

# Digital Image Processing

## **Lecture # 10** **Image Restoration**

# WHAT IS IMAGE RESTORATION?

- The purpose of image restoration is to restore a degraded/distorted image to its original content and quality
- Restoration attempts to reconstruct or recover an image that has been degraded by using a priori knowledge of the degradation phenomenon
- Restoration techniques are oriented toward modeling the degradation and applying the inverse process in order to recover the original image
- Image enhancement is largely a subjective process, while image restoration is for the most part an objective process

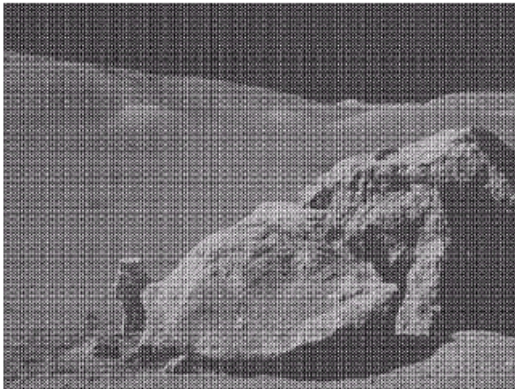
# WHAT IS IMAGE RESTORATION?



- **Image enhancement:** “improve” an image subjectively
- **Image restoration:** remove distortion from image in order to go back to the “original” -> objective process

# WHAT IS IMAGE RESTORATION?

- Image restoration attempts to restore images that have been degraded
  - Identify the degradation process and attempt to reverse it
  - Similar to image enhancement, but more objective



# Noise and Images

The sources of noise in digital images arise during image acquisition (digitization) and transmission

- Imaging sensors can be affected by ambient conditions
- Interference can be added to an image during transmission



# Noise Model

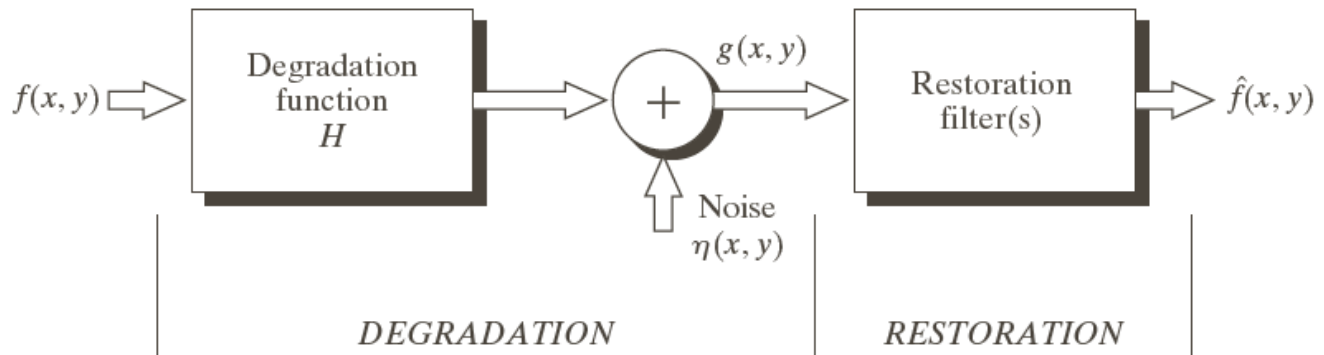
We can consider a noisy image to be modelled as follows:

$$g(x, y) = f(x, y) + \eta(x, y)$$

where  $f(x, y)$  is the original image pixel,  $\eta(x, y)$  is the noise term and  $g(x, y)$  is the resulting noisy pixel

If we can estimate the model the noise in an image is based on this will help us to figure out how to restore the image

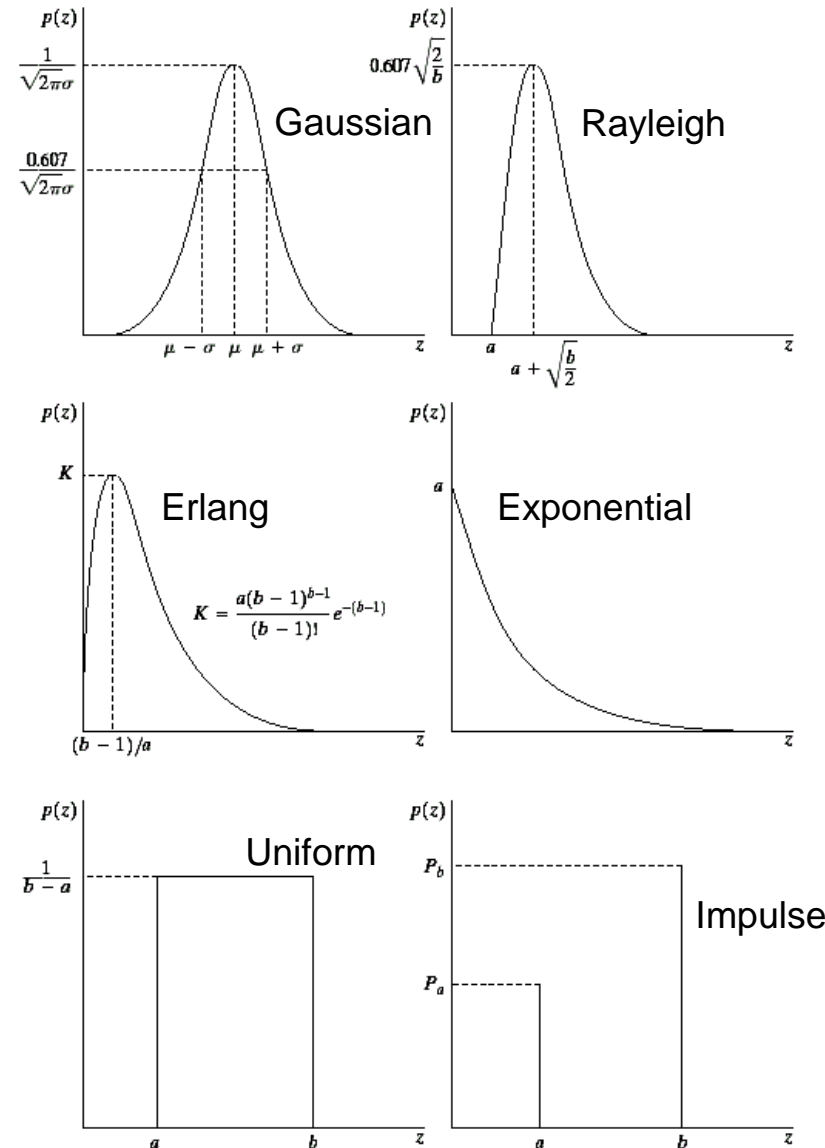
**FIGURE 5.1**  
A model of the image degradation/restoration process.



# Noise Models

There are many different models for the image noise term  $\eta(x, y)$ :

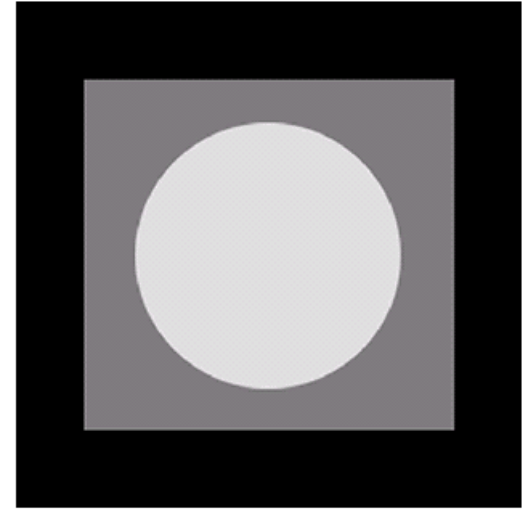
- Gaussian
  - Most common model
- Rayleigh
- Erlang
- Exponential
- Uniform
- Impulse
  - *Salt and pepper* noise



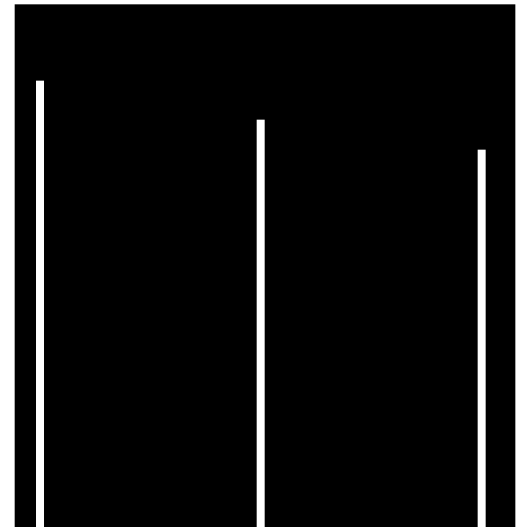
# Noise Example

The test pattern to the right is ideal for demonstrating the addition of noise

The following slides will show the result of adding noise based on various models to this image

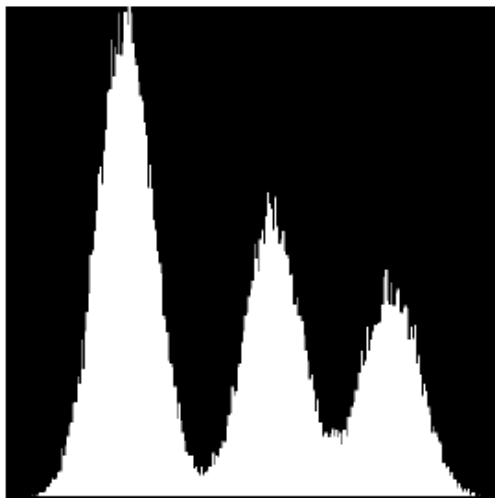
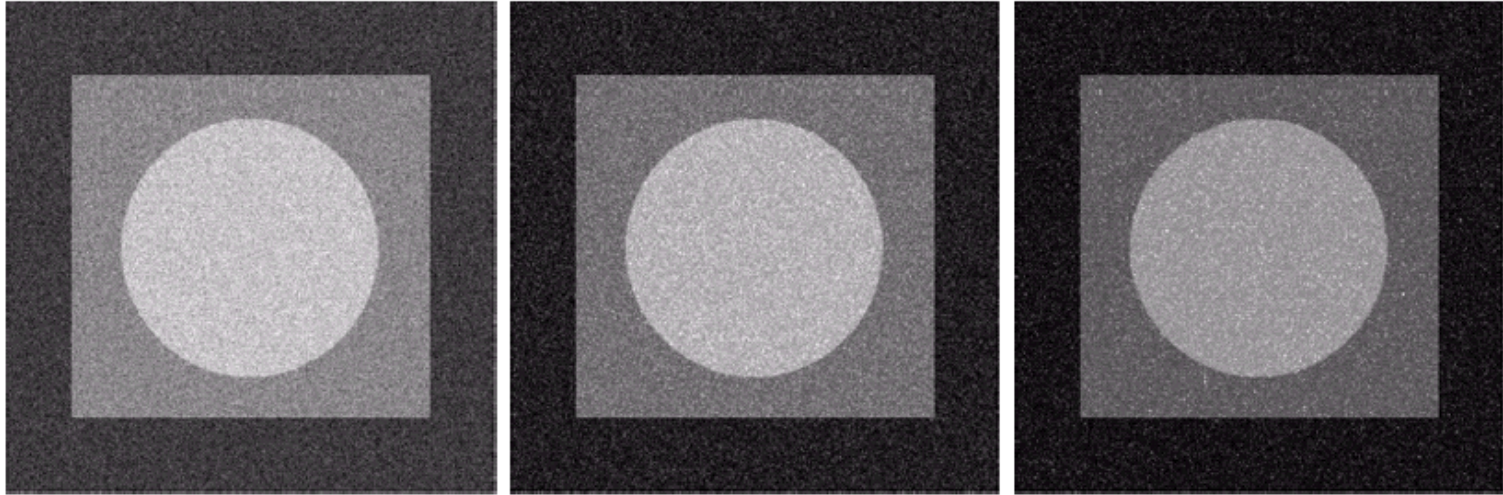


Image

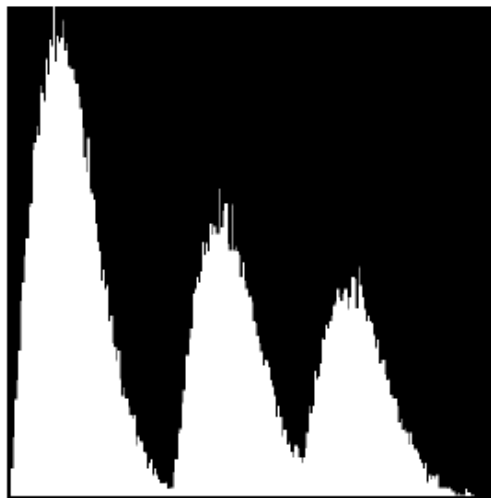


Histogram

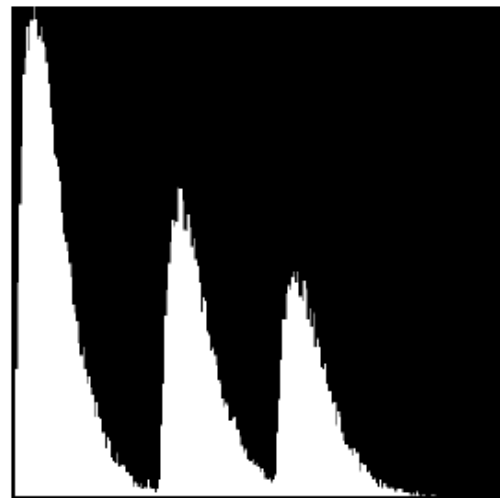
# Noise Example (cont...)



Gaussian

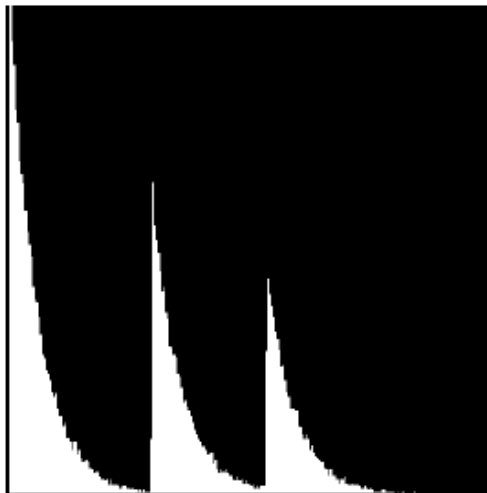
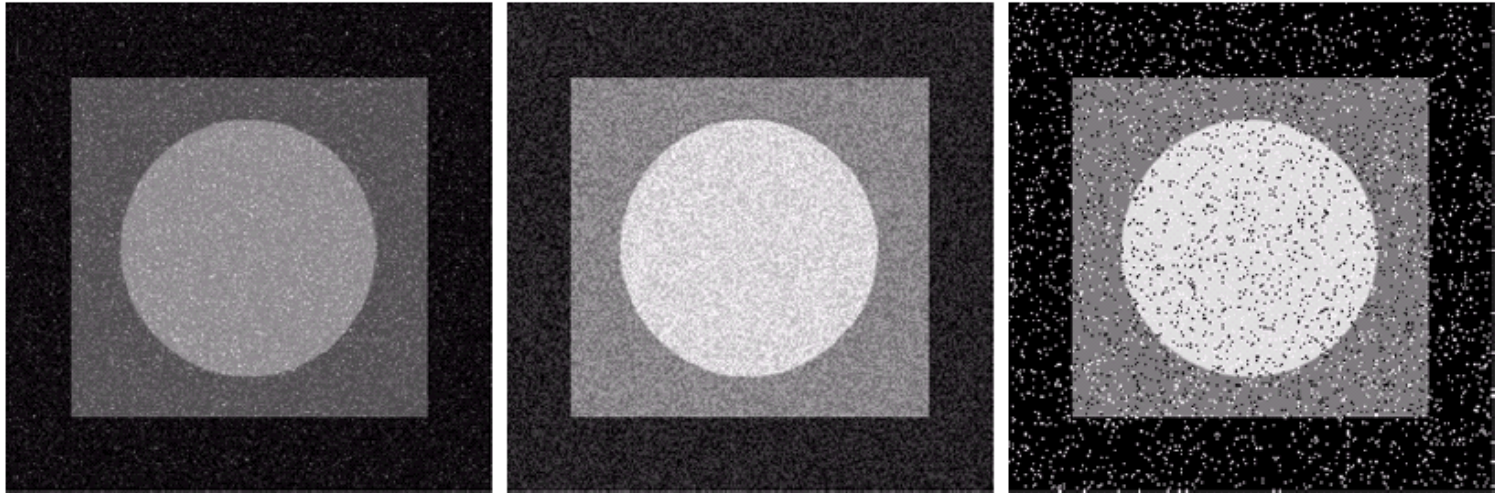


Rayleigh

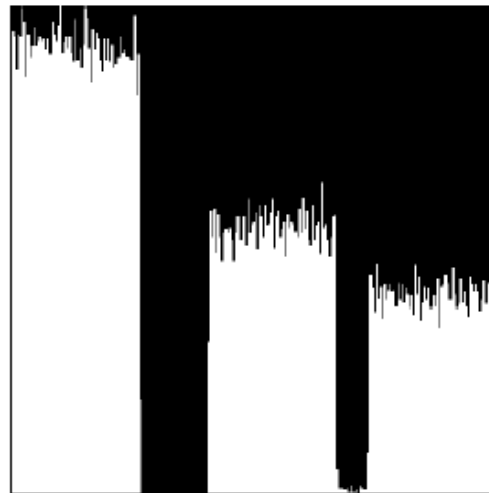


Erlang

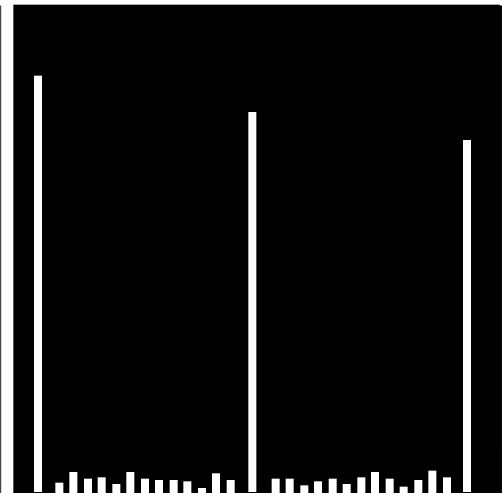
# Noise Example (cont...)



Exponential



Uniform



Impulse

# Filtering to Remove Noise

We can use spatial filters of different kinds to remove different kinds of noise

The *arithmetic mean* filter is a very simple one and is calculated as follows:

$$\hat{f}(x, y) = \frac{1}{mn} \sum_{(s,t) \in S_{xy}} g(s, t)$$

This is implemented as the simple smoothing filter

Blurs the image to remove noise

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

# Noise Removal Examples

Original Image

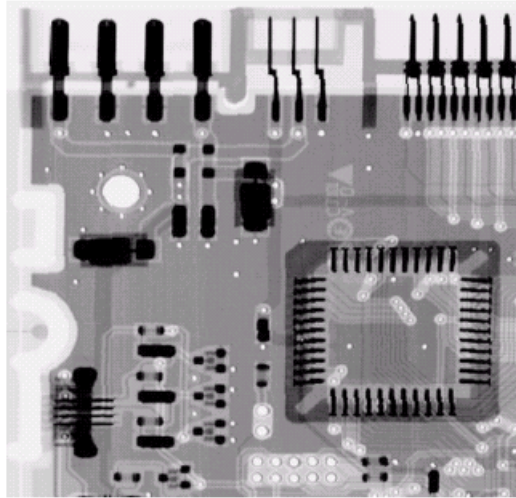
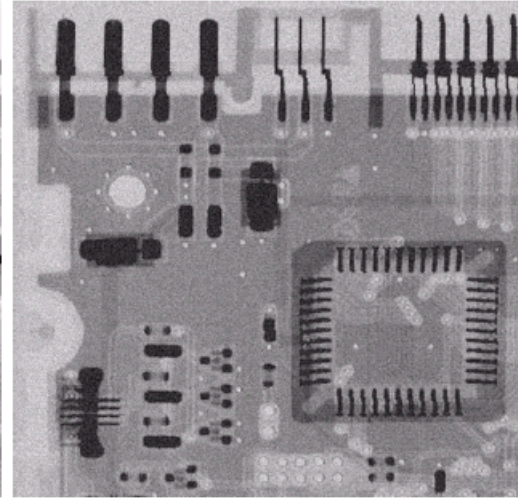
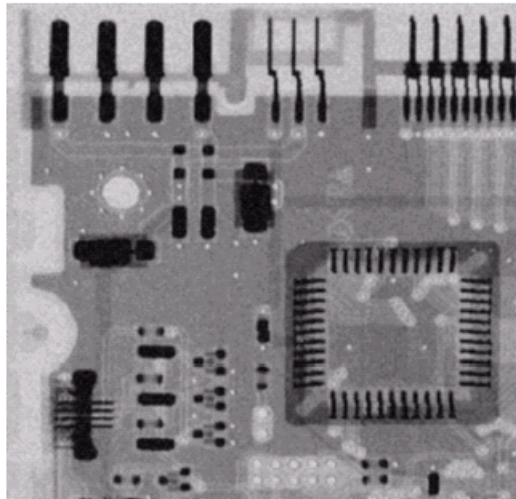


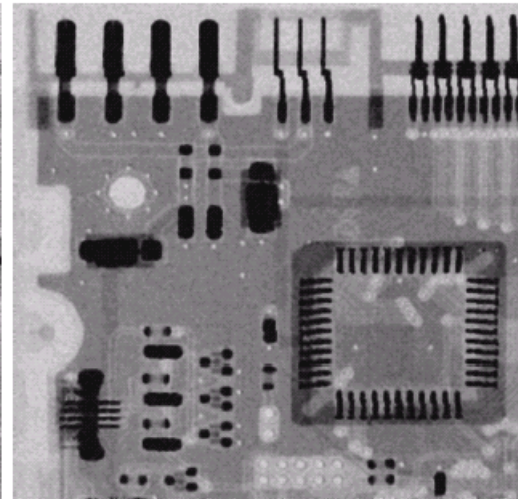
Image Corrupted By Gaussian Noise



After A 3\*3 Arithmetic Mean Filter



After A 3\*3 Geometric Mean Filter



# Mean Filters

- Geometric mean filter:

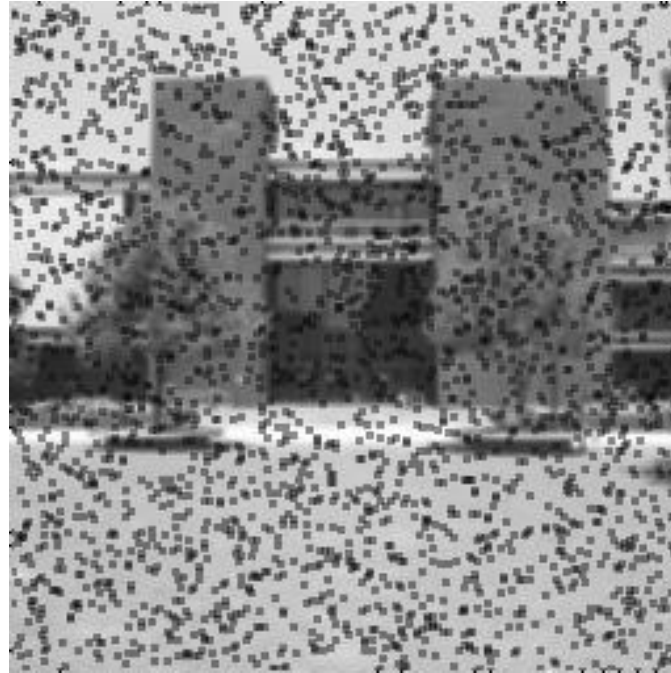
$$\text{Geometric Mean} = \prod_{(r,c) \in W} [d(r,c)]^{\frac{1}{N^2}}$$

- Works best with gaussian noise.
- Retains detail better than arithmetic mean filter.
- Ineffective in the presence of pepper noise (if very low values present in the window, the equation will return a very small number).

# Mean Filters



Image with pepper noise  
Probability = .04

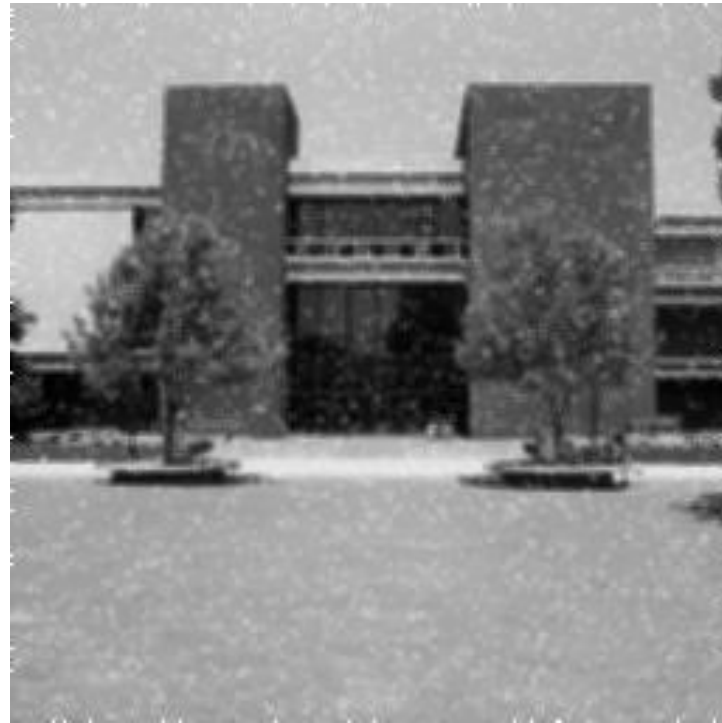


Result of geometric filter  
Mask size = 3

# Mean Filters



Image with salt noise  
Probability=.04



Result of geometric filter  
Mask size = 3

# Mean Filters

- Harmonic mean filter:

$$\text{Harmonic Mean} = \frac{N^2}{\sum_{(r,c) \in \omega} \frac{1}{d(r,c)}}$$

- Works with gaussian noise.
- Retains detail better than arithmetic mean filter.
- Works well with pepper noise.

# Mean Filters



Image with pepper noise  
Probability = .04



Result of harmonic filter  
Mask size = 3

# Mean Filters



Image with salt noise  
Probability=.04



Result of harmonic filter  
Mask size = 3

# Mean Filters

- Contra-harmonic mean filter:

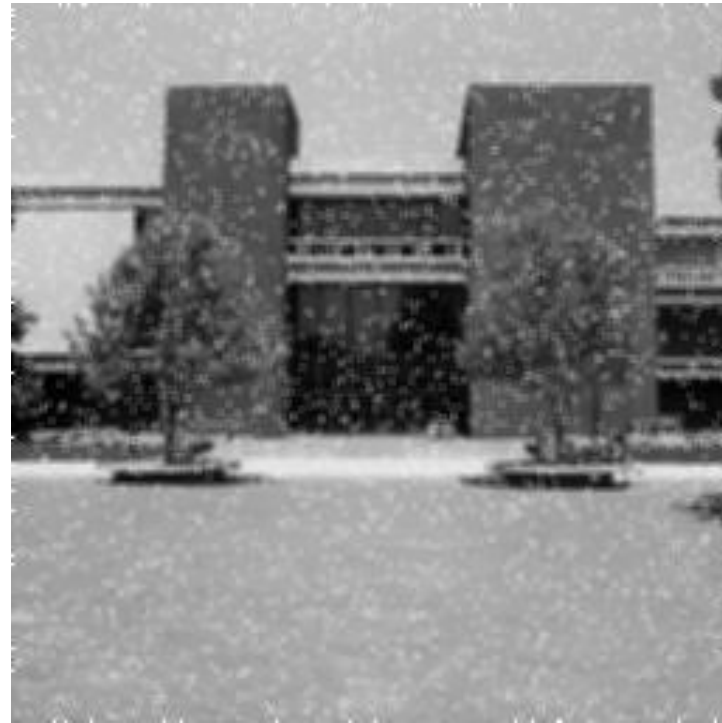
$$\text{Contra-Harmonic Mean} = \frac{\sum_{(r,c) \in W} d(r,c)^{R+1}}{\sum_{(r,c) \in W} d(r,c)^R}$$

- Works for salt OR pepper noise, depending on the filter order R.
- Negative R  $\rightarrow$  Eliminate salt-type noise.
- Positive R  $\rightarrow$  Eliminate pepper-type noise.

# Mean Filters



Image with salt noise  
Probability = .04



Result of contra-harmonic filter  
Mask size = 3; order = 0

# Mean Filters



Result of contra-harmonic filter  
Mask size = 3; order = -1



Result of contra-harmonic filter  
Mask size = 3; order = -5

# Order Statistics Filters

Spatial filters that are based on ordering the pixel values that make up the neighbourhood operated on by the filter

Useful spatial filters include

- Median filter
- Max and min filter
- Midpoint filter
- Alpha trimmed mean filter

# Median Filter

## Median Filter:

$$\hat{f}(x, y) = \underset{(s,t) \in S_{xy}}{\text{median}}\{g(s, t)\}$$

Excellent at noise removal, without the smoothing effects that can occur with other smoothing filters

Particularly good when salt and pepper noise is present

# Examples

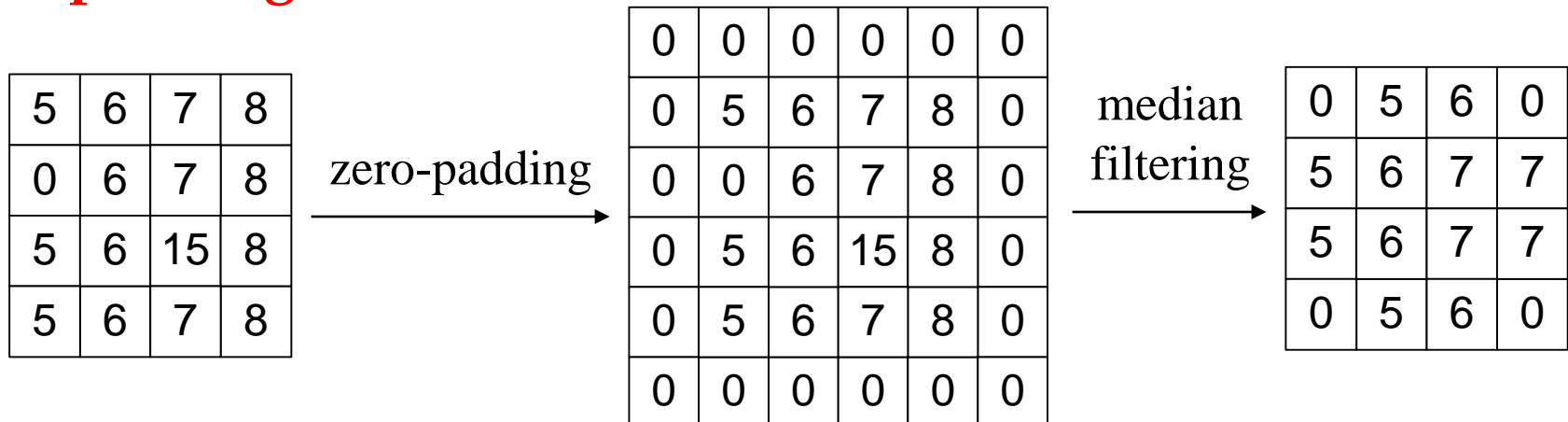
- A 4x4 grayscale image is given by

5	6	7	8
0	6	7	8
5	6	15	8
5	6	7	8

impulse? →

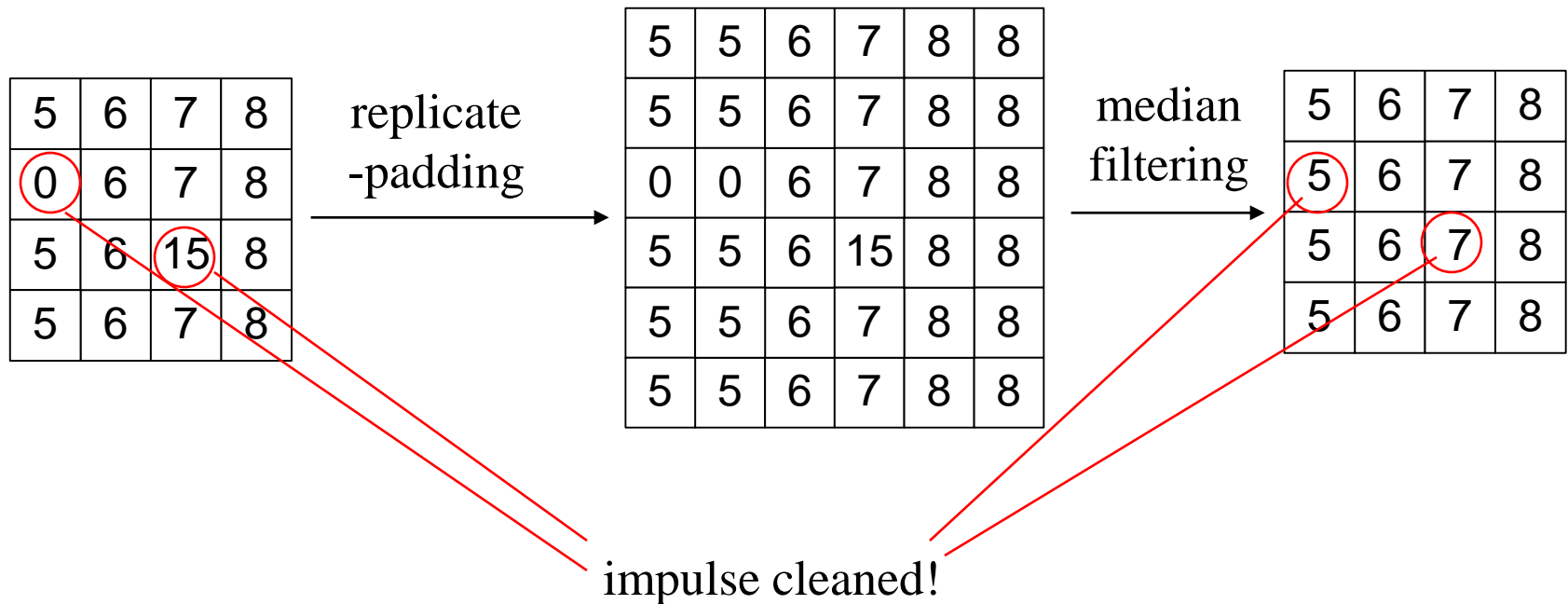
→ impulse?

- Filter the image with a 3x3 median filter, after **zero-padding**

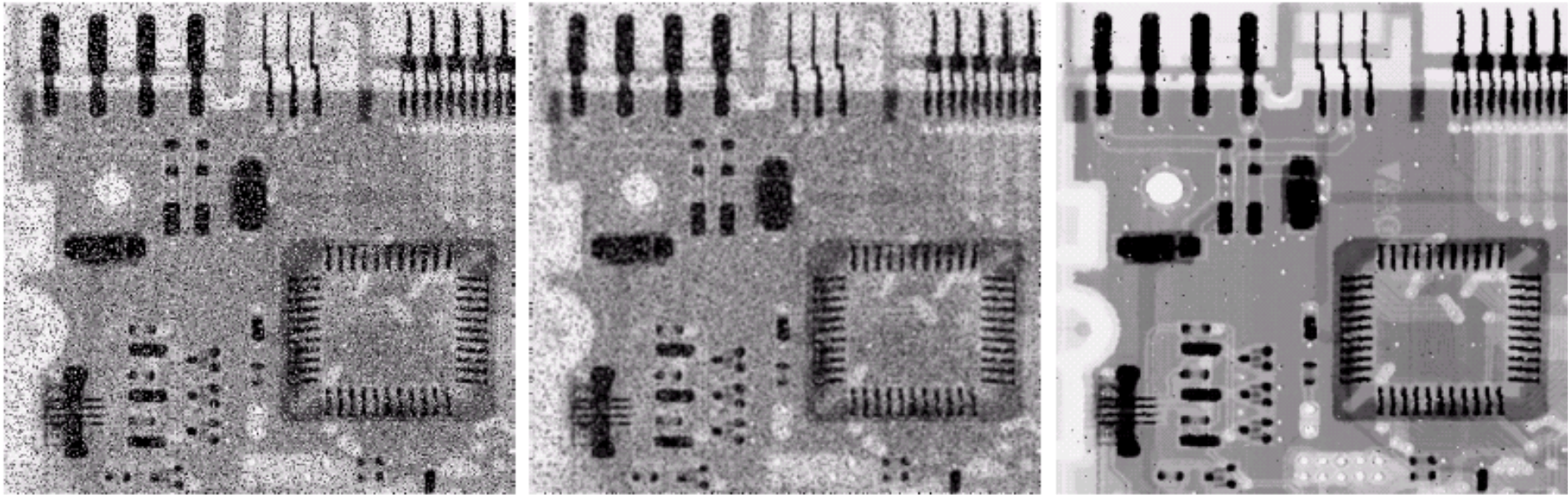


# Examples

- 2) Filter the image with a 3x3 median filter, after **replicate-padding** at the image borders



# Median Filtering

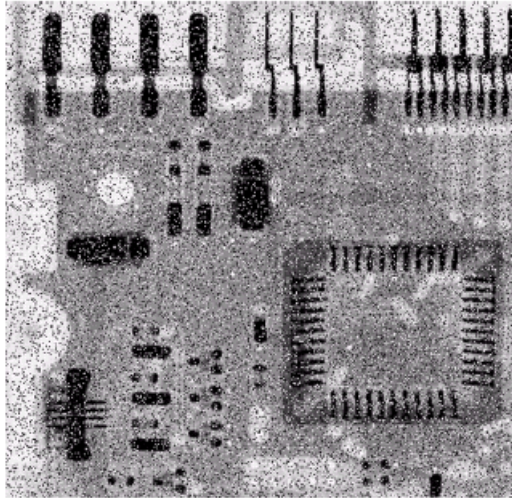


a b c

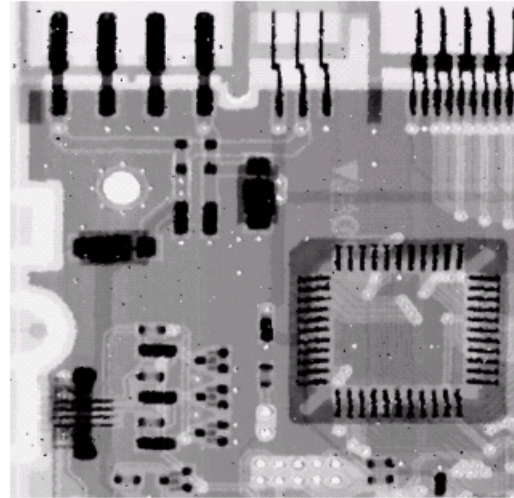
**FIGURE 3.37** (a) X-ray image of circuit board corrupted by salt-and-pepper noise. (b) Noise reduction with a  $3 \times 3$  averaging mask. (c) Noise reduction with a  $3 \times 3$  median filter. (Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)

# Noise Removal Examples

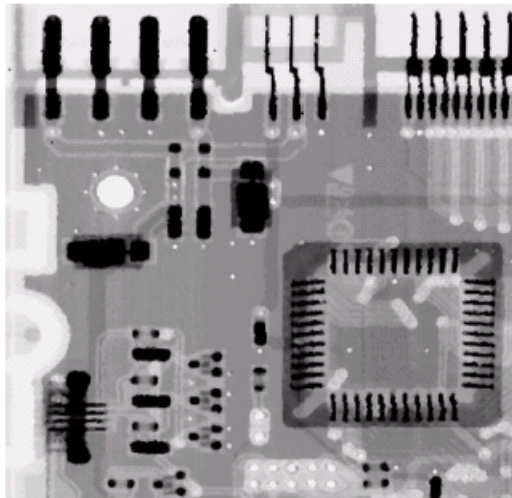
Image  
Corrupted  
By Salt And  
Pepper Noise



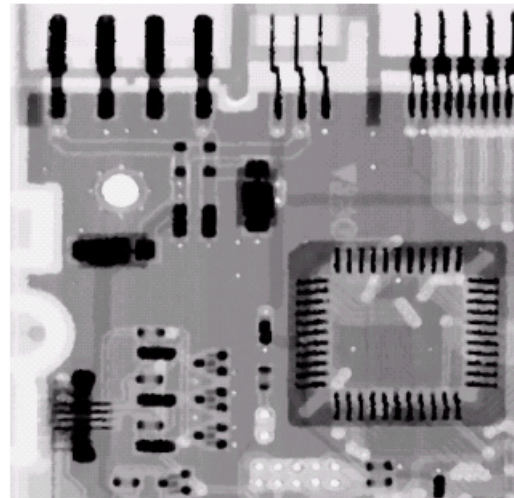
Result of 1  
Pass With A  
3\*3 Median  
Filter



Result of 2  
Passes With  
A 3\*3 Median  
Filter



Result of 3  
Passes With  
A 3\*3 Median  
Filter



# Max and Min Filter

**Max Filter:**

$$\hat{f}(x, y) = \max_{(s,t) \in S_{xy}} \{g(s, t)\}$$

**Min Filter:**

$$\hat{f}(x, y) = \min_{(s,t) \in S_{xy}} \{g(s, t)\}$$

Max filter is good for pepper noise and min is good for salt noise

# Noise Removal Examples (cont...)

Image  
Corrupted  
By Pepper  
Noise

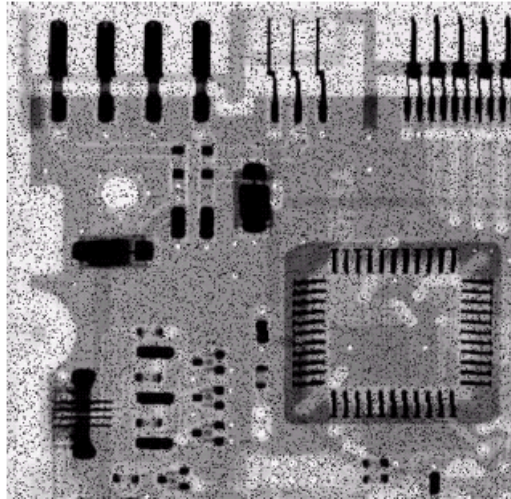
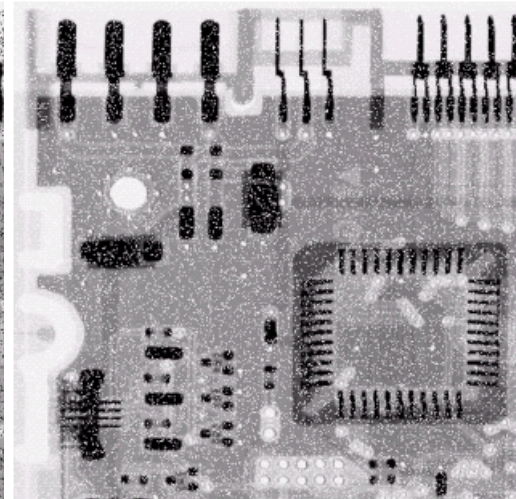
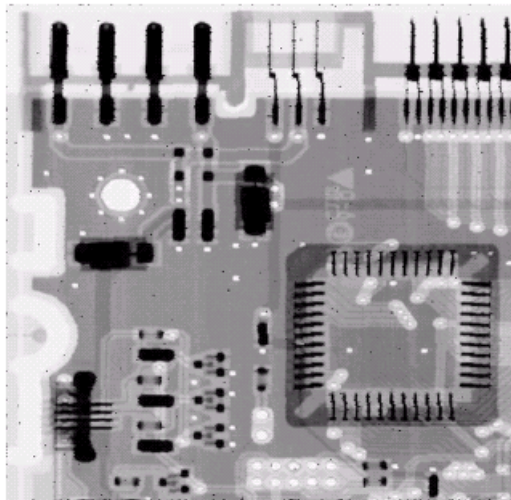


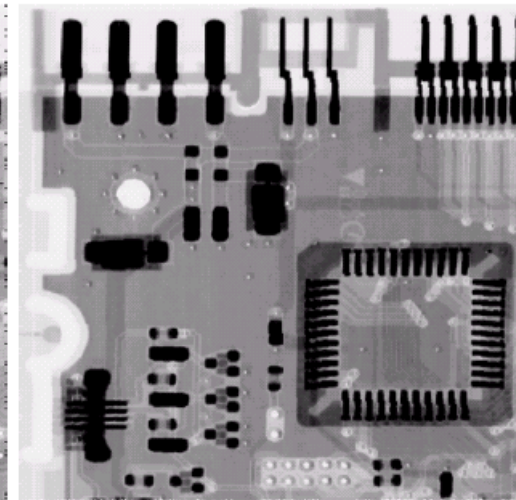
Image  
Corrupted  
By Salt  
Noise



Result Of  
Filtering  
Above  
With A 3\*3  
Max Filter



Result Of  
Filtering  
Above  
With A 3\*3  
Min Filter



# Alpha-Trimmed Mean Filter

**Alpha-Trimmed Mean Filter:**

$$\hat{f}(x, y) = \frac{1}{mn - d} \sum_{(s,t) \in S_{xy}} g_r(s, t)$$

# Alpha-Trimmed Mean Filter

- **Alpha-Trimmed Mean Filter:**

$$\hat{f}(x, y) = \frac{1}{mn - d} \sum_{(s,t) \in S_{xy}} g_r(s, t)$$

- We can delete the  $d/2$  lowest and  $d/2$  highest grey levels
- So  $g_r(s, t)$  represents the remaining  $mn - d$  pixels
- If  $d = 0$ , the filter is reduced to arithmetic mean
- If  $d = mn - 1$ , the filter become median filter
- For other values, the filter is useful in situation involving multiple types of noise
  - Combination of salt-and-pepper and Gaussian noise

# Noise Removal Examples (cont...)

Image  
Corrupted  
By Uniform  
Noise

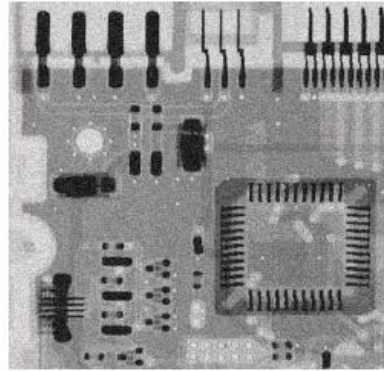
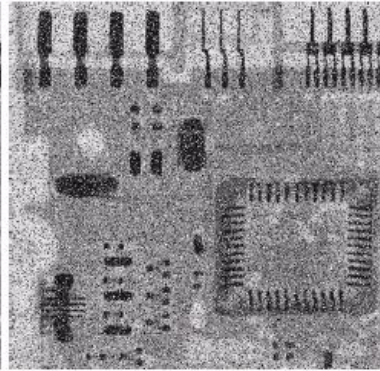
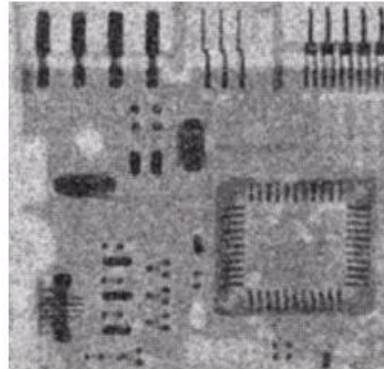


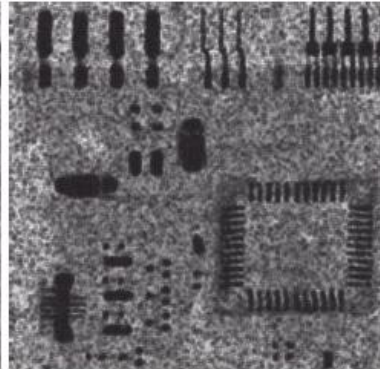
Image Further  
Corrupted  
By Salt and  
Pepper Noise



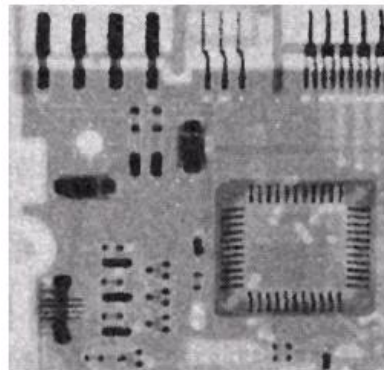
Filtered By  
5\*5 Arithmetic  
Mean Filter



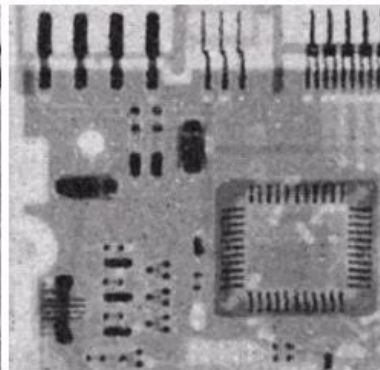
Filtered By  
5\*5 Geometric  
Mean Filter



Filtered By  
5\*5 Median  
Filter



Filtered By  
5\*5 Alpha-Trimmed  
Mean Filter



# Order Filters

- Order filters can also be defined to select a specific pixel rank within the ordered set.
  - For example, we may find the second highest value is the better choice than the maximum value for certain pepper noise.
  - This type of ordered selection is application specific.
- Minimum filter tend to darken the image and maximum filter tend to brighten the image.

# Order Filters

- Midpoint filter:
  - Average of the maximum and minimum within the window.
  - Useful for removing gaussian and uniform noise.

$$\text{Midpoint} = \frac{I_1 + I_{N^2}}{2}$$

# Order Filters



Image with gaussian noise.  
Variance = 300, mean = 0



Result of midpoint filter  
Mask size = 3

# Readings from Book (3<sup>rd</sup> Edn.)

- Image Restoration (Chapter-5)
- Reading Assignment
  - Adaptive Filters
  - Adaptive Median Filtering



# Acknowledgements

- ◆ Digital Image Processing”, Rafael C. Gonzalez & Richard E. Woods, Addison-Wesley, 2002
- ◆ Peters, Richard Alan, II, Lectures on Image Processing, Vanderbilt University, Nashville, TN, April 2008
- ◆ Brian Mac Namee, Digital Image Processing, School of Computing, Dublin Institute of Technology
- ◆ Computer Vision for Computer Graphics, Mark Borg

Material in these slides has been taken from, the following resources