

Image enhancement

Image enhancement belongs to image pre-processing methods.

Objective of image enhancement – process the image (e.g. contrast improvement, image sharpening ,...) so that it is better suited for further processing or analysis



Image enhancement

Image enhancement methods are based on subjective image quality criteria.

No objective mathematical criteria are used for optimizing processing results.

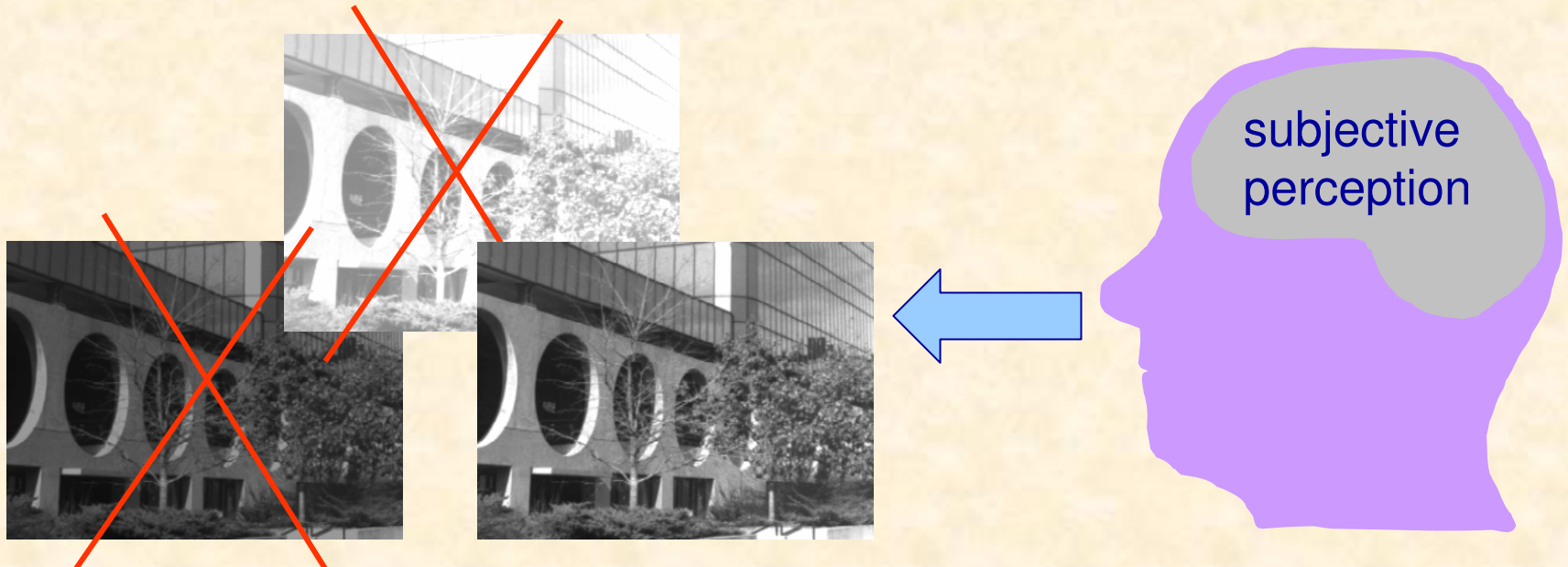


Image enhancement methods

Point processing

Contrast enhancement

Histogram modelling

Image averaging

Spatial filtering

Linear filters

Nonlinear filters

Edge detection

Zooming

Image colouring

Pseudo colouring

False colouring

Image enhancement

Brightness

$$J = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N f(i, j)$$

Contrast

$$C = \sqrt{\frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N [f(i, j) - J]^2}$$

M, N – image dimensions

$f(i, j)$ – gray level value at (i, j)

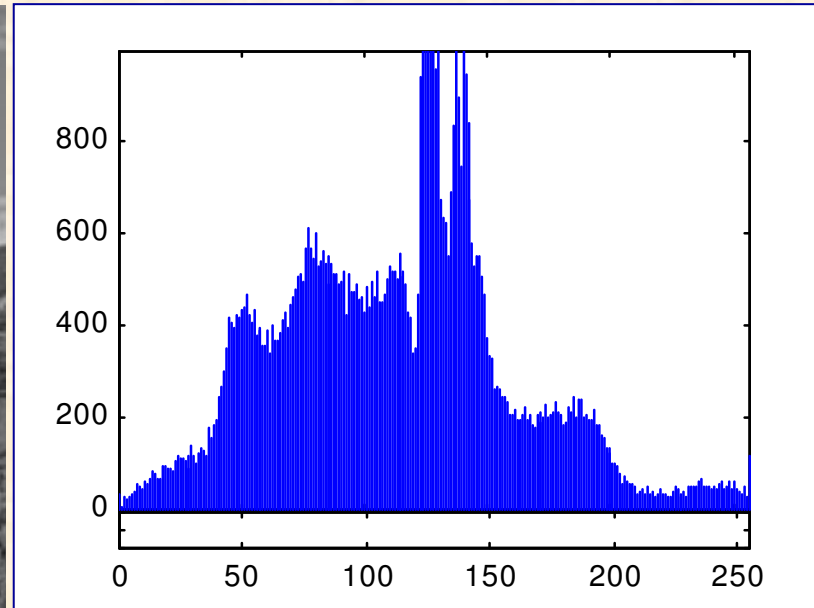
Image histogram



Image **brightness** and **contrast** influence image subjective quality perception



Image histogram



```
Image : array[1..M,1..N] of byte;
```

```
Hist : array[0..L-1] of longint;
```

```
...
```

```
Hist:=0;
```

```
for i:=1 to M do for j:=1 to N do
```

```
    Inc( Hist[ Image[i, j] ] );
```

```
...
```

imhist(I)

Image histogram

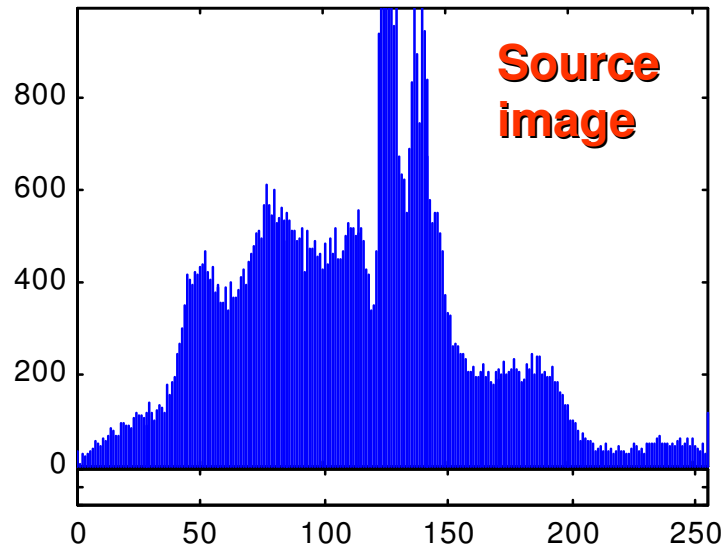
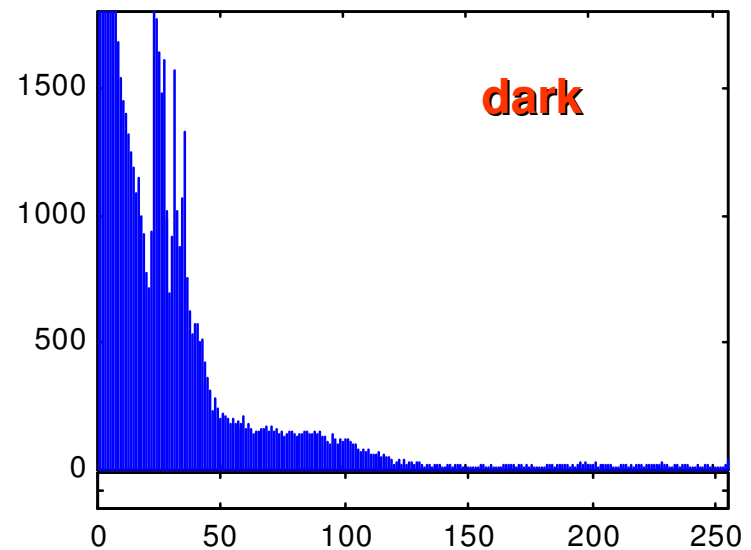
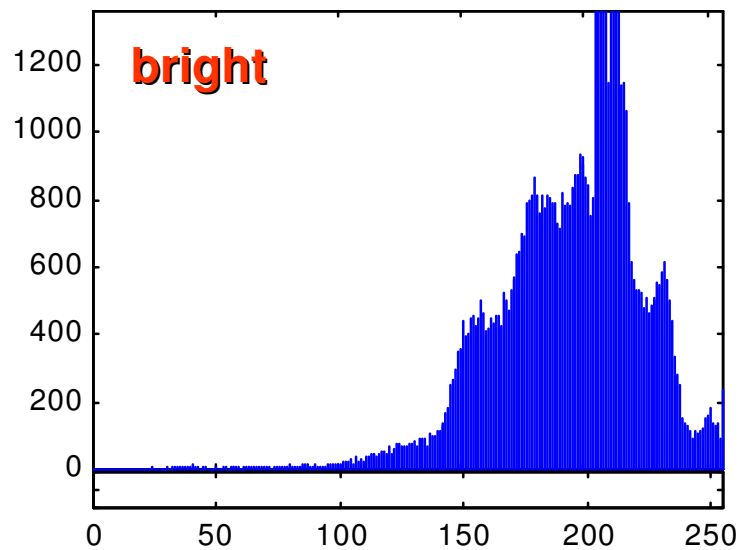
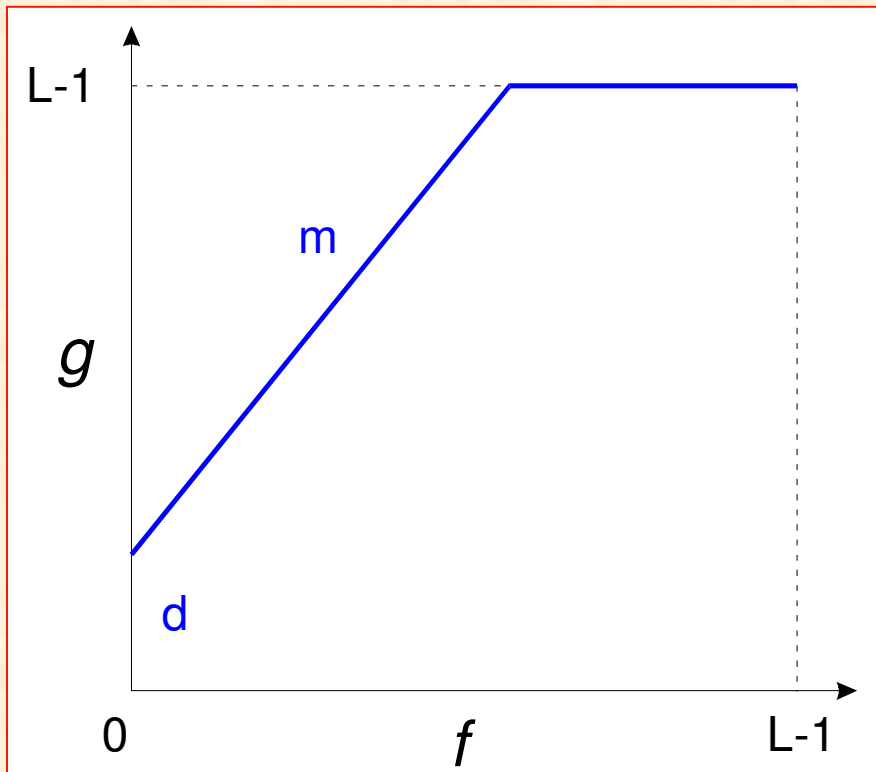


Image histogram
represents statistical
distribution of image
pixel brightnesses



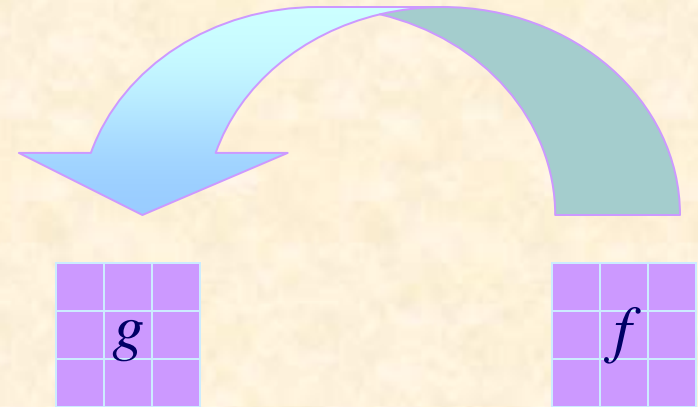
Linear gray scale transformation



$m \sim$ contrast

$d \sim$ brightness

$$g(i,j) = m f(i,j) + d$$

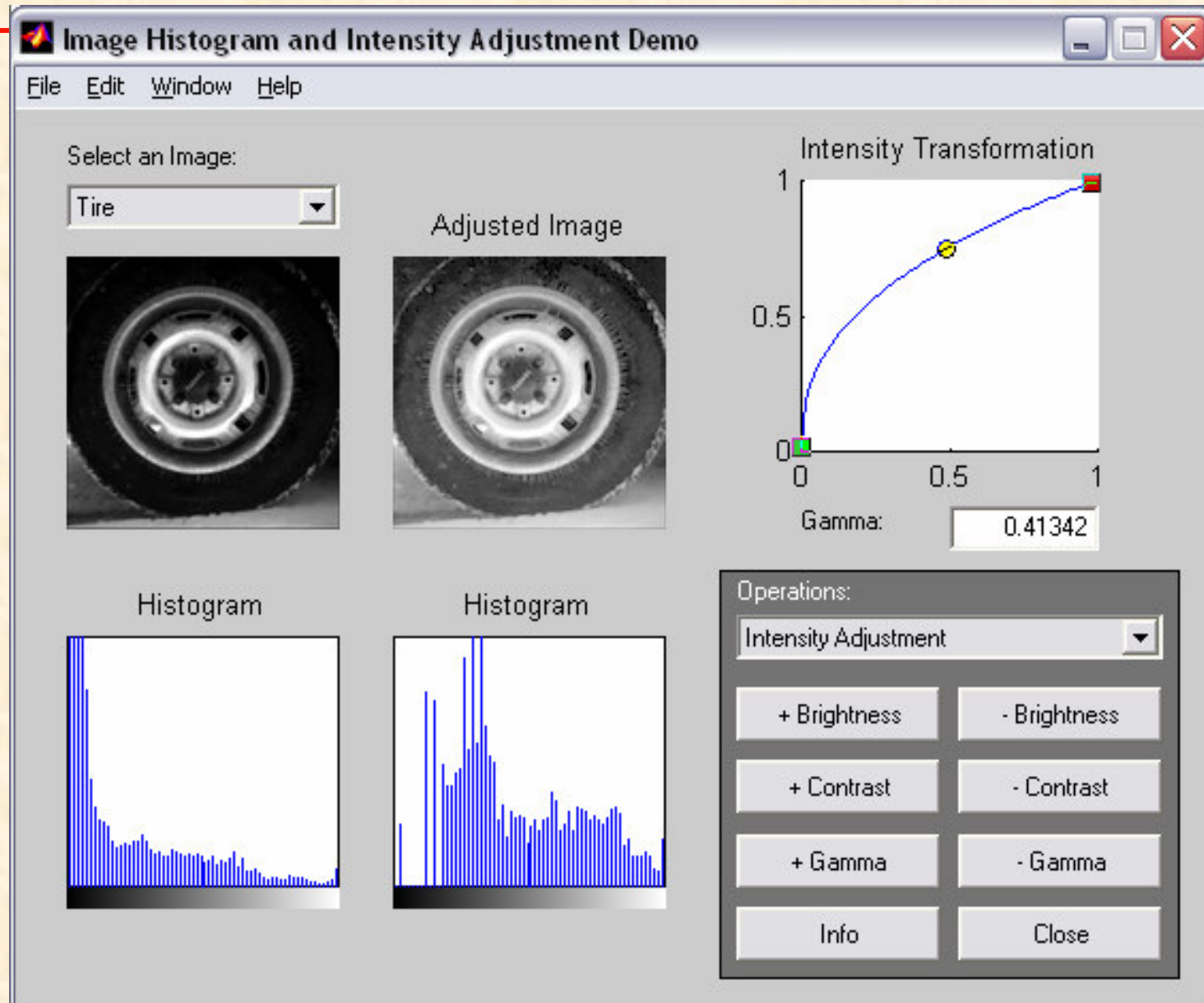


OUTPUT
IMAGE

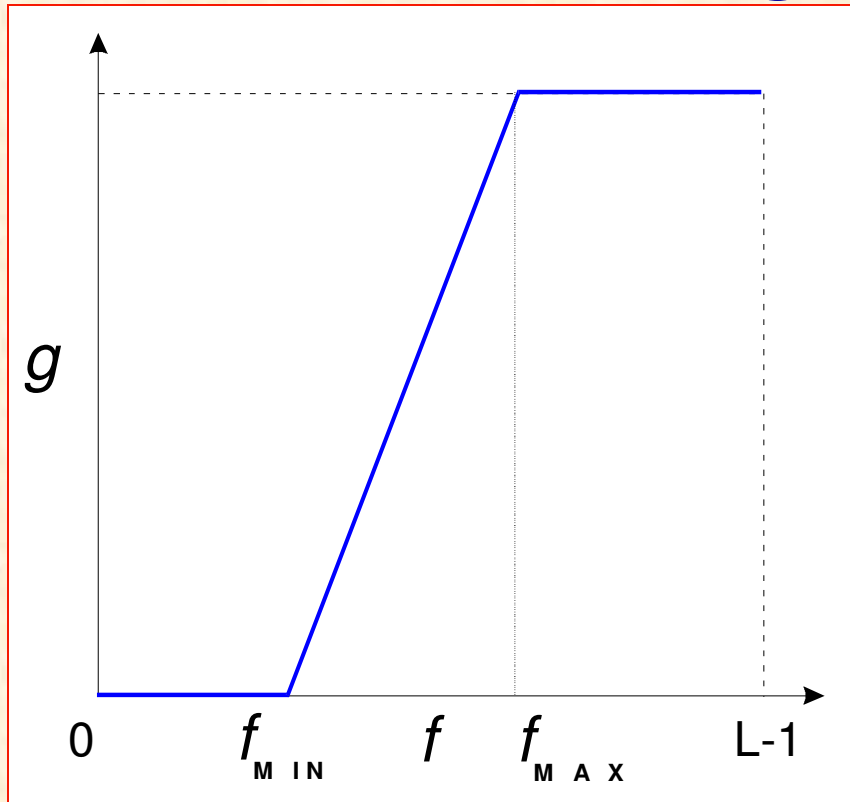
SOURCE
IMAGE

POINT OPERATION

MATLAB Demo – image histogram



Histogram „stretching”

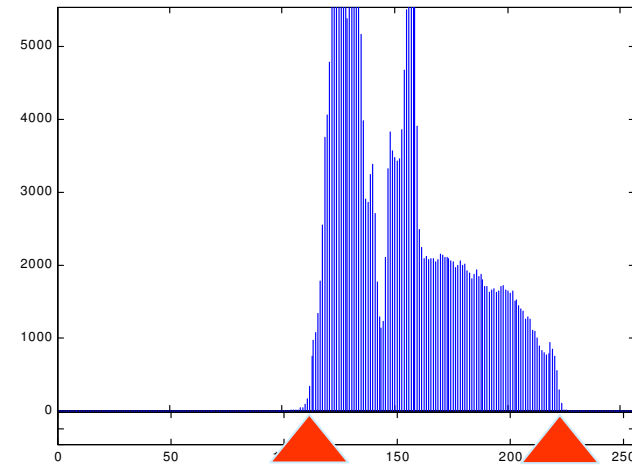


POINT OPERATION?

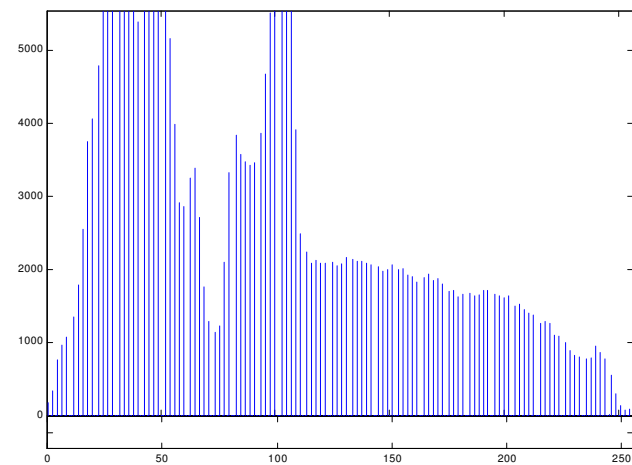
$G = \text{imadjust}(F, [f_{\text{MIN}} \ f_{\text{MAX}}], [g_{\text{MIN}} \ g_{\text{MAX}}])$

$$g(i,j) = \begin{cases} 0 & f(i,j) < f_{\text{MIN}} \\ \frac{L-1}{f_{\text{MAX}} - f_{\text{MIN}}} (f(i,j) - f_{\text{MIN}}), & f_{\text{MIN}} \leq f(i,j) \leq f_{\text{MAX}} \\ L-1 & f(i,j) > f_{\text{MAX}} \end{cases}$$

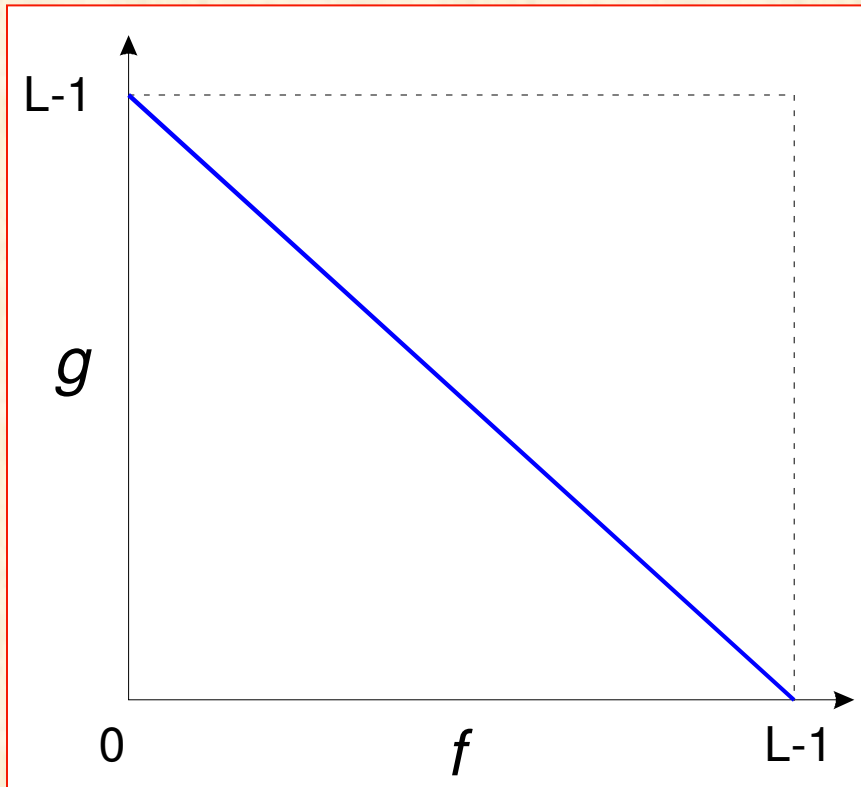
Histogram „stretching” - example



$f_{\text{MIN}}=110, f_{\text{MAX}}=225$



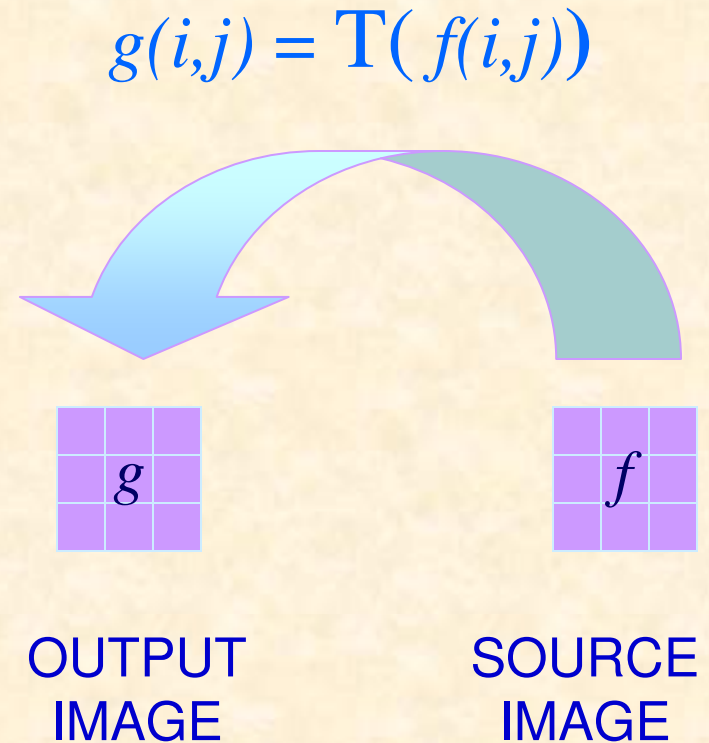
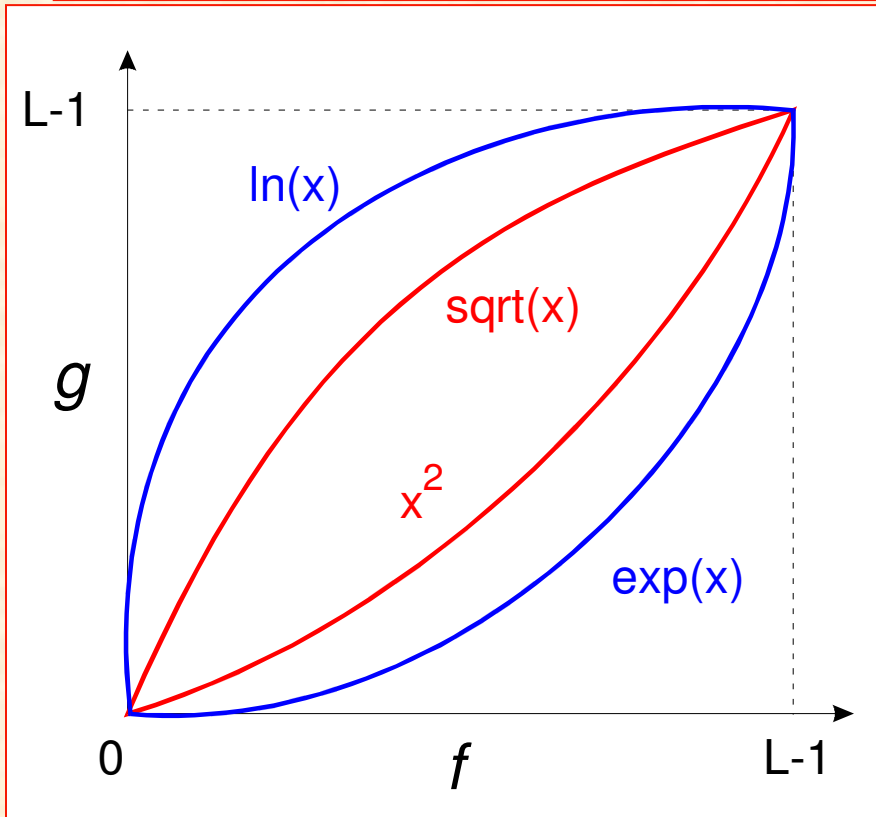
Grayscale inversion



We can use look-up table to implement image point operations



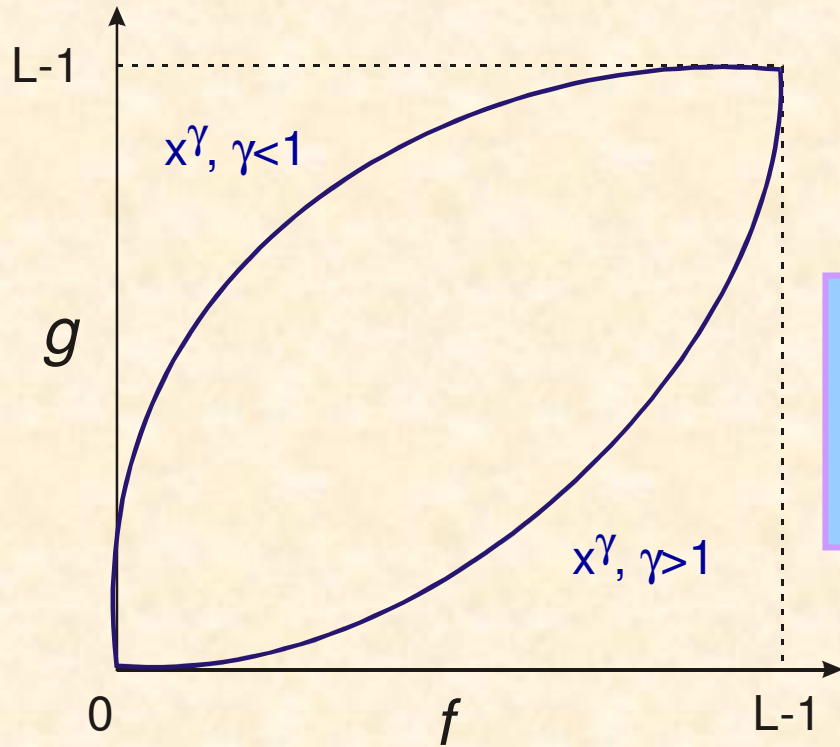
Nonlinear grayscale transformation



Grayscale normalization!

POINT OPERATION

Nonlinear grayscale transformation

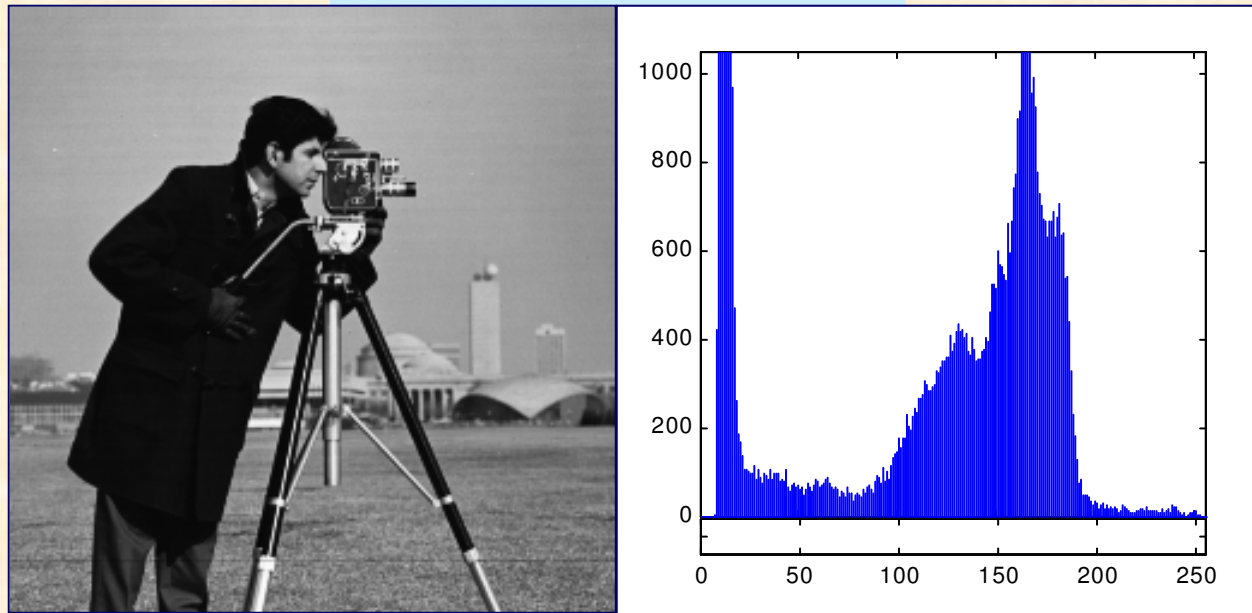


$$G = \text{imadjust}(F, [f_{\text{MIN}} \ f_{\text{MAX}}], [g_{\text{MIN}} \ g_{\text{MAX}}], \gamma)$$

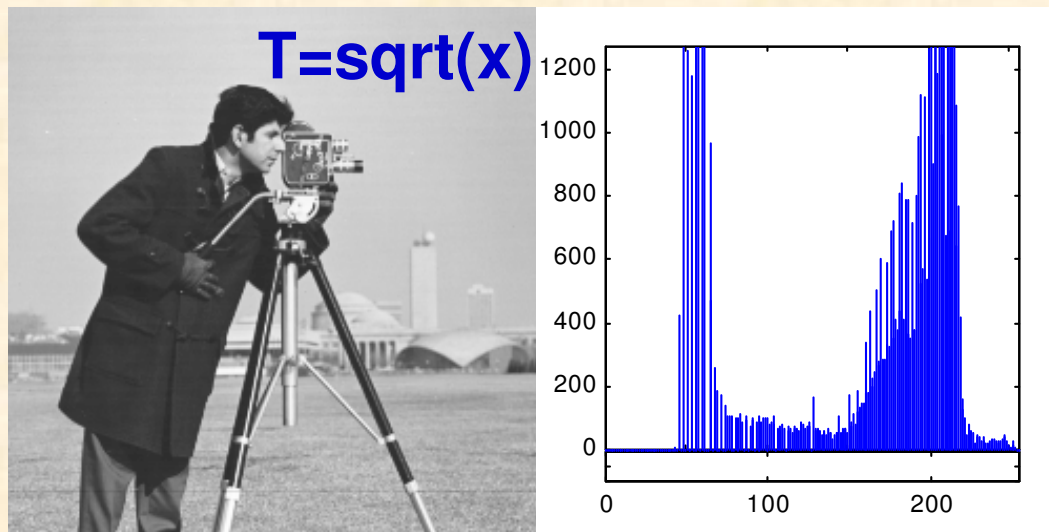
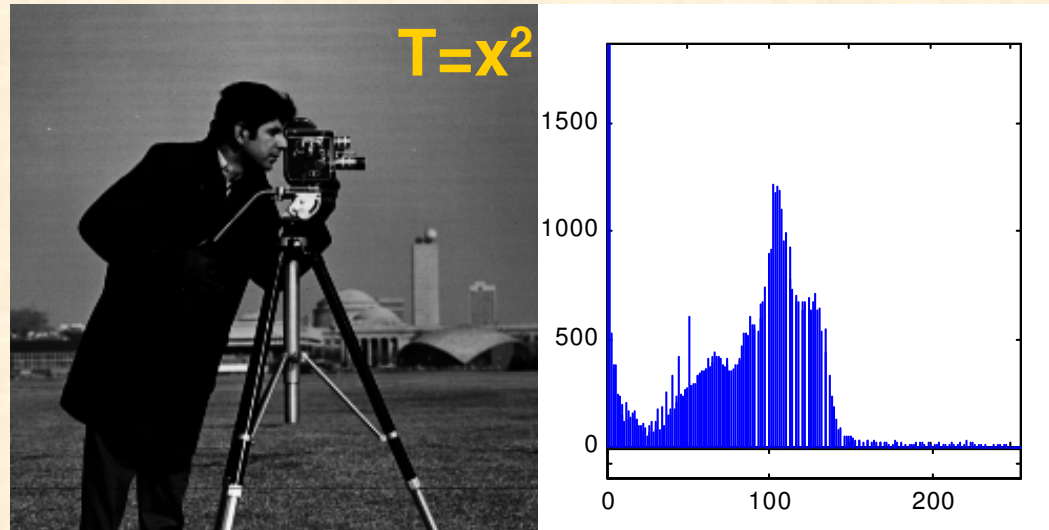
γ correction

Nonlinear grayscale transformation - example

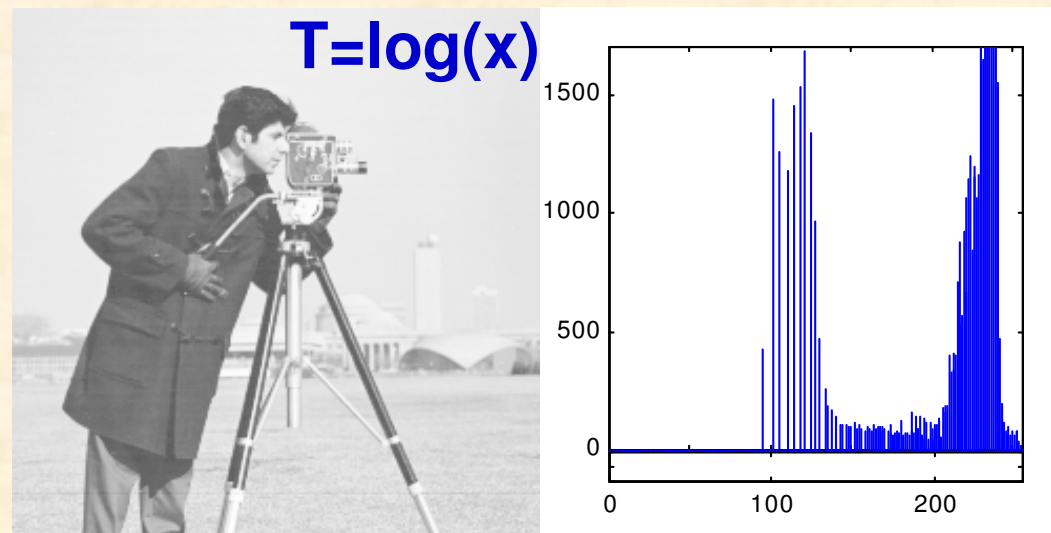
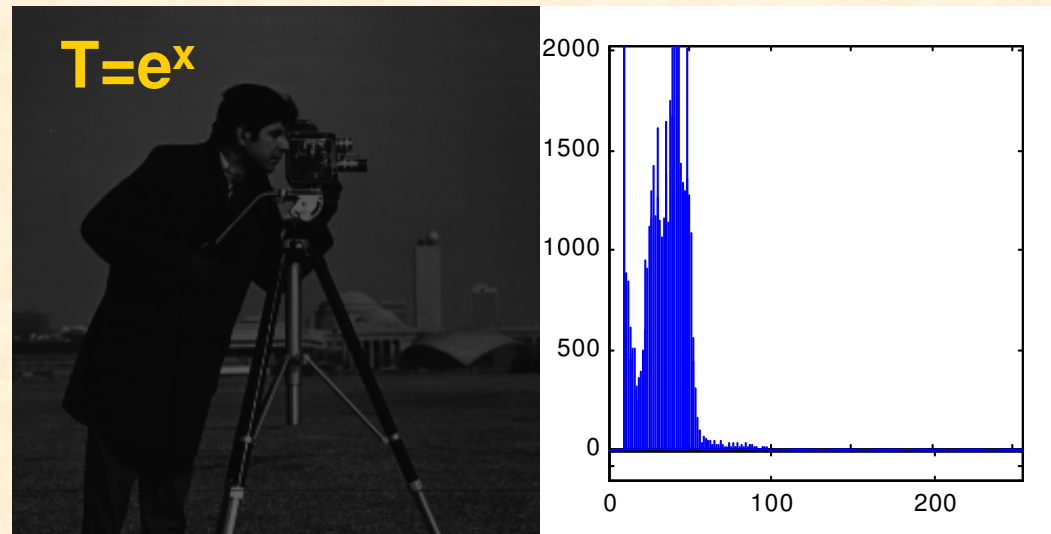
Source image



Nonlinear grayscale transformation - example



Nonlinear grayscale transformation - example



Nonlinear grayscale transformation - algorithm

Example: square function

normalization: minimum value - 0 -> 0

maximum value - 255 -> 255^2

Normalization coefficient: $\text{norm} = 1/255$

...

for i:=1 to M do for j:=1 to N do

$g[i,j] := \text{round}(\text{sqr}(f[i,j]) * \text{norm});$

...

Nonlinear grayscale transformation - algorithm

Example: square function (using look-up-table)

```
lut : array[0..255]of byte;
```

```
...
```

```
for k:=0 to 255 do lut[k]:=round(k*k*norm)
```

```
for i:=1 to M do for j:=1 to N do
```

```
    g[i,j]:=lut[(f[i,j])];
```

```
...
```

Enhancement of a telescope moon image

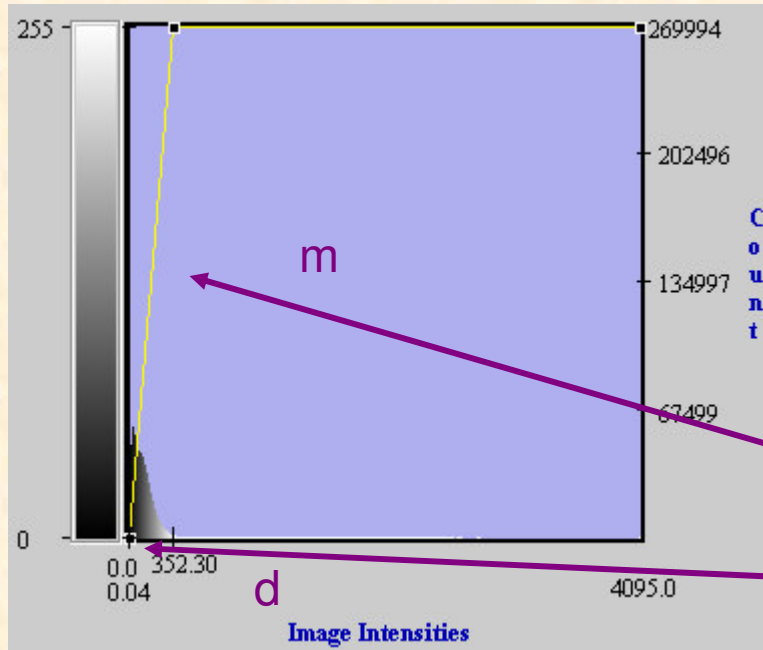


$$T = b \log(ax)$$

Linear gray scale transformation



MR 12 bit image



histogram



Brightness/Contrast adjustment window

Image enhancement by image averaging

Consider a noisy image:

$$g(i, j) = f(i, j) + \eta(i, j)$$

contaminated by additive noise $\eta(i, j)$ of zero average and variance σ_{η}^2 that is not correlated to the image.

We will show that after N averagings (acquisitions) of the noisy image $g(i, j)$ the variance of noise component will be reduced to:

$$\overline{\sigma_{\eta}^2} = \frac{\sigma_{\eta}^2}{N}$$

Image enhancement by image averaging

$$g(i, j) = \frac{1}{N} \sum_{k=1}^N [f(i, j) + n_k(i, j)] = f(i, j) + \frac{1}{N} \sum_{k=1}^N n_k(i, j)$$

WARNING ! – grayscale range

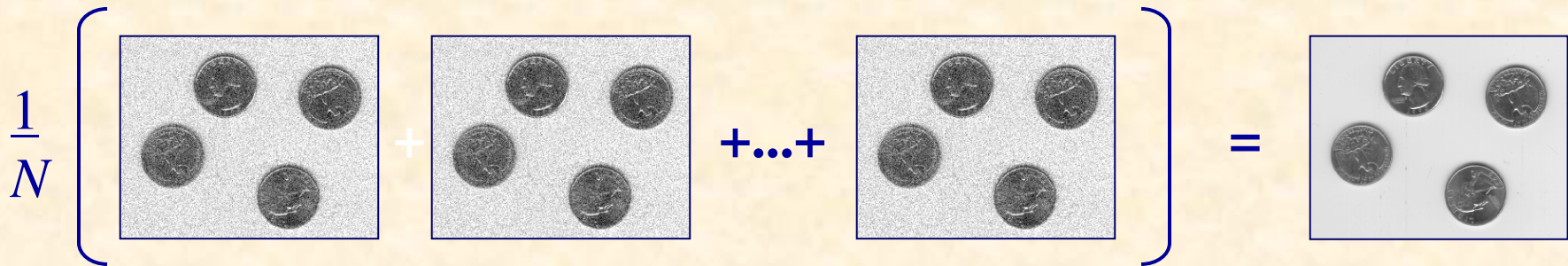


Image enhancement by image averaging

Noise variance in the averaged image:

$$\begin{aligned}\sigma_{\eta}^2 &= E\left\{\left(\frac{1}{N} \sum_{k=1}^N \eta_k\right)^2\right\} = \frac{1}{N^2} \cdot E\left\{\left(\sum_{k=1}^N \eta_k\right)^2\right\} = \\ &= \frac{1}{N^2} \cdot E\left\{(\eta_1 + \eta_2 + \dots + \eta_N)^2\right\} = \frac{1}{N^2} \cdot E\left\{\sum_{k=1}^N \eta_k^2 + 2 \underbrace{\left(\sum_{k \neq p} \eta_k \eta_p\right)}_{=0}\right\} = \\ &= \frac{1}{N^2} E\left\{\sum_{k=1}^N \eta_k^2\right\} = \frac{1}{N^2} N \sigma_{\eta}^2 = \frac{1}{N} \sigma_{\eta}^2\end{aligned}$$

One can also show that the pick value of noise $\{n\}$ is reduced by a factor of \sqrt{N} after N image averagings

Image averaging – example

N=1



Additive
Gaussian noise

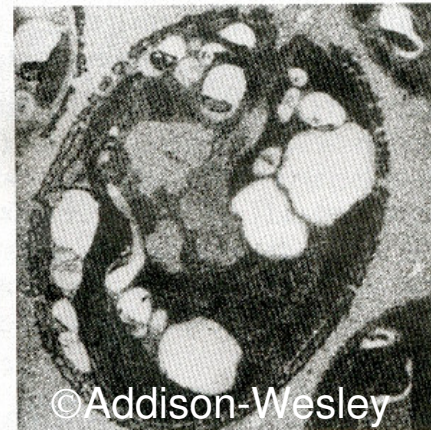
(a)

N=2



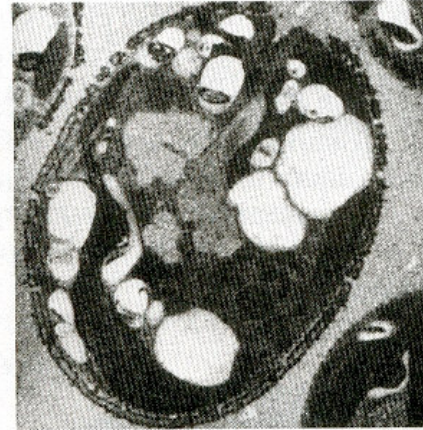
(b)

N=8



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N=16



Microscope image of a cell

Cumulative histogram

hist – image histogram, *histc* – cumulative histogram

hist : array[0..255] of **longint**;

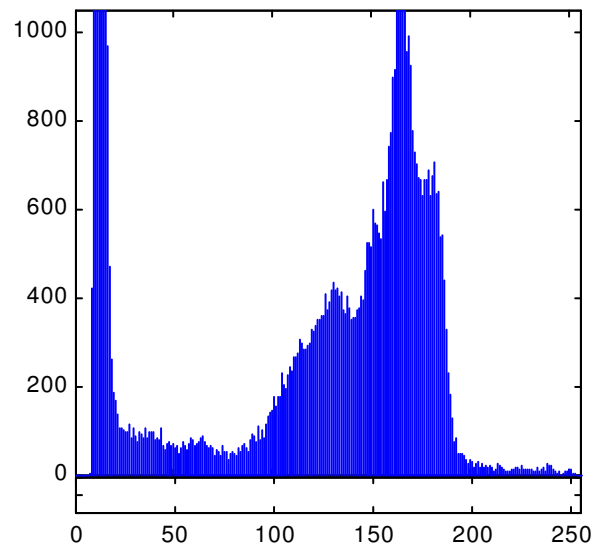
hists : array[0..255] of **single**;

$$histc[i] = \left(\sum_{k=0}^i hist[k] \right) / MN, \quad i = 0, \dots, L-1$$

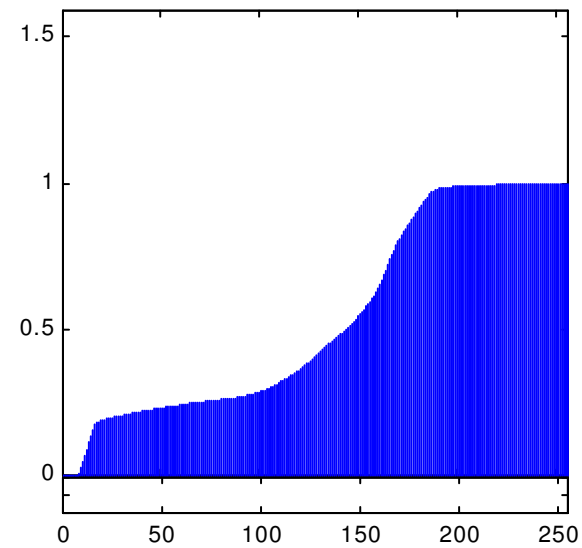
M, N – image dimensions



Cumulative histogram



Histogram



Cumulative histogram

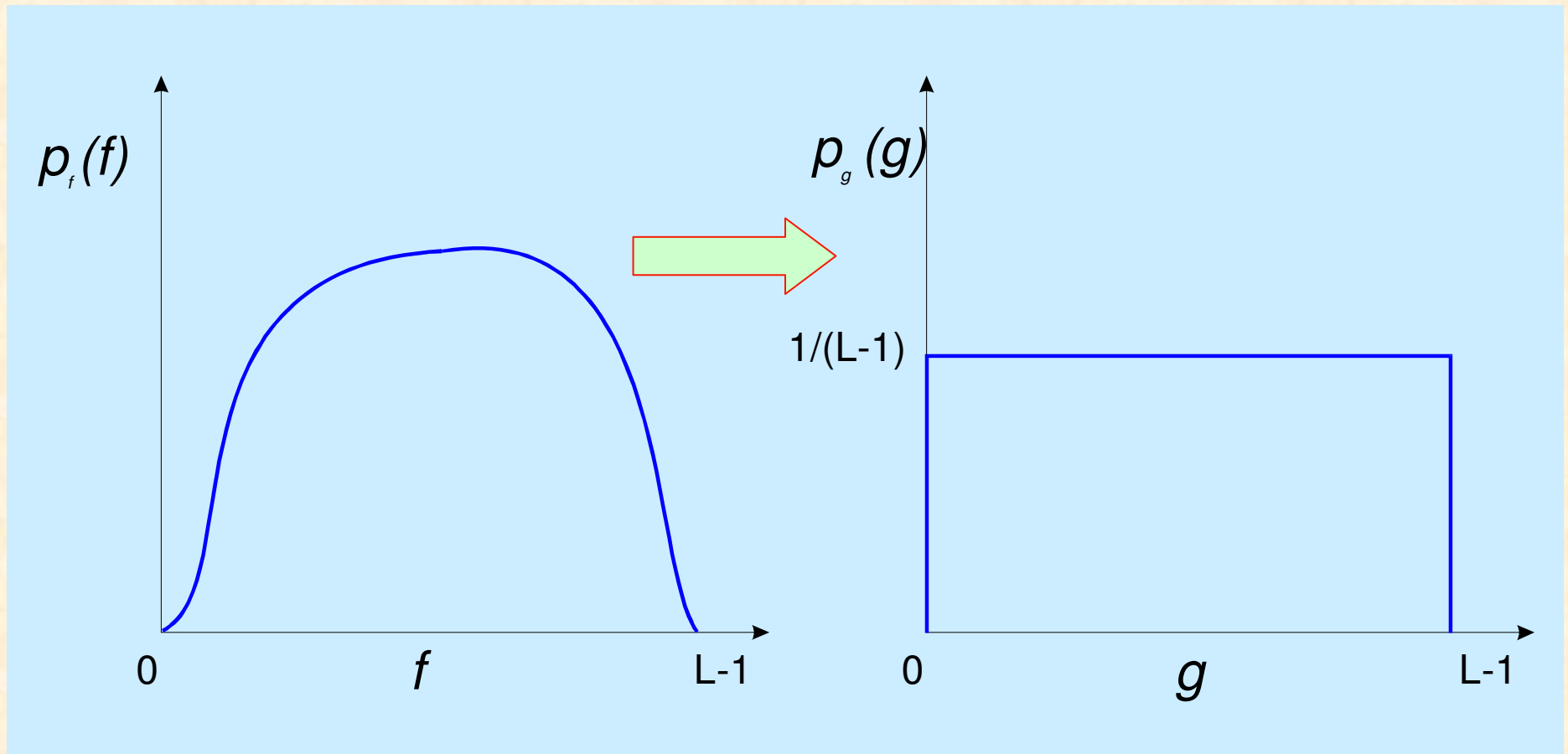
Histogram equalization

Histogram equalization aims at obtaining uniform statistical distribution of image gray levels (uniform probability density function)

By histogram equalization one gets:

- contrast enhancement
- image normalization

Histogram equalization



$$p_f(f) = \text{hist}[f] / MN$$

$$p_g(g) = 1 / (L-1)$$

Histogram equalization

$$\int p_f(h)dh = \int p_g(u)du$$

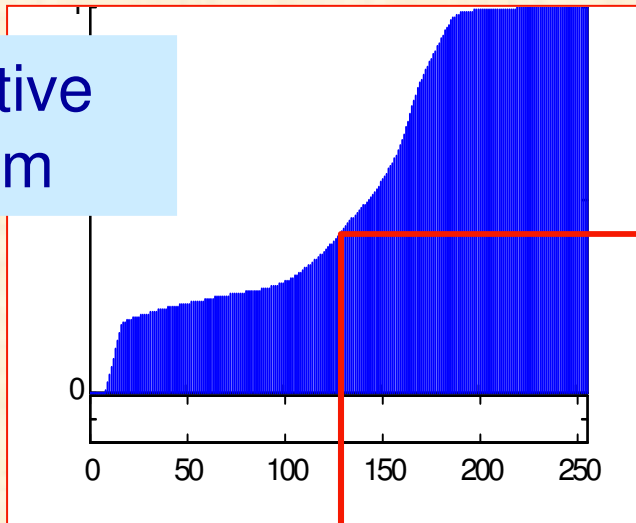
$$\int_0^f p_f(h)dh = \int_0^g \frac{1}{L-1} du = \frac{1}{L-1} u \Big|_0^g = \frac{g}{L-1} \quad 0 \leq f, g \leq L-1$$

$$\sum_{i=0}^f p_f(i) = \frac{g}{L-1} \quad f, g = 0, 1, 2, \dots, L-1$$

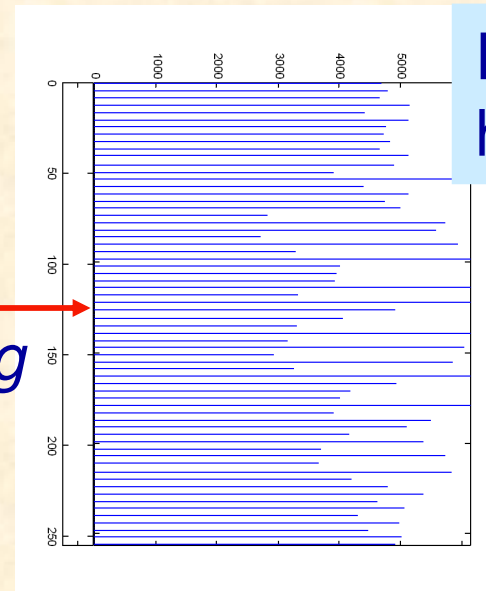
$$g = (L-1) \sum_{i=0}^f p_f(i) = (L-1) \sum_{i=0}^f \frac{hist[i]}{MN} = (L-1) histc[f]$$

Histogram equalization

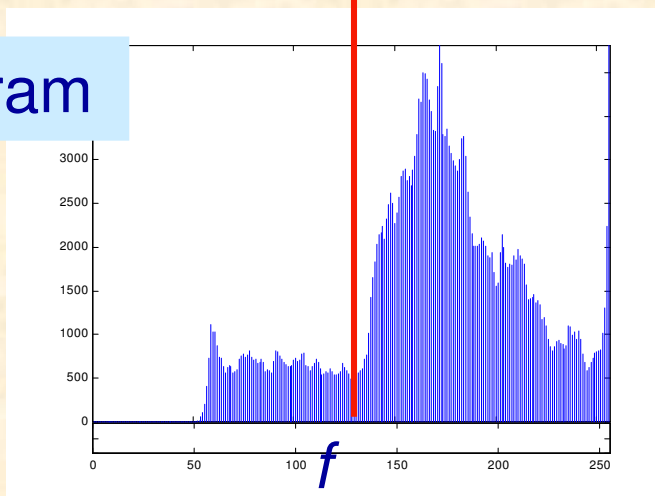
Cumulative histogram



Equalized histogram



Histogram

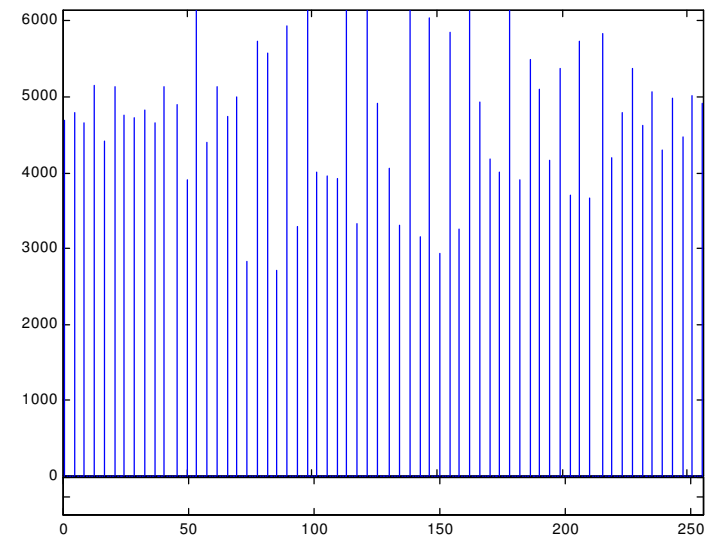
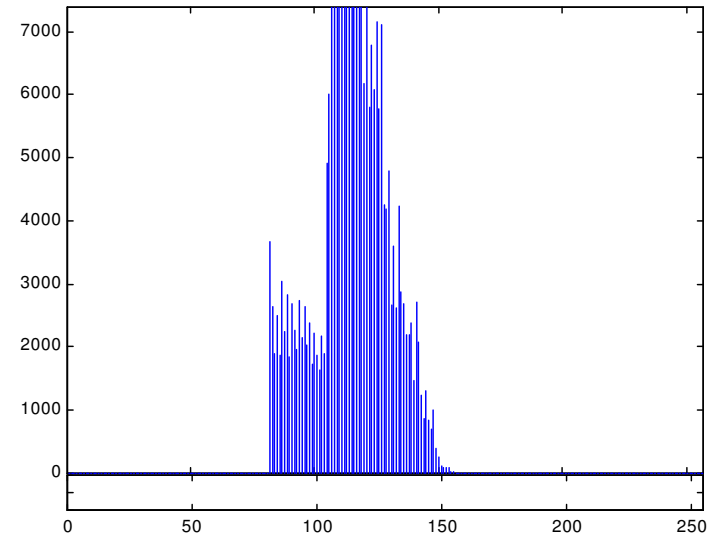


$$g = (L - 1) \text{histc}[f]$$

Cumulative histogram - algorithm

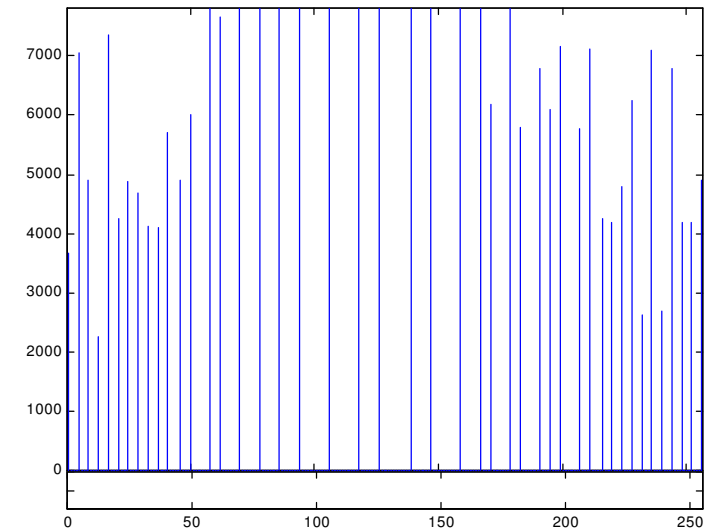
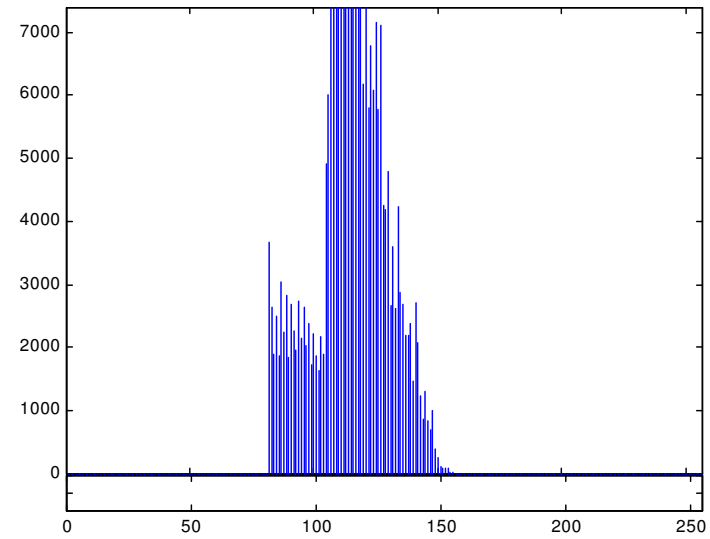
```
hist : array[0..255] of longint;  
histc : array[0..255] of single;  
...  
histc[0]:=hist[0];  
for k:=1 to 255 do  
    histc[k]:=histc[k-1]+hist[k];  
...
```

Histogram equalization



$$J = \text{histeq}(I)$$

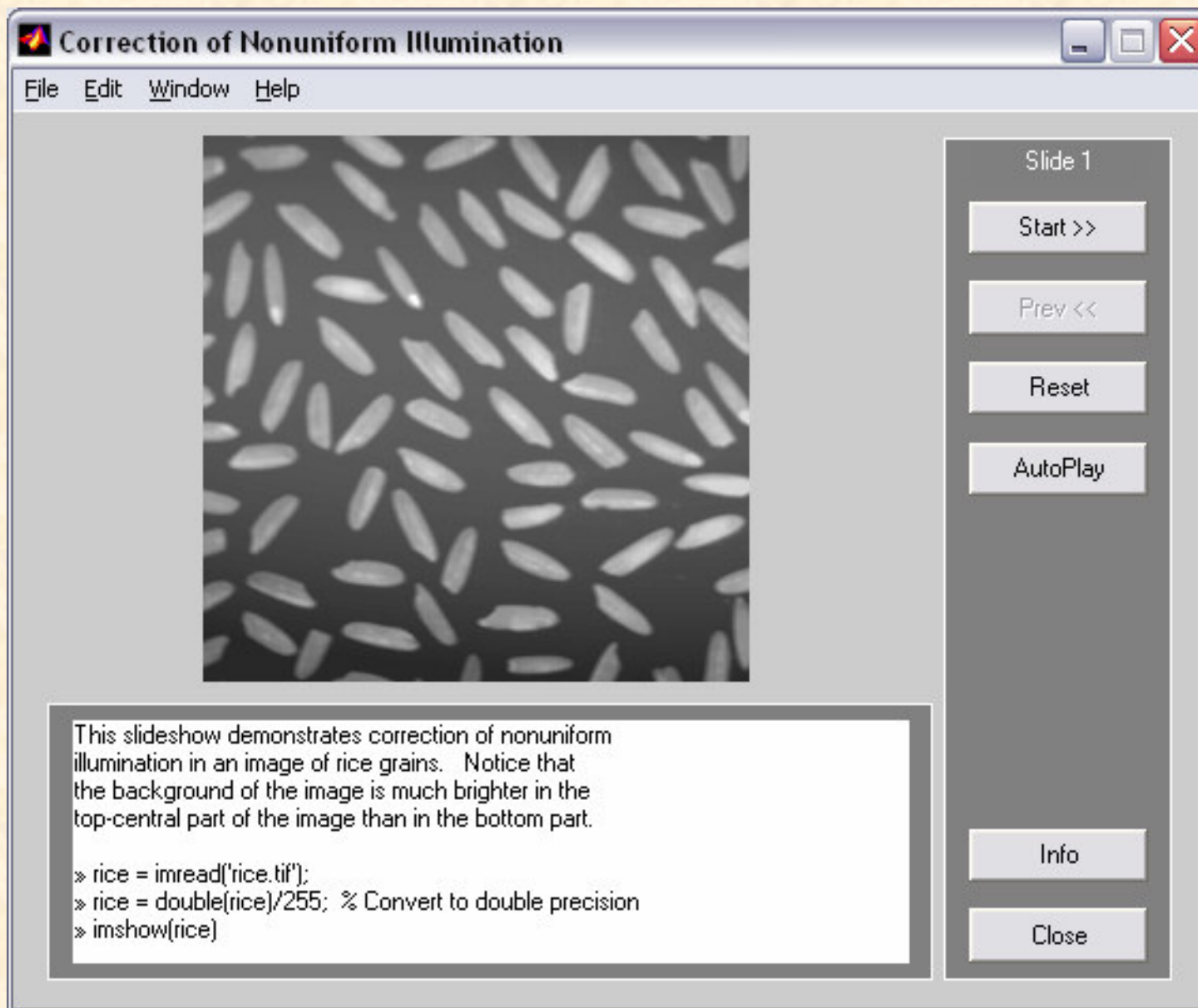
Histogram equalization - example



MATLAB Demo – intensity adjustment

The screenshot shows a MATLAB window titled "Image Histogram and Intensity Adjustment Demo". The window has a menu bar with "File", "Edit", "Window", and "Help". Below the menu bar, there is a "Select an Image:" dropdown menu currently set to "Circuit". To the right of the dropdown is a preview of the "Equalized Image". Below the dropdown and preview are two histograms, both labeled "Histogram". The left histogram shows the original image's intensity distribution, which is skewed towards lower intensities. The right histogram shows the result of histogram equalization, which is a more uniform distribution across the intensity range. To the right of the histograms is a plot titled "Intensity Transformation" showing a blue curve that maps the original intensity values to the equalized values. Below the plot is a "Gamma:" input field set to "1". At the bottom right of the window is a panel titled "Operations:" containing a dropdown menu set to "Histogram Equalization" and several buttons: "+ Brightness", "- Brightness", "+ Contrast", "- Contrast", "+ Gamma", "- Gamma", "Info", and "Close".

Correction of nonuniform illumination



The screenshot shows a software window titled "Correction of Nonuniform Illumination". The window has a menu bar with "File", "Edit", "Window", and "Help". The main area displays a grayscale image of rice grains. The background is noticeably brighter in the top-central region and darker towards the bottom, illustrating nonuniform illumination. To the right of the image is a control panel with the following elements:

- Slide 1
- Start >>
- Prev <<
- Reset
- AutoPlay
- Info
- Close

Below the image, there is a text box containing the following text:

This slideshow demonstrates correction of nonuniform illumination in an image of rice grains. Notice that the background of the image is much brighter in the top-central part of the image than in the bottom part.

```
» rice = imread('rice.tif');  
» rice = double(rice)/255; % Convert to double precision  
» imshow(rice)
```