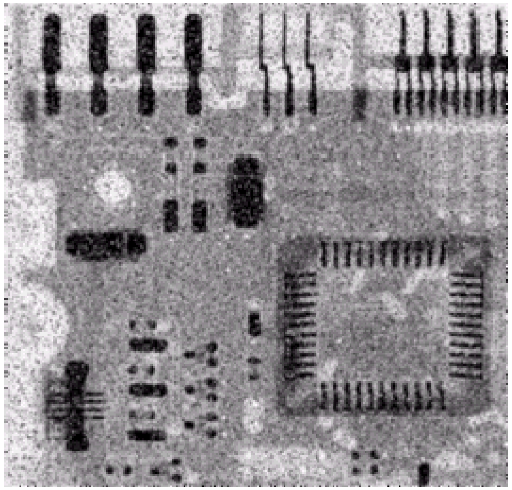


Image After Averaging Filter

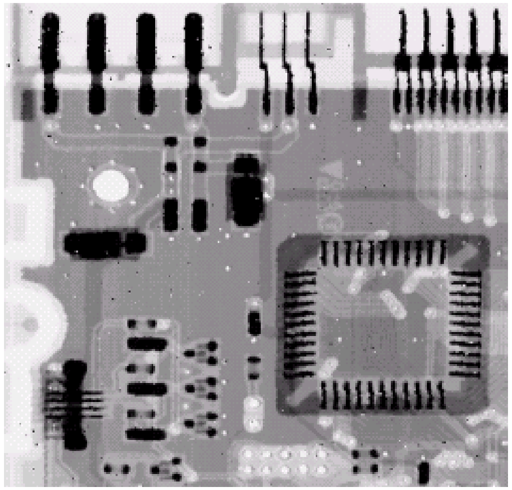
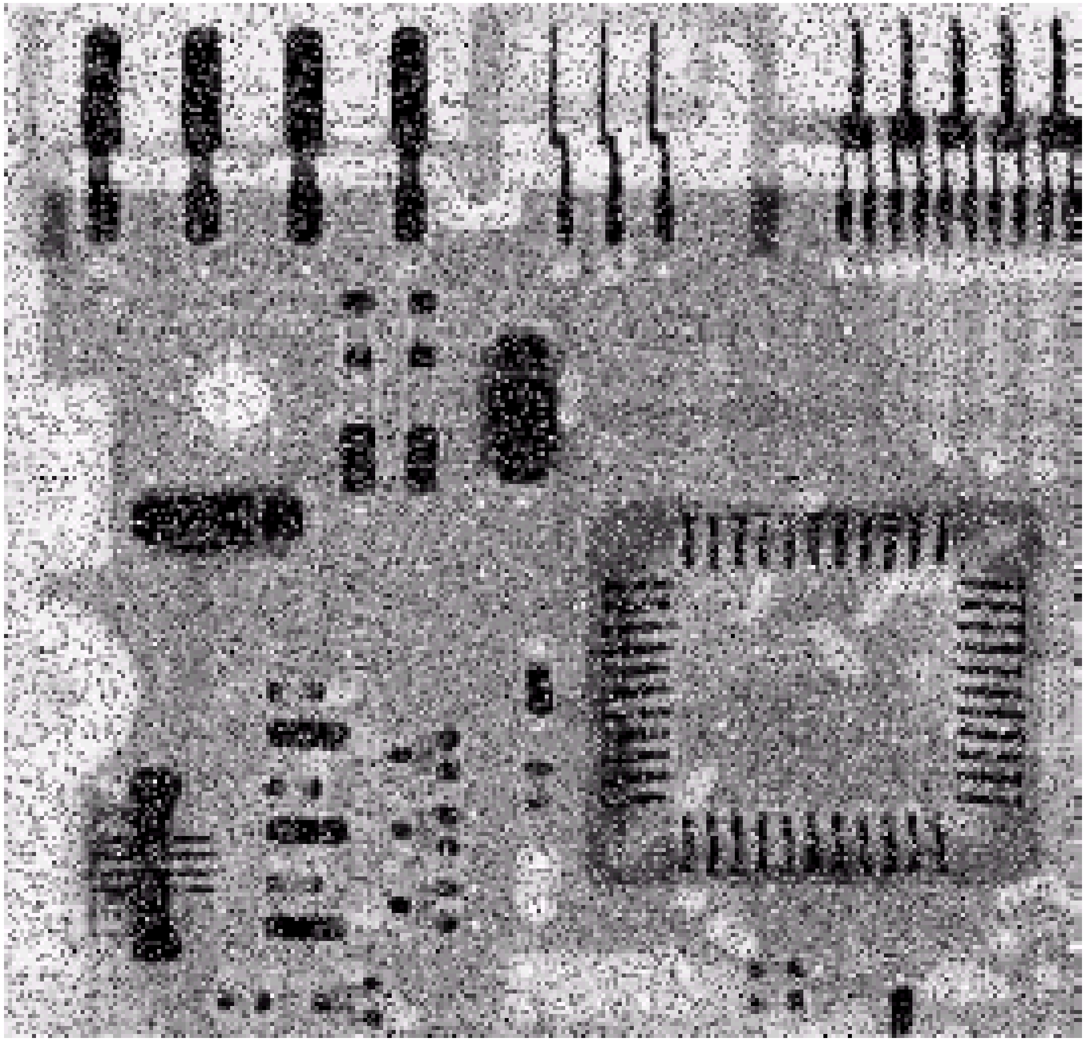


Image After Median Filter

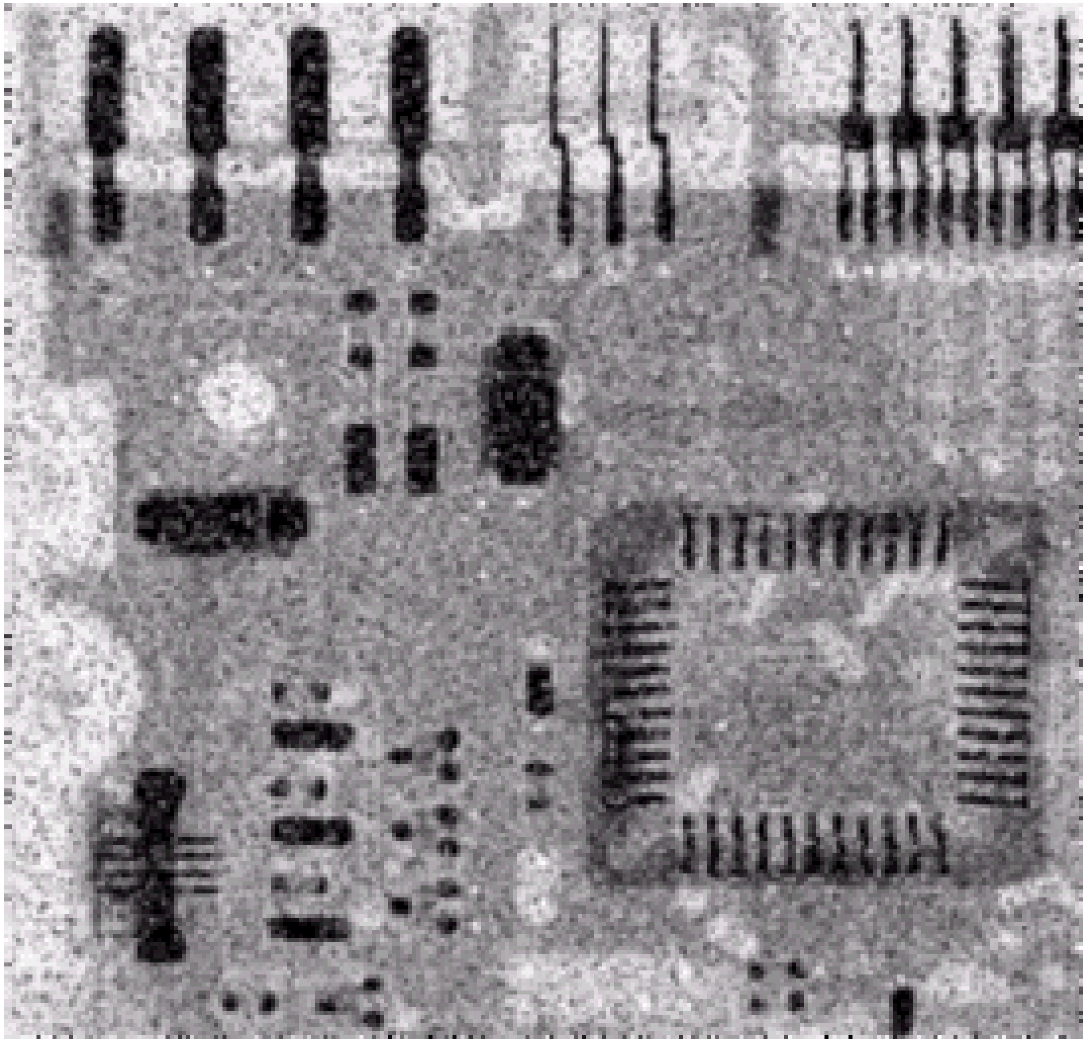
Filtering is often used to remove noise from images

Sometimes a median filter works better than an averaging filter

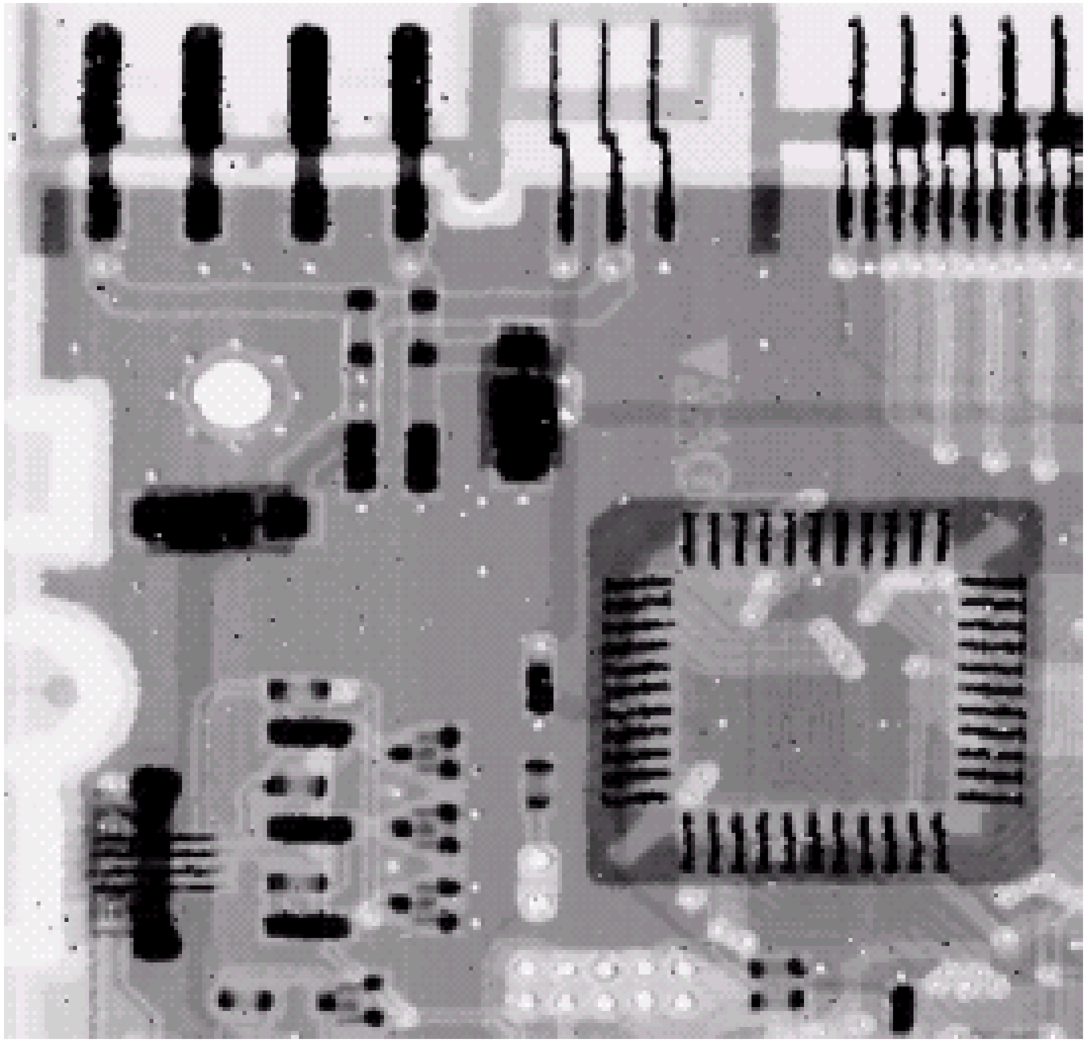
Averaging Filter Vs. Median Filter Example



Averaging Filter Vs. Median Filter Example



Averaging Filter Vs. Median Filter Example

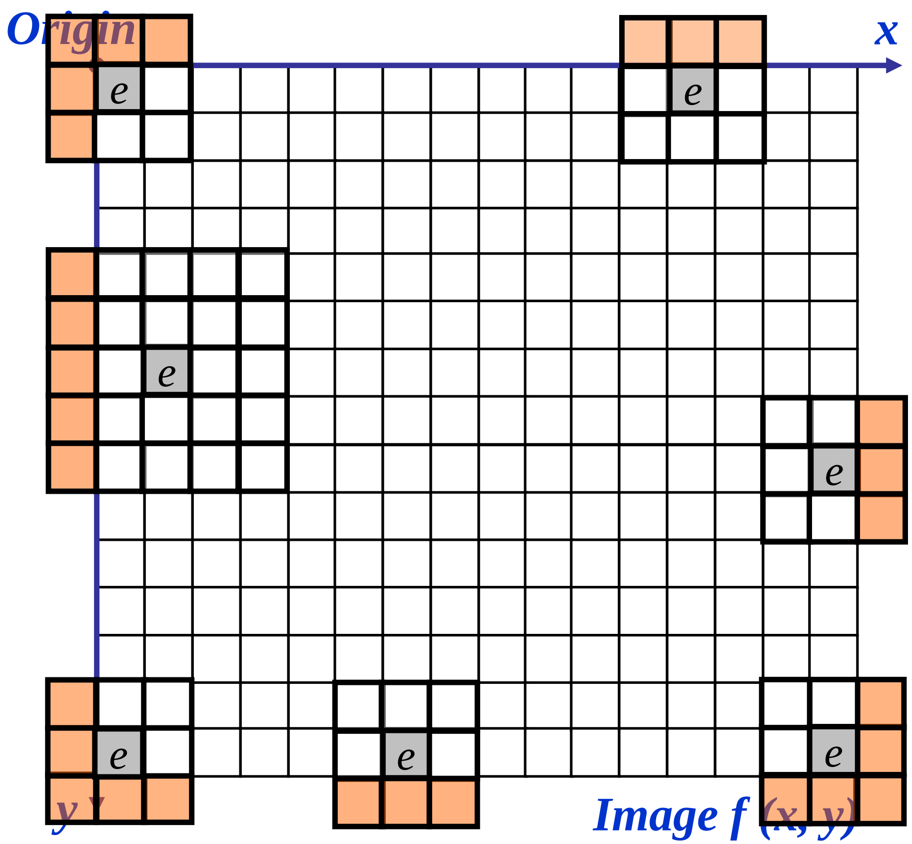


Simple Neighbourhood Operations Example

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



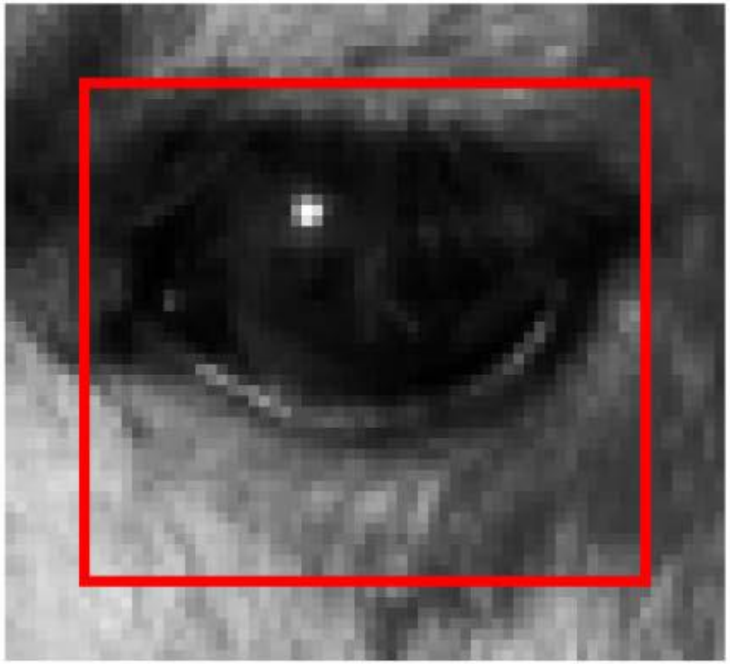
Strange Things Happen At The Edges! (cont…)

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 (Extend)
- Truncate the image (crop)
- Allow pixels *wrap around* the image
  - Can cause some strange image artefacts

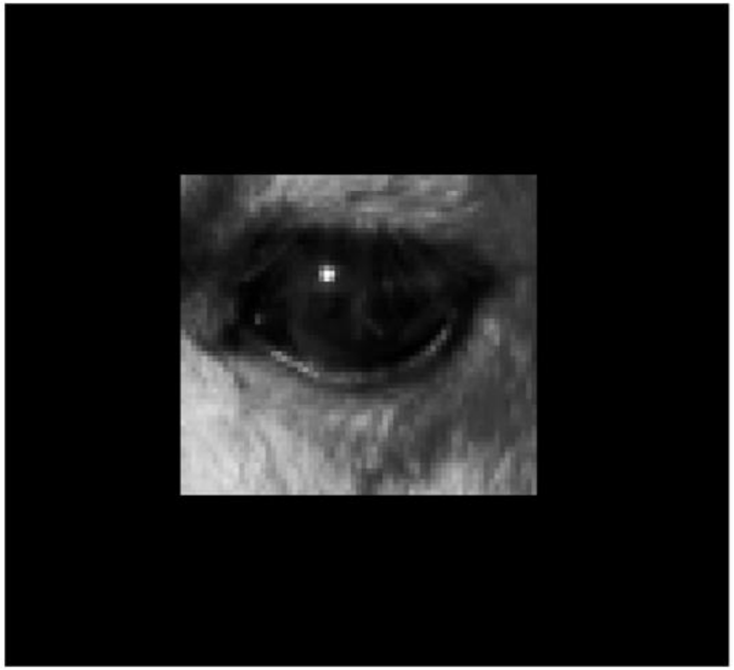
What to do at image boundaries?

Crop



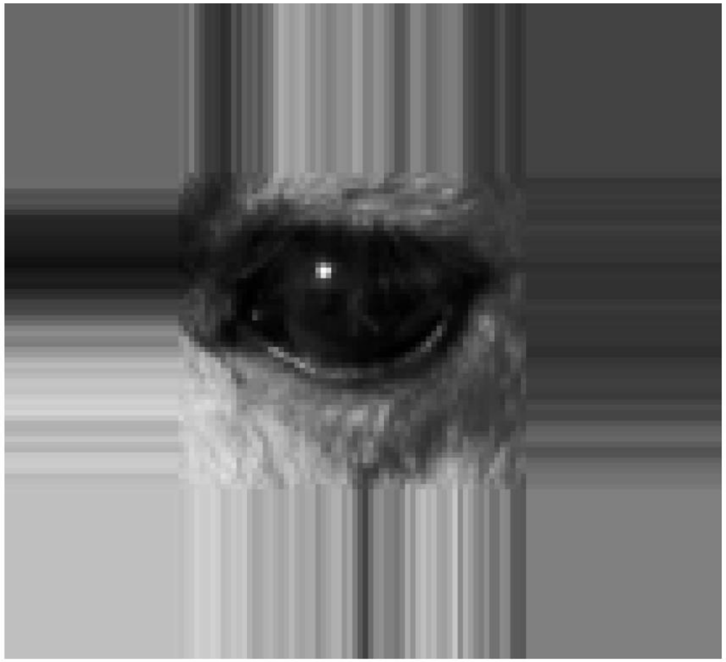
What to do at image boundaries?

Pad



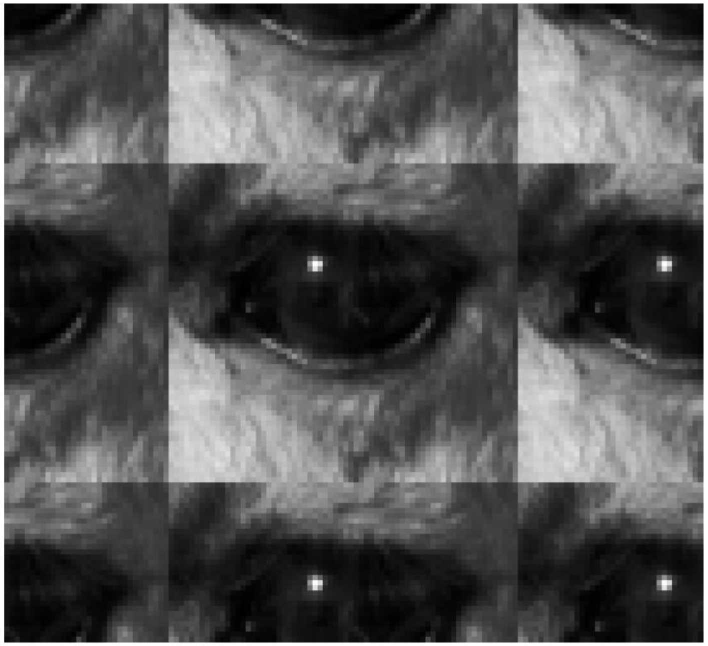
What to do at image boundaries?

Extend



What to do at image boundaries?

Wrap



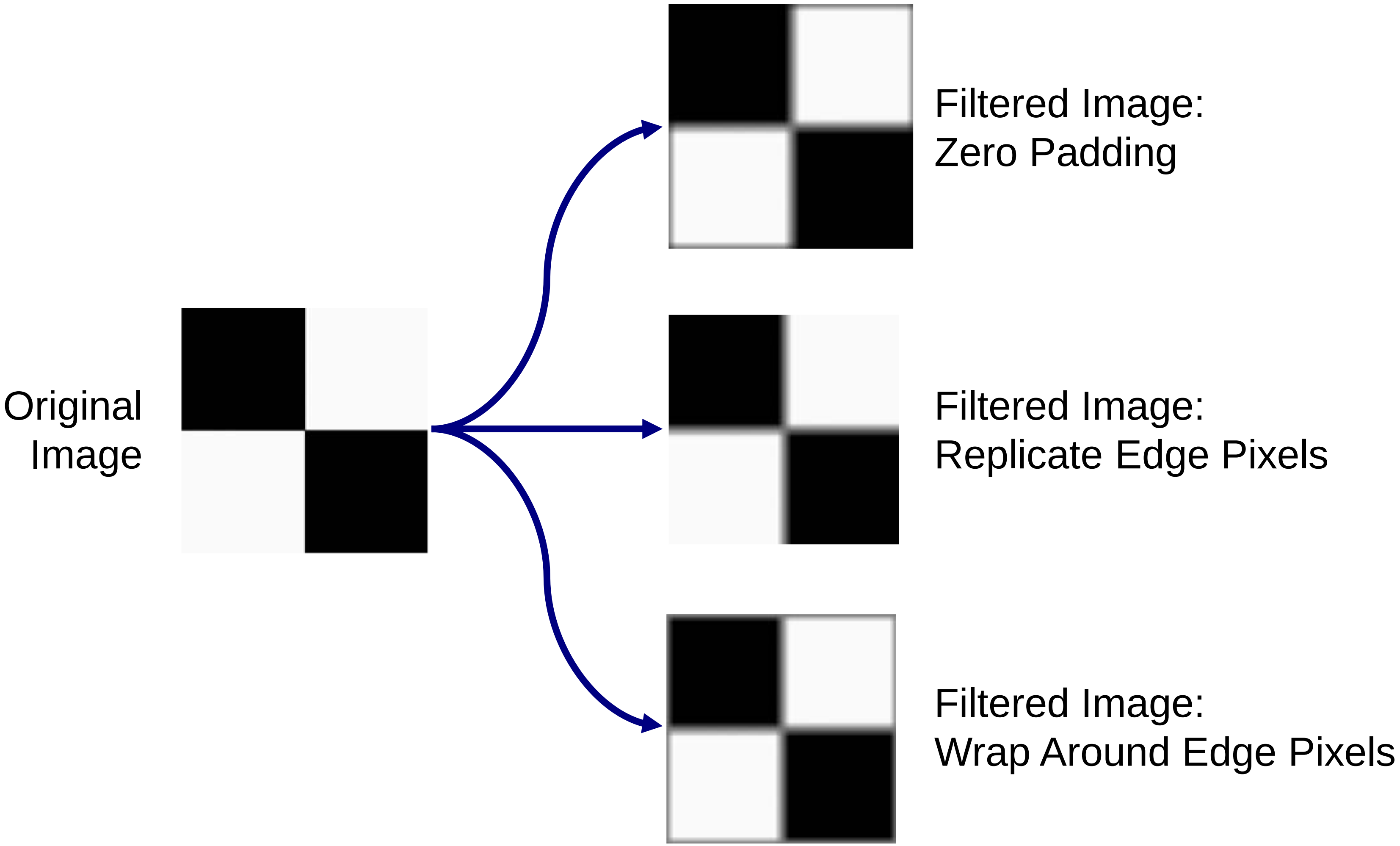
Simple Neighbourhood Operations Example

x

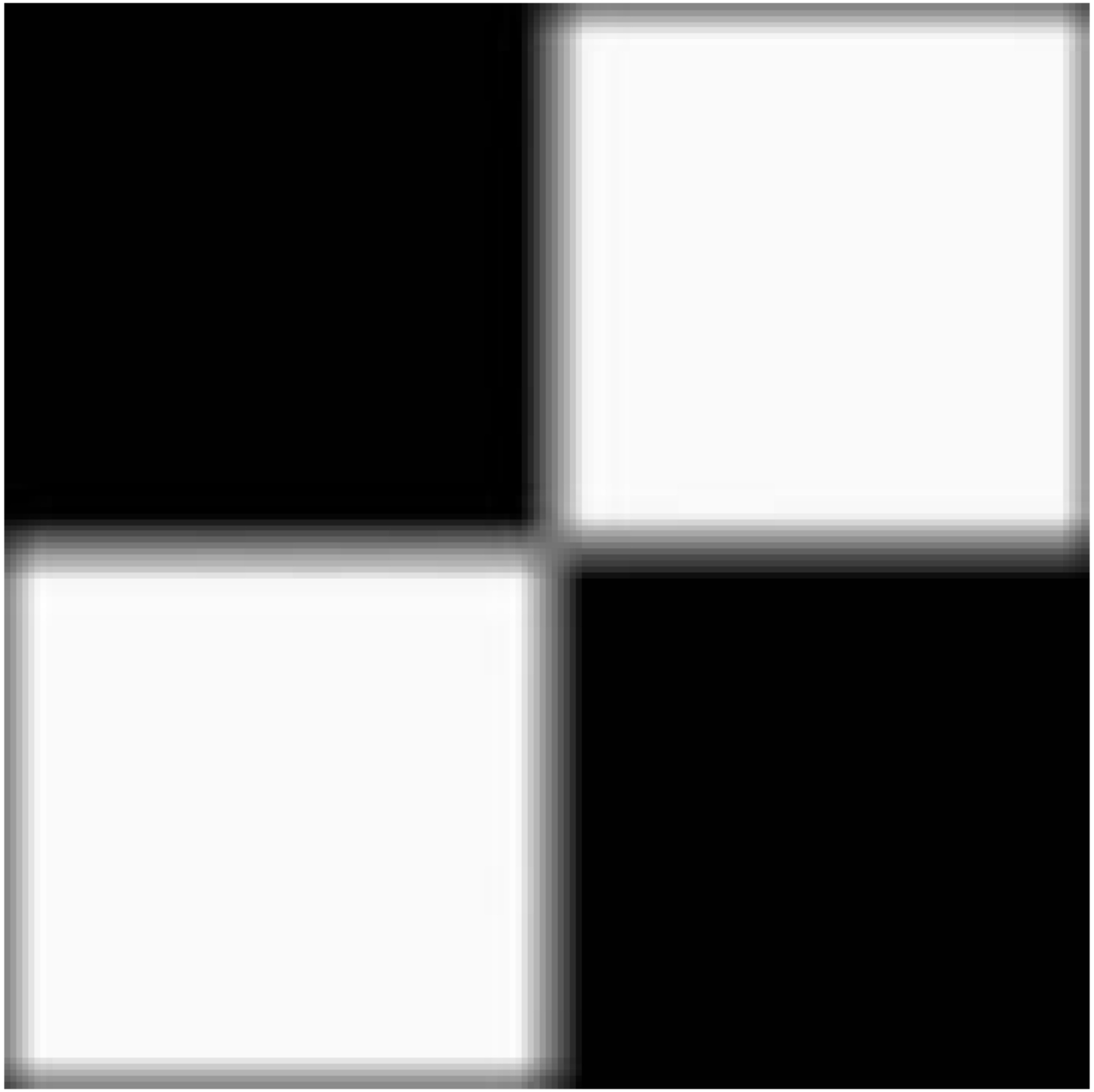
123	127	128	119	115	130
140	145	148	153	167	172
133	154	183	192	194	191
194	199	207	210	198	195
164	170	175	162	173	151

y

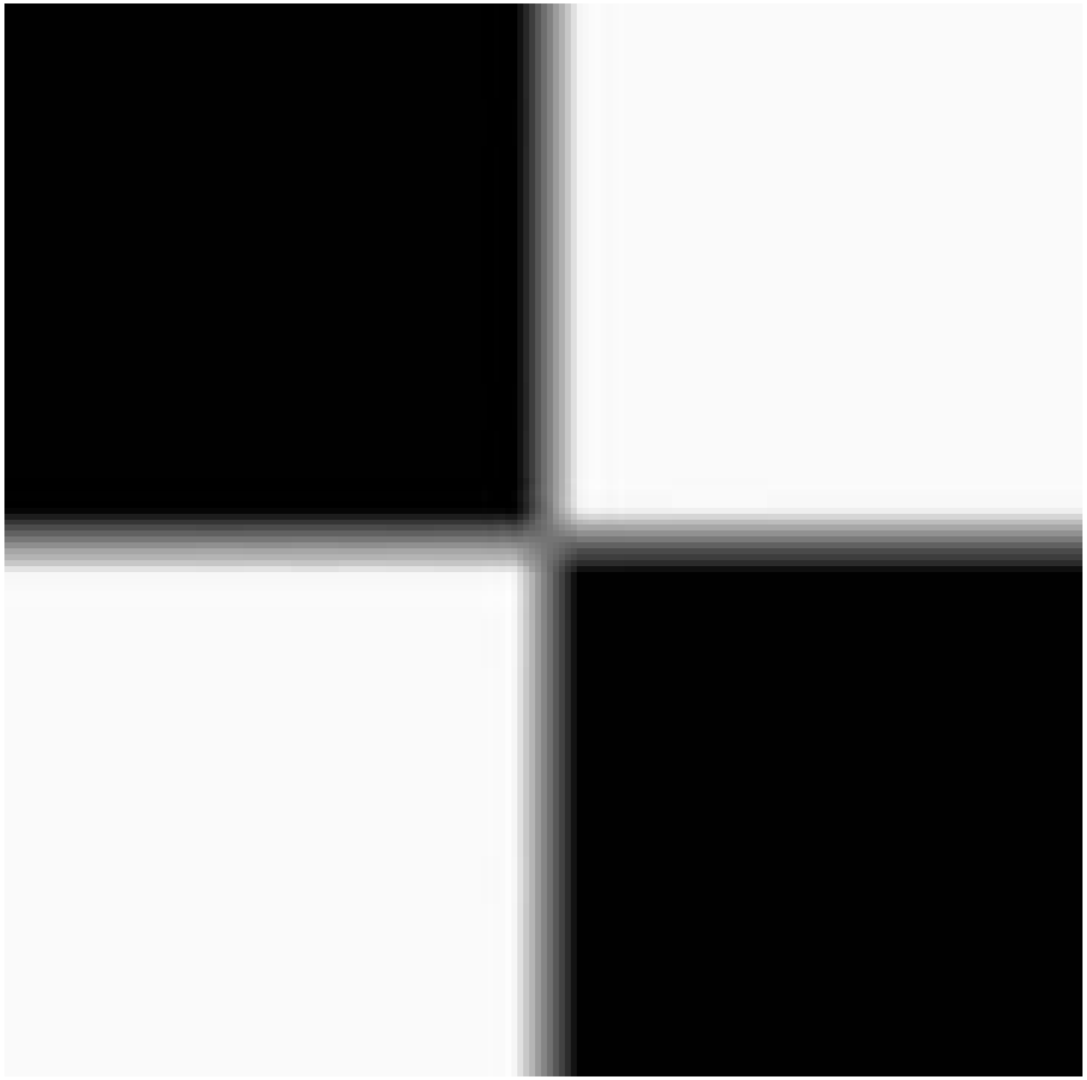
Strange Things Happen At The Edges! (cont…)



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

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

For symmetric filters it makes no difference

Summary

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