Image is NOT Perfect Sometimes

Image Enhancement for Visually Impaired Patients

http://www.eri.harvard.edu/faculty/peli/projects/enhancement.html

Image Enhancement

- Introduction
- Spatial domain techniques
  - Point operations
  - Histogram equalization and matching
  - Applications of histogram-based enhancement
- Frequency domain techniques
  - Unsharp masking
  - Homomorphic filtering*

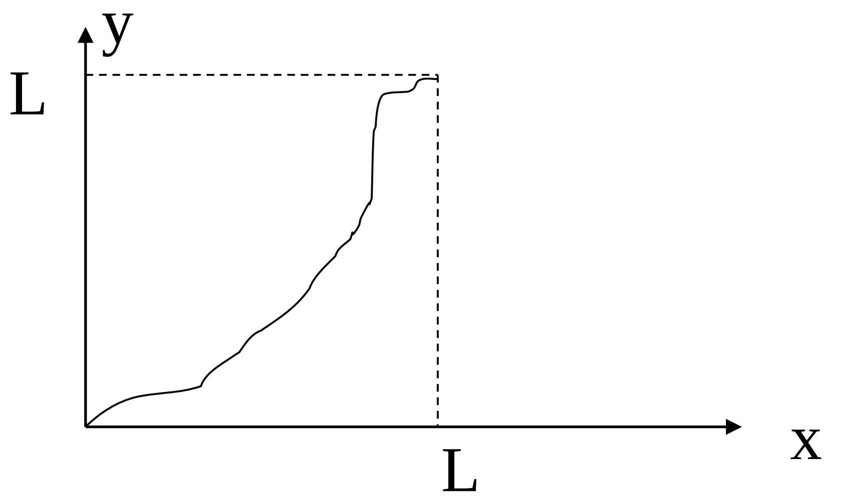
Recall:

- There is no boundary of imagination in the virtual world
- In addition to geometric transformation (warping) techniques, we can also photometrically transform images
  - Ad-hoc tools: point operations
  - Systematic tools: histogram-based methods
  - Applications: repair under-exposed or over-exposed photos, increase the contrast of iris images to facilitate recognition, enhance microarray images to facilitate segmentation.

Point Operations Overview

Point operations are **zero-memory** operations where a given gray level $x \in [0,L]$ is mapped to another gray level $y \in [0,L]$ according to a transformation

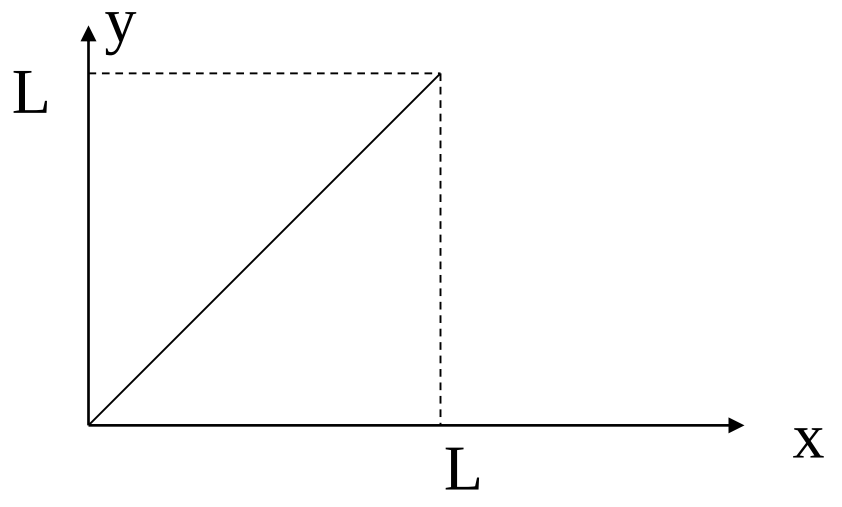
$$y = f(x)$$



L=255: for grayscale images

Lazy Man Operation

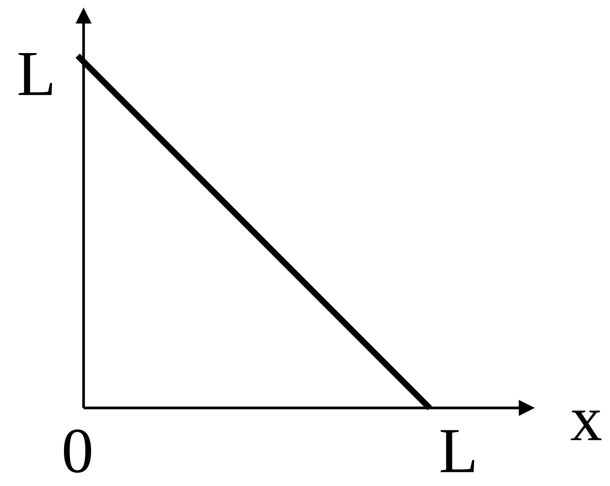
$$y = x$$



No influence on visual quality at all

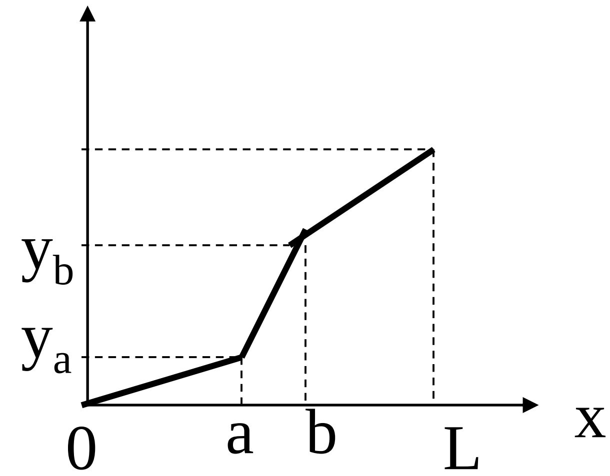
Digital Negative

$$y = L - x$$



Contrast Stretching

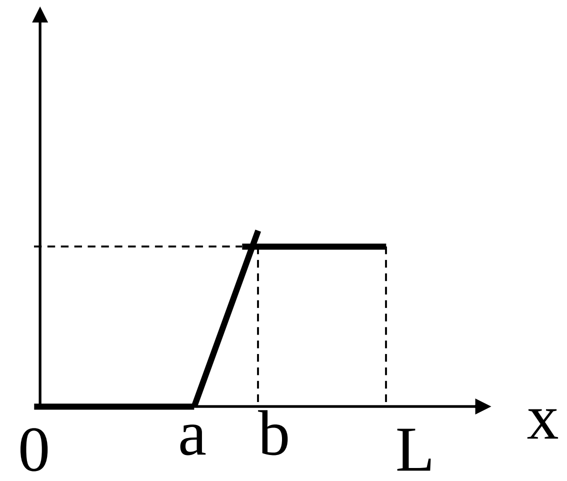
$$y = \begin{cases} \alpha x & 0 \le x < a \\ \beta(x-a) + y_a & a \le x < b \\ \gamma(x-b) + y_b & b \le x < L \end{cases}$$



$a = 50, b = 150, \alpha = 0.2, \beta = 2, \gamma = 1, y_a = 30, y_b = 200$

Clipping

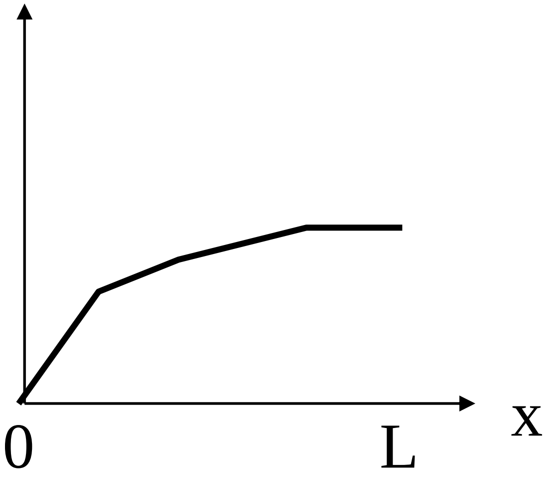
$$y = \begin{cases} 0 & 0 \le x < a \\ \beta(x-a) & a \le x < b \\ \beta(b-a) & b \le x < L \end{cases}$$



$a = 50, b = 150, \beta = 2$

Range Compression

$$y = c\log_{10}(1+x)$$



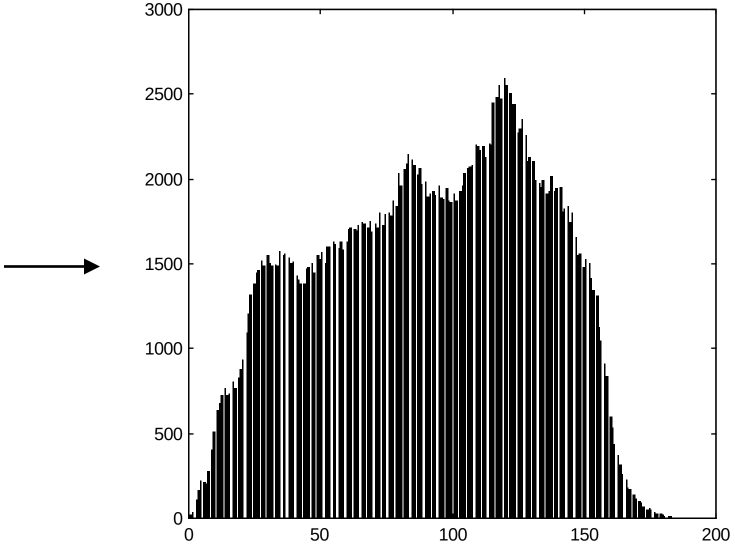
c=100

Summary of Point Operation

- So far, we have discussed various forms of mapping function f(x) that leads to different enhancement results
  - MATLAB function >imadjust
- The natural question is: How to select an appropriate f(x) for an arbitrary image?
- One systematic solution is based on the histogram information of an image
  - Histogram equalization and specification

Histogram based Enhancement

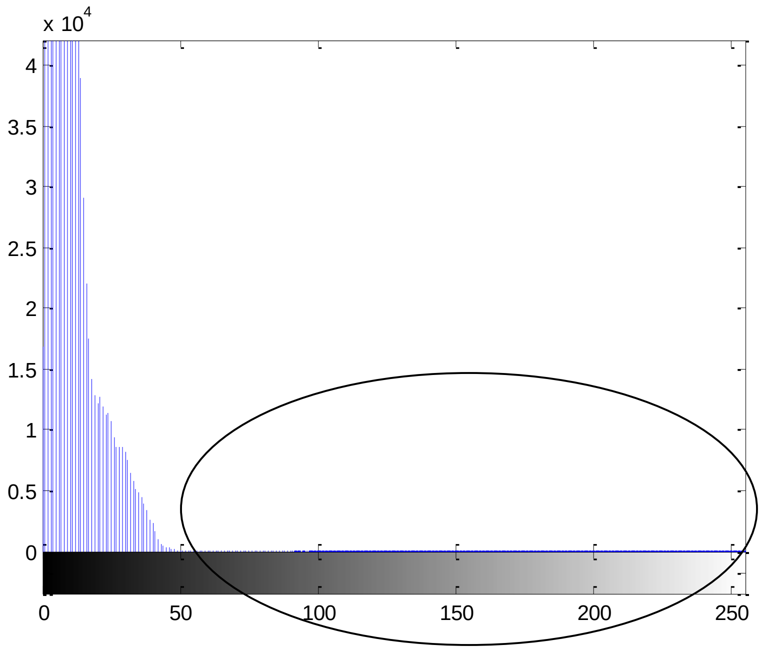
Histogram of an image represents the relative frequency of occurrence of various gray levels in the image



MATLAB function >imhist(x)

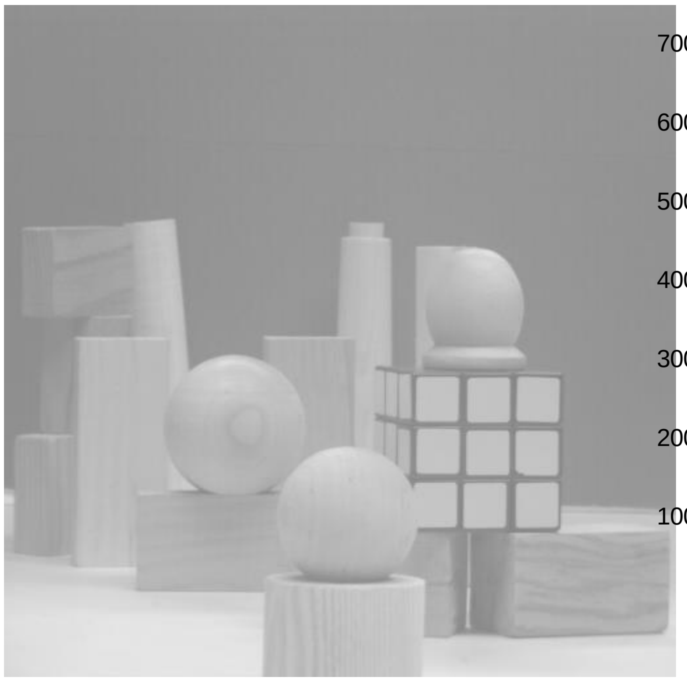
Why Histogram?

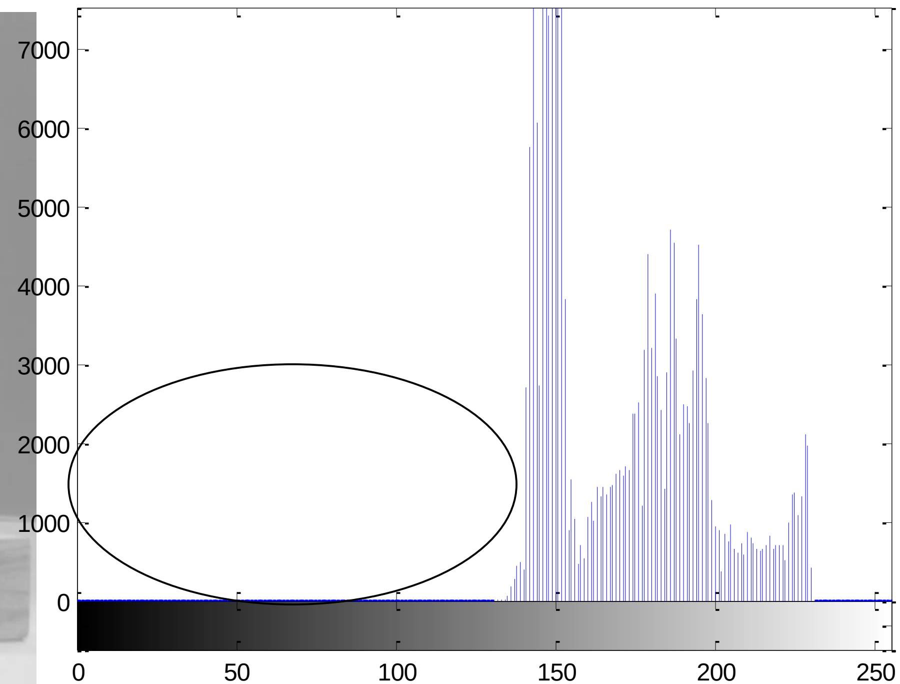
It is a baby in the cradle!



Histogram information reveals that image is under-exposed

Another Example





Over-exposed image

How to Adjust the Image?

- Histogram equalization
  - Basic idea: find a map f(x) such that the histogram of the modified (equalized) image is flat (uniform).
  - Key motivation: cumulative probability function (cdf) of a random variable approximates a uniform distribution

Suppose h(t) is the histogram (pdf) $s(x)=\sum_{t=0}^{x} h(t)$

Histogram Equalization

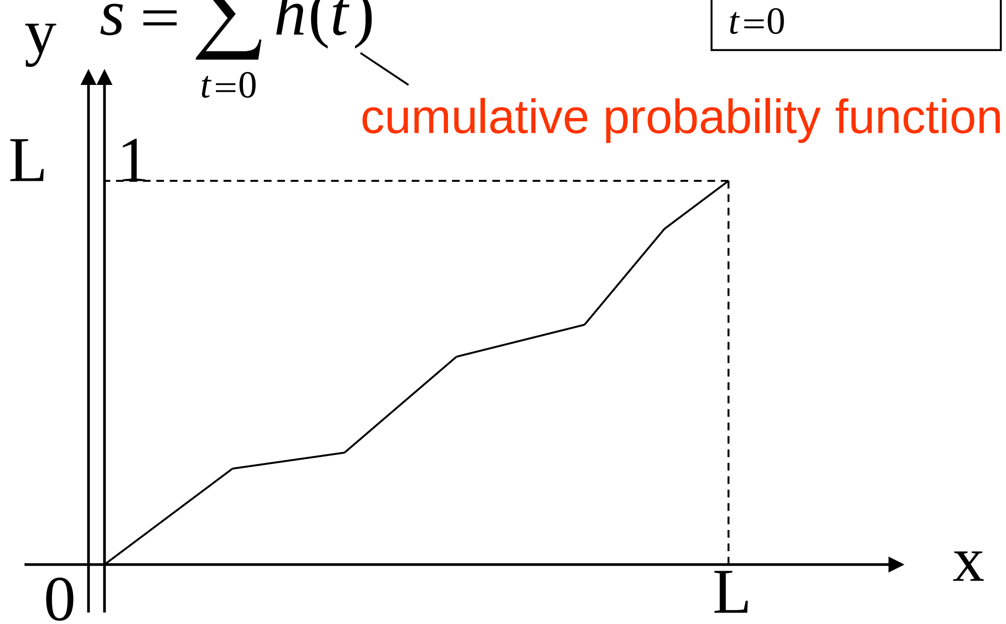
$$y = L \cdot \sum_{t=0}^{x} h(t)$$

Uniform Quantization

Note: $\sum_{t=0}^{L} h(t) = 1$

$$s = \sum_{t=0}^{x} h(t)$$

cumulative probability function



http://en.wikipedia.org/wiki/Inverse_transform_sampling

MATLAB Implementation

```
function y=hist_eq(x)

[M,N]=size(x);
for i=1:256
h(i)=sum(sum(x= =i-1));
End
```

Calculate the histogram of the input image

```
y=x;s=sum(h);
for i=1:256
I=find(x= =i-1);
y(I)=sum(h(1:i))/s*255;
end
```

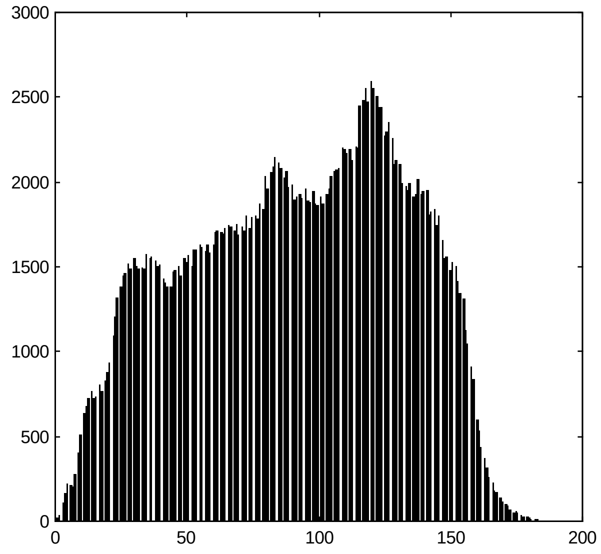
Perform histogram equalization

Image Example

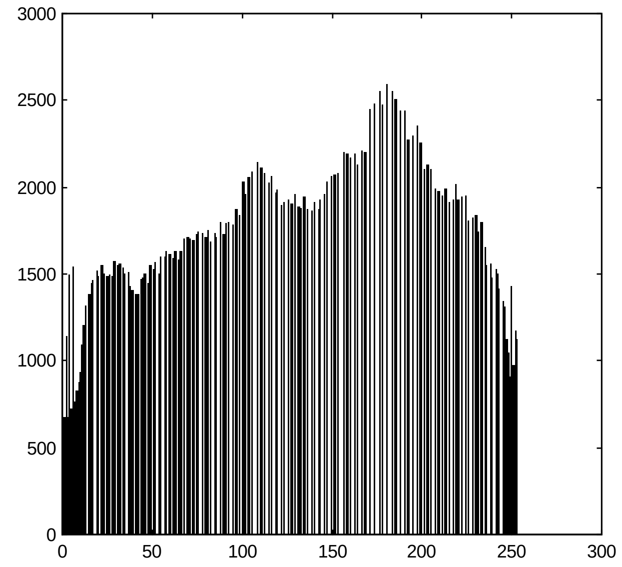
before

after

Histogram Comparison



before equalization



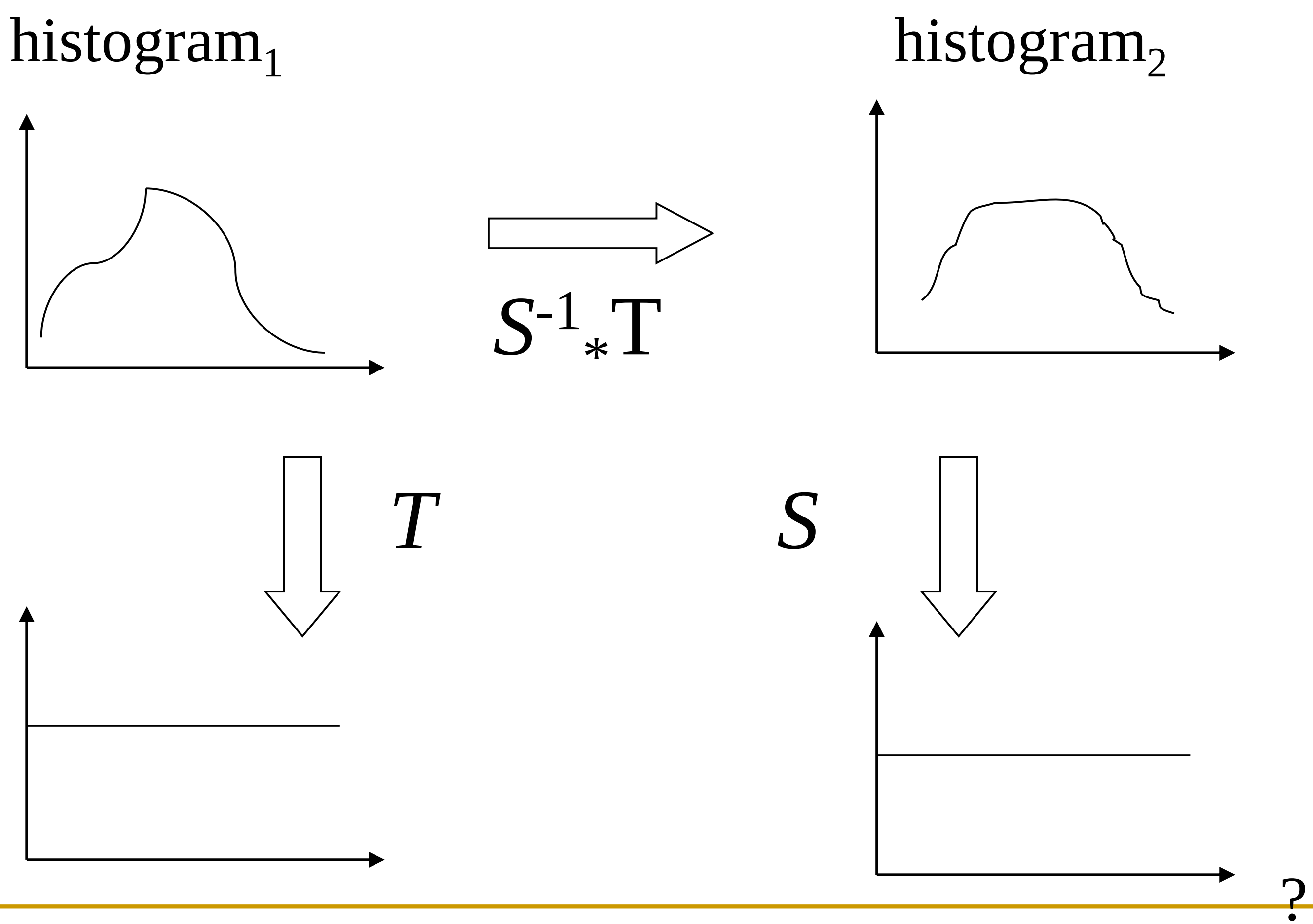
after equalization

Adaptive Histogram Equalization

http://en.wikipedia.org/wiki/Adaptive_histogram_equalization

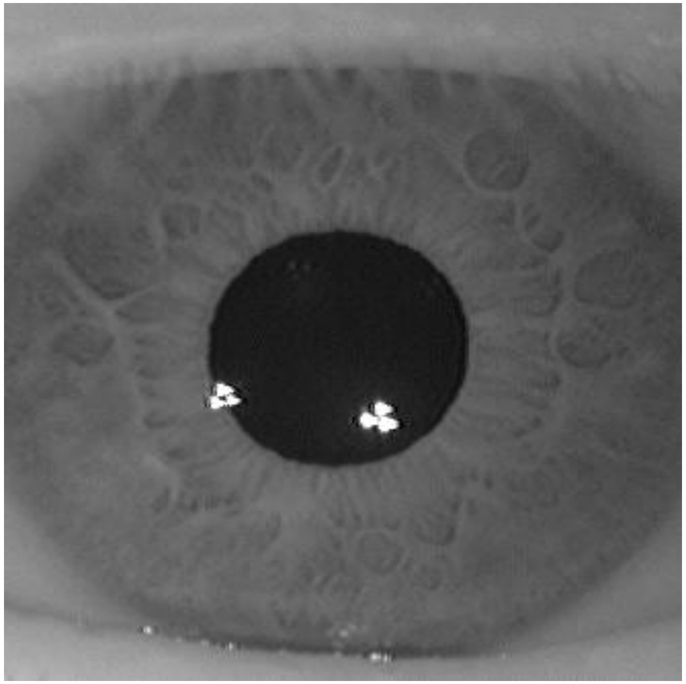
Histogram Specification/Matching

Given a target image B, how to modify a given image A such that the histogram of the modified A can match that of target image B?

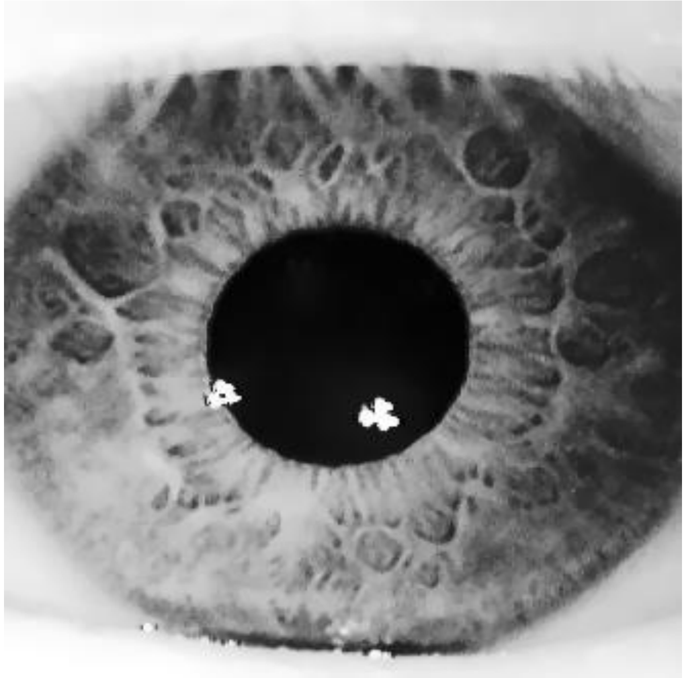


Application (I): Digital Photography

Application (II): Iris Recognition

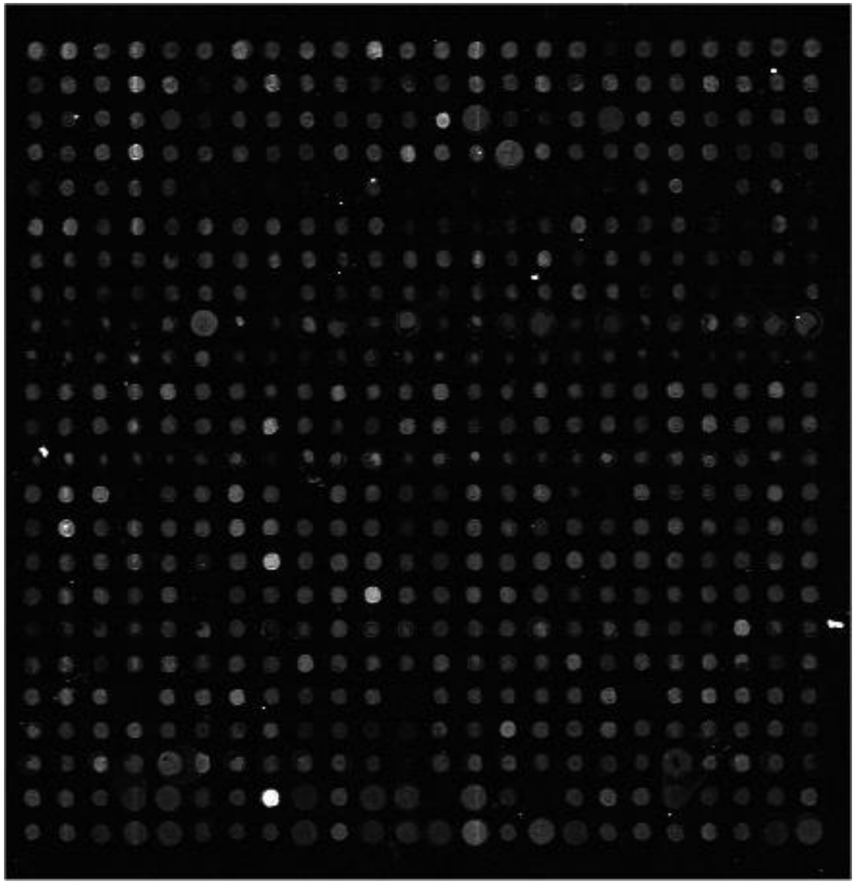


before

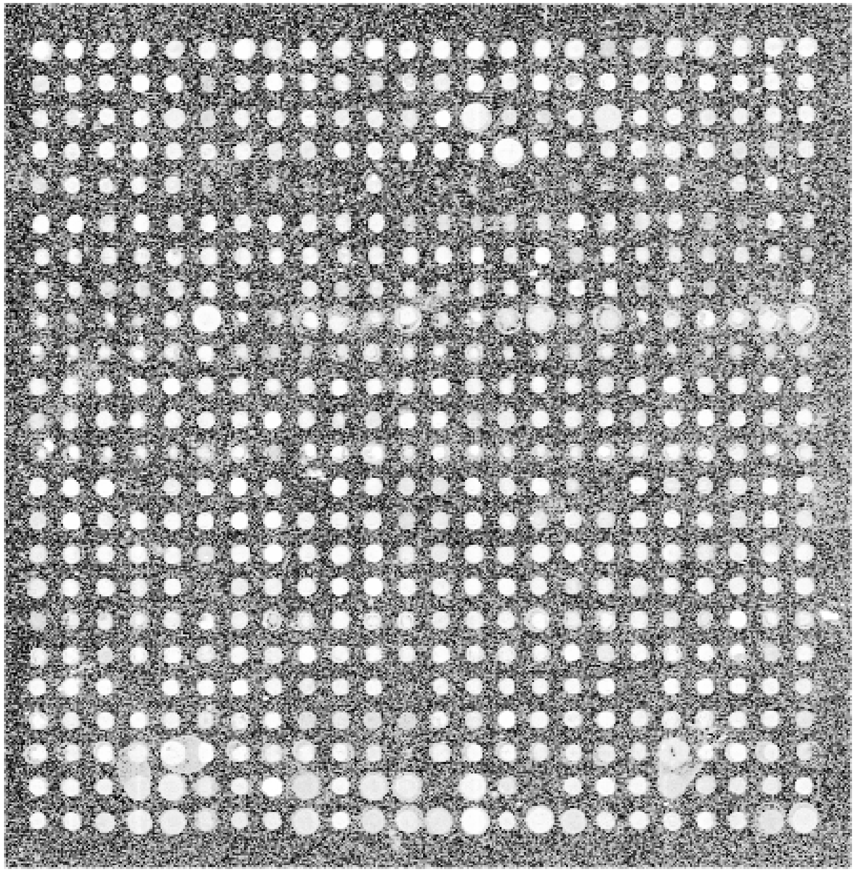


after

Application (III): Microarray Techniques



before



after

Application (IV) Gamma Correction

- Gamma correction is important if displaying an image accurately on a computer screen is of concern
- Reproducing accurate color also requires some knowledge of gamma correction because varing the value of gamma correction changes not only the brightness, but also the ratios of red to green to blue
- Example

Original

gamma=0.45

gamma=2.20

Application (V): Entertainment

HDR video

Histogram-equalized

Adaptive histogram -equalized[1]

[1]Eric P. Bennett and Leonard McMillan. "Video enhancement using per-pixel virtual exposures," In ACM SIGGRAPH 2005

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Frequency-Domain Techniques (I): Unsharp Masking

$$y(m,n) = x(m,n) + \lambda g(m,n), \lambda > 0$$

g(m,n) is a high-pass filtered version of *x(m,n)*

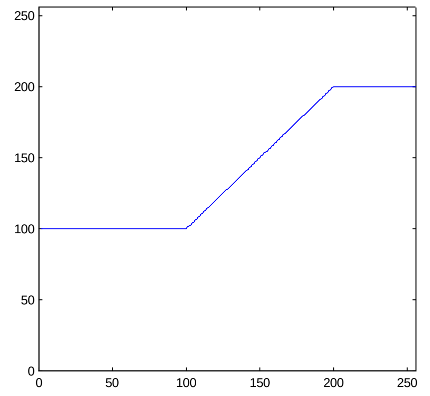
- Example (Laplacian operator)

$$g(m,n) = x(m,n) - \frac{1}{4}[x(m-1,n) + x(m+1,n) +$$
$$x(m,n-1) + x(m,n+1)]$$

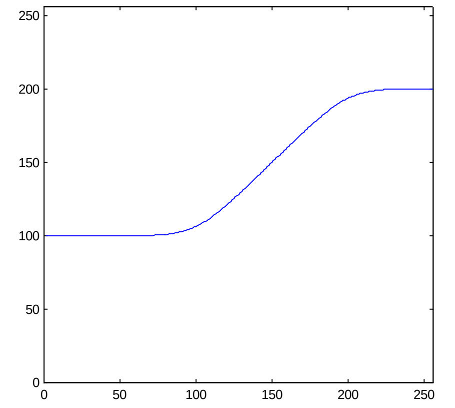
MATLAB Implementation

```
% Implementation of Unsharp masking

function y=unsharp_masking(x,lambda)

% Laplacian operation
h=[0 -1 0;-1 4 -1;0 -1 0]/4;
dx=filter2(h,x);
y=x+lambda*dx;
```

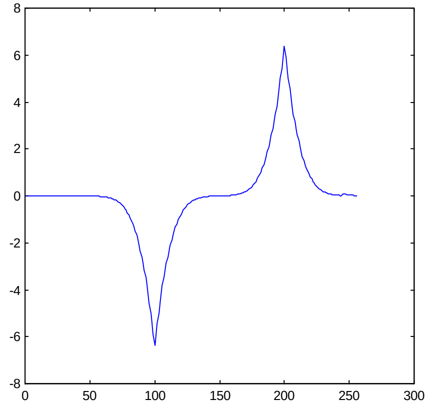
1D Example



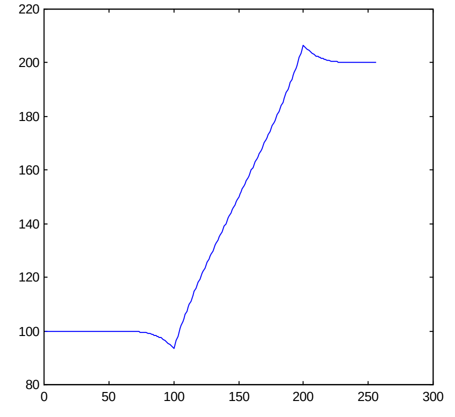
$x(n)$



$x_{lp}(n)$

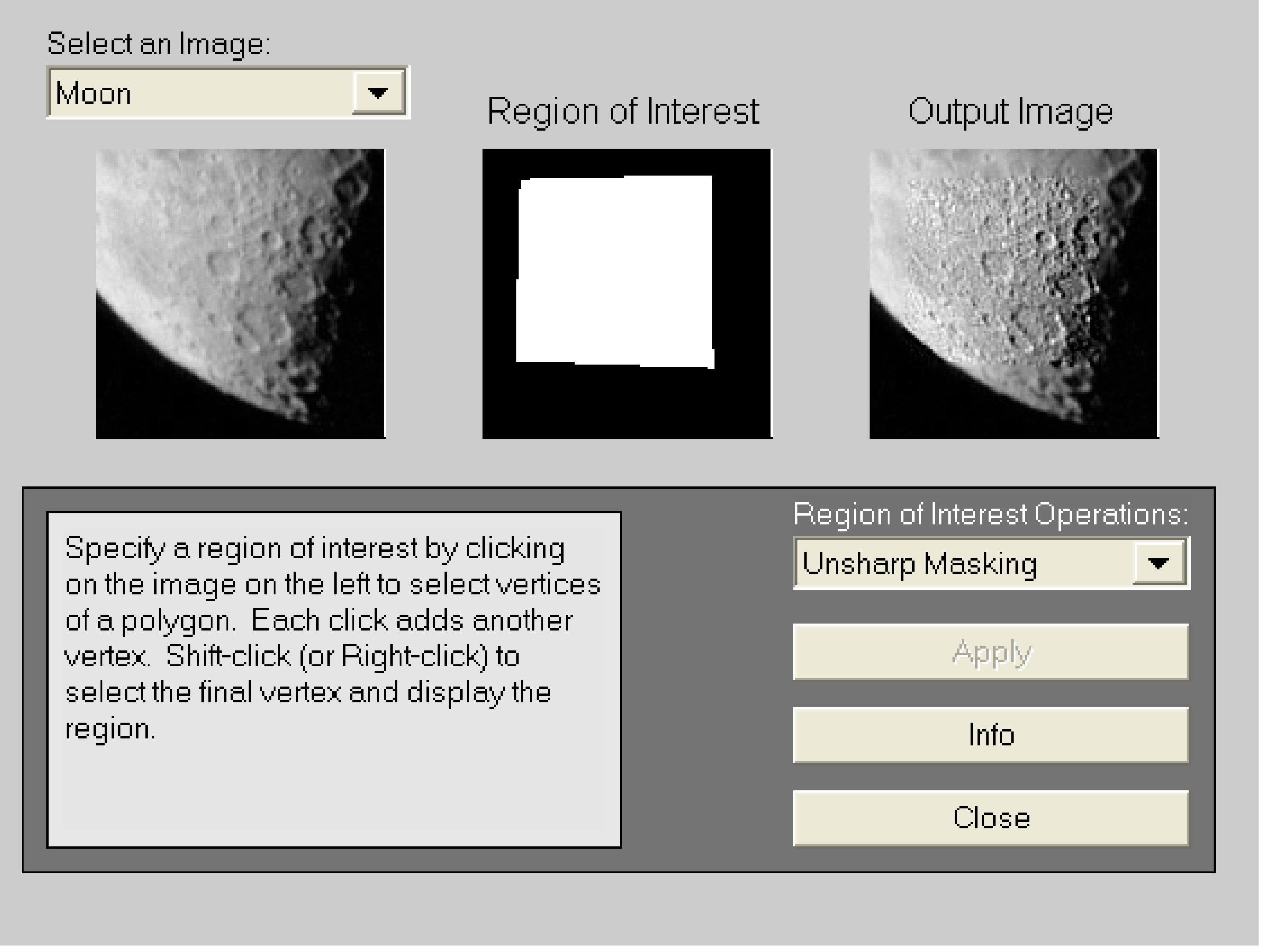


$g(n)=x(n)-x_{lp}(n)$



$$y(n) = x(n) + \lambda g(n)$$

2D Example



MATLAB command >roidemo

Frequency-Domain Techniques (II): Homomorphic filtering

<u>Basic idea:</u>

$$f(x,y) = i(x,y)r(x,y)$$

Illumination
(low freq.)

reflectance
(high freq.)

$$\ln f(x,y) = \ln i(x,y) + \ln r(x,y)$$

freq. domain enhancement

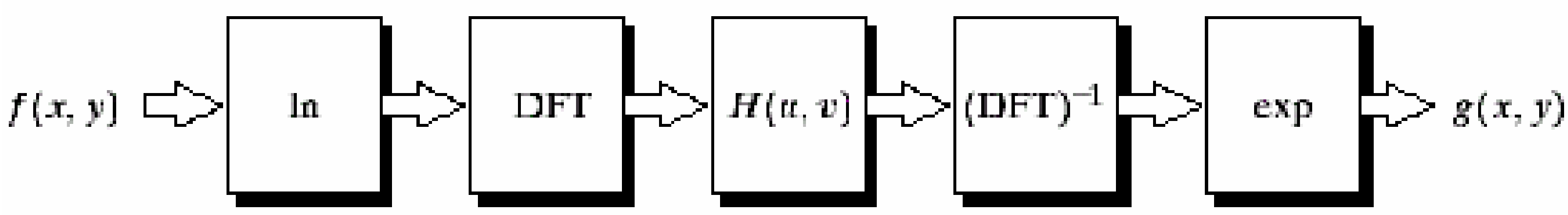
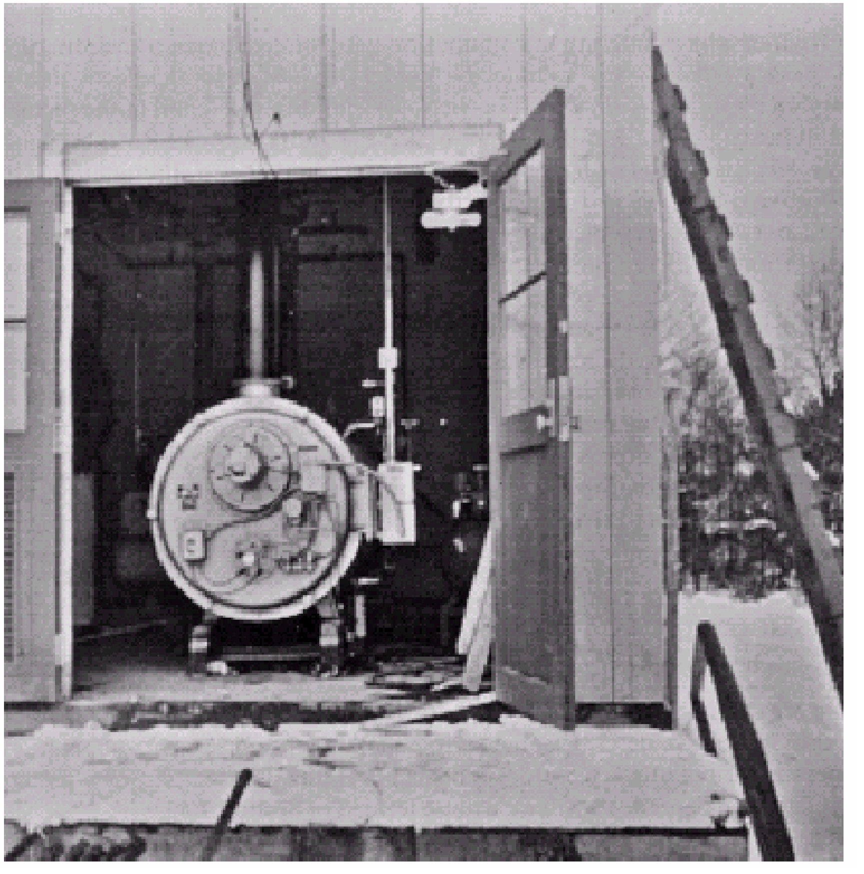


Image Example

before



after

Summary of Nonlinear Image Enhancement

- Understand how image degradation occurs first
  - Play detective: look at histogram distribution, noise statistics, frequency-domain coefficients…
  - Model image degradation mathematically and try inverse-engineering
- Visual quality is often the simplest way of evaluating the effectiveness, but it will be more desirable to measure the performance at a system level
  - Iris recognition: ROC curve of overall system
  - Microarray: ground-truth of microarray image segmentation result provided by biologists