CS370 Computer Imaging

The Fundamentals

Recap

- What is Digital Image?
- What is Digital Image Processing (DIP) ?
- 3-Levels of Processing an Image
- Electromagnetic Spectrum
- DIP Applications
- Key Stages of DIP

Lecture Objectives

- Goal of Image Processing
- Human Visual System
- Image Acquisition
- Digital Image Representation
- Image Sampling And Quantisation
- Image Resolution

Goal of Image Processing

- Create images that look "good".
- What does the phrase "look good" imply?
  - One man's good image may be another's trash!
- **Subjective** vs **Objective**

Which One “Looks Good?”

A

B

Which One “Looks Good?”

A

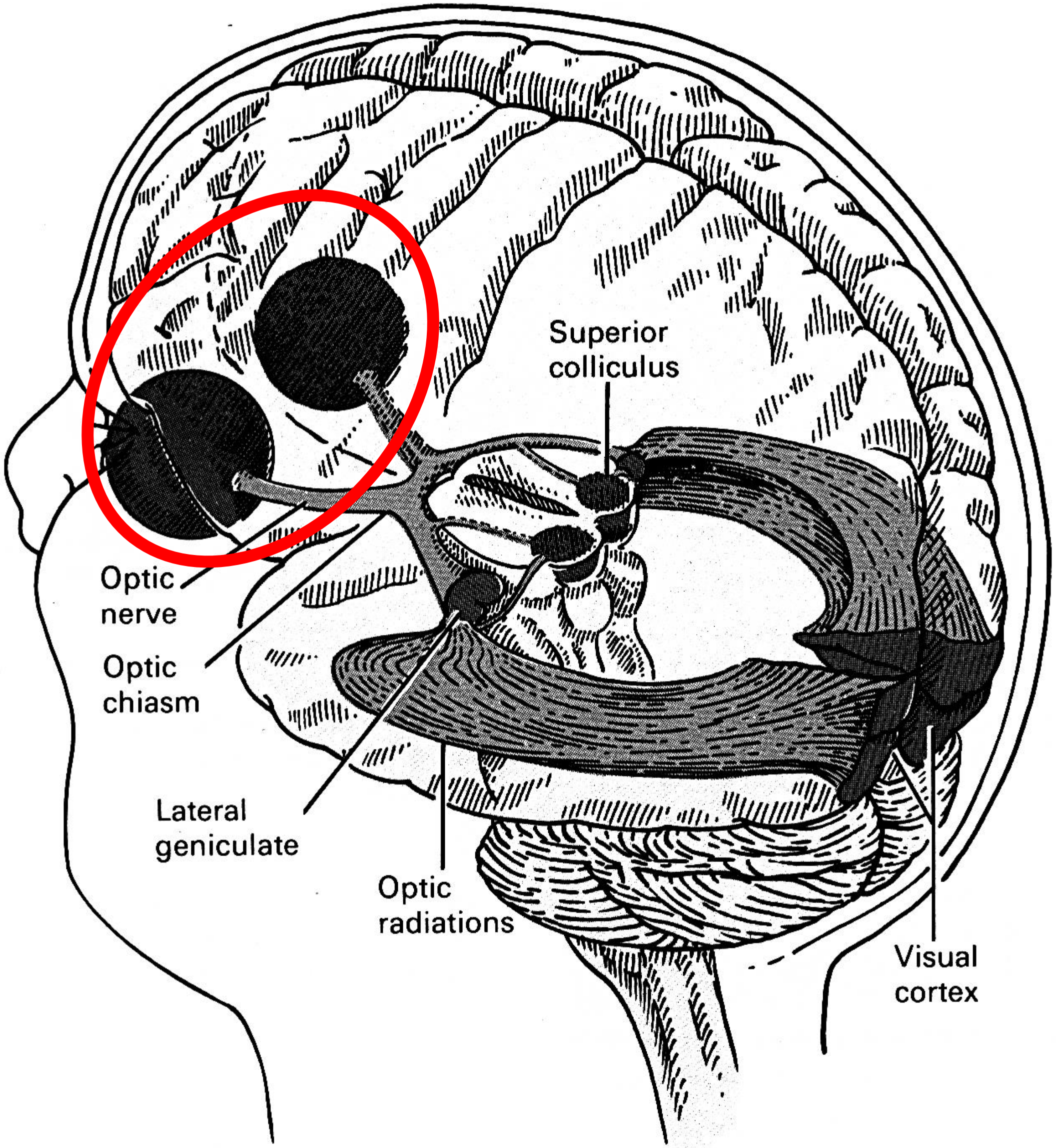
B

Goal of Image Processing

- VERY IMPORTANT TO REMEMBER
  - Image Processing quality assessment is largely **subjective** process.
  - **Typical mechanism**: come up with a mathematical model/algorithm/process that makes the image **appear desirable to the human observer.**

How are Images Formed?

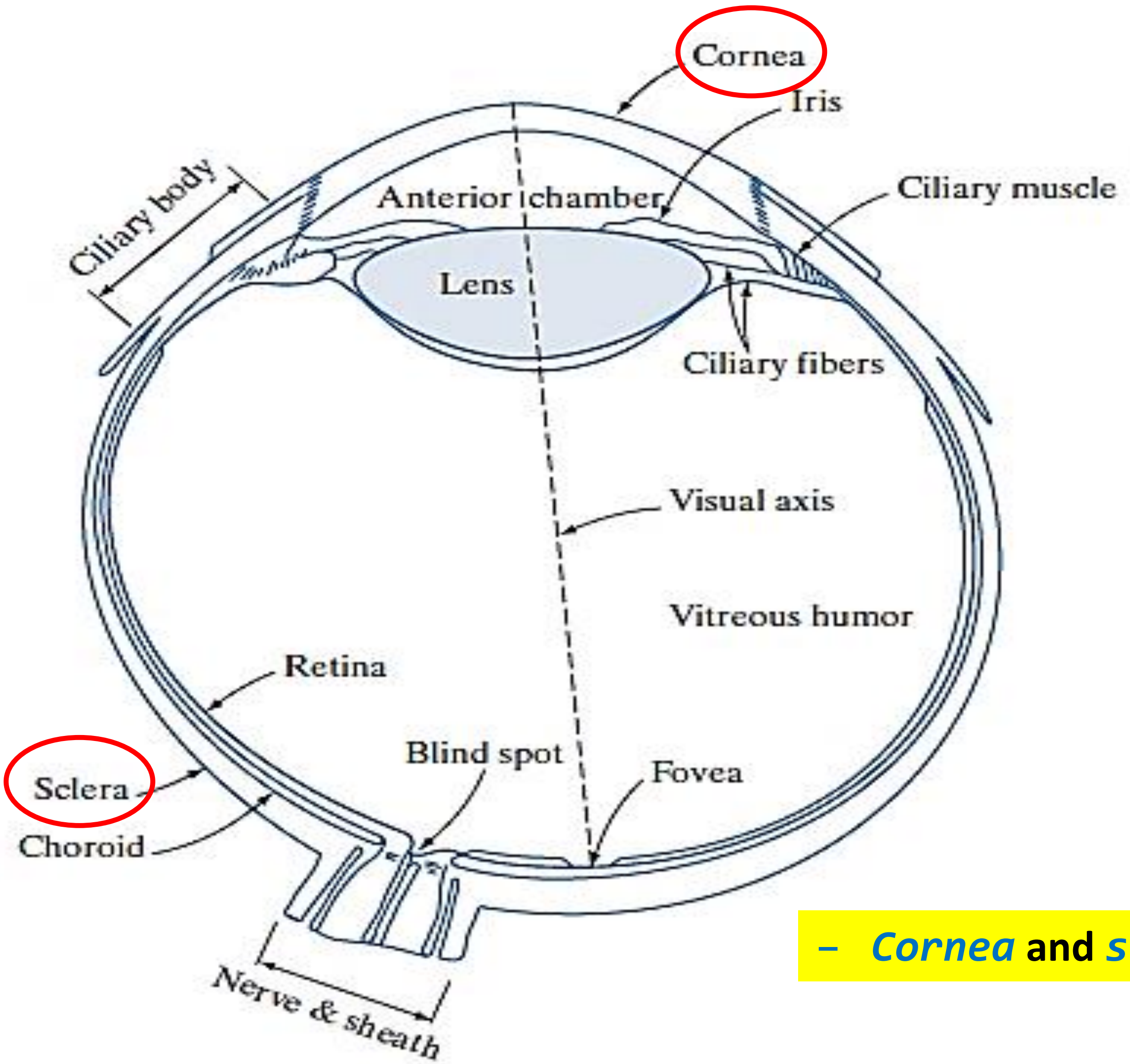
Human Visual System



Human Visual System

- The eye is nearly a sphere (with a diameter of about 20 mm) enclosed by **three membranes**:
  - *Cornea* and *sclera*, the outer membrane
  - *Choroid*, the middle membrane
  - *Retina*, the inner membrane

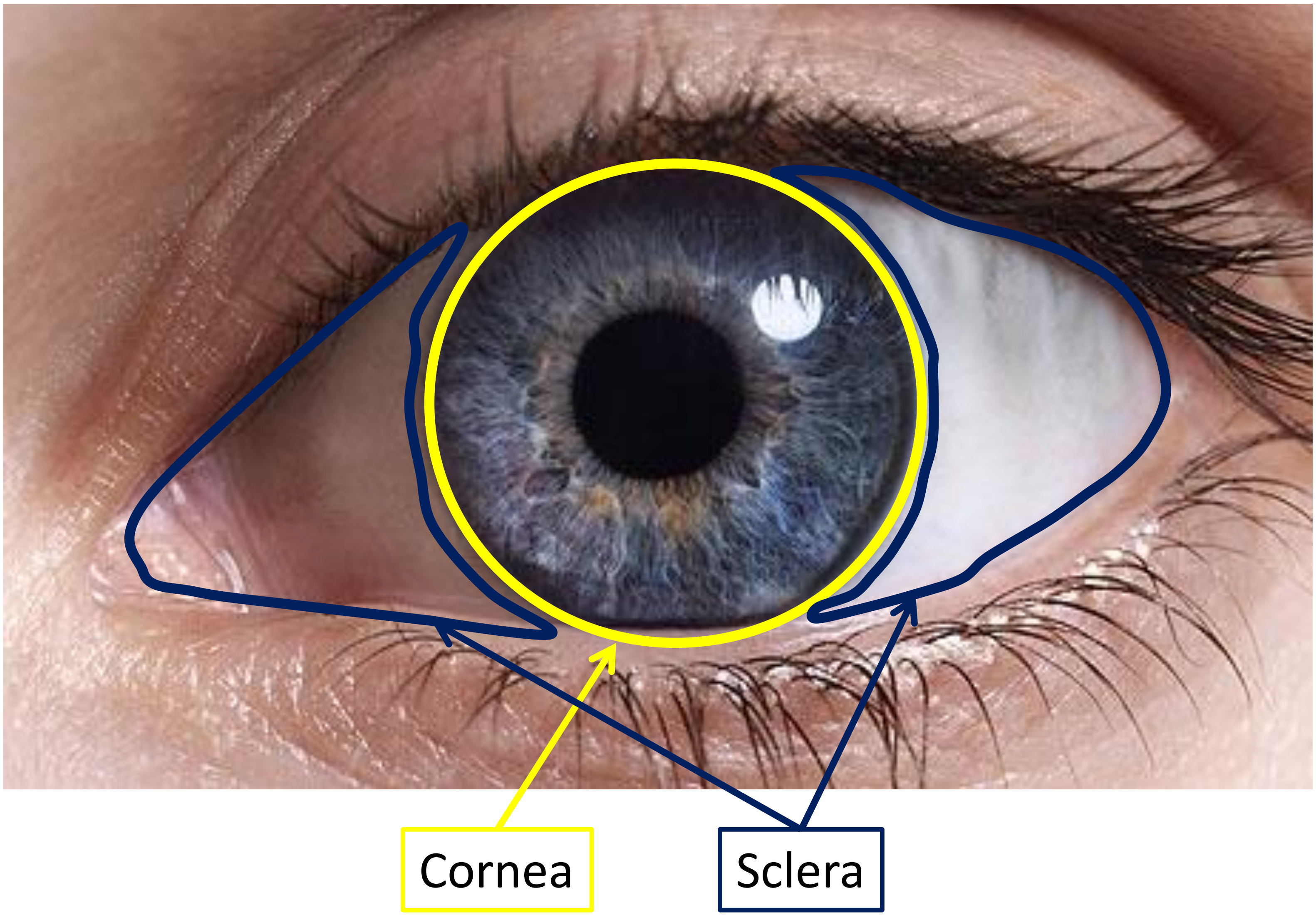
Human Visual System



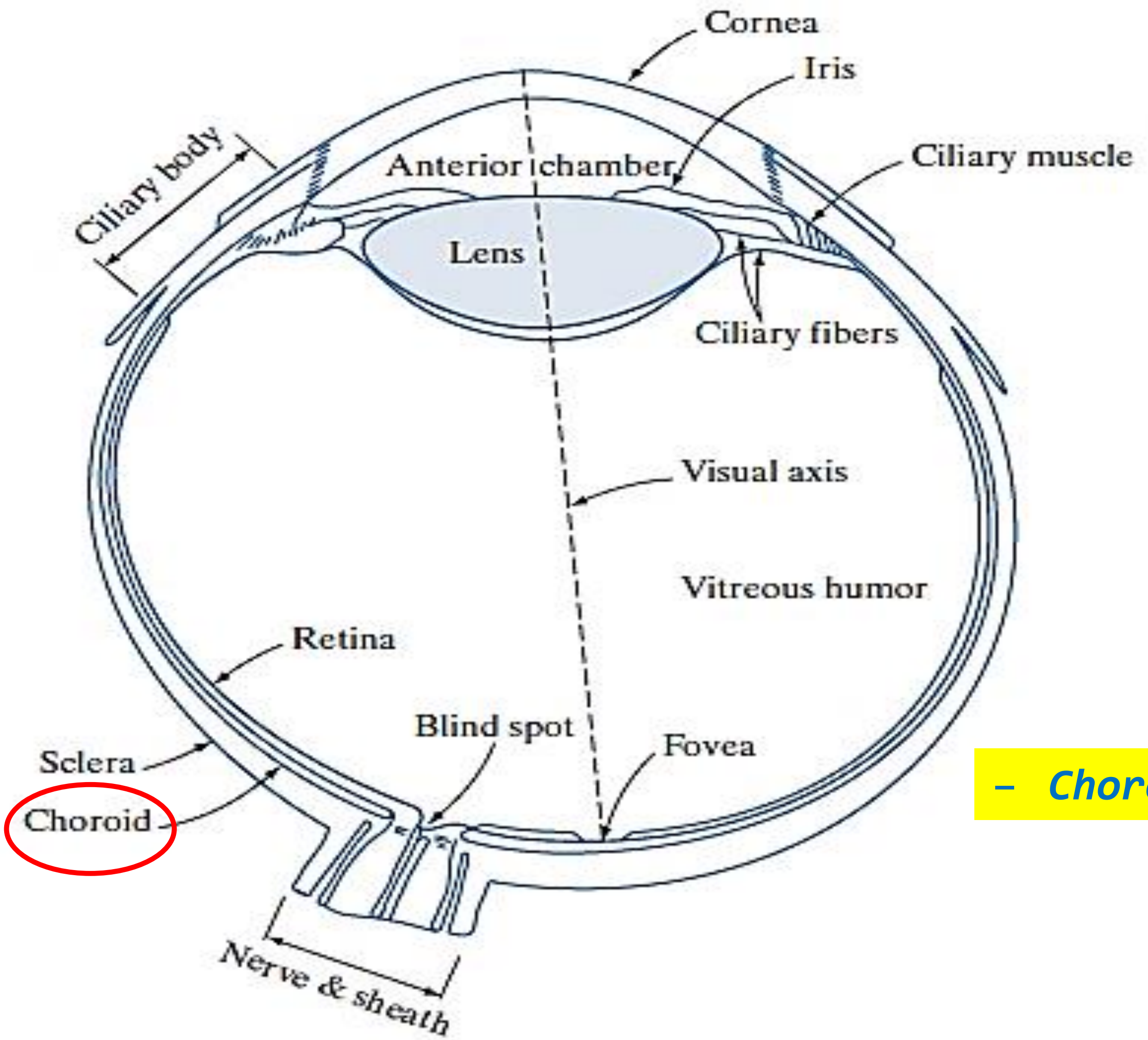
– *Cornea* and *sclera*, **the outer membrane**

Cornea contributes most of the eye's **focusing power**, its focus is fixed.

Human Visual System



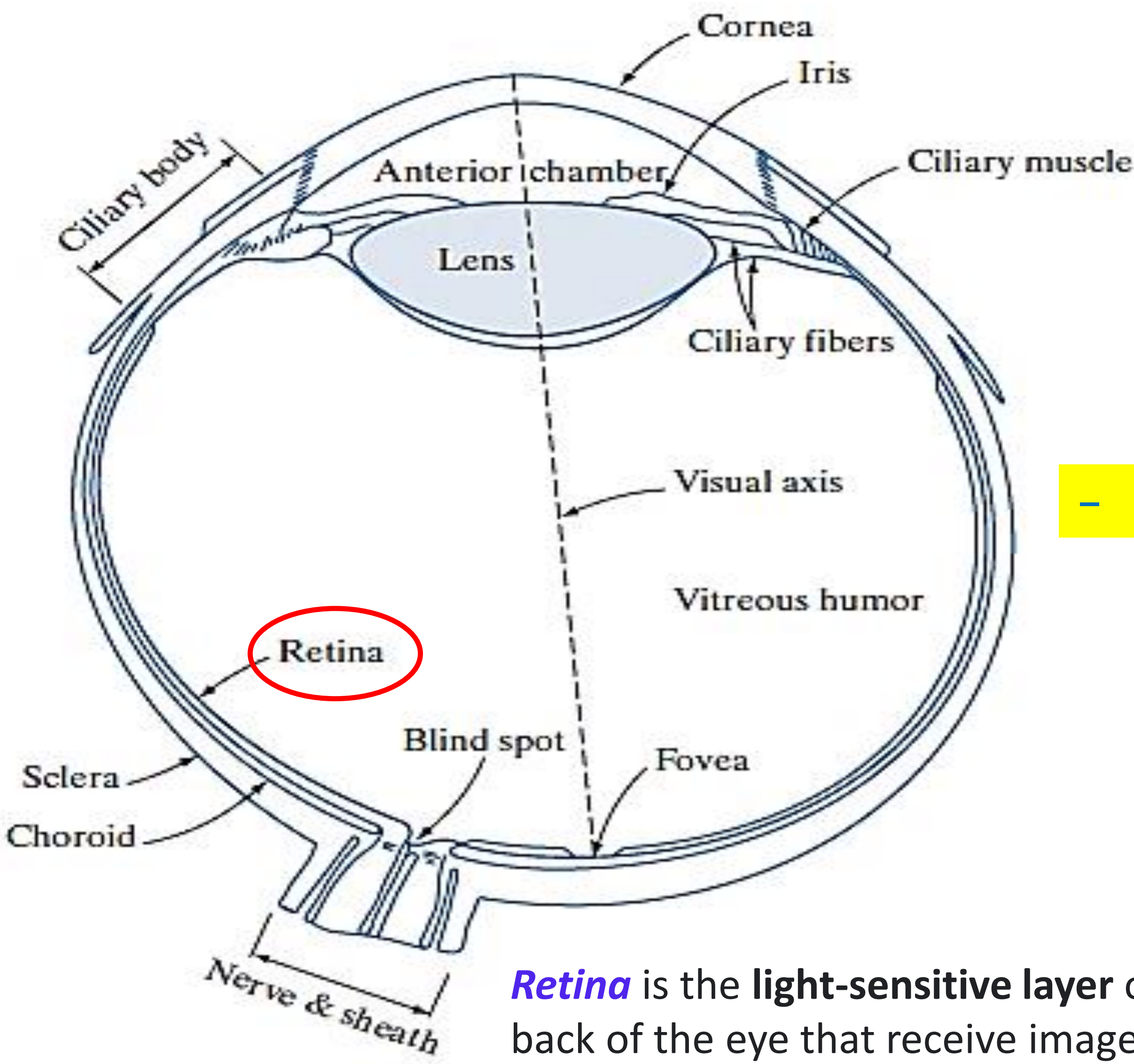
Human Visual System



– ***Choroid*, the middle membrane**

Choroid contains a **network of blood vessels** that serve as the major source of nutrition to the eye.

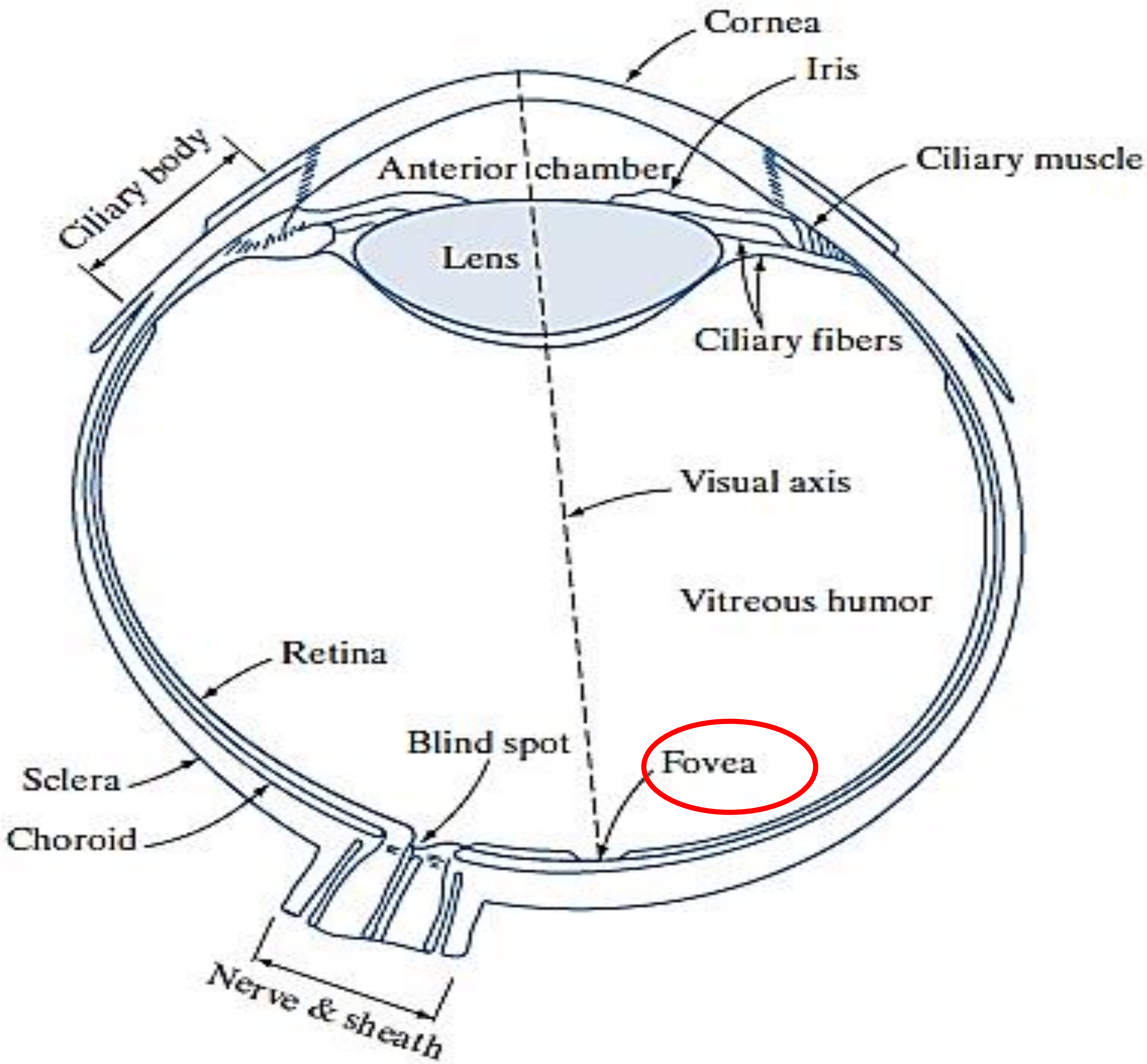
Human Visual System



– *Retina*, **the inner membrane**

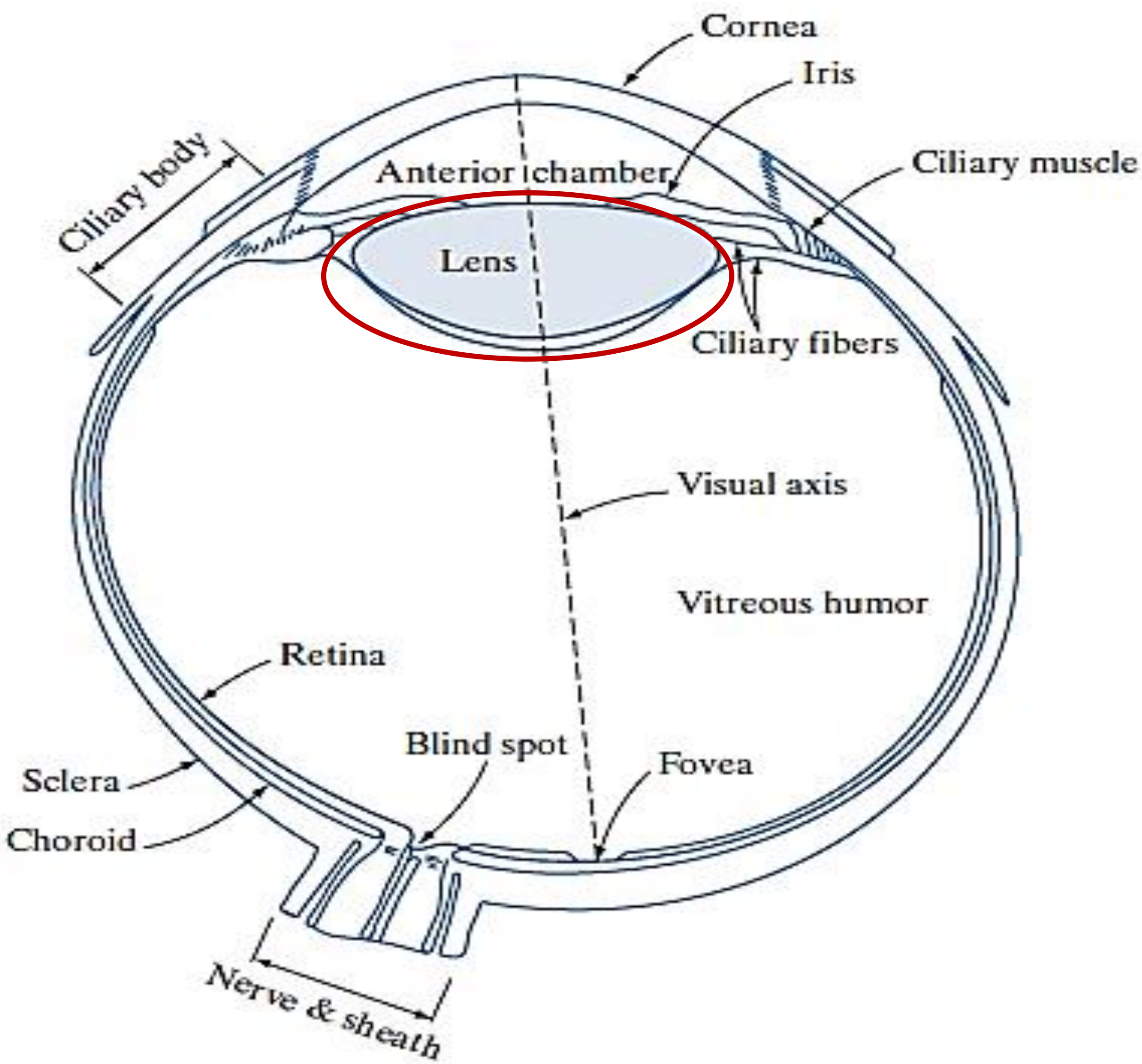
Retina is the **light-sensitive layer** of photoreceptor cells at the back of the eye that receive images and sends them as electric signals through the optic nerve to the brain.

Human Visual System



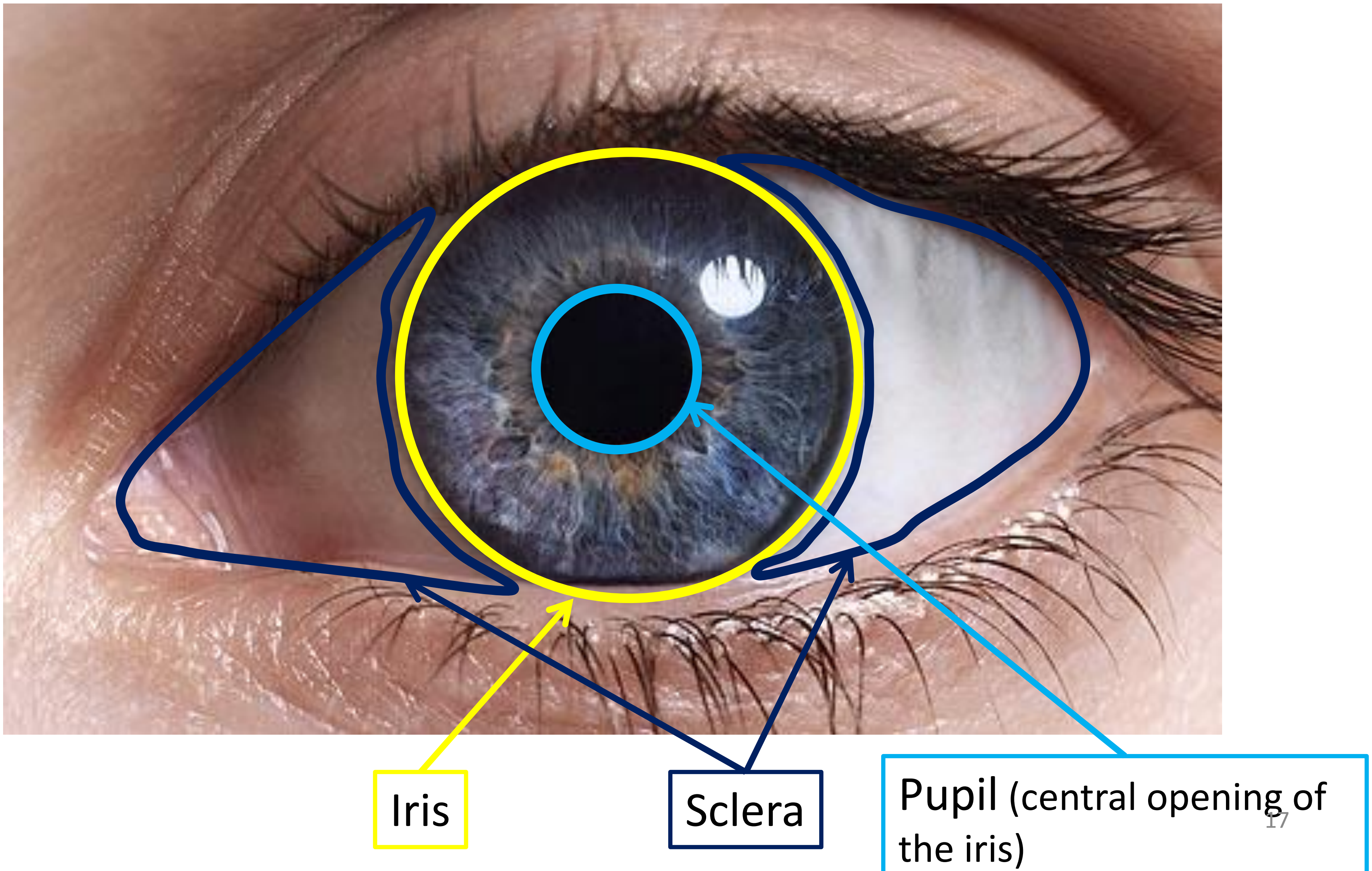
Fovea, is a **small depression** at the center of the retina where visual acuity is the highest.

Human Visual System

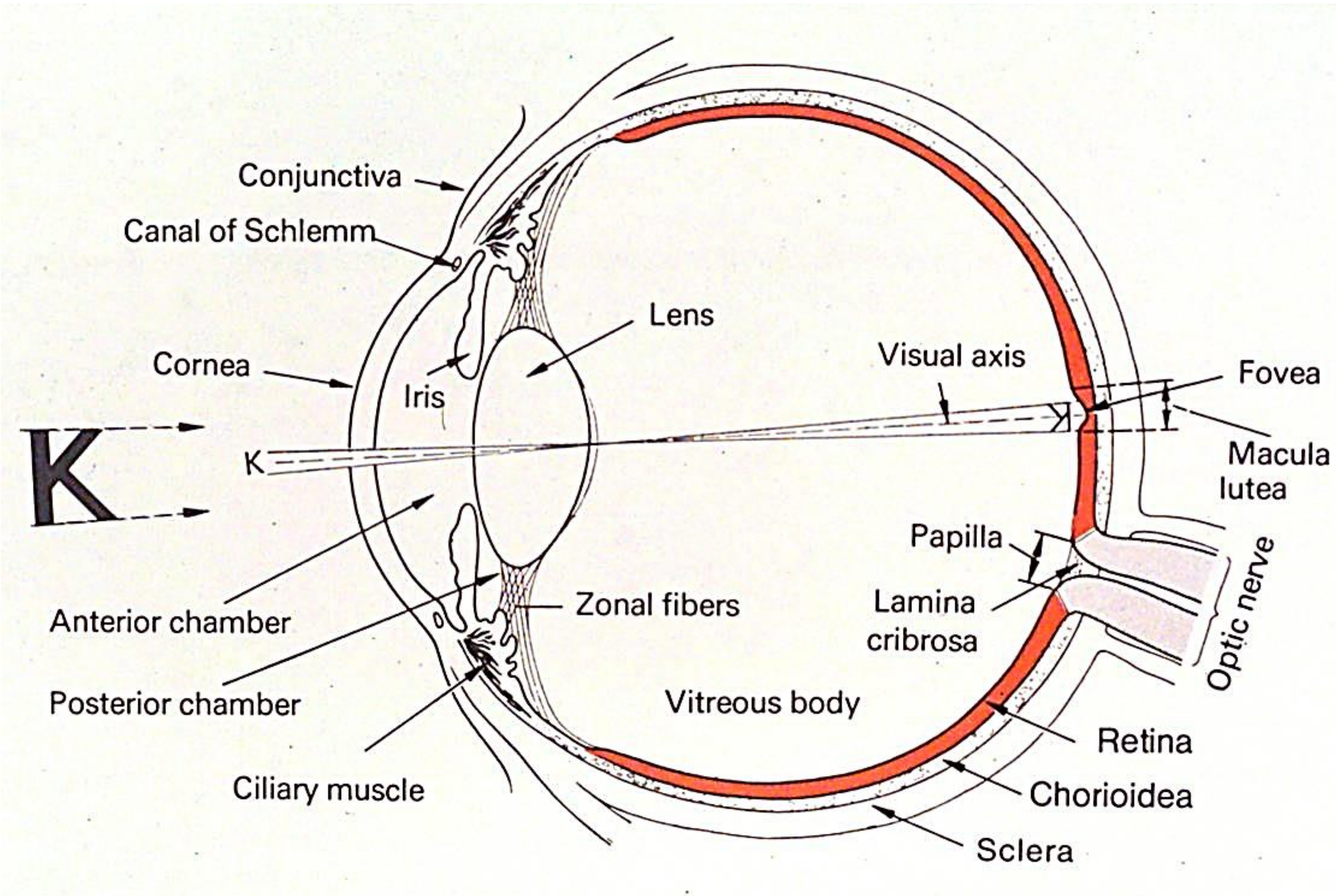


Lens is a nearly transparent biconvex structure suspended behind the iris of the eye whose sole function is to **focus light rays onto the retina**.

Human Visual System



Human Visual System

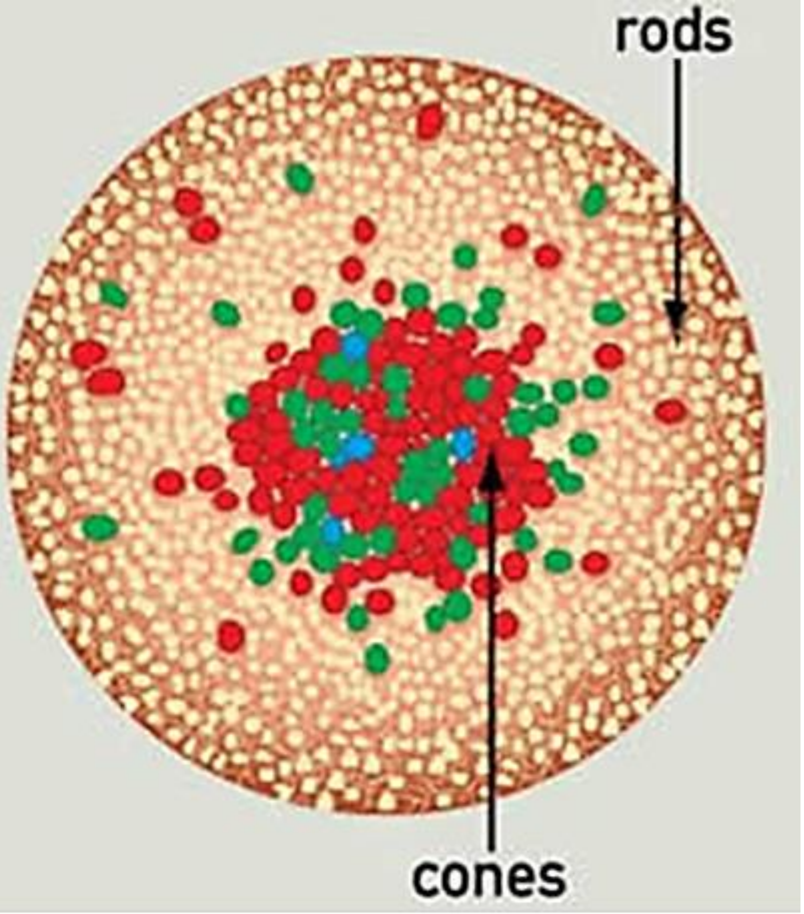


Visual Perception

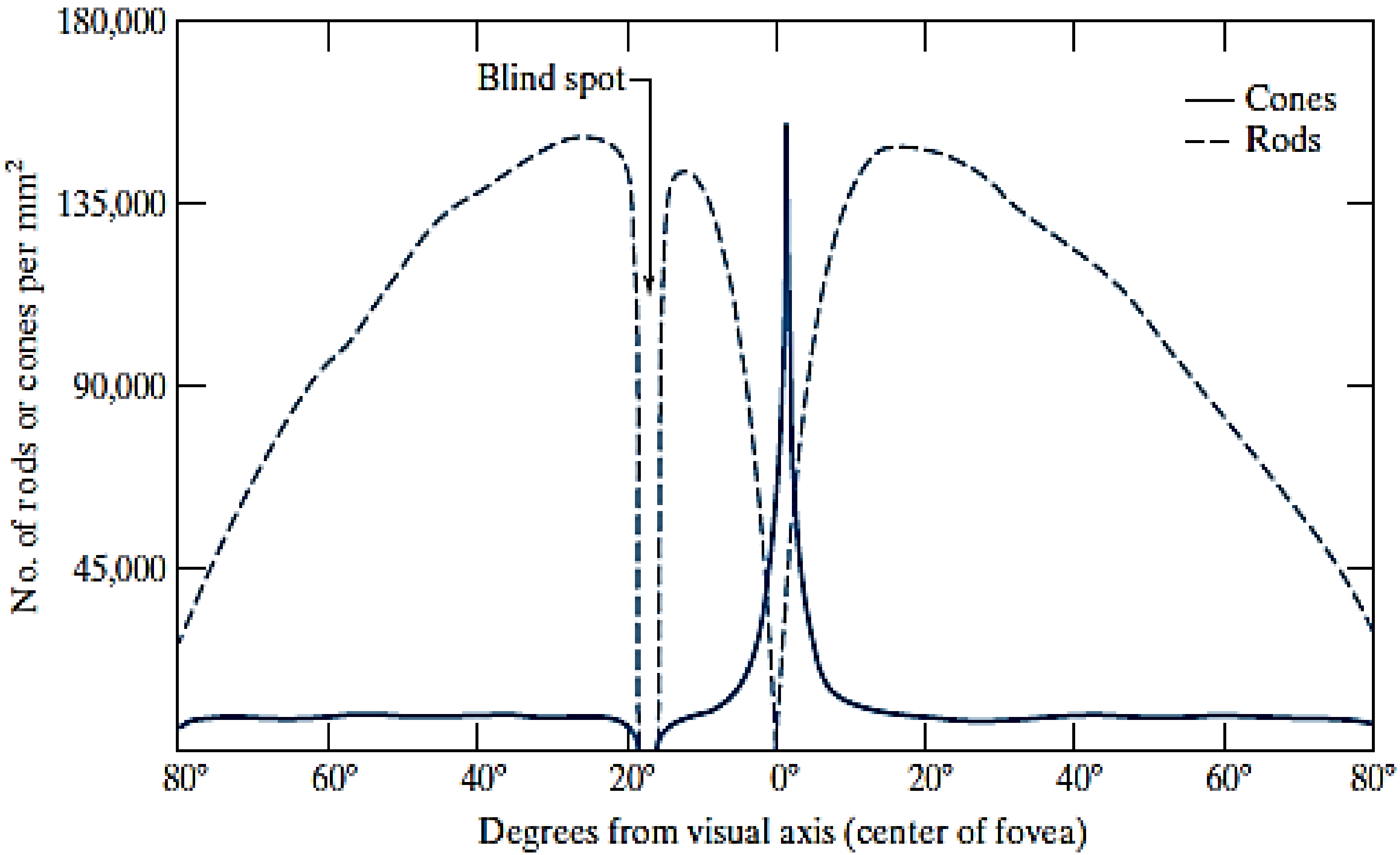
- The retina is covered with **photoreceptor cells** called **cones** (6-7 million) and **rods** (75-150 million).

- **Cones** are concentrated around the **fovea** and are very sensitive to colour.

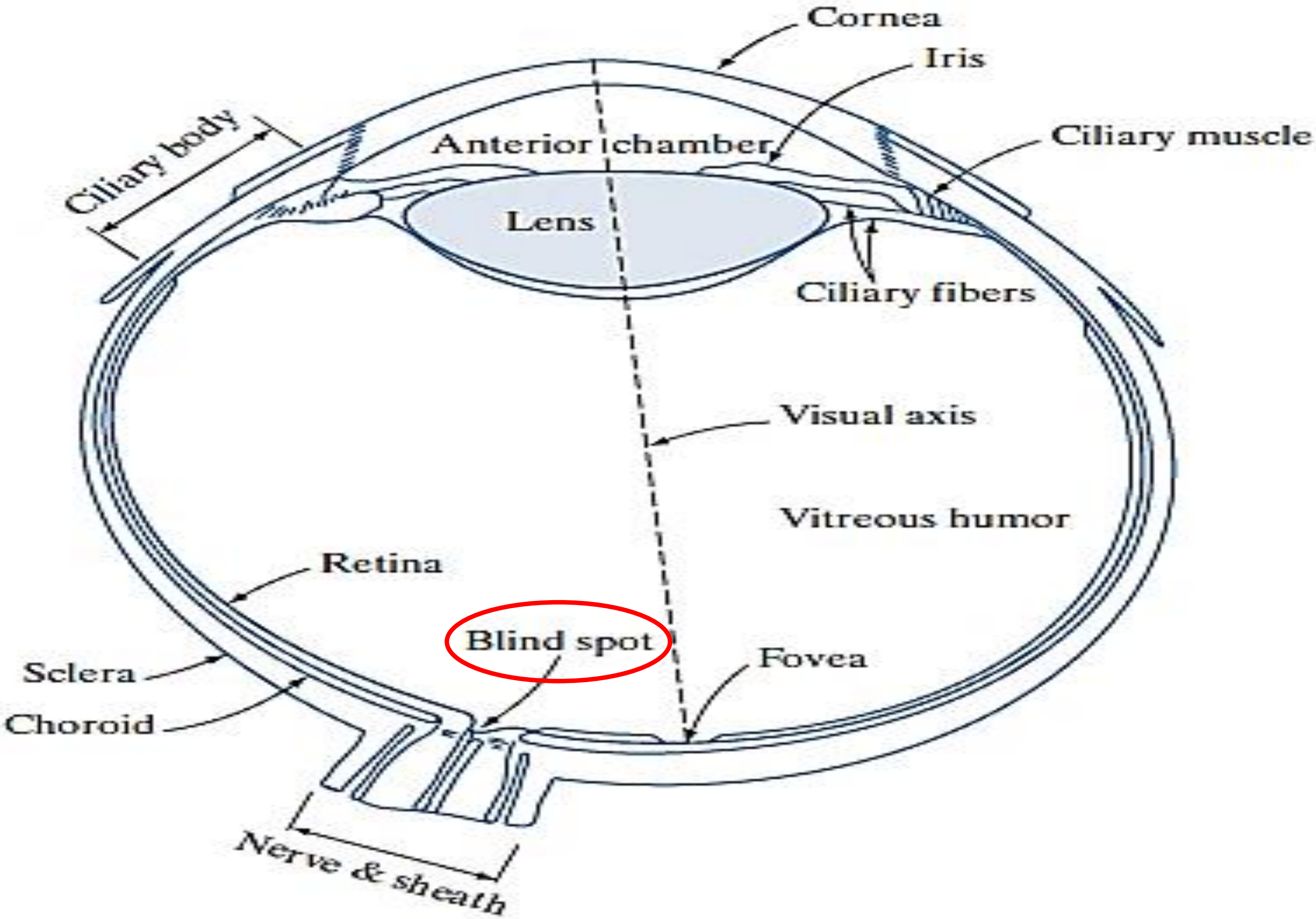
- **Rods** are more spread out and are sensitive to low levels of illumination.



Visual Perception



Visual Perception



Day v.s. Night Vision

Objects identified by color

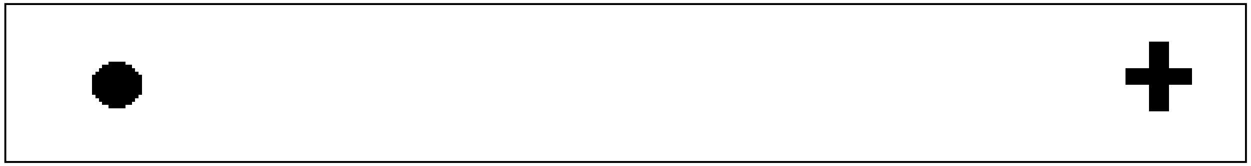
Cones are activated

Objects identified by shape

Rods are activated

Blind-Spot Experiment

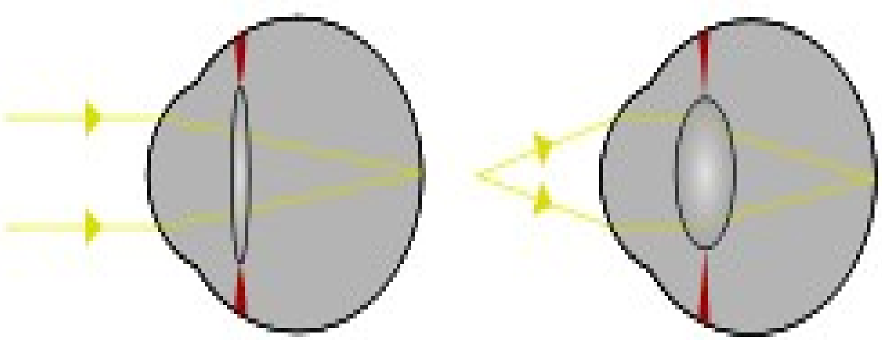
- Draw an image similar to that below on a piece of paper (the dot and cross are about **15 cm** apart).

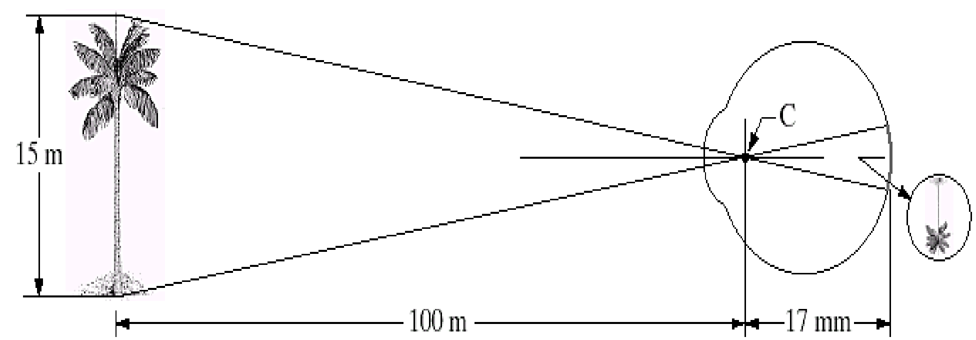


- Close your right eye and focus on the cross with your left eye.
- Hold the image about 50 cm away from your face and move it slowly towards you.
- The dot should disappear!

Image Formation In The Eye

- Muscles within the eye change the **shape of the lens** allowing us to focus on objects that are near or far away.

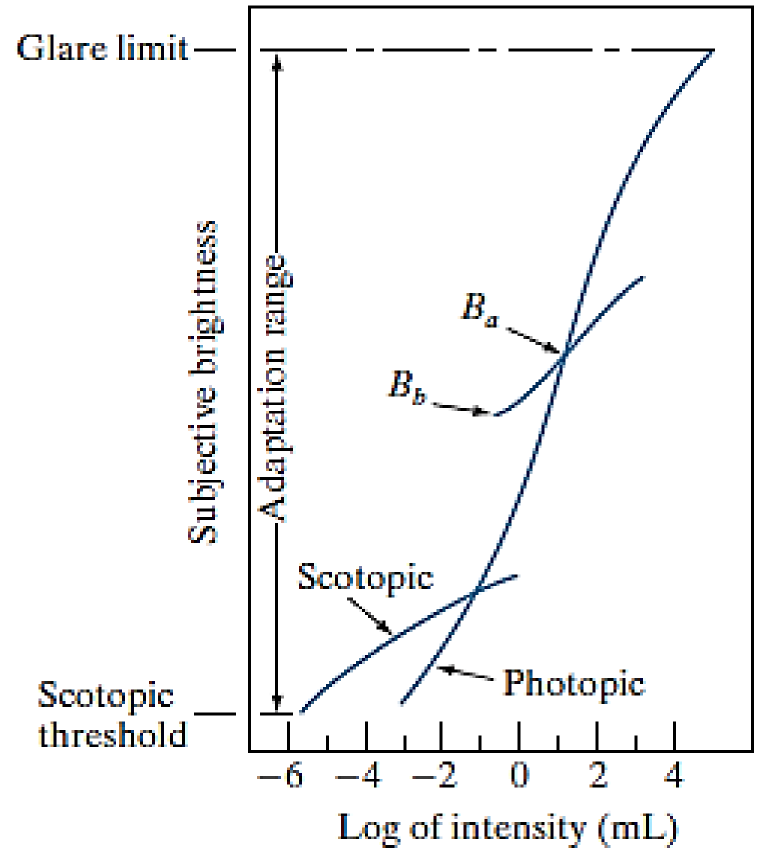




- An image is focused onto the **retina** causing **rods** and **cones** to become excited which ultimately send signals to the brain.

Visual Response - Brightness Adaptation

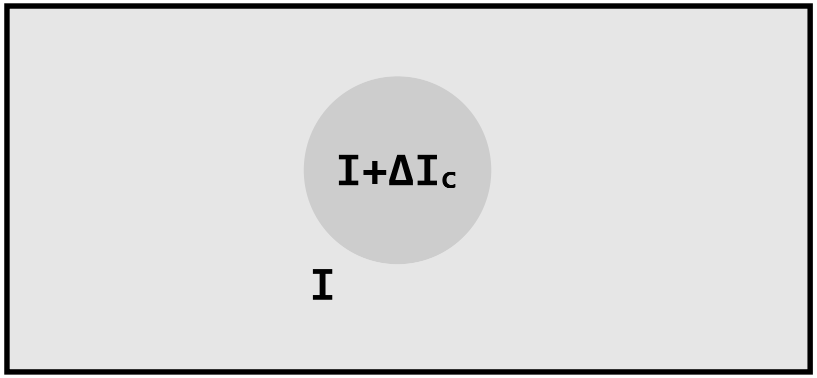
- **Intensity levels discrimination** by the eye is crucial to image understanding.
- Actual dynamic range of the **human eye adaptation** is in the order of 10^{10} from scotopic threshold to glare limit.
- **Essential point**: The human visual system **cannot** operate on the entire dynamic range *simultaneously*.
- **The process of gradually changing the overall sensitivity of the human visual system to adapt to the different intensities in the adaptation range is known as brightness adaptation.**



B_a: Brightness adaptation level
B_b: Bottom threshold for discernible intensities

Scotopic vision uses only **rods** to see, meaning that objects are visible, but appear in black and white, whereas **Photopic vision** uses **cones** and provides color.

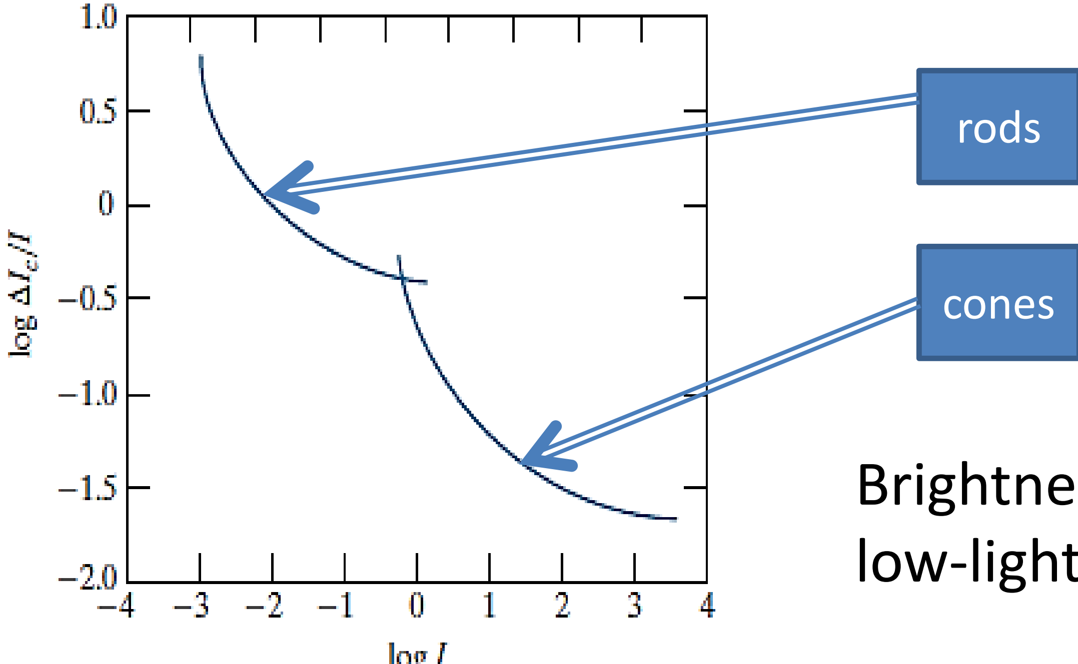
Brightness Discrimination Test



I – light source

ΔI_c – increment of illumination

The quantity $\Delta I_c/I$ which is discriminable **50%** of the time with background illumination **I**, is called the ***Weber Ratio*** (small value represents good brightness discrimination).



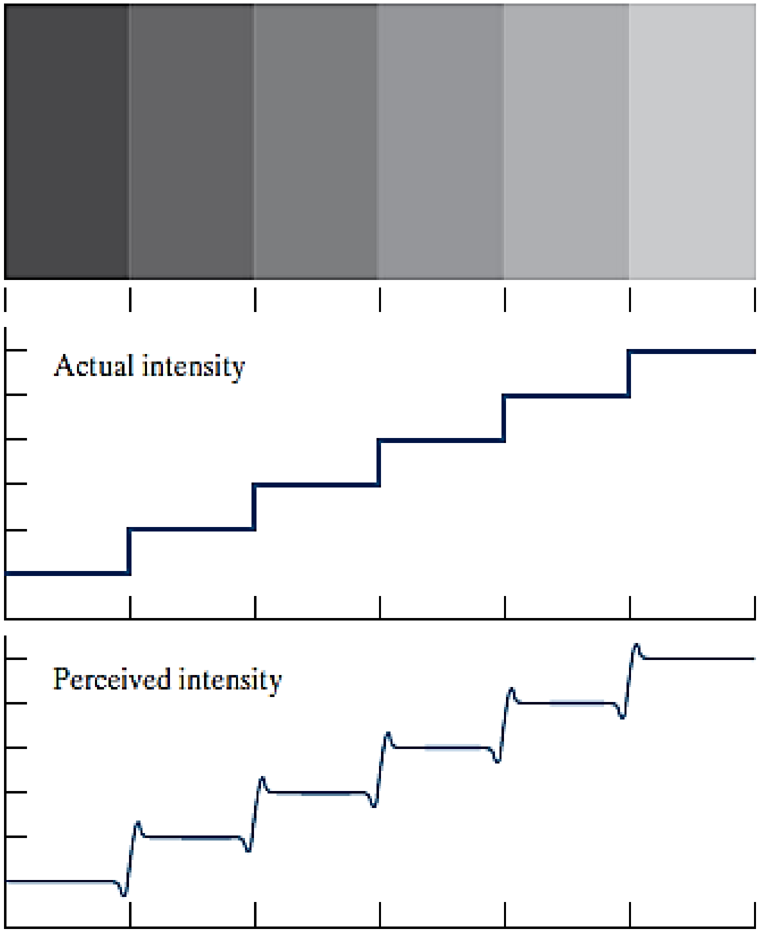
Brightness discrimination is poor in low-light conditions

Intensity Perception

Two phenomena demonstrate that perceived brightness is not a simple function of intensity:

- The **first phenomenon** is based on the fact that the visual system tends to undershoot or overshoot around the boundary of regions of different intensities.

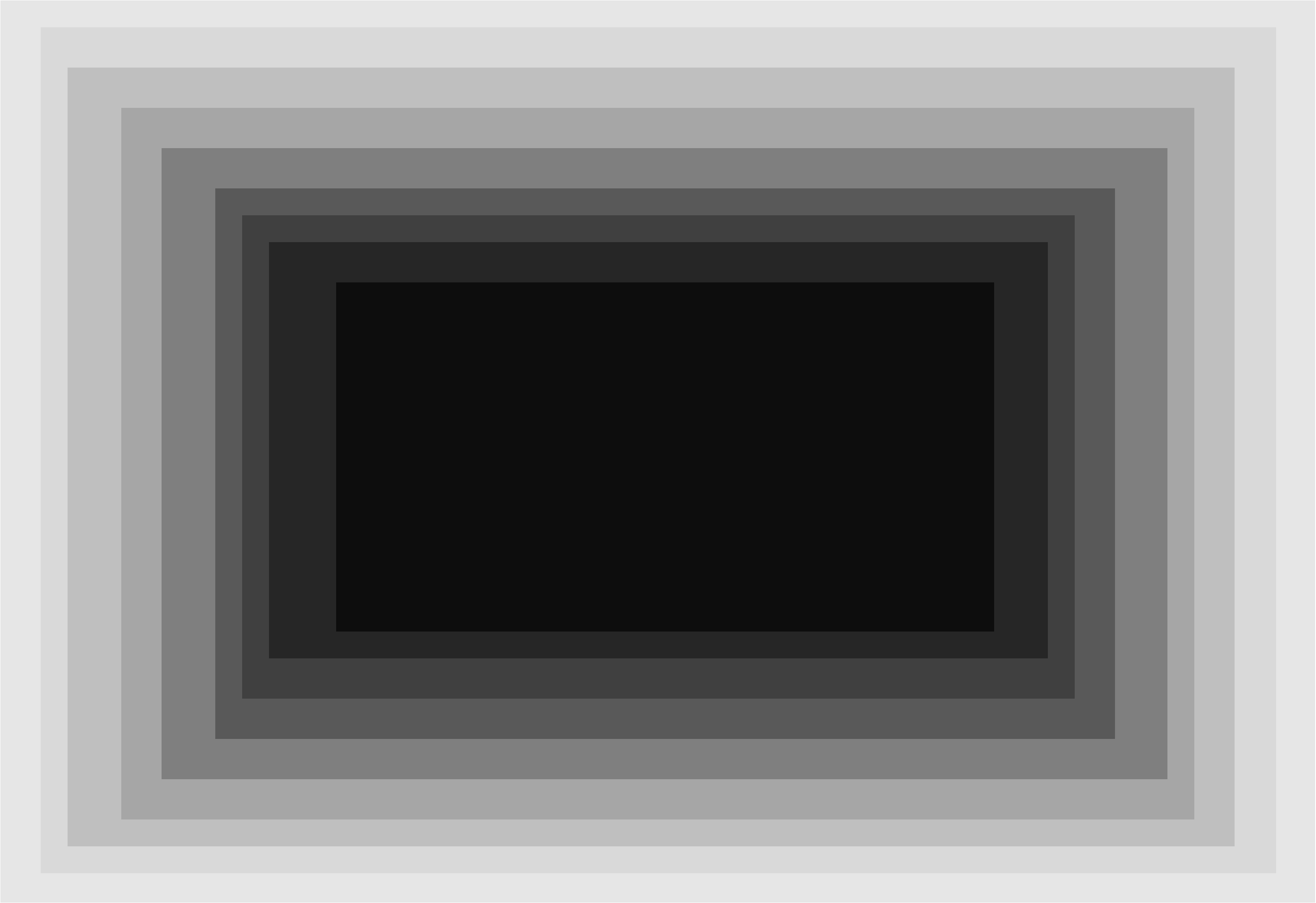
- The color of the individual bands appears **lighter** near its left edge and **darker** near its right edge due to the contrast with it's neighboring patch.



Mach bands

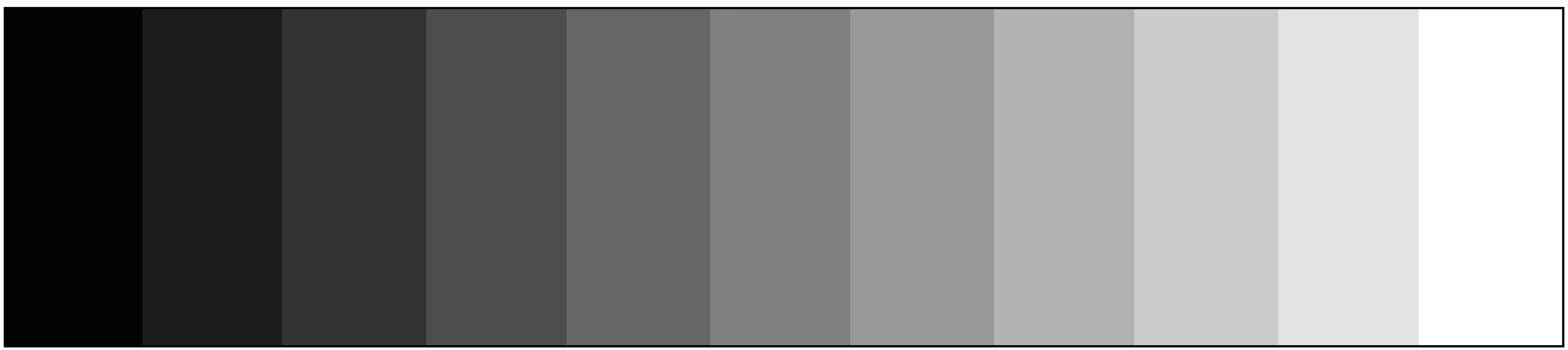
Intensity Perception

first phenomenon



Intensity Perception
first phenomenon

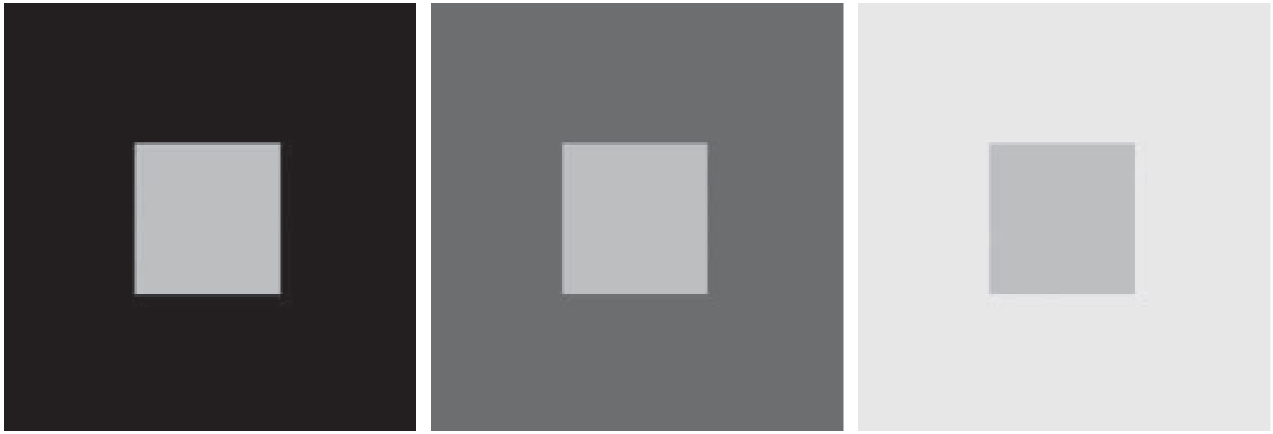
- A typical observer can discern **12-24** different intensity changes



Mach bands

Intensity Perception

- The **second phenomenon**, called *simultaneous contrast*, is that a region's perceived brightness does not depend only on its intensity.



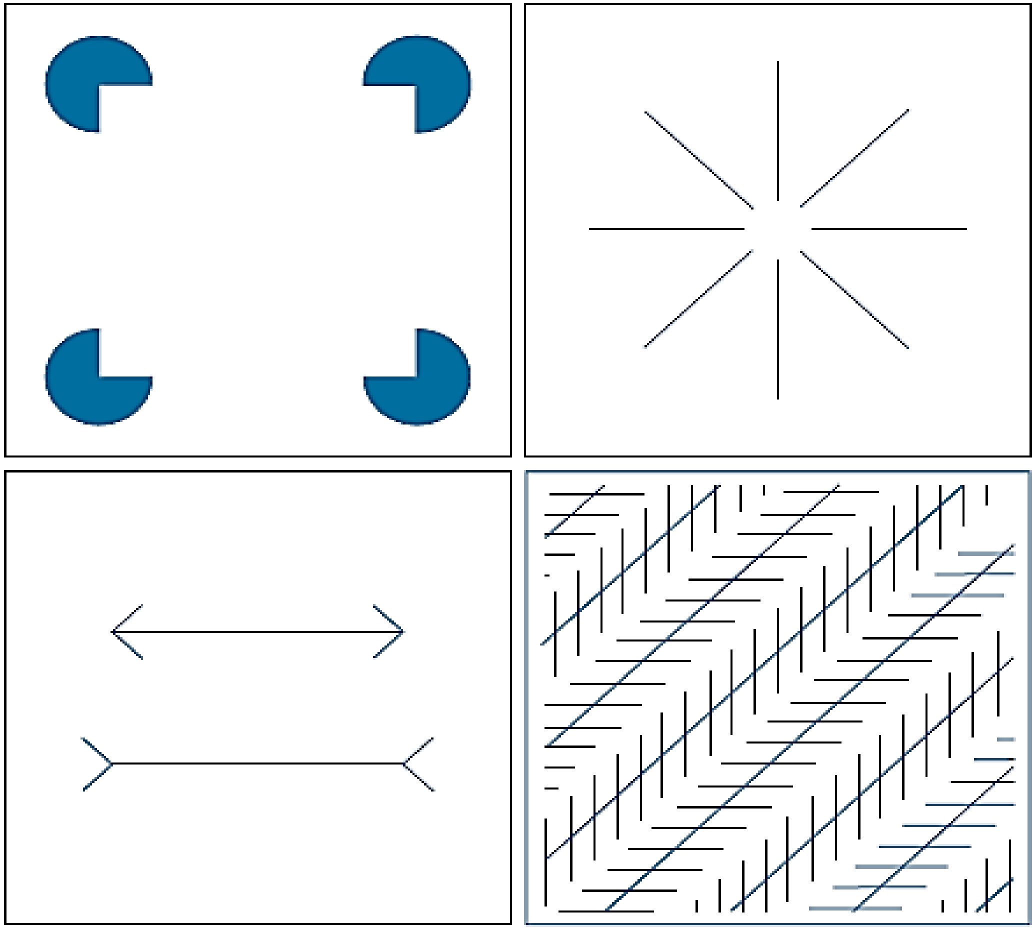
- All the center squares have exactly the same intensity, but each appears to the eye to become darker as the background gets lighter.

Intensity Perception

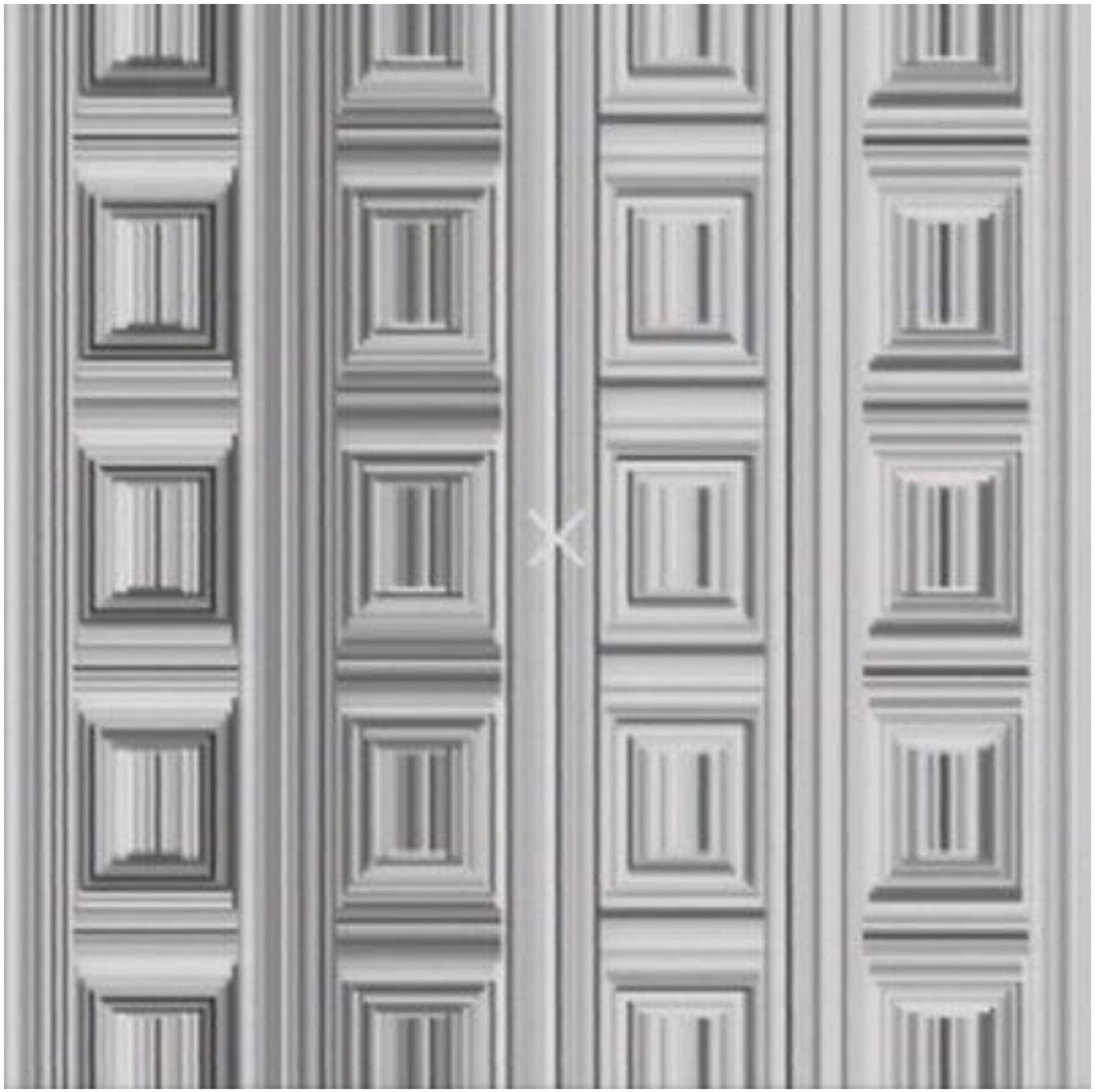
second phenomenon

Optical Illusions

- Other examples of human perception phenomena are ***optical illusions***, in which the eye fills in nonexistent details or wrongly perceives geometrical properties of objects.



Optical Illusions



Stare at the cross in the middle of the image and think circles

Optical Illusions

3D Giraffe

Discussion Question

- When you enter a dark theater on a bright day, it takes some time before you can see well enough to find an empty seat. What of the visual processes is at play in this situation?

This phenomenon is known as **"dark adaptation"** and it typically takes some minutes to reach its maximum, depending on the intensity of light exposure in the previous surroundings and the perseverance of the eye.

Achromatic, Monochromatic, Chromatic

- **Achromatic**
  Achromatic literally means "no color" or "without color." Graphite or charcoal drawings are 'achromatic' or without color, i.e., grayscale in black and white.

- **Monochromatic**
  Monochromatic uses 'mono' or <u>one hue</u> or color only. <u>White</u> is mixed with lightening or 'tint' the color, and <u>black</u> is mixed with darkening or creating a 'shade' of the color.

- **Chromatic**
  Chromatic means having color or <u>multiple hues</u> relating to or produced by color.

Image Acquisition

Key Stages in DIP

Image Acquisition → Image Enhancement → Image Restoration → Image Compression

↓

Morphological Processing

↓

Image Segmentation → Feature extraction → Image pattern classification

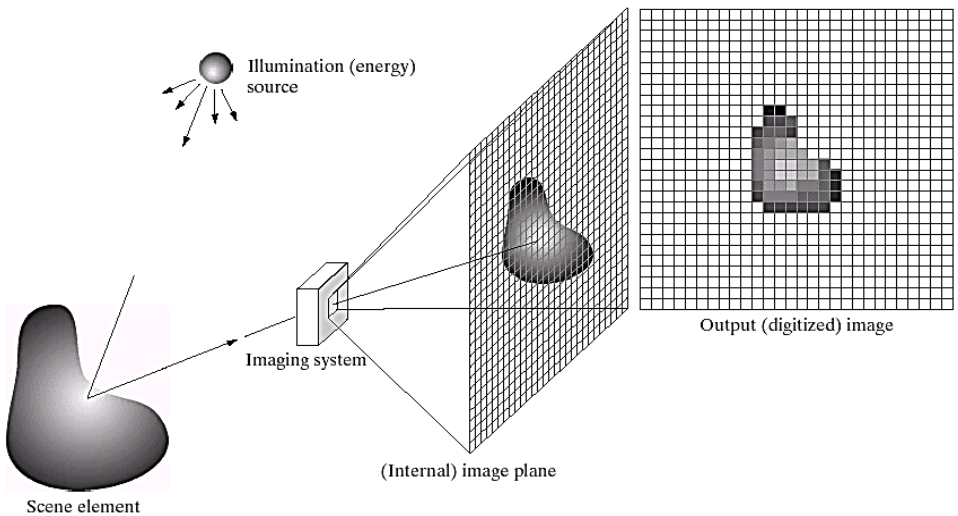


Image Acquisition

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

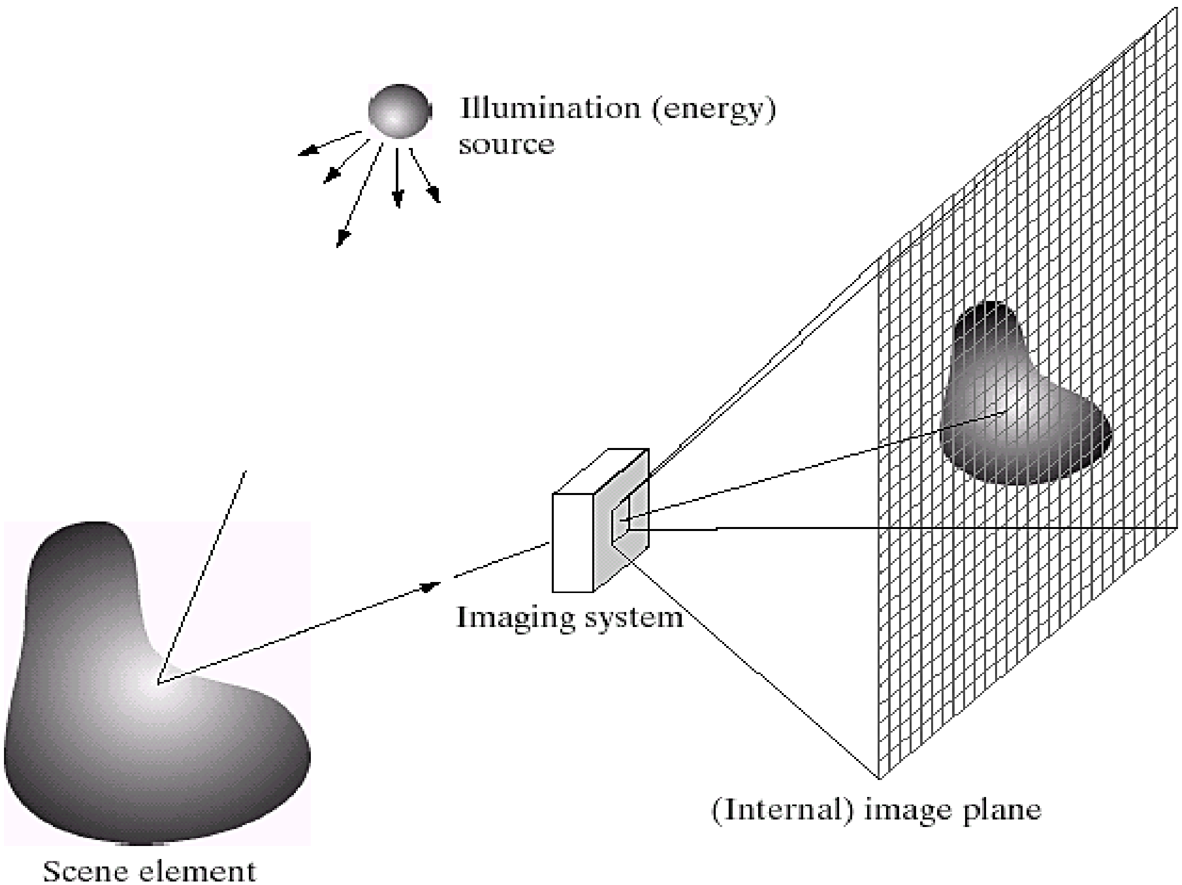
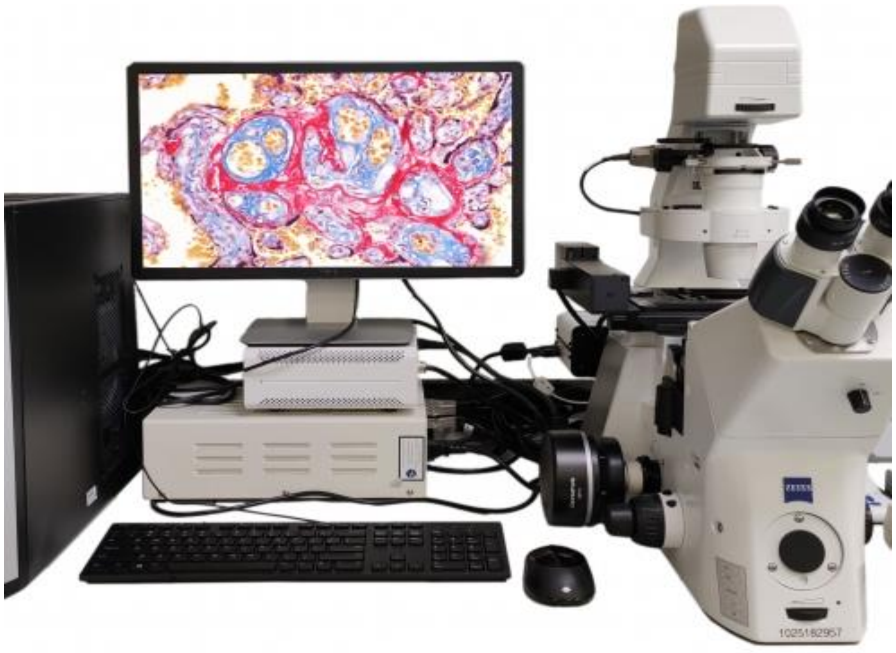


Image Acquisition

- Typical notions of illumination and scene can be different:
  - Satellite imaging (captured by energy reflectance)
  - Microscopic imaging (captured by energy reflectance)
  - Ultrasound imaging (captured by energy reflectance)
  - X-ray imaging (captured by energy transmissivity)
  - MRI imaging (captured by energy transmissivity)

Image Acquisition



Microscopic imaging

Satellite imaging

Image Acquisition

MRI imaging

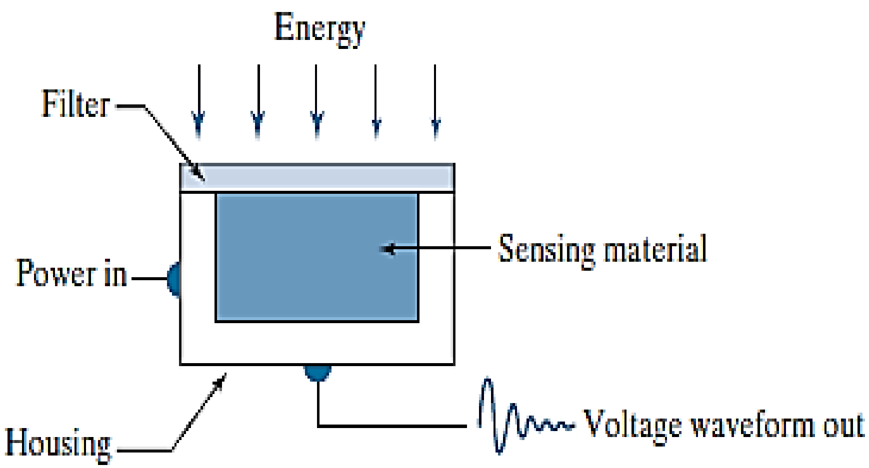
X-ray imaging

Ultrasound imaging

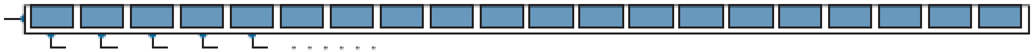
Image Sensors

- Incoming energy (example-light) lands on a **sensor material** responsive to that type of energy and this generates a voltage.

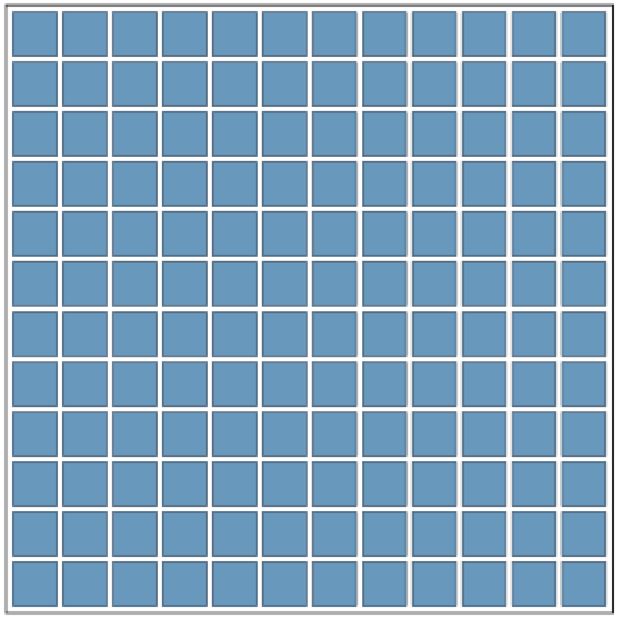
- Collections of sensors are arranged to capture images.



An Imaging Sensor



Line of Image Sensors



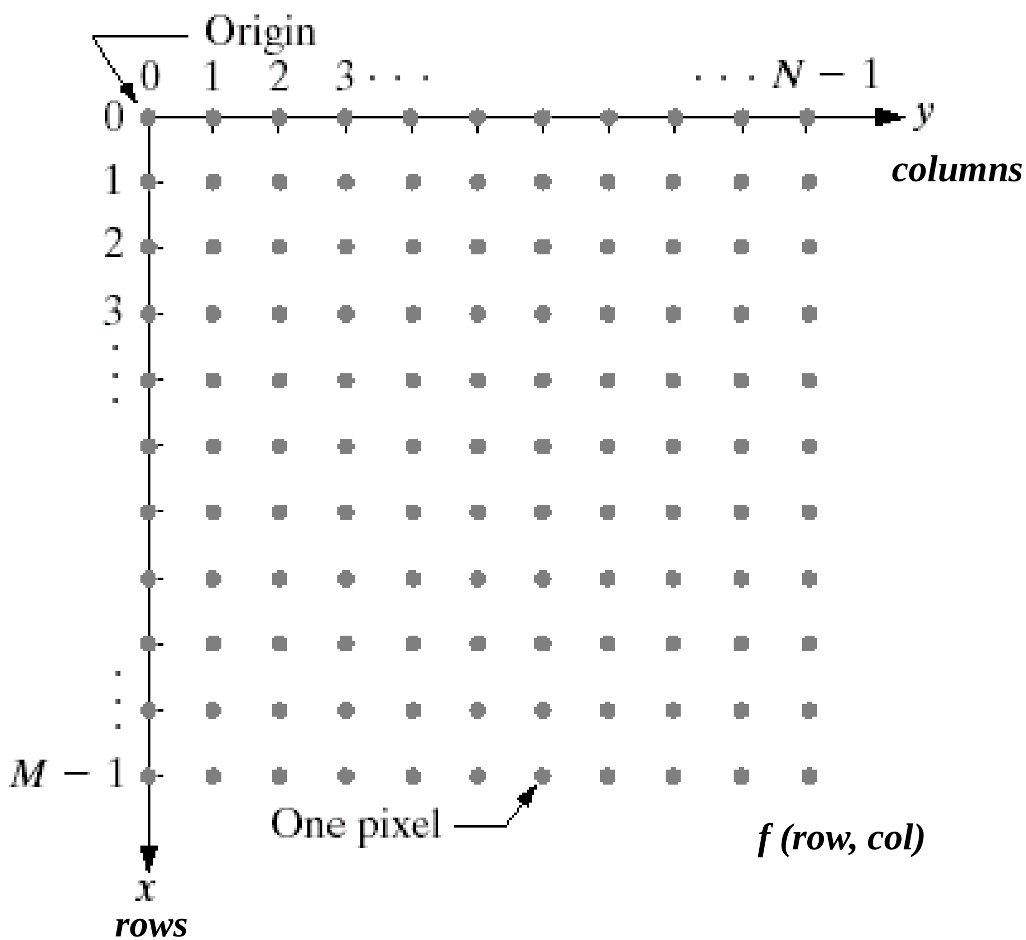
Array of Image Sensors

Digital Image Representation

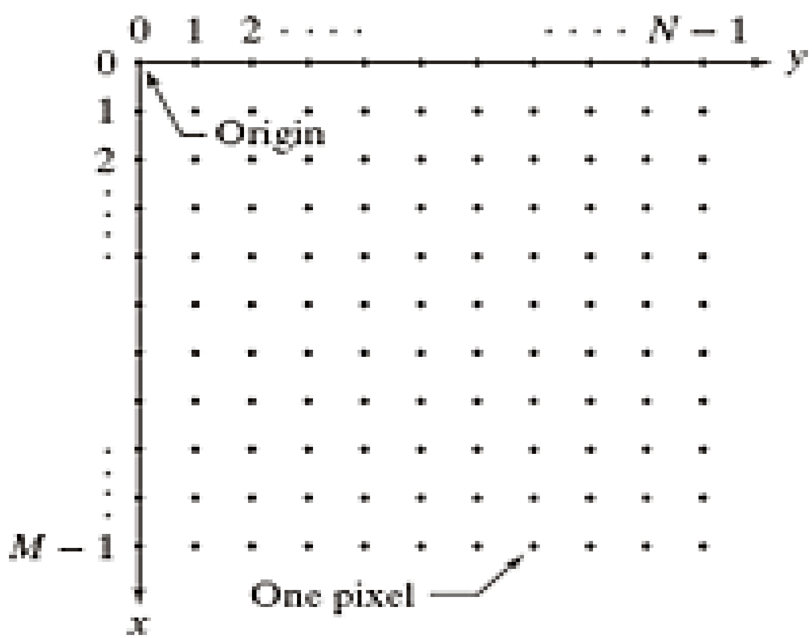
Digital Image Representation

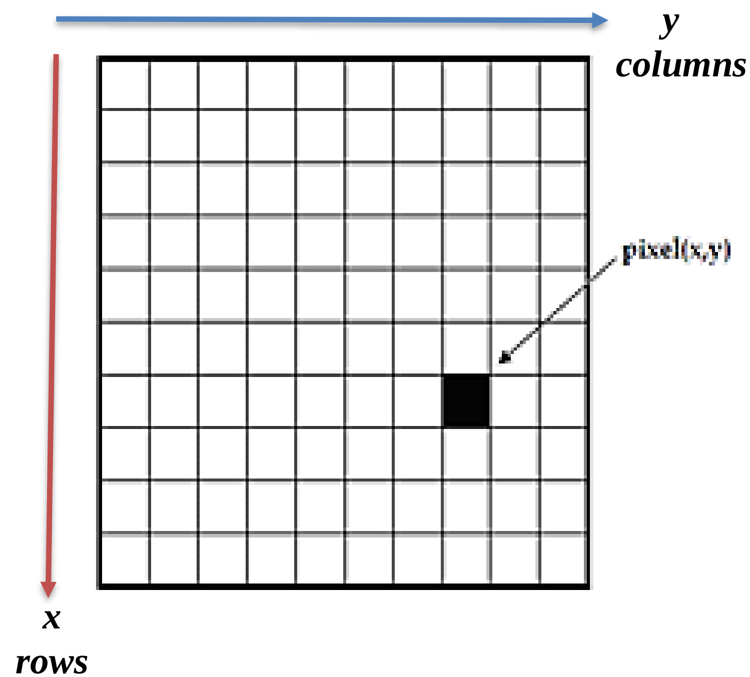
- Before we discuss image acquisition, recall that a digital image is composed of **M-rows and N-columns of pixels** each storing a value.

- We discuss **Greyscale** images having intensity levels in the range **0-255** (black-white)



Digital Image Representation





$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & f(0,2) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & f(1,2) & \dots & f(1,N-1) \\ . & . & . & & . \\ . & . & . & & . \\ . & . & . & & . \\ f(M-1,0) & f(M-1,1) & f(M-1,2) & \dots & f(M-1,N-1) \end{bmatrix}$$

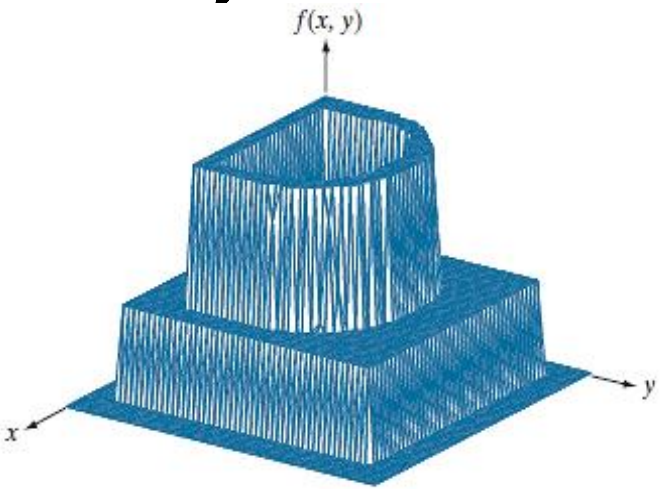
Digital Image Representation

Spatial domain representation:

- The section of the **real plane** spanned by the coordinates of an image is called the ***spatial domain***, with *x* and *y* being referred to as *spatial variables* or *spatial coordinates*.

- There are **three** ways of representing an image ***f* (*x*, *y*)**:

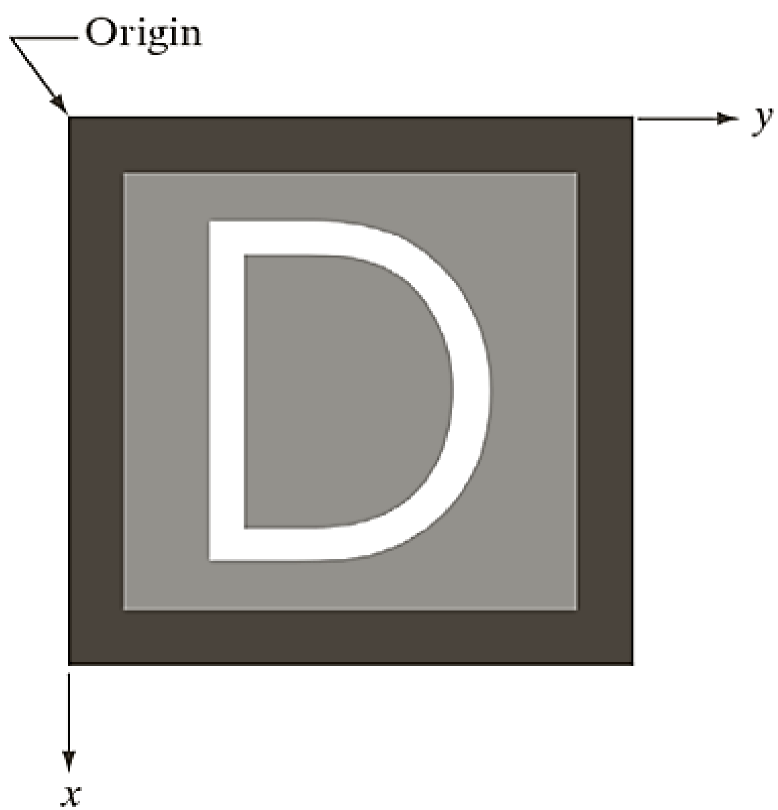
  1. In the **first representation**, an image is displayed as a plot of the function, with two axes determining spatial location and the third axis being the values of ***f*** as a function of ***x*** and ***y*** i.e. (x, y, z).



Digital Image Representation

Spatial domain representation:

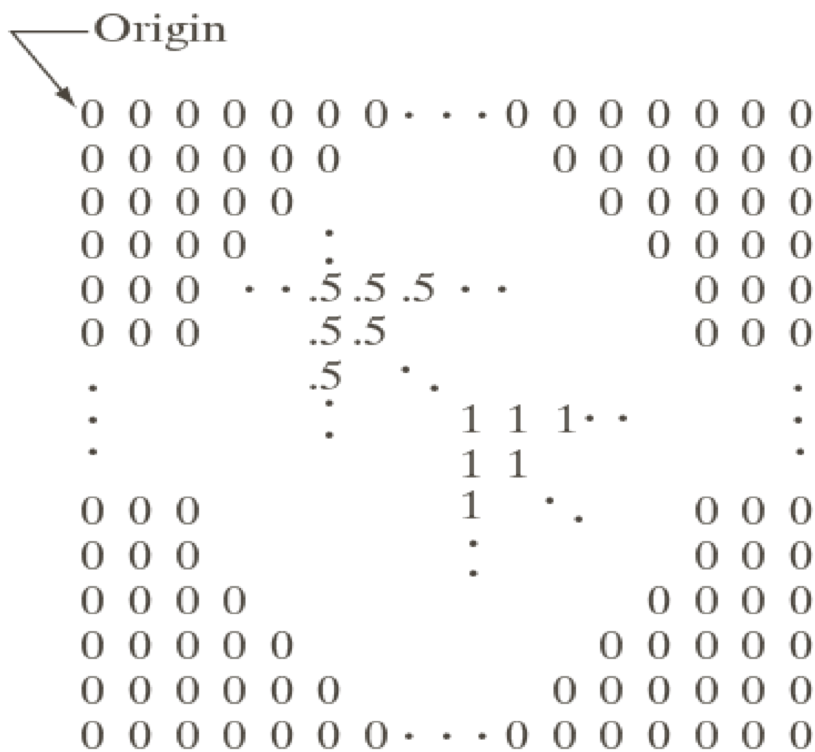
2. Second representation is more common, and it shows ***f*** **(*x*, *y*)** as it would appear on a computer display or photograph. Here, the intensity of each point in the display is proportional to the value of ***f*** at that point.



Digital Image Representation

Spatial domain representation:

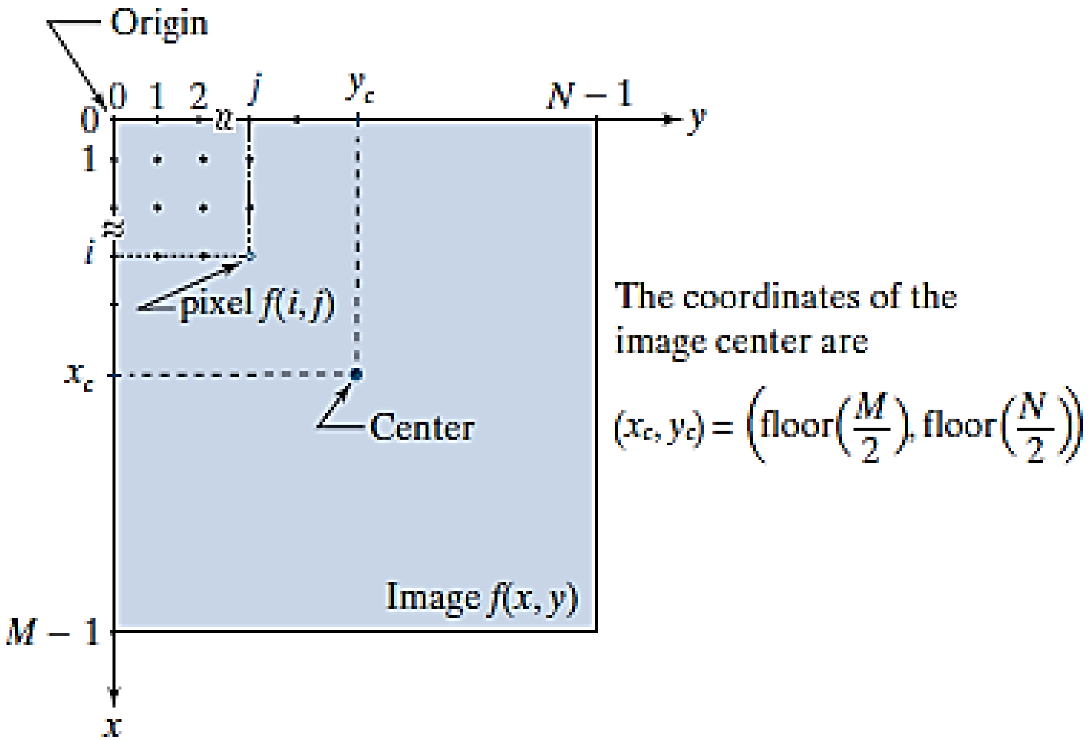
3. Third representation is an array (matrix) composed of the numerical values of $f\ (x,\ y)$. This is the representation used for computer processing.



Digital Image Representation

Spatial domain representation:

- We define the *origin* of an image at the ***top left corner***. This is a convention based on the fact that many image displays (e.g., TV monitors) sweep an image starting at the top left and moving to the right, one row at a time.



Digital Image Representation

Spatial domain representation:

- Digital images are sampled at regular intervals in the X and Y axes.
- **N** = row samples, and **M** = column samples.
- **I = N x M** array of intensity values.

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & \ldots & f(0,M-1) \\ f(1,0) & f(1,1) & \ldots & f(1,M-1) \\ \ldots & \ldots & \ldots & \ldots \\ f(N-1,0) & f(N-1,1) & \ldots & f(N-1,M-1) \end{bmatrix}$$

Mathematical Model of a Digital Image

2D light intensity function:

$$f(x, y) : \mathbb{Z} * \mathbb{Z} \rightarrow \mathbb{R}$$

Integer pair- 2 values

Real values

$$f(3, 6) = 3.56$$

Gray Scale Range

- Let the intensity (gray level) of a monochrome image at any coordinates (*x*, *y*) be denoted by:

$$L = f(x, y)$$

where,

L lies in the range of $L_{min} \leq L \leq L_{max}$

- In theory, the requirement on L_{min} is that it be nonnegative, and on L_{max} that it be finite.

- The interval $[L_{min}, L_{max}]$ is called **Gray (or intensity) Scale**. In practice, the interval starts from 0 to a maximum value L-1:

$I = 0$ is **black**

$I = L-1$ is **white**

Image Sampling And Quantisation

Image Sampling And Quantisation

- The output of most sensors is a ***continuous voltage waveform*** whose amplitude and spatial behavior are related to the physical phenomenon being sensed.

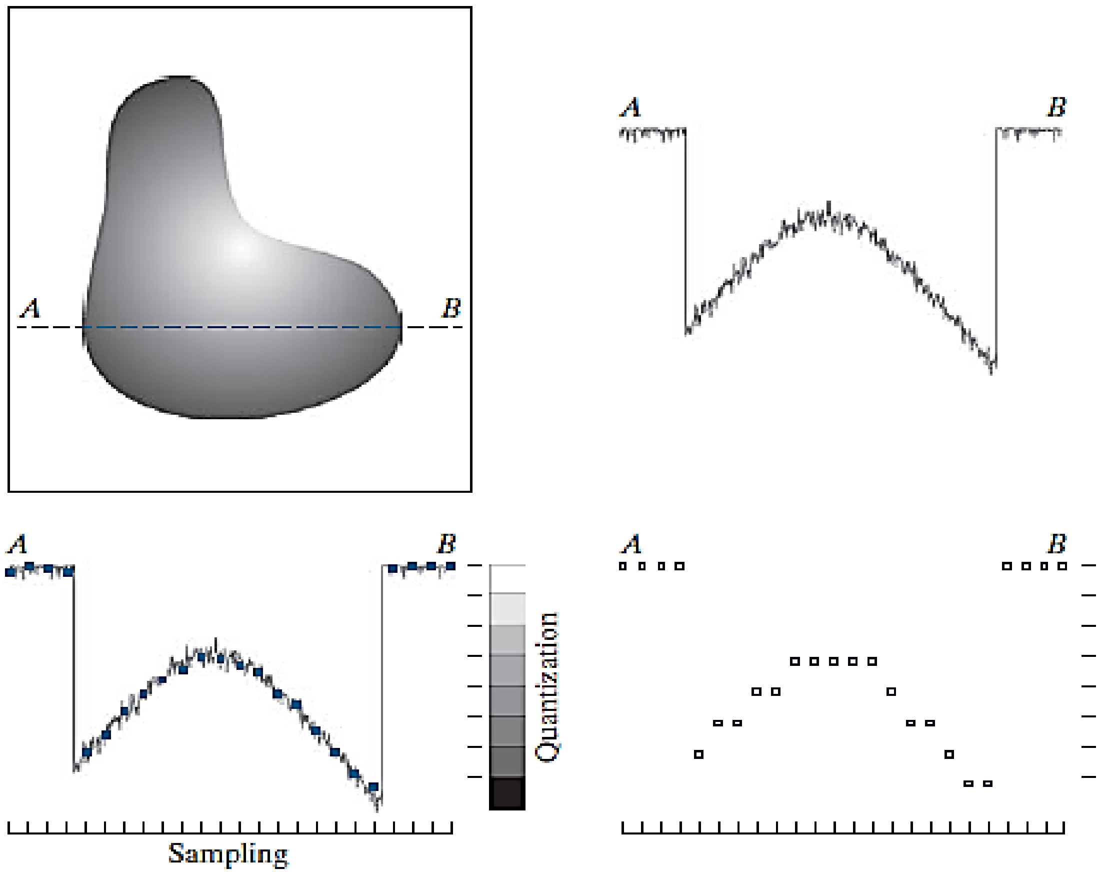
- To create a digital image, we need to *convert the continuous sensed data into a digital format*. This requires two processes: ***sampling*** and ***quantization***.

- To **digitize** a ***continuous function*** **$f(x, y)$**, we have to sample the function in both **coordinates** and also in **amplitude**.

Digitizing the **coordinate values** ***(x, y)*** is called ***sampling***. Digitizing the **amplitude values** ***f*** is called ***quantization***.

Image Sampling And Quantisation

- A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels.
- **More** the number of sampling & quantization levels, **better the quality** of image, but requires **more storage**.



- 24 pixels
- 8 intensity levels

Image Sampling And Quantisation

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

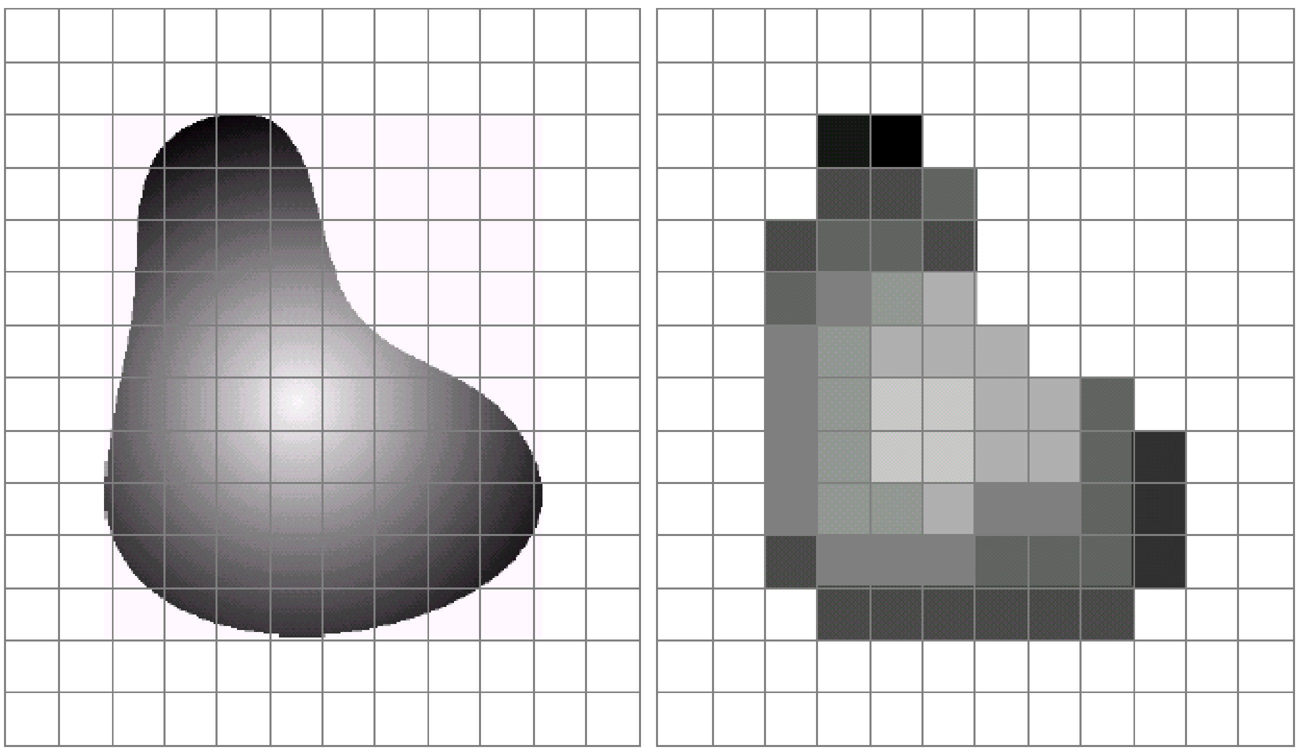
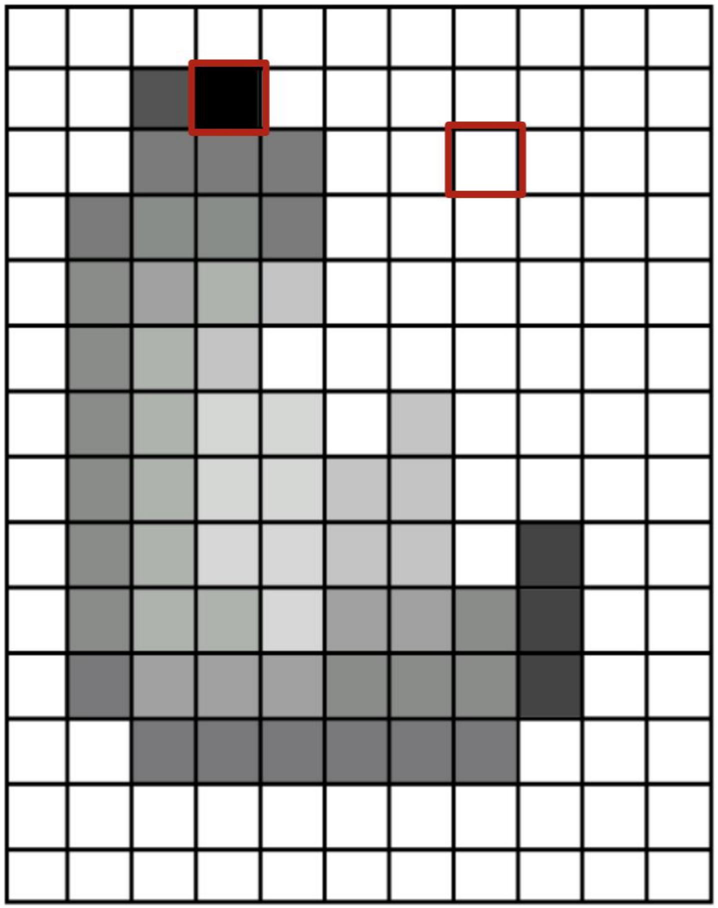


Image Sampling And Quantisation



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255	255	255	255	255	255	255	255	255	255	255
255	255	20	0	255	255	255	255	255	255	255
255	255	75	75	255	255	255	255	255	255	255
255	75	95	95	75	255	255	255	255	255	255
255	96	127	145	175	255	255	255	255	255	255
255	127	145	175	175	175	255	255	255	255	255
255	127	145	200	200	175	175	95	255	255	255
255	127	145	200	200	175	175	95	47	255	255
255	127	145	145	175	127	127	95	47	255	255
255	74	127	127	127	95	95	95	47	255	255
255	255	74	74	74	74	74	74	255	255	255
255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255

0 = black; 255 = white

Image Sampling And Quantisation

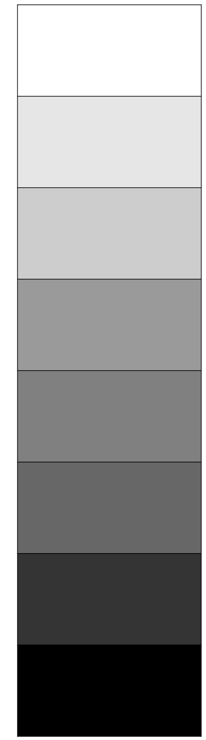
- How to choose the number of samples and the number of quantization level?

- They depend on ...
  - Requirement on image quality
  - Domain of usage
  - etc..

More on Quantization

- Due to storage and hardware consideration, **the number of quantization level** is in power of 2, i.e. **$L=2^k$**

- When an image has **2^k** possible intensity levels, it is common practice to refer to it as a **"*k*-bit image"** (e.g., a *256-level* image is called an *8-bit image*).



Saturation & Noise

- The range of values spanned by the gray scale is referred to as the ***dynamic range***.

- The dynamic range of an imaging system is the **ratio of the** maximum measurable intensity to the minimum detectable intensity level in the system.
  - — The upper limit is determined by ***saturation***
  - — The lower limit is determined by ***noise***

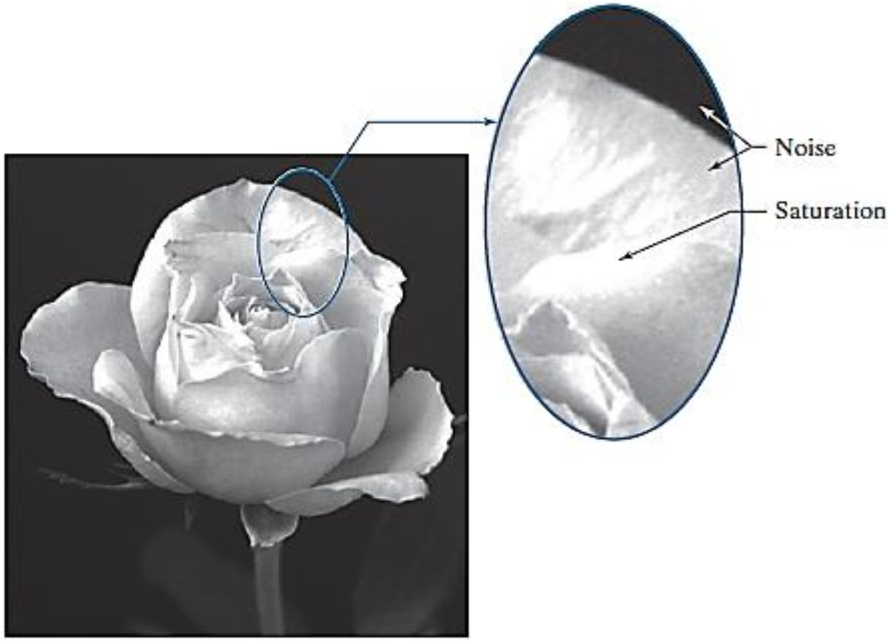


Image Resolution

Image Size

$L = 2^k$

$N = rows$

$M = columns$

# of bits to store a digitized image:

$b = N \times M \times k = N^2 k$, when N=M

N×M	1 (L = 2)	2 (L = 4)	3 (L = 8)	4 (L = 16)	5 (L = 32)	6 (L = 64)	7 (L = 128)	8 (L = 256)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Spatial Resolution

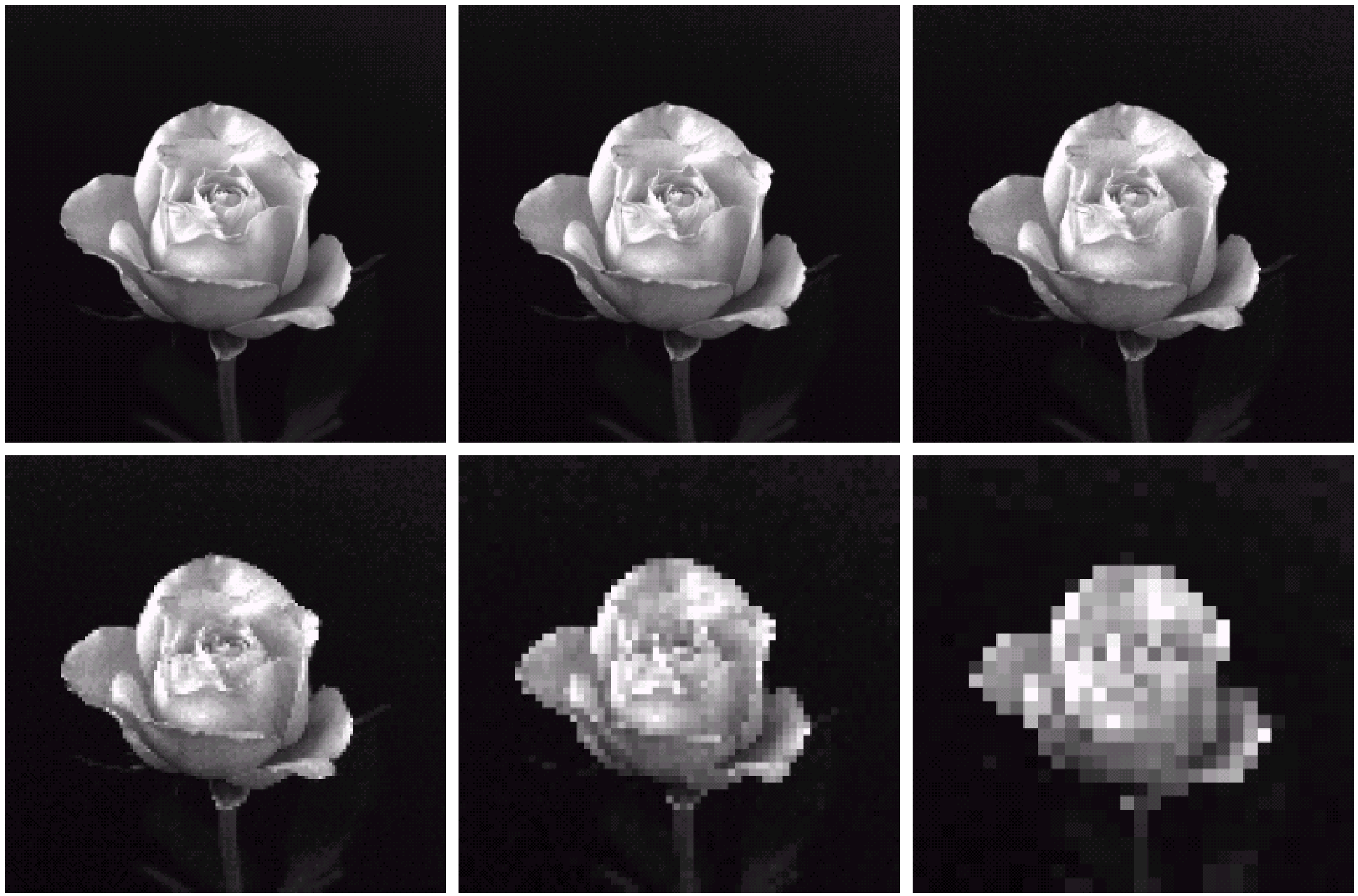
- ***Spatial resolution*** of an image is determined by **<u>the amount of pixels in it</u>**.

- Spatial resolution defines the smallest discernable detail in an image.
  - Vision specialists will often talk about **pixel size**
  - Graphic designers will talk about **dots per inch** (DPI)

- The <u>amount of pixels</u> that a camera catches in a single photograph is known and quantified as its **resolution.**

Spatial Resolution

Spatial Resolution



a b c
d e f

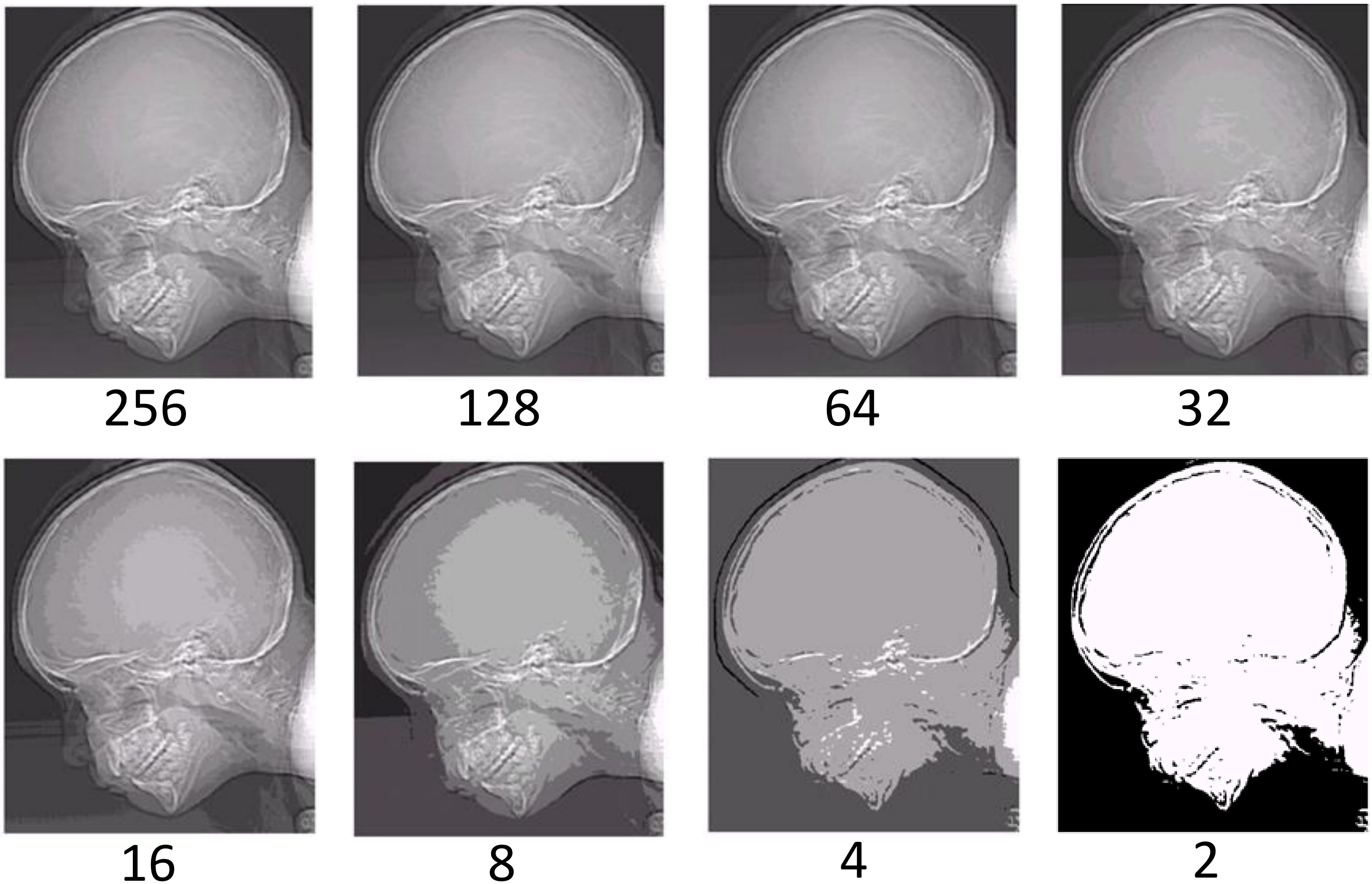
FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

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 discernable 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	Number of Intensity Levels	Examples
1	2	0,1
2	4	00,01,10,11
4	16	0000,0101,1111
8	256	00110011,01010101
16	65,536	1010101000011111

How many levels of Quantization are enough?



CT(computerized tomography) images

- The number of pixels in each image is kept constant
- Less number of intensity levels produce **False contouring**

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?

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

Resolution: How Much Is Enough?

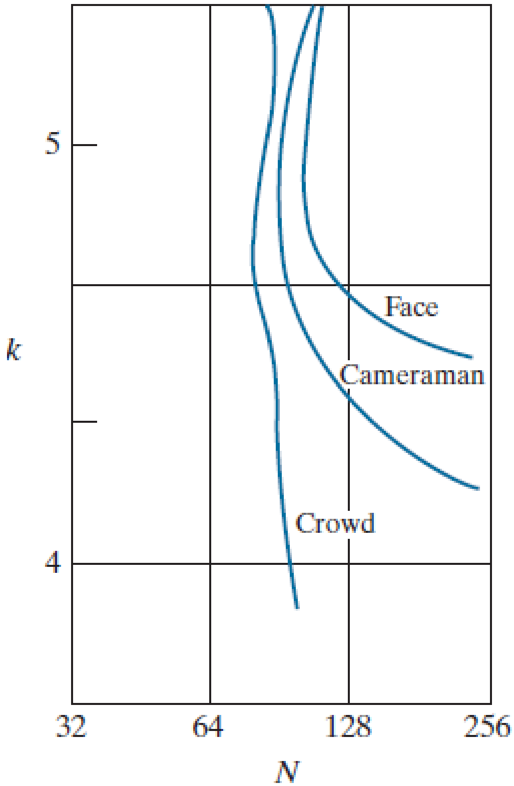
Low Detail

Medium Detail

High Detail

Resolution: How Much Is Enough?

- *Isopreference curve:* ***Intensity level resolution* Vs *Spatial resolution***



Total number of bits $b = N^2 \times k$

For images with a **large amount of detail** only a **few intensity levels** may be needed.

Non-uniform Sampling & Quantization

- Sample more points in regions of details
  - Change of intensity level
  - Edges

Low-detail

Mid-detail

High-detail

Non-uniform sampling - low detail image

Uniform Sampled Image

Non-uniform Sampling

Non-uniform Sampled Image

Difference Image

Next Lecture

- Neighbors of a Pixel
- Adjacency
- Digital Path
- Connectivity
- Region and Boundary
- Proximity Relationship
- Defining Linear Operations