Digital Image Processing

Chapter 2: Digital Image Fundamentals

(Expected duration: 3 hours)

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(Slides are based on Rafael C. Gonzalez and Richard E. Woods, Sufyan Samara, and Samer Arandi)

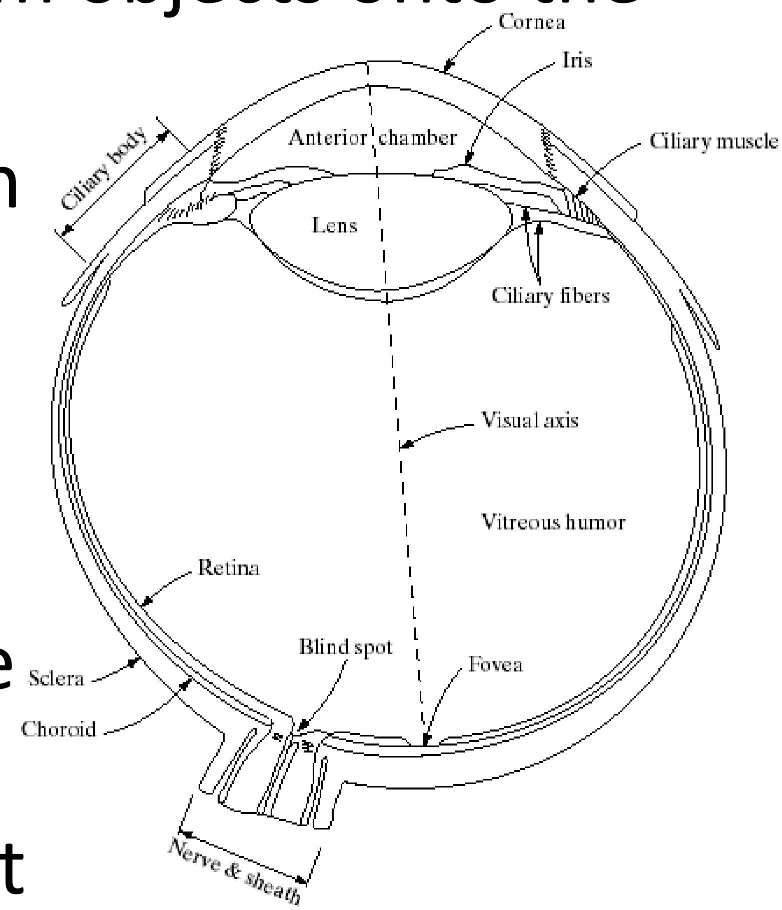
Image Acquistion

- We can’t think of image processing without considering the **human vision system**. We observe and evaluate the images that we process with our visual system.
- Without taking this elementary fact into consideration, we may be much misled in the interpretation of images.

Images are from the Digital Image Processing textbook, see slide 7

Structure Of The Human Eye

- The **lens** focuses light from objects onto the retina
- The retina is covered with **light receptors** called ***cones*** (6-7 million) and ***rods*** (75-150 million)
- **Cones** are concentrated **around the fovea** and are very sensitive to **colour**
- **Rods** are more spread out and are sensitive to **low levels of illumination**



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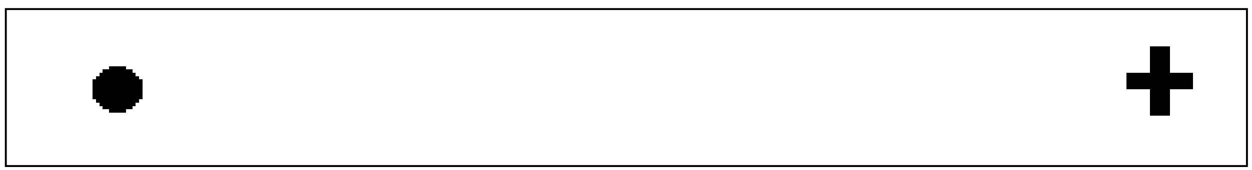
Blind-Spot Experiment

- Draw an image similar to that below on a piece of paper (the dot and cross are about 15 cm apart)



- Close your right eye and focus on the cross with your left eye
- Hold the image about 50 cm away from your face and move it slowly towards you
- The dot should disappear!

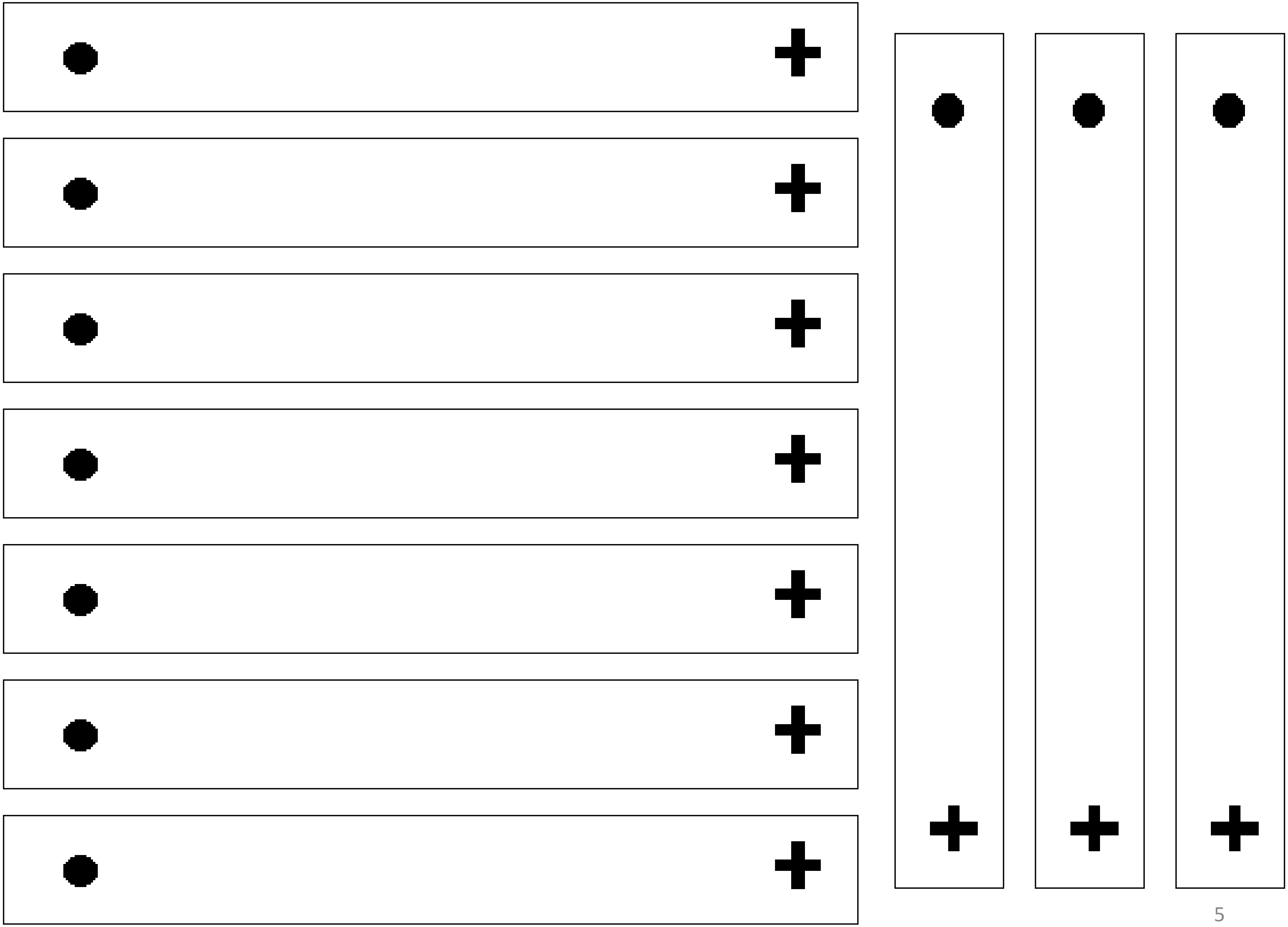
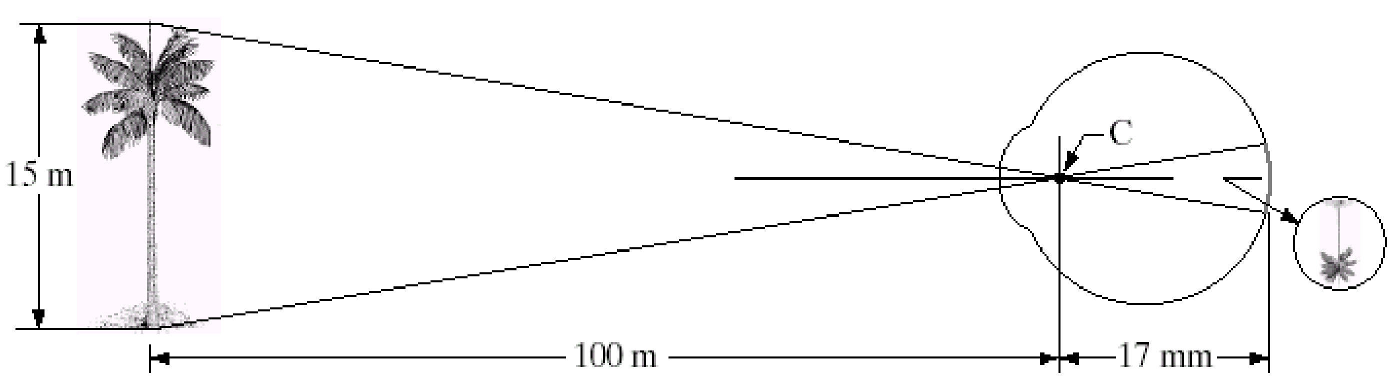


Image Formation In The Eye

- **Muscles** within the eye can be used to change the shape of the **lens** allowing us **focus** on objects that are **near** or **far** away
- An image is focused onto the retina causing rods and cones to become excited which ultimately send signals to the brain



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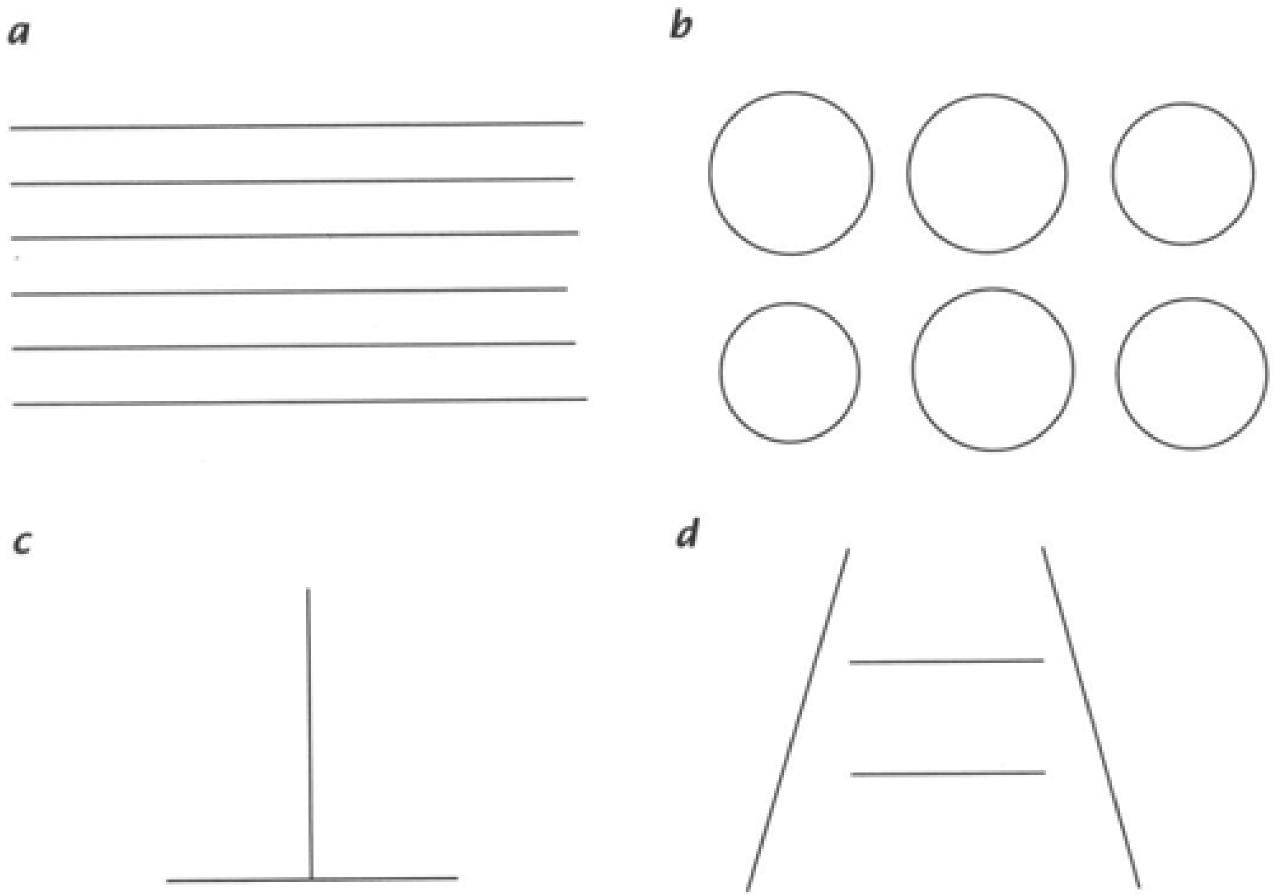
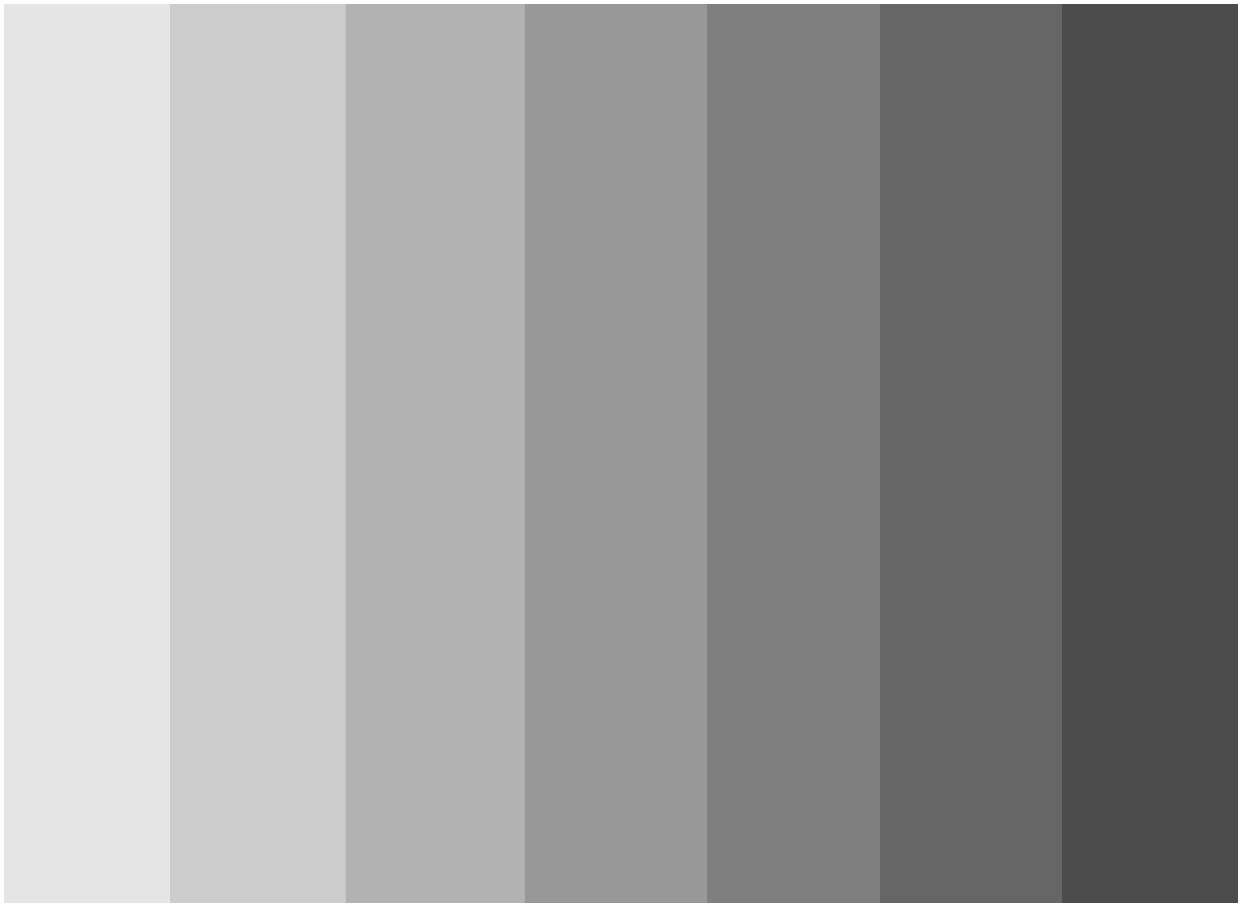
How accurately we estimate and compare distances and areas?



Brightness Adaptation & Discrimination

- The human visual system can perceive approximately **10^{10} different light intensity levels**
- However, at any one time we can only discriminate between a much smaller number – ***brightness adaptation***
- Similarly, the *perceived intensity* of a region is **related to the light intensities of the regions surrounding it**

Brightness Adaptation & Discrimination (cont…)



An example of Mach bands

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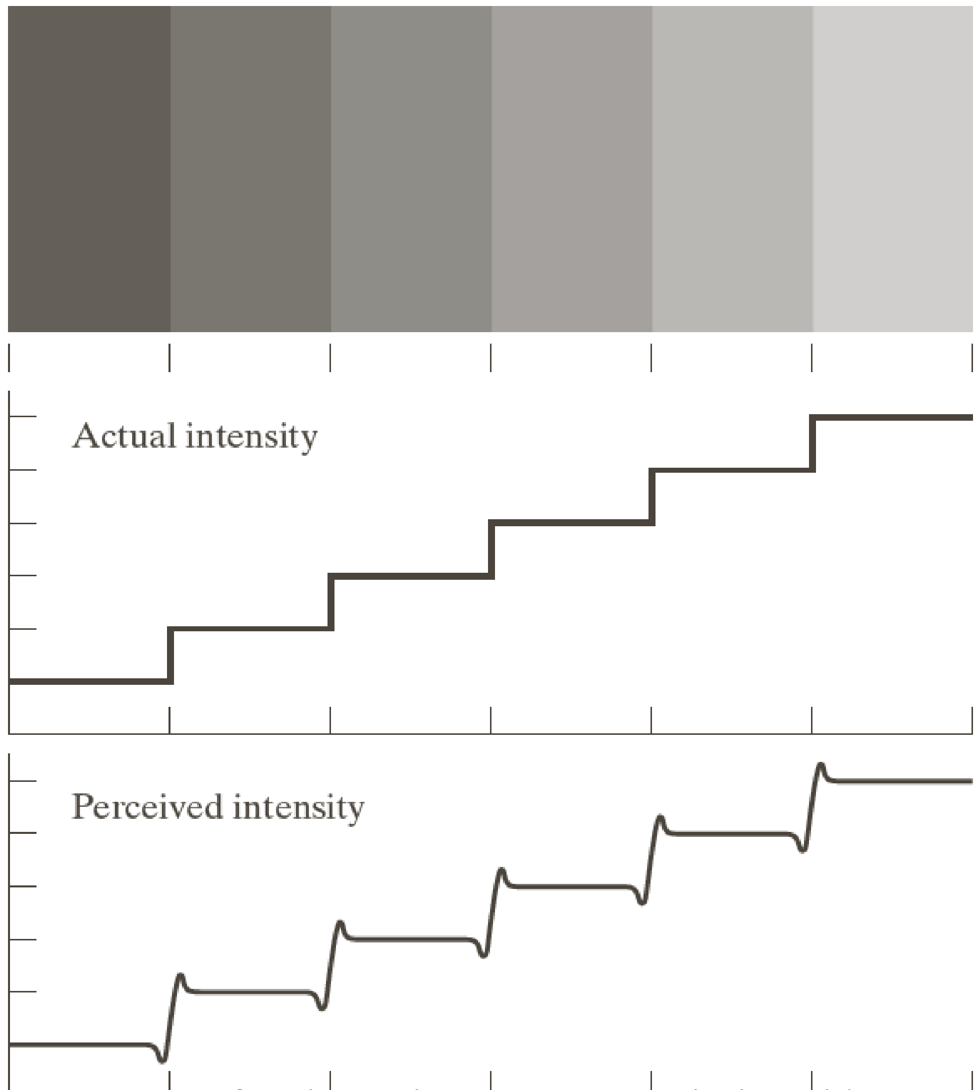
Brightness Adaptation & Discrimination (cont…)



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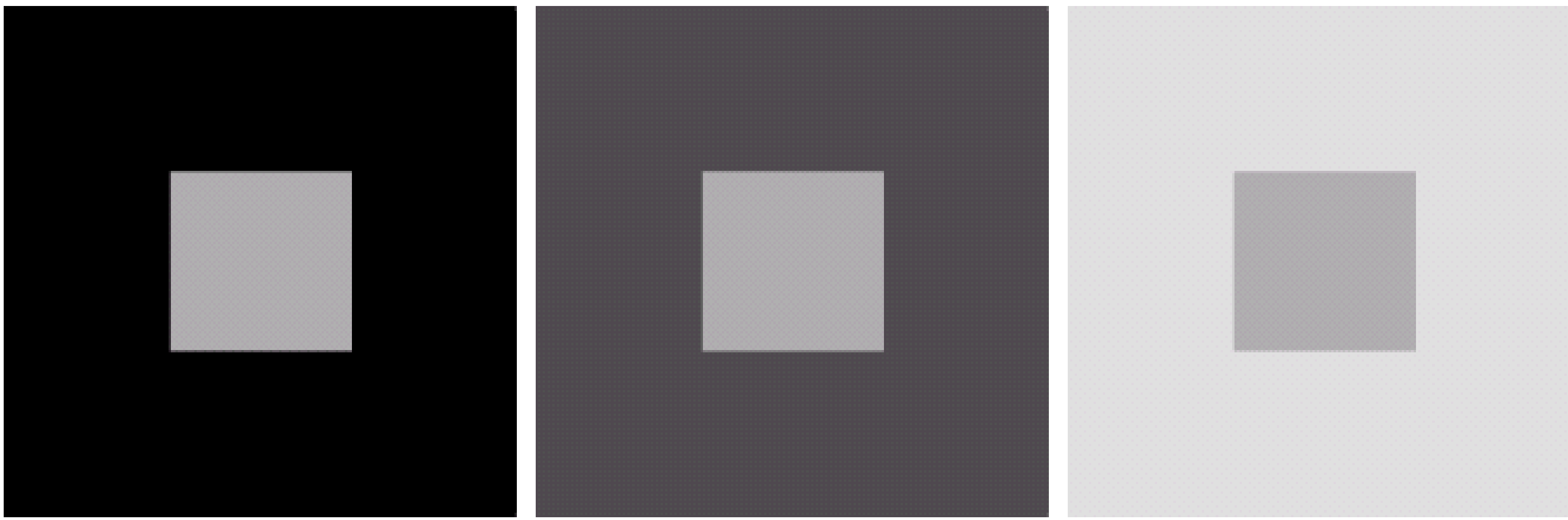
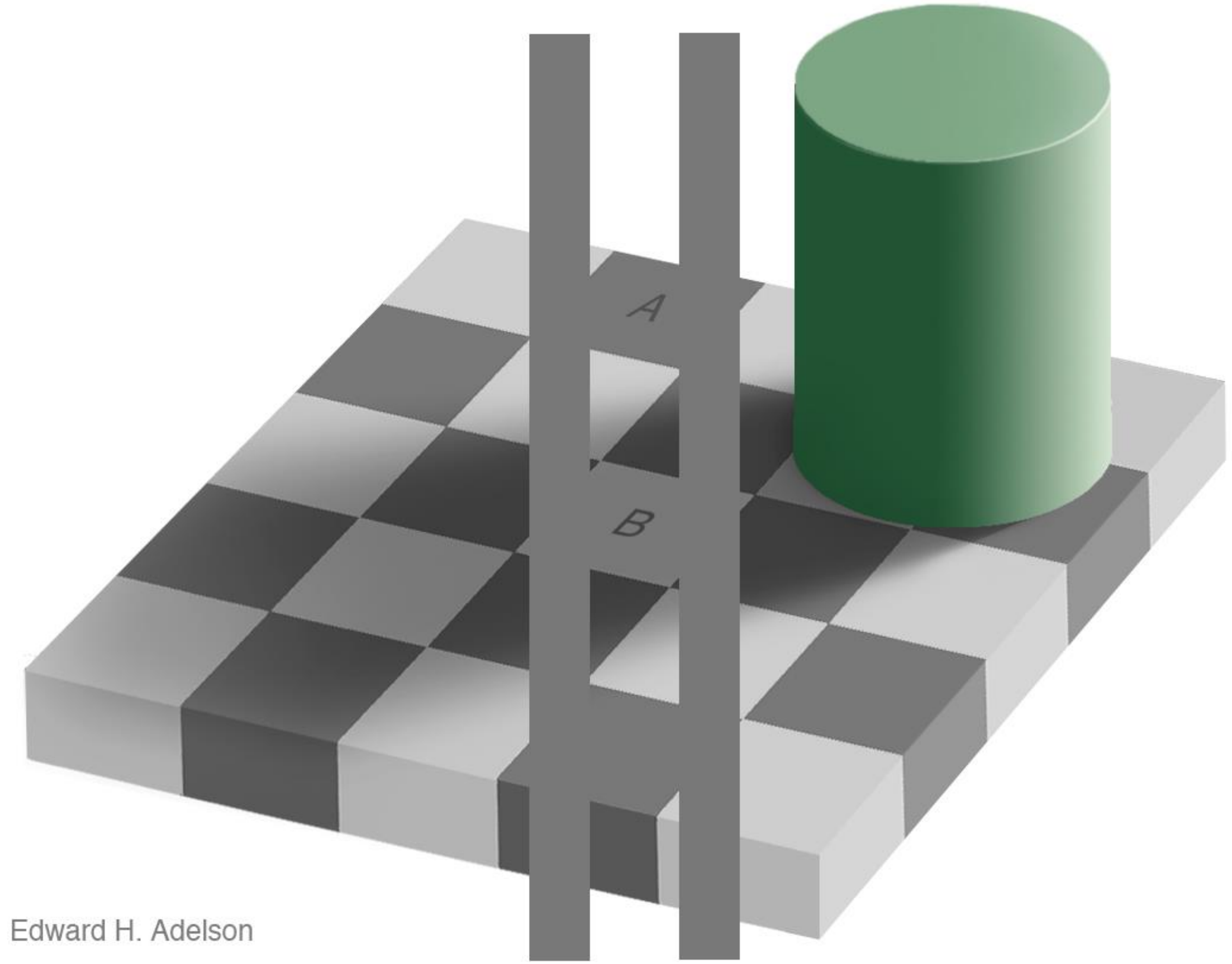
Brightness Adaptation & Discrimination (cont…)



An example of *simultaneous contrast*

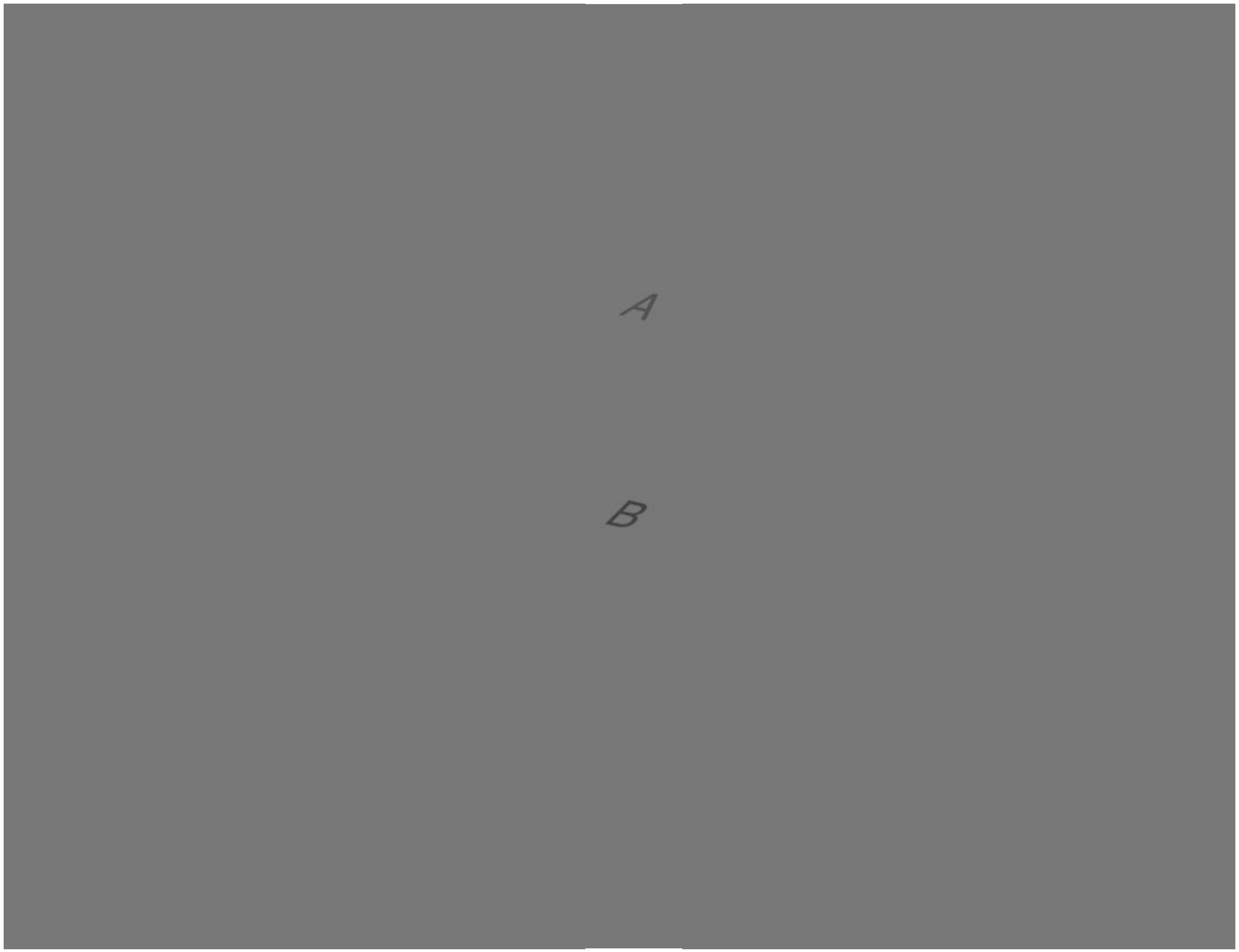
- All the small squares have exactly the same intensity, but they appear to the eye progressively darker as the background becomes brighter.

Brightness Adaptation & Discrimination (cont…)



For more great illusion examples take a look at: http://web.mit.edu/persci/gaz/

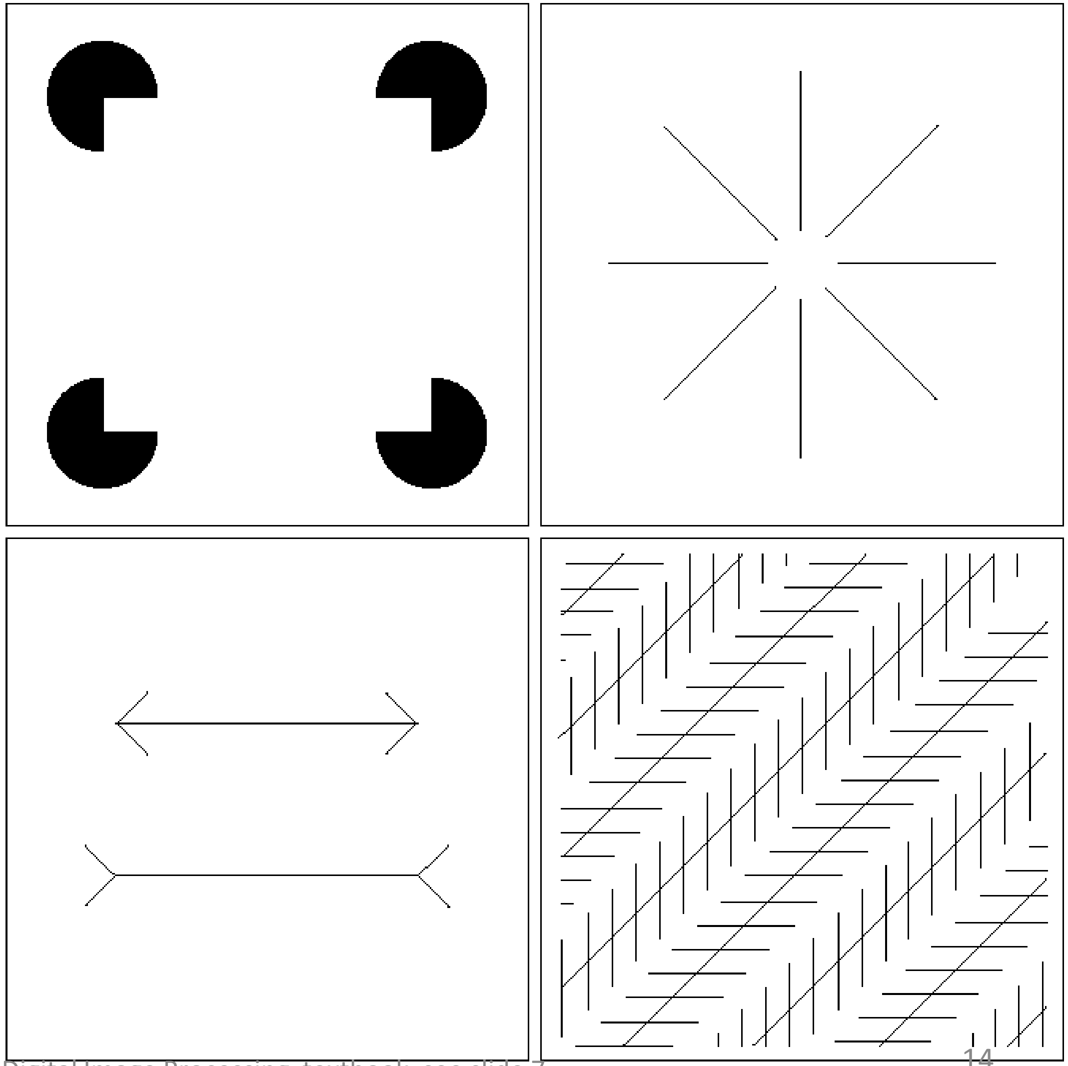
Brightness Adaptation & Discrimination (cont…)



For more great illusion examples take a look at: http://web.mit.edu/persci/gaz/

Optical Illusions

- Our visual systems play lots of interesting tricks on us



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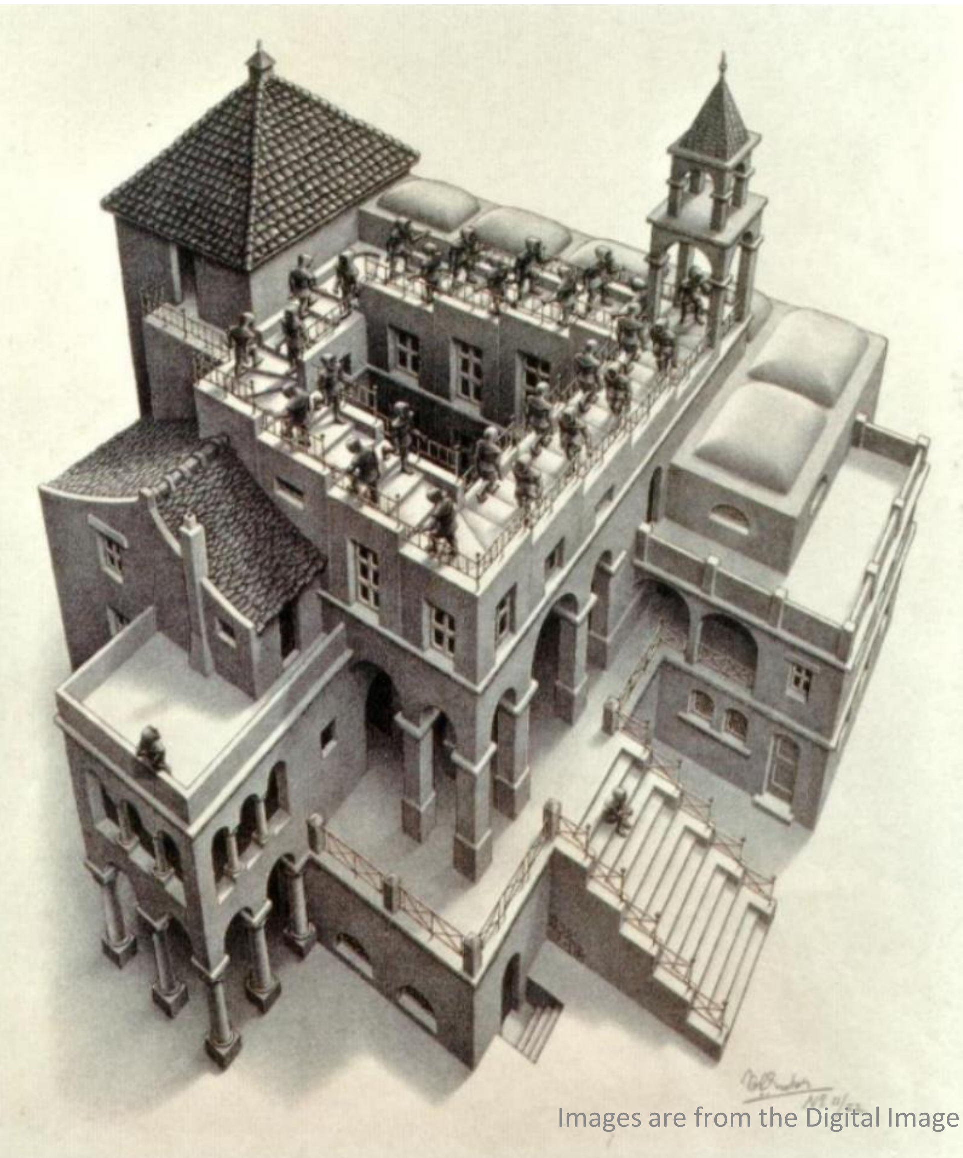
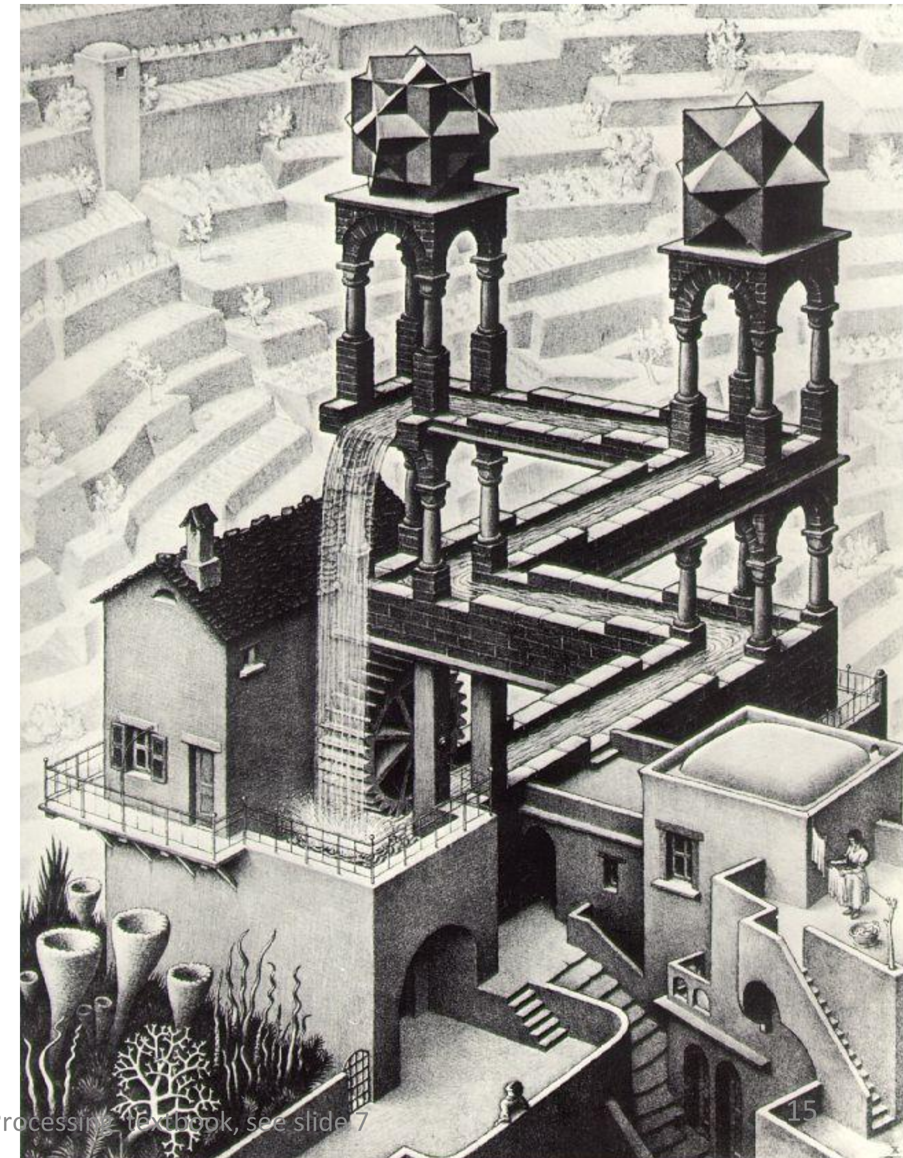
Optical Illusions (cont…)





Mind Map Exercise: Mind Mapping For Note Taking

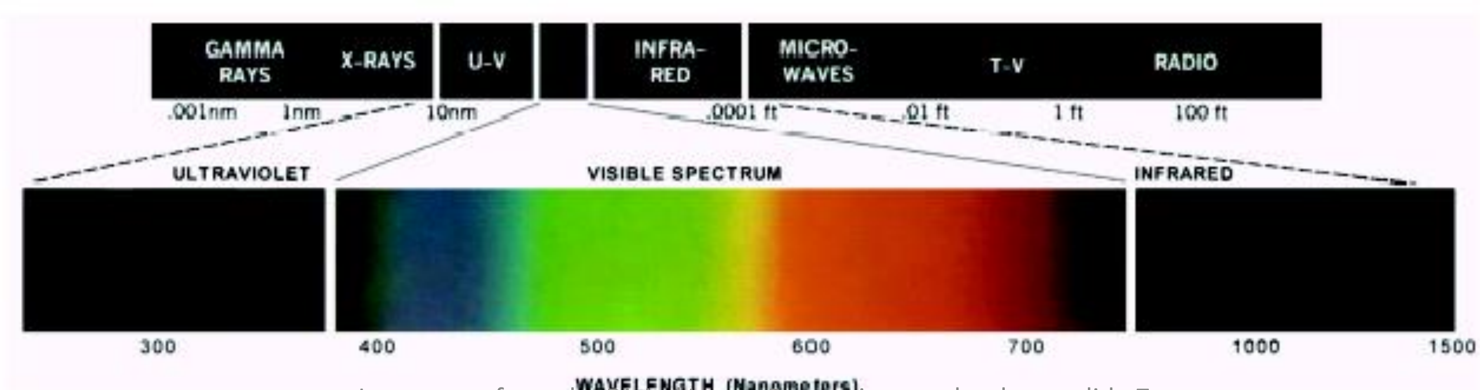
TED Ideas worth spreading

Beau Lotto: Optical Illusions Show How We See

http://www.ted.com/talks/lang/eng/beau_lotto_optical_illusions_show_how_we_see.html

Light And The Electromagnetic Spectrum

- Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye
- The electromagnetic spectrum is split up according to the wavelengths of different forms of energy



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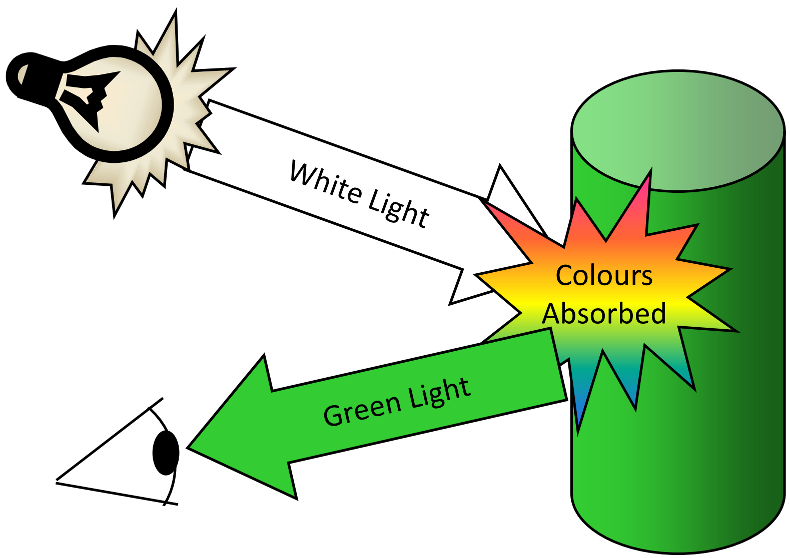
Reflected Light

- The colours that we perceive are determined by the nature of the light reflected from an object
- For example, if white light is shone onto a green object most wavelengths are **absorbed**, while green light is **reflected** from the object



Definitions

- **Monochromatic** (achromatic) light: Light that is void of color
  - Attribute: **Intensity** (amount) . ↑ white ↓ black
  - **Gray level** is used to describe monochromatic intensity.

Signals

- A signal is a function that carries information.
- Usually content of the signal **changes** over some set of **spatiotemporal dimensions**.
  - **Spatiotemporal:** existing in both **space** and **time**; having both spatial extension and temporal duration el image fiha space bas no time
- **Time-Varying Signals** denoted by *f(t)*
  - for example: audio signal

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Spatially-Varying Signals

- An image can be thought of as being a function of **2 spatial dimensions**: ***f(x,y)***

- for monochromatic images, the value of the function is the **amount of light** at that point.

- medical CAT and MRI scanners produce images that are functions of 3 spatial dimensions: *f(x,y,z)*

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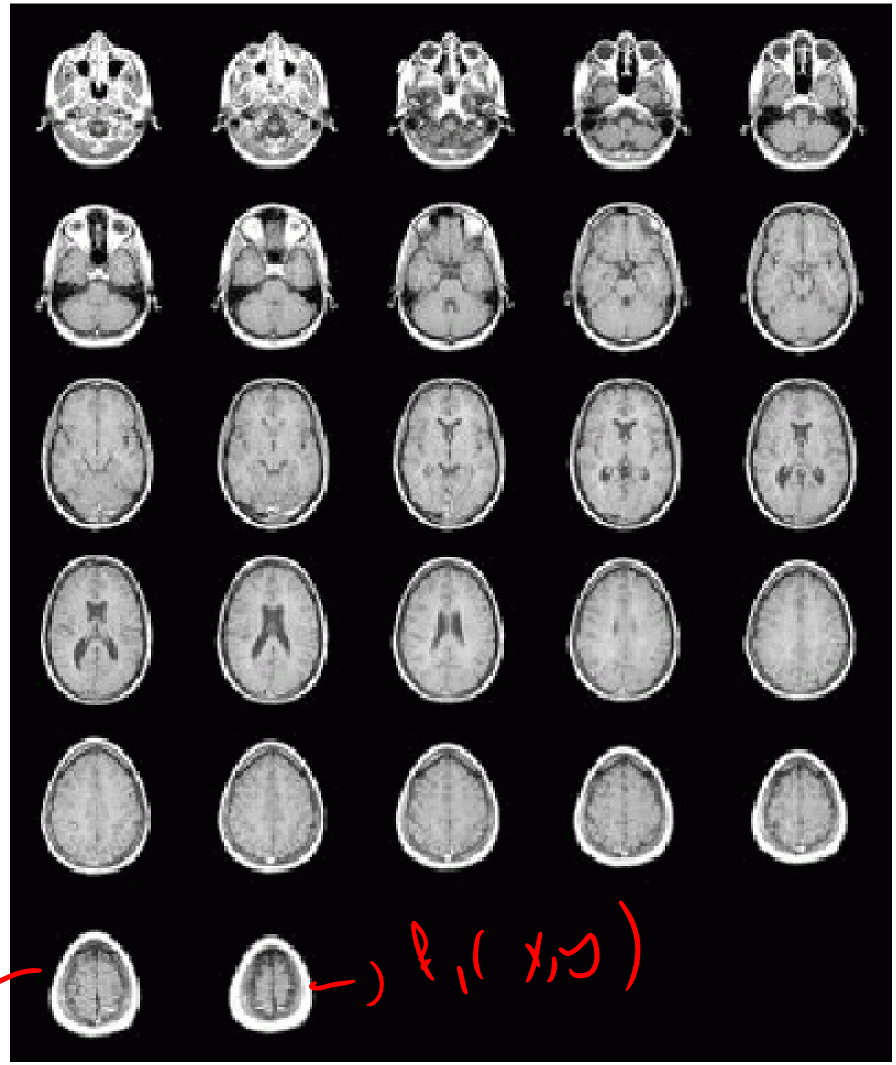
MRI Images

$f_2(x,y)$



$f_1(x,y)$

moving in z dimension

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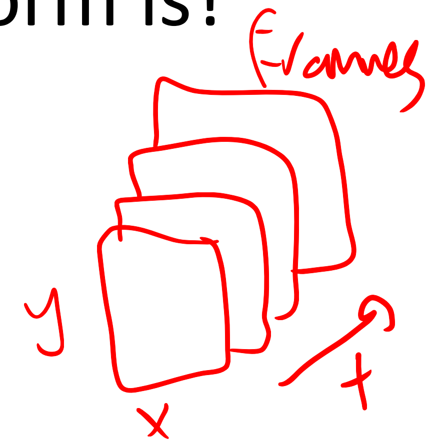
Spatiotemporal Signals

- What do you think a signal of this form is?

  f(x,y,t)

  – *x* and *y* are spatial dimensions;

  – *t* is time.



- Perhaps, it is a video signal, animation, or other time-varying picture sequence.

Image signals

- An image is a 2D matrix.
- Each element in the image can be characterized by two components
  - the amount of **source illumination incident** on the scene being viewed, denoted by $0<i(x. y)<\infty$
  - the amount of **illumination reflected** by the object in the scene, denoted by $0<r(x,y)<1$.
  - These limits are theoretical
- So an element at (x,y) in an image can have an **intensity** (gray level) given as $f(x,y)=i(x,y)*r(x,y)$

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Types of Signals

- Most naturally-occurring signals are functions having a **continuous domain**.
- However, signals in a computer are **discrete** samples of the continuous domain.
- In other words, signals manipulated by computer have **discrete domains**.
- To store and manipulate signals by computer we need to store these numbers with **finite precision**. thus, these signals have a discrete range.

- Signal has continuous domain and range = **analog**
- Signal has discrete domain and range = **digital**

Sampling, Quantization & Resolution

Sampling, Quantisation And Resolution

- In the following slides we will consider what is involved in **capturing a digital image of a real-world scene**
  - Image sensing and representation
  - Sampling and quantisation
  - Resolution

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Image Representation

rows columns

M x N image (resolution)

- Before we discuss image acquisition recall that a digital image is composed of M **rows and** N **columns** of pixels each storing a value

8 bit image (levels)

- Pixel values are most often **grey levels** in the range **0-255** (black-white)
- We will see later on that images can easily be represented as matrices

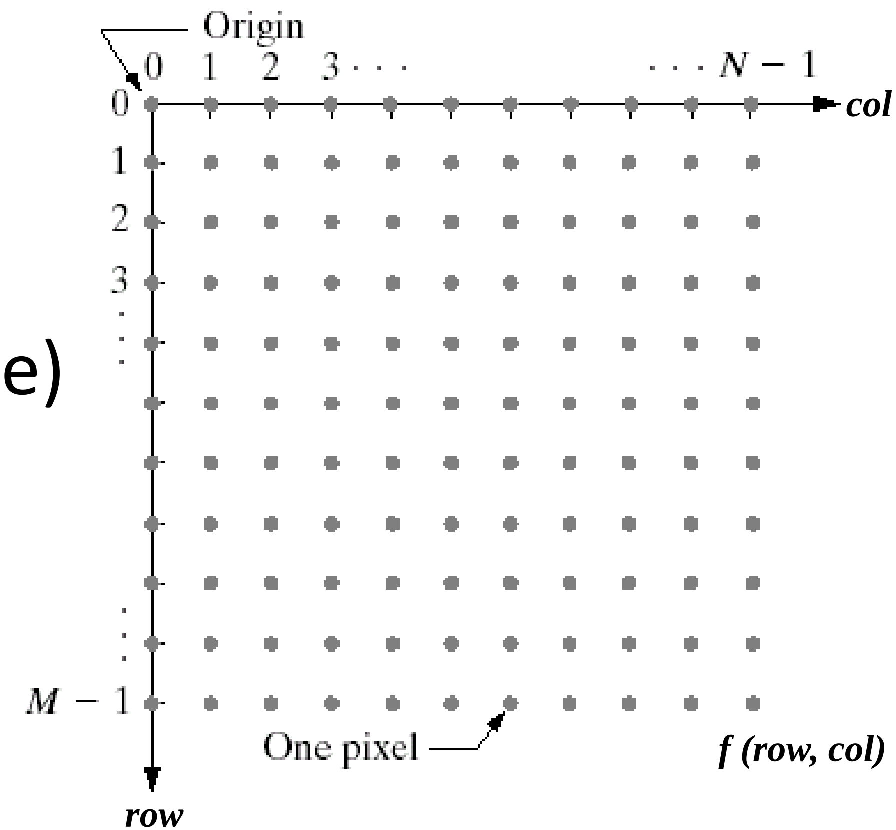

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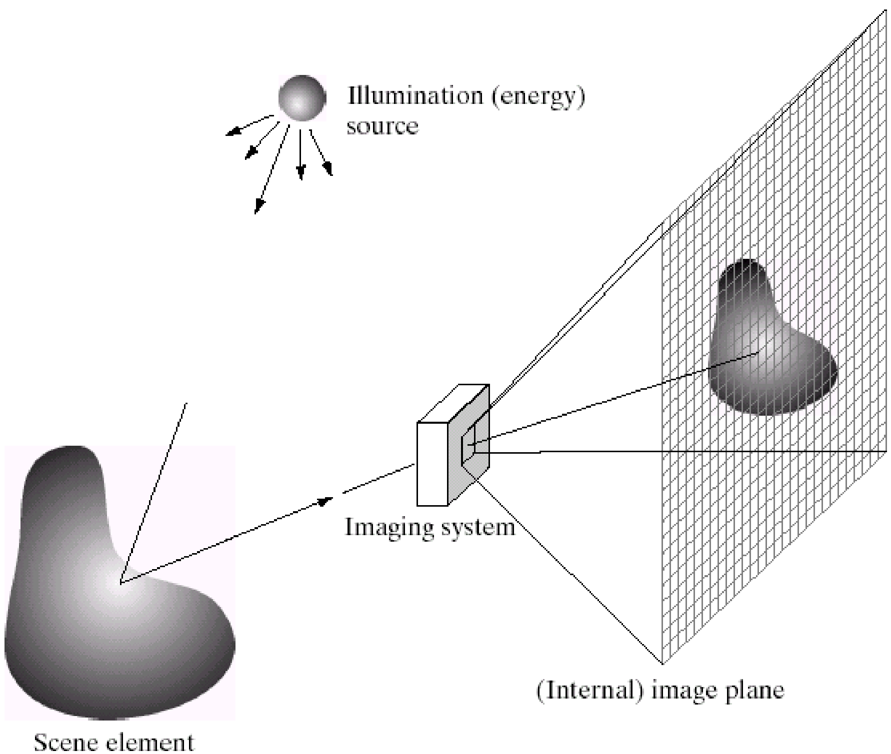
Image Acquisition

- Images are typically generated by ***illuminating*** a *scene* and **absorbing** the energy reflected by the objects in that scene



- Typical notions of illumination and scene can be way off:
  - X-rays of a skeleton
  - Ultrasound of an unborn baby
  - Electro-microscopic images of molecules

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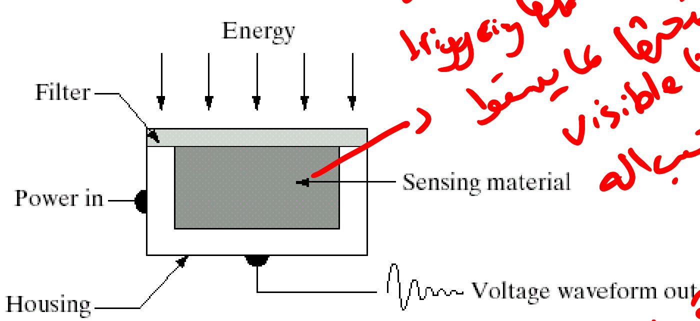
Image Sensing

- Incoming **energy** lands on a sensor material **responsive to that type of energy** and this generates a **voltage**

if i wanna increase the resolution then the area of the sensor must decrease too

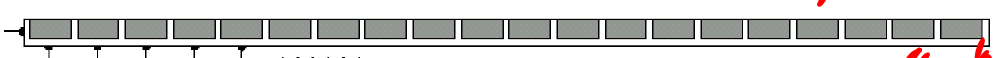
- Collections of sensors are arranged to capture images

في صورة مادة حساسة مصنوعة ومستحقة triggering لما يسقطوا عليها visible light بيستجيب الها

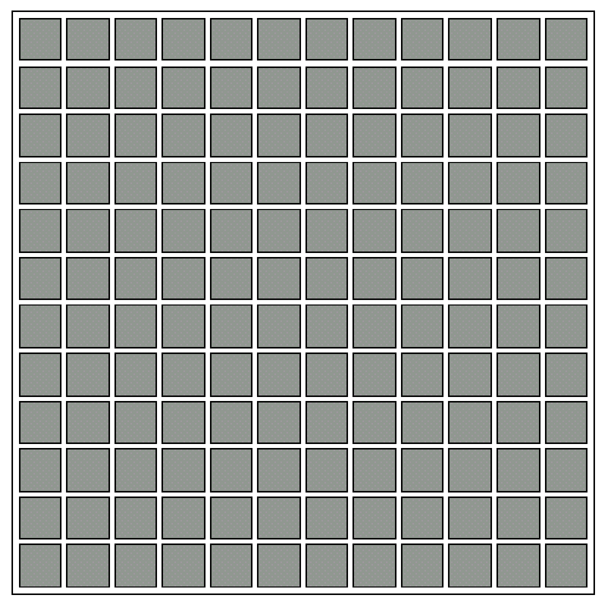


Imaging Sensor

لو كمية الضوء اللي جاية كبيرة حتكون الفولتية عالية وبيلا while يكون الضوء الـ voltage will be flat

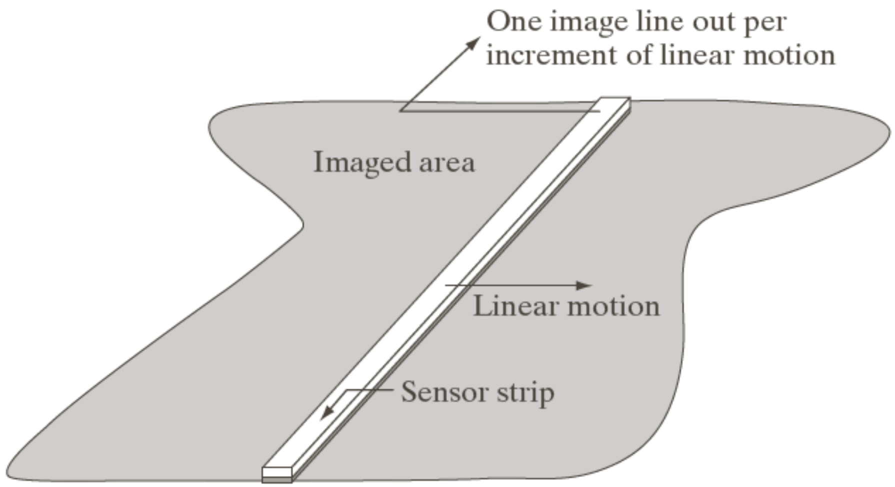


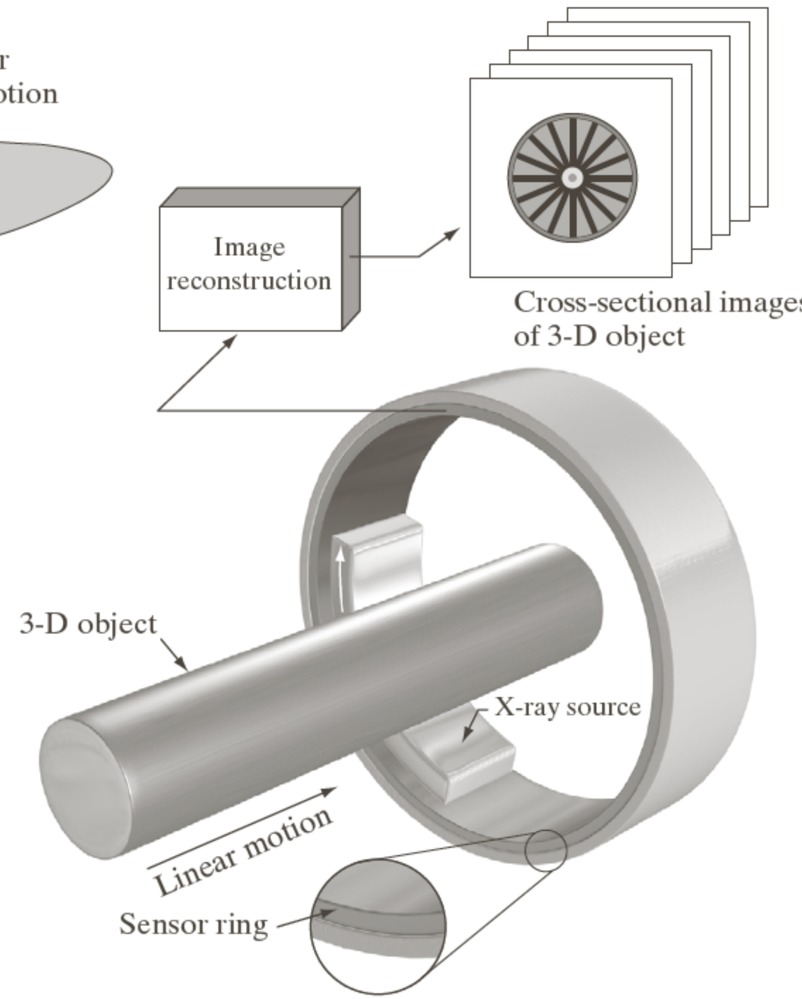
Line of Image Sensors



Array of Image Sensors

Image Sensing





Using Sensor Strips and Rings

Image Sampling And Quantisation

both things do approximation

- A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels
- ***Quantisation*** is the process of converting a **continuous analogue signal into a digital** representation of this signal

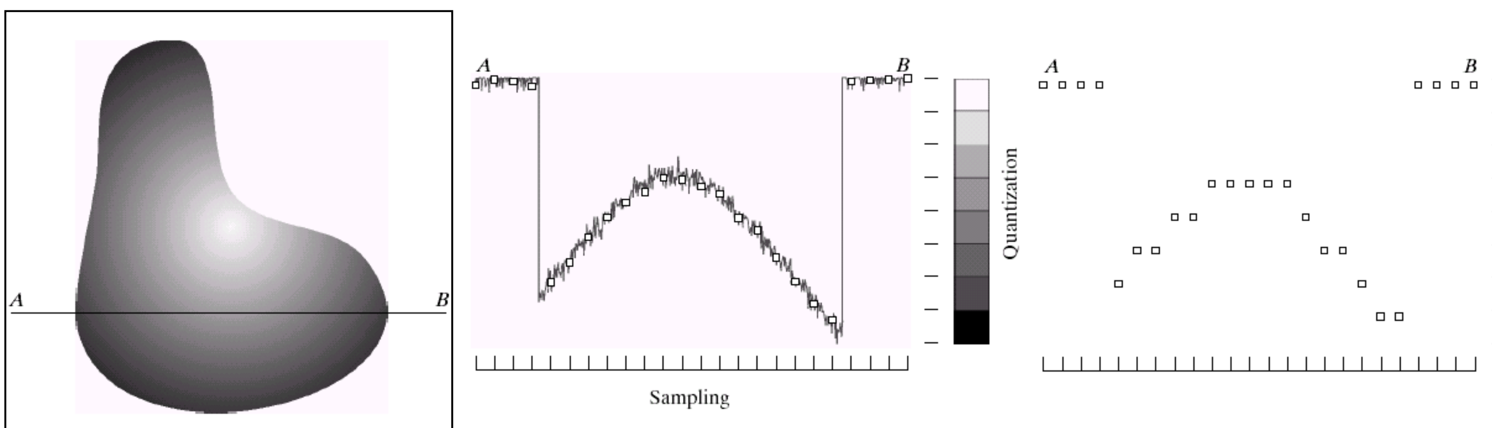


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Image Sampling And Quantisation

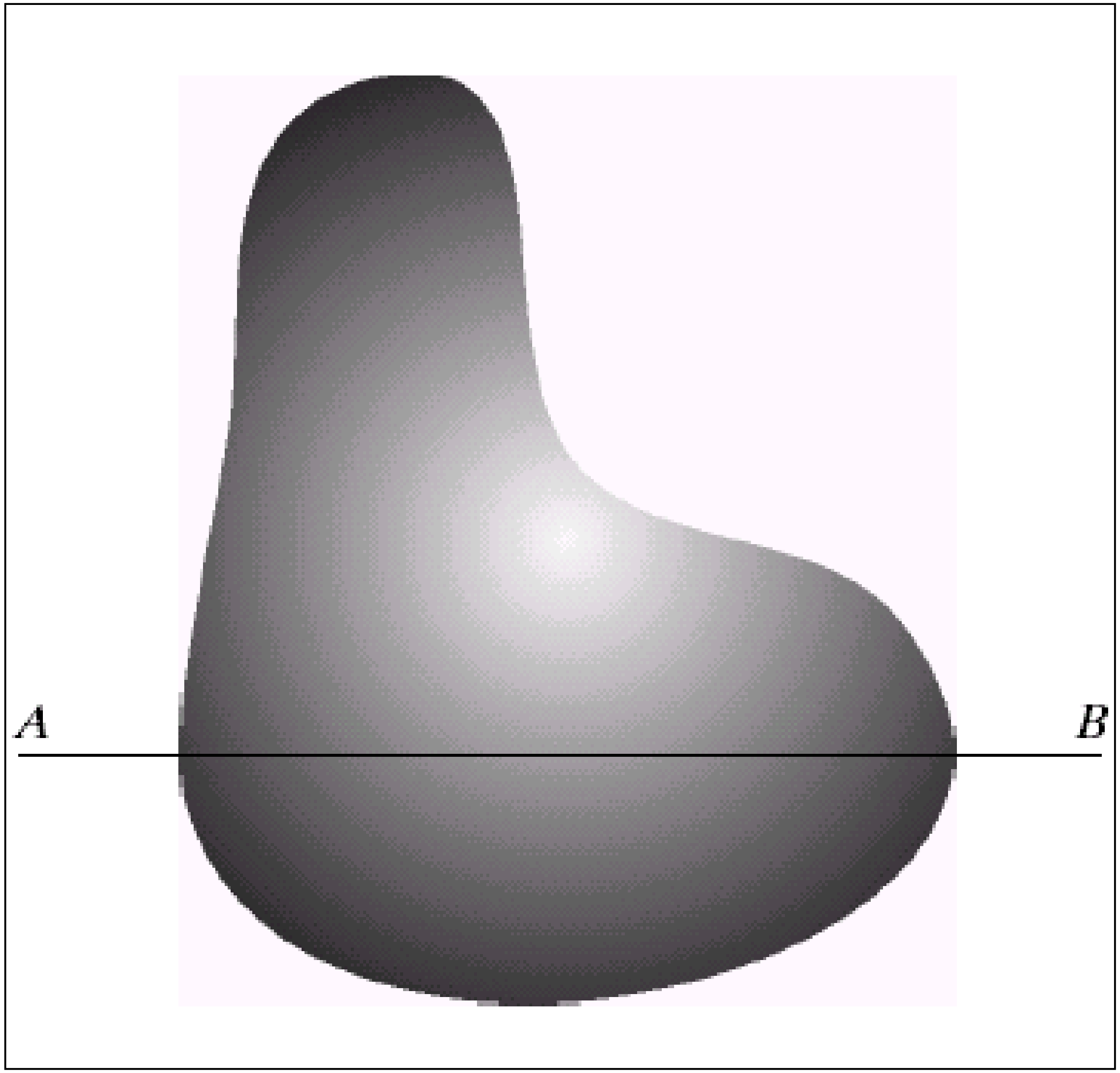

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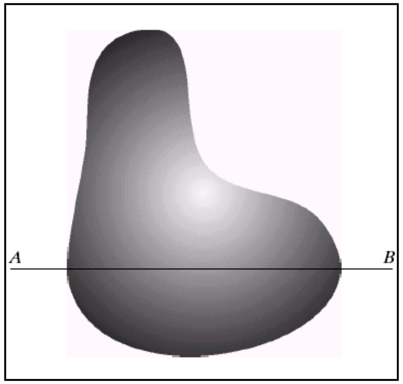
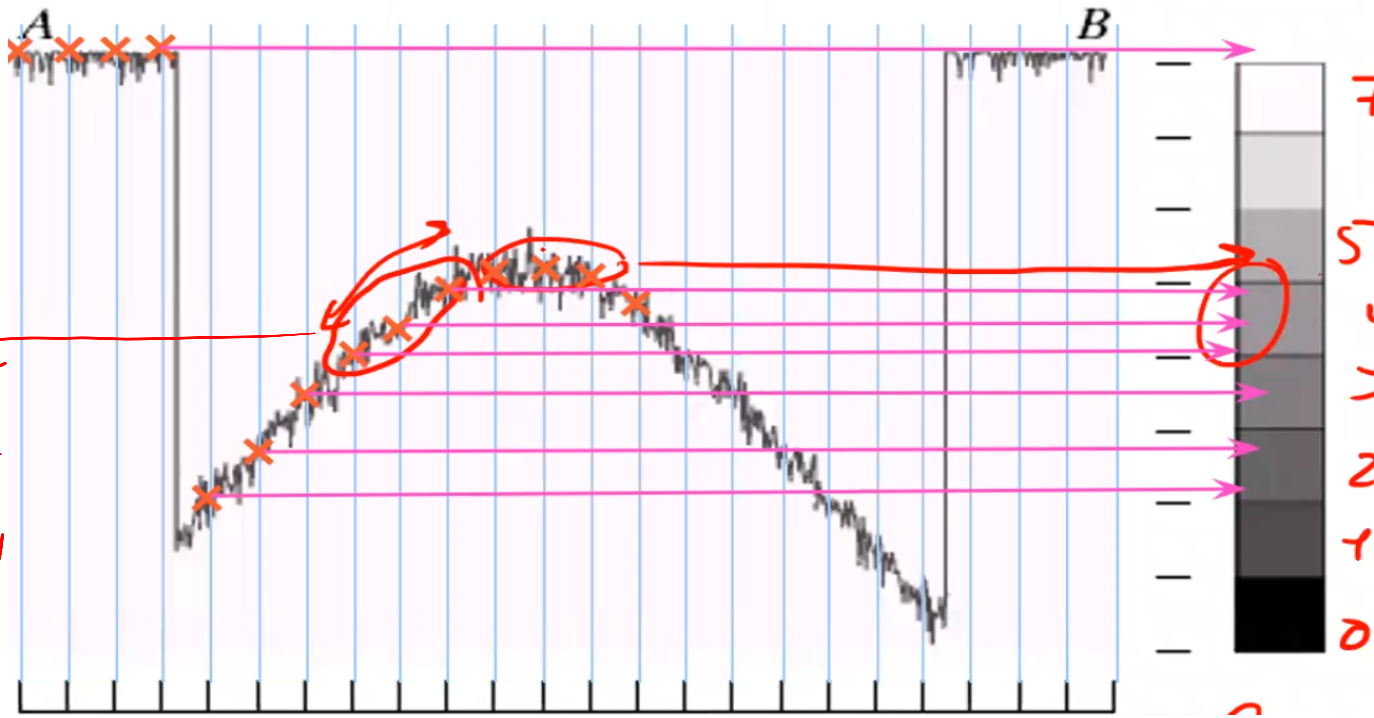
Image Sampling And Quantisation



3 bits → 8 levels



هون عندي 3 بكسلات ←
تصنفوا 4 عطاؤه عندي
عدد levels قليل بس 8
لكن ليسوا بنفس درجة اللون
يعني في variations بينهم

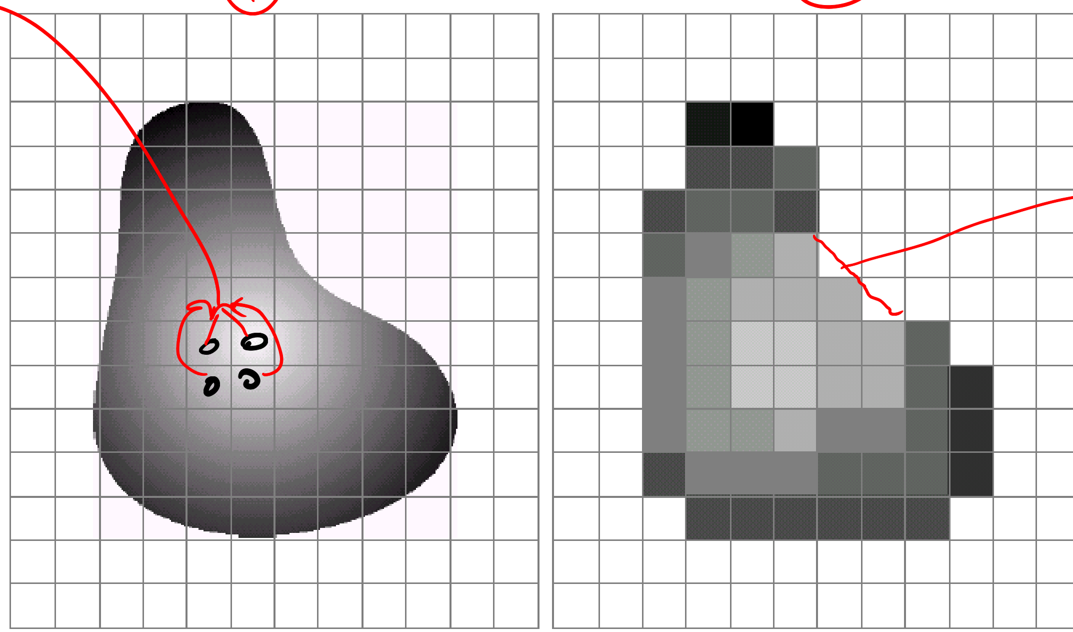
Sampling ← حددت كل كم بدي أقرأ

Quantization ← لشو بدي أقرأ؟ يعني القيمة ياللي بدي أقرأها

في بينهم variations لكن بسبب
ال Quan بنعملها mapping
على 4 level

Image Sampling And Quantisation (cont…)

- Remember that a digital image is always only an **approximation** of a real world scene



متلاحظ وجود اختلافات بالألوان لكن بسبب ال limited number of levels قرأت ال ٤ درجة واحدة

غياب التفاصيل هاي هو بسبب ال sampling

لو قللت ال size تاع ال sensor كان زادت ال resolution و زادت التفاصيل بالرسمة زي المنحنيات الي اختفت بالصورة 2

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Spatial Resolution

the sampling rate is proportional to the spatial resolution

- *The **spatial resolution*** of an image is determined by how sampling was carried out
- Spatial resolution simply refers to **the smallest discernible detail** in an image
  - Vision specialists will often talk about **pixel size** is inversly proportional to the spatial resolution
  - Graphic designers will talk about ***dots per inch*** **(DPI)**

Spatial Resolution (cont…)

resolution decreases

Images are from the Digital Image Processing textbook, see slide 7

Spatial Resolution (cont…)

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Spatial Resolution (cont…)

Images are from the Digital Image Processing textbook, see slide 7

Spatial Resolution (cont…)

Images are from the Digital Image Processing textbook, see slide 7

Spatial Resolution (cont…)

Images are from the Digital Image Processing textbook, see slide 7

Spatial Resolution (cont…)

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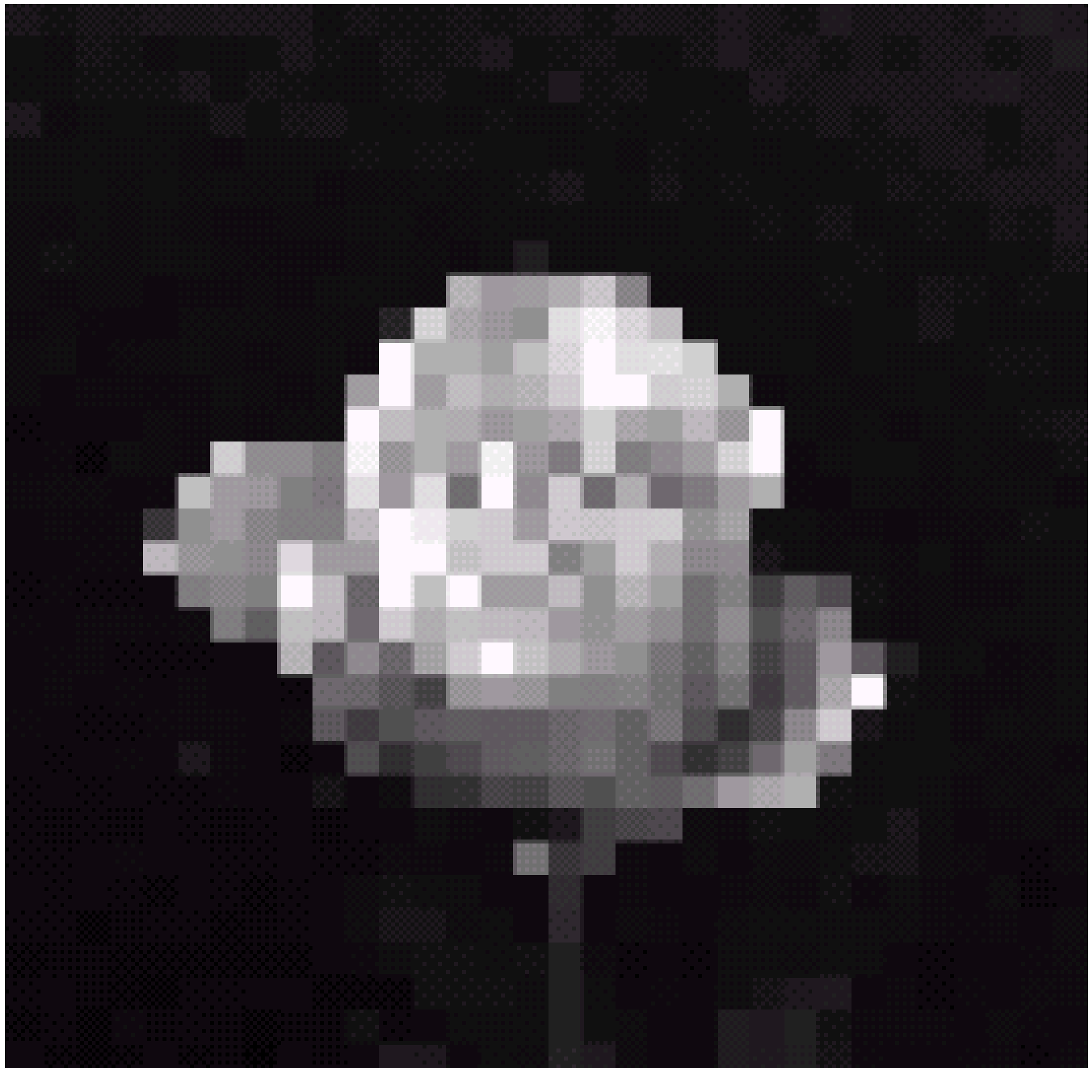
Spatial Resolution (cont…)



- **Very low resolution →**
- **Checkerboard effect**

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Spatial And Gray Level Resolution

- **An *L*-level image of size *M*×*N*** → spatial resolution
- **Spatial resolution**:
  - **Number of samples per unit** length or area. → Pixels
  - Dots Per Inch (DPI): specifies the size of an individual pixel.
- **Gray level resolution**:
  - **Number of bits per pixel**.
  - Usually 8 bits.
  - **Color image** has 3 image planes to yield 8 x 3 = 24 bits/pixel.
  - Too few levels may cause **false contour**.
- **Intensity resolution** refers to the smallest discernible change in intensity level.

Images are from the Digital Image Processing textbook, see slide 7

Intensity Level Resolution

- *Intensity level resolution* refers to the **number of intensity levels used to represent the image**
  - The more intensity levels used, the finer the level of detail discernible in an image
  - Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Number of Bits $= n$	**Number of Intensity Levels** $= 2^n$	**Examples**
1	$2^1 =$ 2	0, 1
2	$2^2 =$ 4	00, 01, 10, 11
4	$2^4 =$ 16	0000, 0101, 1111
8	$2^8 =$ 256	00110011, 01010101
16	$2^{16} =$ 65,536	1010101010101010

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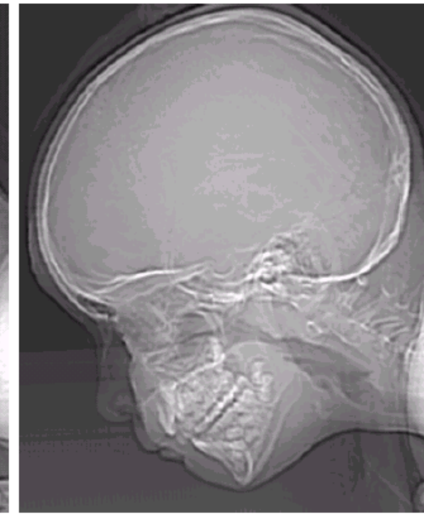
Intensity Level Resolution (cont…)

256 grey levels (8 bits per pixel)

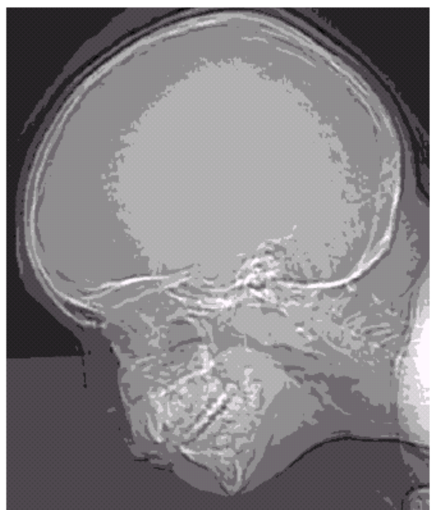
128 grey levels (7 bpp)

64 grey levels (6 bpp)

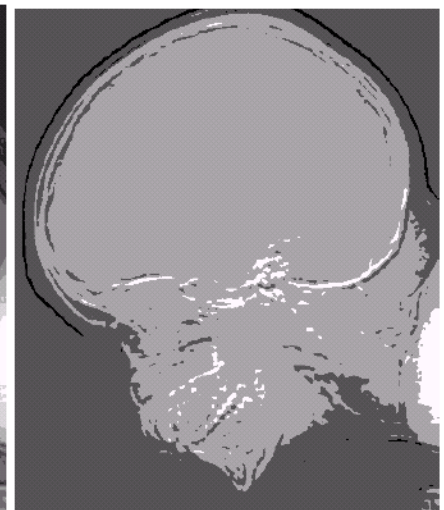
32 grey levels (5 bpp)



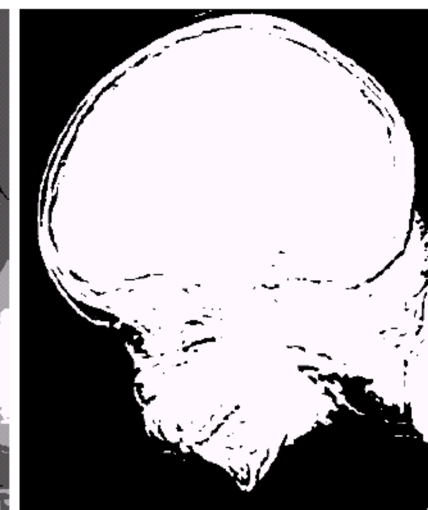
16 grey levels (4 bpp)



8 grey levels (3 bpp)



4 grey levels (2 bpp)



2 grey levels (1 bpp)

Intensity Level Resolution (256)

هون نلاحظ
إنه ظلنا نشوف
الأمواج بشكل ملاحظ
لإنه التدرج بالألوان أخف

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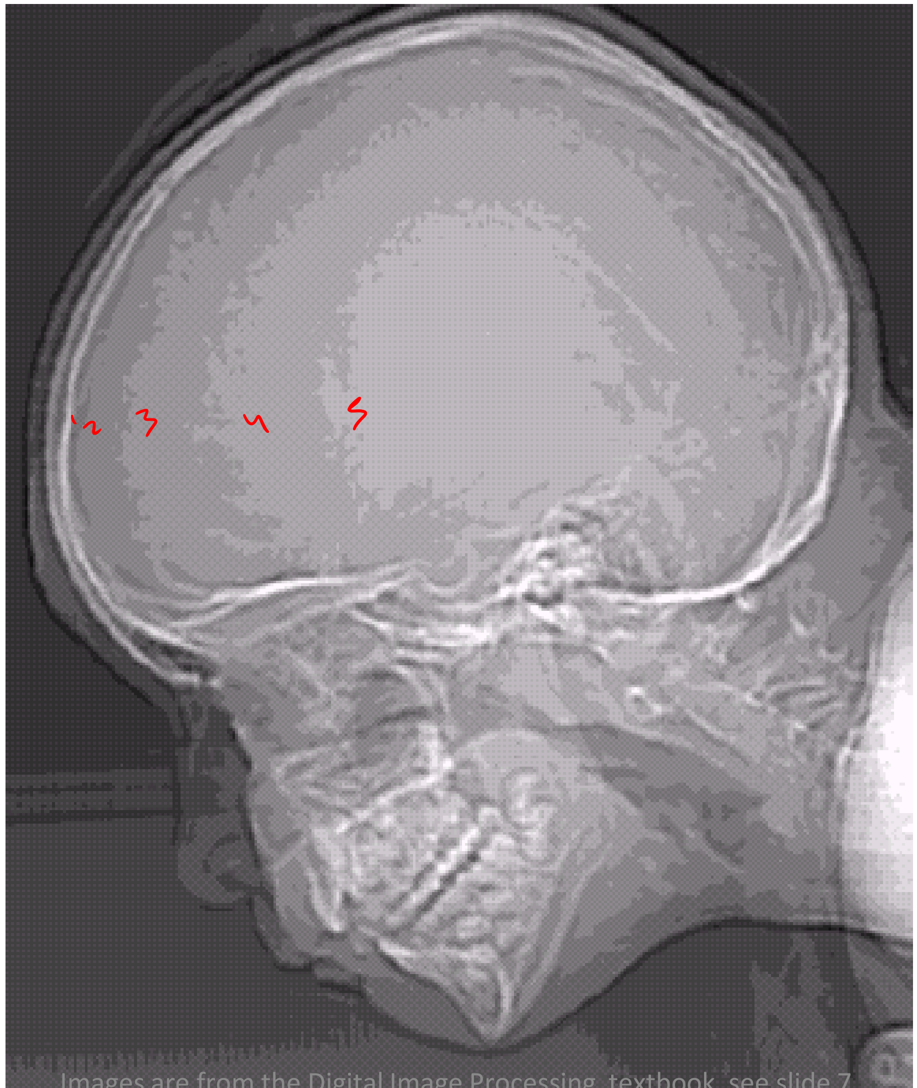
Intensity Level Resolution (128)

Intensity Level Resolution (64)

Intensity Level Resolution (32)

Intensity Level Resolution (16)



صرنا نشوف تفاصيل الأنف و الجبهة

Intensity Level Resolution (8)

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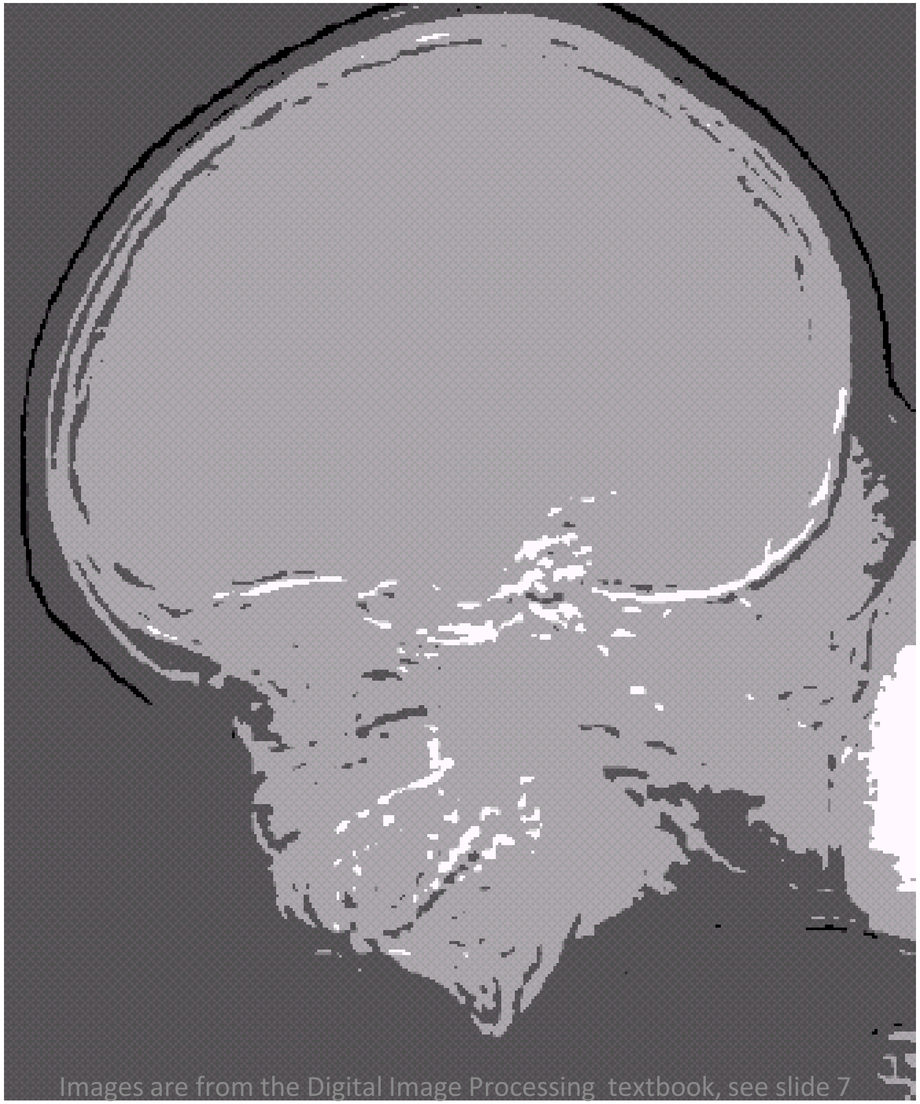
هون بلشت
تشوف عظام
الفك والرقبة

Intensity Level Resolution (4)

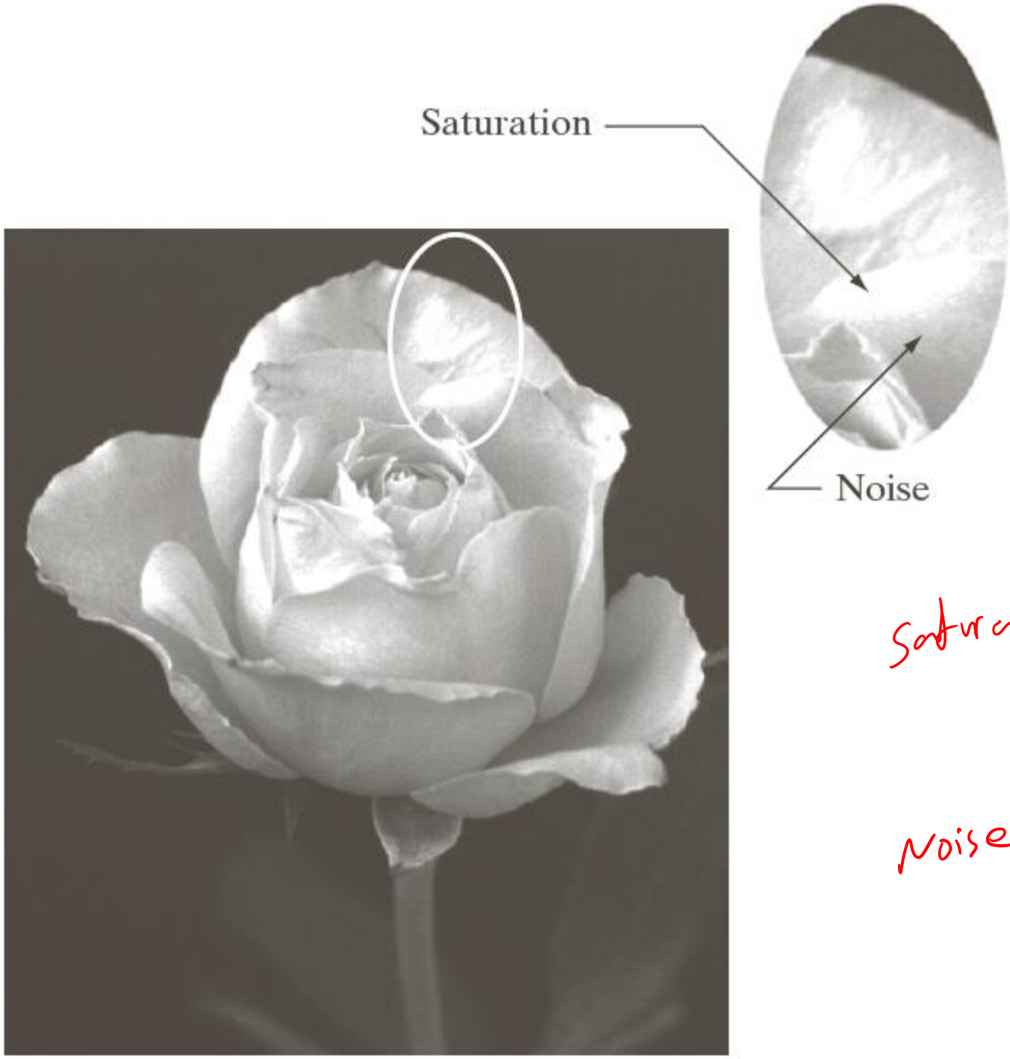


4 levels

Intensity Level Resolution (2)

2 levels

Saturation & Noise



Saturation white

Noise black

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Resolution: How Much Is Enough?

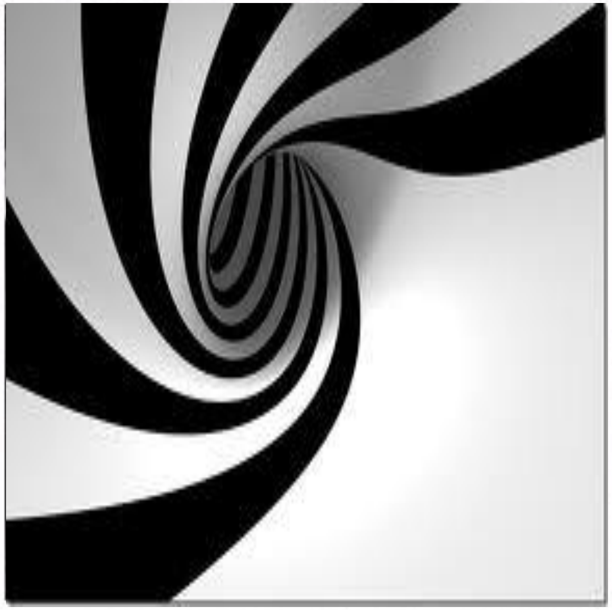
- The big question with resolution is always *how much is enough*?
  - This all depends on **what is in the image** and **what you would like to do with it**
  - Key questions include
    - Does the image look aesthetically pleasing?
    - Can you see what you need to see within the image?

Resolution: How Much Is Enough? (cont…)

can read

- The picture on the right is fine for counting the number of cars, but not for reading the number plate

Intensity Level Resolution (cont…)



Low Detail

Medium Detail

High Detail

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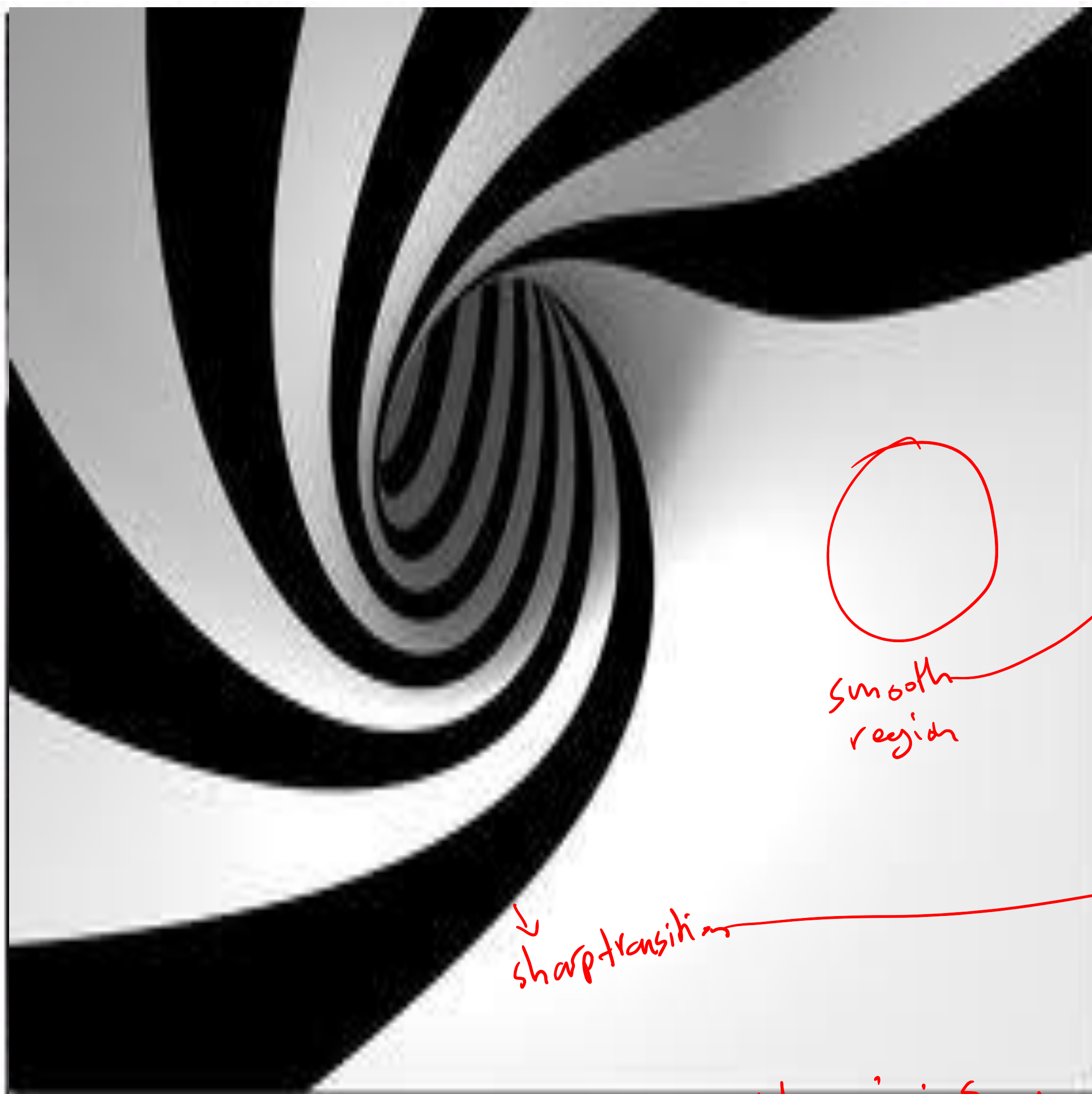
Intensity Level Resolution (cont…)



smooth region

لو قللت عدد ال levels تظهر مشكلة ال false contouring

sharp transition

في صورة مستحيل يظهر false co.... لأنه اصلا قليلة عدد ال levels مستحيل تكون في variation

Intensity Level Resolution (cont…)

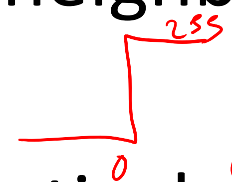
Images are from the Digital Image Processing textbook; see slide 7

Intensity Level Resolution (cont…)


Images are from the Digital Image Processing textbook, see slide 7

Nonuniform sampling

- For a fixed value of spatial resolution, the appearance of the image can be improved by using **adaptive sampling rates**.
- **Fine sampling** required in the neighborhood of sharp gray-level transitions.



to prevent checkerboard effect

- **Coarse sampling** utilized in relatively smooth regions.

Example

- An image with a **face** superimposed on a **uniform background**.
  - background
    - little detailed information
    - **coarse sampling** is enough
  - face
    - more detail
    - **fine sampling**

- If we can use adaptive sampling, the quality of the image is improved.
- Moreover, we should care more around the **boundary of the object**
  - **sharp gray-level transmission** from object to background.

Nonuniform quantization

مرتبط با (false contouring)

- Unequally spaced levels in quantization process influences on the decreasing the number of gray levels.

  – **Use few gray levels in the neighborhood of boundaries**. Why ? eye is relatively poor at estimate shades of gray near abrupt level changes.

  – **Use more gray levels on smooth areas** in order to avoid the "**false contouring**".

Summary

- We have looked at:
  - Human visual system
  - Light and the electromagnetic spectrum
  - Image representation
  - Image sensing and acquisition
  - Sampling, quantisation and resolution

- Next time we start to look at techniques for image enhancement