ECE 472/572 - Digital Image Processing

Lecture 3 - Image Enhancement - Point Processing

08/30/11

Roadmap

- Introduction
  - Image format (vector vs. bitmap)
  - IP vs. CV vs. CG
  - HLIP vs. LLIP
  - Image acquisition
- Perception
  - Structure of human eye
    - rods vs. cones (Scotopic vision vs. photopic vision)
    - Fovea and blind spot
    - Flexible lens (near-sighted vs. far-sighted)
  - Brightness adaptation and Discrimination
    - Weber ratio
    - Dynamic range
  - Image resolution
    - Sampling vs. quantization
- Image enhancement
  - Enhancement vs. restoration
  - Spatial domain methods
    - Point-based methods
      - Negative
      - Log transformation
      - Power-law
      - Contrast stretching
      - Gray-level slicing
      - Bit plane slicing
      - Histogram equalization
      - Averaging
    - Mask-based (neighborhood-based) methods - spatial filter
  - Frequency domain methods

Questions

- Point-based vs. Mask-based (or neighbor-based)
- Spatial domain vs. Frequency domain
- Log transformation vs. Power-law
  - Gamma correction
  - Dynamic range compression
- Contrast stretching vs. Histogram equalization
  - Histogram
  - Uniform histogram
  - HE derivation (572)
- Gray-level vs. Bit-plane slicing
  - MSB
- What's the philosophy behind Image averaging?
  - Derivation (572)

Intuitively

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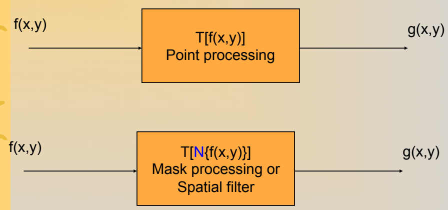
From system point of view



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Different approaches

- Spatial domain
  - Point-based processing
  - Mask-based processing (neighbor-based processing) (spatial filters)
- Frequency domain
  - Frequency domain filters

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Point processing

- Simple gray level transformations
  - Image negatives
  - Log transformations
  - Power-law transformations
  - Contrast stretching
  - Gray-level slicing
  - Bit-plane slicing
- Histogram processing
  - Histogram equalization
  - Histogram matching (specification)
- Arithmetic/logic operations
  - Image averaging

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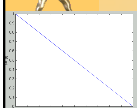
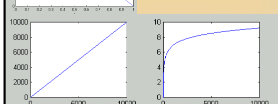
Some transformations

$$s = T(r) = L - 1 - r$$

$$s = T(r) = c\log(1 + |r|)$$

$$s = cr^{\gamma}$$

$$s = T(r) = mr + b$$

$$s = T(r) = \begin{cases} 255 & \text{if } A \le r \le B \\ 0 & \text{otherwise} \end{cases}$$

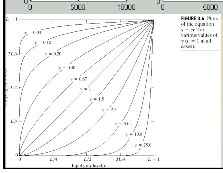
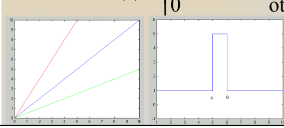



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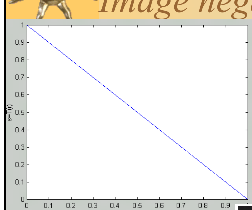
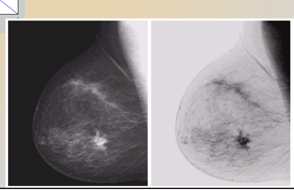
Image negatives



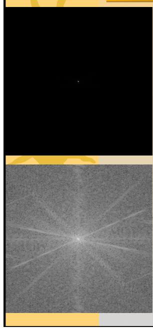
s = T(r) = L – 1 – r

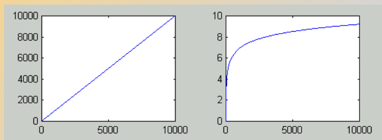


a b

FIGURE 3.4 (a) Original digital mammogram. (b) Negative image obtained using the negative transformation in Eq. (3.2-1). (Courtesy of G.E. Medical Systems.)

Log transformation (Dynamic range compression)





$$s = T(r) = c\log(1 + |r|)$$

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Power-Law transformation

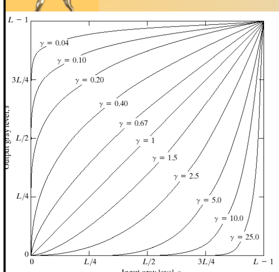
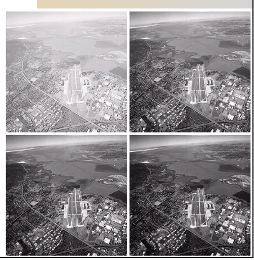


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).

$$s = cr^{\gamma}$$

a b
c d

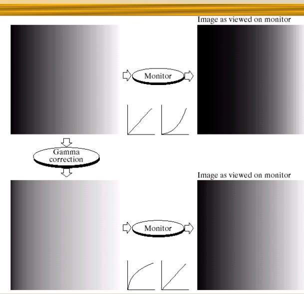
FIGURE 3.9 (a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0$, 4.0, and 5.0, respectively. (Original image for this example courtesy of NASA.)



Gamma correction

a b
c d

FIGURE 3.7 (a) Linear-wedge gray-scale image. (b) Response of monitor to linear wedge. (c) Gamma-corrected wedge. (d) Output of monitor.



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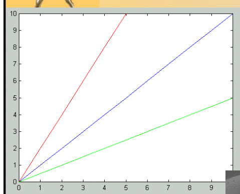
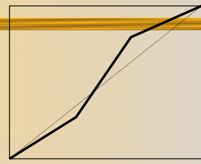
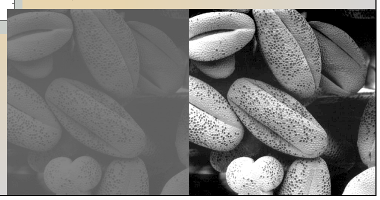
Contrast stretching

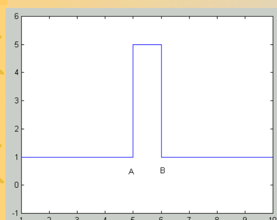




$$s = T(r) = mr + b$$

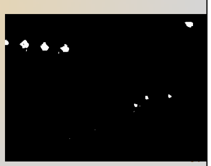


Gray-level slicing



Highlighting an intensity range

$$s = T(r) = \begin{cases} 255 & \text{if } A \le r \le B \\ 0 & \text{otherwise} \end{cases}$$



Bit-plane slicing

- Highlighting the contribution made by a specific bit.
- For pgm images, each pixel is represented by 8 bits.
- Each bit-plane is a binary image

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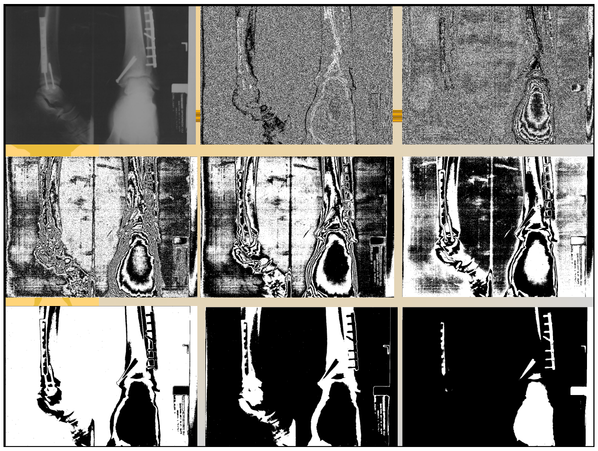

Point processing

- Simple gray level transformations
  - Image negatives
  - Log transformations
  - Power-law transformations
  - Contrast stretching
  - Gray-level slicing
  - Bit-plane slicing
- Histogram processing
  - Histogram equalization
  - Histogram matching (specification)
- Arithmetic/logic operations
  - Image averaging

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Histogram

- Gray-level histogram is a function showing, for each gray level, the number of pixels in the image that have that gray level.

$$n_k = hist[k] = \sum_{f(x,y)=k} 1$$

- Normalized histogram (probability):

$$p_k = n_k / N$$

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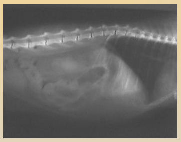
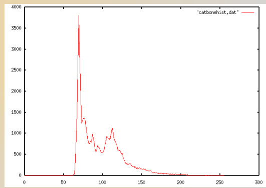
Histogram - Examples





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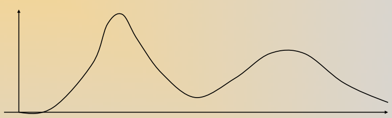
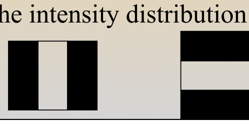
Usage of histogram

- Find threshold



- Reveal the intensity distribution



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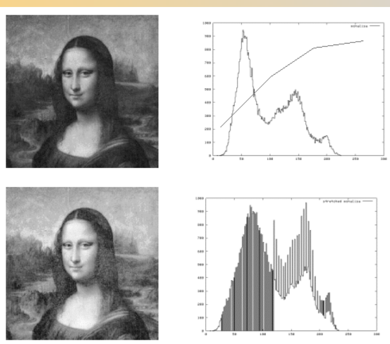

Figure 2. Monalisa and the results of contrast stretching

The histogram of Monalisa shows modes were gray level values accumulate we use linear stretching function in these areas (see upper right Figure), the resulting image and its histogram show a more balanced distribution of gray values.

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Question

- What does the histogram of a low-contrast image look like?
- How about high-contrast?

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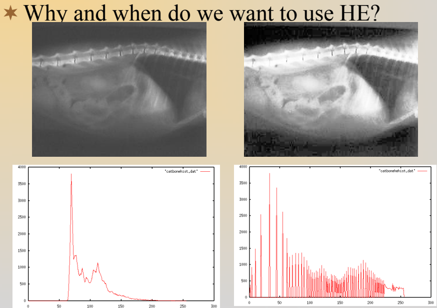
Histogram equalization

- Why and when do we want to use HE?



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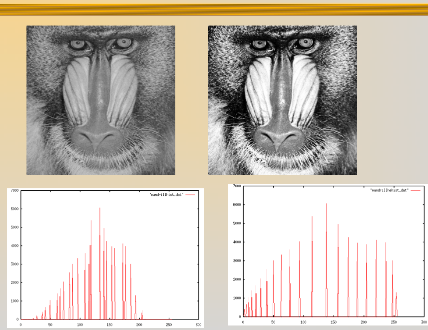
HE – Example 2



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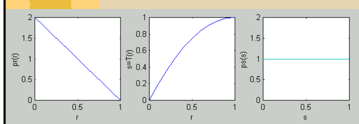
HE – Derivation (572)

$$s = T(r) \Rightarrow r = T^{-1}(s)$$

$$p_s(s) = \frac{p_r(r)}{\frac{ds}{dr}}$$

T(r) is single-valued and monotonically increasing within range of r
T(r) has the same range as r [0, 1]

$$s_k = T(r_k) = \sum_{j=0}^{k} \frac{n_j}{n} = \sum_{j=0}^{k} p_r(r_j)$$



$$s = T(r) = \int_0^r p_r(w)dw$$

$$p_s(s) = \frac{p_r(r)}{\frac{ds}{dr}} = \frac{p_r(r)}{p_r(r)} = 1$$

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Histogram equalization

- Transformation function

$$s = T(r) = \int_0^r p_r(w)dw \qquad 0 \le r \le 1$$

- $p_r(w)$ is the probability density function (*pdf*)
- The transformation function is the cumulative distribution function (CDF)
- To make the *pdf* of the transformed image uniform, i.e. to make the histogram of the transformed image uniform

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HE – Discrete case

$$s_k = T(r_k) = \sum_{j=0}^{k} \frac{n_j}{n} = \sum_{j=0}^{k} p_r(r_j)$$

r	hist(r)
0	10
1	70
2	15
3	5

→

r	s
0	10
1	80
2	95
3	100

→

s	hist(s)
10	10
80	70
95	15
100	5

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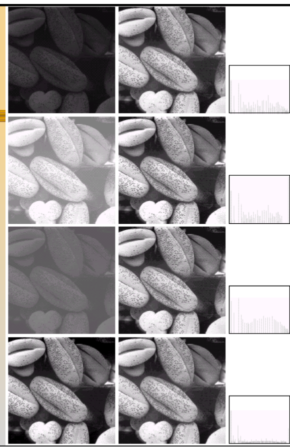

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HE - Discussion

- Can contrast stretching achieve similar result as histogram equalization?
- If it can, why histogram equalization then?
- Why isn't the transformed histogram uniform?

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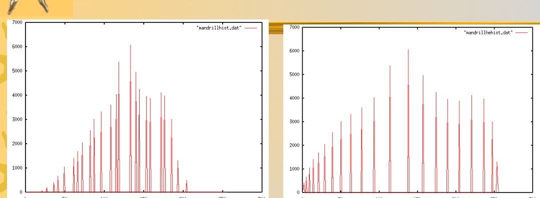

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Problems with HE

- ???
- Solutions
  - ???

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**Histogram specification*

- Step1: Equalize the levels of the original image
- Step2: Specify the desired pdf and obtain the transformation function
- Step3: Apply the inverse transformation function to the levels obtained in step 1

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HS - Example

r	hist(r)
0	10
1	70
2	15
3	5

r	s
0	10
1	80
2	95
3	100

r	z
0	10
1	30
2	60
3	65

Specified histogram

z	hist(z)
10	10
15	20
30	50
60	15

z	G(z)
10	10
15	30
30	80
60	95

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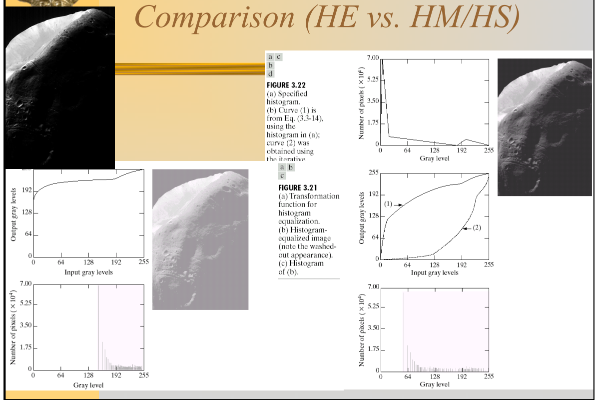
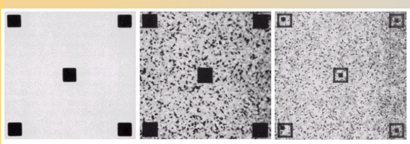
Comparison (HE vs. HM/HS)



Local enhancement



a b c

FIGURE 3.23 (a) Original image. (b) Result of global histogram equalization. (c) Result of local histogram equalization using a 7 × 7 neighborhood about each pixel.

Point processing

- Simple gray level transformations
  - Image negatives
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Image averaging

original image $f(x, y)$ → + → noisy image $g(x, y)$

noise $\eta(x, y)$

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

$$\sum_{i=0}^{M-1} g_i(x,y) = \sum_{i=0}^{M-1} f(x,y) + \sum_{i=0}^{M-1} \eta(x,y)$$

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

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Image average (cont')

- If the noise is uncorrelated and has zero expectation, then

$$E\{\bar{g}(x,y)\} = f(x,y)$$

$$\sigma^2_{\bar{g}(x,y)} = \frac{1}{M}\sigma^2_{\eta(x,y)}$$

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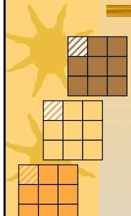
Image averaging – How to generate Gaussian noise? (572)



```
//This function creates a gaussian random number between -3 and 3
double gaussrand() {
  static double V1, V2, S;
  static int phase = 0;
  double X;

  if (phase == 0) {
    do {
      double U1 = (double)rand() / RAND_MAX;
      double U2 = (double)rand() / RAND_MAX;
      V1 = 2 * U1 - 1;
      V2 = 2 * U2 - 1;
      S = V1 * V1 + V2 * V2;
    } while(S >= 1 || S == 0);
    X = V1 * sqrt(-2 * log(S) / S);
  }
  else
    X = V2 * sqrt(-2 * log(S) / S);
  phase = 1 - phase;
  return X;
}
```

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Summary - Point processing

- Simple gray level transformations
  - Image negatives
  - Log transformations
  - Power-law transformations
  - Contrast stretching
  - Gray-level slicing
  - Bit-plane slicing
- Histogram processing
  - Histogram equalization
    - Derivation (572 only)
  - Histogram matching (specification) (572 only)
- Arithmetic/logic operations
  - Image averaging
    - Generation of Gaussian noise (572 only)

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