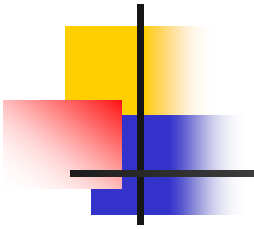


Image Restoration

- Image restoration vs. image enhancement

  Enhancement:

  largely a subjective process

  Priori knowledge about the degradation is not a must (sometimes no degradation is involved)

  Procedures are heuristic and take advantage of the psychophysical aspects of human visual system

  Restoration:

  more an objective process

  Images are degraded

  Tries to recover the images by using the knowledge about the degradation

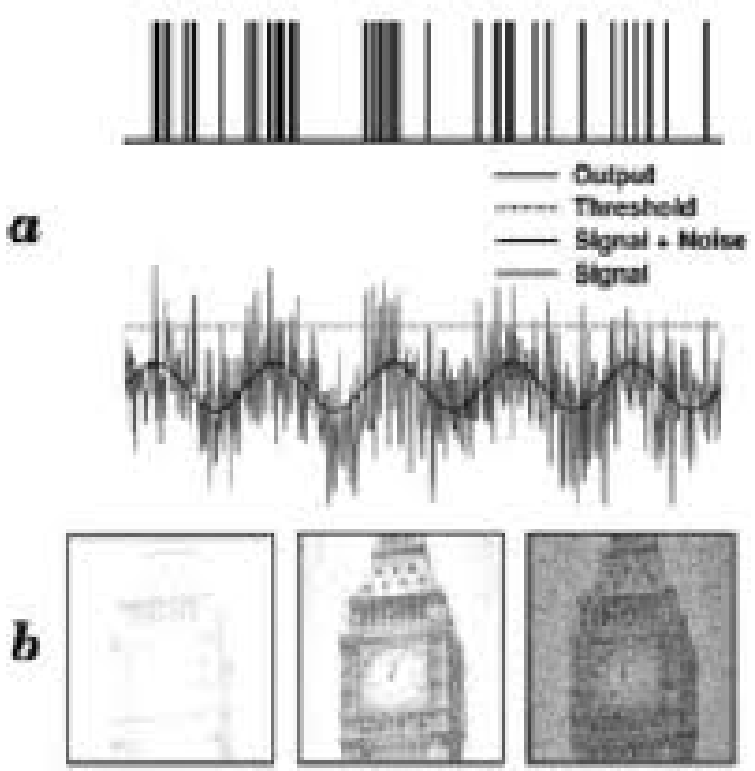
Limitation of Imaging Technology

- Two plagues in image acquisition
  - Noise interference
  - Blur (motion, out-of-focus, hazy weather)
- Difficult to obtain high-quality images as imaging goes
  - Beyond visible spectrum
  - Micro-scale (microscopic imaging)
  - Macro-scale (astronomical imaging)

What is Noise?

- Wiki definition: **noise** means any unwanted signal
- One person's signal is another one's noise
- Noise is not always random and randomness is an artificial term
- Noise is not always bad (see stochastic resonance example in the next slide)

Stochastic Resonance



no noise light noise heavy noise

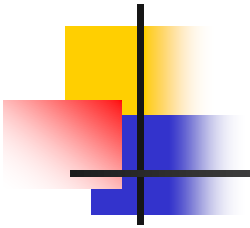
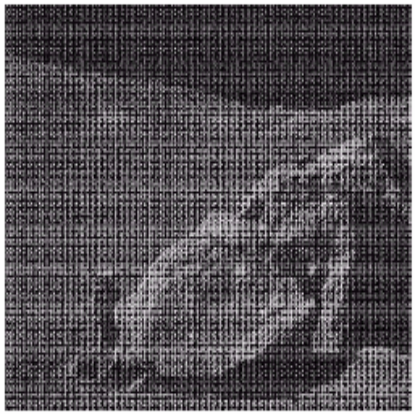


Image Denoising

- Where does noise come from?
  - Sensor (e.g., thermal or electrical interference)
  - Environmental conditions (rain, snow etc.)
- Why do we want to denoise?
  - Visually unpleasant
  - Bad for compression
  - Bad for analysis

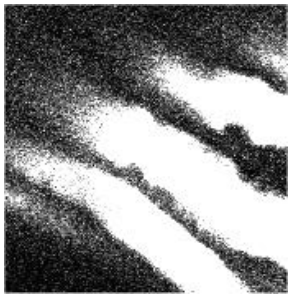
Noisy Image Examples

thermal imaging

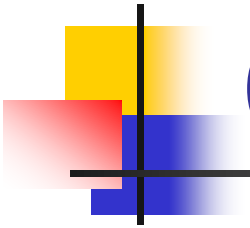


electrical interference

ultrasound imaging



physical interference



(Ad-hoc) Noise Modeling

- Simplified assumptions
  - Noise is independent of signal
- Noise types
  - Independent of spatial location
    - Impulse noise
    - Additive white Gaussian noise
  - Spatially dependent
    - Periodic noise

Image Denoising

- Introduction
- Impulse noise removal
  - Median filtering
- Additive white Gaussian noise removal
  - 2D convolution and DFT
- Periodic noise removal
  - Band-rejection and Notch filter

Impulse Noise (salt-pepper Noise)

Definition

Each pixel in an image has the probability of p/2 (0<p<1) being contaminated by either a white dot (salt) or a black dot (pepper)

$$Y(i,j)=\begin{cases}255 & \text{with probability of p/2}\\ 0 & \text{with probability of p/2}\\ X(i,j) & \text{with probability of 1-p}\end{cases}$$

noisy pixels

clean pixels

$1\le i\le H, 1\le j\le W$

X: noise-free image, Y: noisy image

Note: in some applications, noisy pixels are not simply black or white, which makes the impulse noise removal problem more difficult

Numerical Example

P=0.1

128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128

X

128	128	255	0	128	128	128	128	128	128
128	128	128	128	0	128	128	128	128	0
128	128	128	128	128	128	128	128	128	128
128	128	0	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
0	128	128	128	128	255	128	128	128	128
128	128	128	128	128	128	128	128	128	255
128	128	128	128	128	128	128	255	128	128

Y

Noise level p=0.1 means that approximately 10% of pixels are contaminated by salt or pepper noise (highlighted by red color)

MATLAB Command

```
>Y = IMNOISE(X,'salt & pepper',p)
```

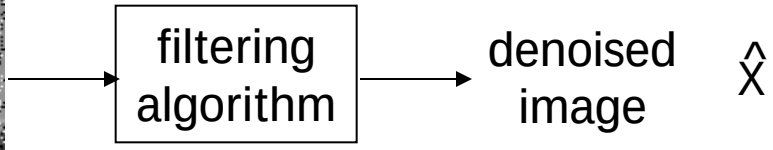
Notes:

- The default value of p is 0.05 (i.e., 5 percent of pixels are contaminated)

- imnoise function can produce other types of noise as well (you need to change the noise type ‘salt & pepper’)

Impulse Noise Removal Problem

Noisy image Y



Can we make the denoised image $\hat{X}$ as close to the noise-free image X as possible?

Median Operator

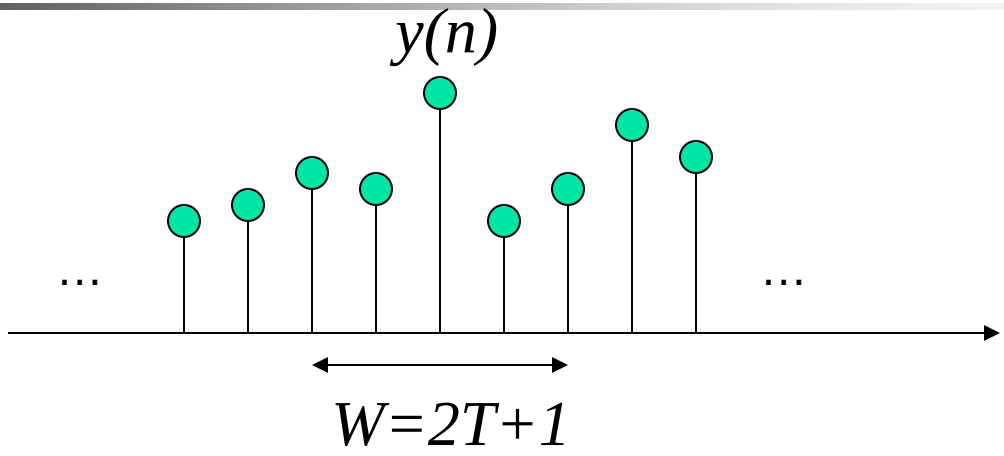
- Given a sequence of numbers $\{y_1,\ldots,y_N\}$
  - Mean: average of N numbers
  - Min: minimum of N numbers
  - Max: maximum of N numbers
  - Median: half-way of N numbers

Example $\vec{y} = [50,0,52,255,54,55,56]$

$$\text{sorted } \vec{y} = [0,50,52,54,55,56,255]$$

$$median(\vec{y}) = 54$$

1D Median Filtering

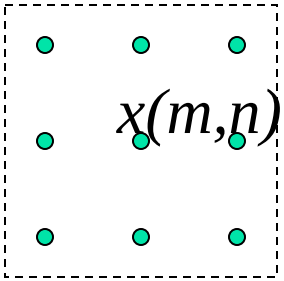


$$\hat{x}(n) = median[y(n-T),..., y(n),..., y(n+T)]$$

MATLAB command: x=median(y(n-T:n+T));

Note: median operator is nonlinear

2D Median Filtering



W: (2T+1)-by-(2T+1) window

$$\hat{x}(m,n) = median[y(m-T,n-T),...,y(m-T,n+T),...,$$
$$y(m,n),...,y(m+T,n-T),...,y(m+T,n+T)]$$

Numerical Example

225	225	225	226	226	226	226	226
225	225	255	226	226	226	225	226
226	226	225	226	**0**	226	226	255
255	226	225	**0**	226	226	226	226
225	255	**0**	225	226	226	226	255
255	225	224	226	226	0	225	226
226	225	225	226	255	226	226	228
226	226	225	226	226	226	226	226

Y

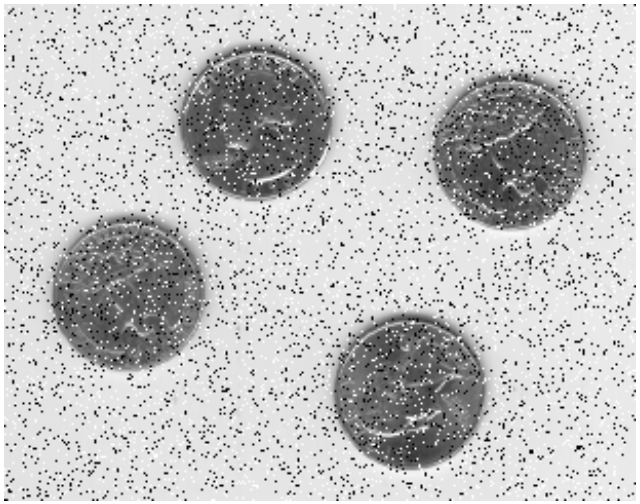
0	225	225	226	226	226	226	226
225	225	226	226	226	226	226	226
225	226	226	226	226	226	226	226
226	226	225	**225**	226	226	226	226
225	225	225	225	226	226	226	226
225	225	225	226	226	226	226	226
225	225	225	226	226	226	226	226
226	226	226	226	226	226	226	226

$\hat{X}$

Sorted: [0, 0, 0, 225, **225**, 225, 226, 226, 226]

Image Example

P=0.1



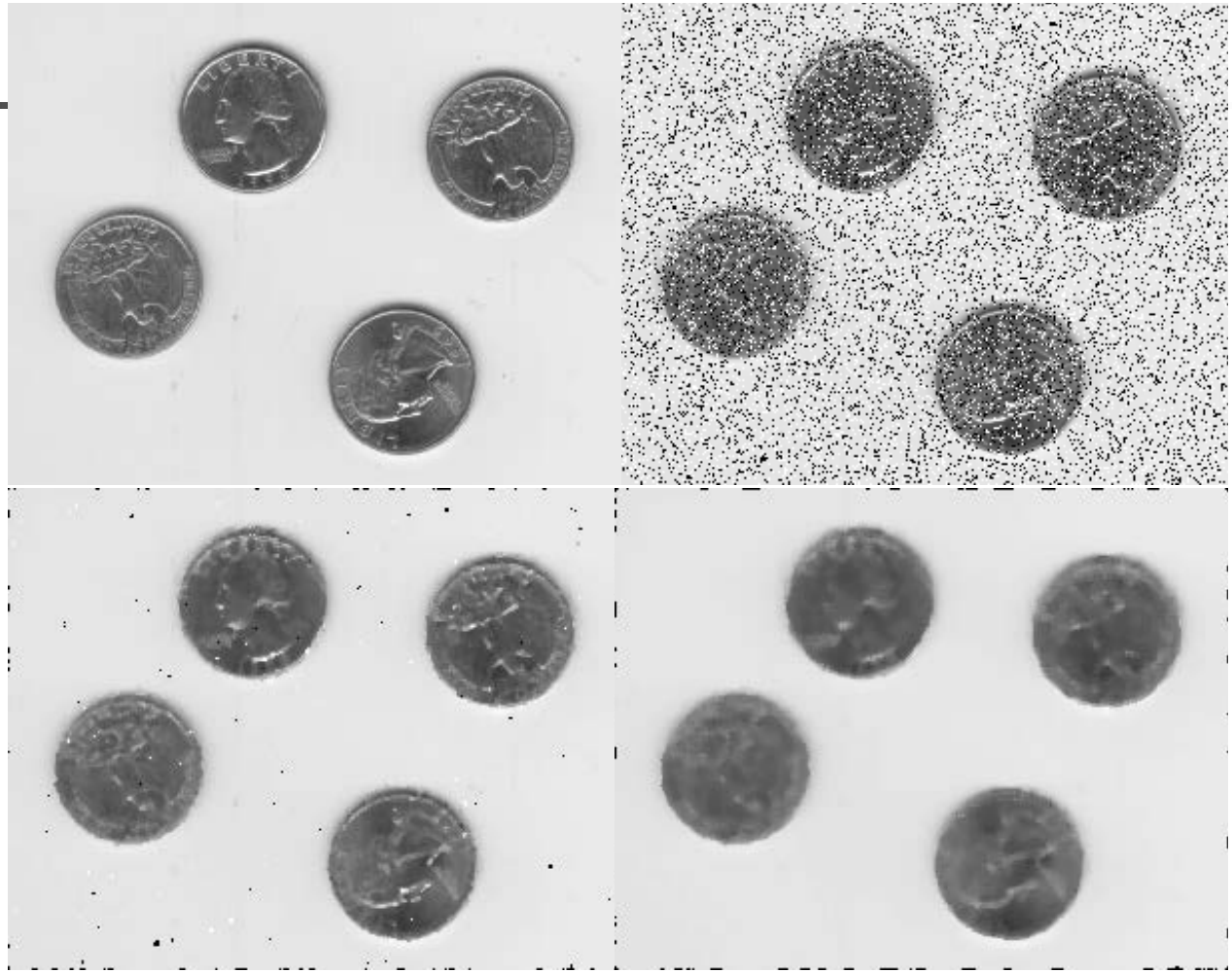
Noisy image Y

denoised image $\hat{X}$

3-by-3 window

Image Example (Con't)

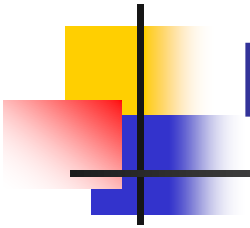
clean



noisy
(p=0.2)

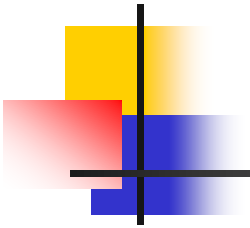
3-by-3 window

5-by-5 window



Reflections

- What is good about median operation?
  - Since we know impulse noise appears as black (minimum) or white (maximum) dots, taking median effectively suppresses the noise
- What is bad about median operation?
  - It affects clean pixels as well
  - Noticeable edge blurring after median filtering



Idea of Improving Median Filtering

- Can we get rid of impulse noise without affecting clean pixels?
  - Yes, if we know where the clean pixels are

  or equivalently where the noisy pixels are
- How to detect noisy pixels?
  - They are black or white dots

Median Filtering with Noise Detection

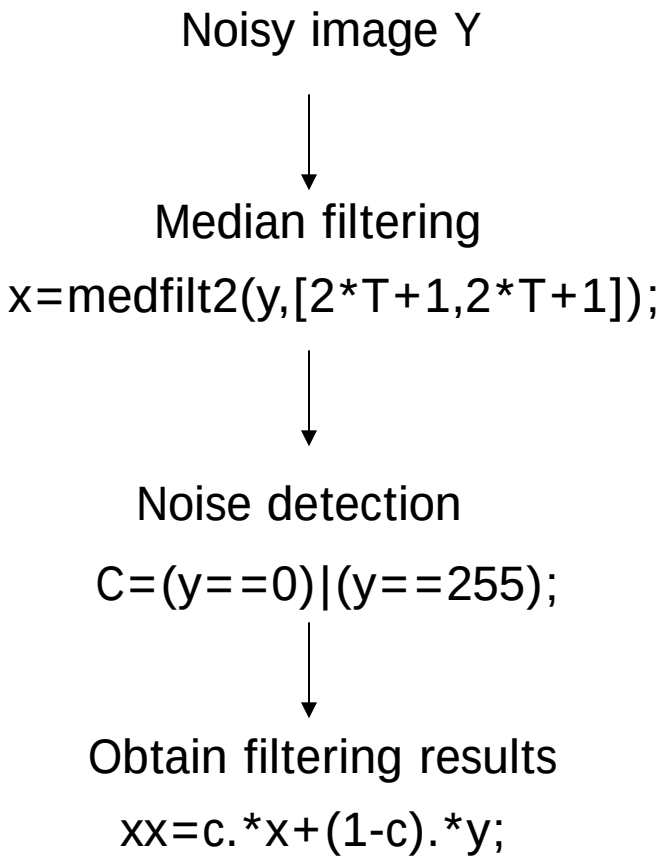
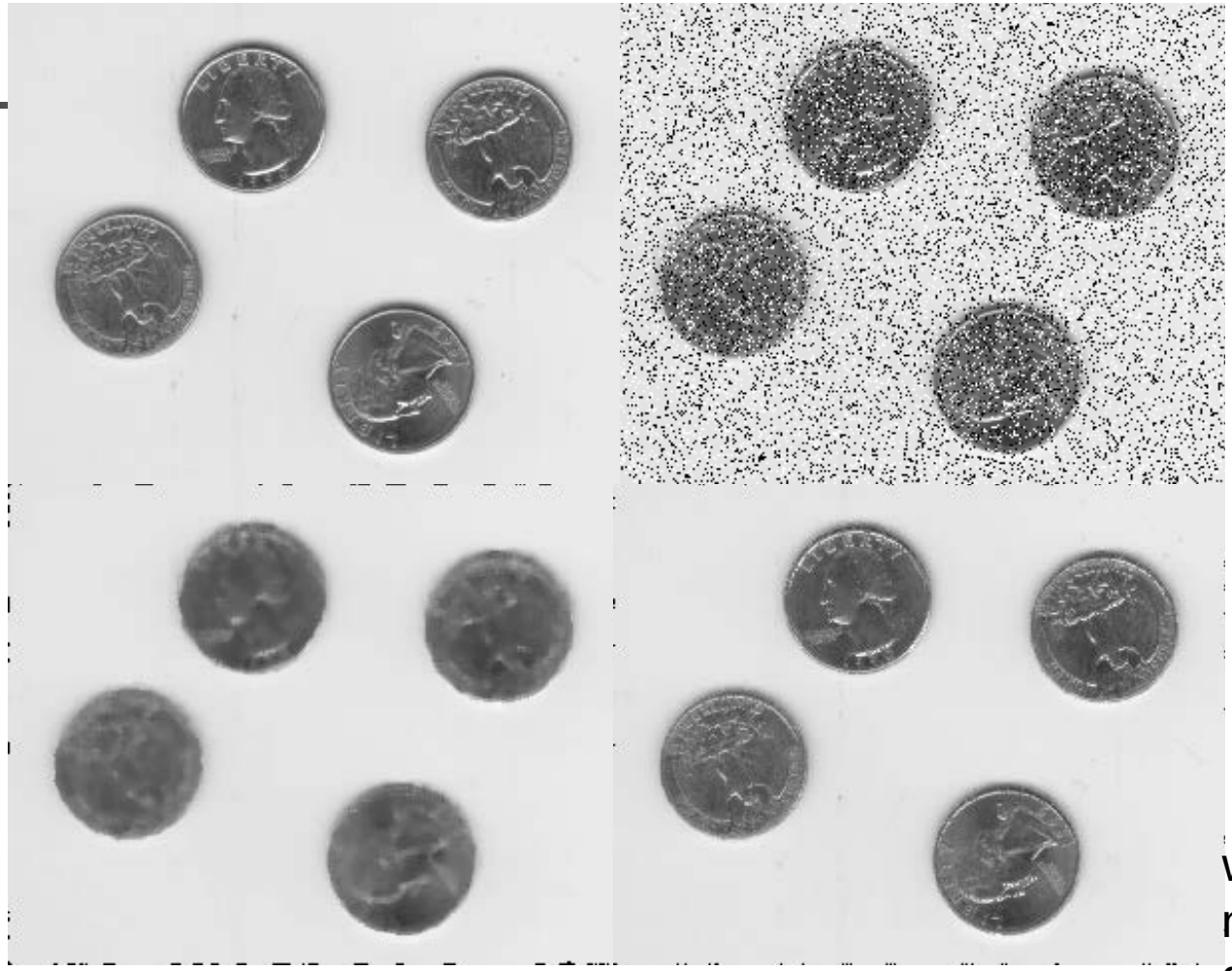


Image Example

clean



noisy
(p=0.2)

w/o
noise
detection

with
noise
detection

Mean Filter size = 7 x 7

Median Filter size = 7 x 7

The maximum filter selects the largest value within of pixel values, whereas the minimum filter selects the smallest value.

Minimum filtering

(mask size =3 x 3)

Minimum filtering causes the darker regions of an image to swell in size and dominate the lighter regions (mask size =7 x 7)

Result from Maximum filtering with mask (3 x 3)

Result from Maximum filtering with mask (7 x 7)

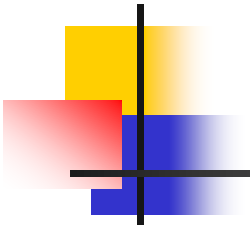


Image Denoising

- Introduction
- Impulse noise removal
  - Median filtering
- Additive white Gaussian noise removal
  - 2D convolution and DFT
- Periodic noise removal
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Additive White Gaussian Noise

Definition

Each pixel in an image is disturbed by a Gaussian random variable
With zero mean and variance σ^2

$$Y(i,j) = X(i,j) + N(i,j),$$

$$N(i,j) \sim N(0,\sigma^2), 1 \le i \le H, 1 \le j \le W$$

X: noise-free image, Y: noisy image

Note: unlike impulse noise situation, every pixel in the image contaminated by AWGN is noisy

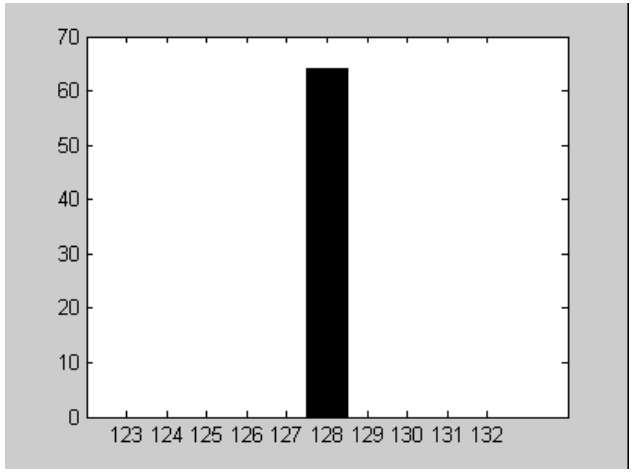
Numerical Example

128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128

$\sigma^2 = 1$

128	128	129	127	129	126	126	128
126	128	128	129	129	128	128	127
128	128	128	129	129	127	127	128
128	129	127	126	129	129	129	128
127	127	128	127	129	127	129	128
129	130	127	129	127	129	130	128
129	128	129	128	128	128	129	129
128	128	130	129	128	127	127	126

X



Y

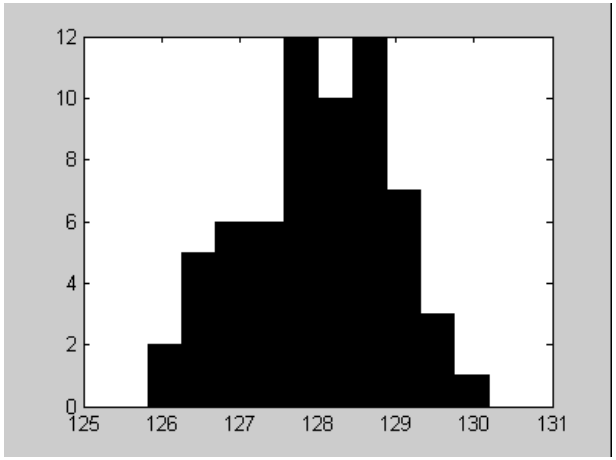
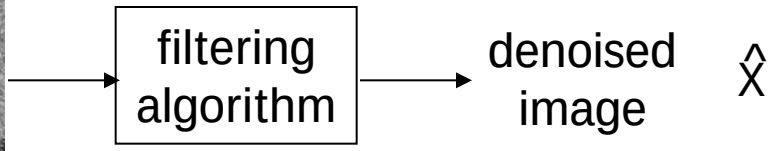


Image Denoising

Noisy image Y



Question: Why not use median filtering?
Hint: the noise type has changed.