

# Image Enhancement:

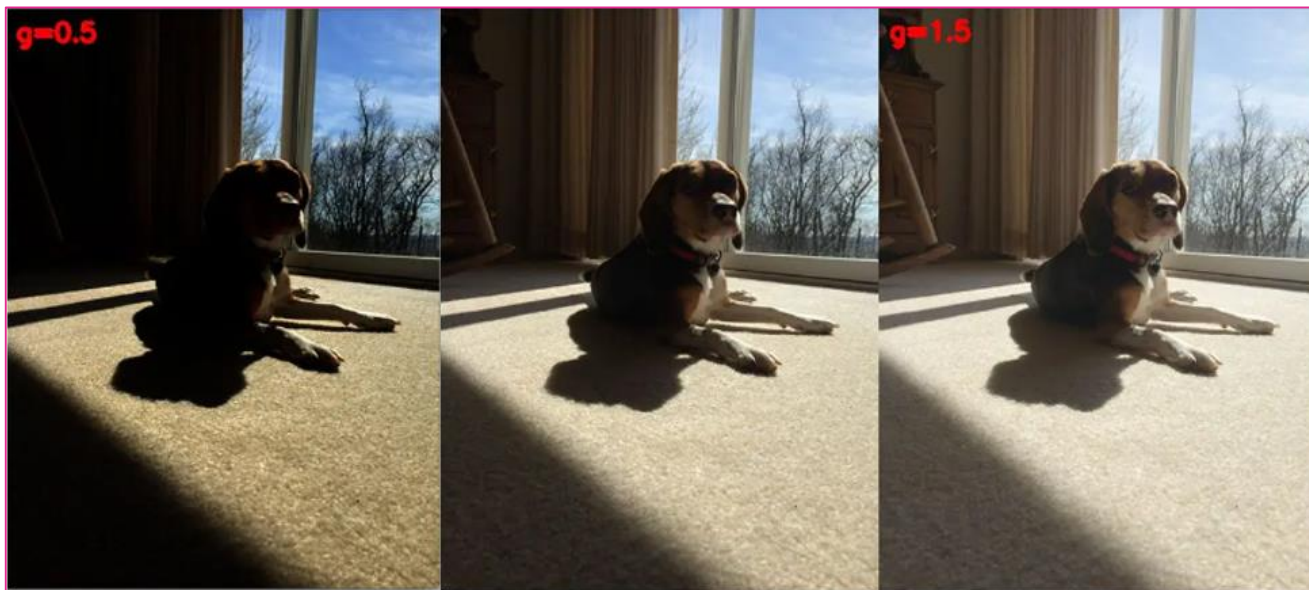
## Spatial domain

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Dr. Tushar Sandhan

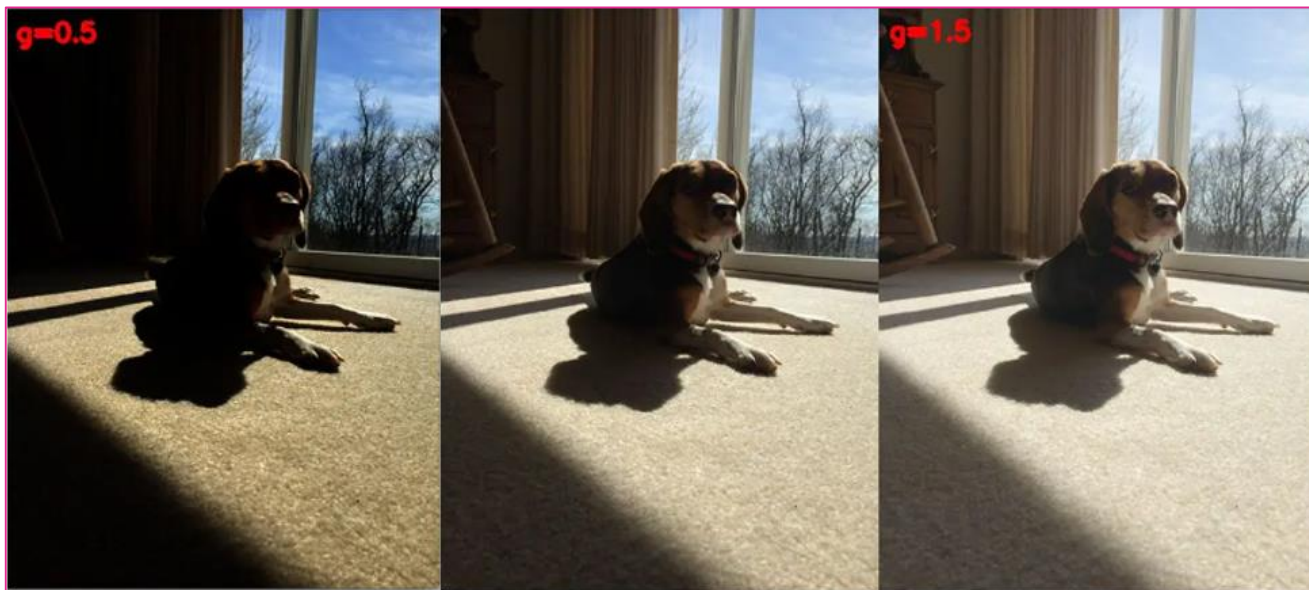
# Introduction

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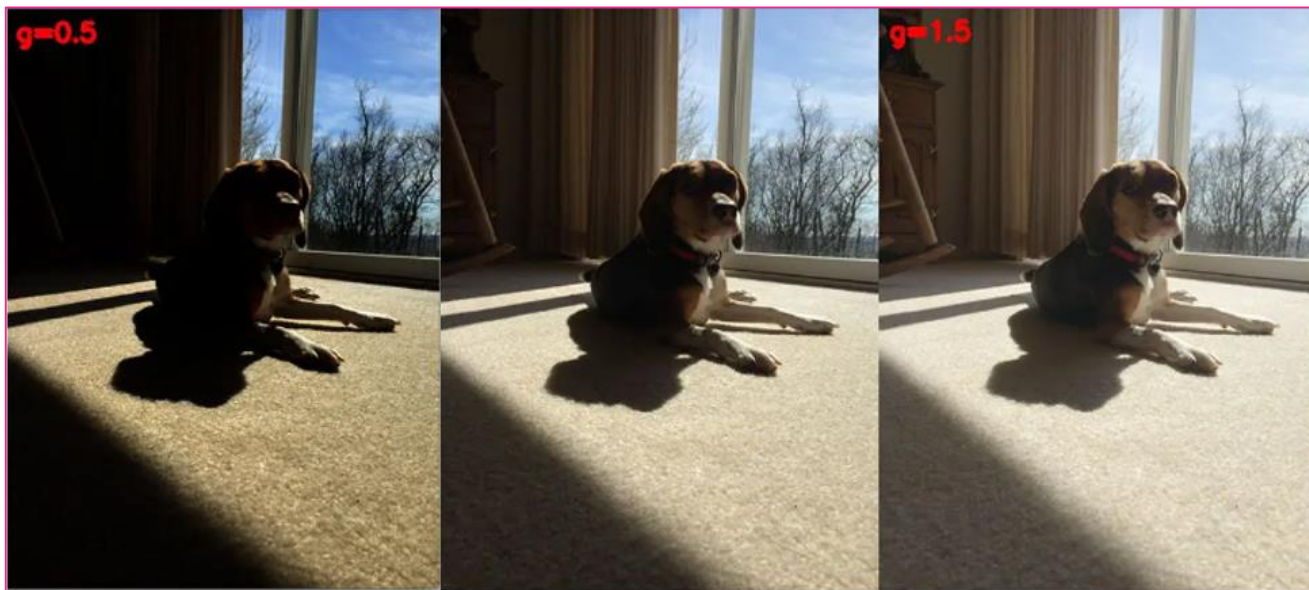
# Introduction

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# Introduction

- Intensity transformations



- Distribution transformation



# Spatial domain enhancements

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- Transformations

- intensity transformations

- negatives
    - logs
    - power-law (gamma)
    - contrast stretching
    - level slicing
    - bit-plane slicing

- distribution transformations

- histogram equalization

- Spatial filtering

- image filtering

# Spatial domain enhancements

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## ■ Transformations

### ○ intensity transformations

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### ○ distribution transformations

- histogram equalization

## ■ Spatial filtering

### ○ image filtering

$$g(x, y) = T_i(f(x, y))$$



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$$s \leftarrow r$$

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$$g(x, y) = T_i(p(f(x, y)))$$



# Negatives

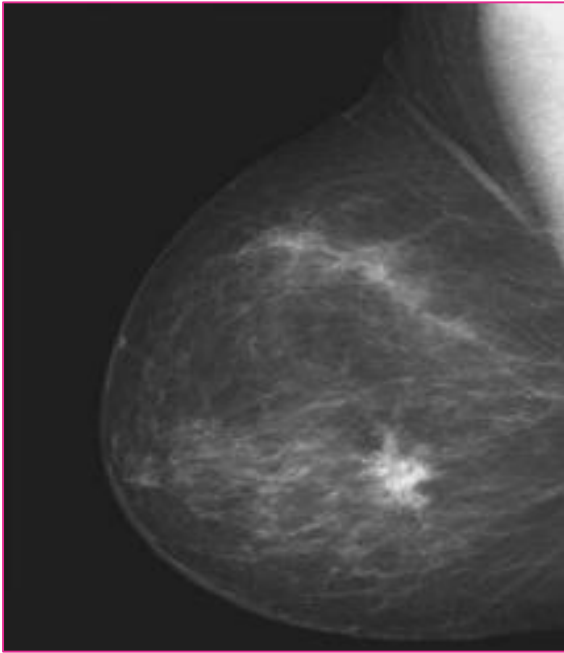
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$$s = L - 1 - r$$

# Negatives

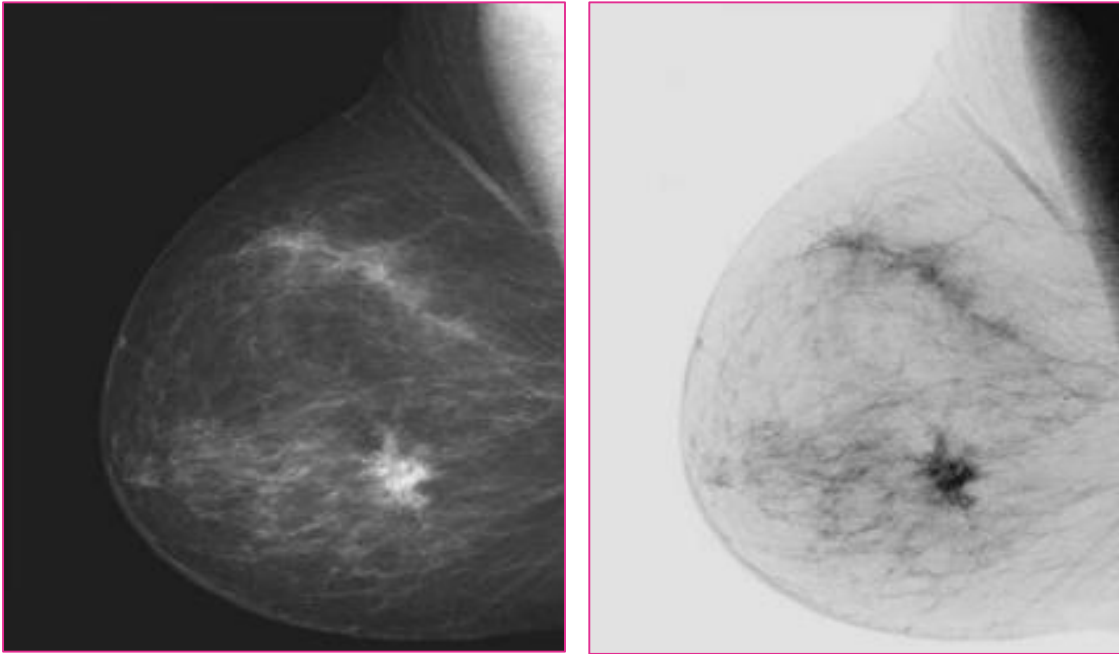
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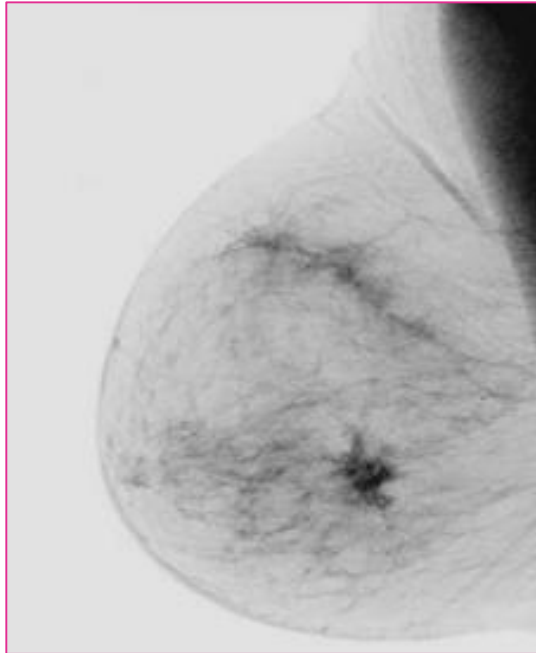
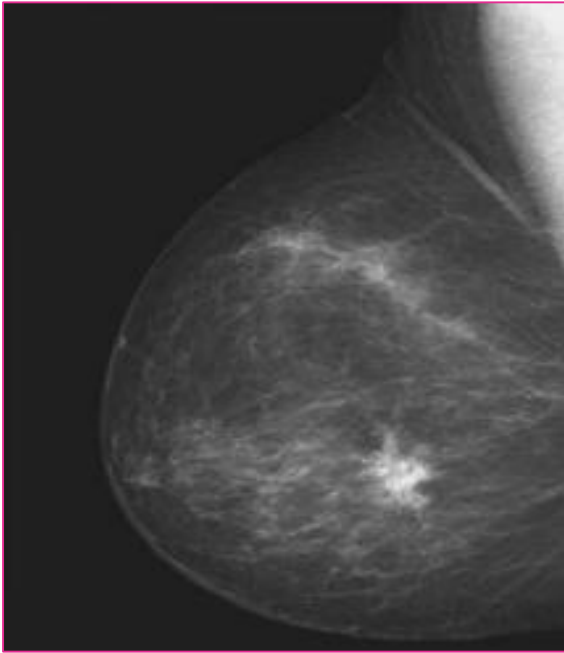
# Negatives

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# Logs

$$s = c \cdot \log(1 + r)$$

- Log transformations

- used to expand values of dark pixels
- simultaneously compressing bright pixels
- compresses dynamic range of images
  - Fourier spectrum

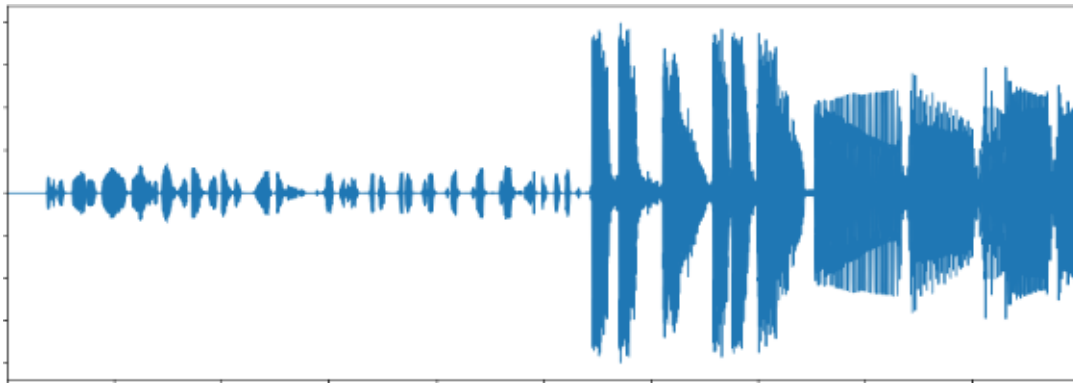


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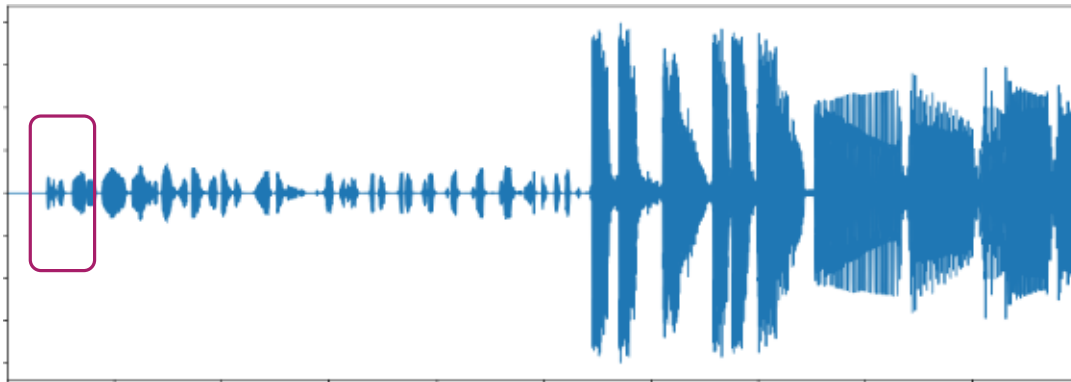


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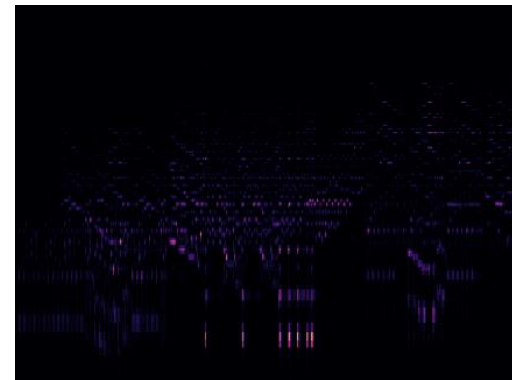
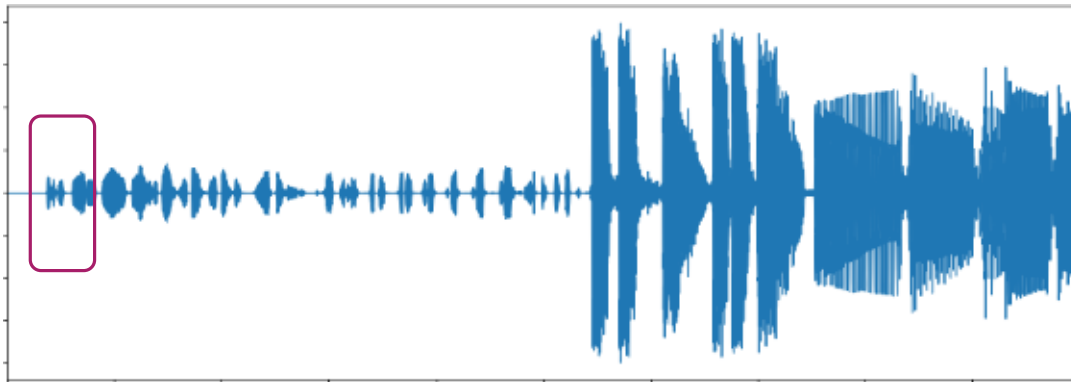


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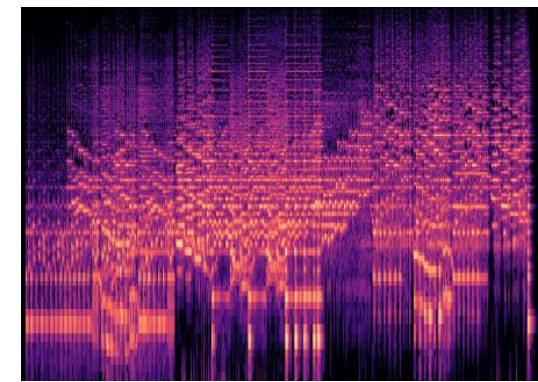
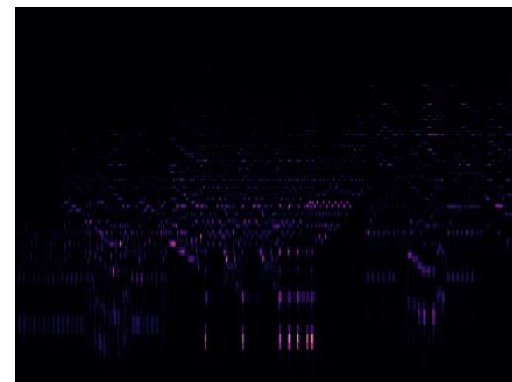
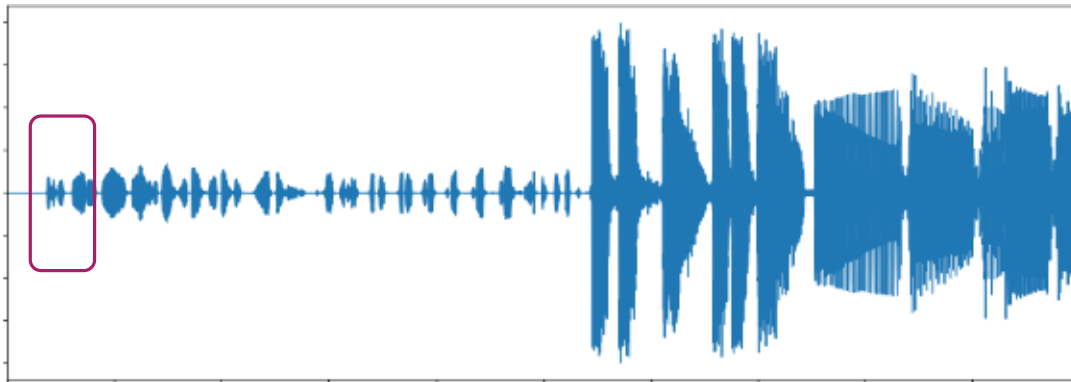


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# Gammas

$$s = c \cdot r^\gamma$$

- Power-law transformations

- sensors respond according to power law
  - CMOS, scanners, printing, displays
  - CRT: intensity to voltage response as power function ( $\gamma' = 1.8 \sim 2.5$ )
- gamma correction
  - device dependent  $\gamma$
  - $\gamma$  variation also varies the color ratios
  - correct color reproduction needs knowledge of  $\gamma$
- gamma injection
  - post image processing for contrast manipulation

# Gammas

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## ■ Power-law transformations

### ○ sensors respond according to power law

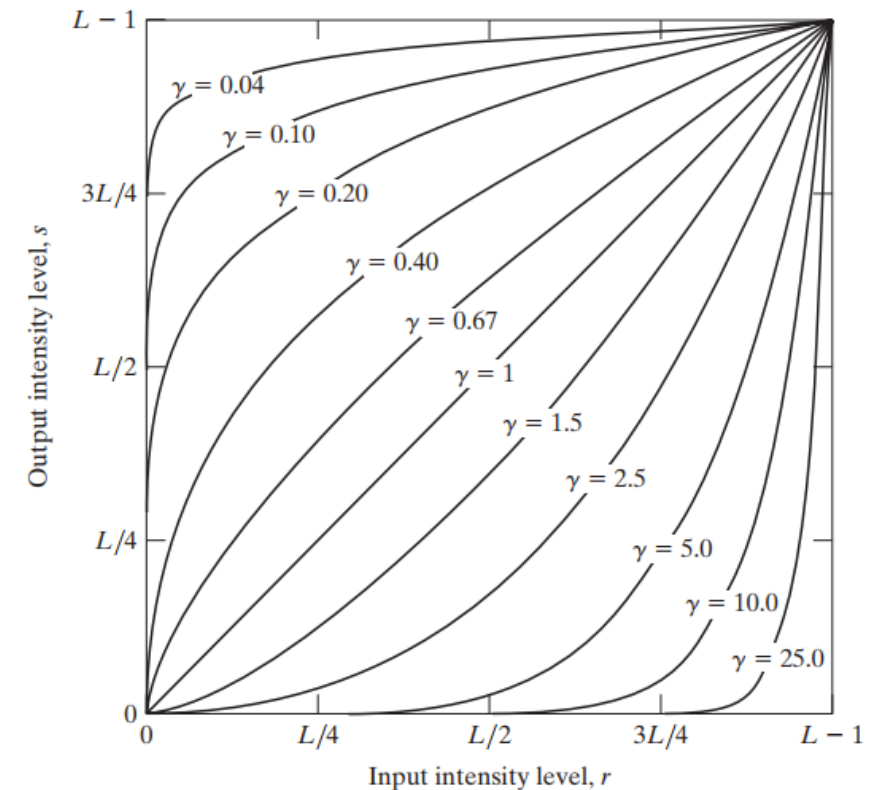
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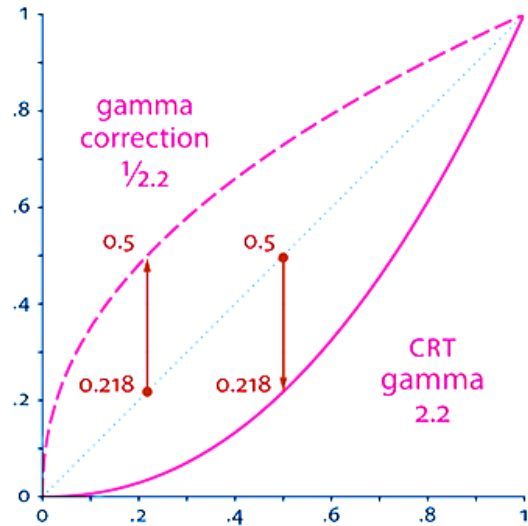
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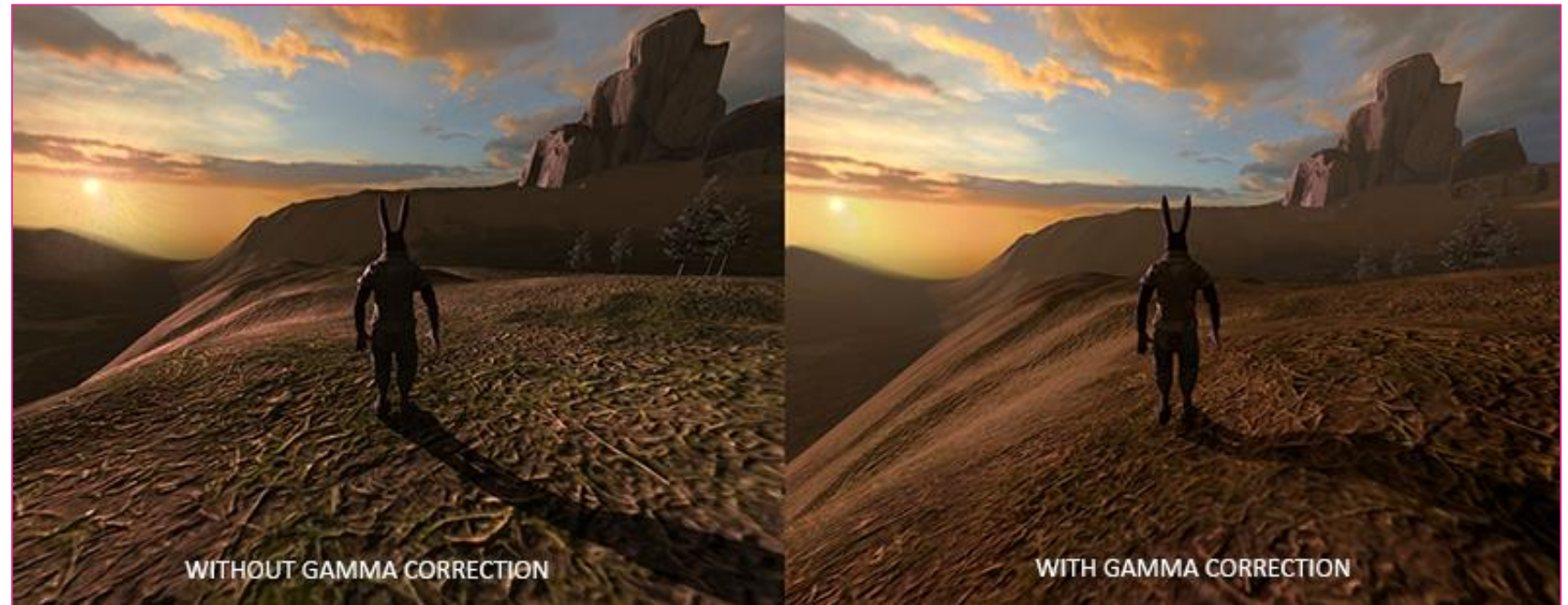
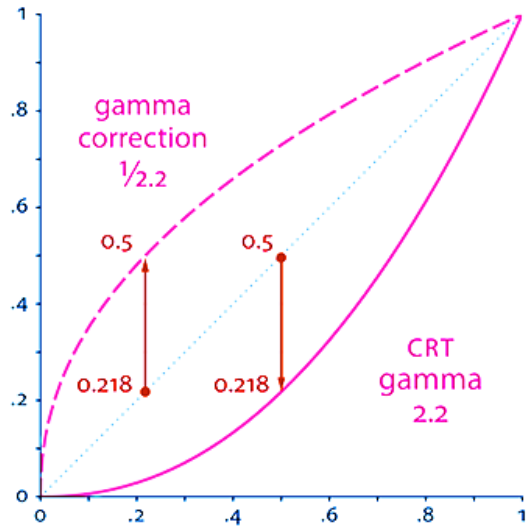
## ■ $\gamma$ correction



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credit: blog.wolfire.com

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1.0



0.6



0.4



0.3



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0.6



0.4



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1.0



3.0



4.0



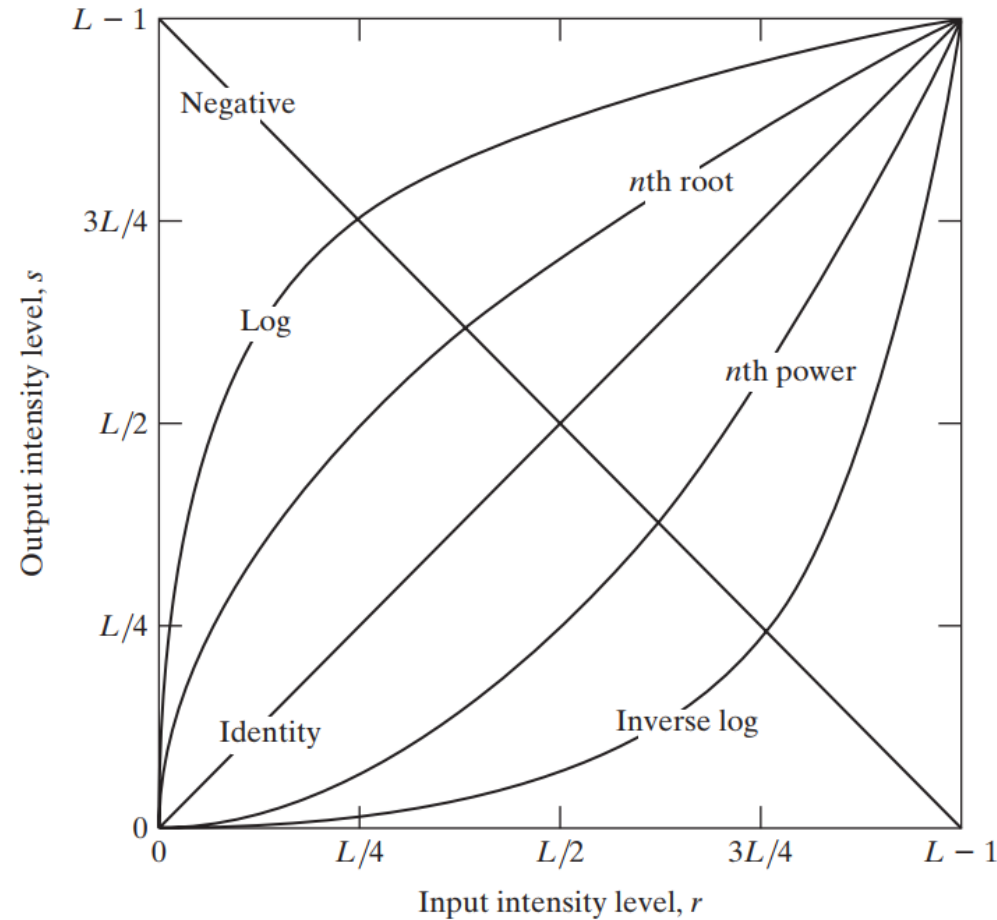
5.0



# Transformations

## ■ Compositions

- piecewise combinations
- piecewise linear
  - many  $T_i$  formulated with this
  - need more user input paras



# Contrast stretching

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- Contrast

- Low contrast images

- due to poor illumination, low dynamic range sensors
    - wrong setting of lens aperture

- full range stretching

- $(r_1, s_1) = (r_{min}, 0)$
    - $(r_2, s_2) = (r_{max}, L - 1)$

- thresholding

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70~140

0~255

pixel ranges



# Contrast stretching

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### ○ Low contrast images

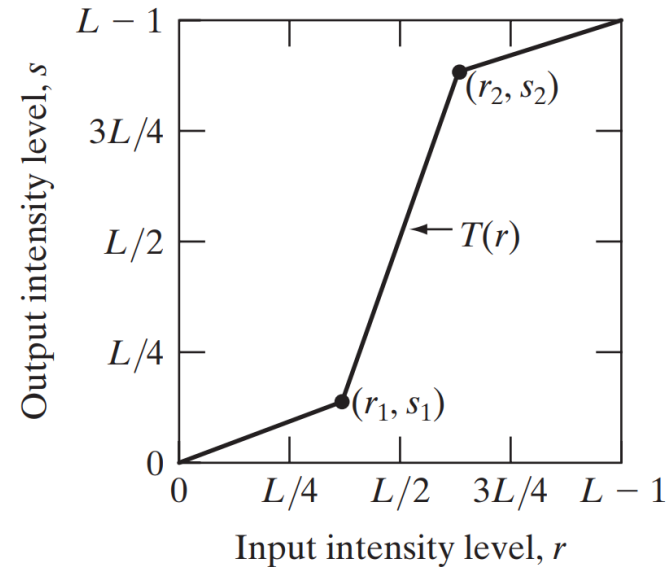
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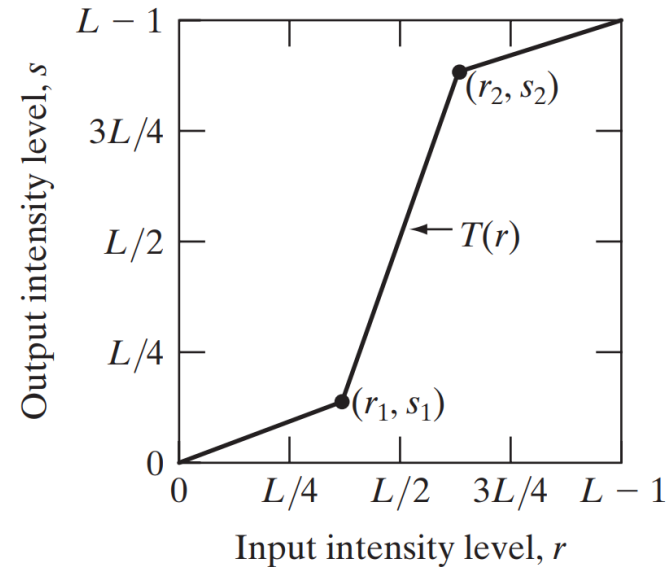
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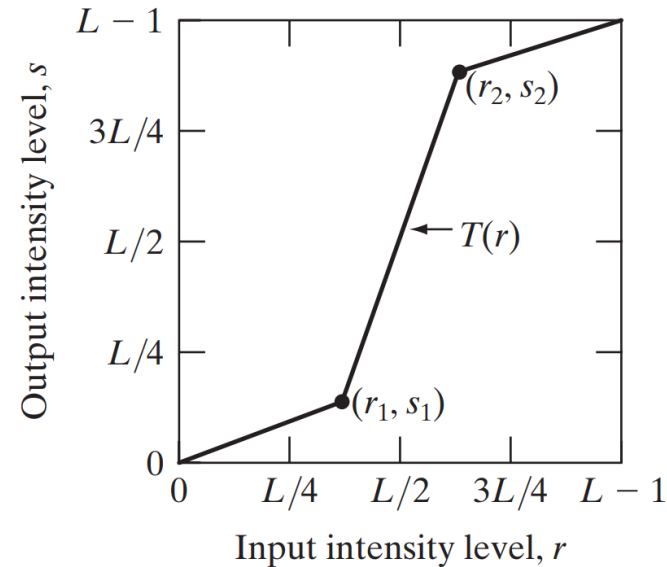
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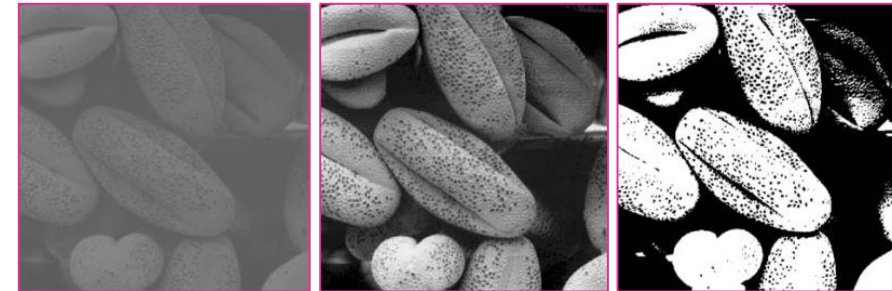


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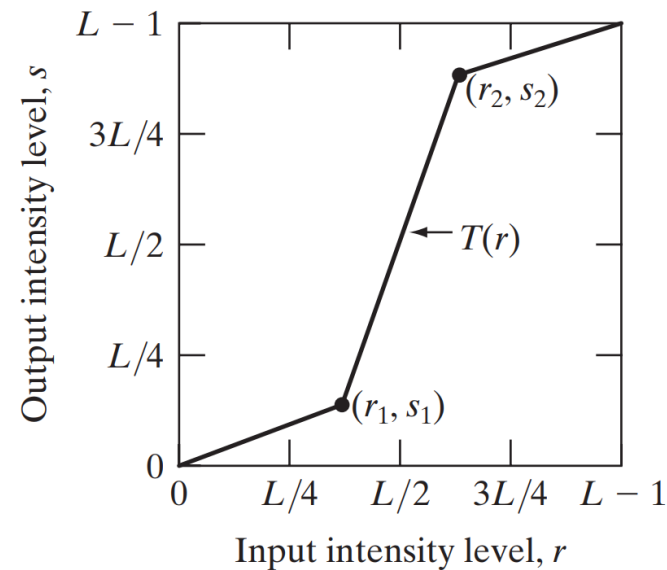
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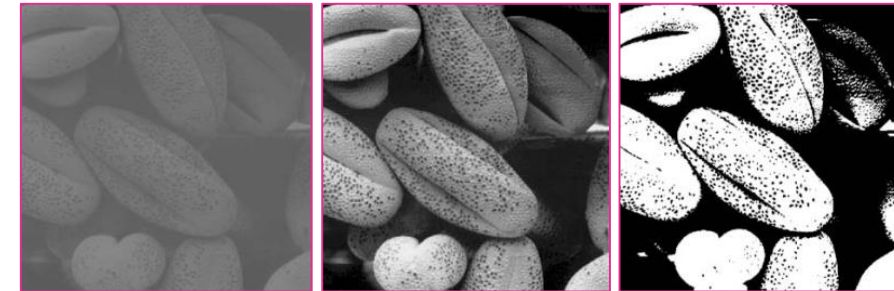
70~140



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pixel ranges

SEM image of pollen grains



# Level slicing

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- Intensity levels
  - local thresholding, stretching
  - enhancing only specific intensities
    - e.g. detecting water, wetland in sat. images

# Level slicing

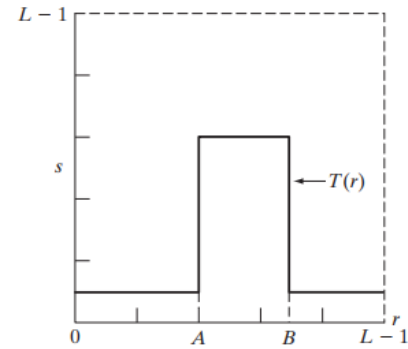
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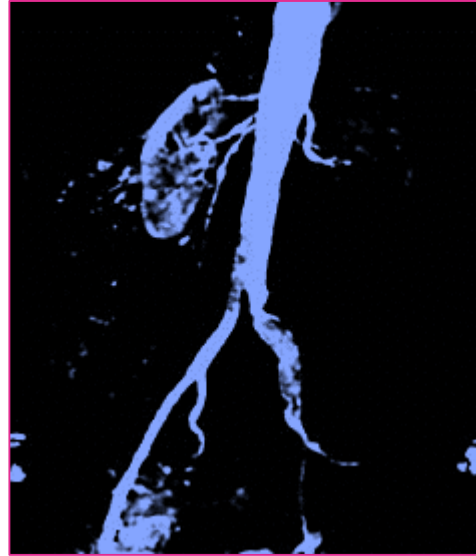
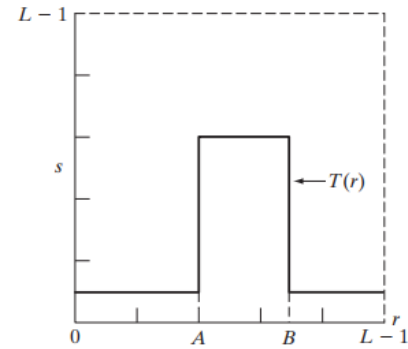
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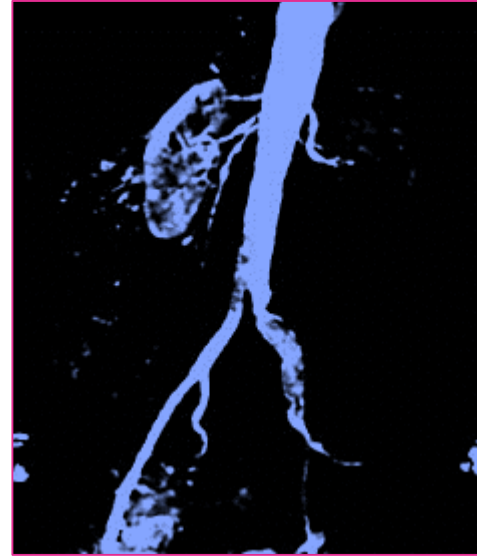
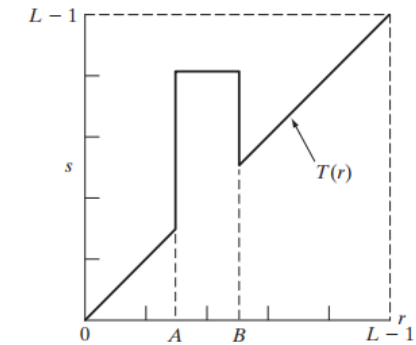
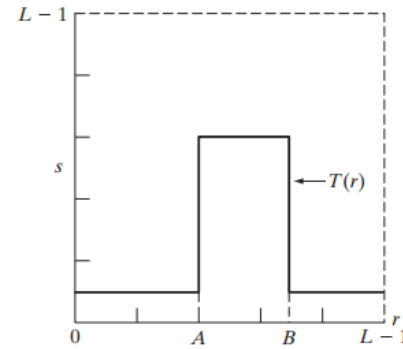
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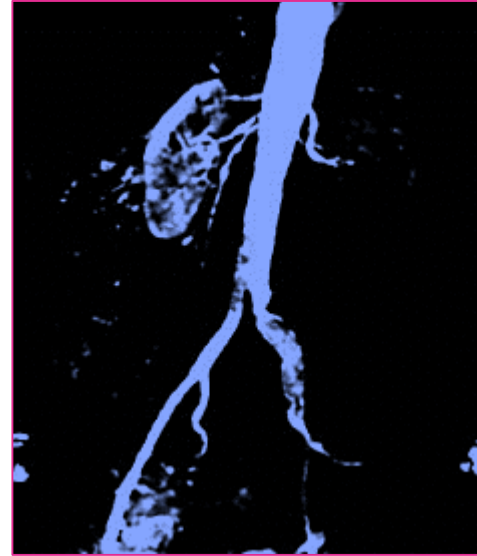
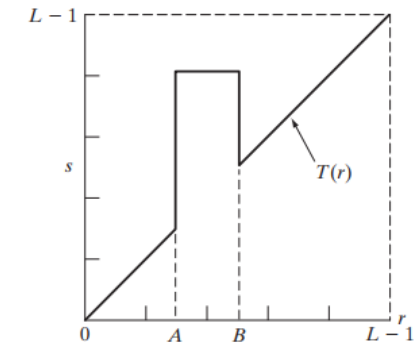
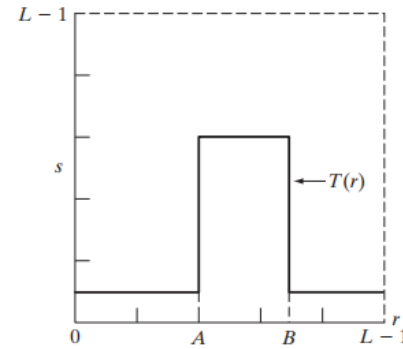
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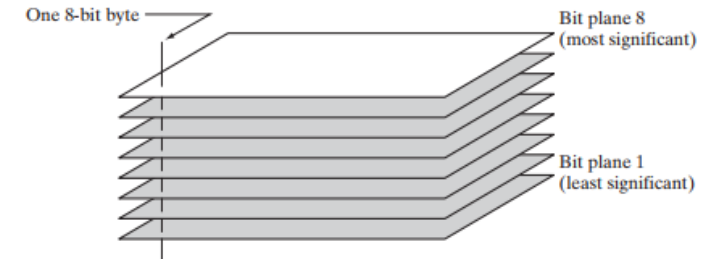
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# Bitplane slicing

- Bitplanes

- contribution of each bit for total image appearance
- gives clue for a compression

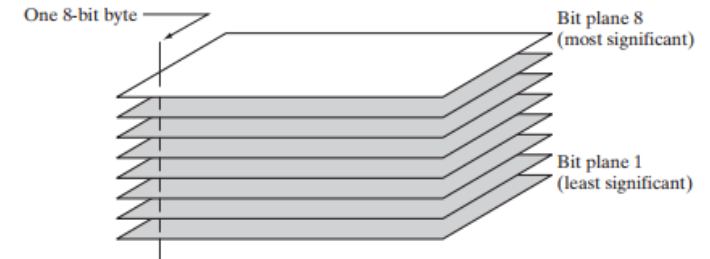


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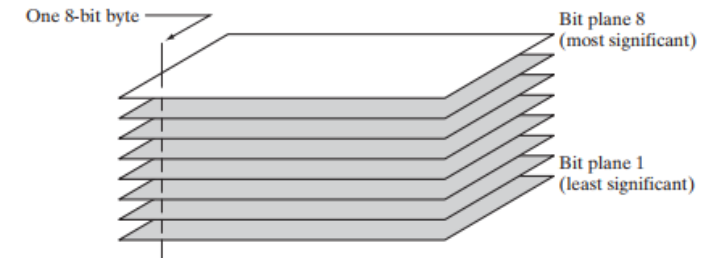


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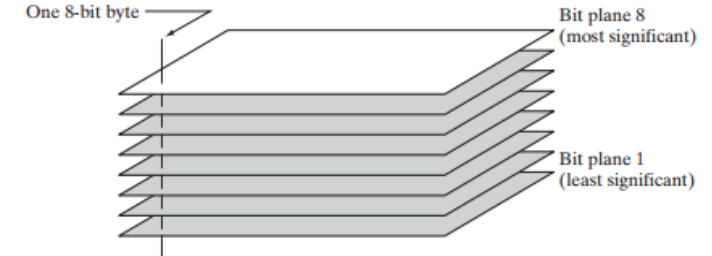


- reconstruction

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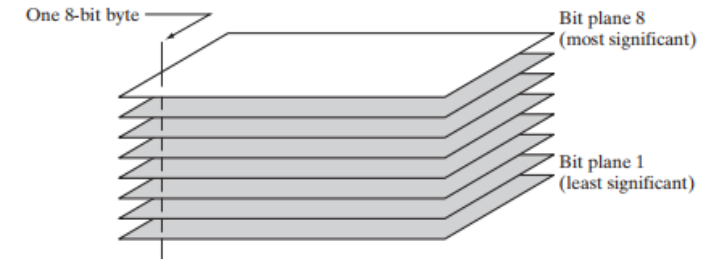
- bitplanes (8+7)



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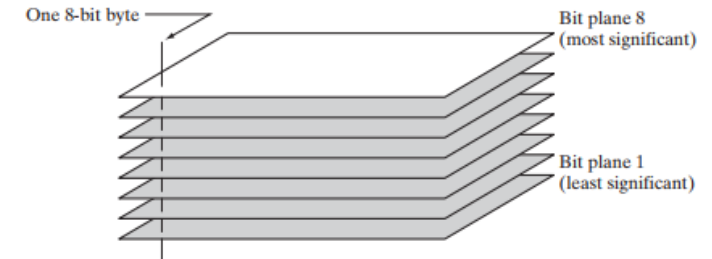


- bitplanes (8+7)
- bitplanes (8+7+6)

# Bitplane slicing

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- bitplanes (8+7)
- bitplanes (8+7+6)
- bitplanes (8+7+6+5)



# Spatial domain enhancements

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## ■ Transformations

### ○ intensity transformations

- negatives
- logs
- power-law (gamma)
- contrast stretching
- level slicing
- bit-plane slicing

### ○ distribution transformations

- histogram equalization

## ■ Spatial filtering

### ○ image filtering

$$g(x, y) = T_i(f(x, y))$$



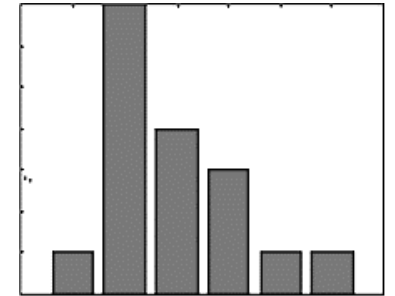
$$s \leftarrow r$$

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# Histograms

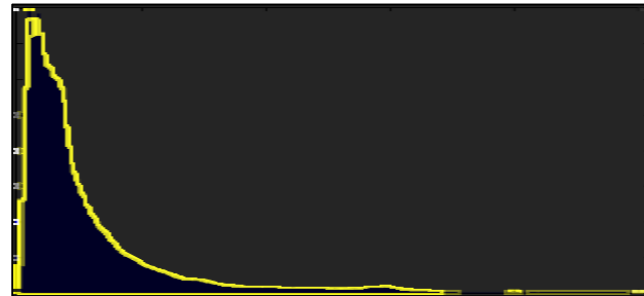
- distribution of discrete intensities
  - distribution is also discrete

4	1	3	2
3	1	1	1
0	1	5	2
1	1	2	2

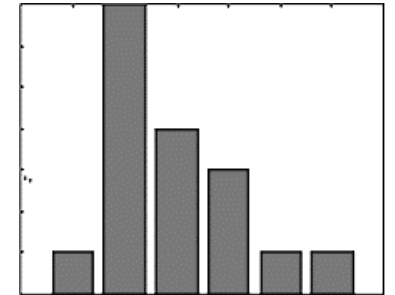


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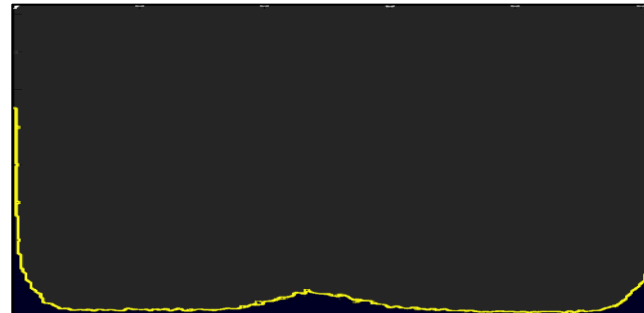
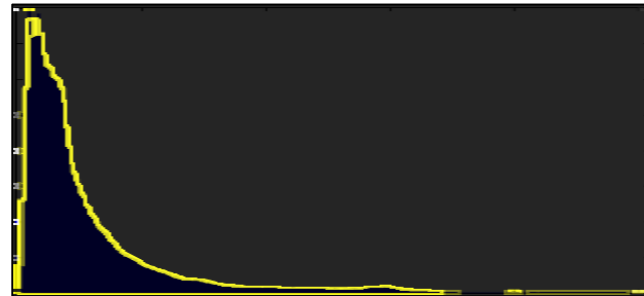


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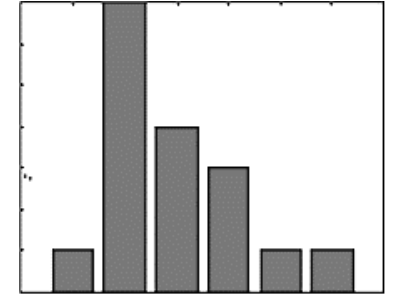


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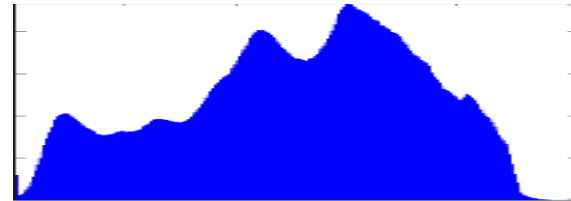
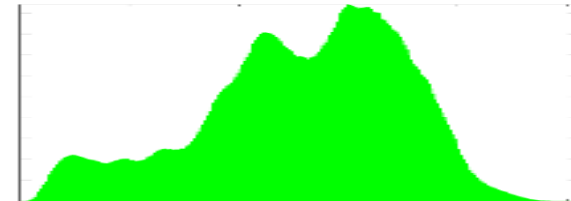
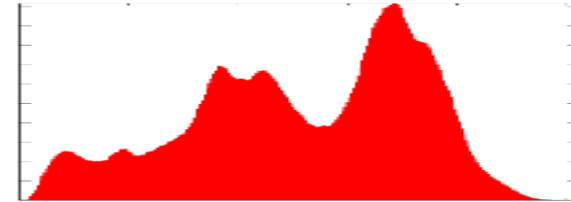
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- Color images



# Histograms

- Color images

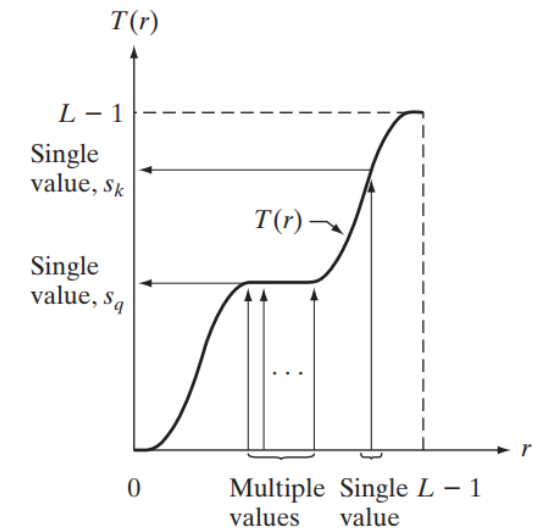
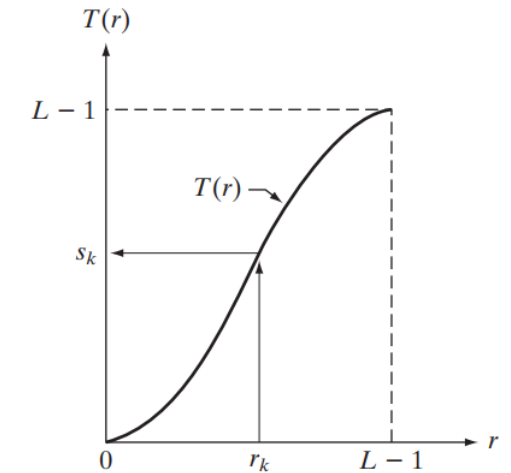


# Histogram equalization

- Assume

- $T(r)$  is monotonic  $\uparrow$
- bounded  $0 \leq T(r) \leq L - 1$
- variable equivalence
  - to cover all notations

$$s = T(r) \quad 0 \leq r \leq L - 1$$

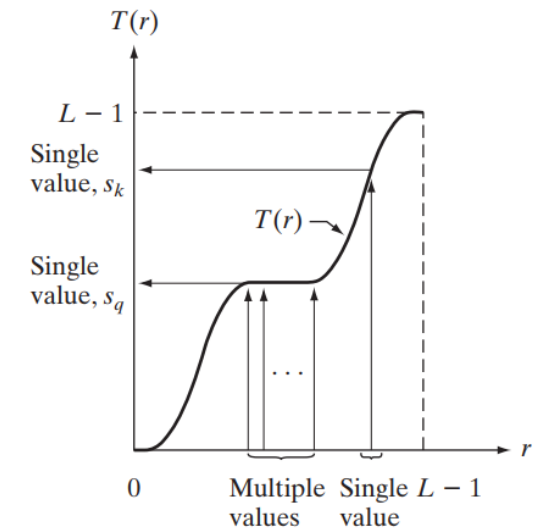
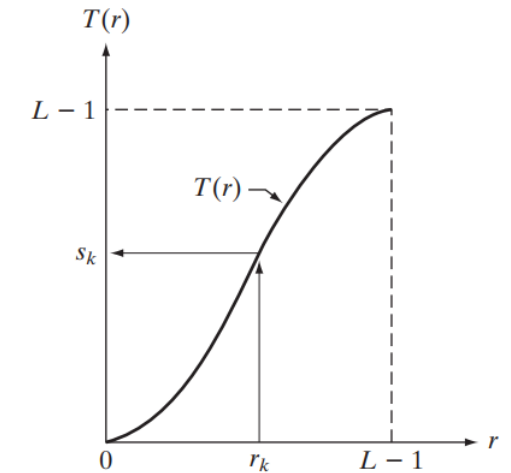


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$$Y = T(X) \quad 0 \leq r \leq L - 1$$
$$s = T(r)$$




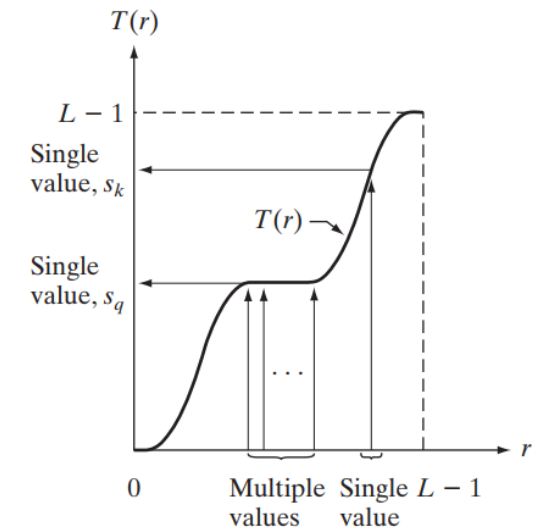
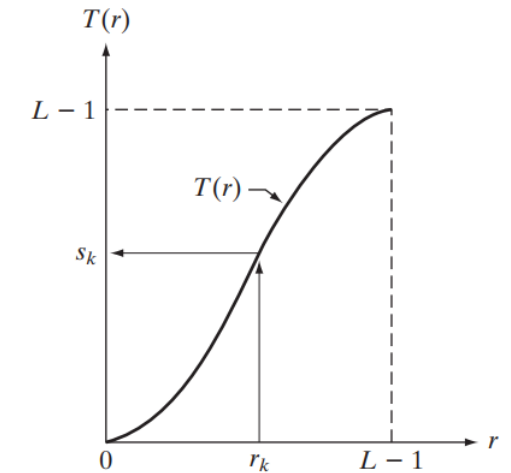


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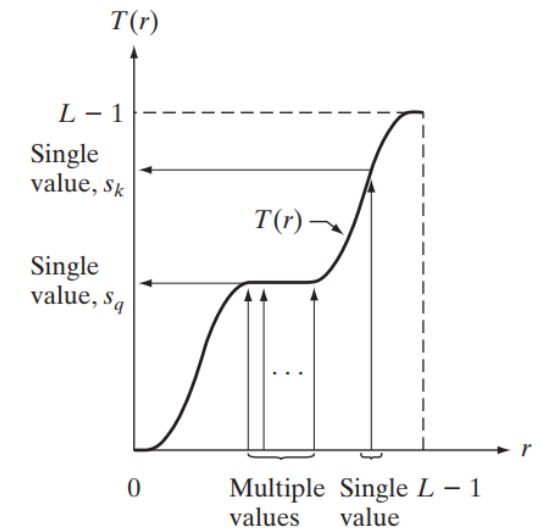
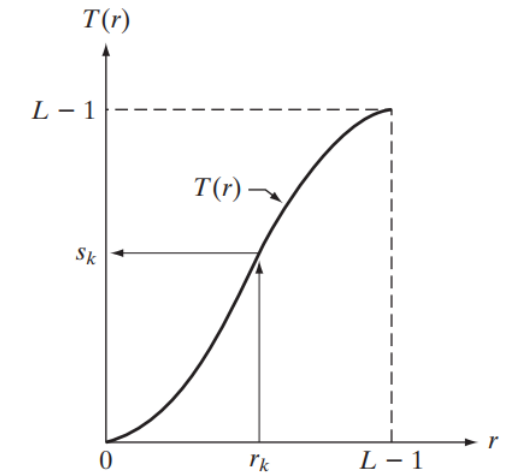
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- $T(r)$  is monotonic  $\uparrow$
- bounded  $0 \leq T(r) \leq L - 1$
- variable equivalence
  - to cover all notations

$$Y = T(X) \quad 0 \leq r \leq L - 1$$
$$s = T(r)$$

$\swarrow \quad \searrow$

$p_s(s) \quad p_r(r)$

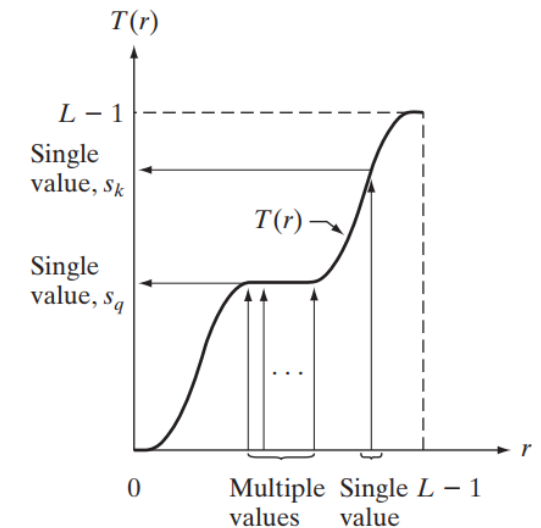
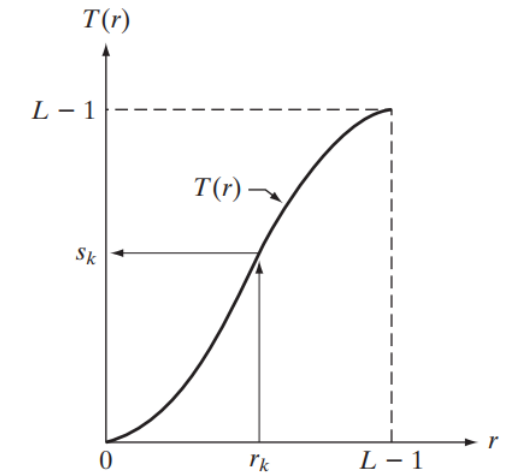


# Histogram equalization

- Assume

- $T(r)$  is monotonic  $\uparrow$
- bounded  $0 \leq T(r) \leq L - 1$
- variable equivalence
  - to cover all notations

$$Y = T(X) \quad 0 \leq r \leq L - 1$$
$$s = T(r)$$
$$\begin{array}{cc} \swarrow & \searrow \\ p_s(s) & p_r(r) \\ p_Y(y) & p_X(x) \end{array}$$



# Histogram equalization

■ Assume

- $T(r)$  is monotonic  $\uparrow$
- bounded  $0 \leq T(r) \leq L - 1$
- variable equivalence
  - to cover all notations

$$Y = T(X)$$

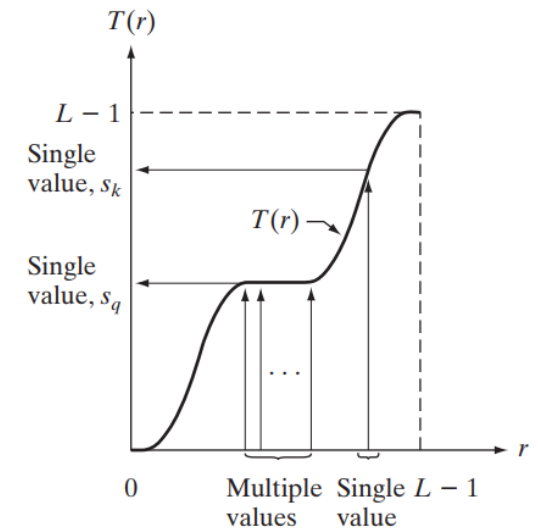
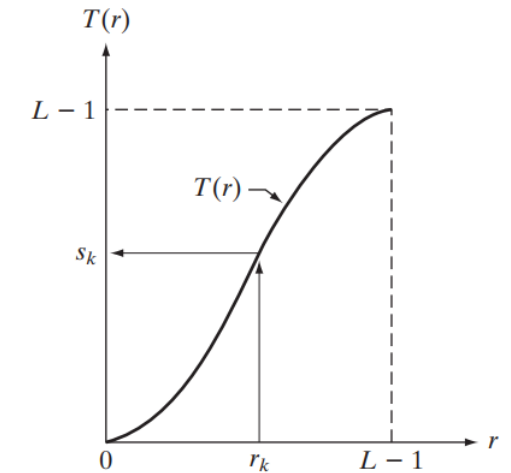
$$s = T(r)$$

$p_s(s)$   
 $p_Y(y)$

$p_r(r)$   
 $p_X(x)$

$$0 \leq r \leq L - 1$$

$T(r)$  is cts & differentiable



# Histogram equalization

- Assume

- $T(r)$  is monotonic  $\uparrow$
- bounded  $0 \leq T(r) \leq L - 1$
- variable equivalence
  - to cover all notations

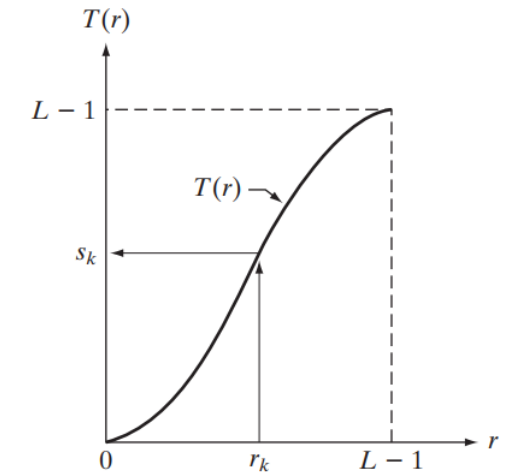
$$Y = T(X)$$

$$s = T(r)$$

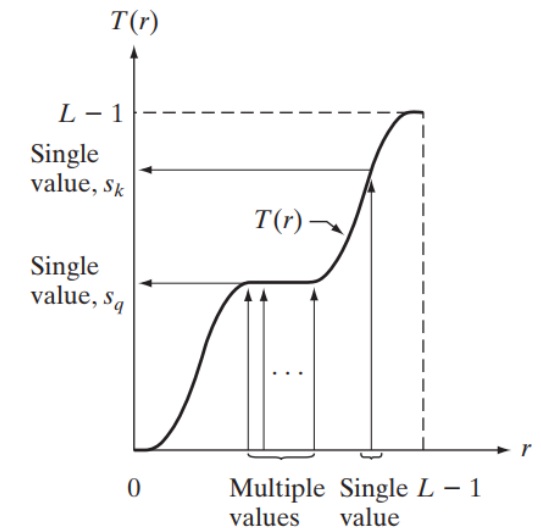
$$\begin{array}{cc} \swarrow & \searrow \\ p_s(s) & p_r(r) \\ p_Y(y) & p_X(x) \end{array}$$

$$0 \leq r \leq L - 1$$

$T(r)$  is cts & differentiable



- cumulative function satisfies above properties for  $T(r)$



# Histogram equalization

- Assume

- $T(r)$  is monotonic  $\uparrow$
- bounded  $0 \leq T(r) \leq L - 1$
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  - to cover all notations

$$Y = T(X)$$

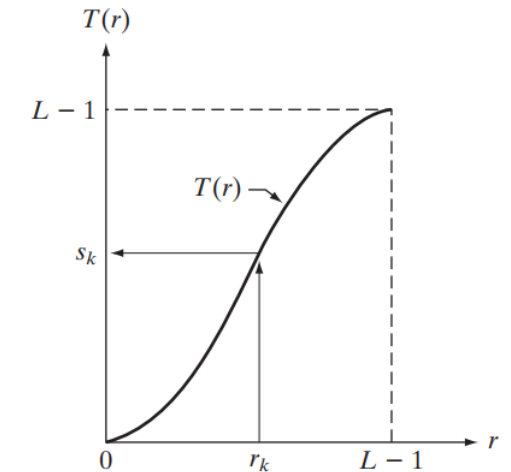
$$s = T(r)$$

$p_s(s)$   
 $p_Y(y)$

$p_r(r)$   
 $p_X(x)$

$$0 \leq r \leq L - 1$$

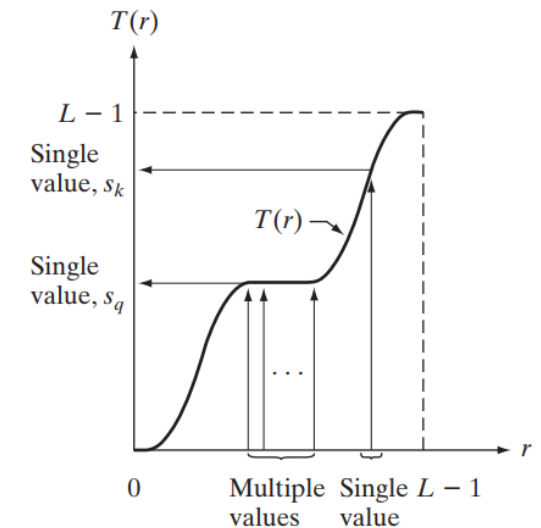
$T(r)$  is cts & differentiable



- cumulative function satisfies above properties for  $T(r)$

$$s = T(r) = (L - 1) \int_0^r p_r(w) dw$$

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$



# Histogram equalization

- Assume

- $T(r)$  is monotonic  $\uparrow$
- bounded  $0 \leq T(r) \leq L - 1$
- variable equivalence
  - to cover all notations

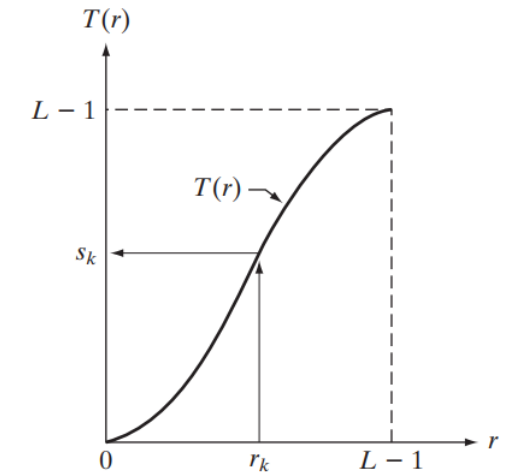
$$Y = T(X)$$

$$s = T(r)$$

$$\begin{array}{cc} \swarrow & \searrow \\ p_s(s) & p_r(r) \\ p_Y(y) & p_X(x) \end{array}$$

$$0 \leq r \leq L - 1$$

$T(r)$  is cts & differentiable



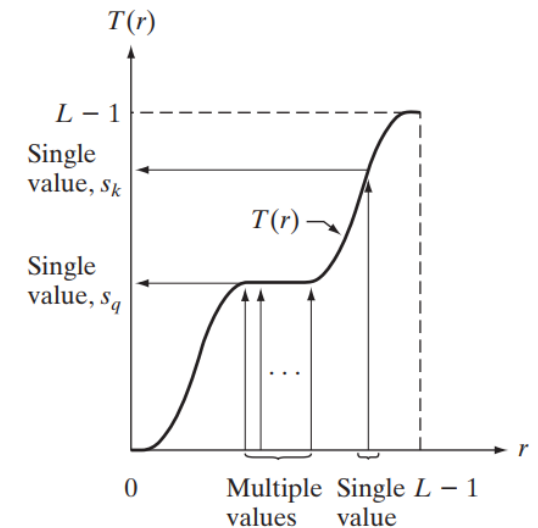
- cumulative function satisfies above properties for  $T(r)$

$$s_k = T(r_k) = (L - 1) \sum_{j=0}^k p_r(r_j)$$

$$= \frac{(L - 1)}{MN} \sum_{j=0}^k n_j \quad k = 0, 1, 2, \dots, L - 1$$

$$s = T(r) = (L - 1) \int_0^r p_r(w) dw$$

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$



# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^x p_X(x) dx$$

What is  $p_Y(y)$ ?

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable



# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$\int_0^y p_Y(z) dz = \text{probability that } 0 \leq Y \leq y$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$\begin{aligned} \int_0^y p_Y(z) dz &= \text{probability that } 0 \leq Y \leq y \\ &= \text{probability that } 0 \leq X \leq T^{-1}(y) \end{aligned}$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$\int_0^y p_Y(z) dz = \text{probability that } 0 \leq Y \leq y$$

$$= \text{probability that } 0 \leq X \leq T^{-1}(y)$$

$$= \int_0^{T^{-1}(y)} p_X(w) dw$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

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What is  $p_Y(y)$ ?

$$\int_0^y p_Y(z) dz = \int_0^{T^{-1}(y)} p_X(w) dw$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$\int_0^y p_Y(z) dz = \int_0^{T^{-1}(y)} p_X(w) dw$$

$$\frac{d}{dy} \left( \int_0^y p_Y(z) dz \right)$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$\int_0^y p_Y(z) dz = \int_0^{T^{-1}(y)} p_X(w) dw$$

$$\frac{d}{dy} \left( \int_0^y p_Y(z) dz \right) = p_X(T^{-1}(y)) \frac{d}{dy} (T^{-1}(y))$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

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$$\int_0^y p_Y(z) dz = \int_0^{T^{-1}(y)} p_X(w) dw$$

$$\frac{d}{dy} \left( \int_0^y p_Y(z) dz \right) = p_X(T^{-1}(y)) \frac{d}{dy} (T^{-1}(y))$$

$$p_Y(y)$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

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What is  $p_Y(y)$ ?

$$\int_0^y p_Y(z) dz = \int_0^{T^{-1}(y)} p_X(w) dw$$

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$$p_Y(y) = p_X(T^{-1}(y)) \frac{d}{dy} (T^{-1}(y))$$



# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$p_Y(y) = p_X(T^{-1}(y)) \frac{d}{dy}(T^{-1}(y))$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$p_Y(y) = p_X(T^{-1}(y)) \frac{d}{dy}(T^{-1}(y))$$

$$= \frac{1}{L-1} \cdot \frac{dT}{dx} \Big|_{x=T^{-1}(y)} \frac{d}{dy}(T^{-1}(y))$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$p_Y(y) = p_X(T^{-1}(y)) \frac{d}{dy}(T^{-1}(y))$$

$$= \frac{1}{L-1} \cdot \frac{dT}{dx} \Big|_{x=T^{-1}(y)} \frac{d}{dy}(T^{-1}(y))$$

$$\frac{d}{dy}T(T^{-1}(y)) = \frac{d}{dy}y = 1$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable

What is  $p_Y(y)$ ?

$$p_Y(y) = p_X(T^{-1}(y)) \frac{d}{dy}(T^{-1}(y))$$

$$= \frac{1}{L-1} \cdot \frac{dT}{dx} \Big|_{x=T^{-1}(y)} \frac{d}{dy}(T^{-1}(y))$$

$$\frac{d}{dy}T(T^{-1}(y)) = \frac{d}{dy}y = 1$$

$$= \frac{1}{L-1}$$

# Histogram equalization

---

$$Y = T(X) = (L - 1) \int_0^x p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

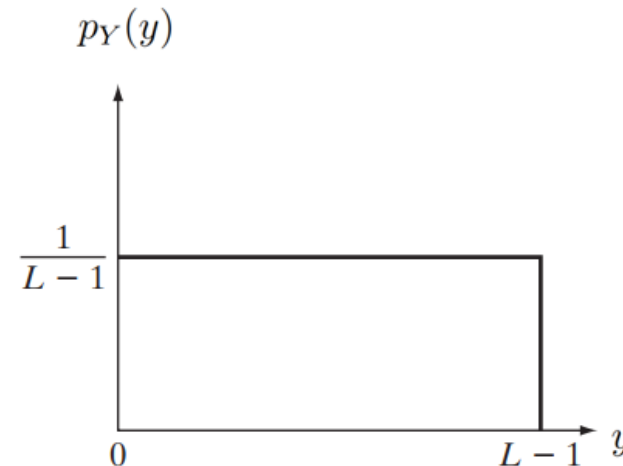
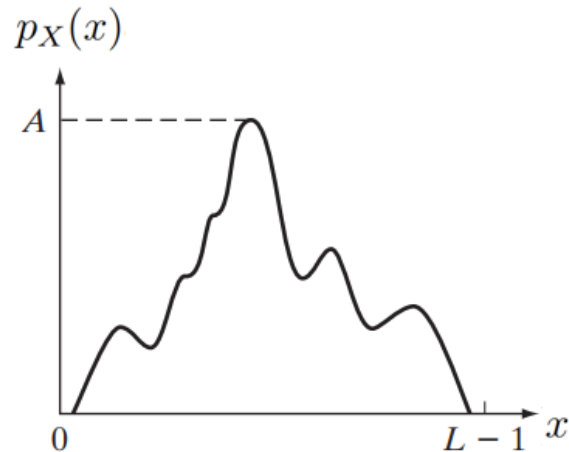
$T(X)$  is cts & differentiable

# Histogram equalization

$$Y = T(X) = (L - 1) \int_0^X p_X(x) dx$$

$$\begin{array}{ccc} Y = T(X) & & \\ \swarrow & & \searrow \\ p_Y(y) & & p_X(x) \end{array}$$

$T(X)$  is cts & differentiable



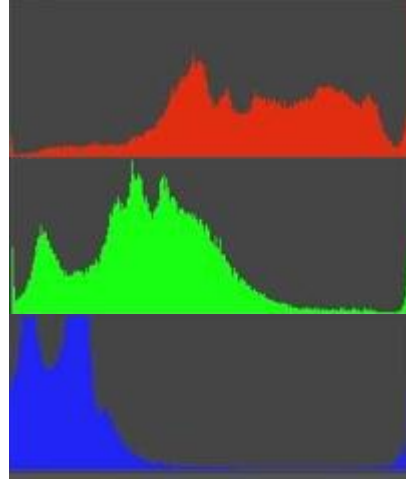
# Histogram equalization

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# Histogram equalization

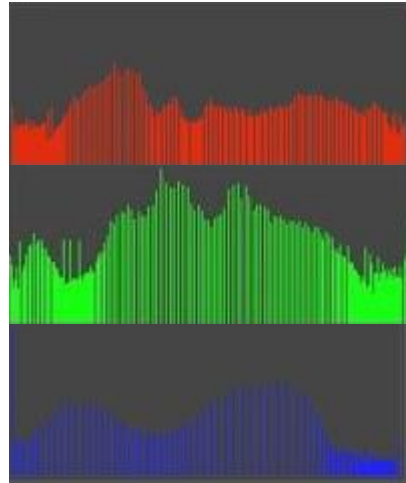
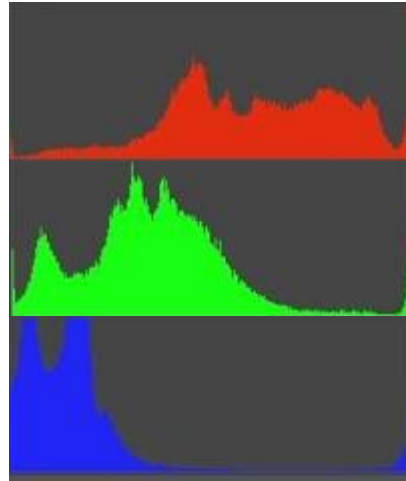
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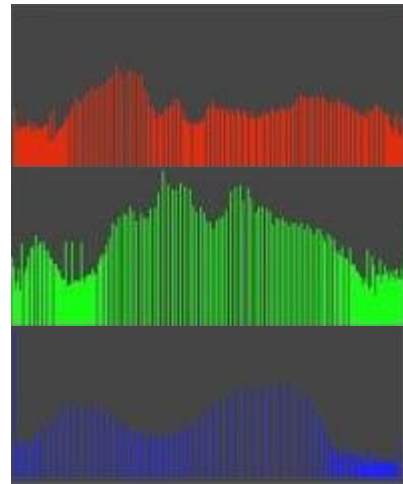
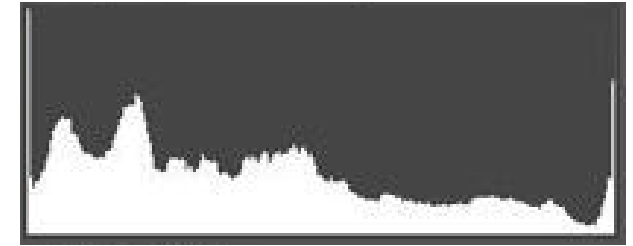
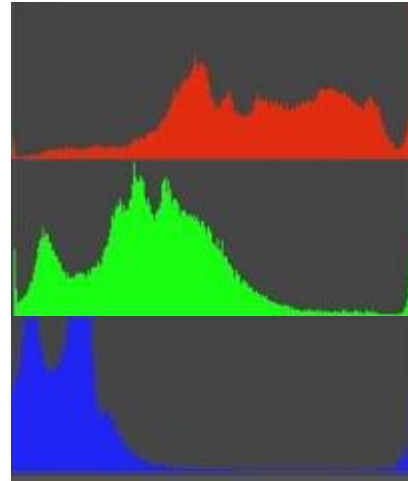


# Histogram equalization

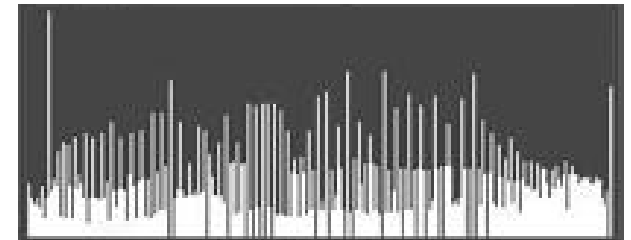
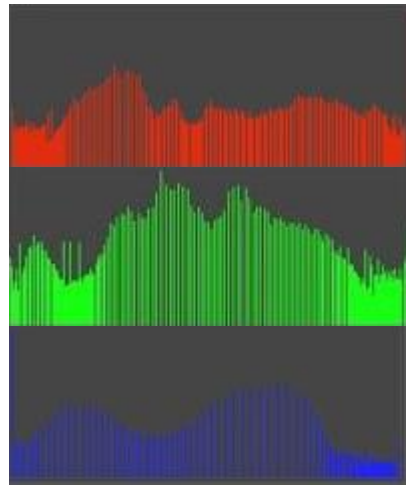
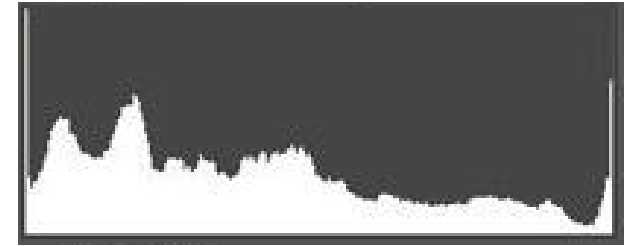
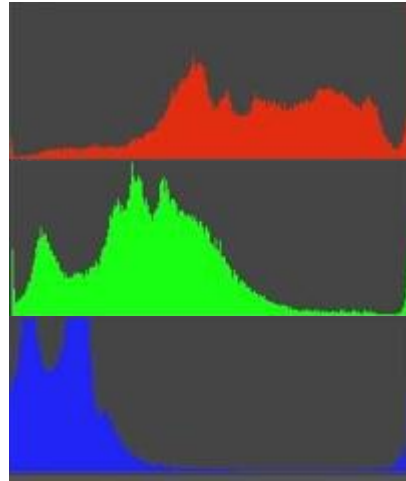
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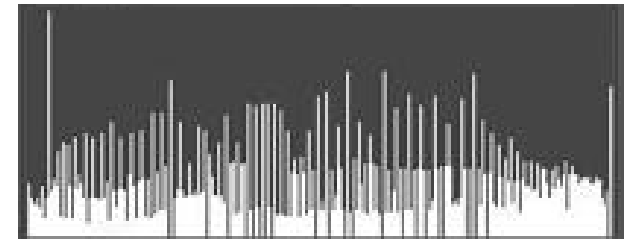
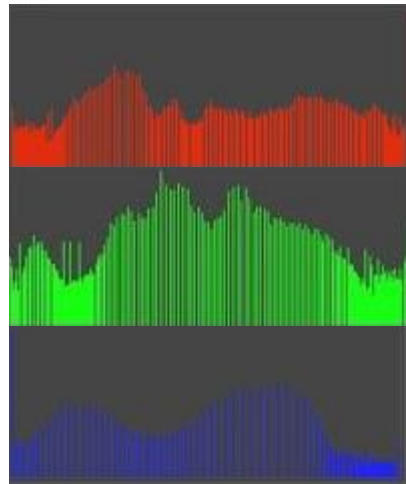
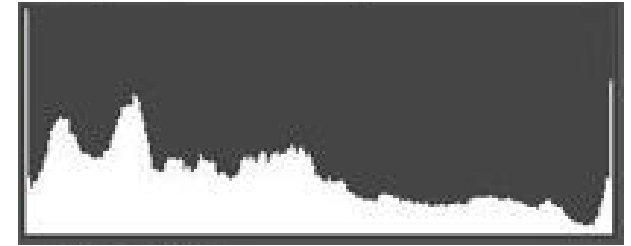
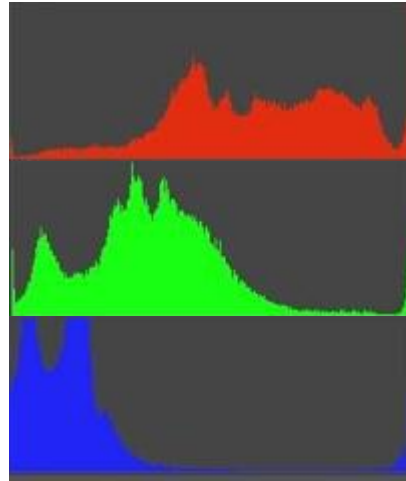
# Histogram equalization



# Histogram equalization





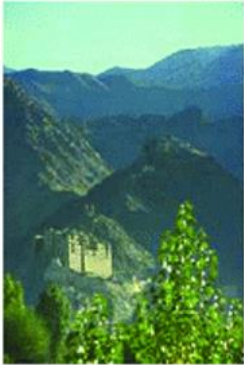
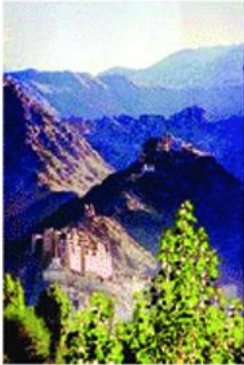
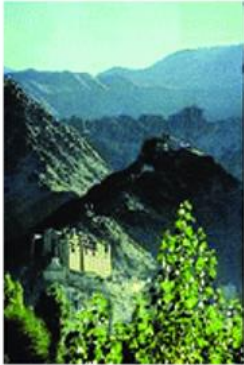
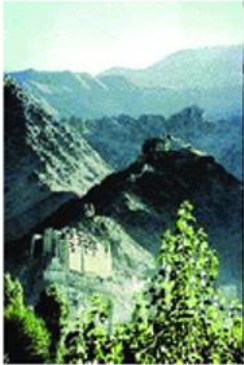
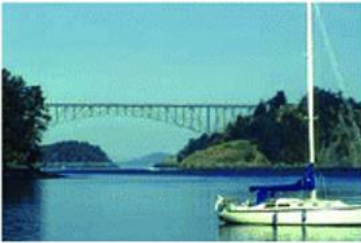
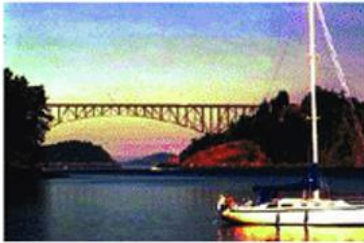
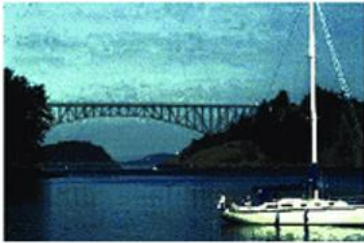







# Histogram equalization









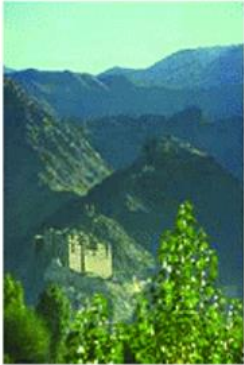

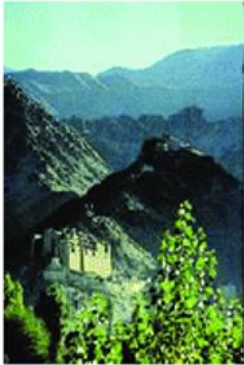
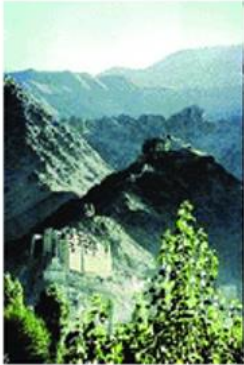
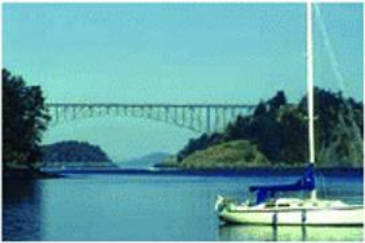
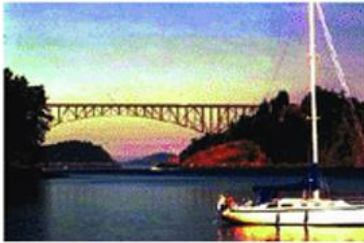

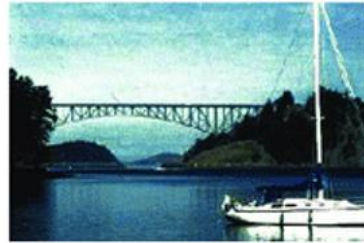




# Histogram equalization

Original image	Color functions & Histogram equalization results		
	RGB	$f_1(\text{RGB})$	$f_2(\text{RGB})$
			
			
			
			



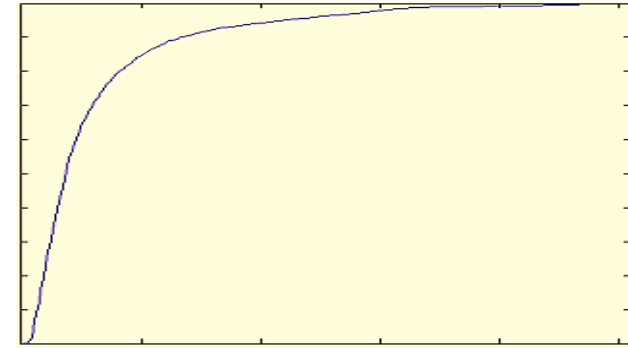
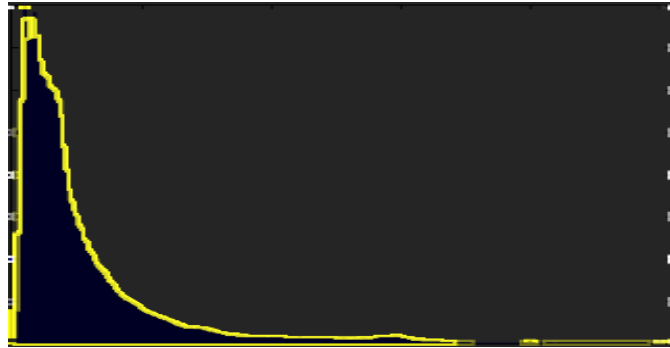
# Histogram equalization

- Color conversions
  - colors can be mapped with certain functions
  - mapped images then histogram equalized

Original image	Color functions & Histogram equalization results		
	RGB	$f_1(\text{RGB})$	$f_2(\text{RGB})$
			
			
			
			

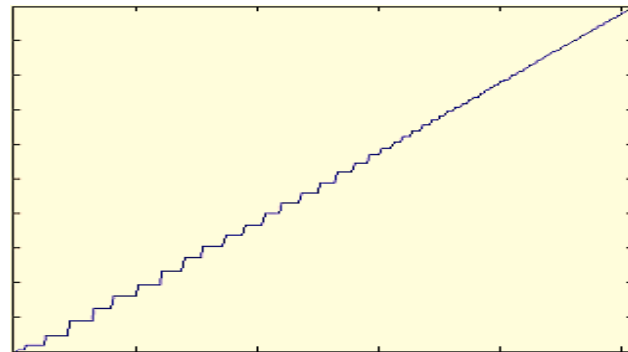
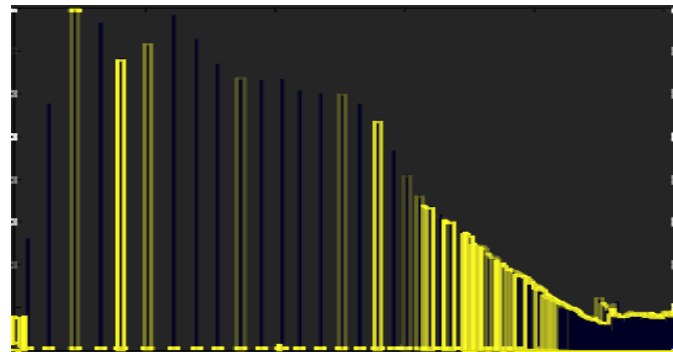
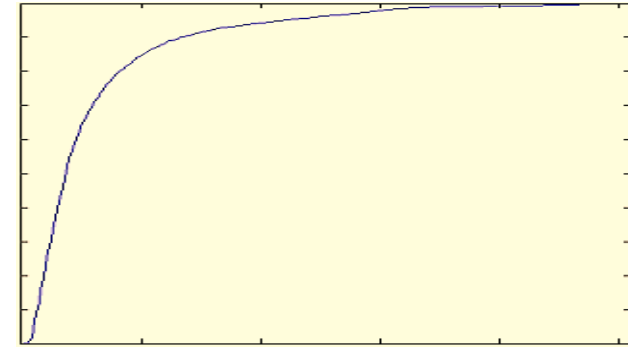
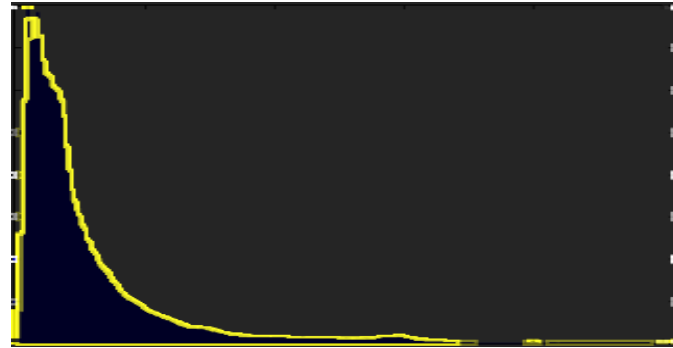
# Histogram equalization

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# Histogram equalization

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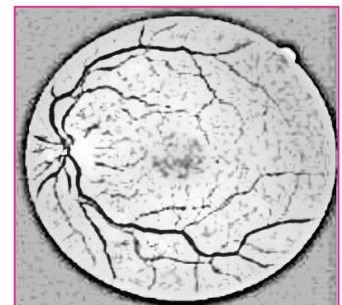
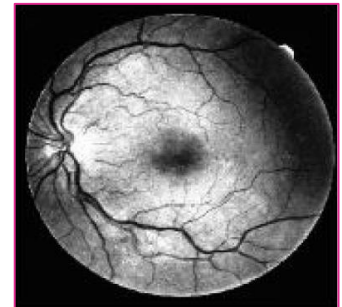


# Conclusion

- Intensity transforms
- Distribution transforms

# Conclusion

- Intensity transforms
- Distribution transforms



# Conclusion

- Intensity transforms
- Distribution transforms

## □ Intensity transformations

- negatives
- logs
- power-law (gamma)
- contrast stretching
- level slicing
- bit-plane slicing

## □ Distribution transformations

- Histogram equalization

