Digital Image Processing

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Lecture 02

Announcement

- Class Information
  - Class website
    - NTU COOL
    - Lecture #1_Part II
    - Lecture #2
    - Submission guideline
    - Homework #1
      - Please be sure to read the guideline carefully
      - Deadline: 11:59pm on Mar. 09, 2022

Image Enhancement

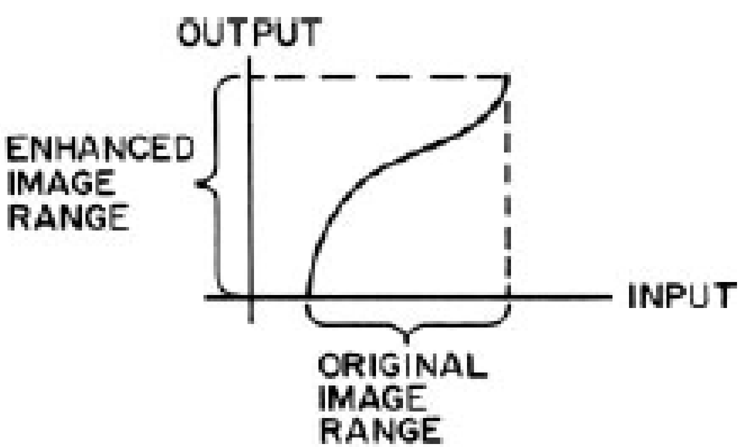
Image Enhancement

- **Goal of Image Enhancement**
  - make images more appealing
  - no theory, ad-hoc rules, derived with insights

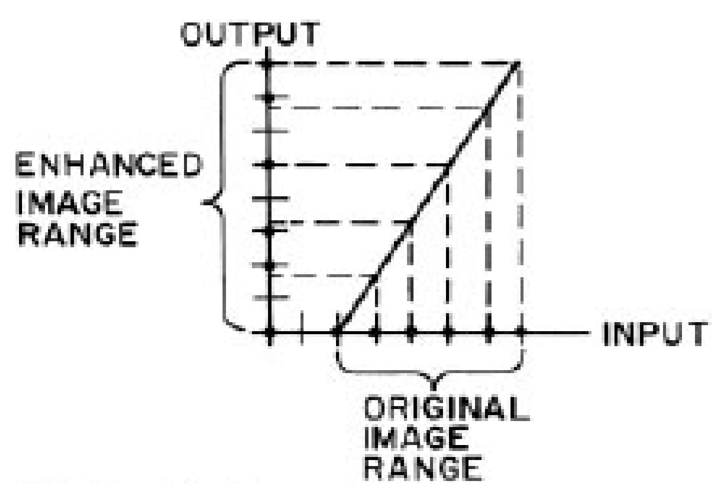
- **Two Approaches**
  - Contrast Manipulation
  - Histogram Modification

Contrast Manipulation

- **Transfer Function**
  - Linear
  - Nonlinear
  - Piecewise



Continuous Image

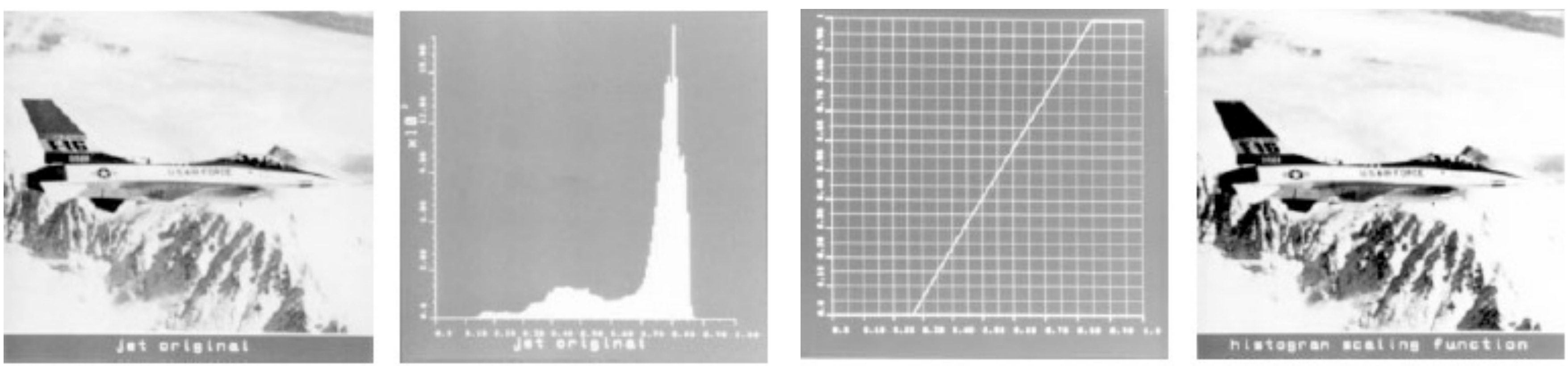


Quantized Image

Contrast Manipulation

- **Linear scaling and clipping**

$$G(j,k) = T\left[F(j,k)\right] \quad 0 \le F(j,k) \le 1$$

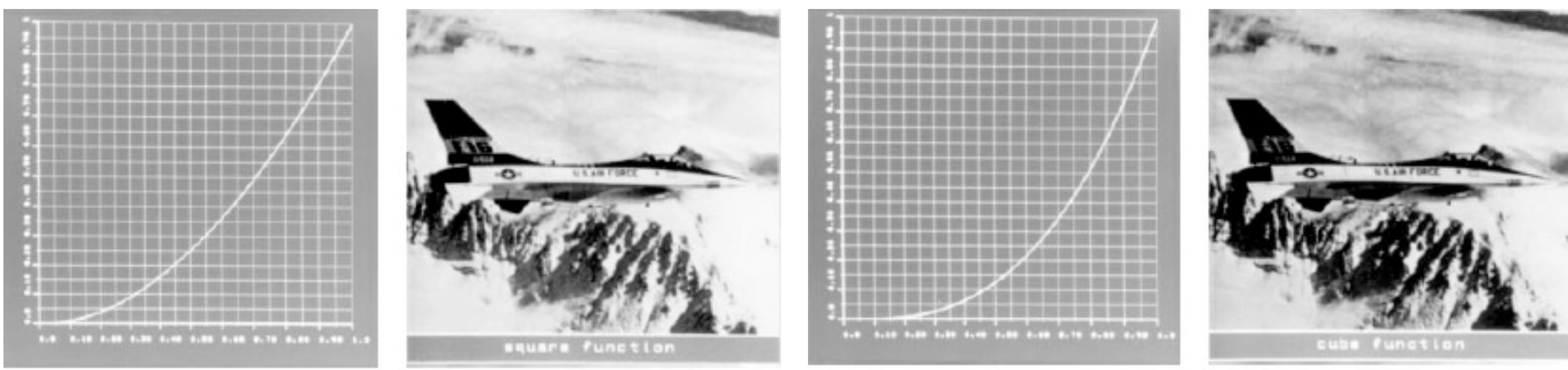


(a) Original (b) Original histogram (c) Transfer function (d) Contrast stretched

Contrast Manipulation

- **Power-Law**

$$G(j,k) = \left[F(j,k)\right]^{p} \qquad 0 \le F(j,k) \le 1$$

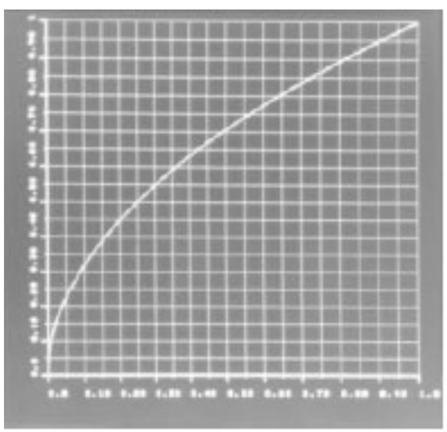


(*a*) Square function (*b*) Square output (*c*) Cube function (*d*) Cube output

Contrast Manipulation

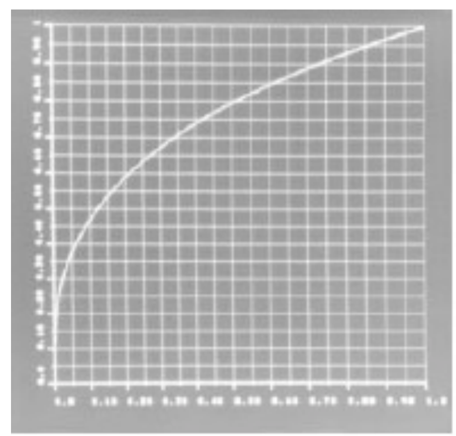
- **Power-Law**

$$G(j,k) = \left[F(j,k)\right]^{p} \quad 0 \le F(j,k) \le 1$$



(a) Square root function

(b) Square root output

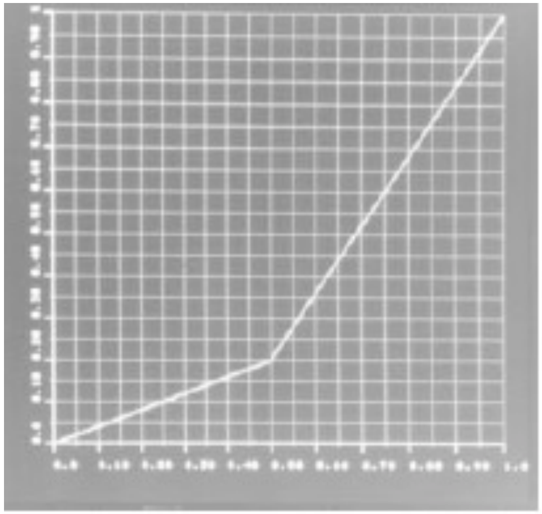


(c) Cube root function

(d) Cube root output

Contrast Manipulation

- Rubber Band Transfer Function
  - Piecewise linear transformation
  - Inflection point (control point)



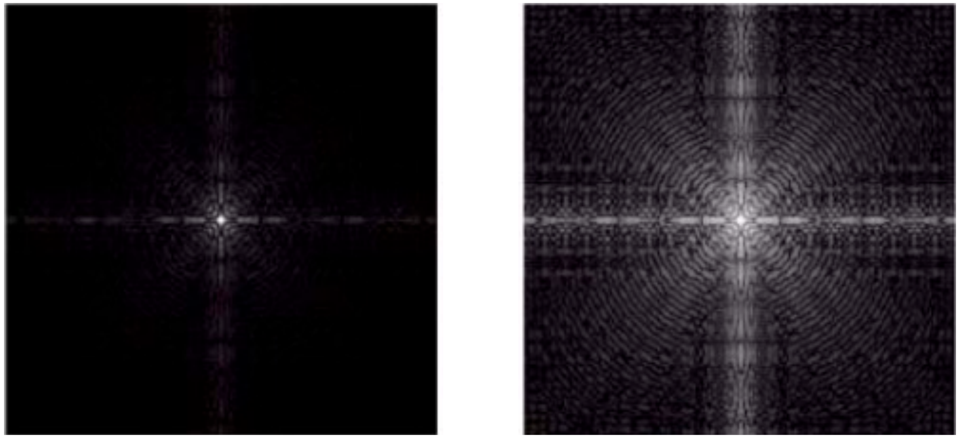
Can choose the area where we want to stretch or reduce the contrast

Contrast Manipulation

- **Logarithmic Point Transformation**

$$G(j,k) = \frac{\log_e\{1 + aF(j,k)\}}{\log_e\{2.0\}} \qquad 0 \le F(j,k) \le 1$$

Fourier Spectrum



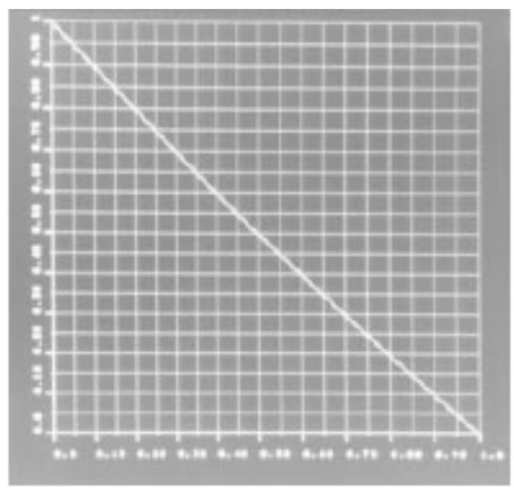
$0 \sim 1.5\times10^6 \longrightarrow$ 0~6.2

Useful for scaling image arrays with a very wide dynamic range

Contrast Manipulation

- **Reverse Function**

$$G(j,k) = 1 - F(j,k) \qquad 0 \le F(j,k) \le 1$$



(*a*) Reverse function

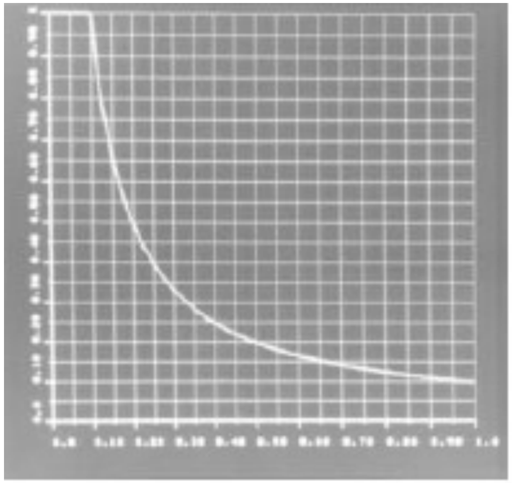
(*b*) Reverse function output

Able to see more details in dark areas of an image

Contrast Manipulation

- **Inverse Function**

$$G(j,k)=\begin{cases}1 & 0\le F(j,k)\le 0.1\\ \dfrac{0.1}{F(j,k)} & 0.1\le F(j,k)\le 1\end{cases}$$

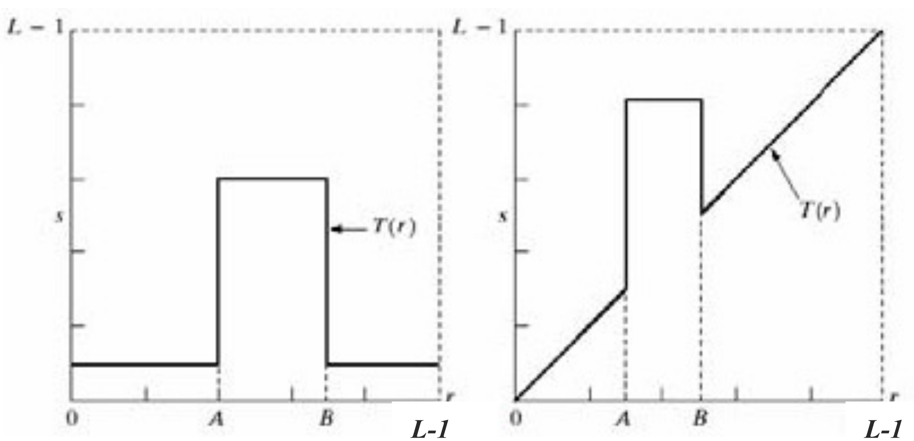


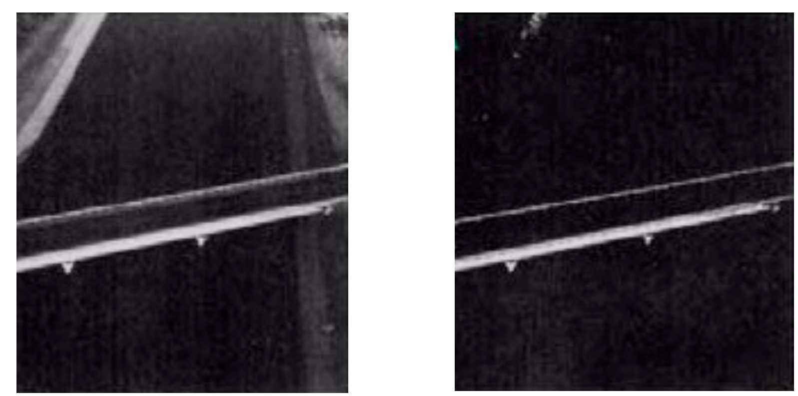
(c) Inverse function

(d) Inverse function output

Contrast Manipulation

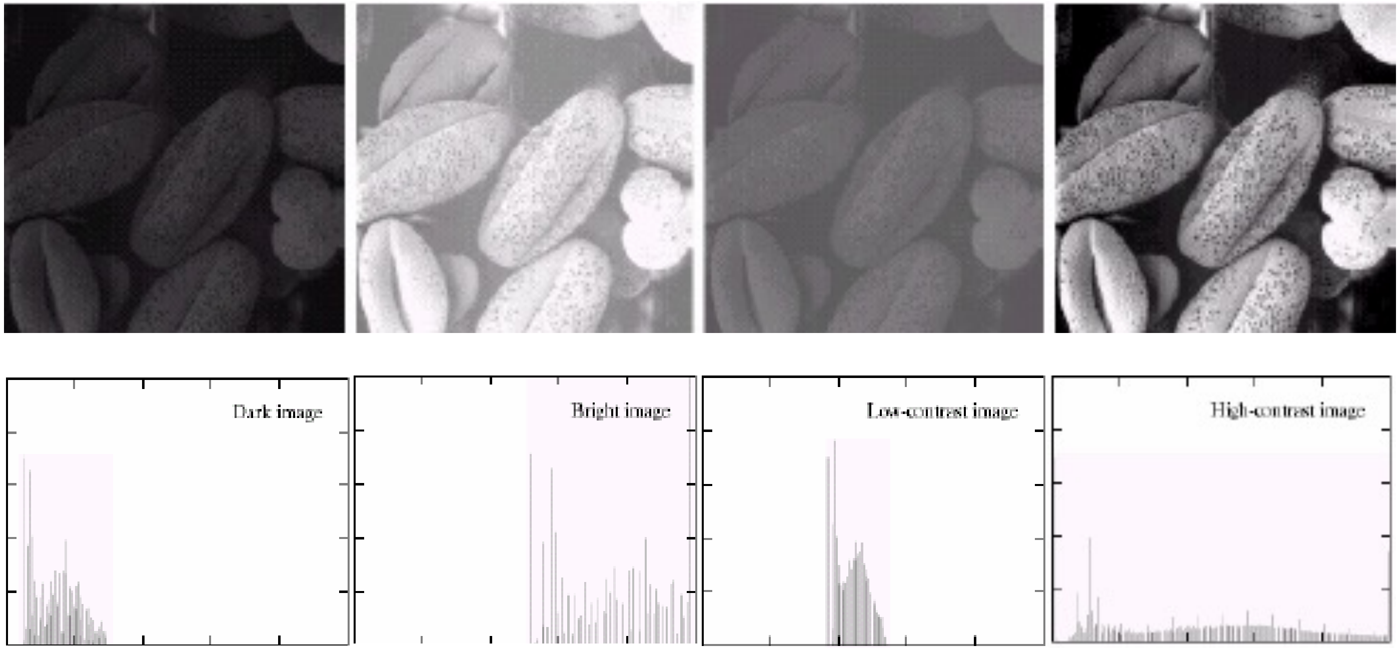
- **Amplitude-Level Slicing (Gray-Level Slicing)**





Histogram Modification

- **Goal**
  - Rescale the original image so that the histogram of the enhanced image follows some desired form

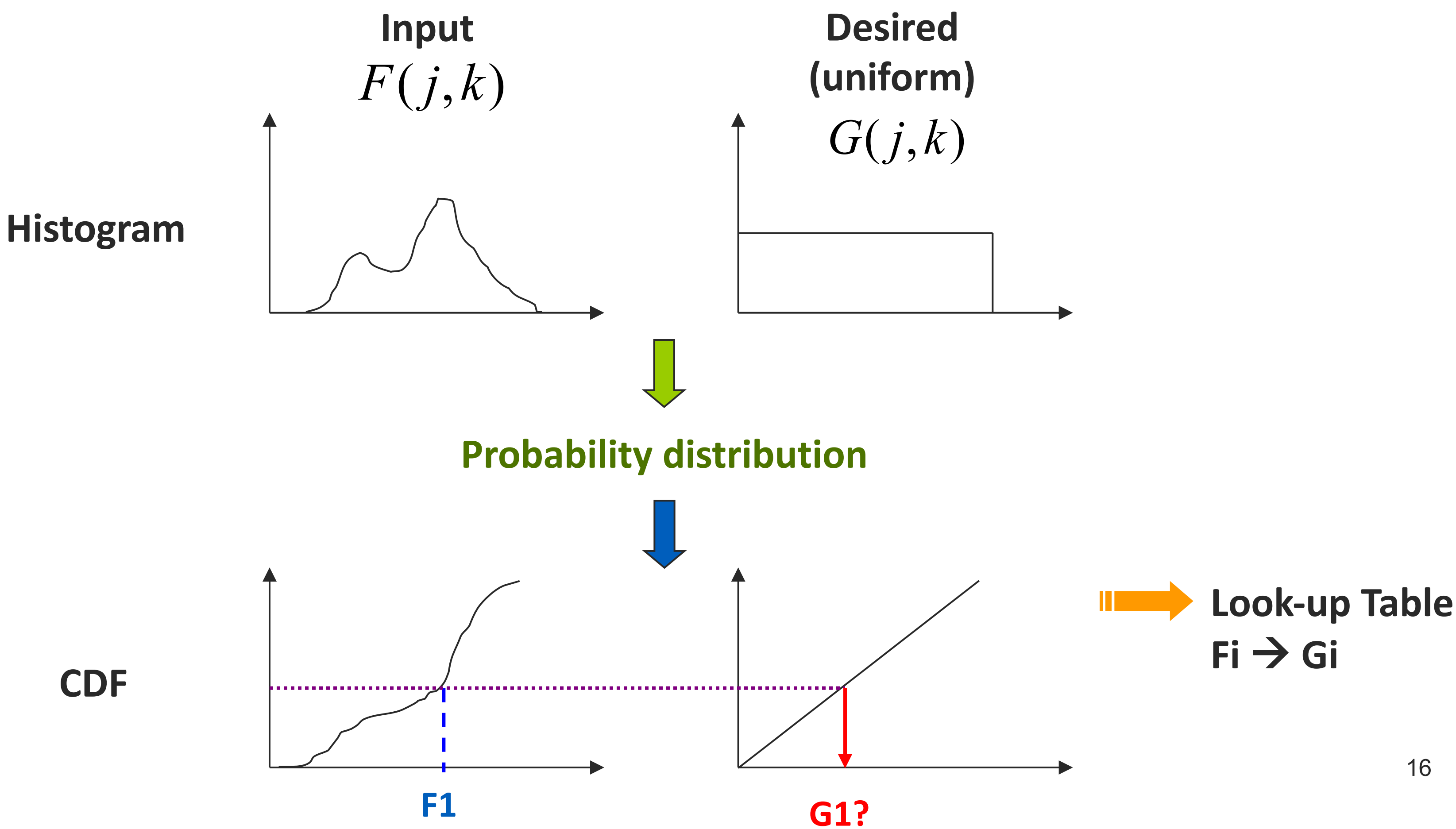


Histogram Modification

- Histogram Equalization
  - make the output histogram to be uniformly distributed
    - Transfer function
    - Bucket filling

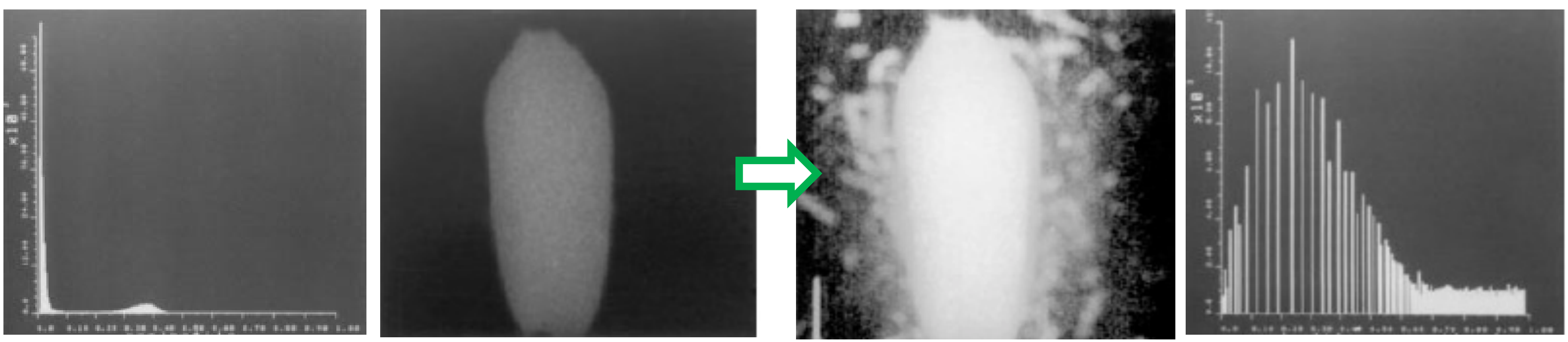
Histogram Equalization

- **Transfer Function**



Histogram Equalization

- Transfer Function
  - Output histogram not really uniformly distributed
  - Still keep the shape
  - More flat than the original histogram



Histogram Equalization

- Bucket Filling

arbitrary

F(j,k)	# of pixels
0	1
1	2
2	5
⋮	⋮
255	3

uniform

G(j,k)	# of pixels
0	N/256
1	N/256
2	N/256
⋮	⋮
255	N/256

N: # of total pixels

  - Not 1-1 mapping
  - Accumulated probability may not end exactly at the boundary of a bin → split it out

Reference

- Gamma correction
- Tone mapping
- HDR – High Dynamic Range Imaging

Noise Cleaning

Noise Cleaning

- **Noise**
  - electrical sensor noise
  - photographic grain noise
  - channel error
  - etc.
- **Characteristics of the noise**
  - discrete
  - not spatially correlated
  - higher spatial frequency

Noise Cleaning

- Two types of noise
  - Uniform Noise
    - Additive uniform noise, Gaussian noise
  - Impulse Noise
    - Salt and pepper noise

- Solutions
  - Uniform Noise → low-pass filtering
  - Impulse Noise → non-linear filtering

Basics of Spatial Filtering

- **Mask**
  - filter, kernel, template
  - m x n
    - m=2a+1, n=2b+1,
      where a and b are nonnegative integers
    - e.g. 3x3 mask

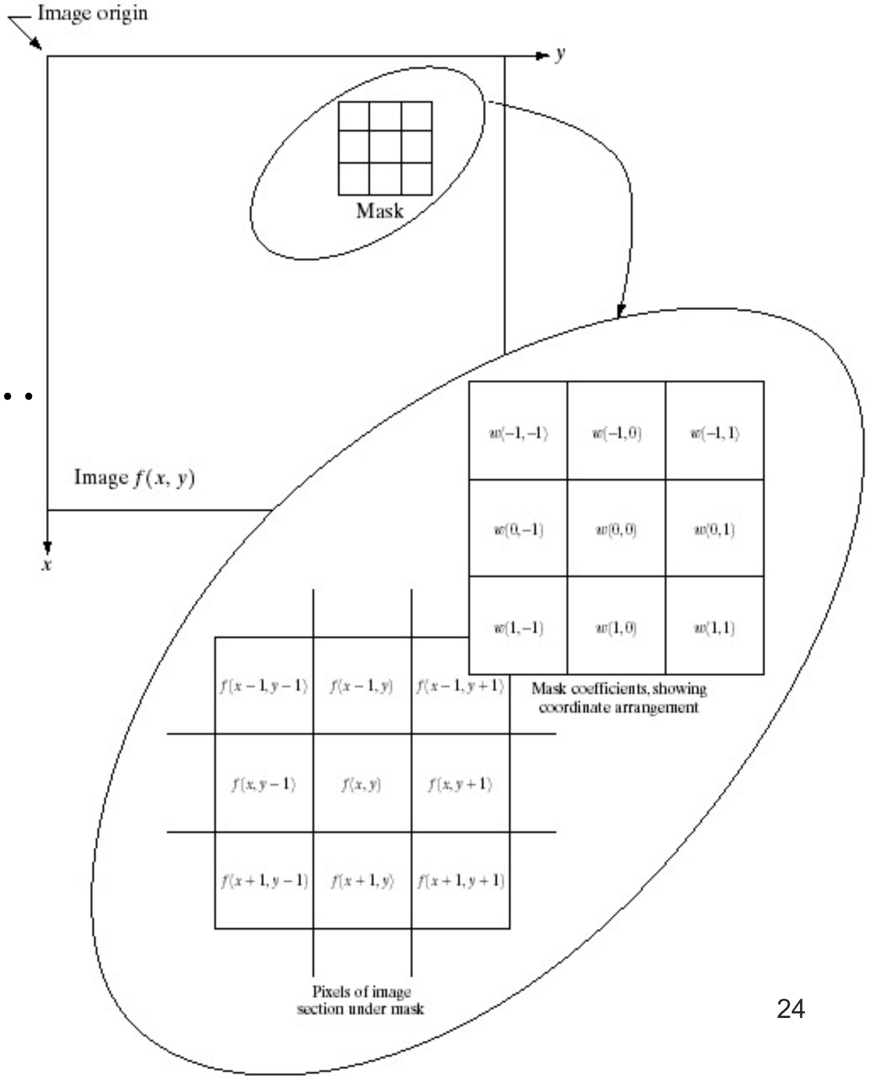
$w(-1,-1)$	$w(-1,0)$	$w(-1,1)$
$w(0,-1)$	W(0,0)	$w(0,1)$
$w(1,-1)$	$w(1,0)$	$w(1,1)$

- **Spatial Filtering/Convolution**

$$
\begin{aligned}
G(j,k) \quad = \quad & w(-1,-1)F(j-1,k-1) + w(-1,0)F(j-1,k) + \cdots \\
& + w(0,0)F(j,k) + \cdots \\
& + w(1,0)F(j+1,k) + w(1,1)F(j+1,k+1)
\end{aligned}
$$

Basics of Spatial Filtering

$$
\begin{aligned}
G(j,k) \quad = \quad & w(-1,-1)F(j-1,k-1) \\
& + w(-1,0)F(j-1,k) + \cdots \\
& + w(0,0)F(j,k) + \cdots \\
& + w(1,0)F(j+1,k) \\
& + w(1,1)F(j+1,k+1)
\end{aligned}
$$

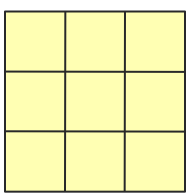


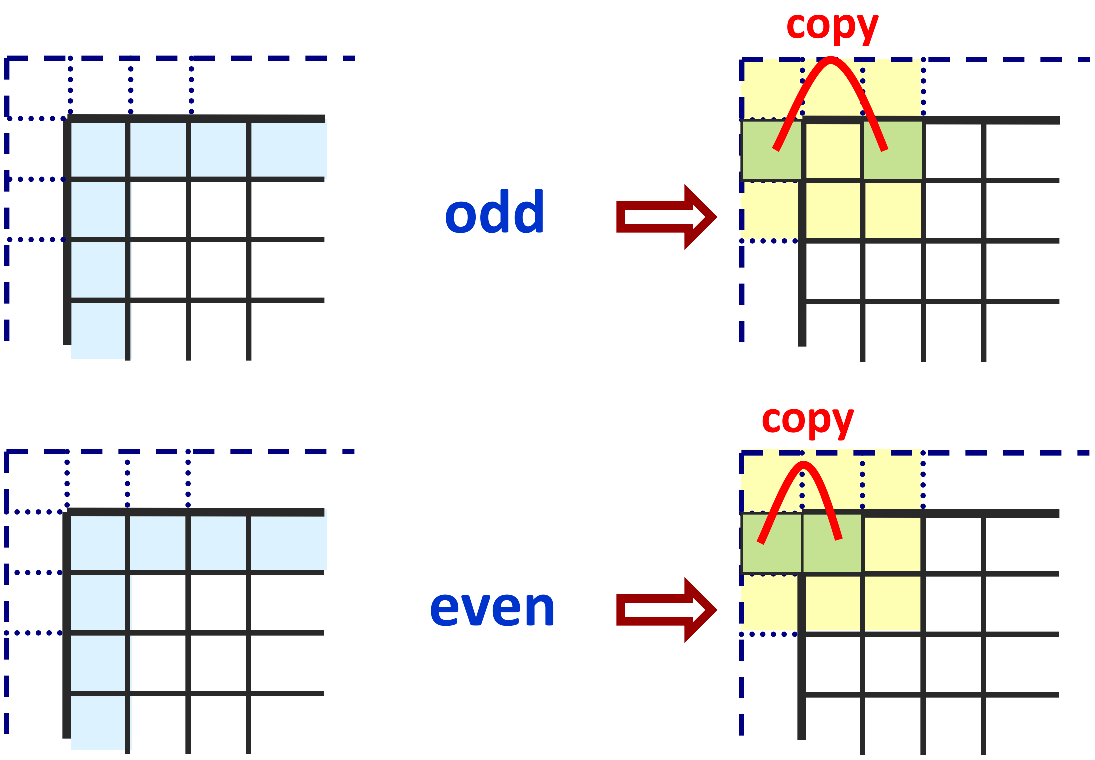
Q: Boundary pixels?

Basics of Spatial Filtering

- **Boundary Extension (3x3 mask)**

e.g.
3x3 mask, w





Q: 5x5 mask?

Noise Cleaning

- **Uniform noise**
  - **Perform low-pass filtering**

$$H = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \quad H = \frac{1}{10}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{bmatrix} \quad H = \frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

  - **General form**

$$H = \frac{1}{(b+2)^2}\begin{bmatrix} 1 & b & 1 \\ b & b^2 & b \\ 1 & b & 1 \end{bmatrix}$$

e.g.

$$F = \begin{bmatrix} 0 & 0 & 180 & 180 \\ 0 & 0 & 180 & 180 \\ 0 & 0 & 180 & 180 \\ 0 & 0 & 180 & 180 \end{bmatrix}$$

High Frequency Noise Removal

- Low-pass filtering
  - Normalized to unit weighting
  - Averaging
  - Smaller/Larger filter size ?

3x3

7x7

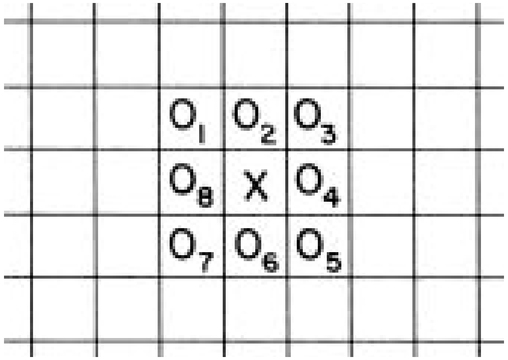
Noise Cleaning

- Impulse noise
  - black: pixel value =0 → dead sensor
  - white: pixel value=255 → saturated sensor

- Solutions
  - Outlier detection
  - Median filtering
  - Pseudo-median filtering (PMED)

Impulse Noise Removal

- **Outlier detection**



$$\text{if} \quad \left| x - \frac{1}{8}\sum_{i=1}^{8} O_i \right| > \varepsilon \qquad \text{then} \quad x = \frac{1}{8}\sum_{i=1}^{8} O_i$$

How to choose ε ?

Larger window?

Impulse Noise Removal

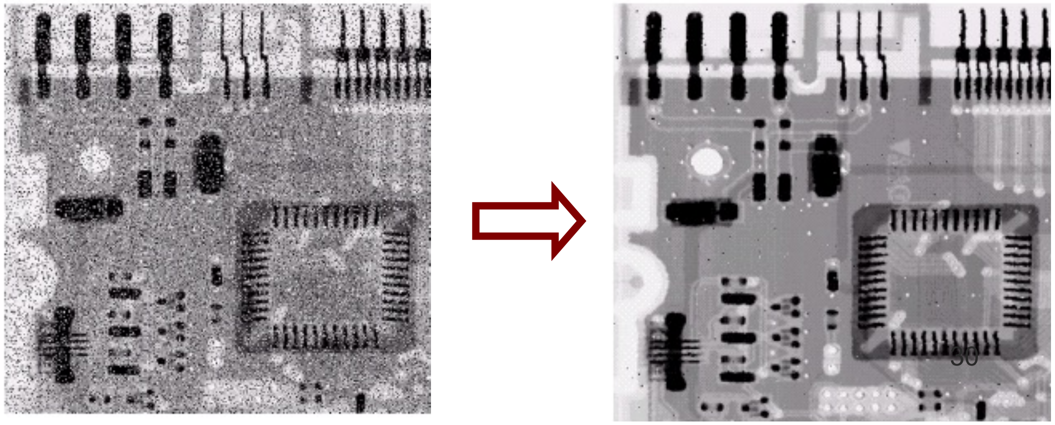
- **Median filtering**

  $$a_1, \ldots, a_N \quad where \quad N \quad is \quad odd$$

  - **sort those values in order**
  - **pick the middle one in the sorted list**
  - **e.g. 3x3 mask:**

$$I = \begin{bmatrix} 1 & 2 & 3 \\ 3 & 8 & 7 \\ 1 & 5 & 6 \end{bmatrix}$$

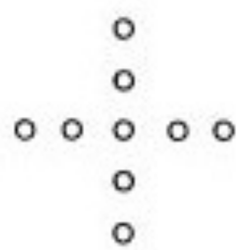
→ Median is 3



Impulse Noise Removal

- Median filtering
  - Preserve sharp edges
  - Effective in removing impulse noise
  - 1D/2D (directional)
    - e.g. 2D

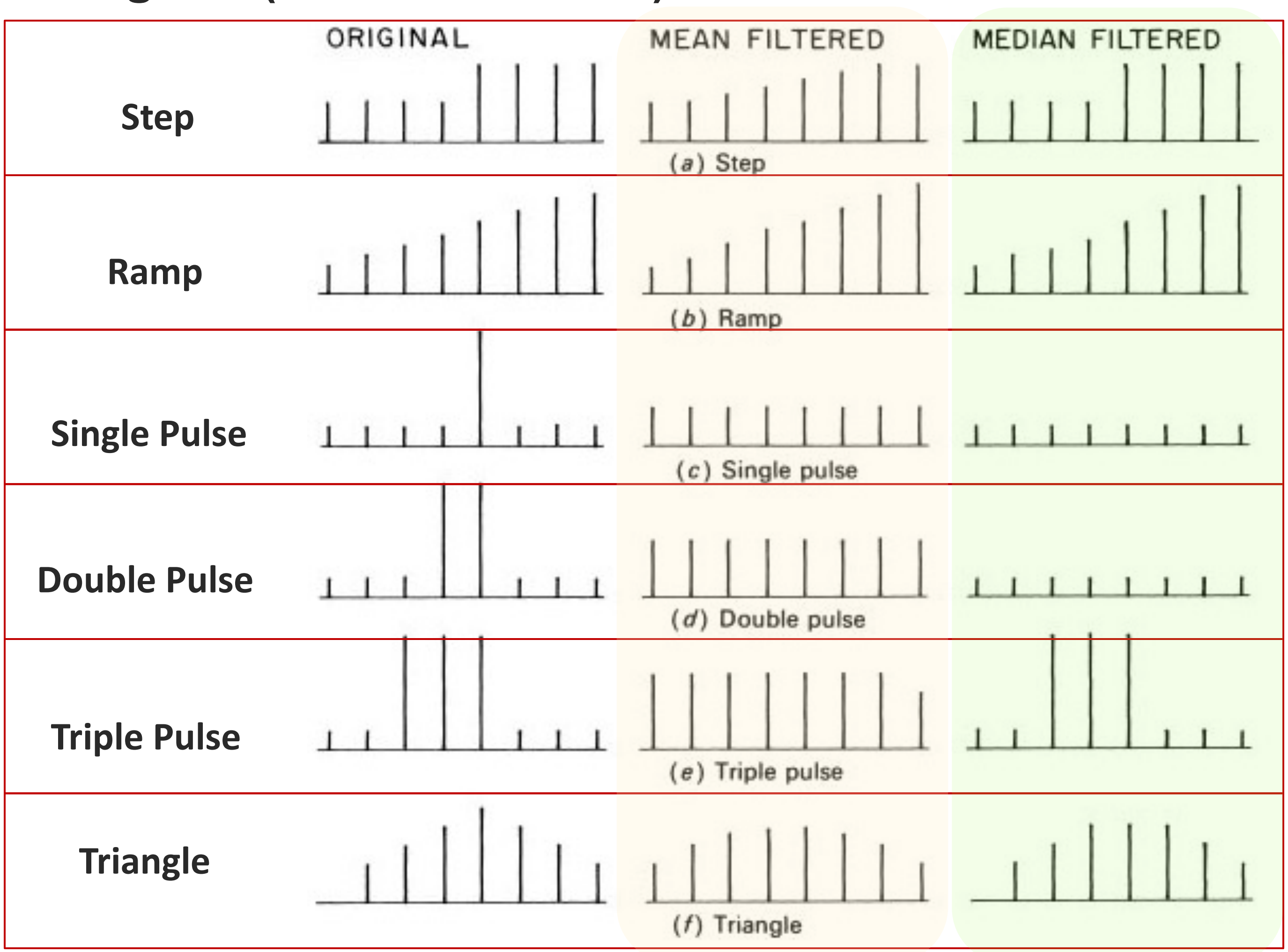
square



cross

Impulse Noise Removal

- e.g. 1D (window size = 5)



Impulse Noise Removal

- Median filtering
  - Fast computation
    - Approximation of median
      - e.g. 5-element filter

        a, b, c, d, e

        → MED(a, b, c, d, e)

        =max(min(a,b,c) , min(a,b,d), …)

        =min(max(a,b,c) , max(a,b,d), …)

        → there are 10 possible choices

        → could be narrowed down

Impulse Noise Removal

- Pseudomedian filtering (PMED)
  - e.g. 5-element filter

    a, b, c, d, e → spatially ordered

    MAXMIN = A (under estimated)

    = max(min(a,b,c) , min(b,c,d) , min(c,d,e))

    MINMAX = B (over estimated)

    = min(max(a,b,c) , max(b,c,d) , max(c,d,e))

    → PMED(a, b, c, d, e)

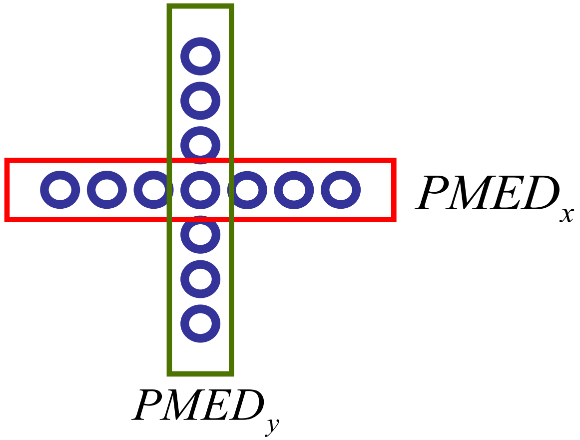
    = 0.5 * (A + B) = 0.5 * (MAXMIN + MINMAX)

    ~ MED(a, b, c, d, e)

Impulse Noise Removal

- **Pseudomedian filtering (PMED)**
  - **2D case**

$$PMED = \frac{1}{2}\left(PMED_x + PMED_y\right)$$



$$\begin{aligned} PMED &= \frac{1}{2}\max\left(MAXMIN(x_c), MAXMIN(y_R)\right) \\ &+ \frac{1}{2}\min\left(MINMAX(x_c), MINMAX(y_R)\right) \end{aligned}$$

Impulse Noise Removal

- Pseudomedian filtering (PMED)
  - MAXMIN
    - Remove salt noise
  - MINMAX
    - Remove pepper noise
  - May cascade two operations
    - Remove salt and pepper noise

Impulse Noise Removal

Original noisy image

MAXMIN

MINMAX of MAXMIN

MINMAX

MAXMIN of MINMAX

Q: same results?

Quality Measurement

- Peak signal-to-noise ratio (PSNR)
  - Mean squared error (MSE)

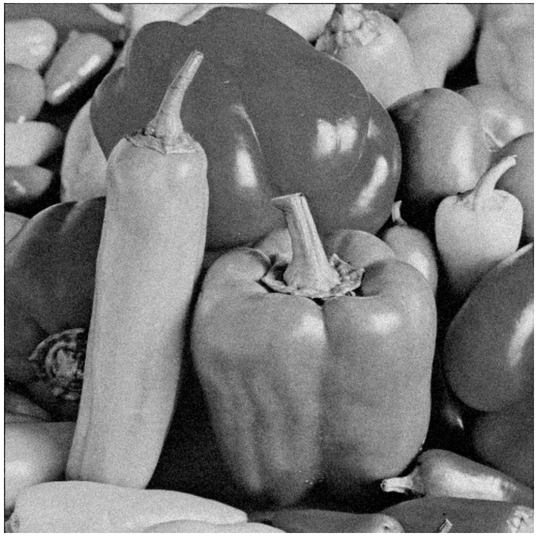
$$MSE = \frac{1}{w*h}\sum_j \sum_k \left[F(j,k) - F'(j,k)\right]^2$$

  - The PSNR is defined as

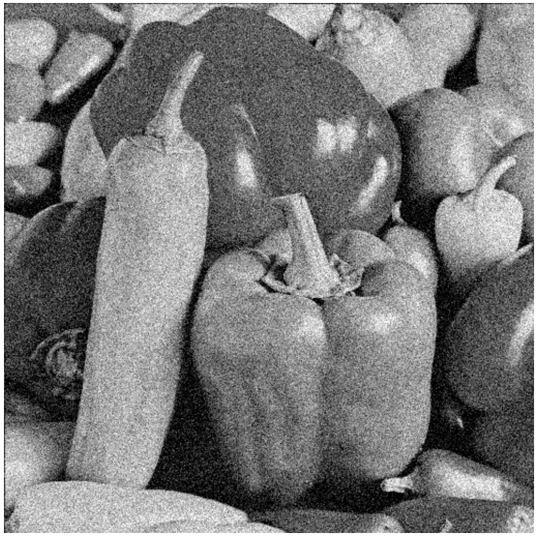
$$PSNR = 10 \times \log_{10}\left(\frac{255^2}{MSE}\right)$$

Example

Original image



Gaussian noise (σ=10)
PSNR : 28.18dB



Gaussian noise (σ=30)
PSNR : 18.81dB

Q: Does PSNR represent perceived visual quality?

Reference

- **EPLL**
  - Zoran, D., and Weiss, Y., "From learning models of natural image patches to whole image restoration," in IEEE International Conference on Computer Vision (ICCV), pp. 479-486, 2011.
- **BM3D**
  - Dabov, K., Foi, A., Katkovnik, V., and Egiazarian, K., "Image denoising by sparse 3-D transform-domain collaborative filtering," in IEEE Transactions on image processing (TIP), Vol. 16, No. 8, pp. 2080-2095, 2007.