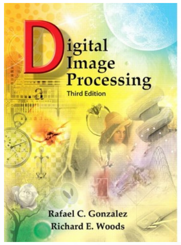
Lecture 2 – Pointwise processing

Ch. 2.6-2.6.4
3.1-3.3 in
Gonzales & Woods



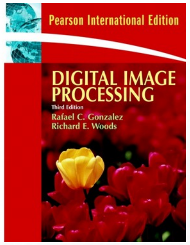


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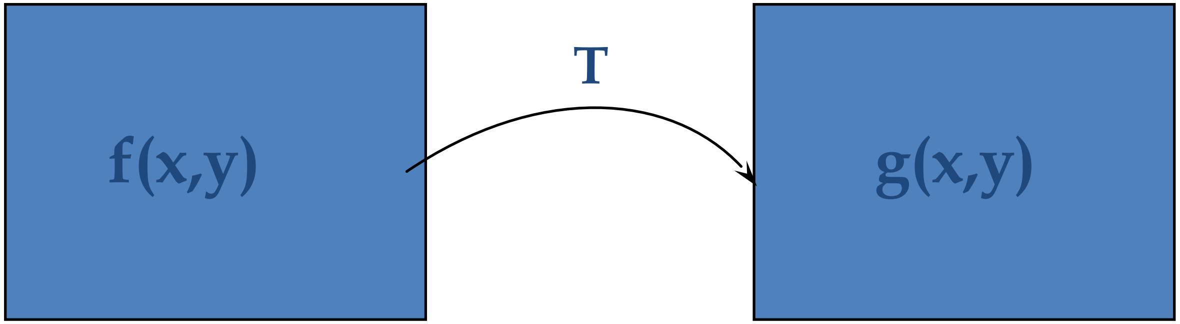
Image enhancement

- http://www.youtube.com/watch?v=Vxq9yj2pVWk

- an image processing technique to enhance certain features of the image

Image processing



f(x,y)

T

g(x,y)

Original image

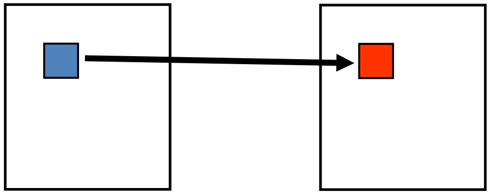
New image

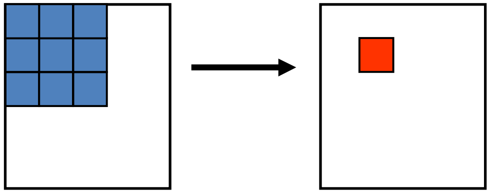
- We want to create an image which is ”better” in some sense.
- For example
- Image restoration (reduce noise)
- Image enhancement (enhance edges, lines etc.)
- Make the image more suitable for visual interpretation
- **Image enhancement does NOT increase image information**

Image processing

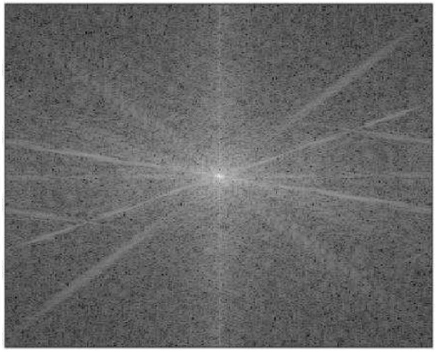
- can be performed in the:

- **Spatial domain**
  - Pointwise processing → Lecture 2
    - Works per pixel
  - Spatial filtering → Lecture 3
    - Works on small neighborhood
- **Frequency domain** → Lecture 4

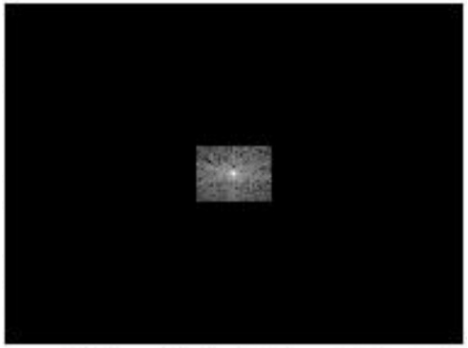




Original image in spatial domain



Original image in frequency domain



Processed image in frequency domain

Processed image in spatial domain

Problem solving using image analysis: fundamental steps

image acquisition

preprocessing,
enhancement

segmentation

feature extraction,
description

classification,
interpretation,
recognition

result

Knowledge
about the
application

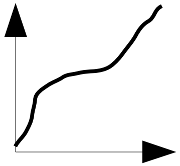
Overview

i. repetition

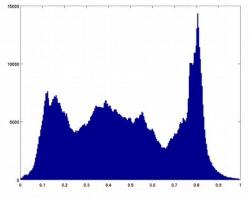
ii. image arithmetics

'+','-', '*'

iii. intensity transfer functions

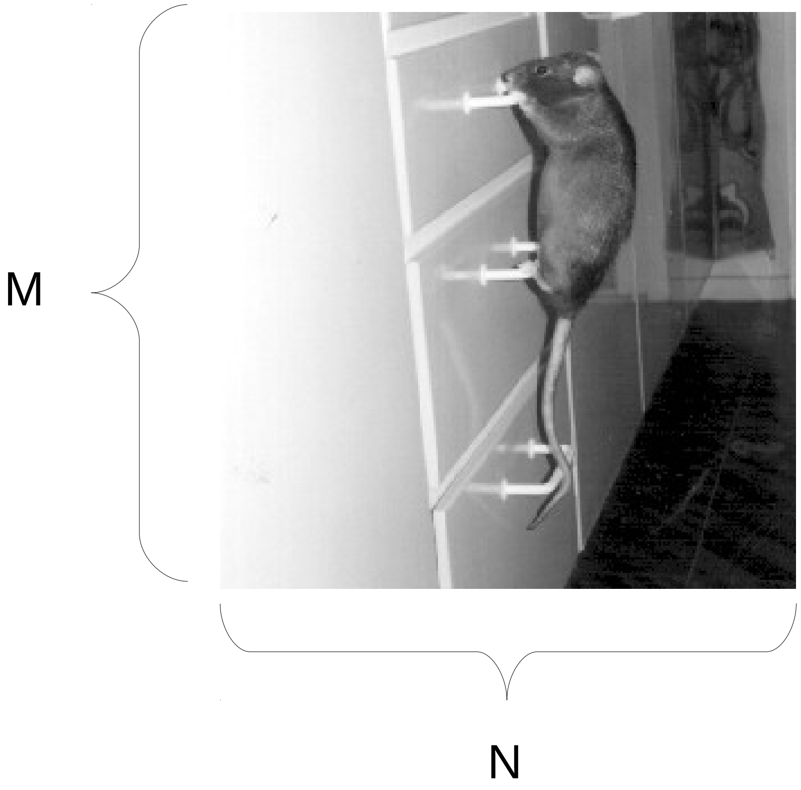


iv. histograms and histogram equalization



Last lecture

- Digitization
  - Sampling in space (x,y)
  - Sampling in amplitude (intensity)
- Pixel/Voxel
- How often should you sample in space to see details of a certain size?



Bit depth

2 gray levels, 1bit/pixel

- Number of bits that are used to store the intensity information
- Images are typically of 8- or 16-bit
  - 1bit = 2^1 → 2 steps (0,1)
  - 2 bit = 2^2 → 4 steps
  - 8 bit = 2^8 → 256 steps
  - 16 bit = 2^16 → 65 536 steps

64 gray levels, 6bit/pixel

256 gray levels, 8bit/pixel

I. Image arithmetics in the spatial domain

Image arithmetics

- **A(x,y) = B(x,y)** ○ **C(x,y)** for all x,y.

  B, C → images with the same (spatial) dimensions

  → images + constant value

  ○ can be

  - Standard arithmetic operation: **+**, **-**, *****.
  - Logical operator (binary images): **AND**, **OR**, **XOR**,...

- Any pitfalls?

Arithmetics with binary images

■ min value

□ max value

image1

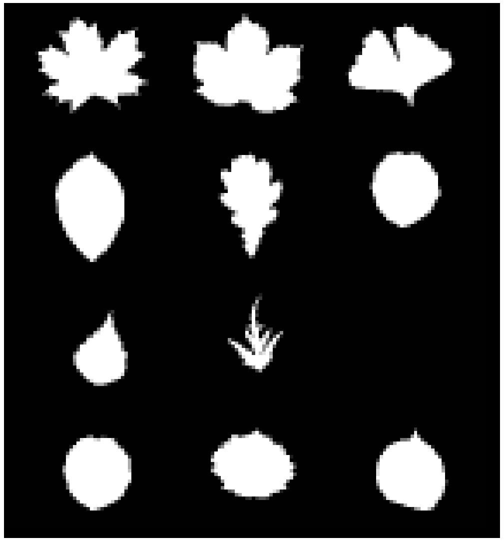


image2

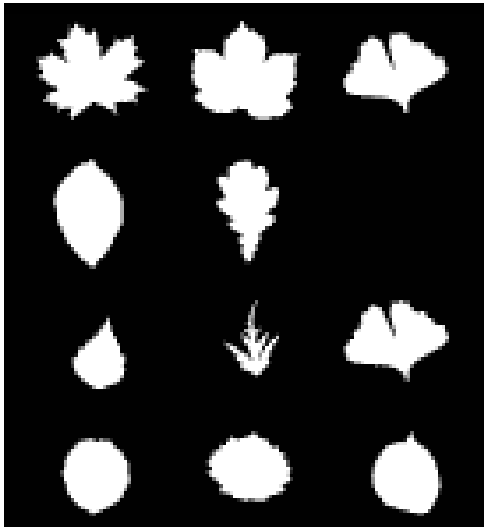


image1-image2

image2-image1

Arithmetics with binary images

■ min value

□ max value

image1

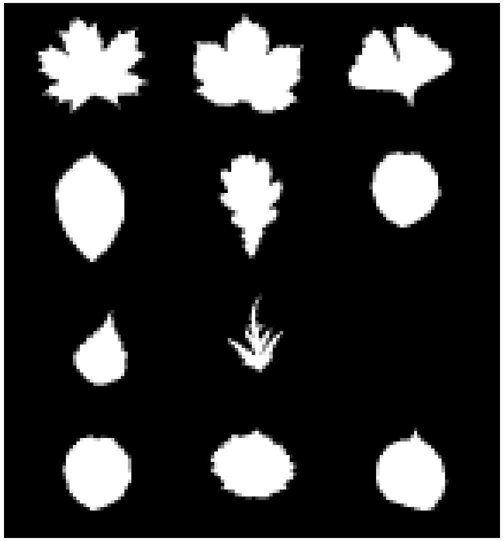
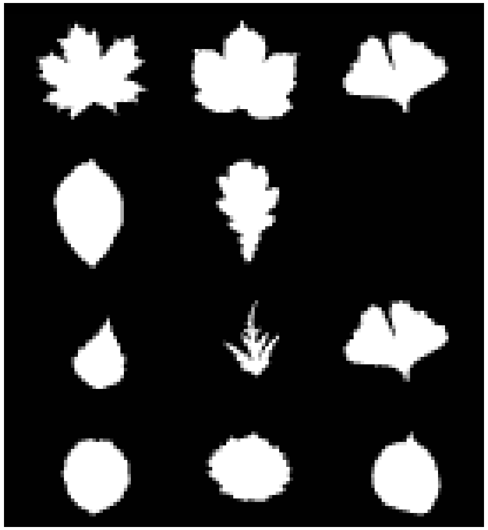


image2



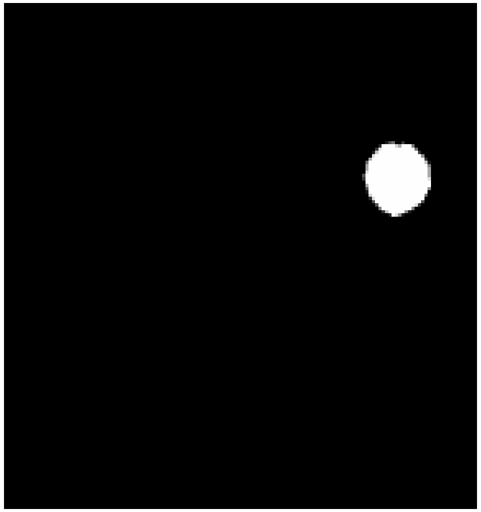


image1-image2

image2-image1

Arithmetics with binary images

■ min value

□ max value

image1

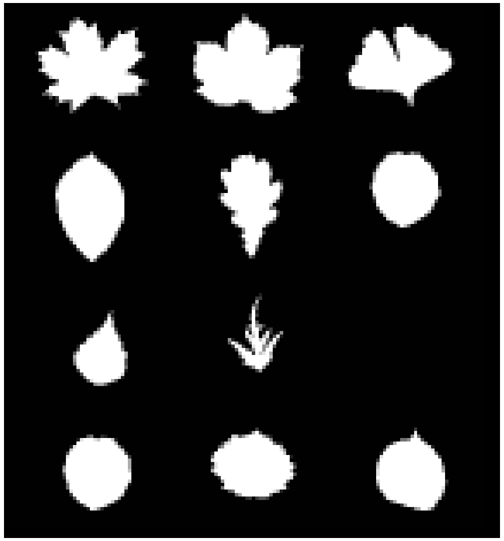
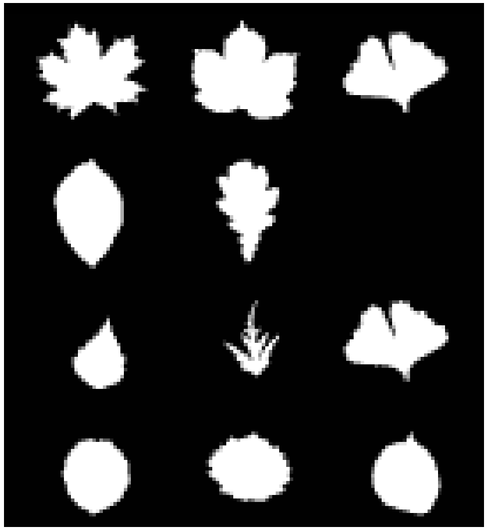


image2



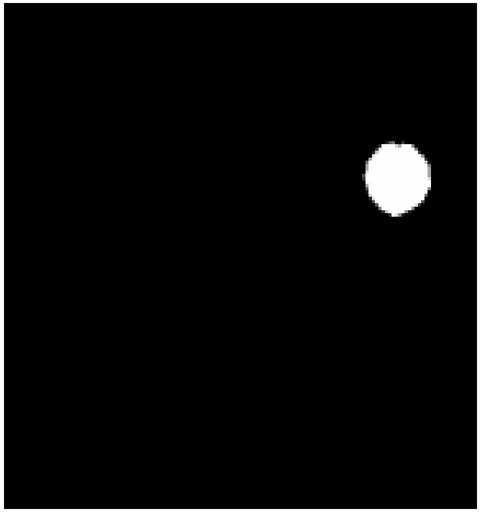


image1-image2

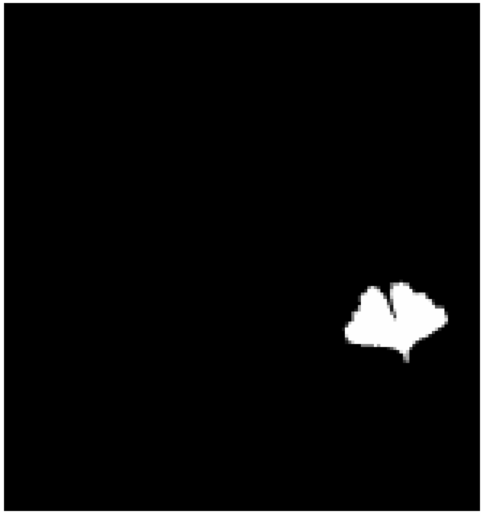
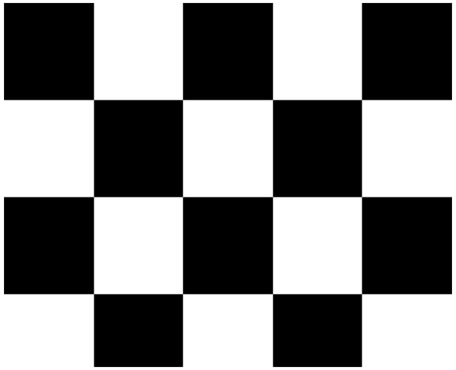


image2-image1

Arithmetics with greyscale images

+



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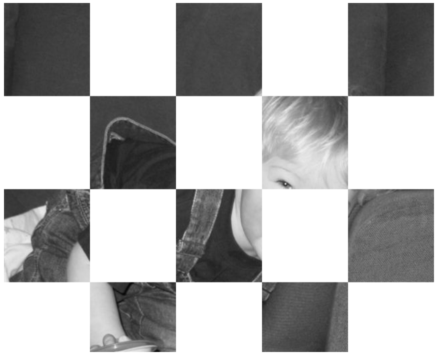

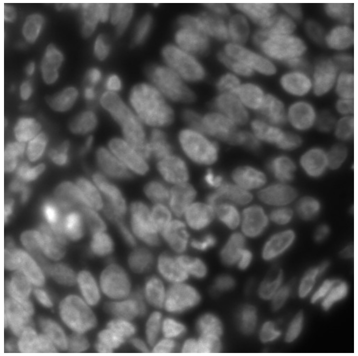

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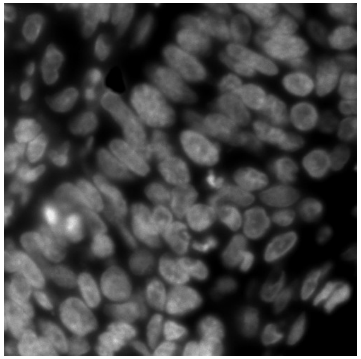

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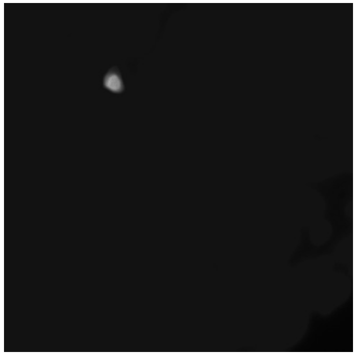
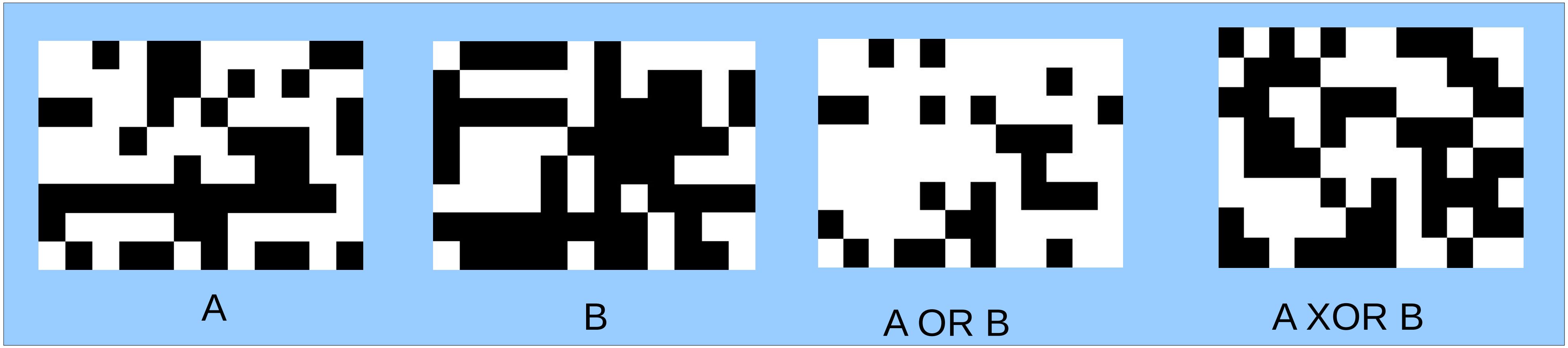


Logical operations on binary images


A

B

A OR B

A XOR B

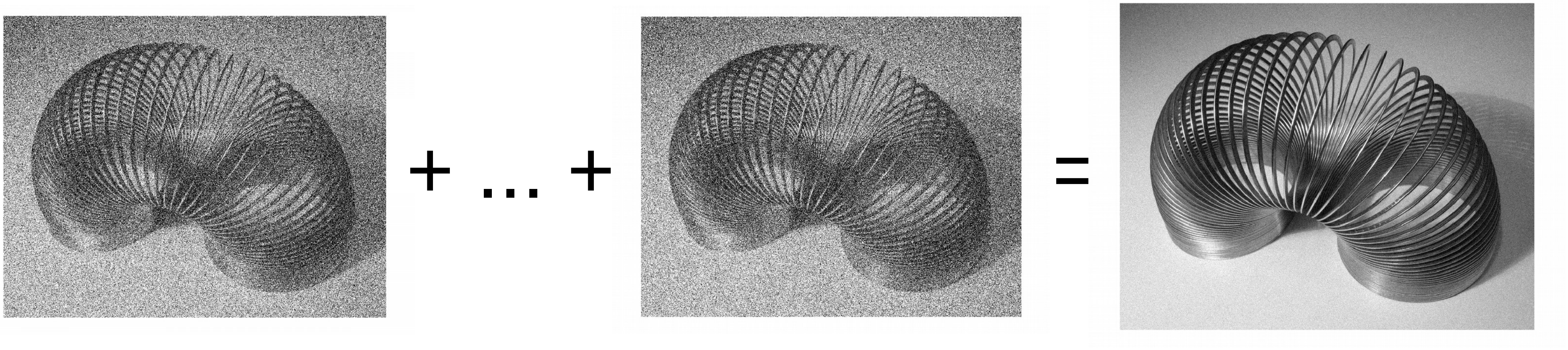
INPUT		OUTPUT
A	B	A OR B
0	0	0
0	1	1
1	0	1
1	1	1

INPUT		OUTPUT
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0

Applications

- **Noise reduction** using image mean or median

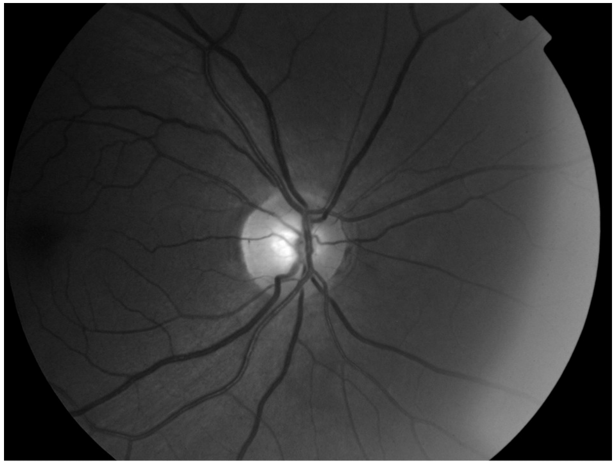
$$I = \frac{1}{n} \sum_{k=1..n} I_k$$



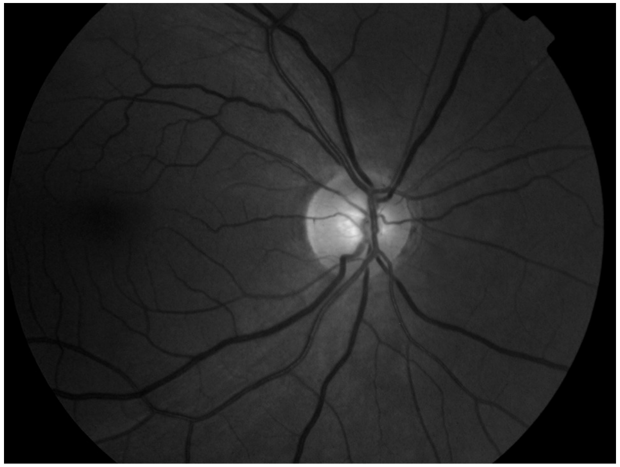
I_1 + … + I_n = I

Applications

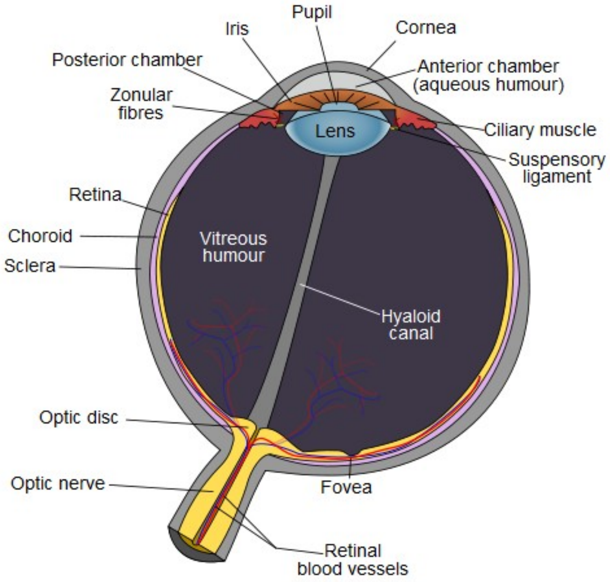
- **Change detection** using subtraction



2015



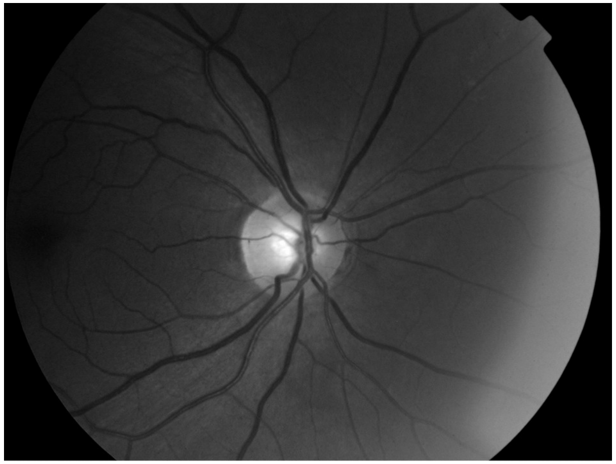
2016



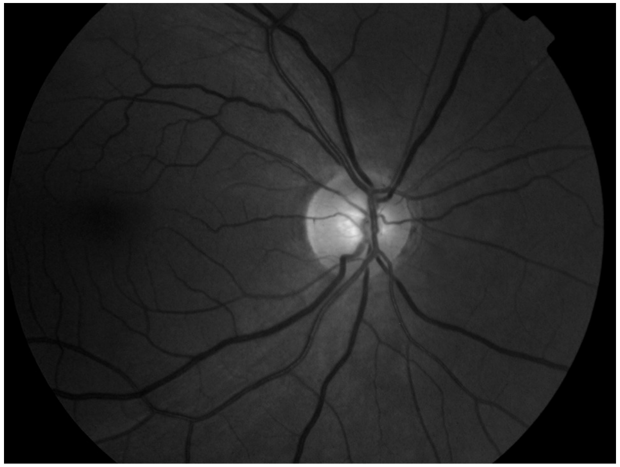
Has anything changed?

Applications

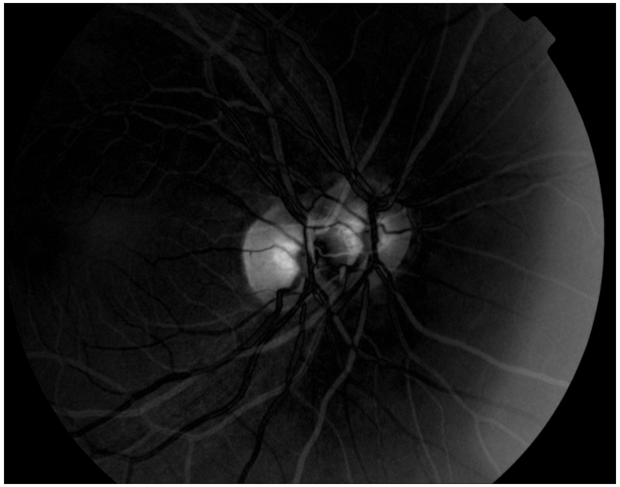
- **Change detection** using subtraction



2015



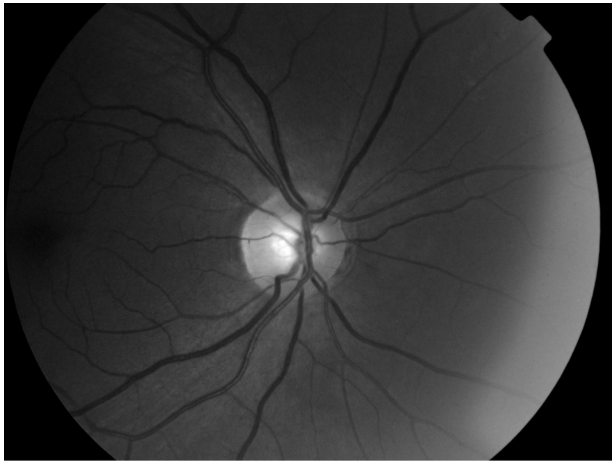
2016



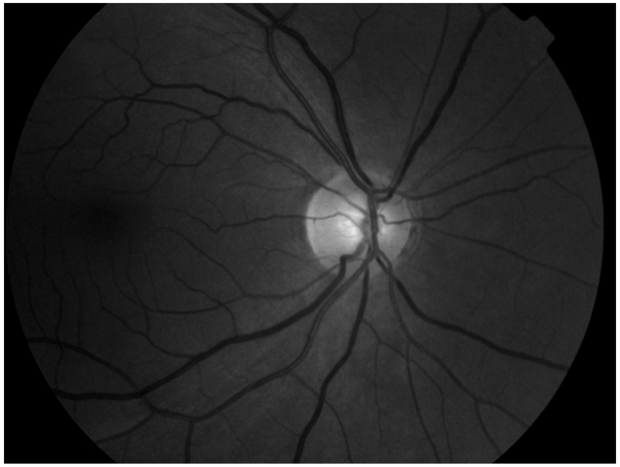
direct difference

Applications

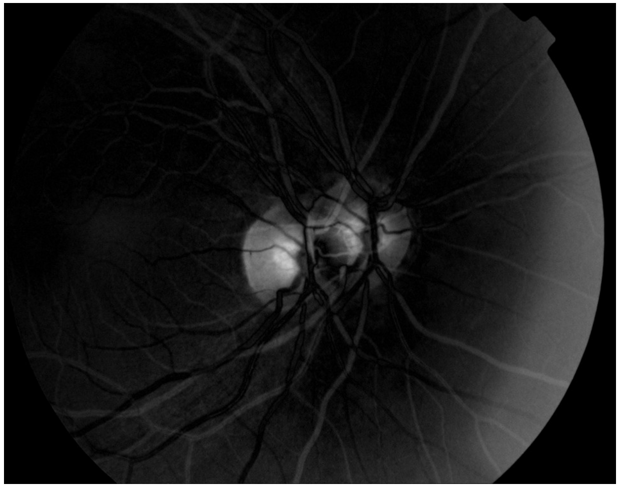
- **Change detection** using subtraction



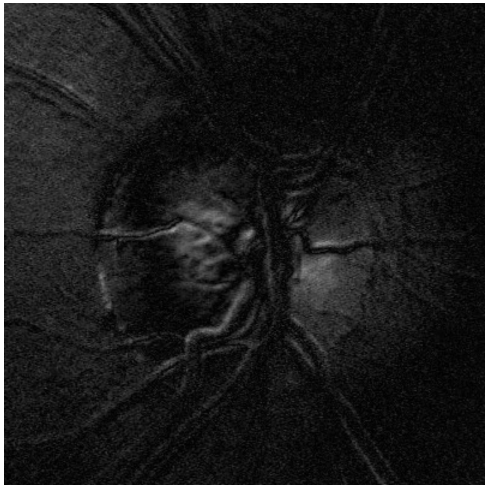
2015



2016



direct difference



difference after registration

Applications

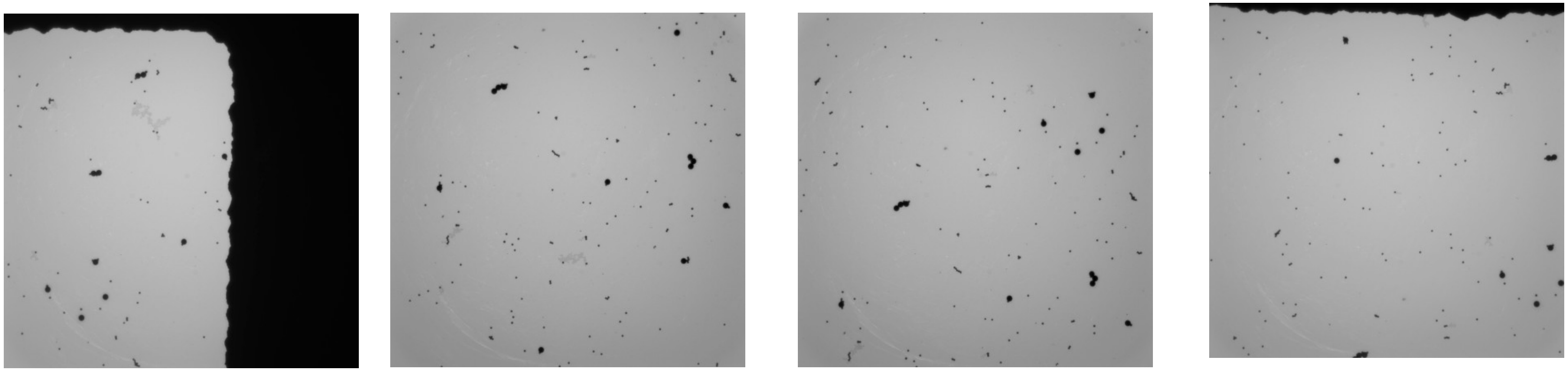
- **Change/motion detection** using subtraction

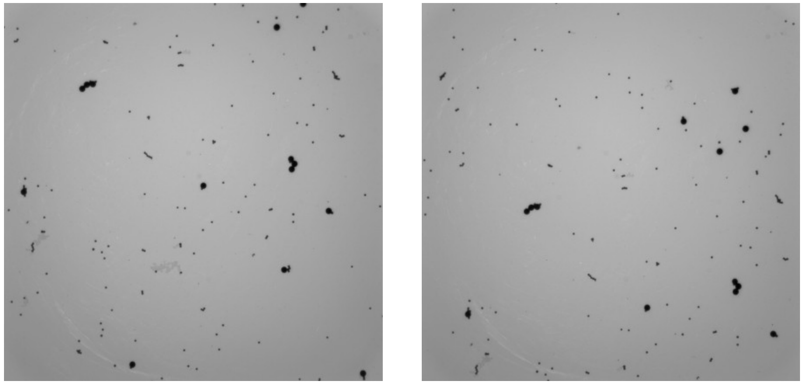
Applications

- **Background removal**

image - background image

  - Creating a background image

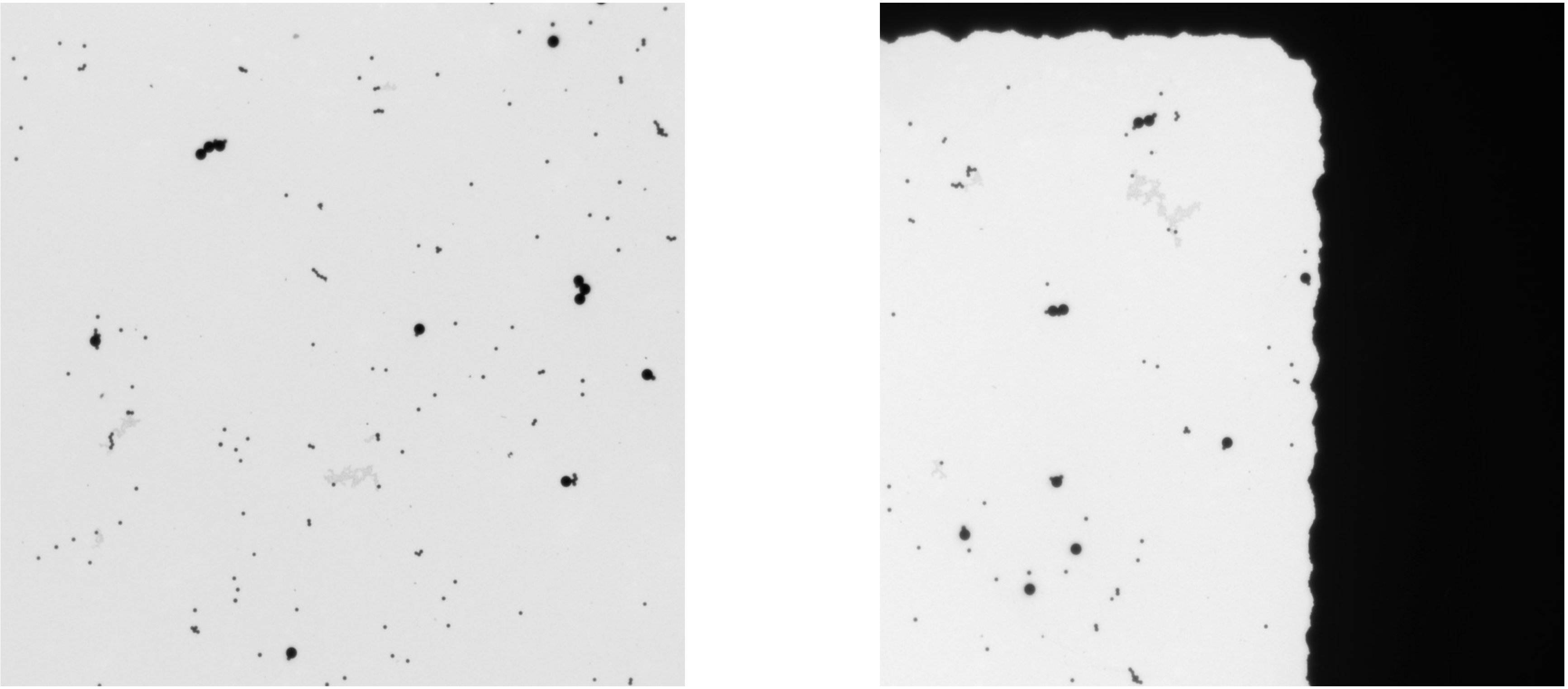




Max or median of
the pixel intensities
at all positions.

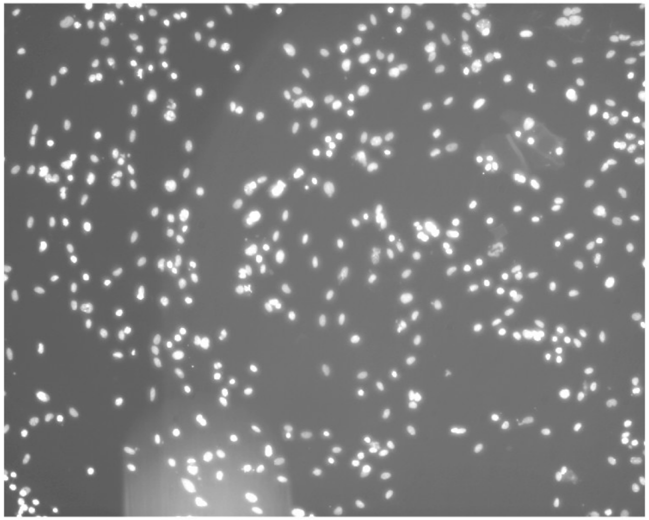
Applications

- **Background removal** - result



Applications

- Subtracting a background image/correcting for uneven illumination



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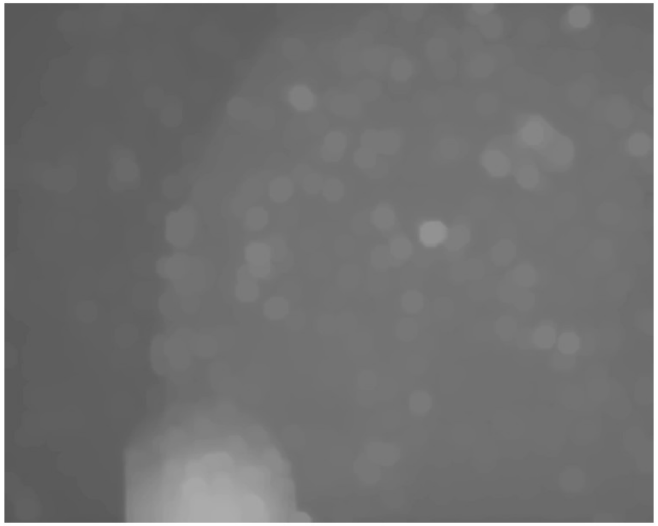

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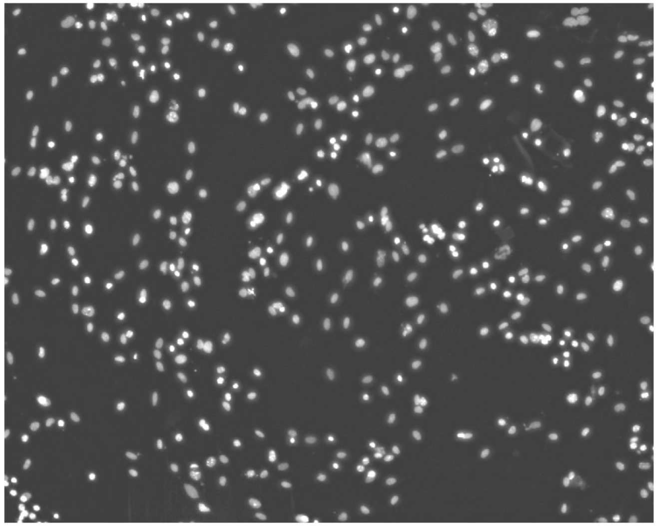
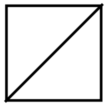
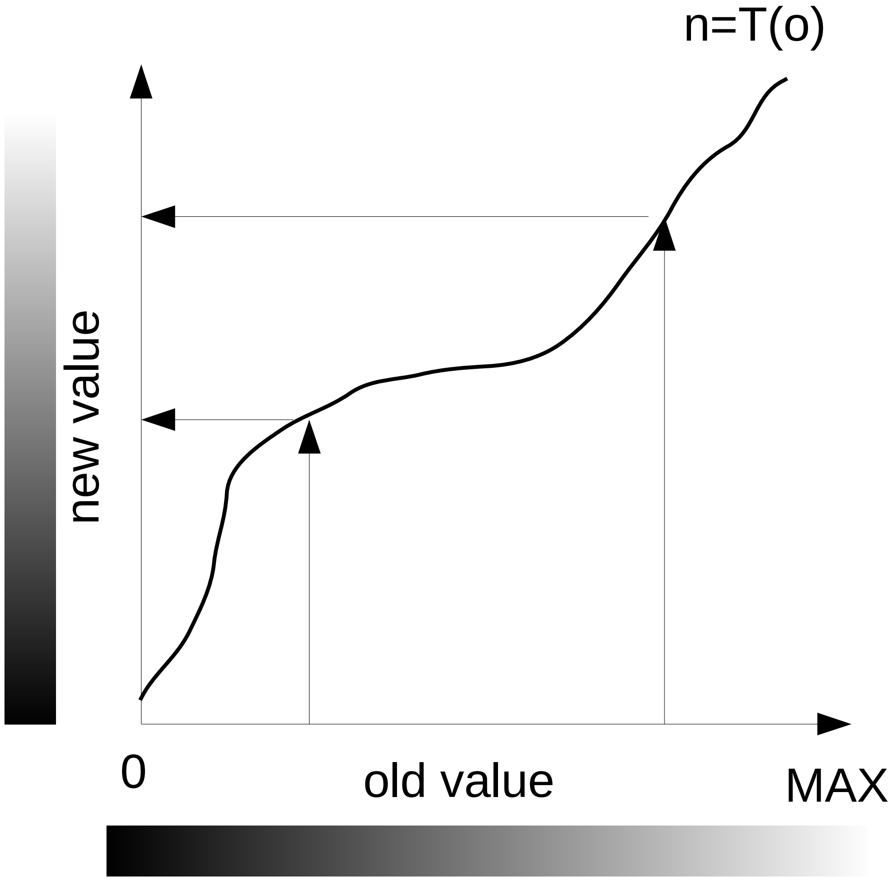


II. Intensity transfer functions

Intensity transfer functions

$$g(x,y) = Tf(x,y)$$

- i. **linear** (neutral  , negative, contrast, brightness)
- ii. **smooth** (gamma, log)
- iii. **arbitrarily**

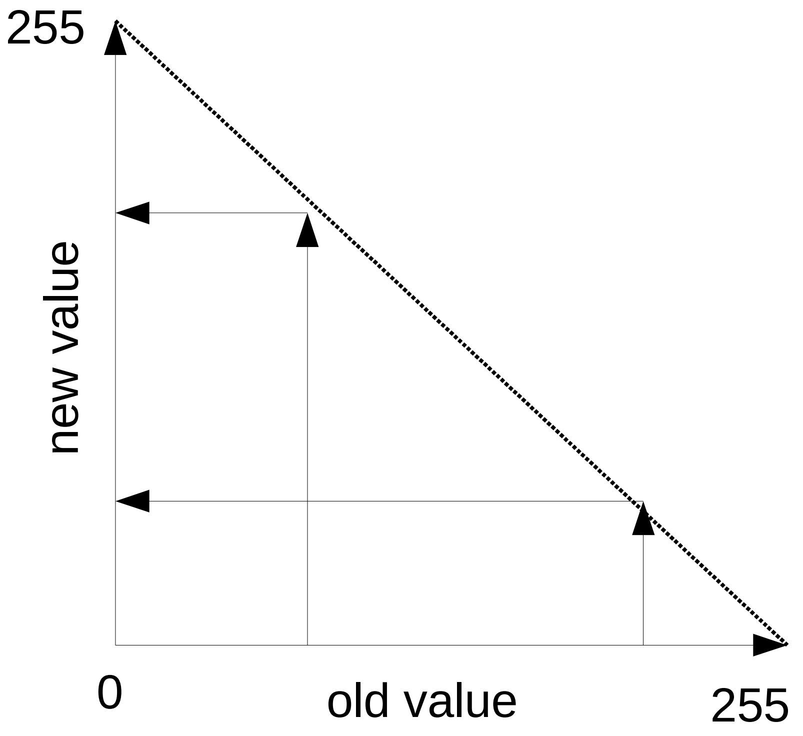


The negative transformation

$$g(x,y) = max - f(x,y)$$

- For eight bit image:

$$g(x,y) = 2^8 - 1 - f(x,y)$$



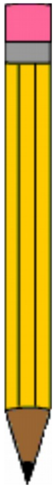
The rules of how to transfer values from the old image to the new one.

The negative transformation

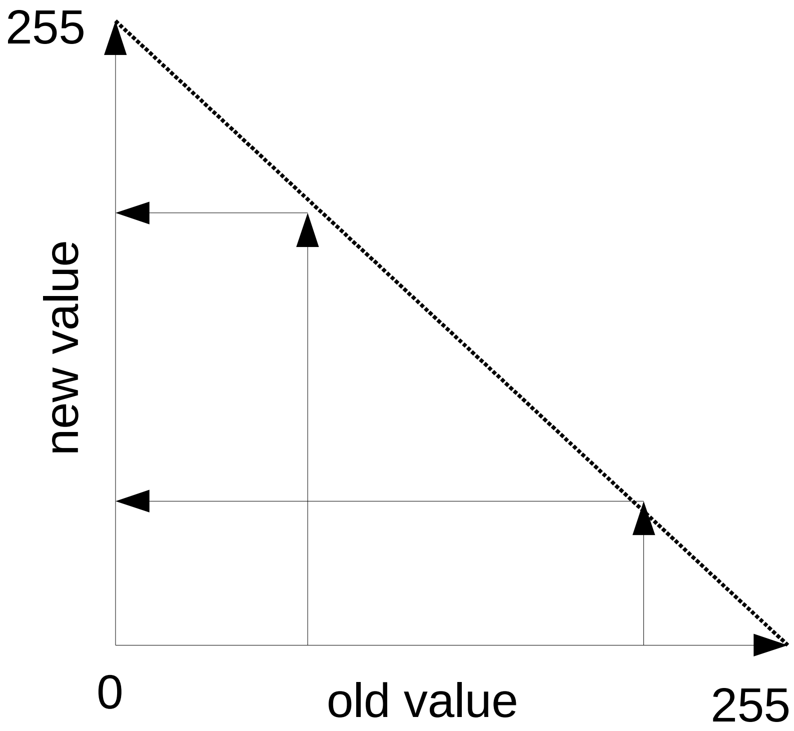
$$g(x,y) = max - f(x,y)$$

- For eight bit image:

$$g(x,y) = 2^8 - 1 - f(x,y)$$



255	254	253
125	130	110
4	3	0



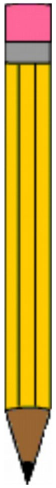
The rules of how to transfer values from the old image to the new one.

The negative transformation

$$g(x, y) = max - f(x, y)$$

- For eight bit image:

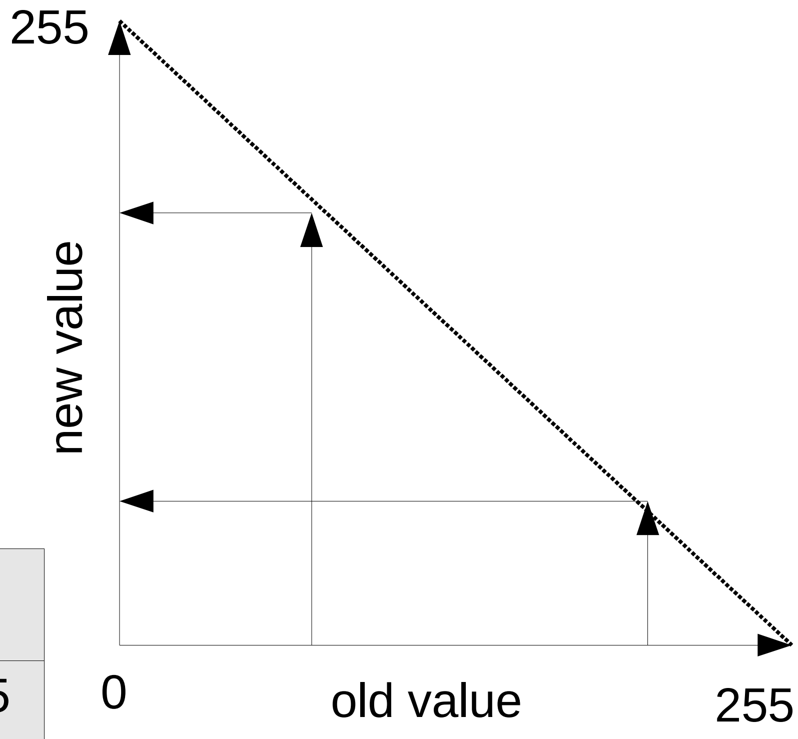
$$g(x, y) = 2^8 - 1 - f(x, y)$$



255	254	253
125	130	110
4	3	0

0	1	2
130	125	145
251	252	255

Negative image

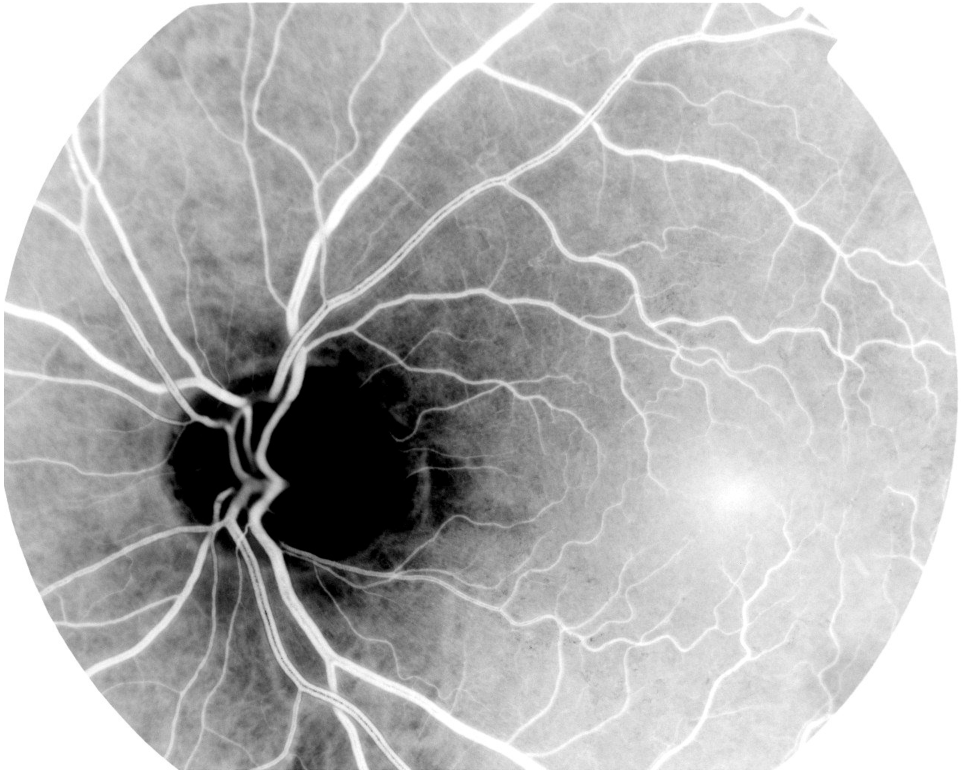


The rules of how to transfer values from the old image to the new one.

The negative transform

- Example

Original



Negative

The negative transform

original digital mammogram

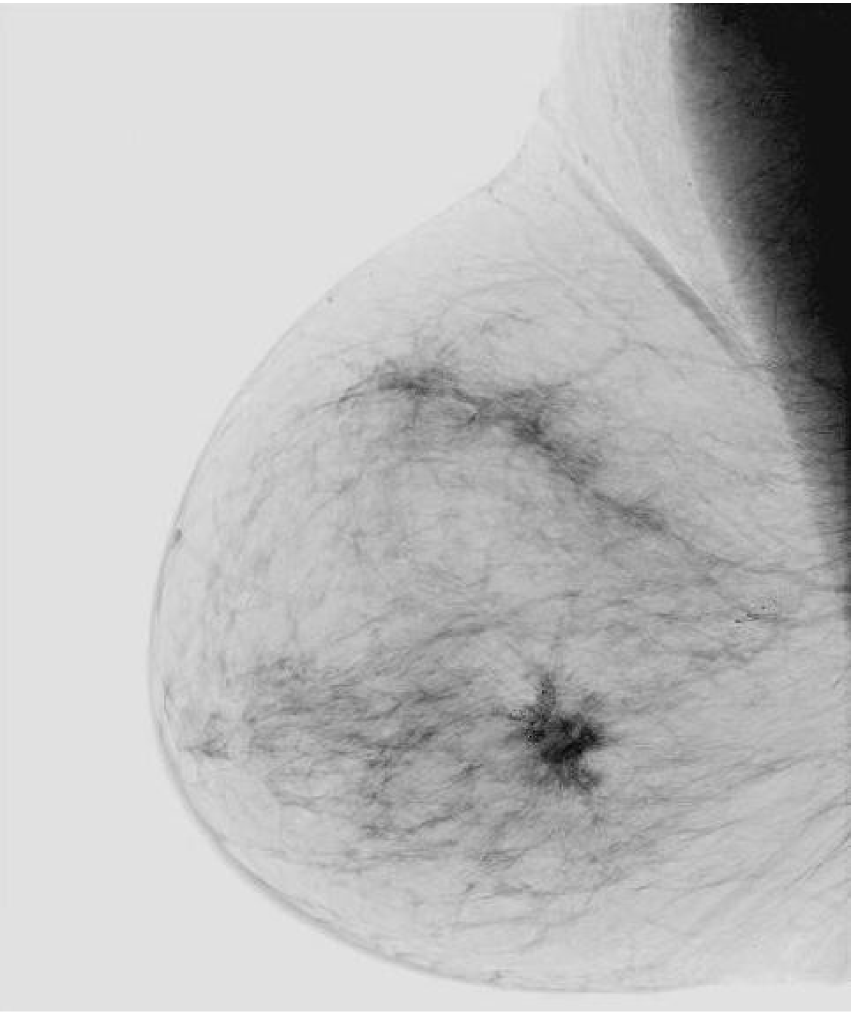
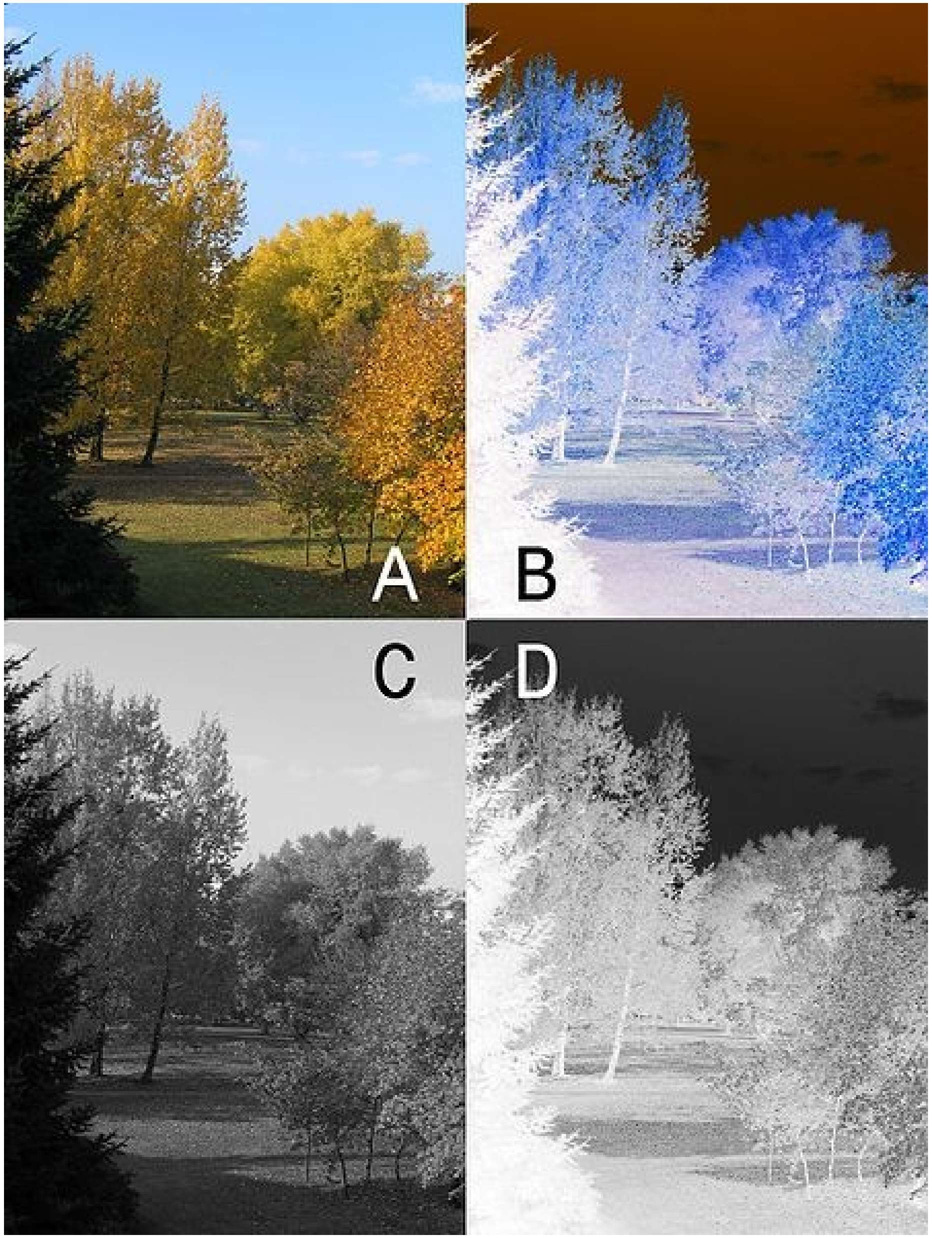


image negative to (visually) enhance white or gray details embedded in dark regions

The negative transformation

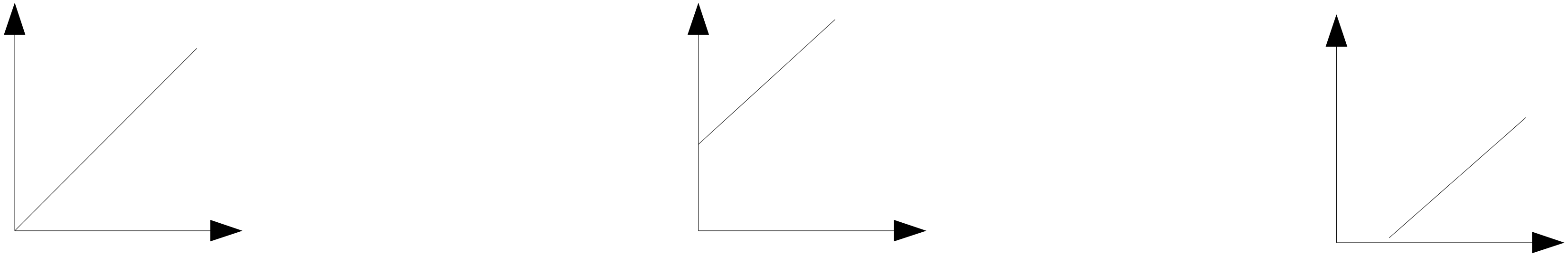
- Careful with color images



Brightness

$$g(x, y) = f(x, y) + C$$

Brightness



$$g(x,y) = f(x,y) + C$$

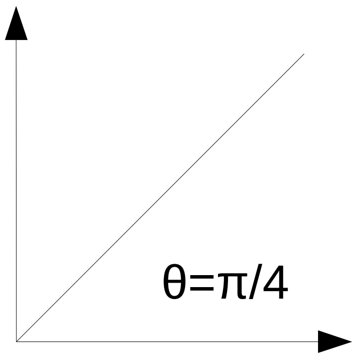
$$g(x,y) = f(x,y) - C$$

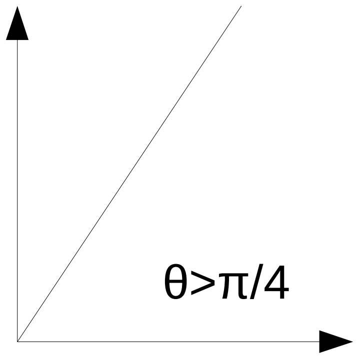
Brightness

$$g(x,y) = f(x,y) + C$$

$$g(x,y) = f(x,y) - C$$

Contrast

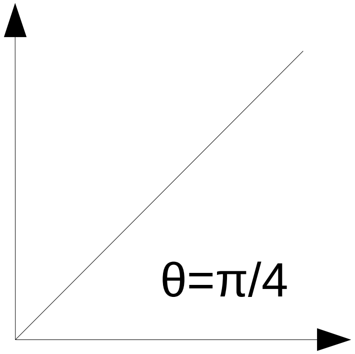


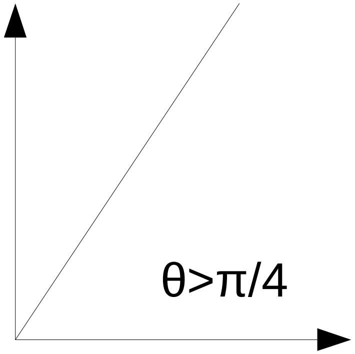


$$g(x,y) = f(x,y) \times C$$

$$C > 1$$

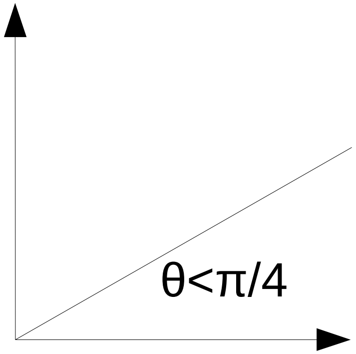
Contrast





$$g(x,y) = f(x,y) \times C$$

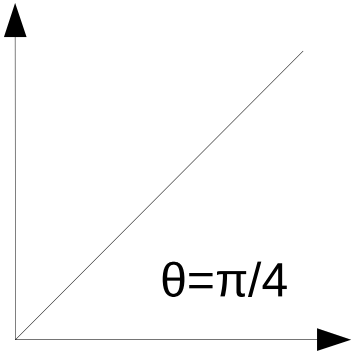
$$C > 1$$

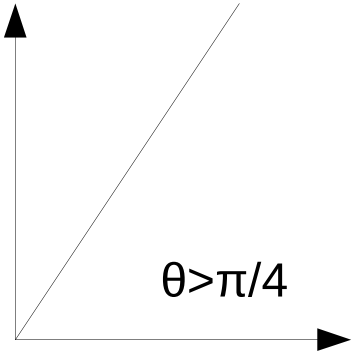


$$g(x,y) = f(x,y) \times C$$

$$C < 1$$

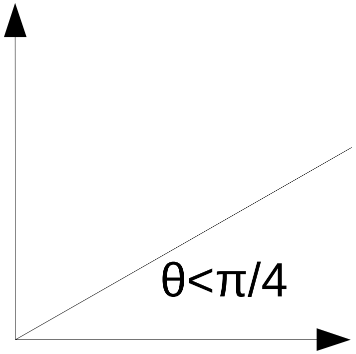
Contrast





$$g(x,y) = f(x,y) \times C$$

$$C > 1$$



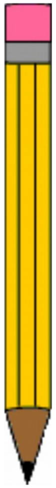
$$g(x,y) = f(x,y) \times C$$

$$C < 1$$

Examples

- Decrease the brightness by 10

$$g(x, y) = f(x, y) - 10$$



255	254	253
125	130	110
4	3	0

- Decrease the contrast by 2

$$g(x, y) = f(x, y) \times 0.5$$

Examples

- Decrease the brightness by 10

$$g(x,y) = f(x,y) - 10$$

- Decrease the contrast by 2

$$g(x,y) = f(x,y) \times 0.5$$

255	254	253
125	130	110
4	3	0

245	244	243
115	120	100
0	0	0

Decreased brightness

128	127	127
63	65	55
2	2	0

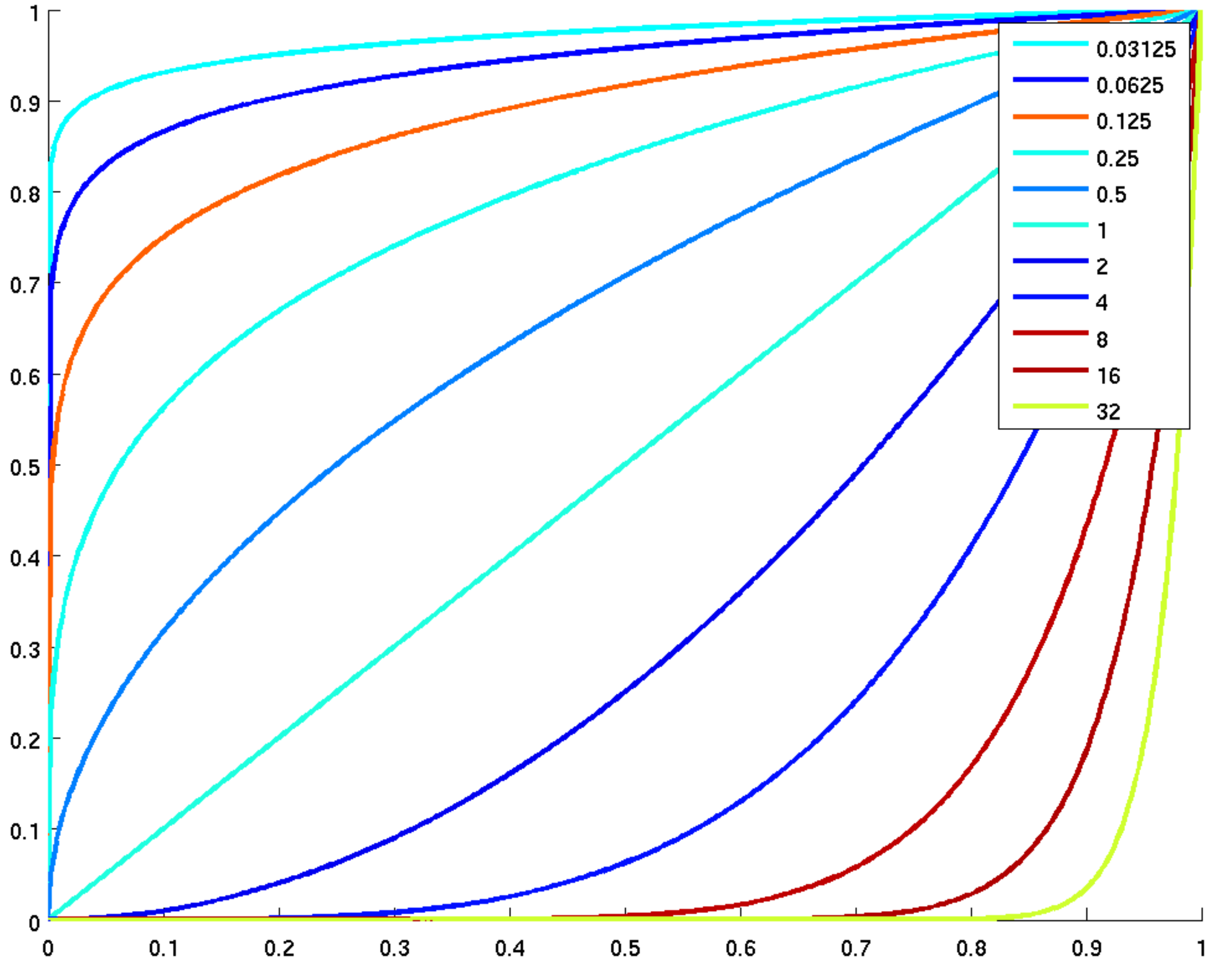
Decreased contrast

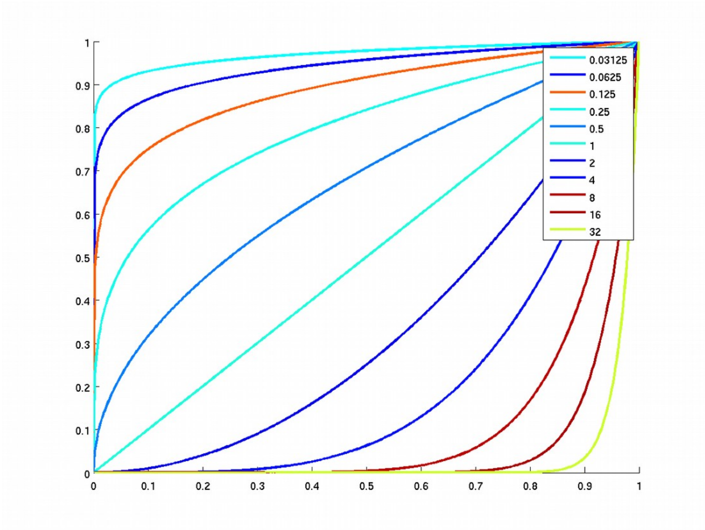

17
20
28
35
1
3
∞

Gamma transformation

$$g(x,y) = C \times f(x,y)^{\gamma}$$

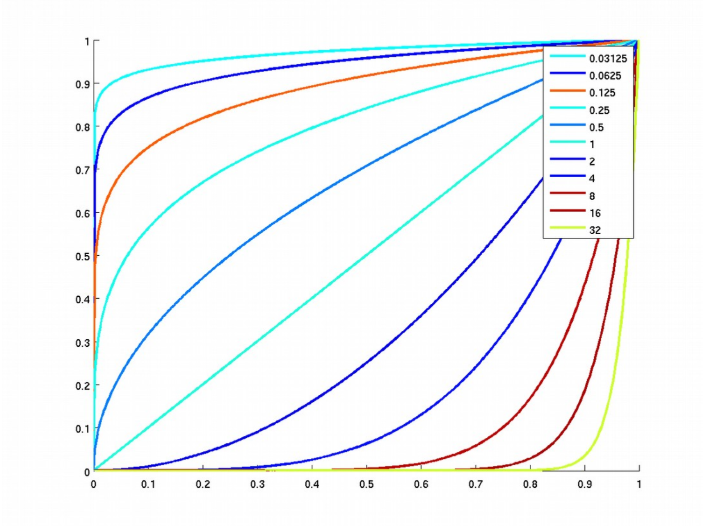
- Computer monitors have γ~2.2
- Eyes have γ~0.45
- Microscopes should have γ=1





γ=0.25

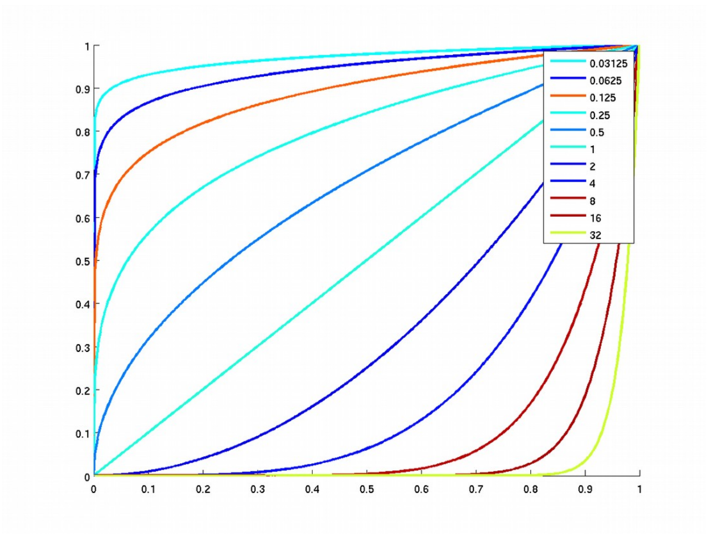
γ=1



γ=0.25

γ=4

γ=1


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.03125
0.0625
0.125
0.25
0.5
1
2
4
8
16
32

γ=0.25


γ=0.25

γ=1

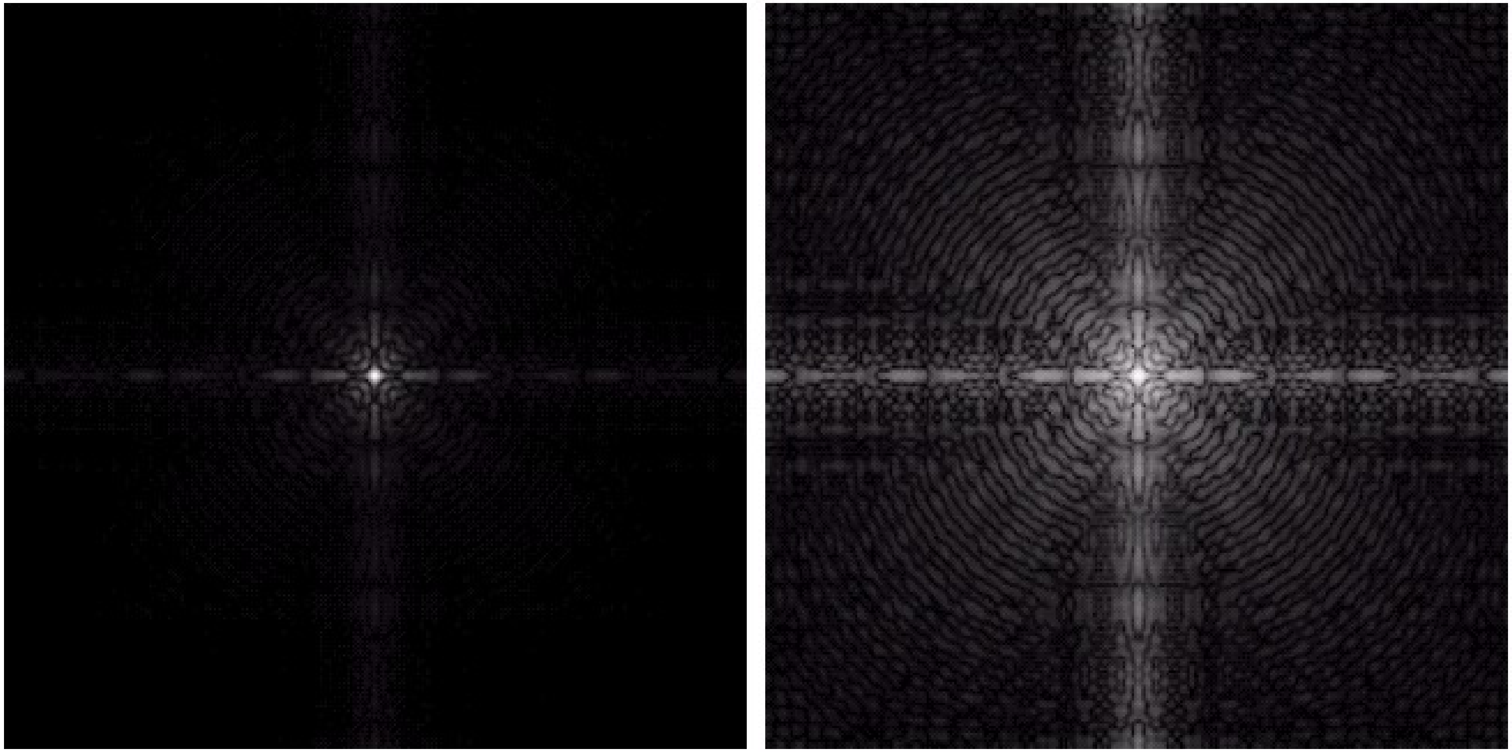
γ=4


γ=4

Log transformations

- Log transformation to visualize patterns in the dark regions of an image

$$g(x, y) = C\log(1 + f(x, y))$$

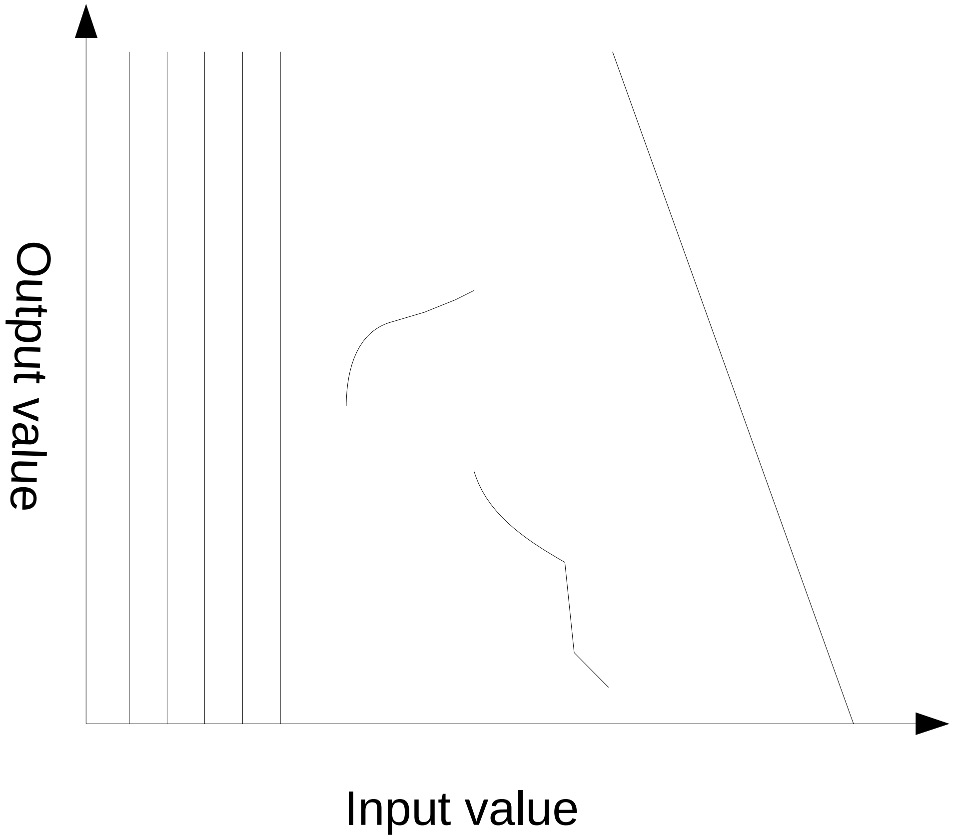


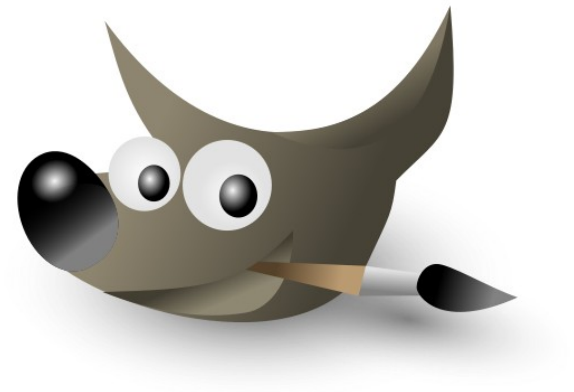
a b

FIGURE 3.5 (a) Fourier spectrum. (b) Result of applying the log transformation given in Eq. (3.2-2) with $c = 1$.

Arbitrary transfer functions

- Only one output per input.
- Possibly non-continuous.
- Usually no inverse





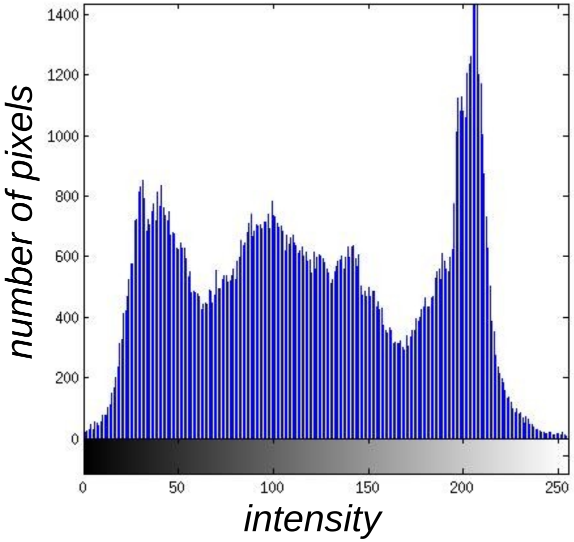
III. Histograms and histogram equalization

Image histogram

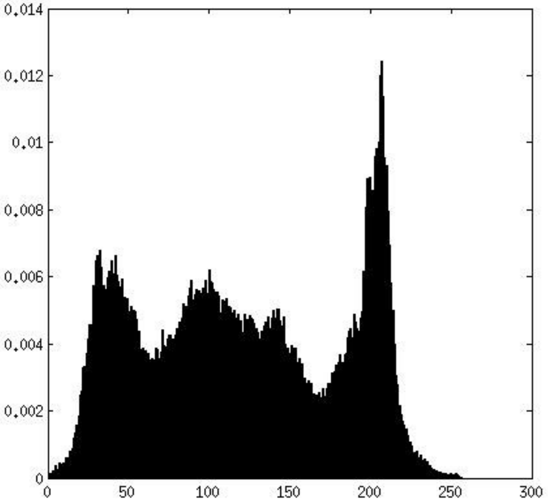
- A gray scale histogram shows how many pixels there are at each intensity level.

- width = 340 px
- height = 370 px
- bit-depth = 8 bits → 0..255

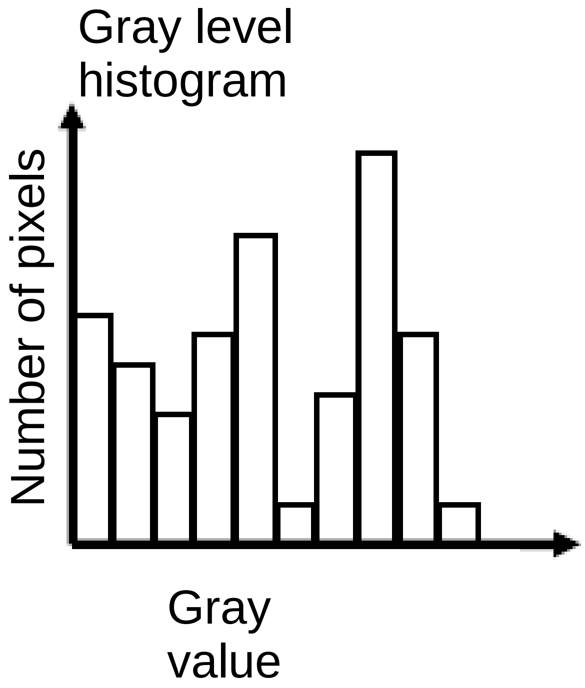
Histogram

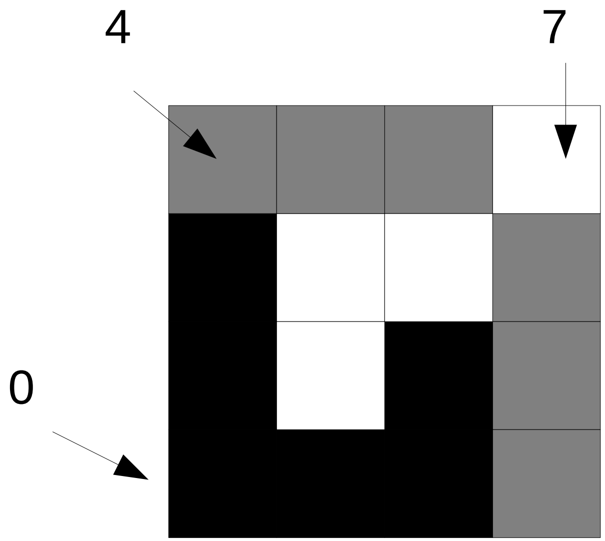


Normalized histogram



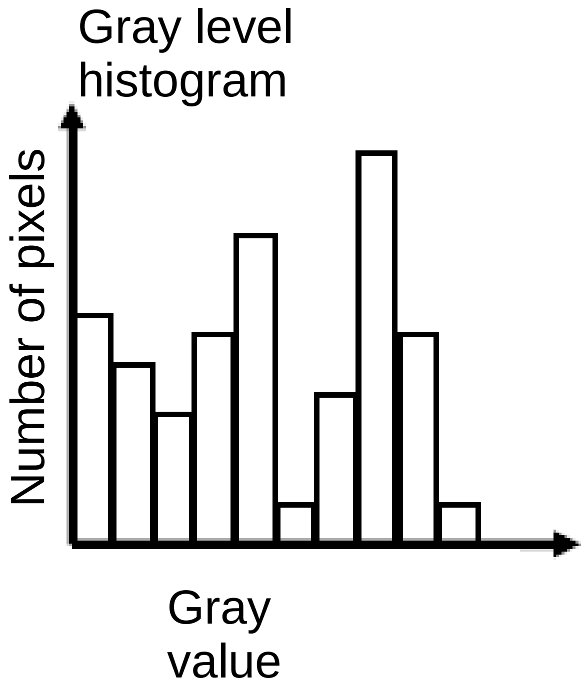
Exercise



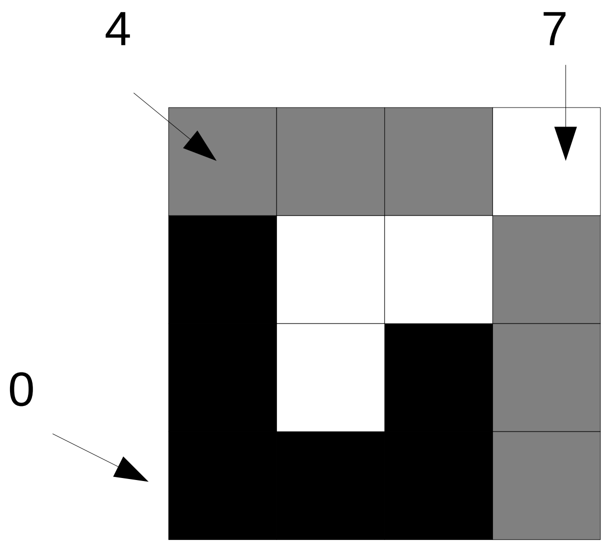


- width = 4px
- height = 4px
- bit-depth = 3 bits

Exercise



- width = 4px
- height = 4px
- bit-depth = 3 bits



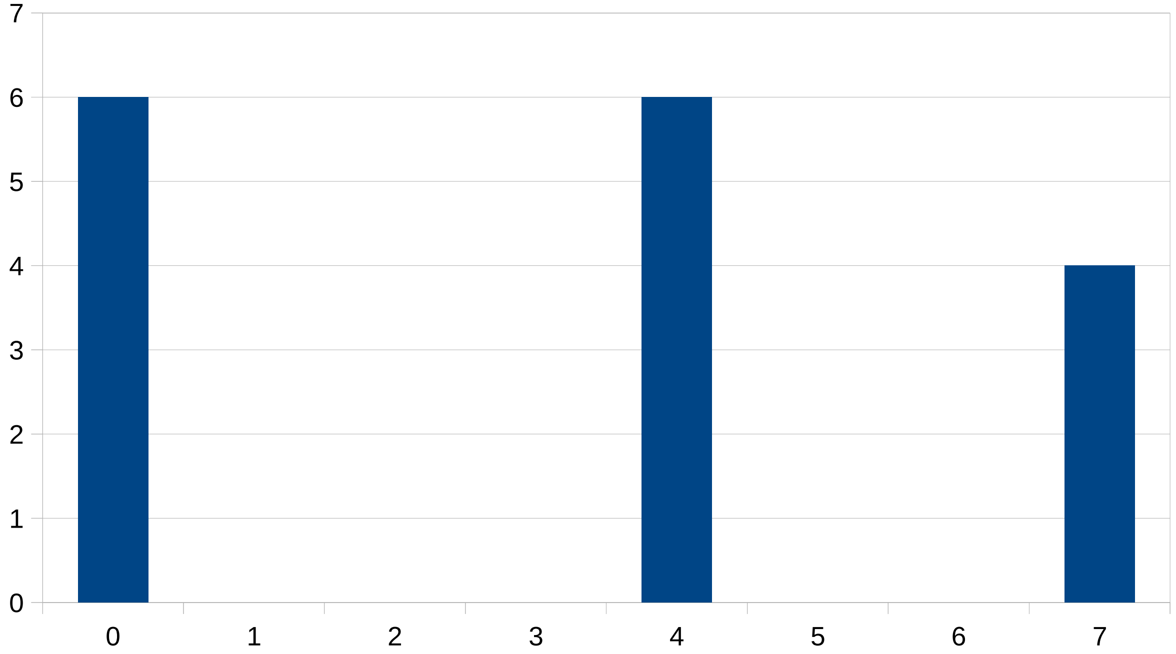
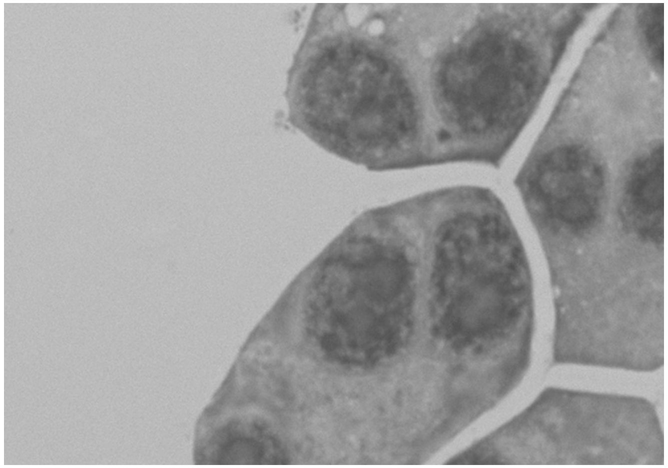
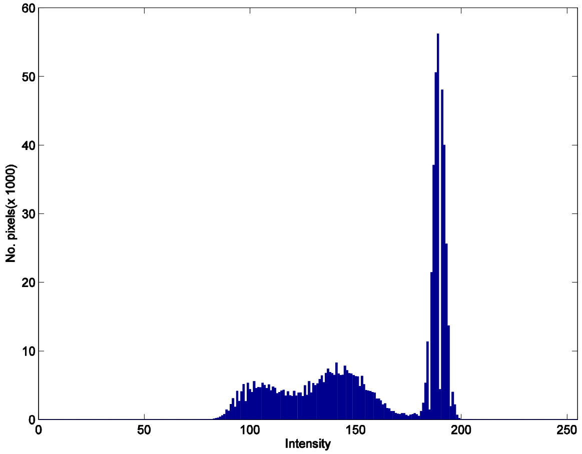
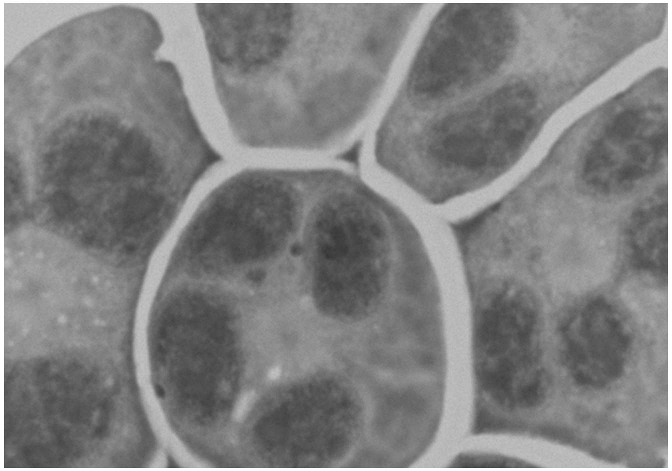


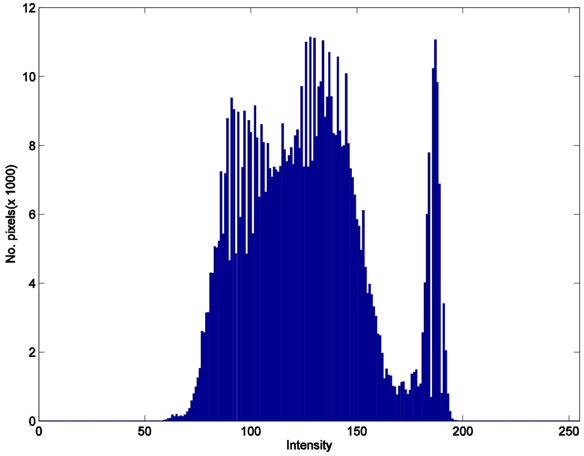
Image histogram

- Gray-level histogram shows intensity distribution



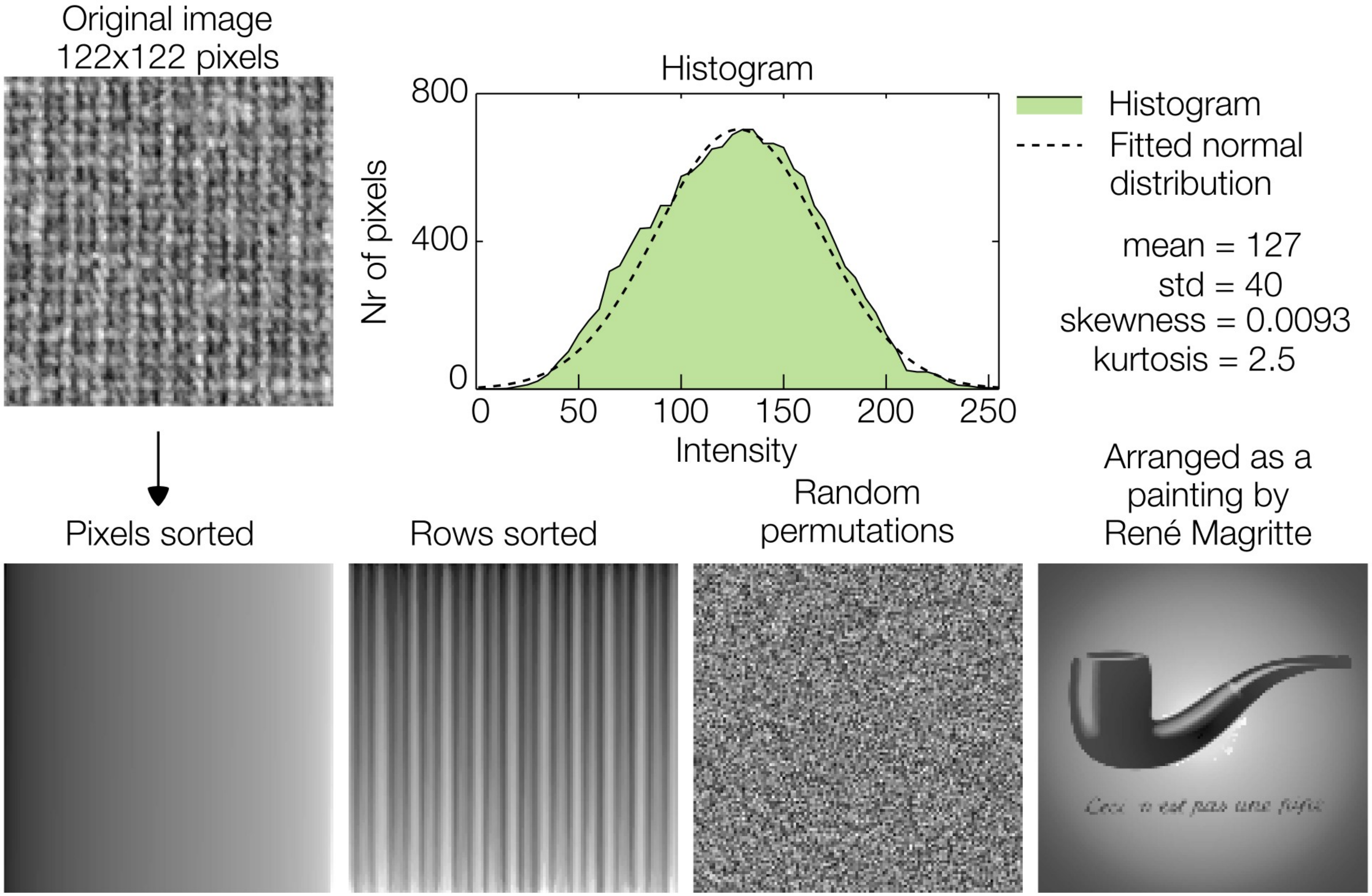






Beware

- Intensity histogram says nothing about the spatial distribution of the pixel intensities



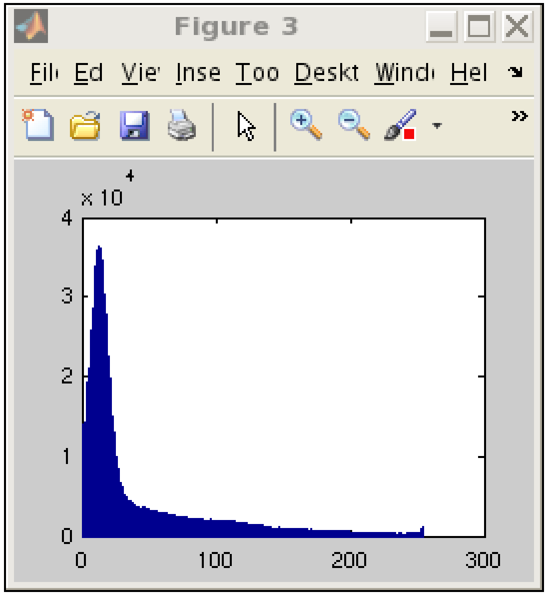
A

B

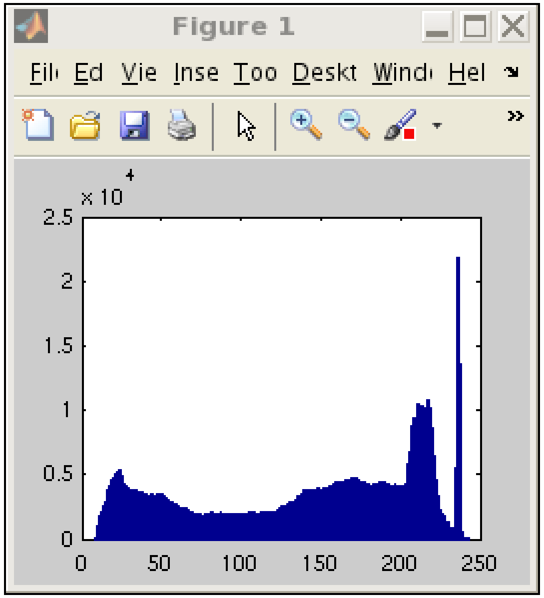
C

Pair images and
histograms!

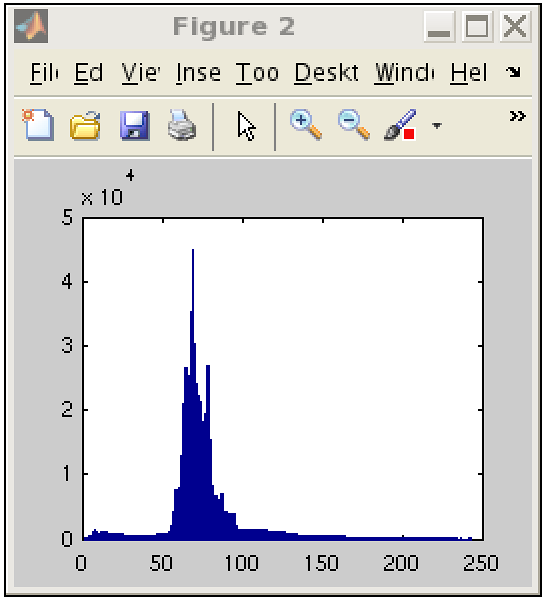
E



F



G




84-342 DC
205-671

A

B

C

E

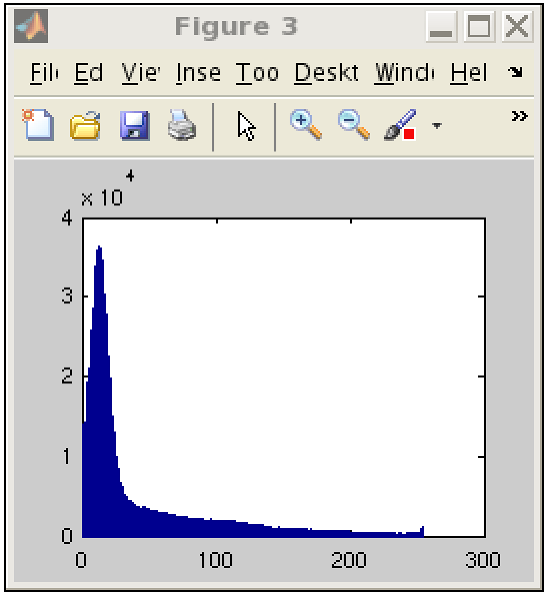


Figure 3
Fil Ed Vie Inse Too Deskt Wind Hel
x 10^4
4
3
2
1
0
0
100
200
300

F

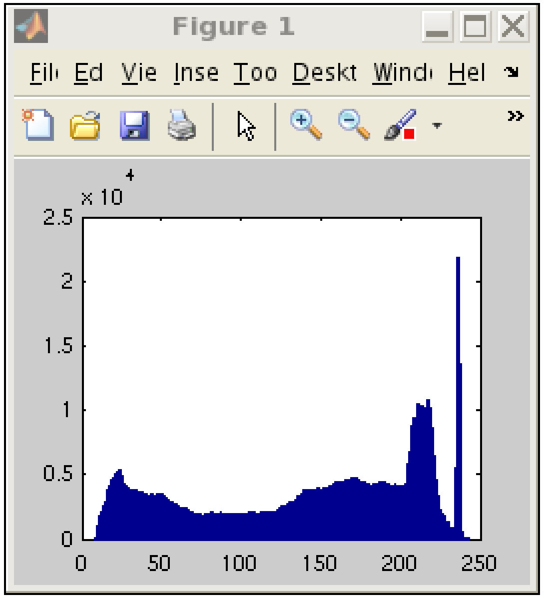


Figure 1
Fil Ed Vie Inse Too Deskt Wind Hel
x 10^4
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250

G

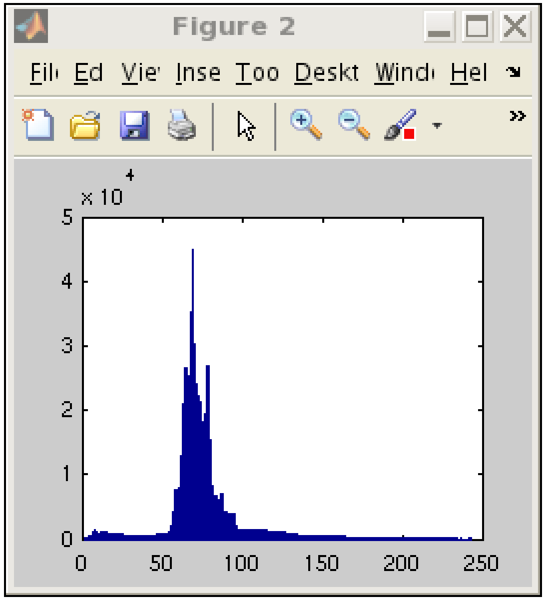
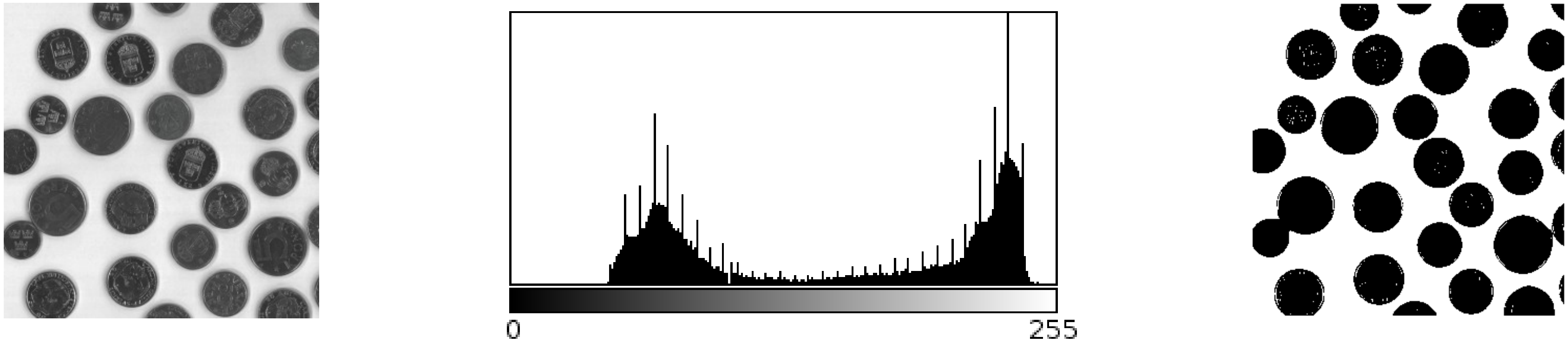


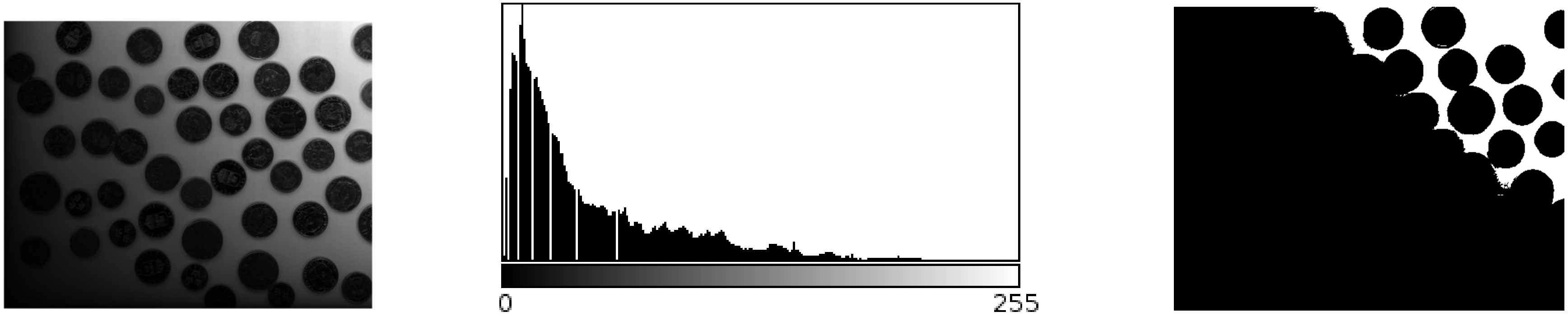
Figure 2
Fil Ed Vie Inse Too Deskt Wind Hel
x 10^4
5
4
3
2
1
0
0
50
100
150
200
250

Use of histogram

- Thresholding → decide the best threshold value
- ***works well with bi-modal*** **histograms**

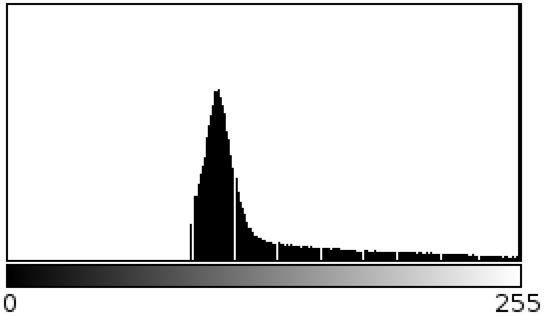


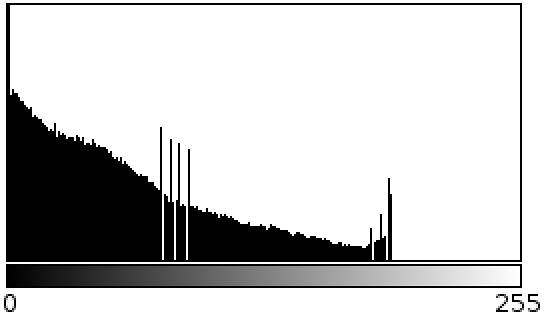
- ***does not work with uni-modal*** **histograms**



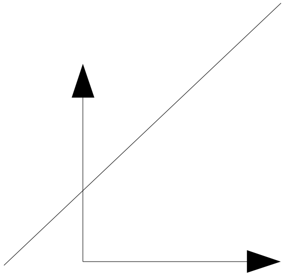
- Analyze the brightness and contrast of an image
- Histogram equalization

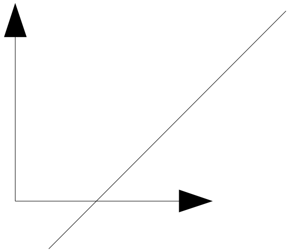
Analyze the brightness





- Increase brightness - shift histogram to the right
- Decrease brightness - shift histogram to the left



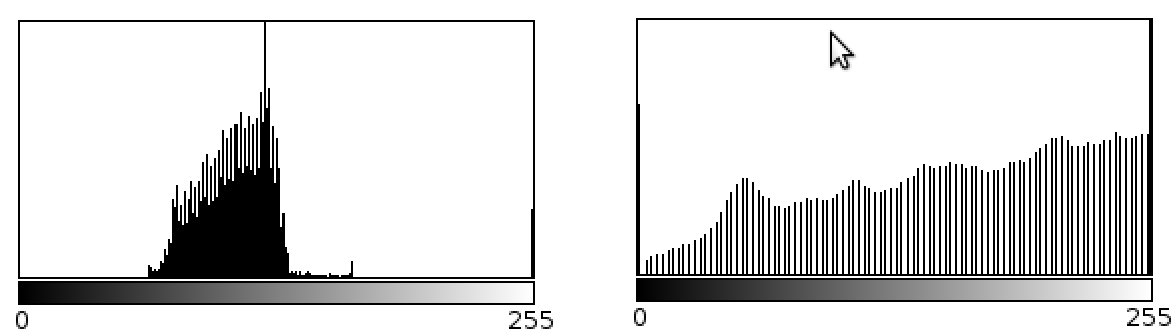


Greylevel transform:

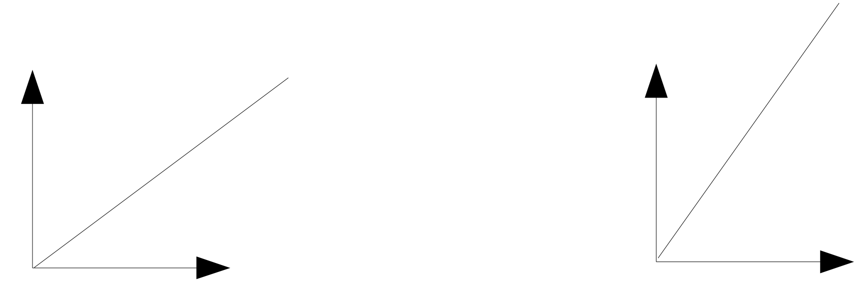
up → increased brightness

down → decreased brightness

Analyze the contrast



- Decreased contrast - compressed histogram.
- When contrast is increased - the histogram is stretches.

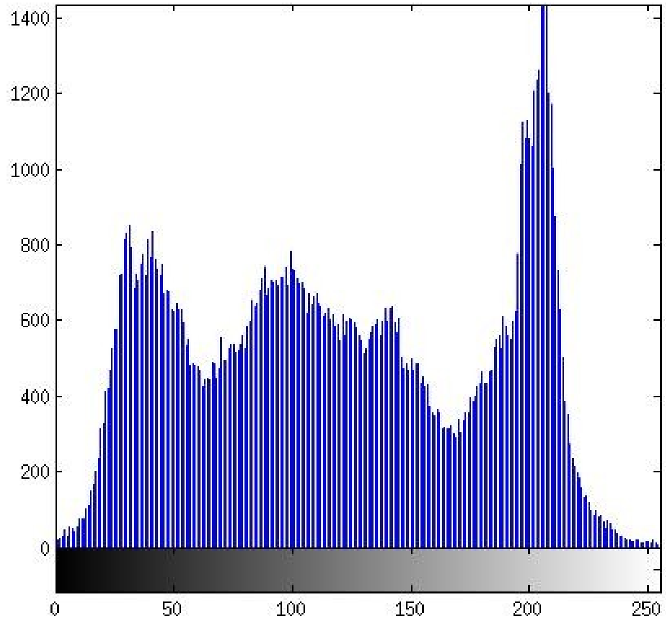


- Greylevel transform:
  <45 ° → decreased contrast
  >45 ° → increased contrast

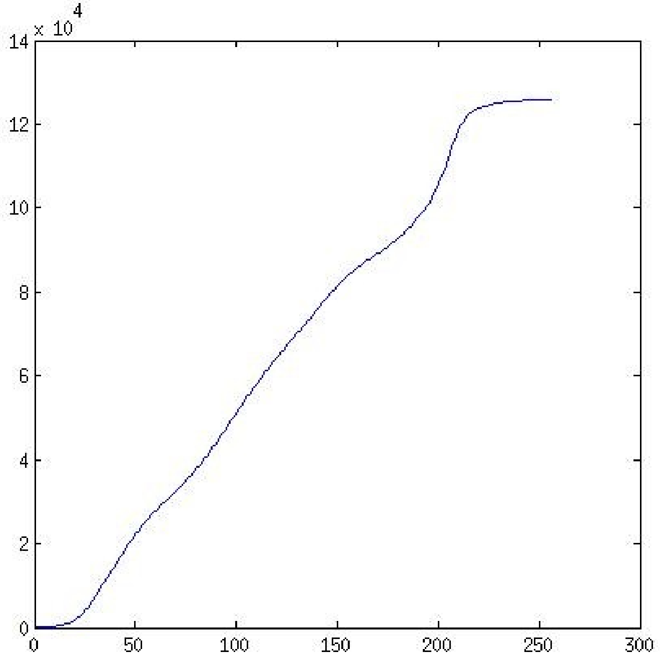
Cumulative histogram

- Easily constructed from the histogram

$$c_j = \sum_{i=0}^{j} h_i$$



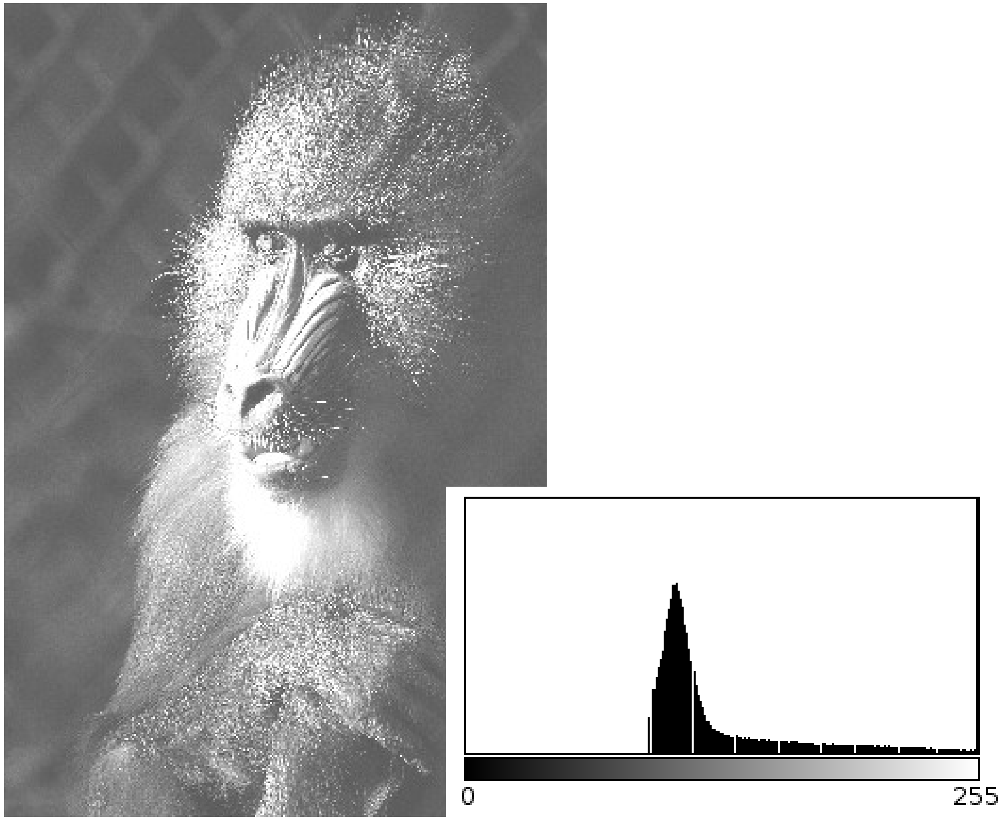
Histogram

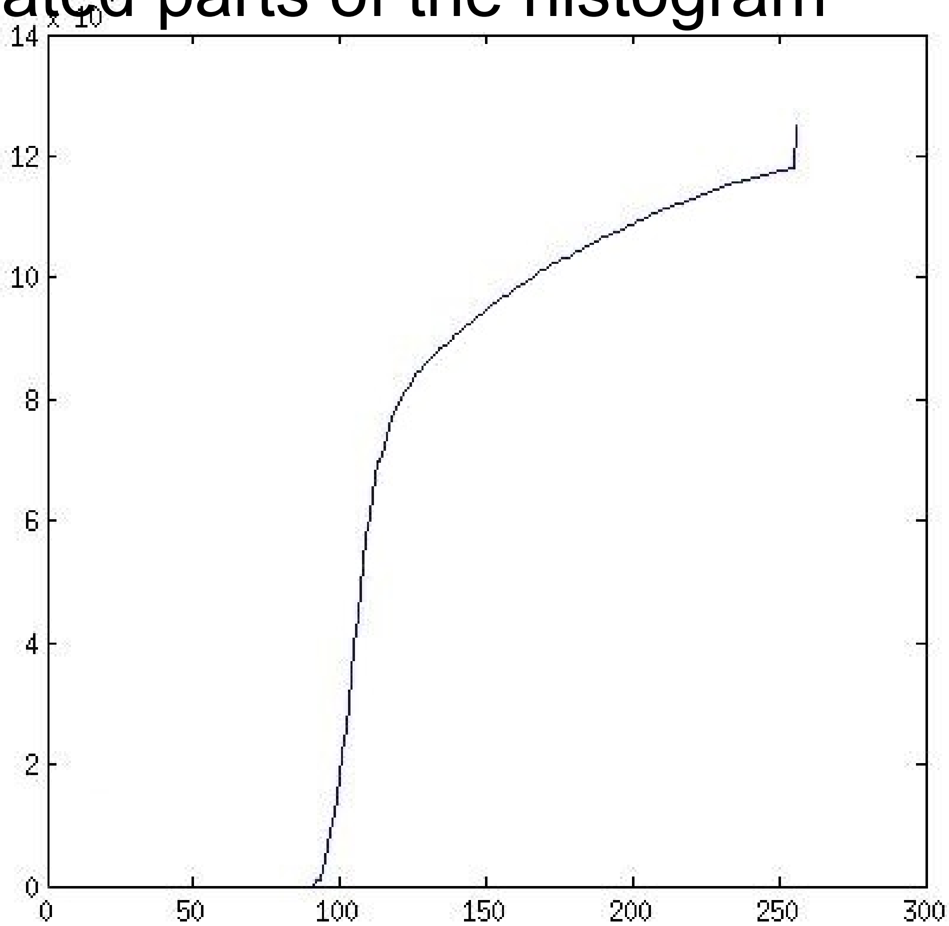


Cumulative histogram

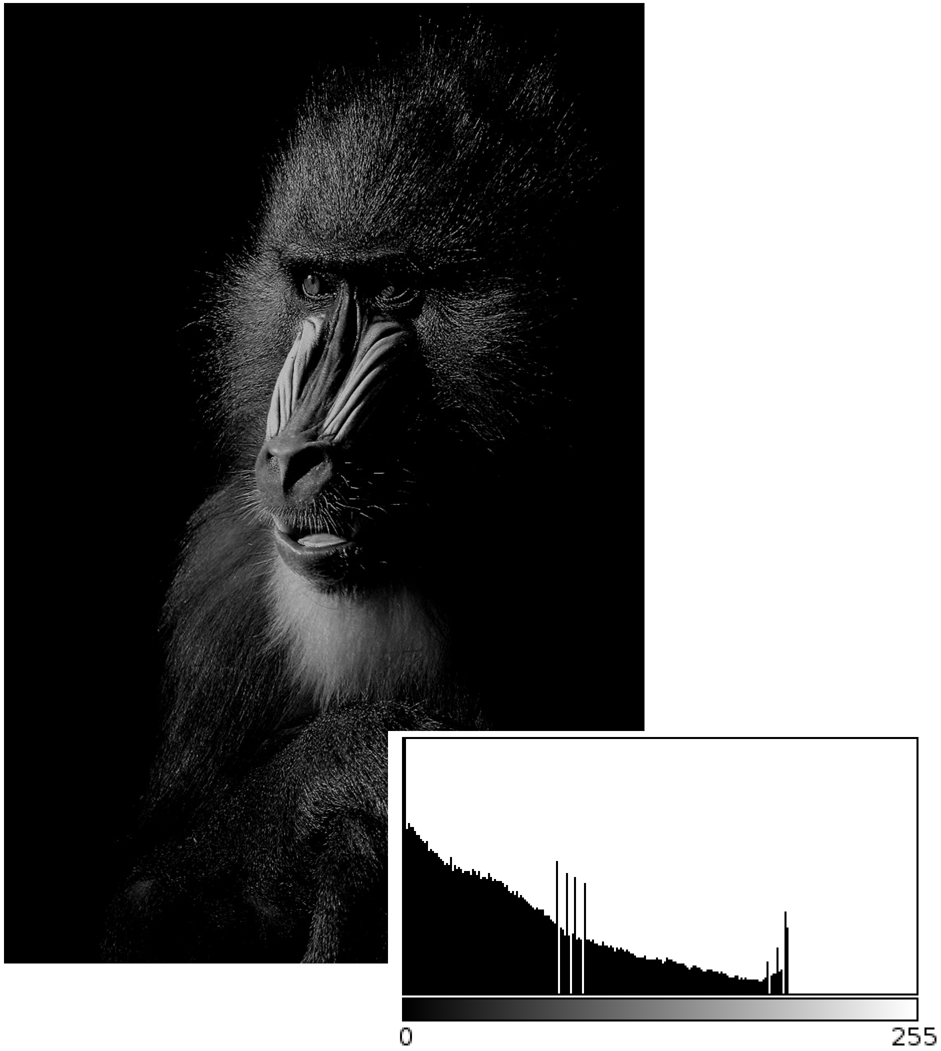
Cumulative histogram

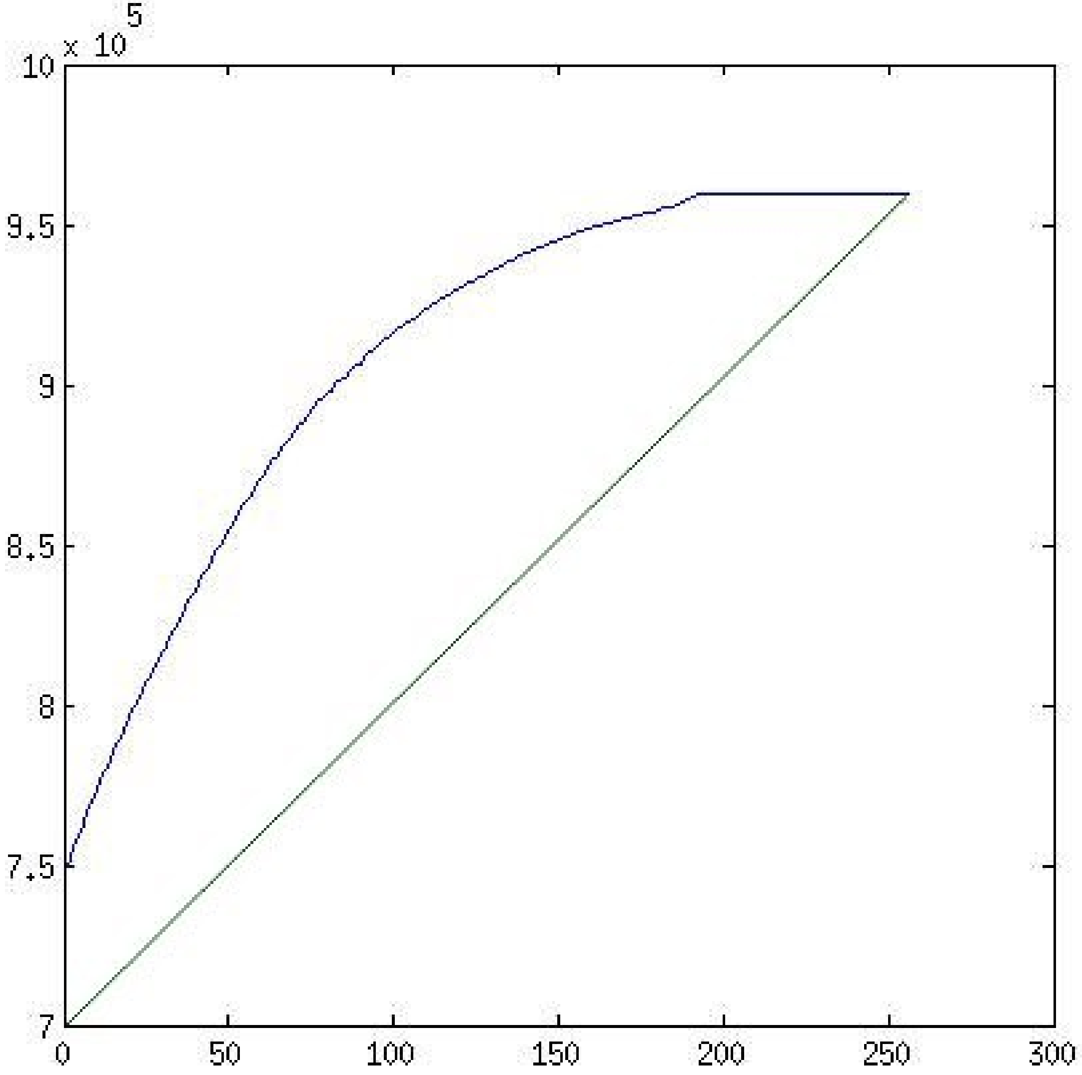
- Slope
  - Steep → intensely populated parts of the histogram
  - Gradual → in sparsely populated parts of the histogram





Cumulative histogram



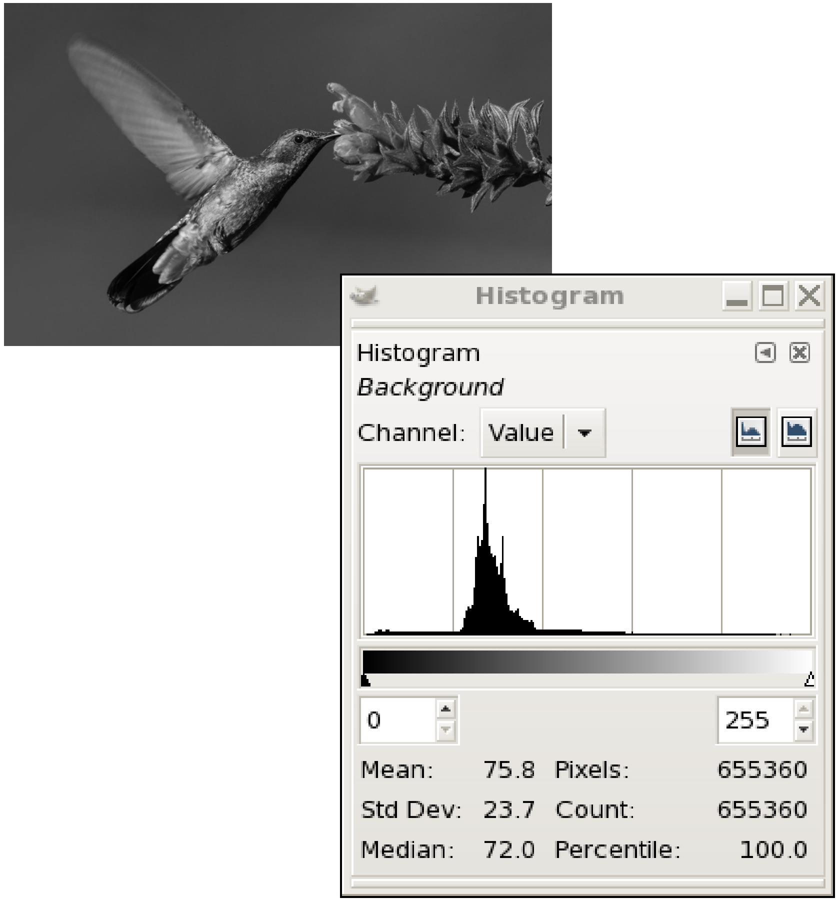


Histogram equalization

- Idea: Create an image with evenly distributed greylevels, for visual contrast enhancement
- Goal: Find the transformation that produces the most even histogram → cumulative histogram curve
- Equalization flattens the histogram, linearizes cumulative histogram
- Automatic contrast enhancement

Histogram equalization

original image

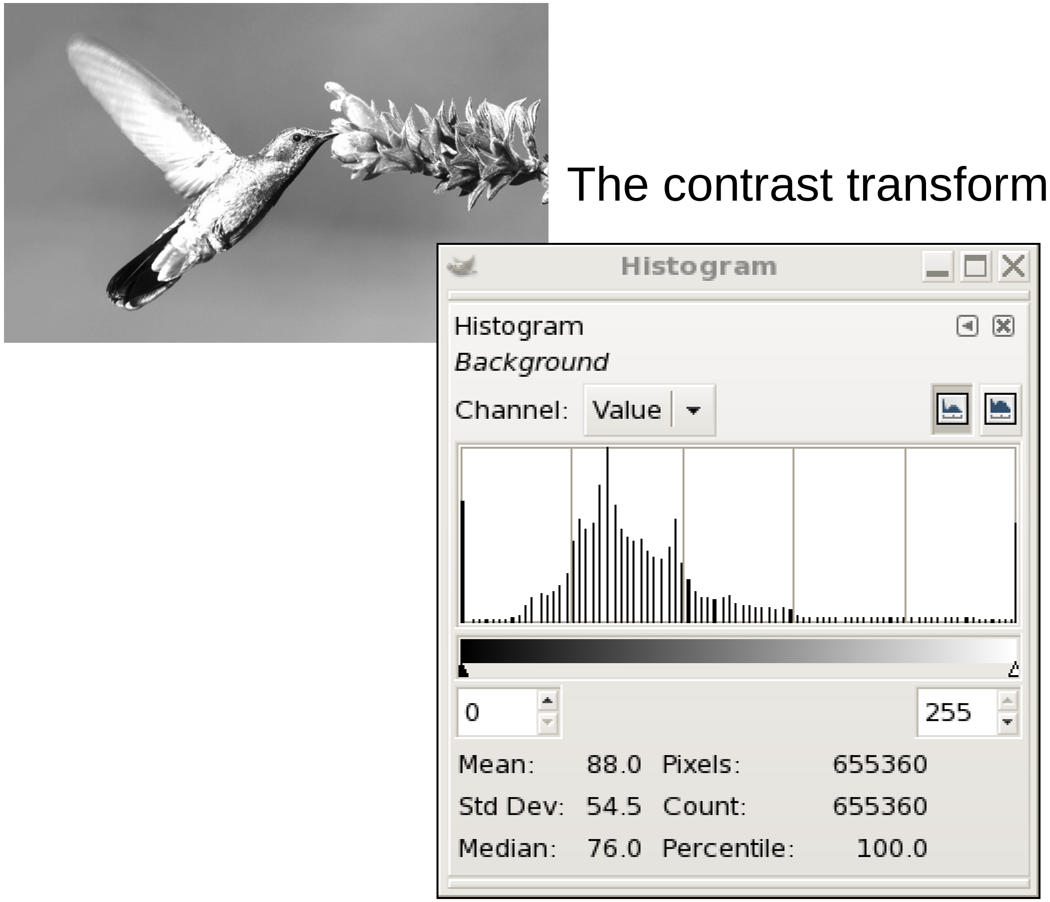


Channel: Value

0
255

Mean: 75.8
Std Dev: 23.7
Median: 72.0
Pixels: 655360
Count: 655360
Percentile: 100.0

result of histogram equalization



Channel: Value

0
255

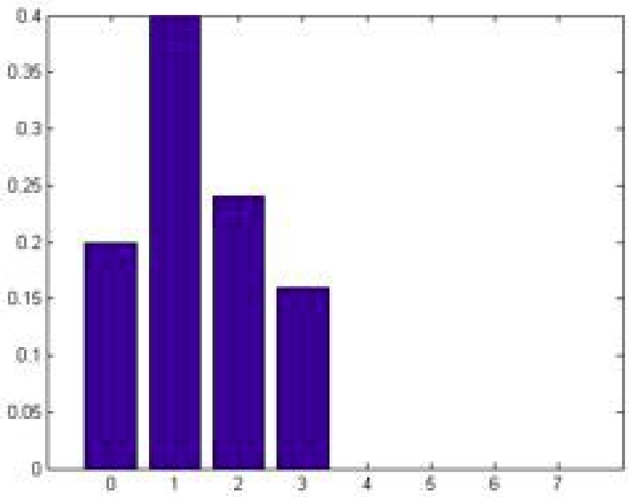
Mean: 88.0
Std Dev: 54.5
Median: 76.0
Pixels: 655360
Count: 655360
Percentile: 100.0

The contrast transform

Hist eq: small example

Intensity	0	1	2	3	4	5	6	7
Number of pixels	10	20	12	8	0	0	0	0

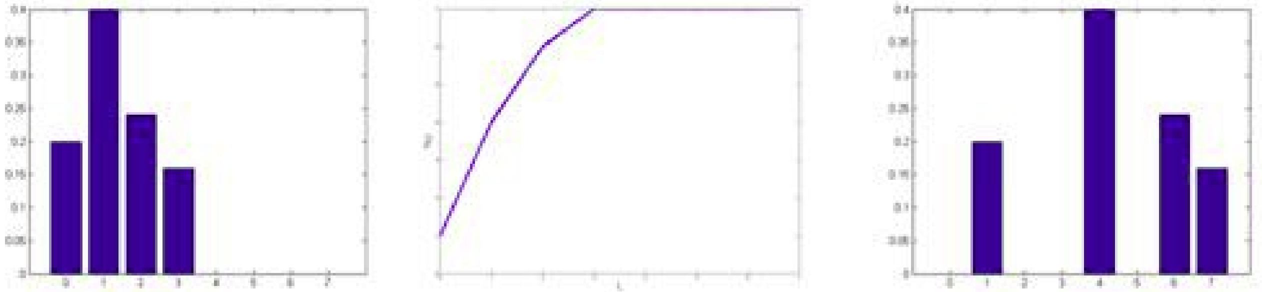
- p(0) = 10/50 = 0.2, cdf(0)=0.2
- p(1) = 20/50 = 0.4, cdf(1)=0.6
- p(2) = 12/50 = 0.24, cdf(2)=0.84
- p(3) = 8/50 = 0.16, cdf(3)=1
- p(r) = 0/50 = 0, r = 4, 5, 6, 7 cdf(r)=1



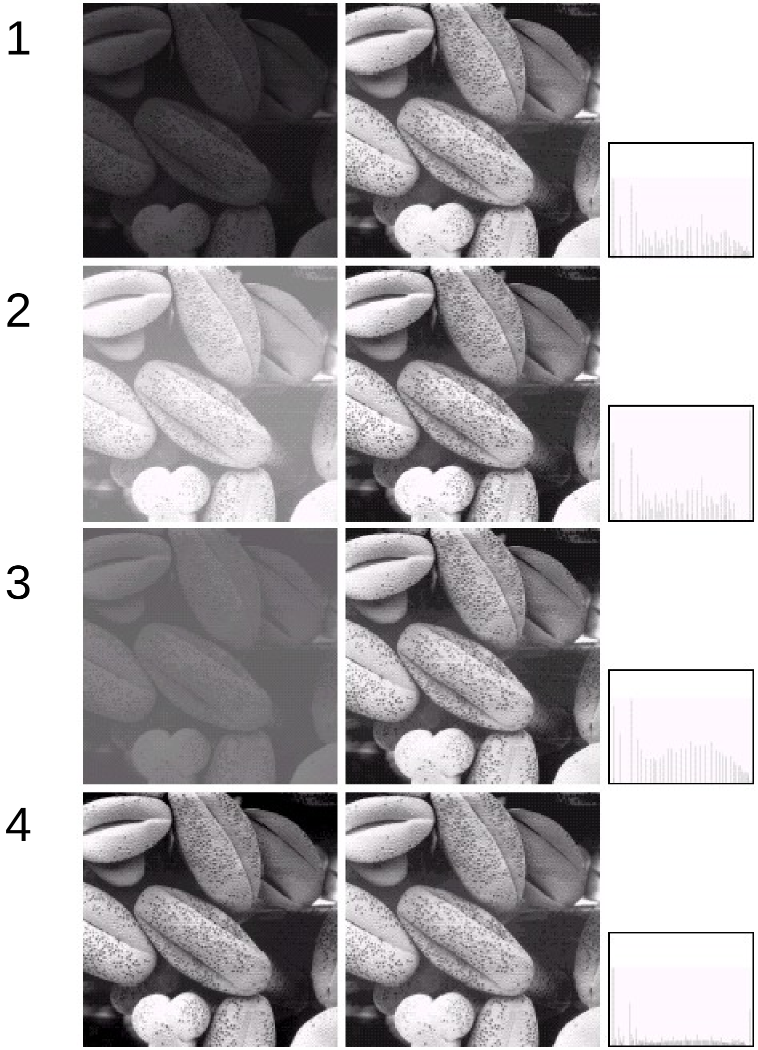
Hist eq: small example

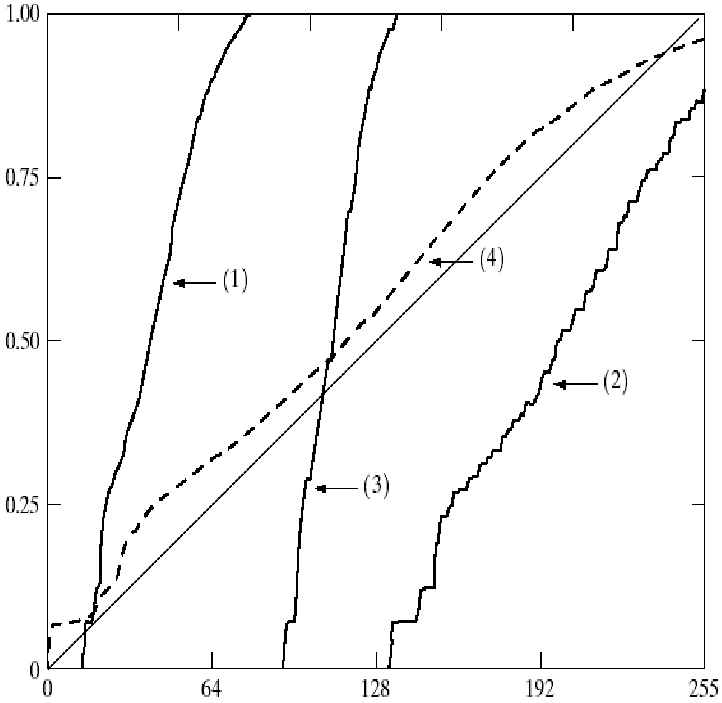
- T(0) = 7 * (p(0)) = 7 * 0.2 = 1.4 ≈ 1
- T(1) = 7 * (p(0) + p(1)) = 7 * 0.6 = 3.6 ≈ 4
- T(2) = 7 * (p(0) + p(1) + p(2)) ≈ 6
- T(3) = 7 * (p(0) + p(1) + p(2) + p(3)) ≈ 7
- T(r) = 7, r = 4, 5, 6, 7

Intensity	0	1	2	3	4	5	6	7
Number of pixels	0	10	0	0	20	0	12	8



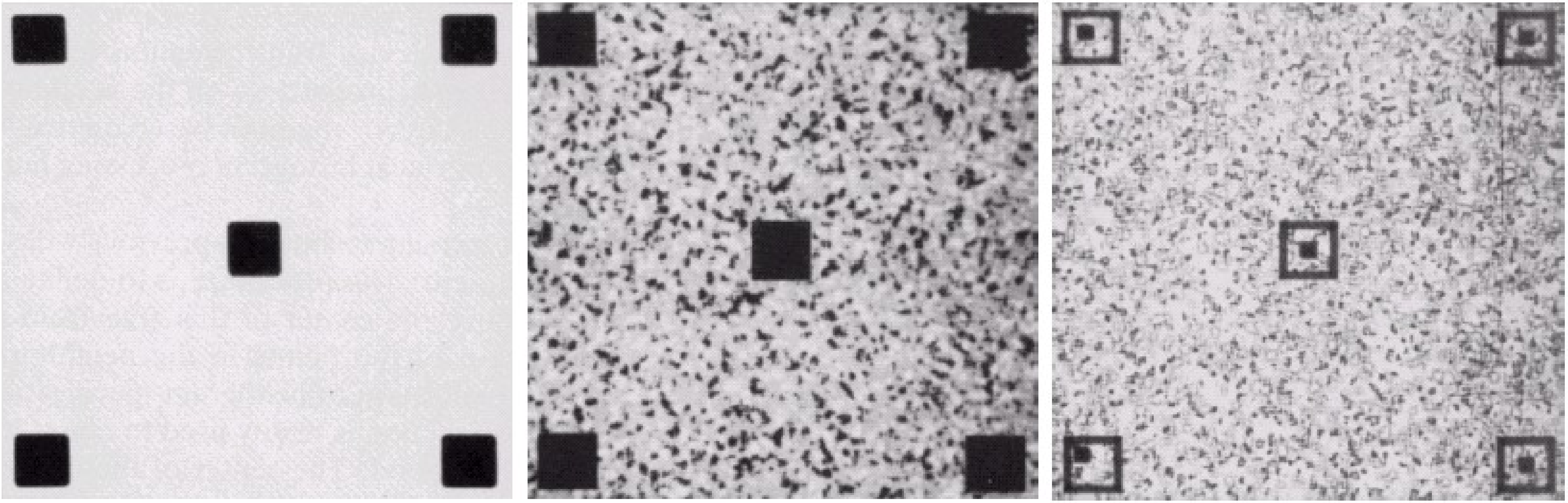
More examples of hist eq





Transformations for image 1-4. Note that the transform for figure 4 (dashed) is close to the neutral transform (thin line).

Local histogram equalization

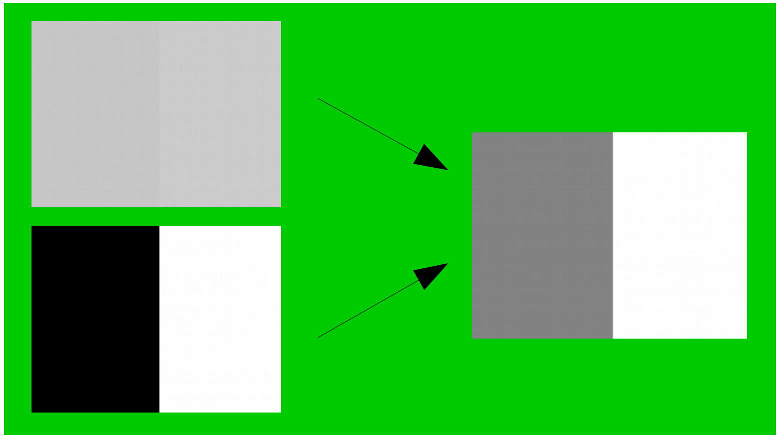


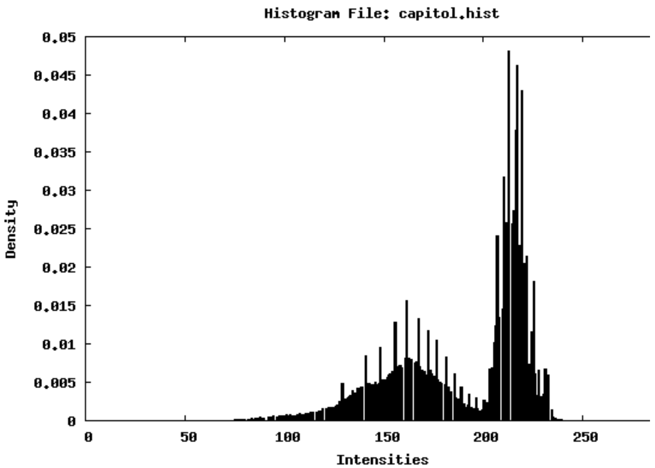
a b c

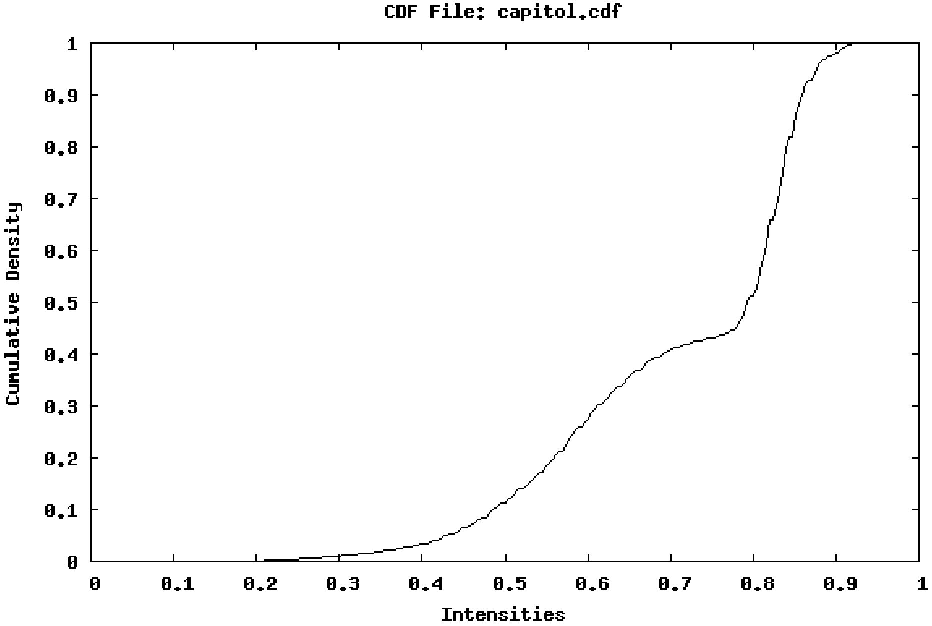
FIGURE 3.23 (a) Original image. (b) Result of global histogram equalization. (c) Result of local histogram equalization using a 7 × 7 neighborhood about each pixel.

Histogram equalization

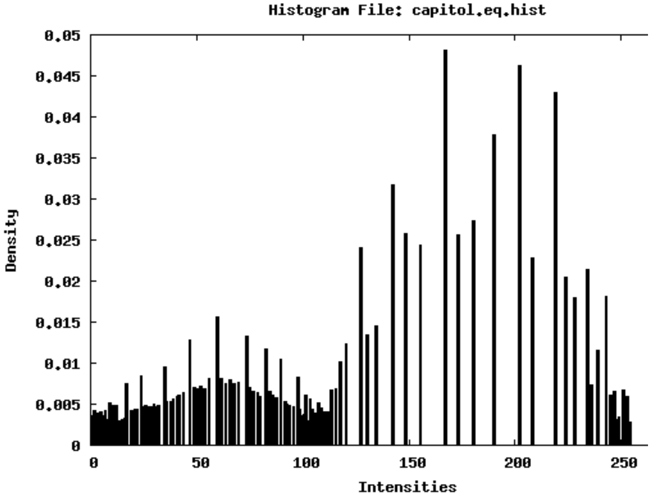
- Useful when much information is in a narrow part of the histogram
- Drawbacks:
    - Amplifies noise in large homogenous areas
    - Can produce unrealistic transformations
    - Information might be lost, no new information is gained
    - Not invertible, usually destructive

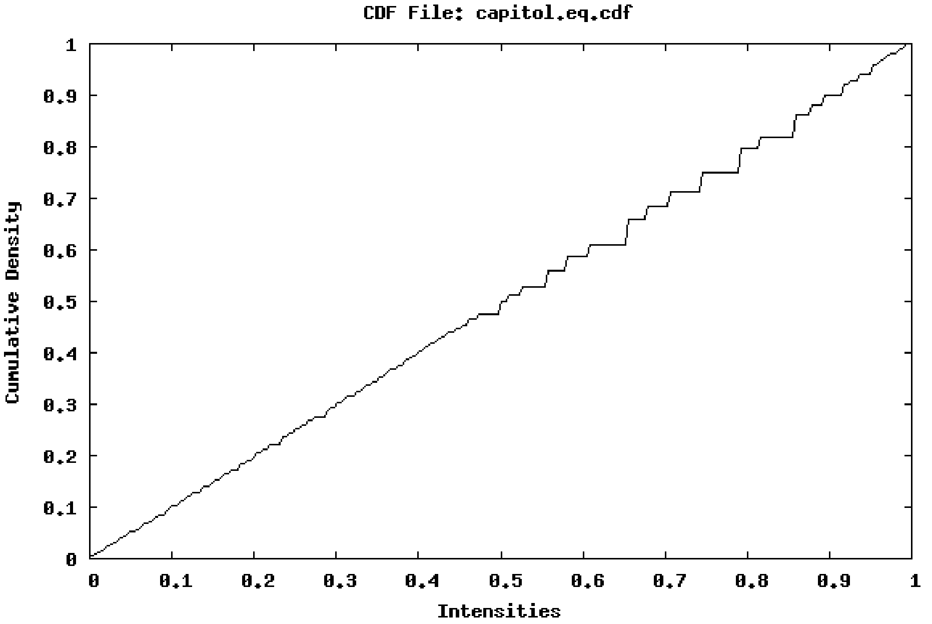




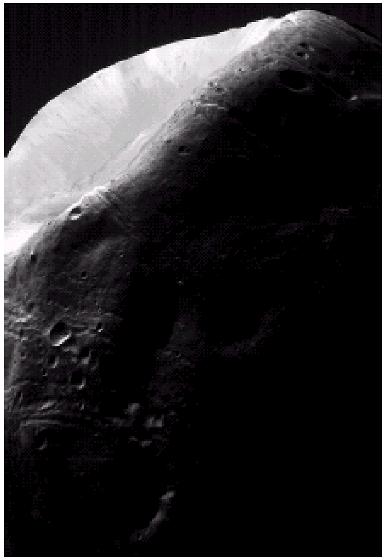


- Does not work well in all cases!





- Histogram equalization is not always “optimal” for visual quality



original image

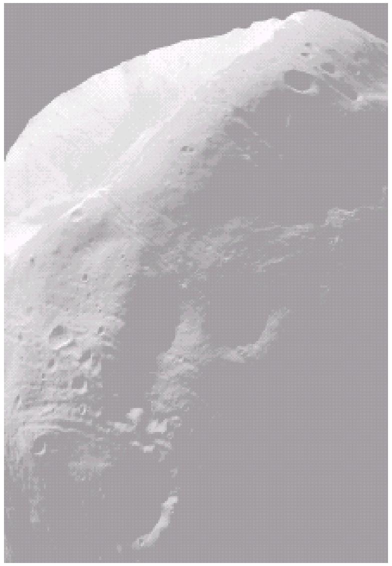
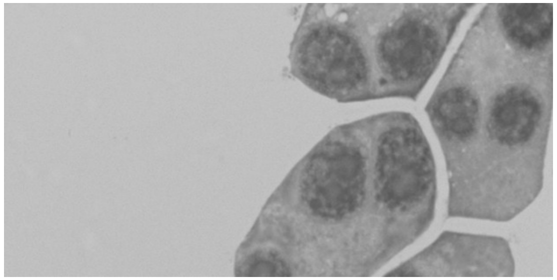
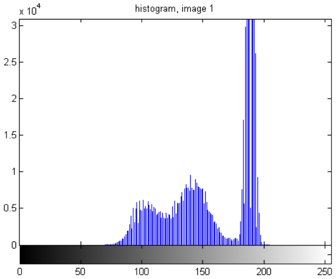


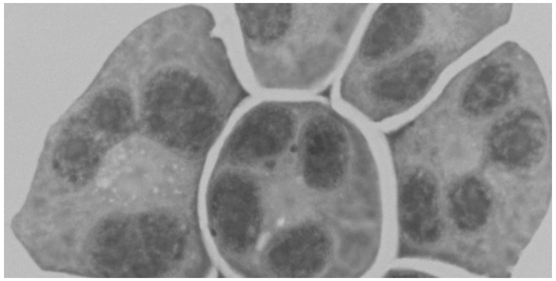
image after histogram equalization

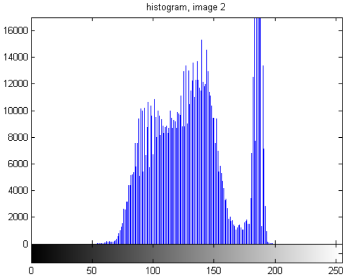
image after manual choice of transform

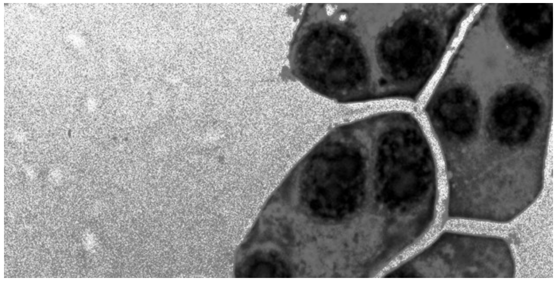
- Histogram eq: the result depends on the amount of different intensities

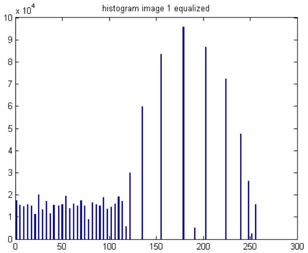


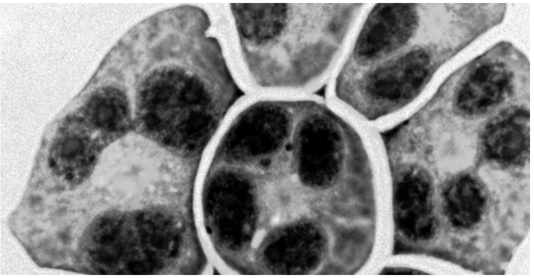


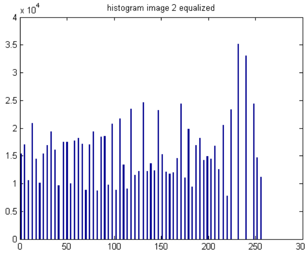










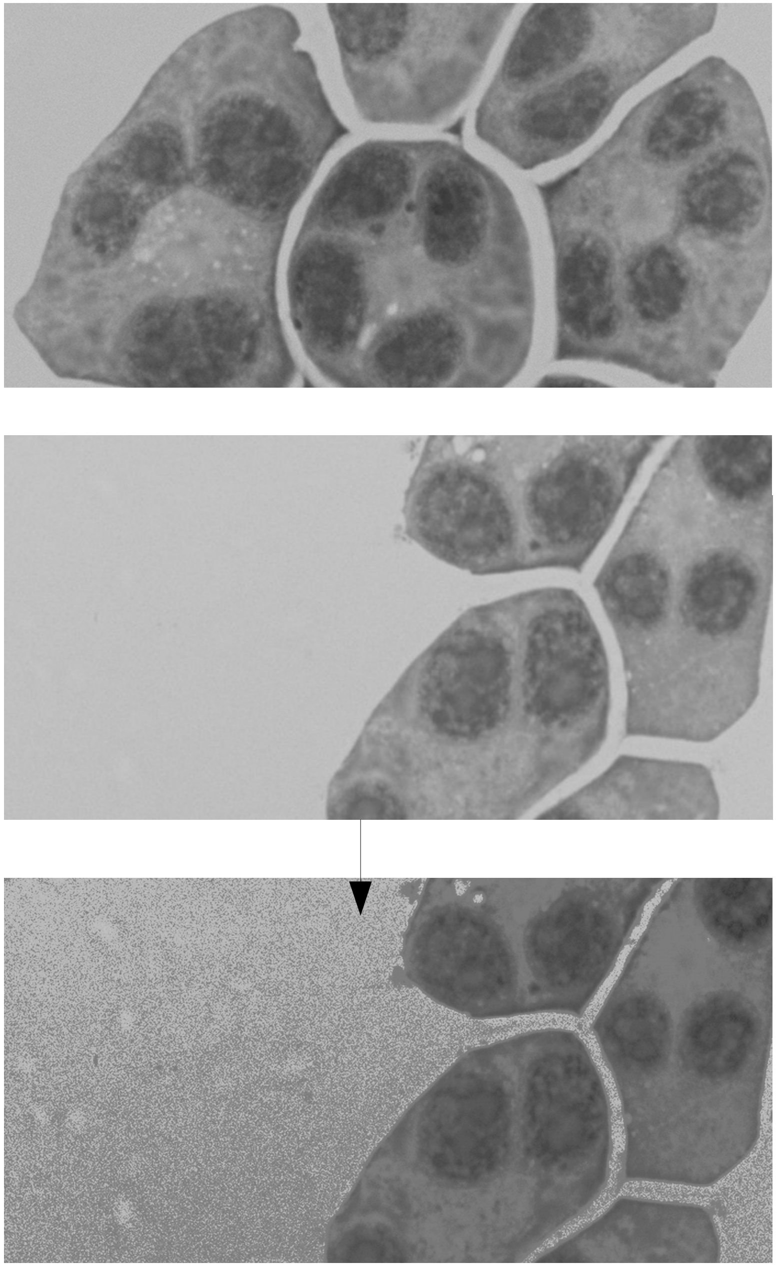


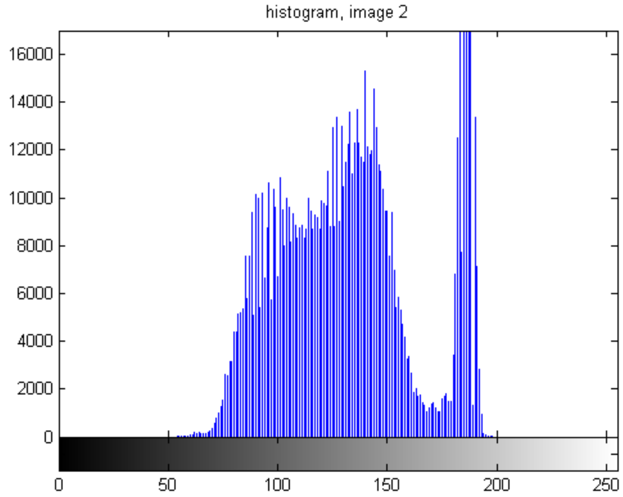
Histogram matching

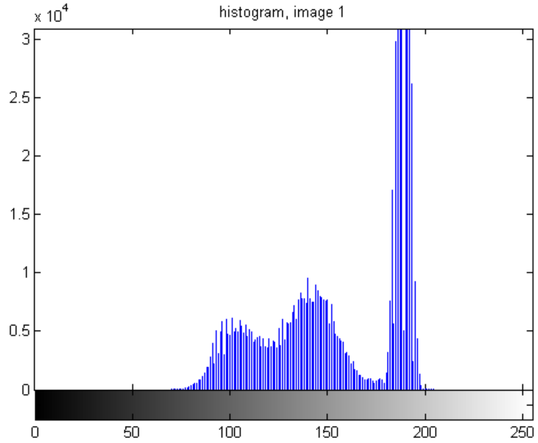
- In histogram equalization a **flat distribution** is the goal
- In histogram matching the **distribution of another image** is the goal

For an image, I, find the transformation, T, that gives the histogram some ideal shape, s.

Image 1 histogram matched to image 2







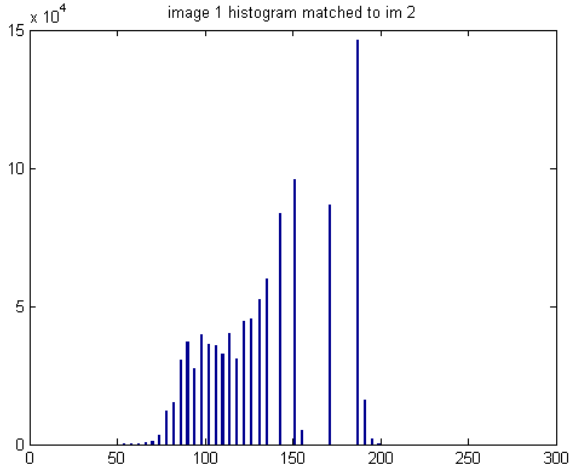
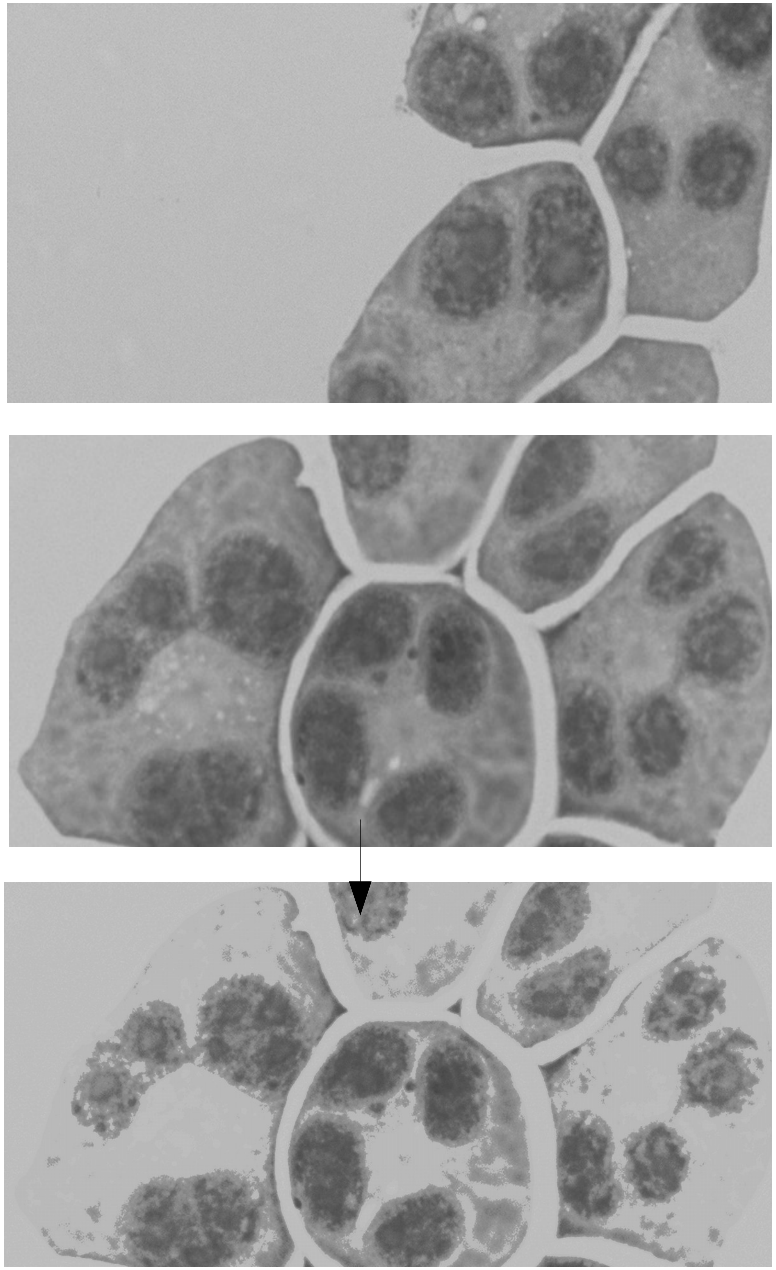
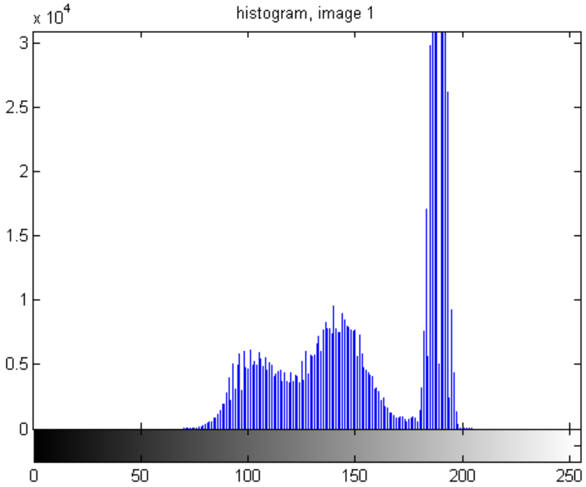
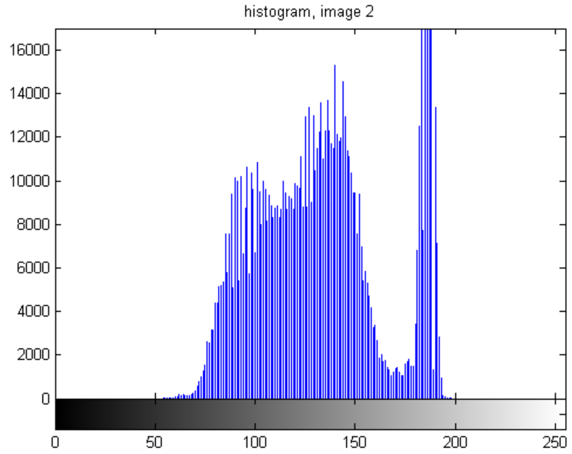
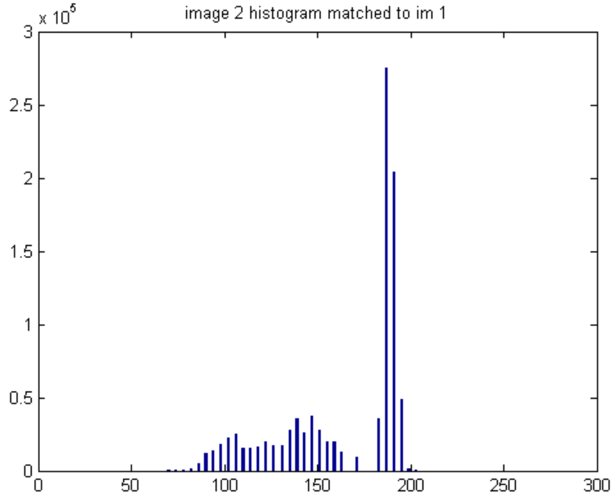


Image 2 histogram matched to image 1



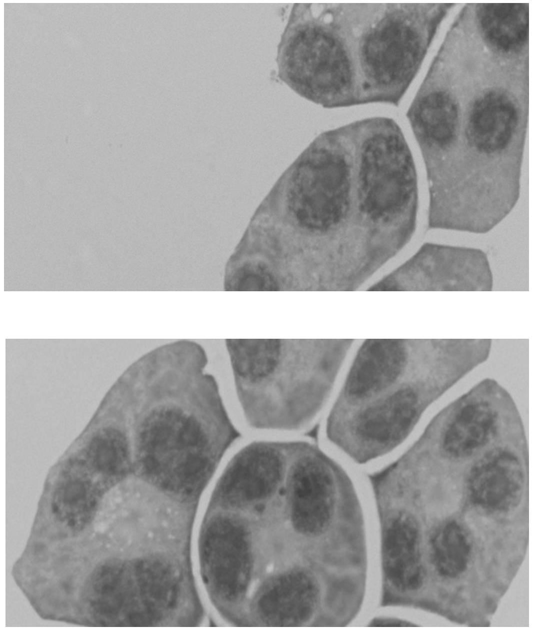


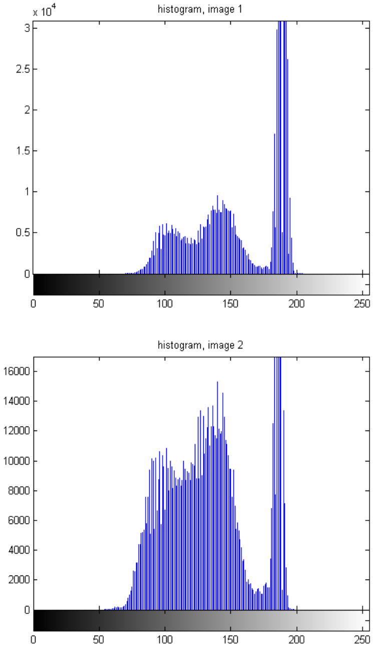


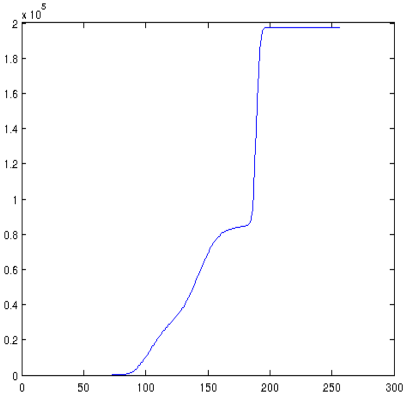


Histogram matching

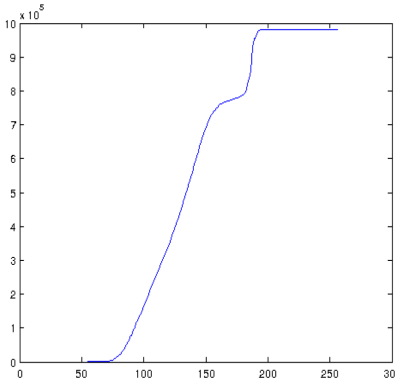
- Compute the histograms for image I_1 , I_2
- Calculate the cumulative distribution function $F_1()$,$F_2()$
- For each gray level G_1 [0,255] find gray level G_2 for which $F_1(G_1)=F_2(G_2)$
- Histogram matching function $M(G_1) = G_2$







img1



img2

Summary

- Many common tasks can be described by image arithmetics.
- Histogram equalizations can be useful for visualization.
- Watch out for information leaks!

Try at home!

A few things to think about....

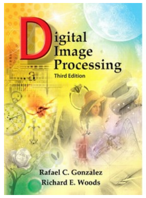
- What is the relation between image arithmetics and linear transfer functions?
- What can you know about an image from the histogram?
- If you have an 8-bit image, A; how will the 8-bit image B=255*(A+1) look like (exactly!)?
- What conclusions can you draw from the histogram if the first/last column is really high?
- Can you get better resolution by combining multiple images of the same sample?

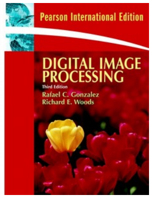
Suggested problems:

2.22, 2.18, 2.9, 3.1, 3.6

Next lecture:

Spatial filtering (Ch. 3.4-3.8)






84-342 D.C.
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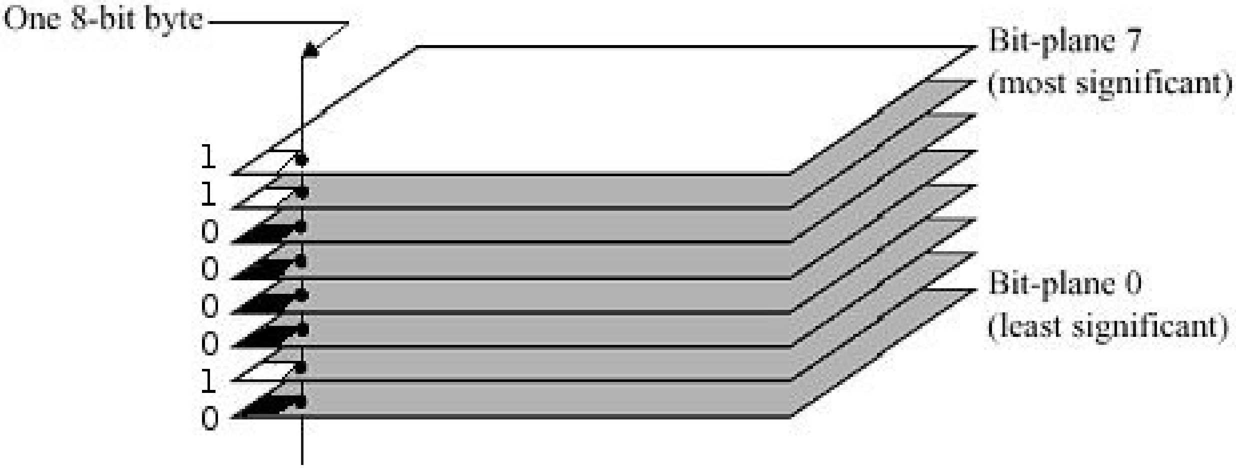
Bit plane slicing

- Pixels → digital numbers composed of bits
- Computer → Binary number system
- Basic unit, bit



194 = 11000010

- 8- and 16- bits are common for file formats.

But how many bits are necessary?

Next slides:

- The eight bit planes for an image.
- The same image using 7,...,0 bit planes.