# Computação Visual e Multimédia

10504: Mestrado em Engenharia Informática

Chap. 3 — Image Processing: Pointwise Operations

Pointwise Operations

# Outline

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- Spatial domain versus frequency domain
- Intensity transformations and pointwise operations
    - Image negative
    - High dynamic range
    - Contrast stretching
    - Histogram equalization

# SPATIAL DOMAIN vs. FREQUENCY DOMAIN

# Representations for images

**Spatial domain (I):**

- It is the "normal" image space
- Consequently, changes in pixel positions of I correspond to changes in the scene
- Also, distances in I correspond to real distances

**Frequency domain (F):**

- Changes in image position correspond to changes in the spatial frequency
- This is the rate at which image intensity values are changing in the spatial domain image I

Images have both ***spatial*** and ***frequency*** representations

# How is an image processed?

http://www.cse.lehigh.edu/~spletzer/rip_f06/lectures/lec012_Frequency.pdf

**Spatial domain (I):**

- *Directly* process the input image pixel array

**Frequency domain (F):**

- *Transform* the image to its frequency representation
- Perform image processing
- Compute inverse transform back to the spatial domain

**Operations:**

- Convolution and multiplication are duals in the spatial/frequency domains
- Although multiplication is MUCH more efficient than convolution, there is a high cost in computing the DFT (Discrete Fourier Transform) and inverse DFT
- As such, most convolutions are carried out in the spatial domain (unless the kernel is sufficiently large)

# What is the meaning of frequencies in an image?

**Frequencies in an image:**

- Any spatial or temporal signal has an equivalent frequency representation
- What do frequencies mean in an image ?
  - High frequencies correspond to pixel values that change rapidly across the image (e.g. text, texture, leaves, etc.)
  - Strong low frequency components correspond to large scale features in the image (e.g. a single, homogenous object that dominates the image)
- We will investigate Fourier transformations to obtain frequency representations of an image

http://www.cse.lehigh.edu/~spletzer/rip_f06/lectures/lec012_Frequency.pdf

# INTENSITY TRANSFORMATIONS

## (pointwise operations)

# Image processing in the spatial domain

http://www.bioen.utah.edu/wiki/index.php?title=Spatial_Domain_Image_Processing

## Definition:

- Manipulating or changing an image representing an object in space to enhance the image for a given application.
- One way in which images are processed is to look at the *neighborhood* around the pixel or voxel that you wish to manipulate.

## Enhancement operation:

- Can be expressed as $g(x,y)=T[f(x,y)]$, where $T$ is a transformation operates on a window of the following types:
  - complete image
  - region
  - pixel

# Pixel or point operations

## Definition:

- A pixel or point operation is a spatial operation whose window reduces to a pixel.
  - Transformed value is independent of neighbor pixels $\Longrightarrow$ pointwise operation

## Operation classification:

- Image negative
- Dynamic range
- Histogram equalization

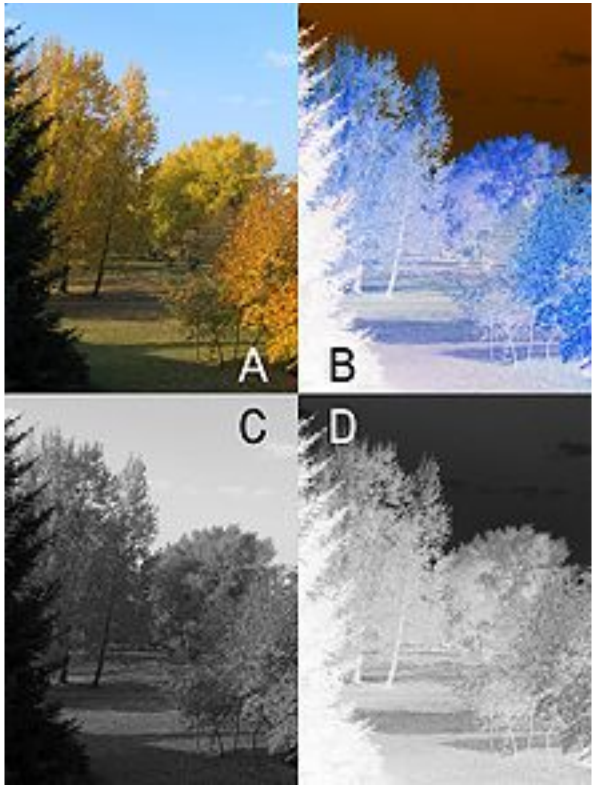
# Image negative

**Definition:**

- A positive image is a normal image.
- A negative image is a total inversion of a positive image, in which light areas appear dark and vice versa.
- A negative color image is additional color reversed, with red areas appearing cyan, greens appearing magenta and blues appearing yellow..

**Applications:**

- Corrects certain image acquisition methods
- Improves the phsico-visual perception




http://en.wikipedia.org/wiki/Negative_(photography)

$$g(x,y)=T[f(x,y)]=MAX-f(x,y)$$
$$=255-f(x,y)$$

# Dynamic range

The human senses of sight and hearing have a very high dynamic range.

## Definition:

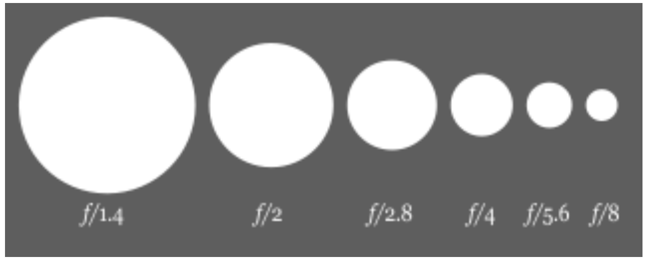
– In imaging, it is the ratio between the maximum and minimum measurable light intensities (white and black, respectively).

## Human dynamic range:

– The human eye can actually perceive a greater dynamic range than is ordinarily possible with a camera. If we were to consider situations where our pupil opens and closes for varying light, our eyes can see over a range of nearly 24 f-stops.

– A human can see objects in starlight (although colour differentiation is reduced at low light levels) or in bright sunlight, even though on a moonless night objects receive 1/1,000,000,000 of the illumination they would on a bright sunny day: that is a dynamic range of 90 dB.

Diagram of decreasing apertures, that is, increasing f-numbers, in one-stop increments; each aperture has half the light gathering area of the previous one.




In optics, the f-number (sometimes called focal ratio, f-ratio, f-stop, or relative aperture) is the focal length divided by the "effective" aperture diameter. It is a quantitative measure of *lens speed*, an important concept in photography.

| ***Factor (power)*** | ***Decibels*** | ***f-stops*** |
|---:|---:|---:|
| 1 | 0 | 0 |
| 2 | 3.01 | 1 |
| 3.16 | 5 | 1.66 |
| 4 | 6.02 | 2 |
| 5 | 6.99 | 2.32 |
| 8 | 9.03 | 3 |
| 10 | 10 | 3.32 |
| 16 | 12 | 4 |
| 20 | 13 | 4.32 |
| 31.6 | 15 | 4.98 |
| 32 | 15.1 | 5 |
| 50 | 17 | 5.64 |
| 100 | 20 | 6.64 |
| 1 000 | 30 | 9.97 |
| 1 024 | 30.1 | 10 |
| 10 000 | 40 | 13.3 |
| 100 000 | 50 | 16.6 |
| 1 000 000 | 60 | 19.9 |
| 1 048 576 | 60.2 | 20 |
| 100 000 000 | 80 | 26.6 |
| 1 073 741 824 | 90.3 | 30 |
| 10 000 000 000 | 100 | 33.2 |

http://en.wikipedia.org/wiki/F-number

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

# Effects of the f-number on image quality

## Depth of field:

– Depth of field increases with f-number, as illustrated in the image on the right hand side.

– Photos taken with a low f-number will tend to have subjects at one distance in focus, with the rest of the image (nearer and farther elements) out of focus (This is frequently useful for nature photography, portraiture, and certain special effects).

## Picture sharpness:

– Picture sharpness also varies with f-number. The optimal f-stop varies with the lens characteristics. For modern standard lenses having 6 or 7 elements, the sharpest image is often obtained around f/5.6–f/8, while for older standard lenses having only 4 elements (Tessar formula) stopping to f/11 will give the sharpest image.

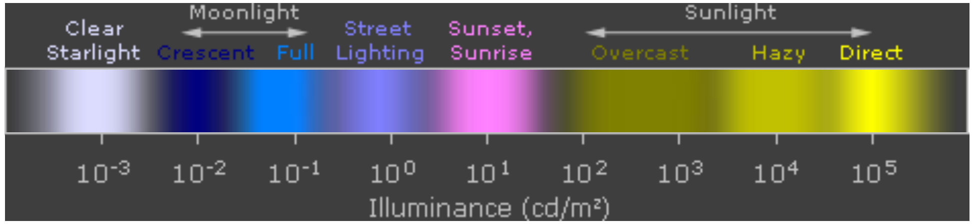
Comparison of f/32 (top-left corner) and f/5 (bottom-right corner)


A 35 mm lens set to f/11, as indicated by the white dot above the f-stop scale on the aperture ring. This lens has an aperture range of f/2.0 to f/22

http://en.wikipedia.org/wiki/F-number

# Dynamic range in digital photography

Here we see the vast variation possible for incident light, since the following diagram is scaled to powers of ten. If a scene were unevenly illuminated by both direct and obstructed sunlight, this alone can greatly increase a scene's dynamic range (as apparent from the canyon sunset example with a partially-lit cliff face).

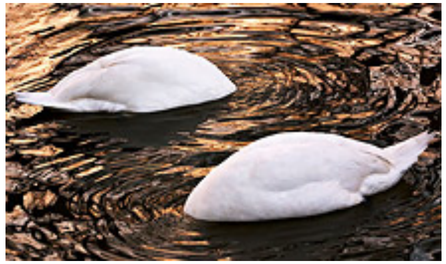



## Influence of light: illuminance and reflectivity:

– Light intensity can be described in terms of incident and reflected light; both contribute to the dynamic range of a scene.

– Scenes with high variation in reflectivity, such as those containing black objects in addition to strong reflections, may actually have a greater dynamic range than scenes with large incident light variation. Photography under either scenario can easily exceed the dynamic range of your camera — particularly if the exposure is not spot on.

– Accurate measurement of light intensity, or luminance, is therefore critical when assessing dynamic range. Here we use the term illuminance to specify only incident light. Both illuminance and luminance are typically measured in candelas per square meter (cd/$m^2$).



Strong Reflections

Uneven Incident Light

http://www.cambridgeincolour.com/tutorials/dynamic-range.htm

# Contrast

| Bit Precision of Analog/ Digital Converter | Contrast Ratio | Dynamic Range |
|---|---|---|
| | | *f-stops* |
| 8 | 256:1 | 8 |
| 10 | 1024:1 | 10 |
| 12 | 4096:1 | 12 |
| 14 | 16384:1 | 14 |
| 16 | 65536:1 | 16 |


Left side of the image has low contrast, the right has higher contrast.

## Definition:

- Contrast is the difference in visual properties that makes an object (or its representation in an image) distinguishable from other objects and the background.
- In visual perception of the real world, contrast is determined by the difference in the **color** and **brightness** of the object and other objects within the same field of view.
- Because the human visual system is more sensitive to contrast than absolute luminance, we can perceive the world similarly regardless of the huge changes in illumination over the day or from place to place.

## Contrast vs. Dynamic Range

- The most commonly used unit for measuring dynamic range in digital cameras is the f-stop, which describes total light range by powers of 2.
- A contrast ratio of 1024:1 could therefore also be described as having a dynamic range of 10 f-stops (since $2^{10} = 1024$). Depending on the application, each unit f-stop may also be described as a "zone" or "eV.".

http://en.wikipedia.org/wiki/Contrast_(vision)

# High dynamic range (HDR)


–8 stops


–2 stops


+2 stops


+4 stops

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

**Definition:**

- Technique of combining several differently exposed images to produce a single HDR image (1997, Paul Debevec ).
- In image processing, computer graphics, and photography, high dynamic range imaging (HDRI or just HDR) is a set of techniques that allow a greater dynamic range between the lightest and darkest areas of an image than current standard digital imaging techniques or photographic methods.

Examples**:**

- The 4 standard dynamic range images above are combined to produce the following two resulting tone mapped images:


Simple contrast reduction


Local tone mapping

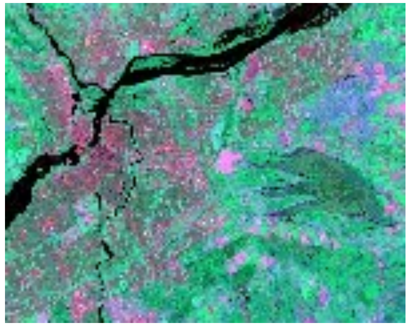
*HDR photography functionality was added to the iPhone 4 in iOS version 4.1 on September 8th 2010*

# Contrast stretching

$$P_{OUT} = (P_{IN} - L)\left(\frac{MAX - MIN}{H - L}\right) + MIN$$

L : lowest pixel value in image
H : highest pixel value in image
MAX: maximum pixel value allowed in image
MIN: minimum pixel value allowed in image

Before linear stretch



After linear stretch

## Definition:

– Contrast stretching (often called normalization) is a *simple image enhancement* technique that attempts to improve the contrast in an image by `stretching' the range of intensity values it contains to span a desired range of values, e.g. the the full range of pixel values that the image type concerned allows.

– It differs from the more sophisticated histogram equalization in that it can only apply a linear scaling function to the image pixel values.

## Effect on image:

– The linear contrast stretch enhances the contrast in the image with light toned areas appearing lighter and dark areas appearing darker, making visual interpretation much easier.

http://homepages.inf.ed.ac.uk/rbf/HIPR2/stretch.htm

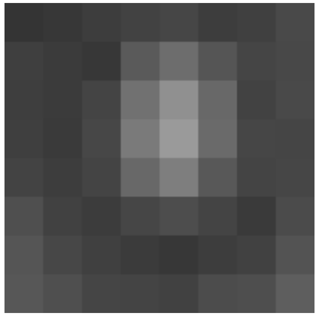
http://hosting.soonet.ca/eliris/remotesensing/bl130lec10.html

# Histogram equalization

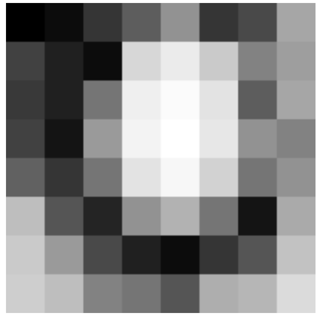
Equalization formula:

$$h(v) = \text{round}\left(\frac{cdf(v) - cdf_{min}}{(M \times N) - cdf_{min}} \times (L-1)\right)$$

L : number of amplitude or intensity levels
MxN : resolution of image
cdf : cumulative distribution function



original



equalized

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

## Definition:

– It is a method of dynamic range and contrast adjustment using the image's histogram.

## How does it work?:

– This method usually increases the global contrast of many images, especially when the usable data of the image is represented by close contrast values.

– Through this adjustment, the *intensities (amplitudes) can be better distributed* on the histogram. This allows for areas of lower local contrast to gain a higher contrast.

$$\begin{bmatrix} 52 & 55 & 61 & 66 & 70 & 61 & 64 & 73 \\ 63 & 59 & 55 & 90 & 109 & 85 & 69 & 72 \\ 62 & 59 & 68 & 113 & 144 & 104 & 66 & 73 \\ 63 & 58 & 71 & 122 & 154 & 106 & 70 & 69 \\ 67 & 61 & 68 & 104 & 126 & 88 & 68 & 70 \\ 79 & 65 & 60 & 70 & 77 & 68 & 58 & 75 \\ 85 & 71 & 64 & 59 & 55 & 61 & 65 & 83 \\ 87 & 79 & 69 & 68 & 65 & 76 & 78 & 94 \end{bmatrix}$$

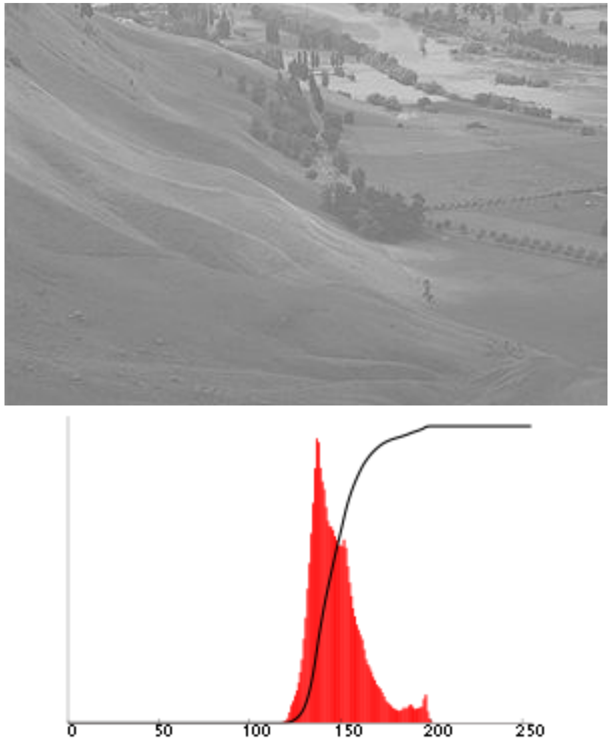
original image matrix

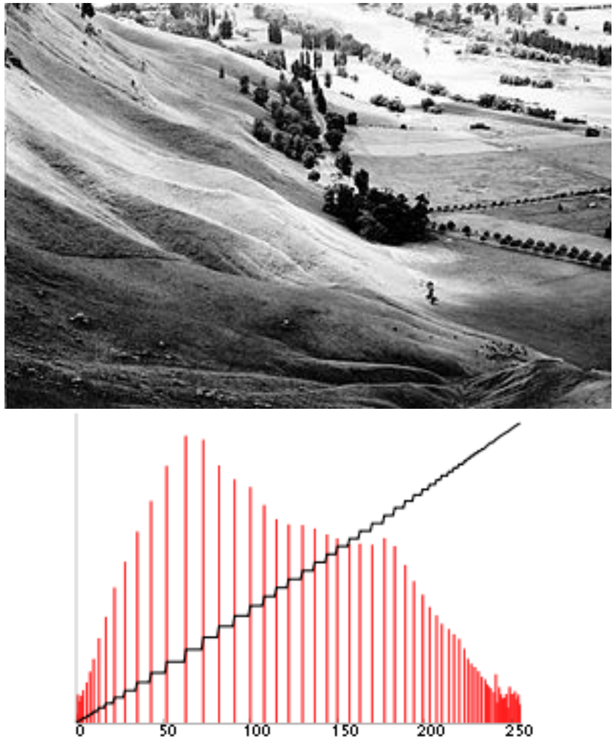
$$\begin{bmatrix} 0 & 12 & 53 & 93 & 146 & 53 & 73 & 166 \\ 65 & 32 & 12 & 215 & 235 & 202 & 130 & 158 \\ 57 & 32 & 117 & 239 & 251 & 227 & 93 & 166 \\ 65 & 20 & 154 & 243 & 255 & 231 & 146 & 130 \\ 97 & 53 & 117 & 227 & 247 & 210 & 117 & 146 \\ 190 & 85 & 36 & 146 & 178 & 117 & 20 & 170 \\ 202 & 154 & 73 & 32 & 12 & 53 & 85 & 194 \\ 206 & 190 & 130 & 117 & 85 & 174 & 182 & 219 \end{bmatrix}$$

equalized image matrix

http://homepages.inf.ed.ac.uk/rbf/HIPR2/histeq.htm

# Histogram equalization (cont'd)



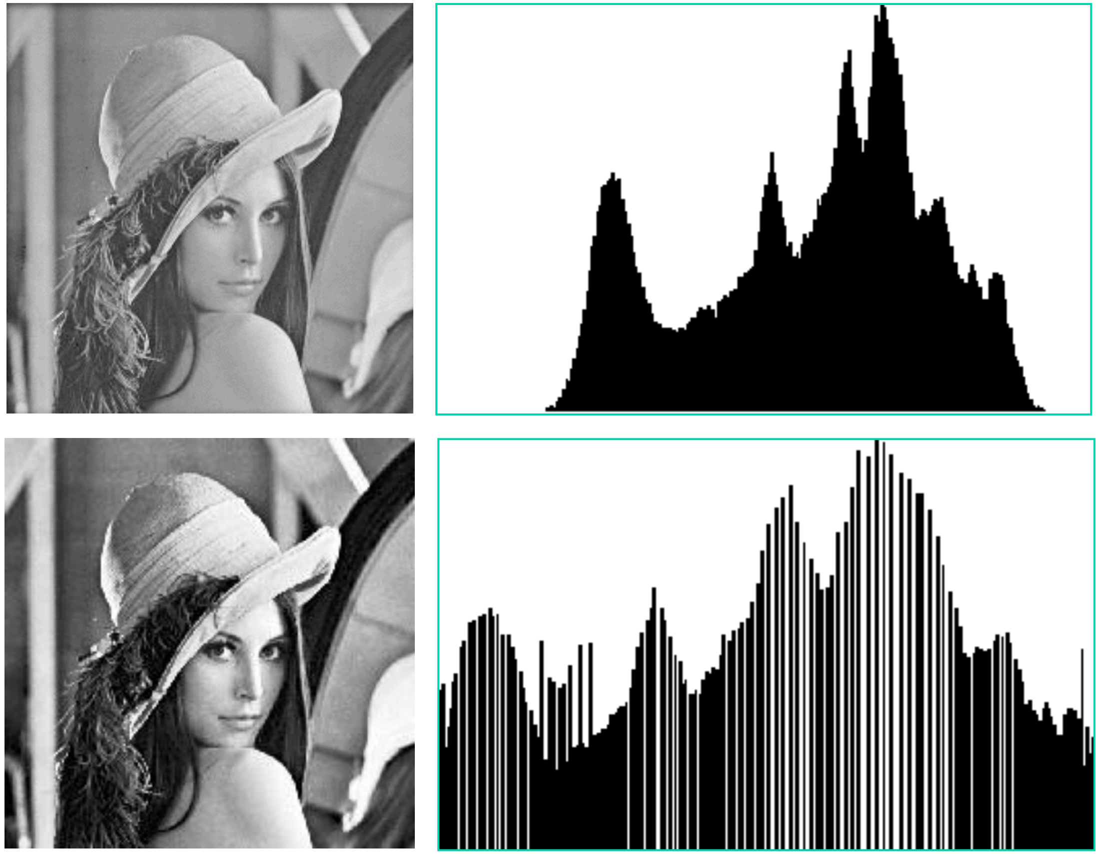




http://en.wikipedia.org/wiki/Histogram_equalization

## Applications:

- The method is useful in images with backgrounds and foregrounds that are both bright or both dark.
- In particular, the method can lead to better views of bone structure in x-ray images, and to better detail in photographs that are over or under-exposed.

# Histogram equalization (cont'd)



http://effbot.org/zone/pil-histogram-equalization.htm

## Effect on image:

– Peaks in the image histogram (indicating commonly used grey levels) are widened, while the valleys are compressed.

# Summary:

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- Spatial domain versus frequency domain
- Intensity transformations and pointwise operations
  - Image negative
  - High dynamic range
  - Contrast stretching
  - Histogram equalization