Digital Image Processing
CS-601, IT-613

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Lecture 2(week 4, 5 & 6)

Lecture # 2
Basic Concepts in Digital Image Processing,
Image acquisition and digital image representation

Now,

Introducing some basic concepts in digital image processing

- **Human vision system**
- **Basics of image acquisition**
- **Image Representation**

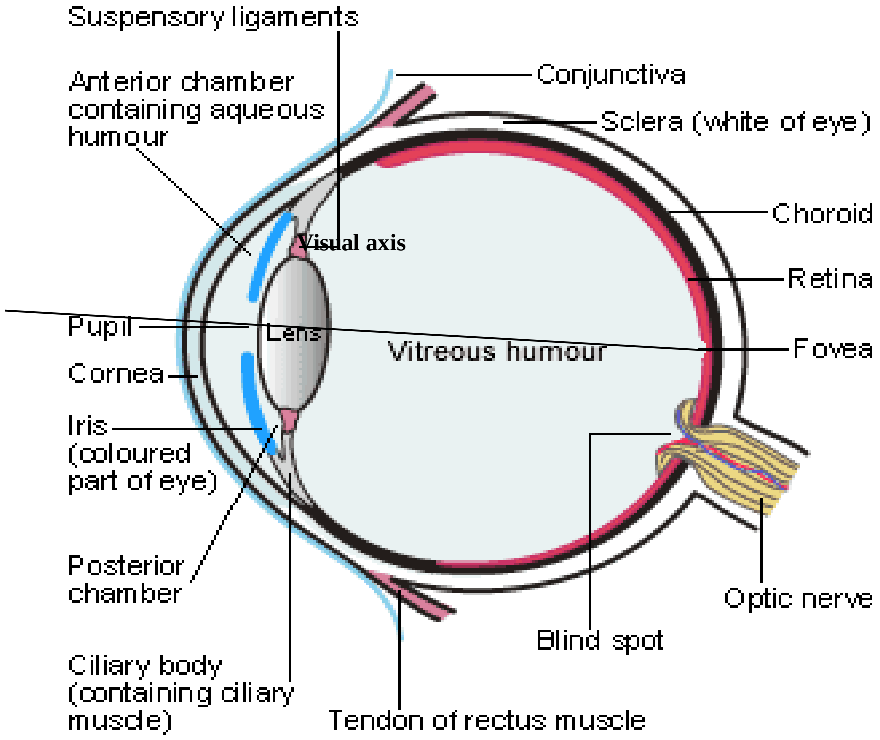
Elements of Human Visual Perception

Human visual perception plays a key role in selecting a technique

Lens and Cornea: focusing on the objects

Two receptors in the retina:

- Cones and rods
- Cones located in fovea and are highly sensitive to color
- Rods give a general overall picture of view, are insensitive to color and are sensitive to low level of illumination



http://www.mydr.com.au/eye-health/eye-anatomy

Distribution of Rods and Cones in the Retina

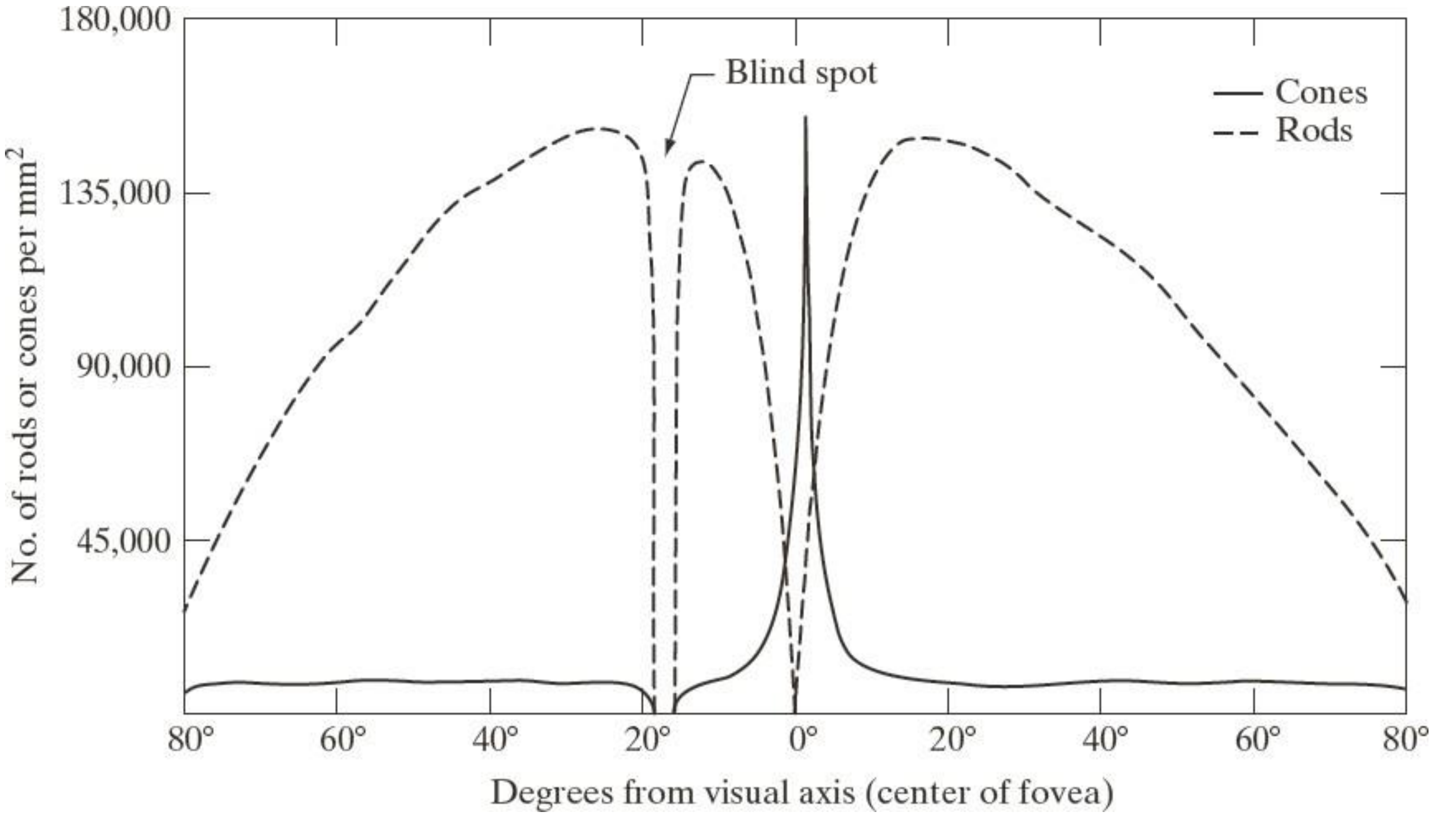


FIGURE 2.2 Distribution of rods and cones in the retina.

Sensitivity of human eye to intensity

Brightness Adaptation: Subjective Brightness

Scotopic:

- **Vision under low illumination**
- **rod cells are dominant**

Photopic:

- **Vision under good illumination**
- **cone cells are dominant**

The total range of distinct intensity levels the eye can discriminate *simultaneously* is rather small

Brightness adaptation level

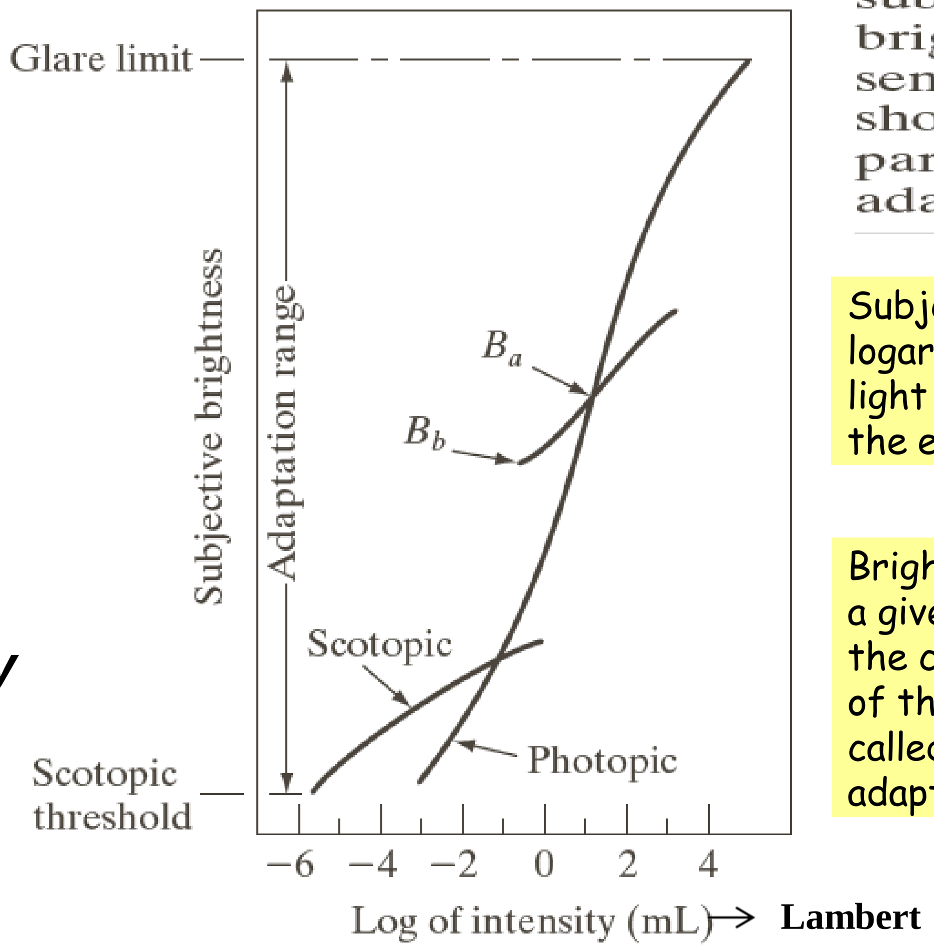


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

Subjective brightness is a logarithmic function of the light intensity incident on the eye

Brightness adaptation: For a given set of conditions, the current sensitivity level of the visual system is called brightness adaptation level

Weber ratio

Brightness Discrimination

Weber Ratio/Fraction

$$\frac{\Delta I_c}{I}$$

$I + \Delta$

Short-duration flash

Small ratio: good brightness discrimination

Large ratio: poor brightness discrimination

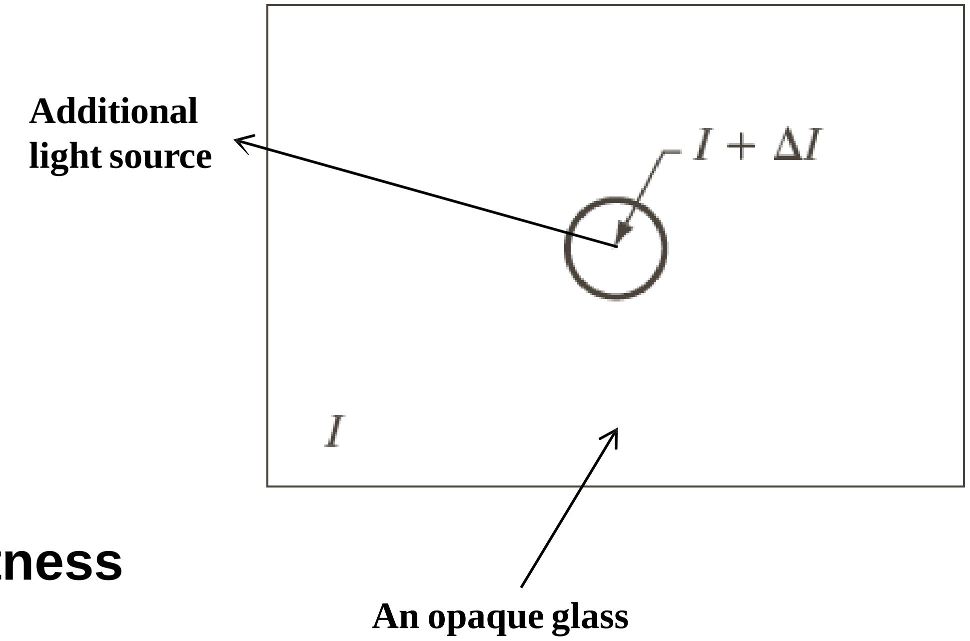


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Brightness discrimination setup.

Weber ratio

Brightness Discrimination at Different Intensity Levels

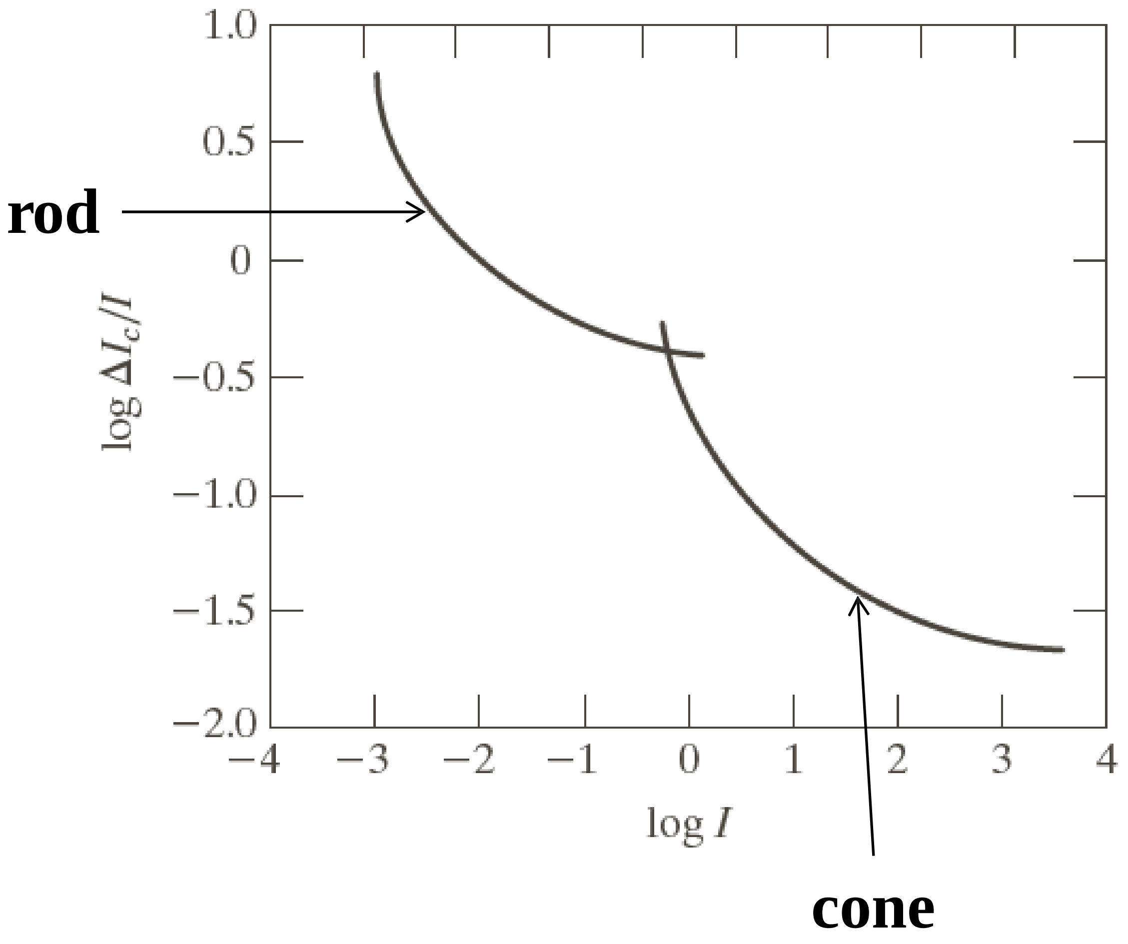
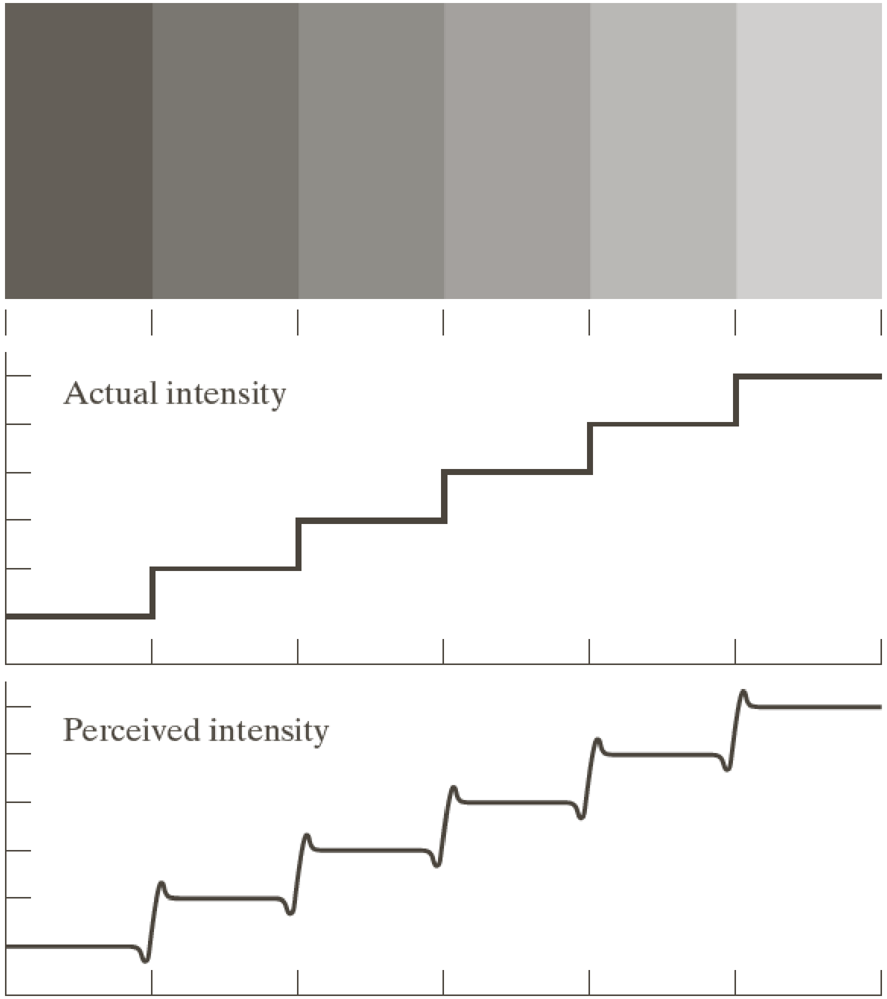


FIGURE 2.6 Typical Weber ratio as a function of intensity.

Weber ratio is defined as dI/I, where dI is the increment of illumination discriminable 50% of the time with background illumination I

Perceived Intensity is Not a Simple Function of the Actual Intensity (1)

(a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.



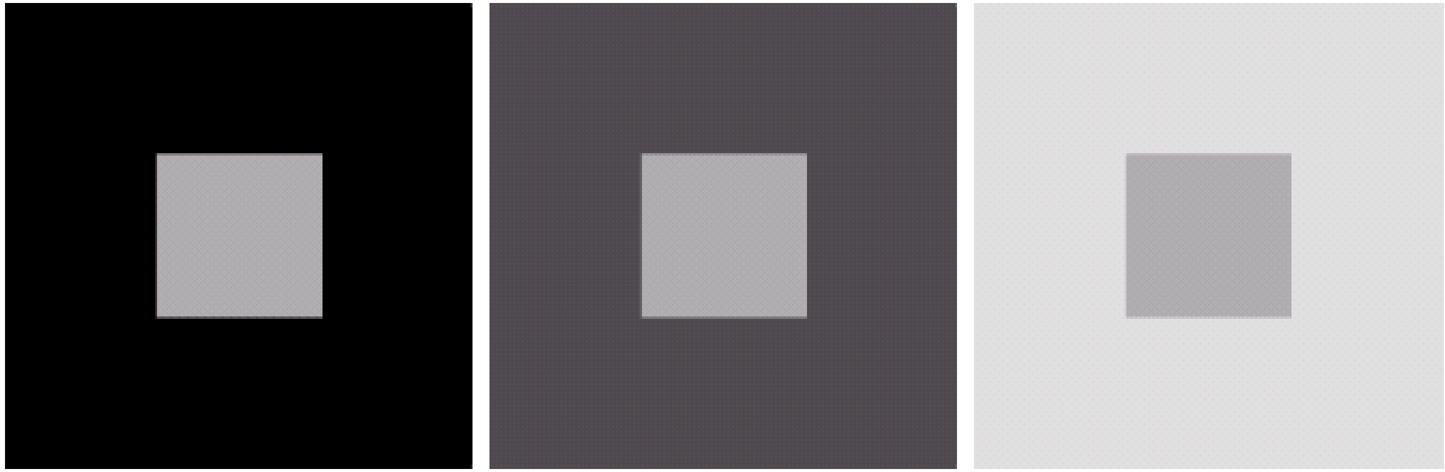
a
b
c

FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

Mach bands: The visual system tends to overshoot or undershoot around the boundary regions of different intensities.

Perceived Intensity is Not a Simple Function of the Actual Intensity – Simultaneous Contrast

Simultaneous contrast: a region perceived brightness does not simply depend on its intensity!



a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Optical Illusions: Complexity of Human Vision

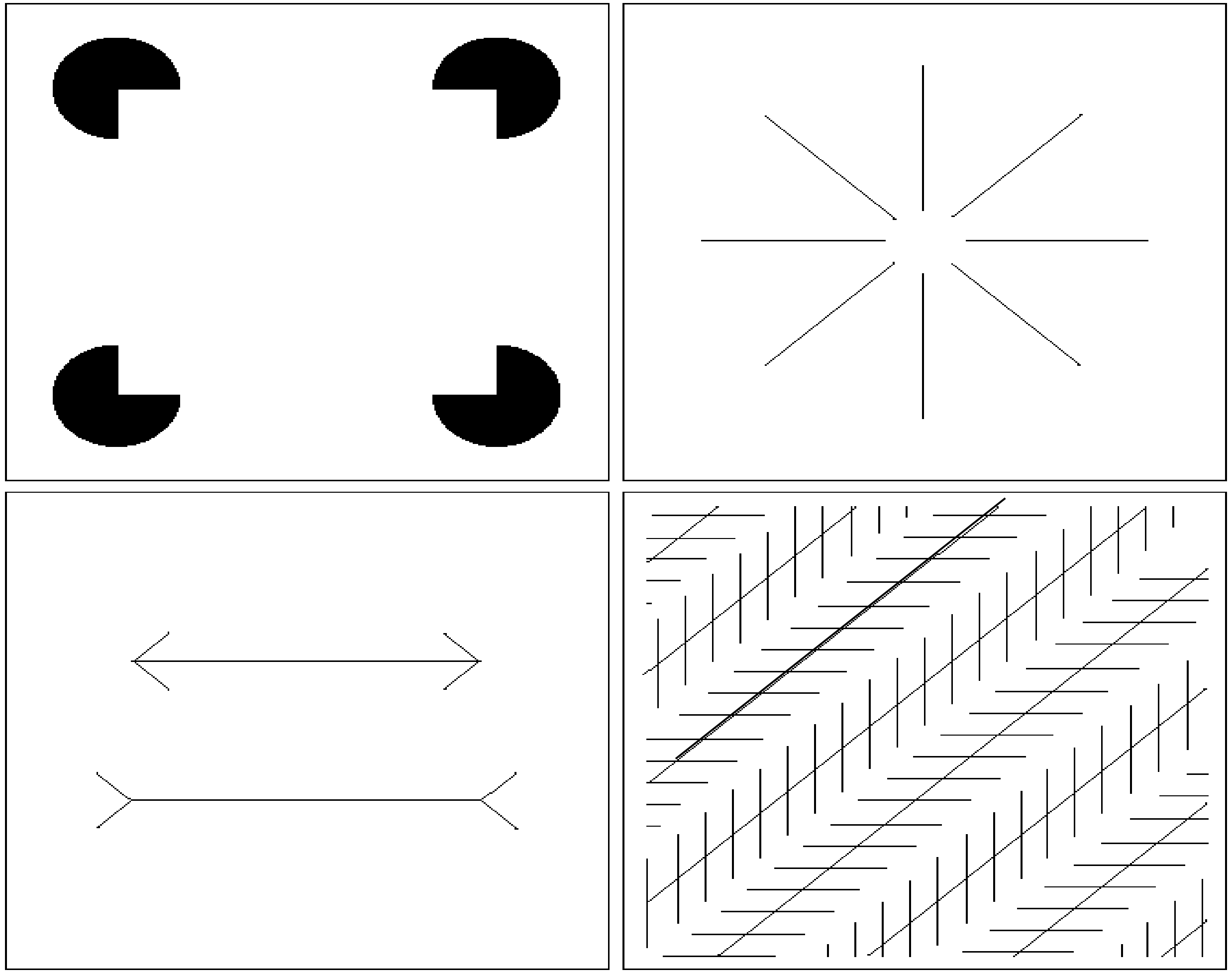
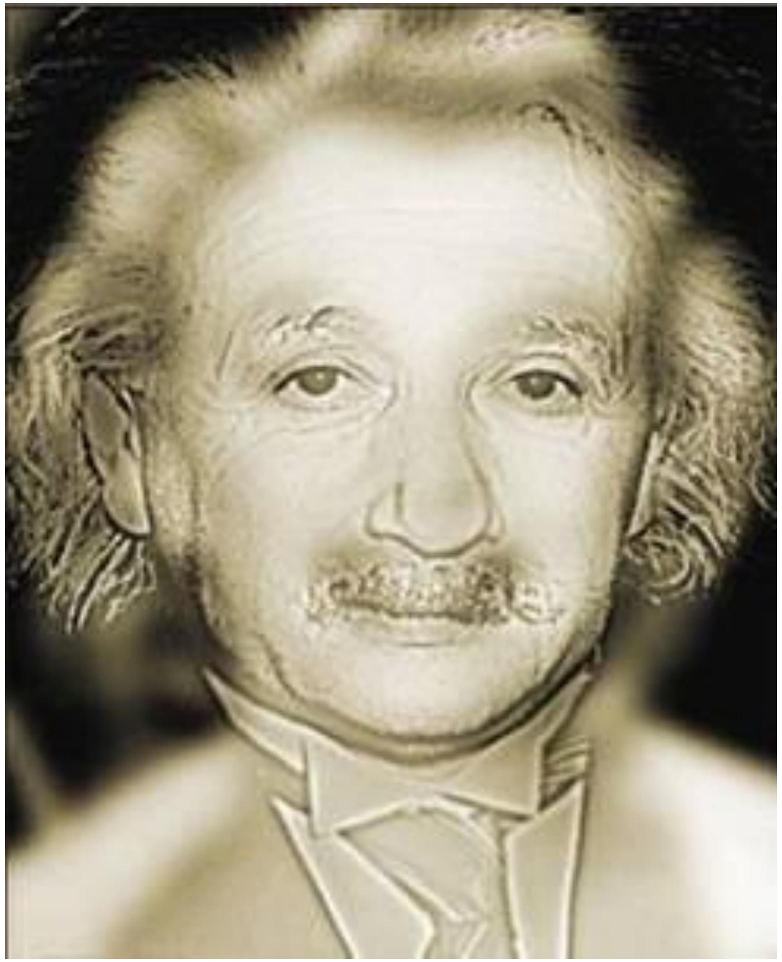


FIGURE 2.9 Some well-known optical illusions.

More Optical Illusions



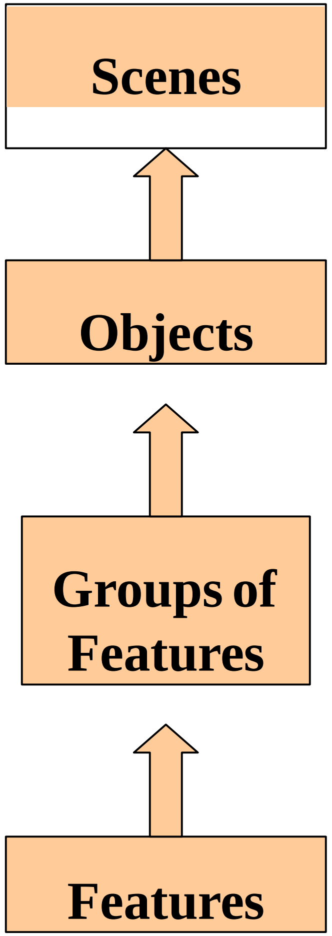
http://www.123opticalillusions.com/

http://brainden.com/optical-illusions.htm

Object Perception

How do we perceive separate features, objects, scenes, etc. in the environment?

- Perception of a scene involves multiple levels of perceptual analysis.



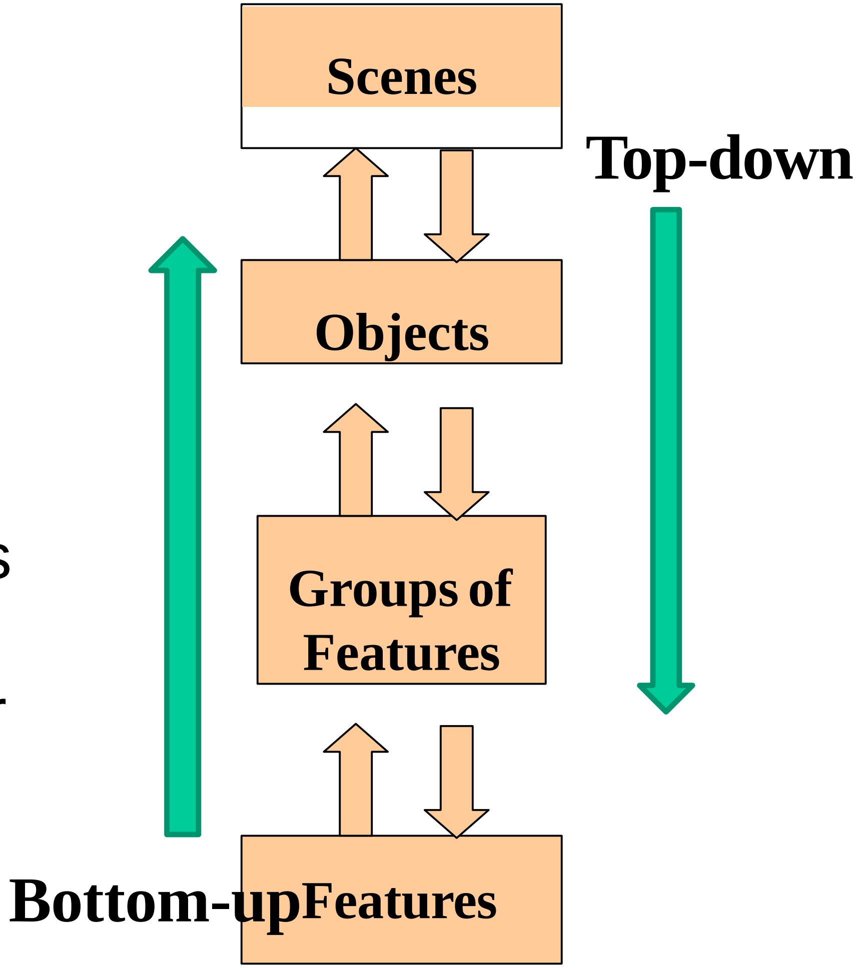
What Do We Do With All Of This Visual Information??

"Bottom up processing"

- Data-driven
- Sensation reaches brain, and then brain makes sense of it

"Top down processing"

- Cognitive functions informs our sensation
- E.g., walking to refrigerator in middle of night



Now,

Introducing some basic concepts in digital image processing

- **Human vision system. Why we need to study human eye?**
- **Basics of image acquisition**
  - Geometry – size, location, …
  - Appearance – color, intensity

Image Formation in the Eye

Image is upside down in the retina/imaging plane!

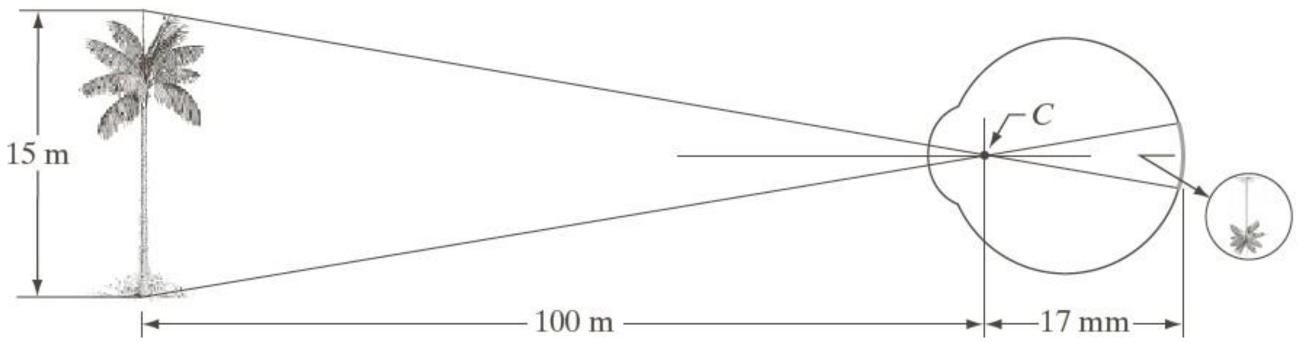
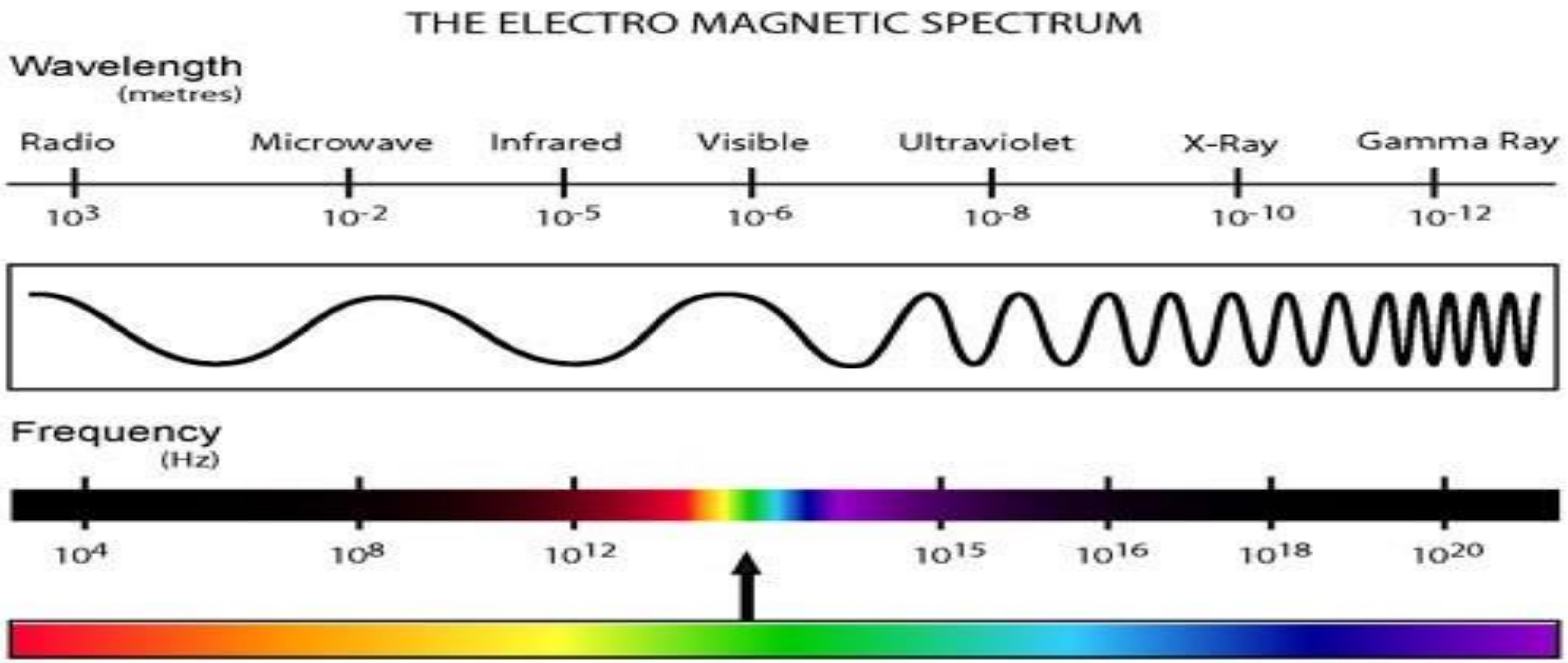


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Adjust focus length

- **Camera**
- **Human eye**

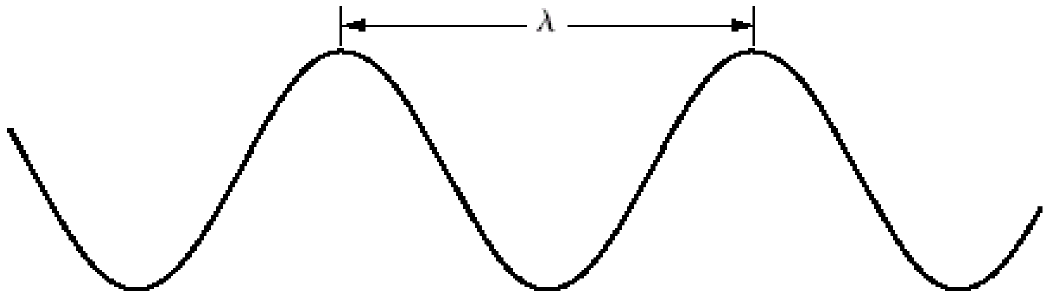
Light and EM Spectrum



http://www.kollewin.com/blog/electromagnetic-spectrum/

Relation Among Wavelength, Frequency and Energy

FIGURE 2.11
Graphical representation of one wavelength.



wavelength (λ), frequency (v), and energy (E)

$\lambda = \frac{c}{v}$, $c = 2.998 \times 10^8\, m/s$ is the speed of light

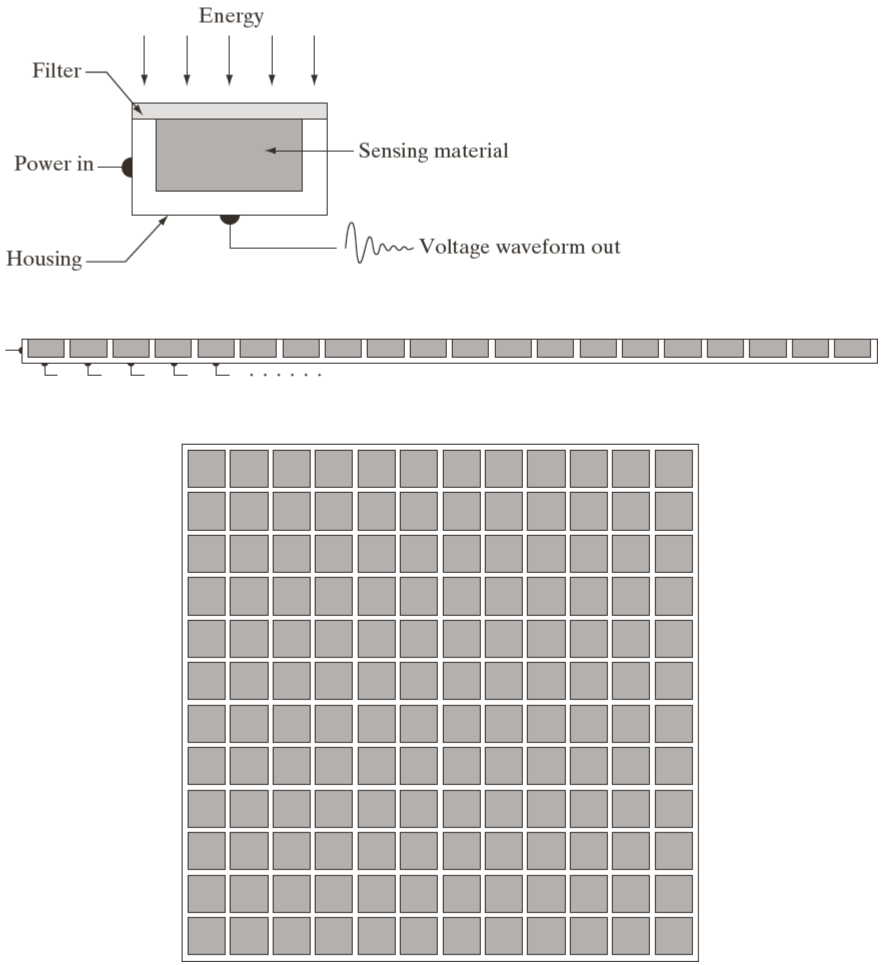
$E = hv$, h is the Planck's constant, 6.626068×10^{-34} $\mathrm{m^2\ kg / s}$

Image Sensing and Acquisition

Illumination energy → digital images

Incoming energy is transformed into a voltage

Digitizing the response



a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Definitions

$$0 < f(x, y) < \infty$$

Images generated from a physical process,

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

$$0 < i(x, y) < \infty$$

$$0 < r(x, y) < 1$$

Characterized by two components: illumination and reflectance (transmittance)

Definitions

$$l = f(x_0, y_0)$$

$$L_{\min} \le l \le L_{\max}$$

$$L_{\min} = i_{\min} r_{\min}$$

$$L_{\max} = i_{\max} r_{\max}$$

$$[L_{\min}, L_{\max}]$$

$$[0, L-1]$$

The interval [0, L-1] is called the gray scale. l = 0 for black and L-1 is considered white on gray scale

Definitions

- *Radiance* is the total amount of energy that flows from a light source
- *Luminance* is a measure of the amount of energy an observer perceives from a light source
- *Brightness* is a subjective descriptor of light perception

Image formation

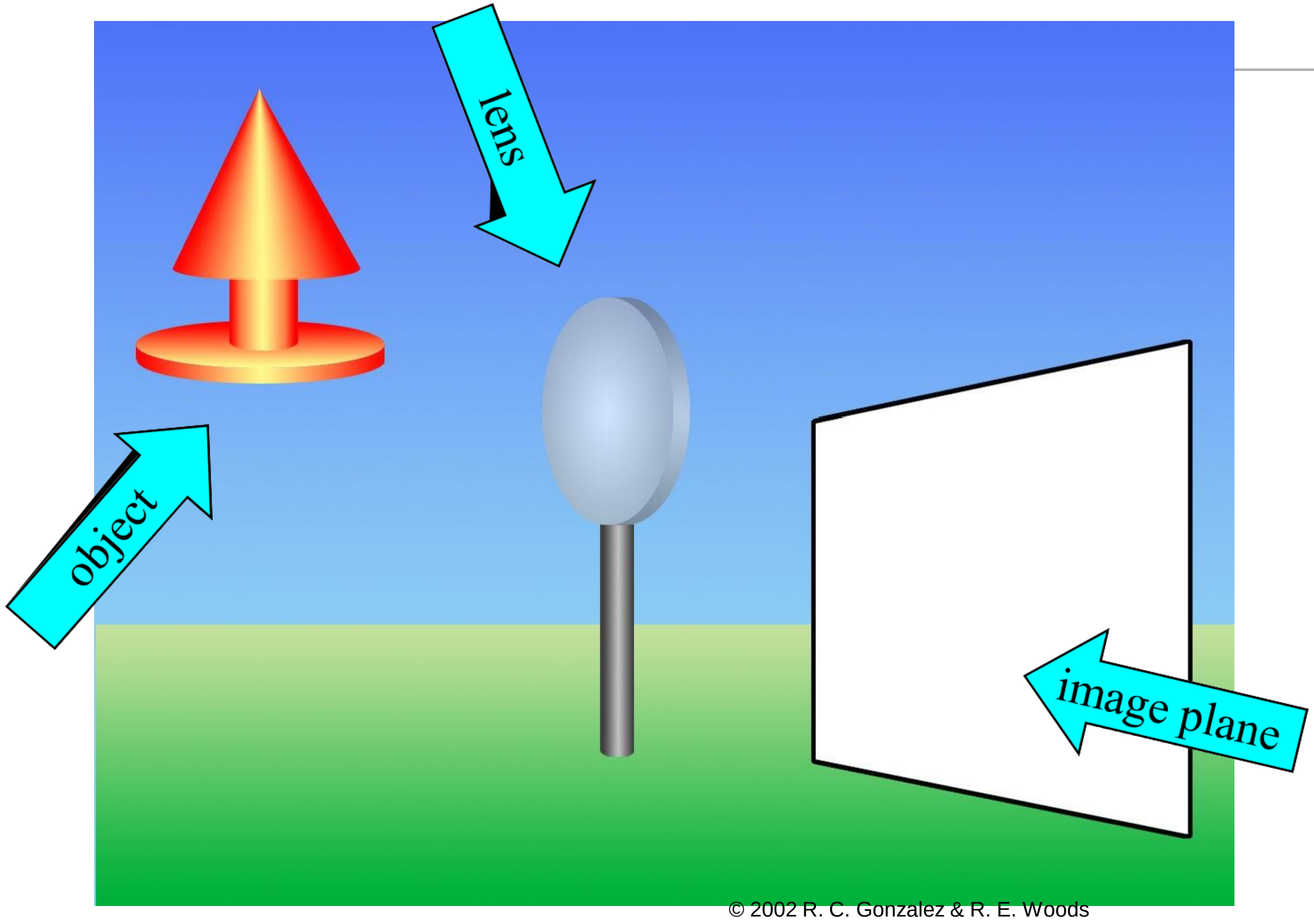
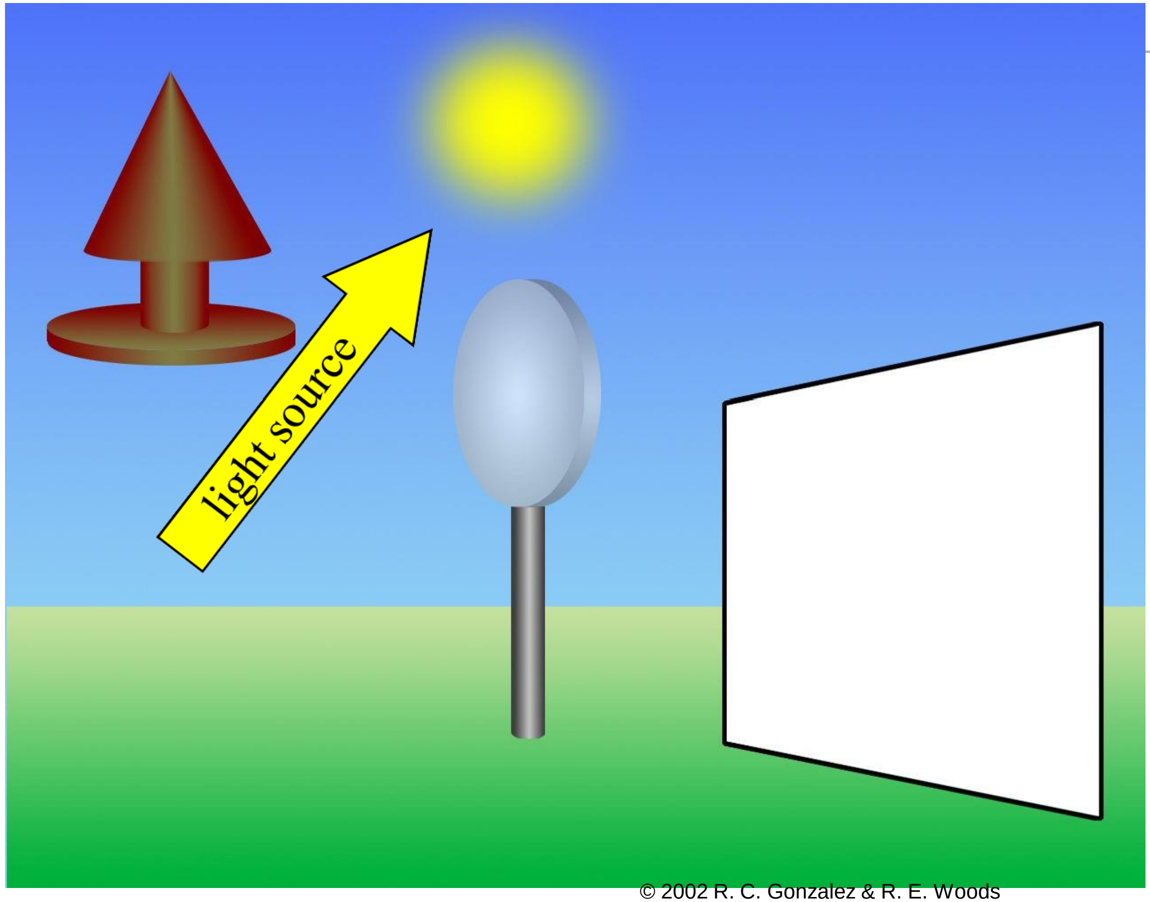


Image formation



by Richard Alan Peters II

Image formation

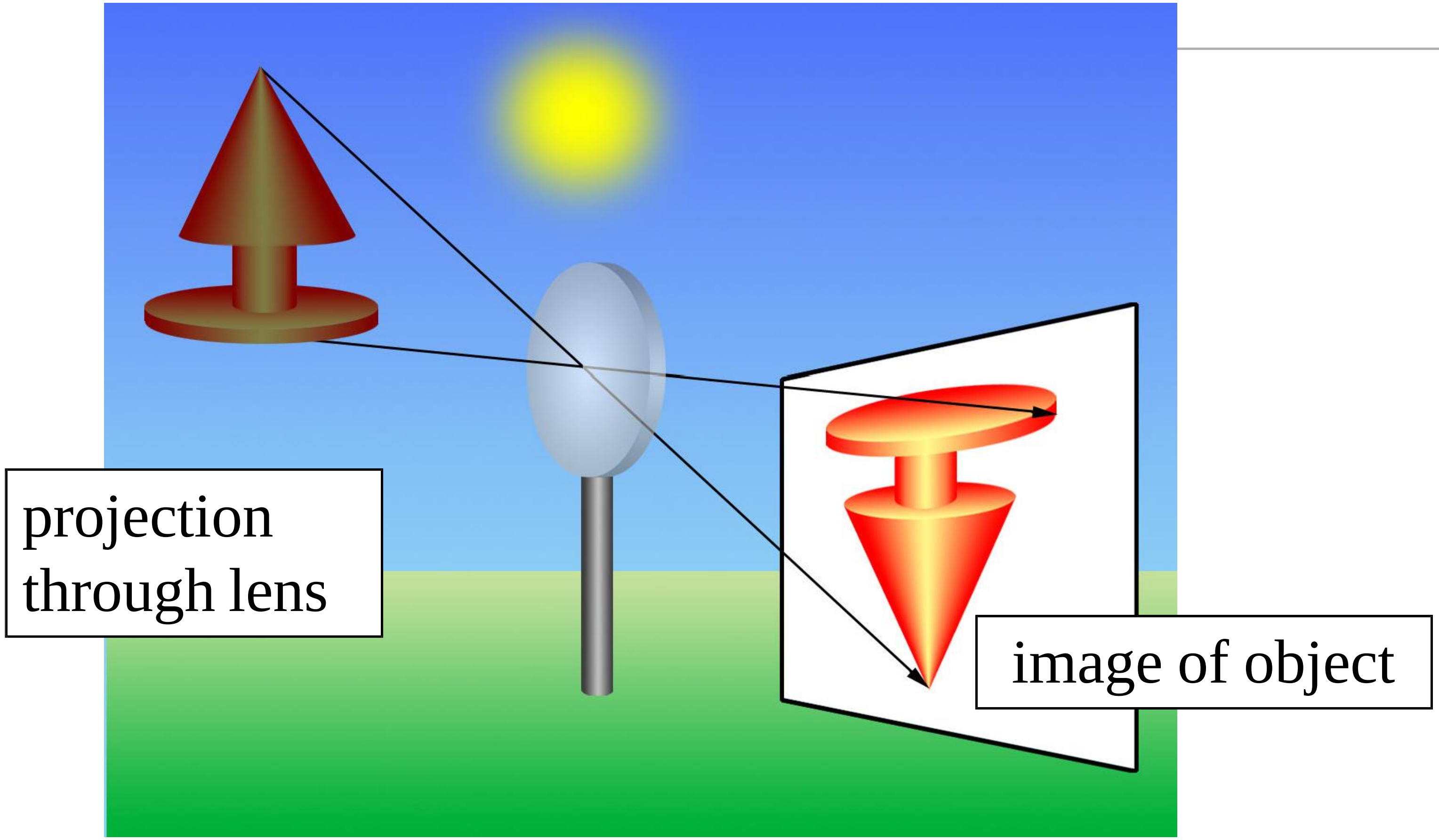


Image formation

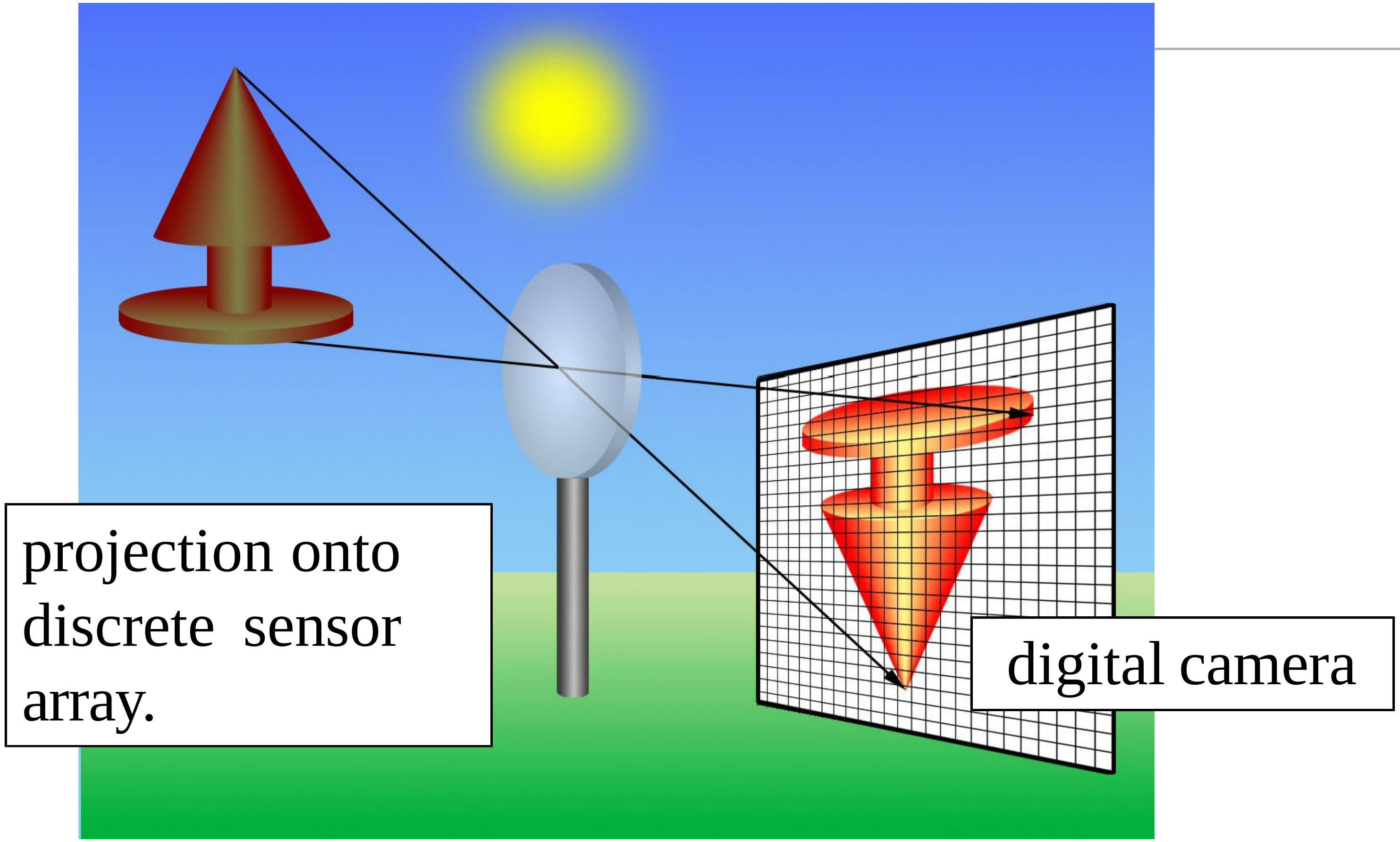


Image formation

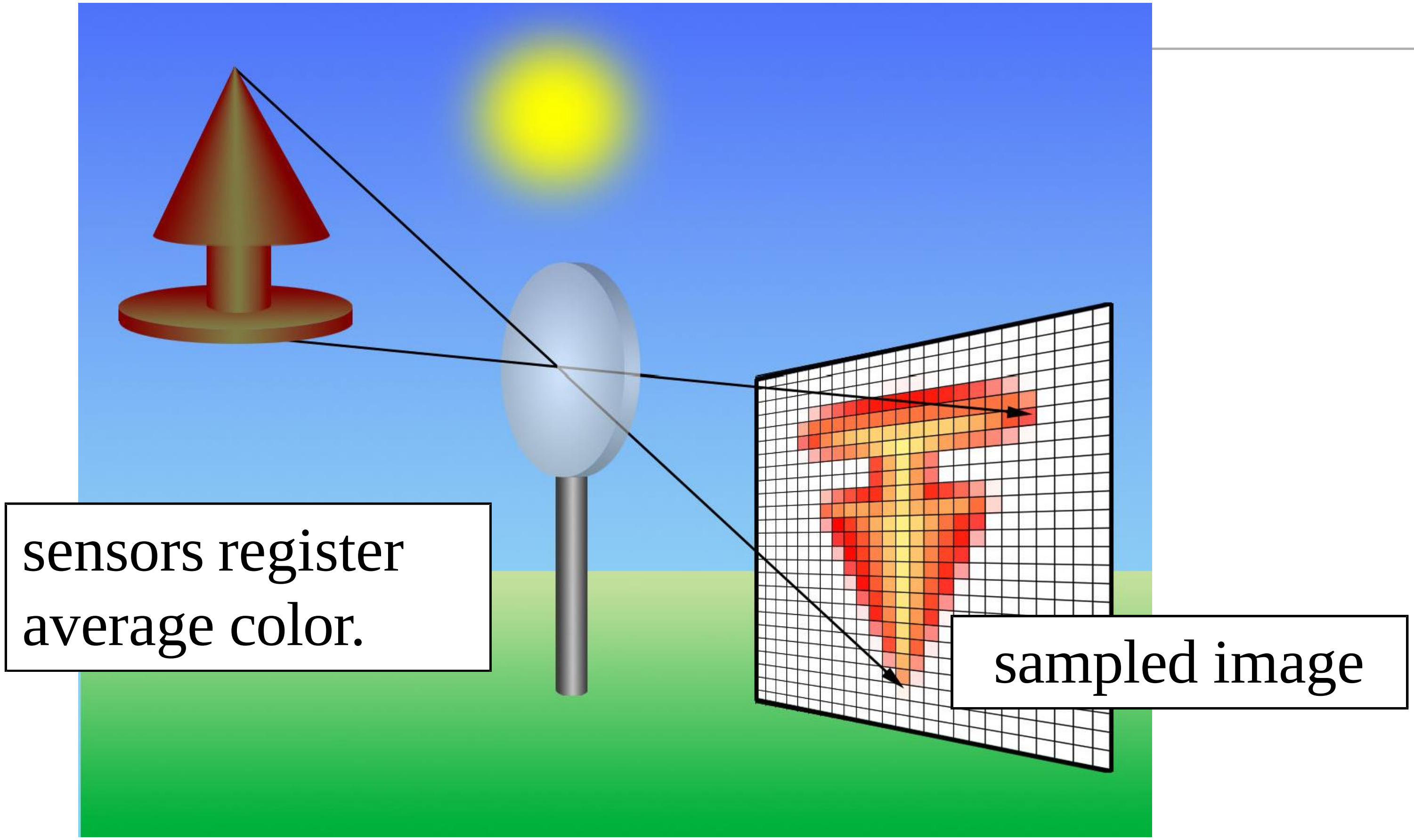


Image formation

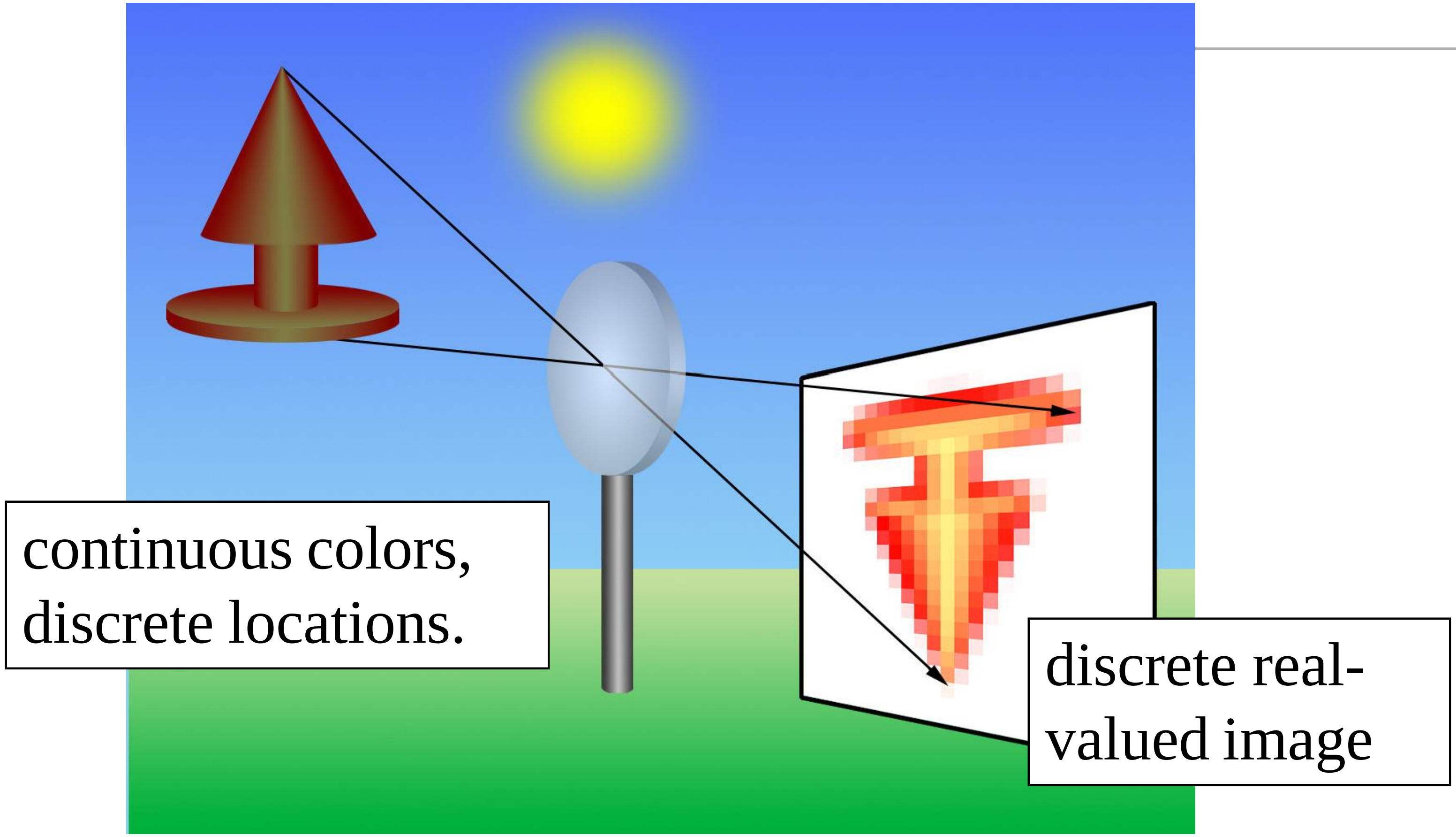
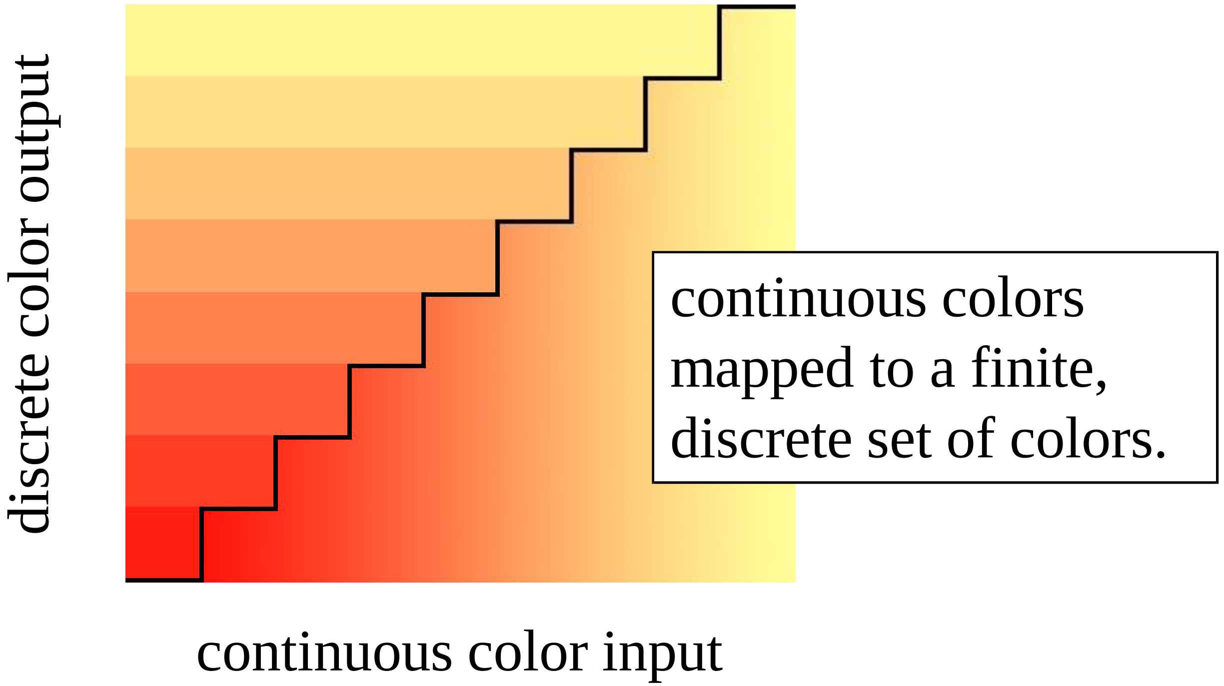


Image formation: Quantization



Sampling and quantization

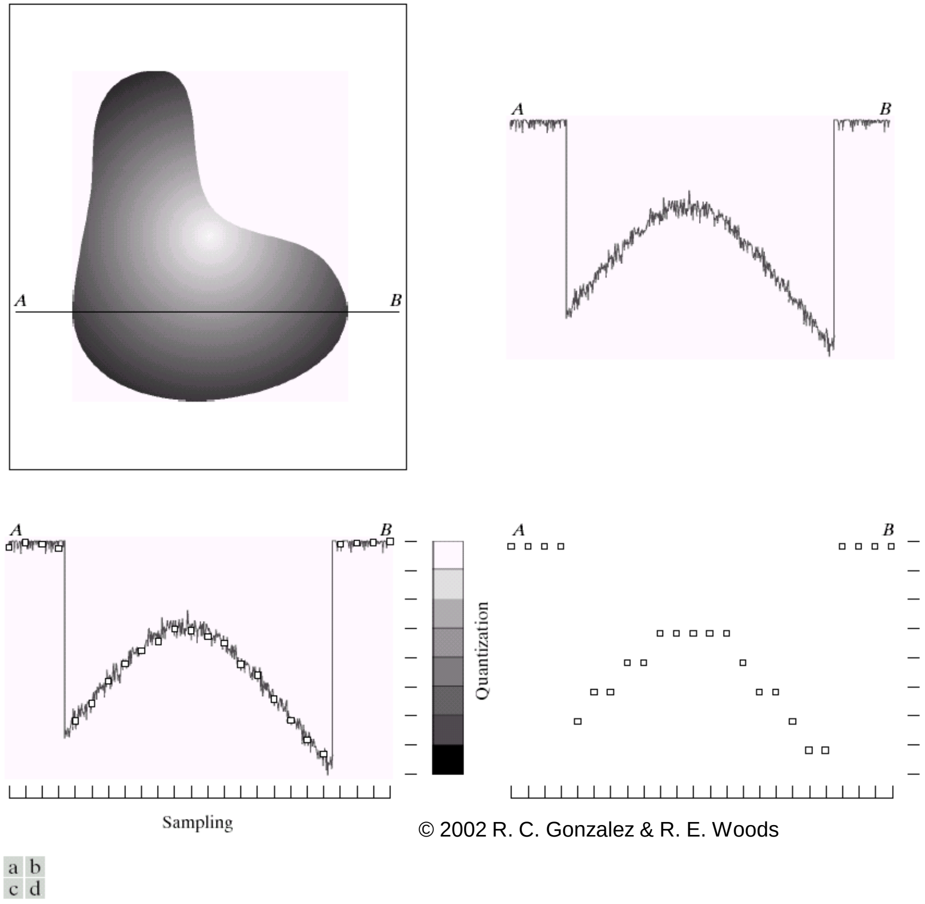
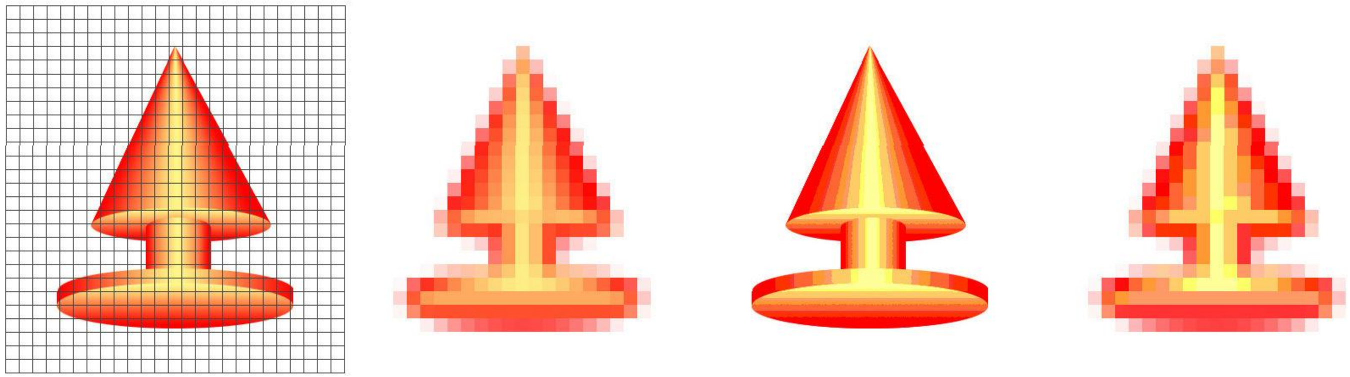


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling and quantization

pixel grid



real image | sampled | quantized | sampled & quantized

Representation of digital images

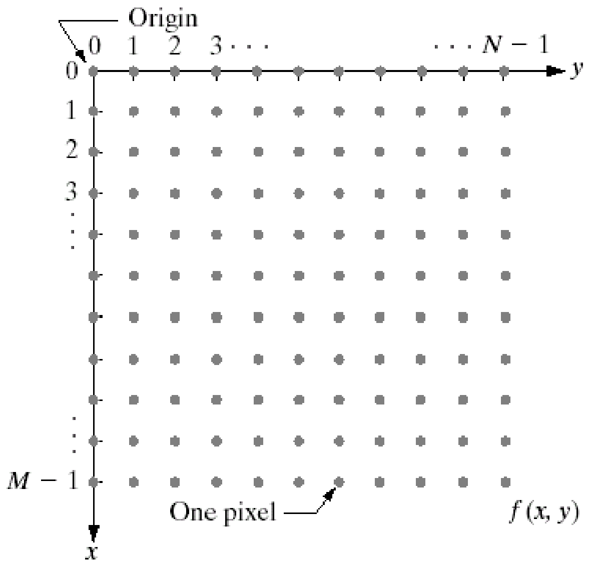


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Number of bits required to store an $M \times N$ image with 2^k gray levels:

$$b = M \times N \times k$$

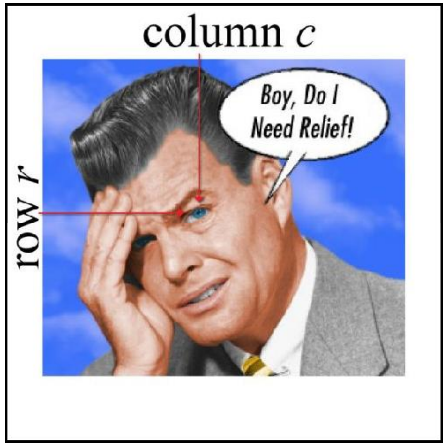
Pixels

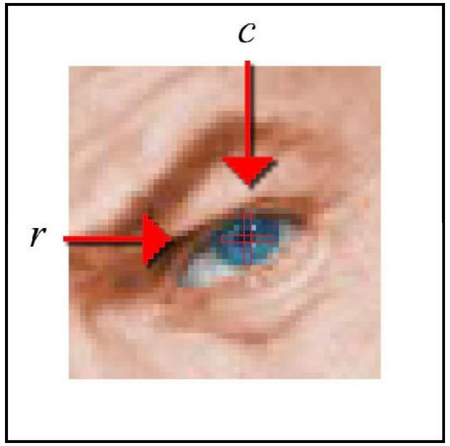
- A digital image, I, is a mapping from a 2D grid of uniformly spaced discrete points, $\{p = (r,c)\}$, into a set of positive integer values, $\{I(p)\}$, or a set of vector values, *e.g.*, $\{[R\ G\ B]^T(p)\}$.
- At each column location in each row of I there is a value.
- The pair $(p, I(p))$ is called a "pixel" (for *picture element*).

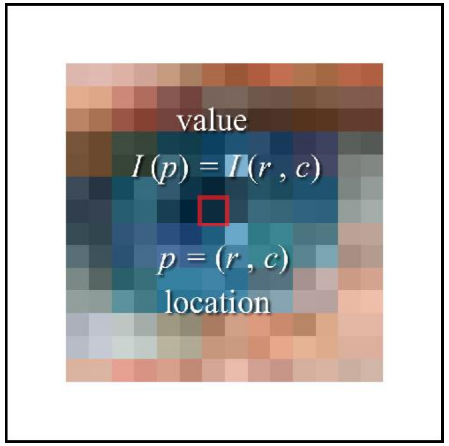
Pixels

- $p = (r,c)$ is the pixel location indexed by row, r, and column, c.
- $I(p) = I(r,c)$ is the value of the pixel at location p.
- If $I(p)$ is a single number then I is monochrome.
- If $I(p)$ is a vector (ordered list of numbers) then I has multiple bands (*e.g.*, a color image).

Pixels







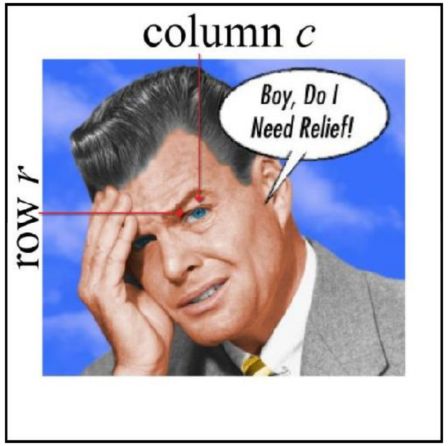
Pixel Location: $p = (r, c)$

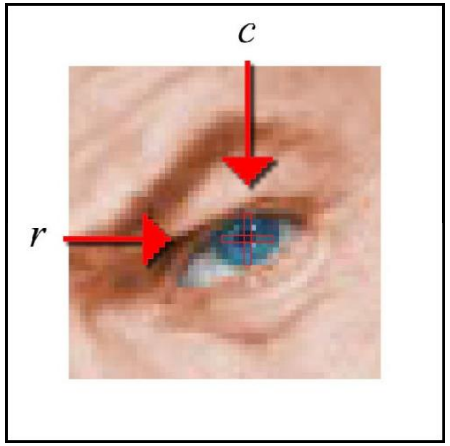
Pixel Value: $I(p) = I(r, c)$

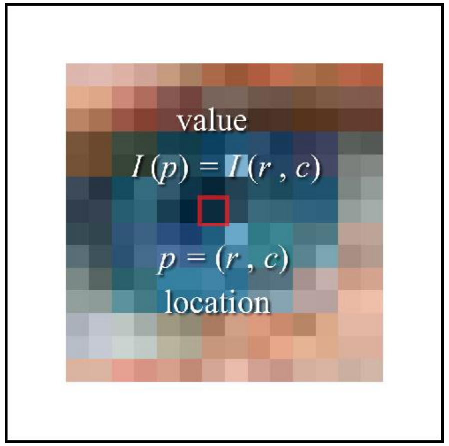
Pixel : $[p, I(p)]$

Pixels

$$\text{Pixel} : [\, p, I(p) \,]$$



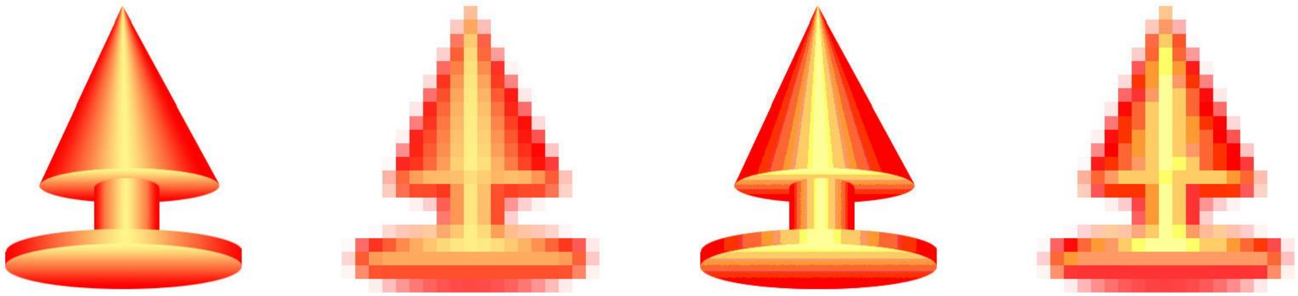




$$\begin{aligned} p &= (r, c) \\ &= (\text{row \#},\ \text{col \#}) \\ &= (272,\ 277) \end{aligned}$$

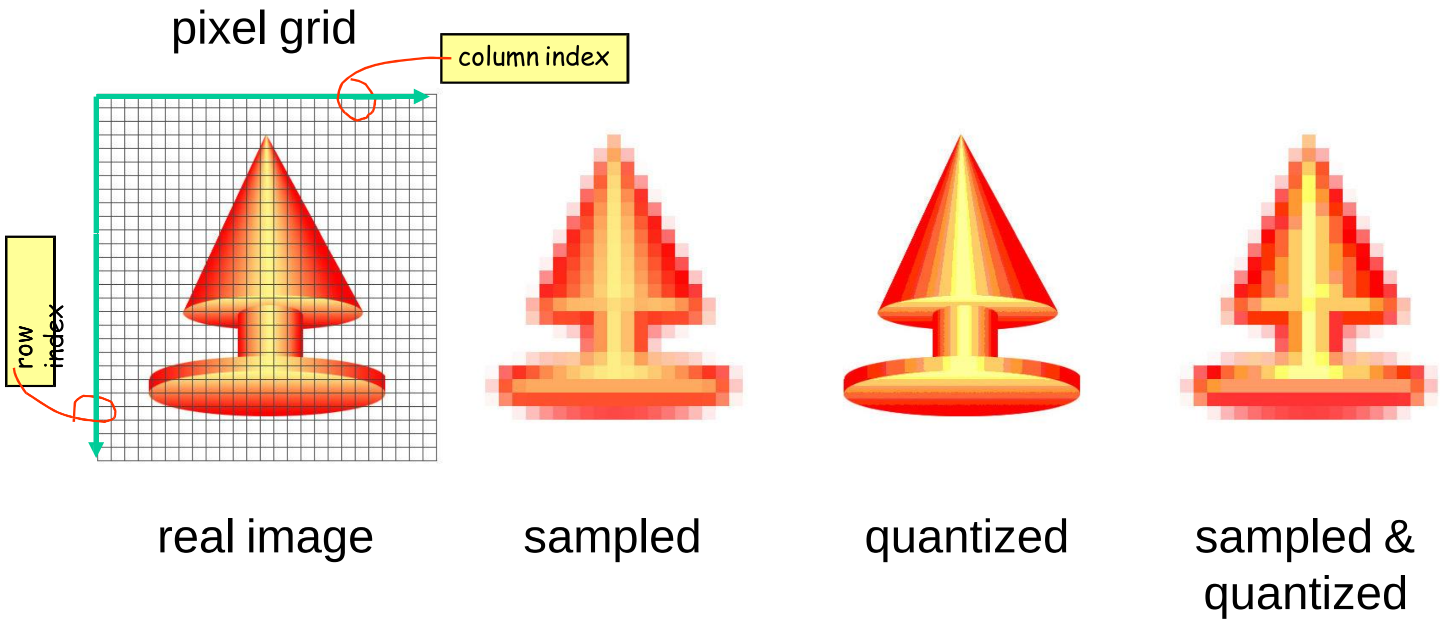
$$I(p) = \begin{bmatrix} \text{red} \\ \text{green} \\ \text{blue} \end{bmatrix} = \begin{bmatrix} 12 \\ 43 \\ 61 \end{bmatrix}$$

Sampling and quantization



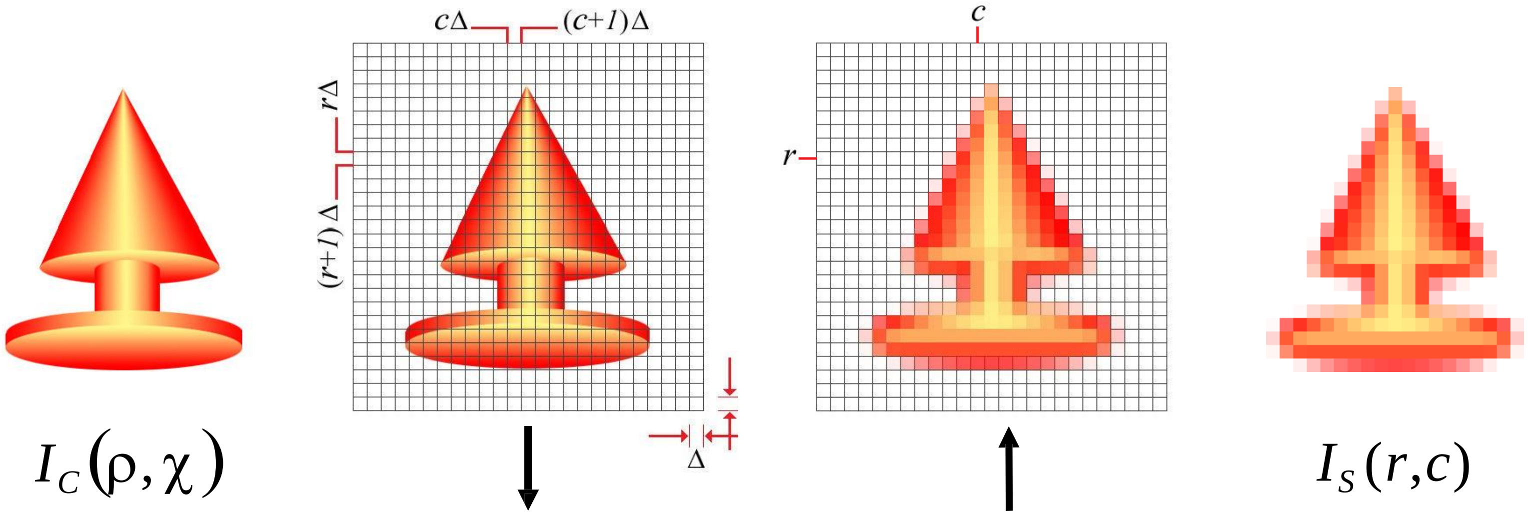
real image | sampled | quantized | sampled & quantized

Sampling and quantization



Sampling and quantization

Take the average within each square.



$I_C(\rho,\chi)$

continuous image

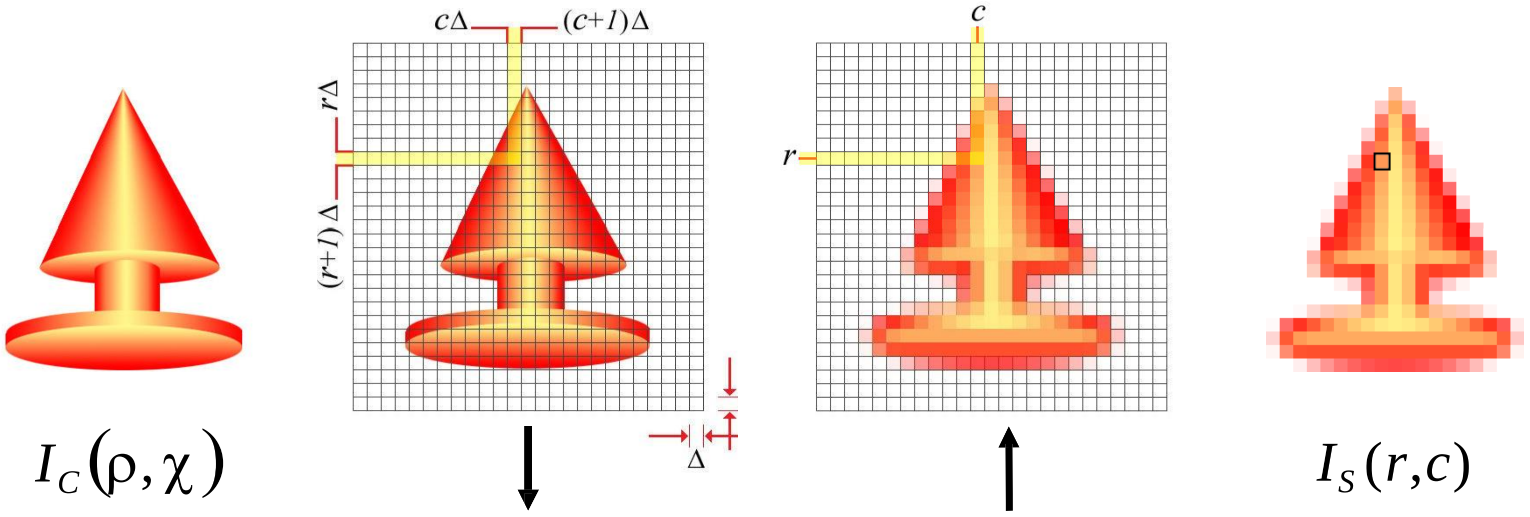
$$I_S(r,c) = \frac{1}{\Delta^2} \int_{r\Delta}^{(r+1)\Delta} \int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

$I_S(r,c)$

sampled image

Sampling and quantization

Take the average within each square.



$I_C(\rho,\chi)$

continuous image

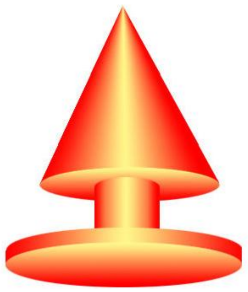
$$I_S(r,c)=\frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

$I_S(r,c)$

sampled image

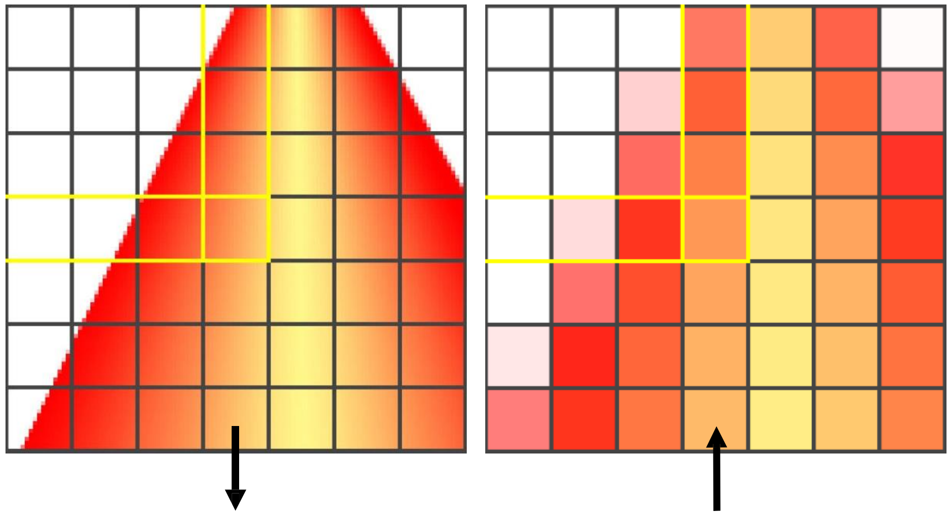
Sampling and quantization

Take the average within each square.



$I_C(\rho,\chi)$

continuous image



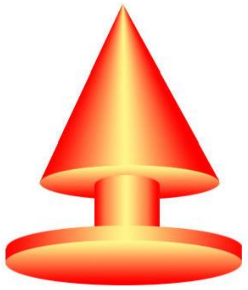
$$I_S(r,c) = \frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

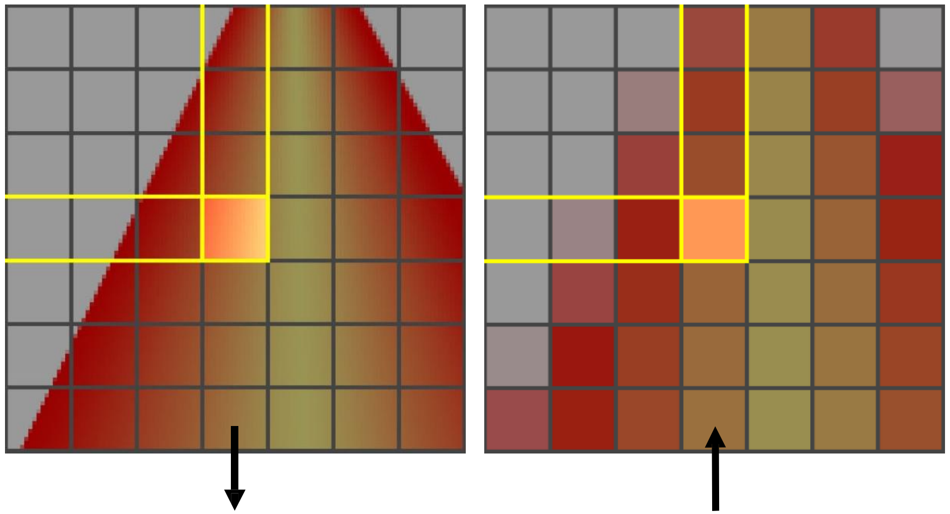
$I_S(r,c)$

sampled image

Sampling and quantization

Take the average within each square.





$I_C(\rho,\chi)$

continuous image

$I_S(r,c)$

sampled image

$$I_S(r,c) = \frac{1}{\Delta^2} \int_{r\Delta}^{(r+1)\Delta} \int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

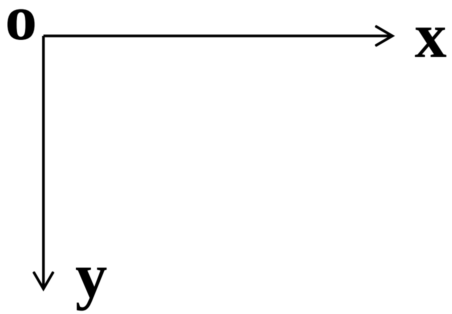
Spatial and gray level resolution

- Resolution refer to the smallest discernible change
- M x N…spatial resolution
- L…gray level resolution

A (2D) Image

An image = a 2D function *f*(*x*,*y*) where

- *x* and *y* are spatial coordinates
- *f*(*x*,*y*) is the intensity or gray level



An digital image:

- *x*, *y*, and *f*(*x*,*y*) are all finite
- For example $x \in \{1,2,\ldots,M\}$, $y \in \{1,2,$

$$f(x,y) \in \{0,1,2,\ldots,255\}$$

Digital image processing → processing digital images by means of a digital computer

Each element (*x*,*y*) in a digital image is called a pixel (picture element)

A Simple Image Formation Model

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

$0 < f(x,y) < \infty$: • Image (positive and finite)

Source: $0 < i(x,y) < \infty$: • Illumination component

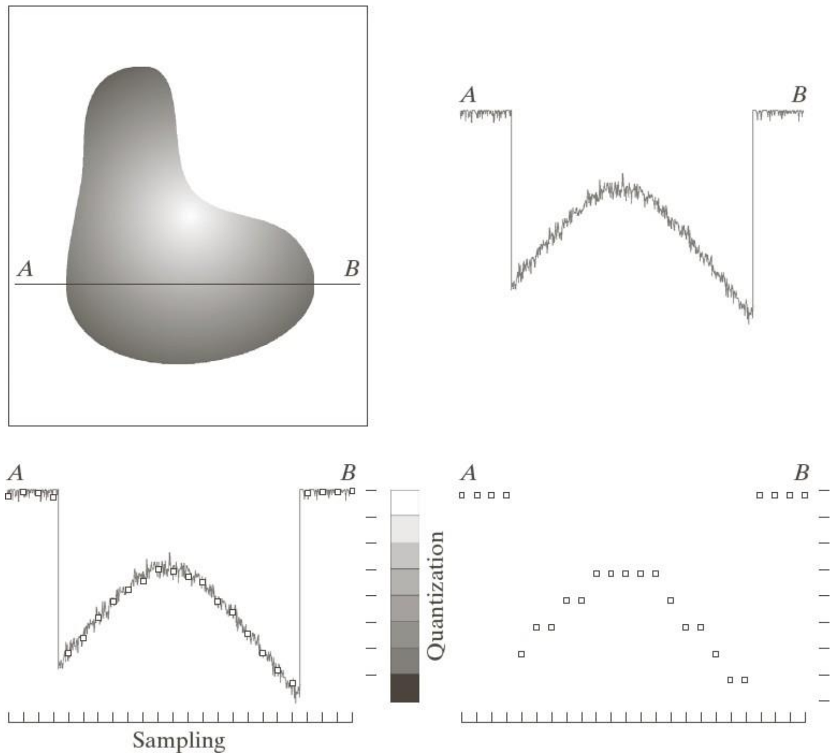
Object: $0 < r(x,y) < 1$: • Reflectance/transmission component

$L_{\min} < f(x,y) < L_{\max}$ **in practice** **where** $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

i(x,y): **Sunlight: 10,000 lm/m² (cloudy), 90,000lm/m² clear day**
Office: 1000 lm/m²

r(x,y): **Black velvet 0.01; 0.93 snow**

Image Sampling and Quantization



a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling: Digitizing the coordinate values (usually determined by sensors)

Quantization: Digitizing the amplitude values

Image Sampling and Quantization in a Sensor Array

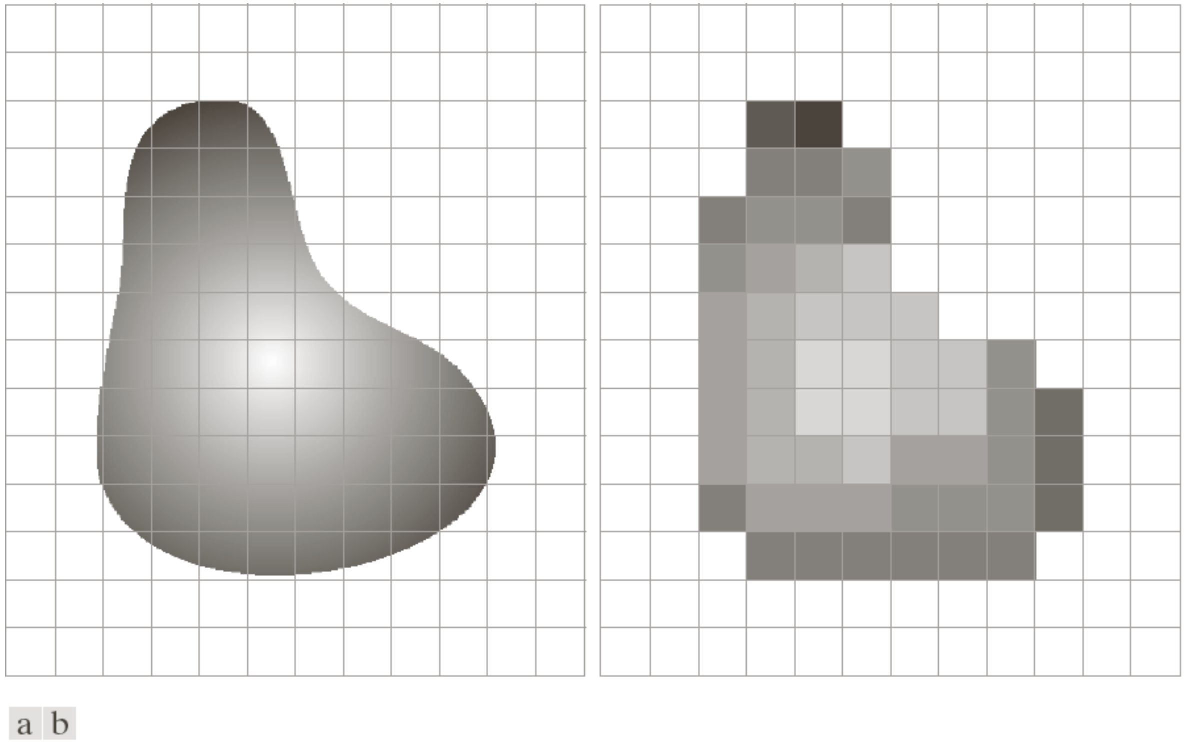


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

CCD array