Basic Concepts in Digital Image Processing

Now,

Introducing some basic concepts in digital image processing

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

Reading: Chapter 2.

Properties of Human Vision System

Rods vs Cones

Brightness adaptation

Brightness discrimination: Weber Ratio

Human Vision Perception

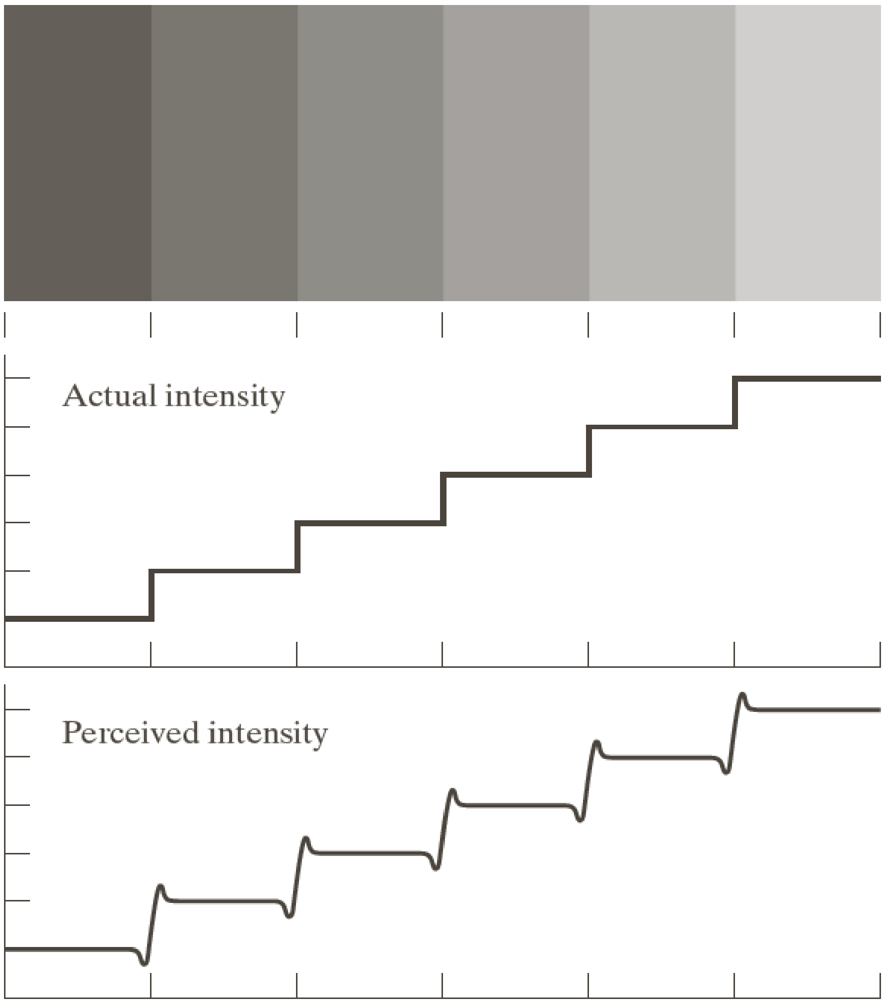
Perceived intensity is not a simple function of intensity

- Edge
- Simultaneous contrast

Optical illusion

- Illusory contours
- Figure/ground

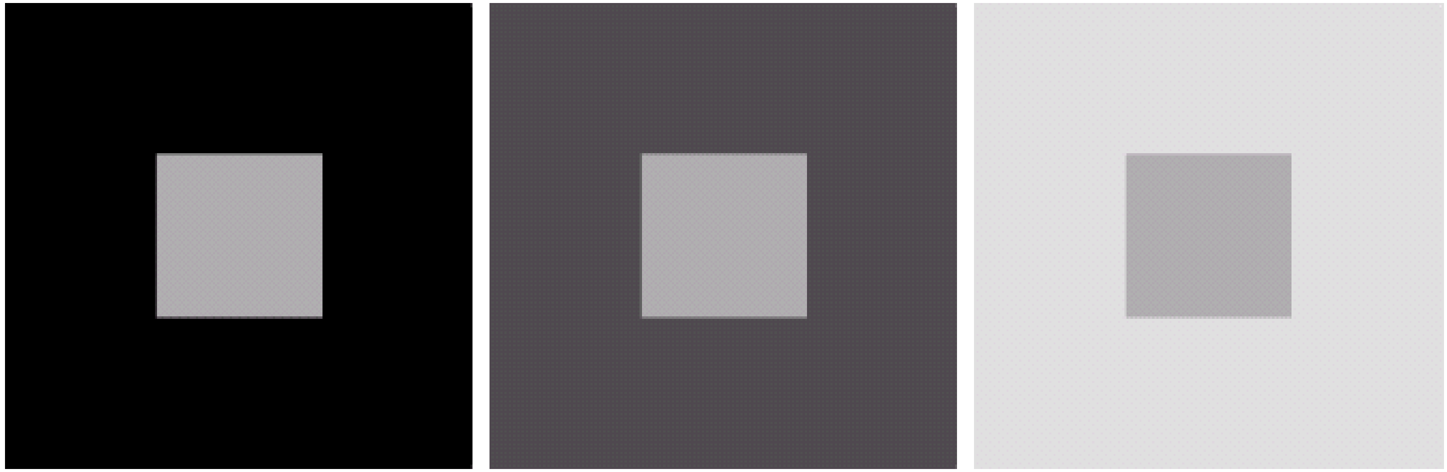
Perceived Intensity is Not a Simple Function of the Actual Intensity (1)



a
b
c

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

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



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.

Human Vision Perception

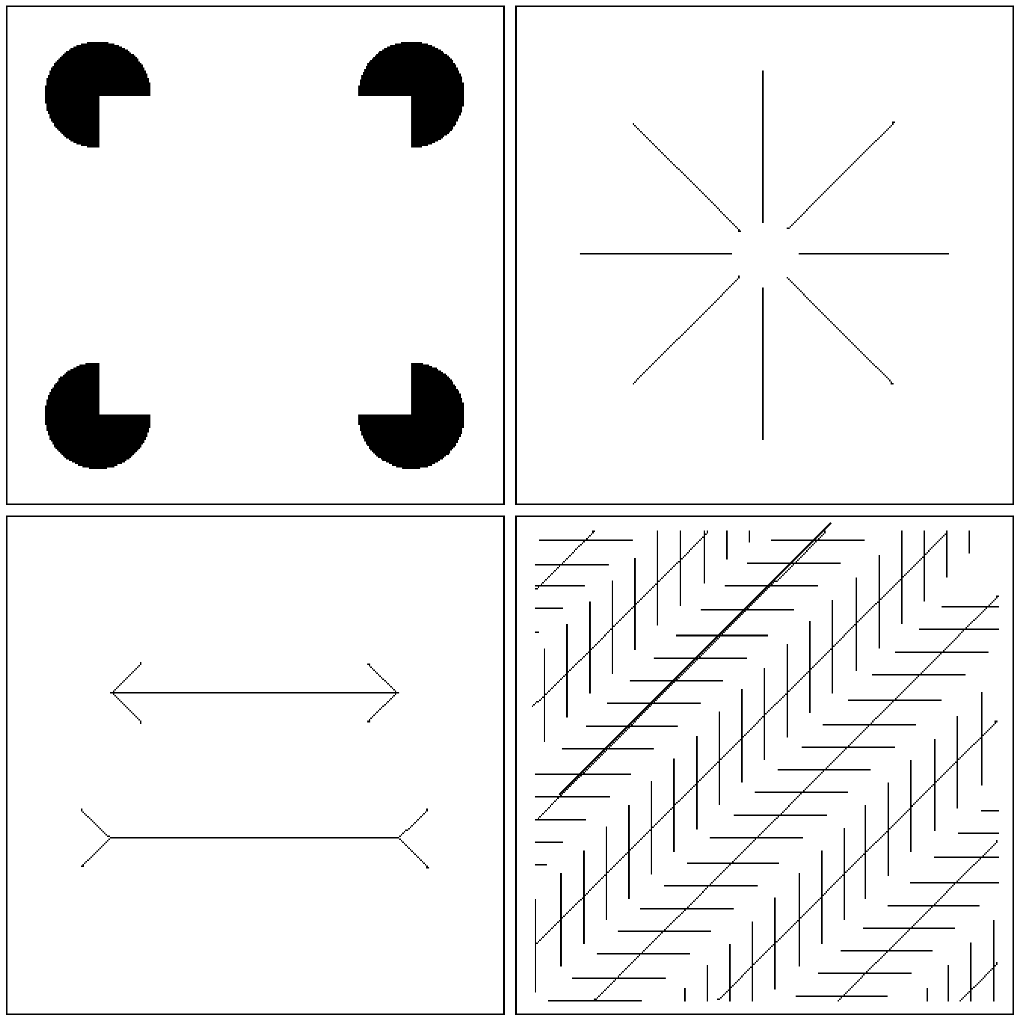
Perceived intensity is not a simple function of intensity

- Edge
- Simultaneous contrast

Optical illusion

- Illusory contours
- Figure/ground

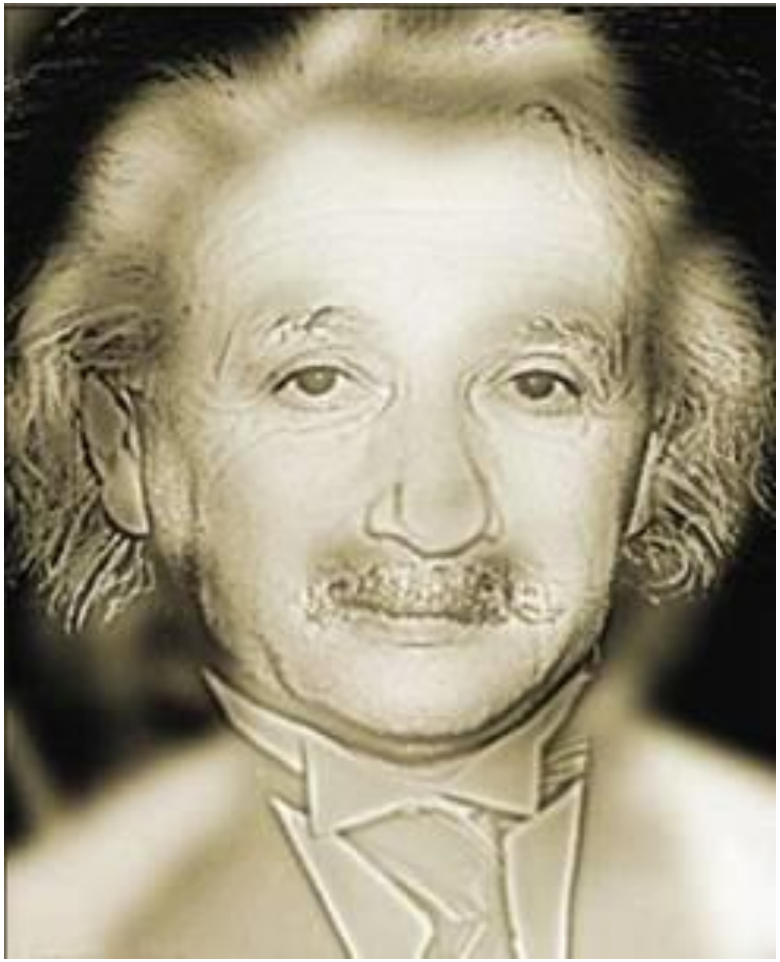
Optical Illusions: Complexity of Human Vision



a b
c d

FIGURE 2.9 Some well-known optical illusions.

More Optical Illusions



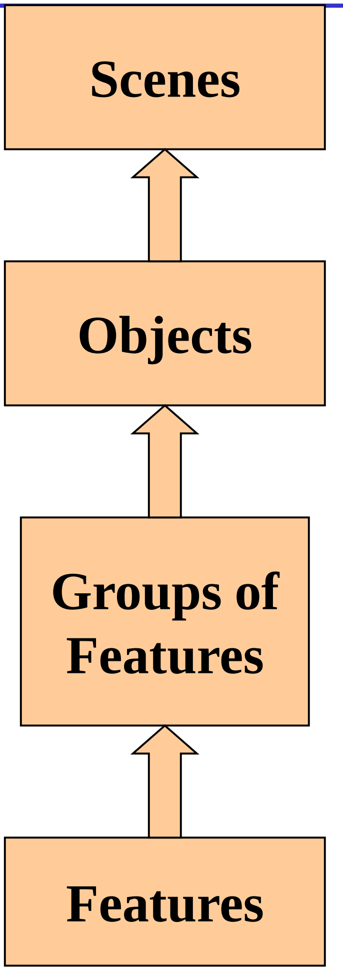
http://www.123opticalillusions.com/

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.



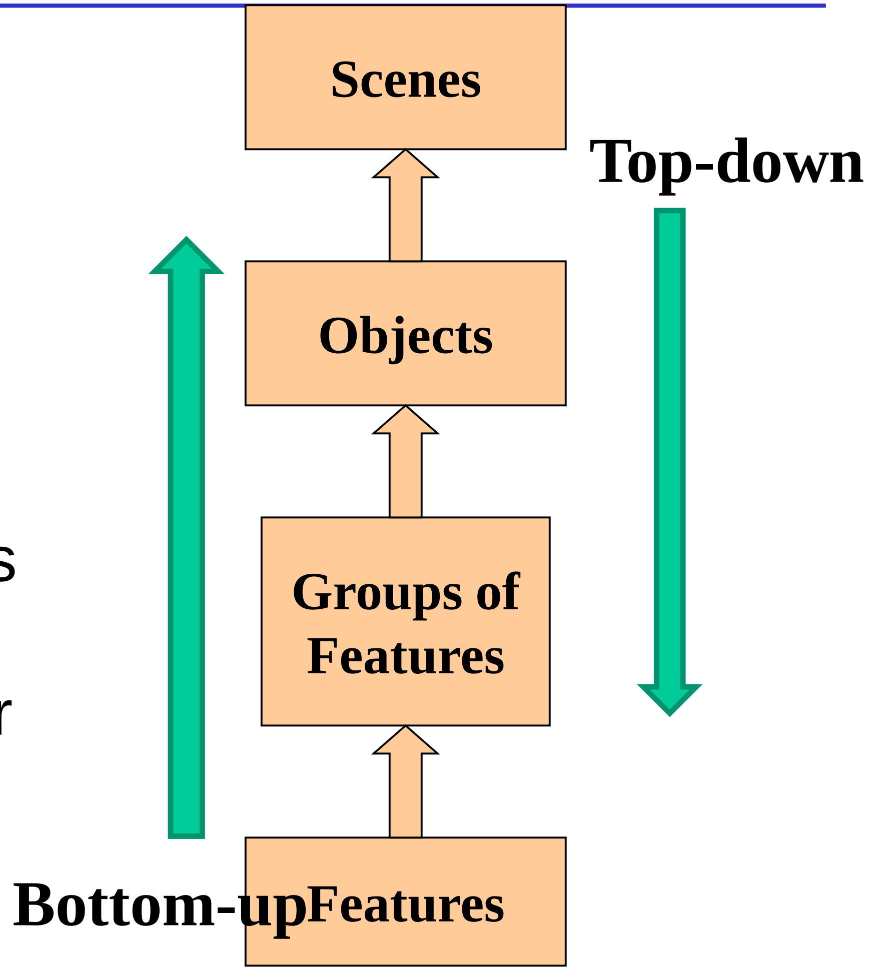
What do we do with all of this visual information??

“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!

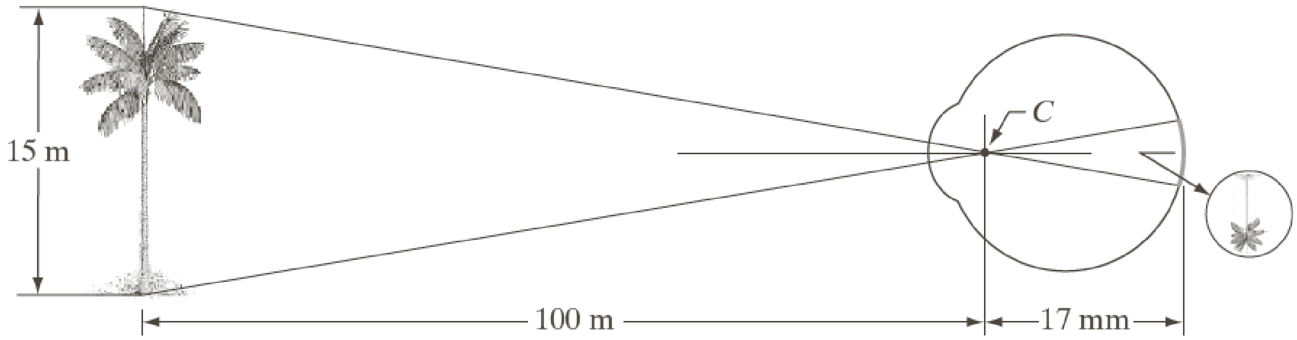
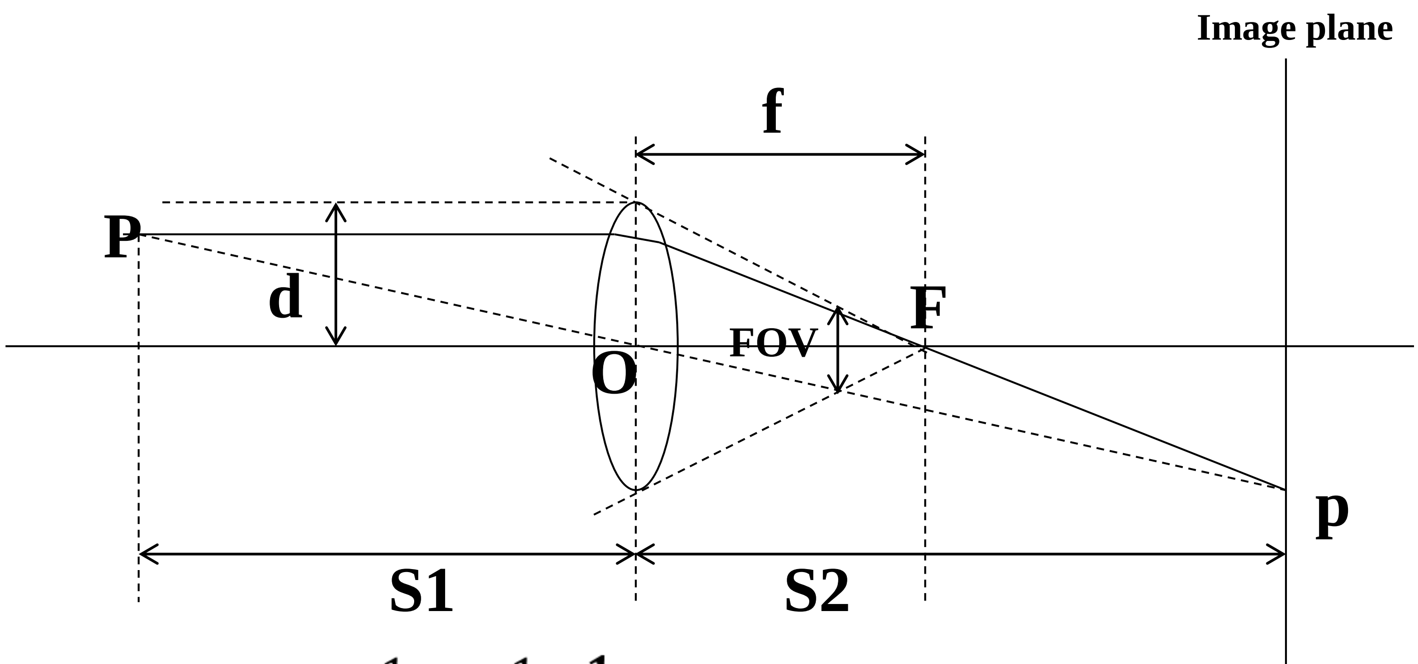


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

Adjust focus length

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

Lens Parameters



Thin lens theory: $\frac{1}{S1} + \frac{1}{S2} = \frac{1}{f}$

Field of View: $\omega = 2arctan\frac{d}{f}$

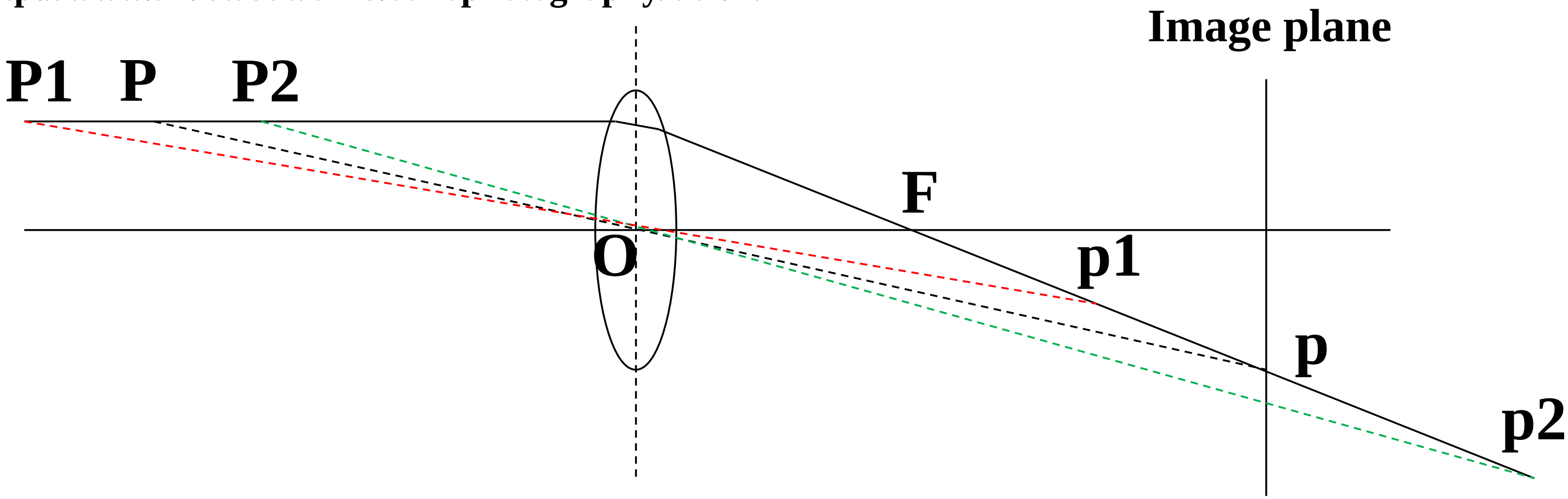
FOV

- Increasing the distance from the object to the lens will reduce the size of image
- Large focus length will give a small FOV

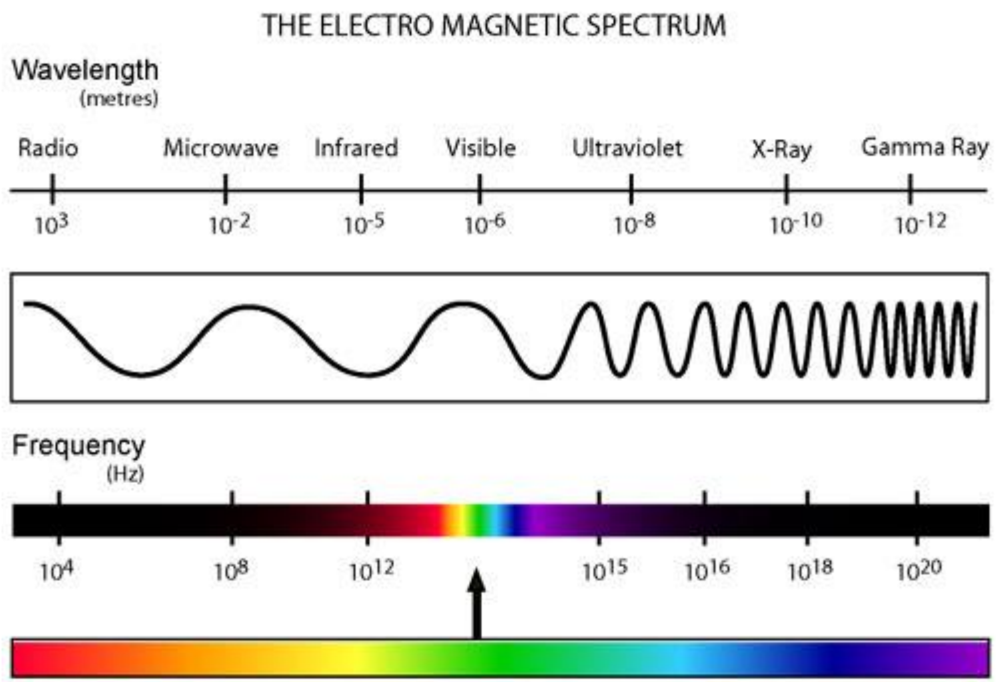
Depth of Field & Out of Focus

http://www.azuswebworks.com/photography/dof.html

- DOF is inversely proportional to the focus length
- DOF is proportional to S1



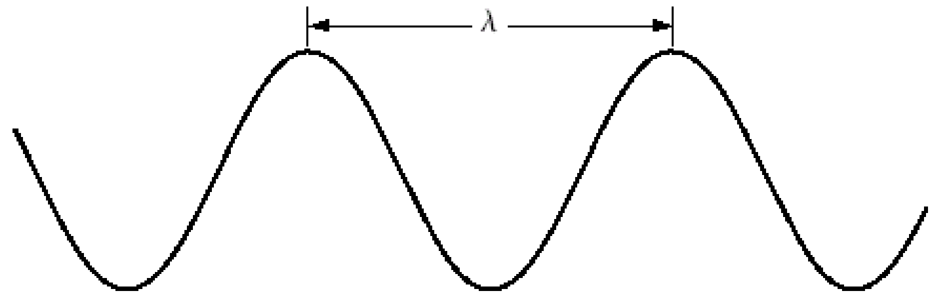
Light and EM Spectrum



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

Relation Among Wavelength, Frequency and Energy

FIGURE 2.11
Graphical representation of one wavelength.



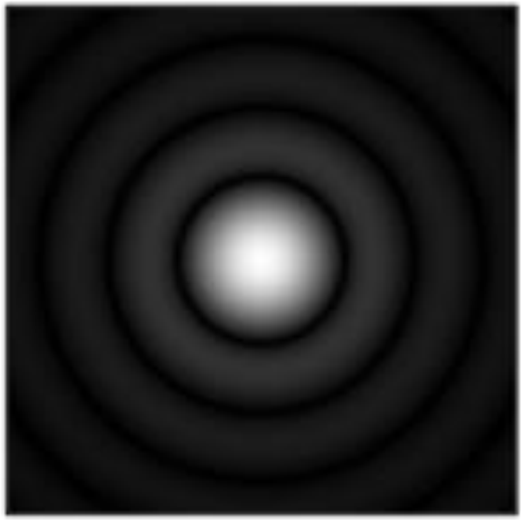
$$\text{wavelength } (\lambda), \text{ frequency } (v), \text{ and energy } (E)$$

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

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

Light and EM Spectrum

What size of the object you can "see"? Diffraction-limit.

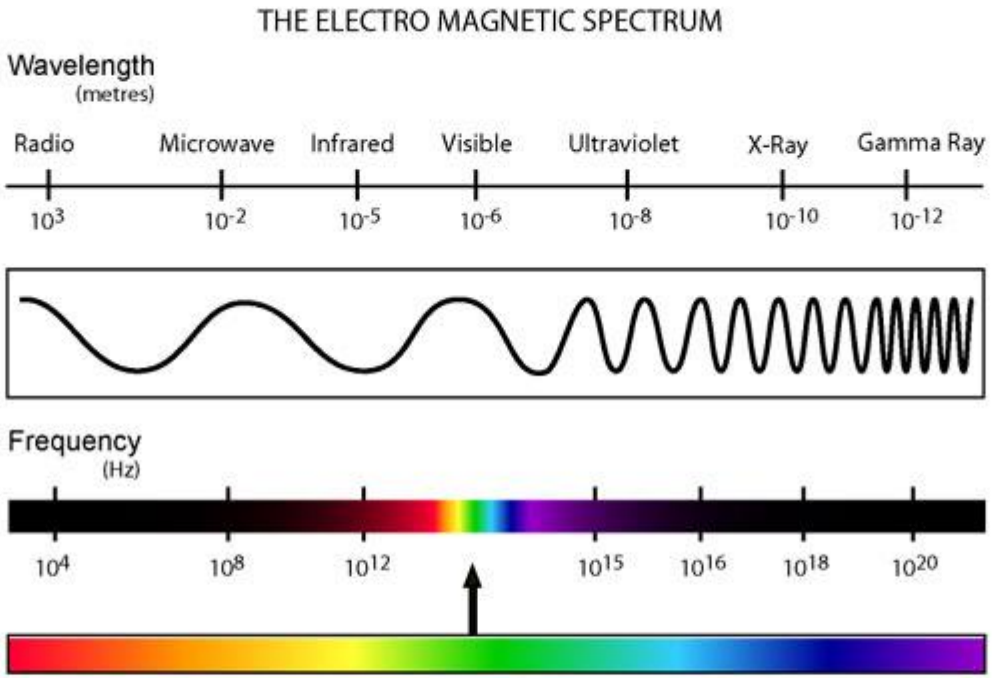


http://en.wikipedia.org/wiki/Airy_disc

Airy disk: the size is proportional to wavelength and f-number (focal length/lens dimension)

$$\sim\lambda \frac{f}{d}$$

Light and EM Spectrum



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

Image Sensing and Acquisition

Illumination energy → digital images

Incoming energy is transformed into a voltage

Digitizing the response

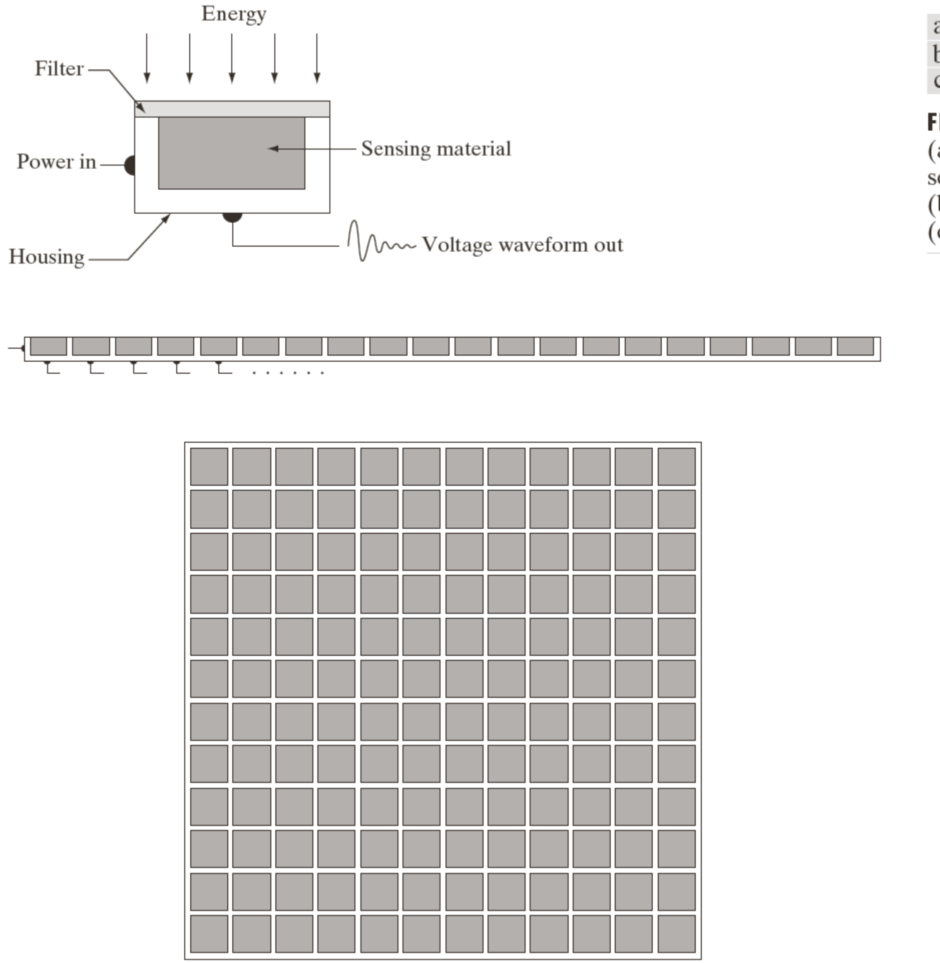
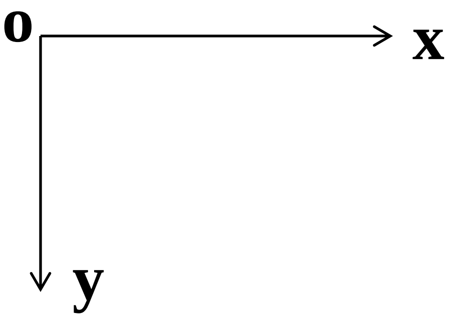


FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

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 $x \in \{1, 2, \ldots, M\}$, $y \in \{1, 2, \ldots, N\}$

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

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**

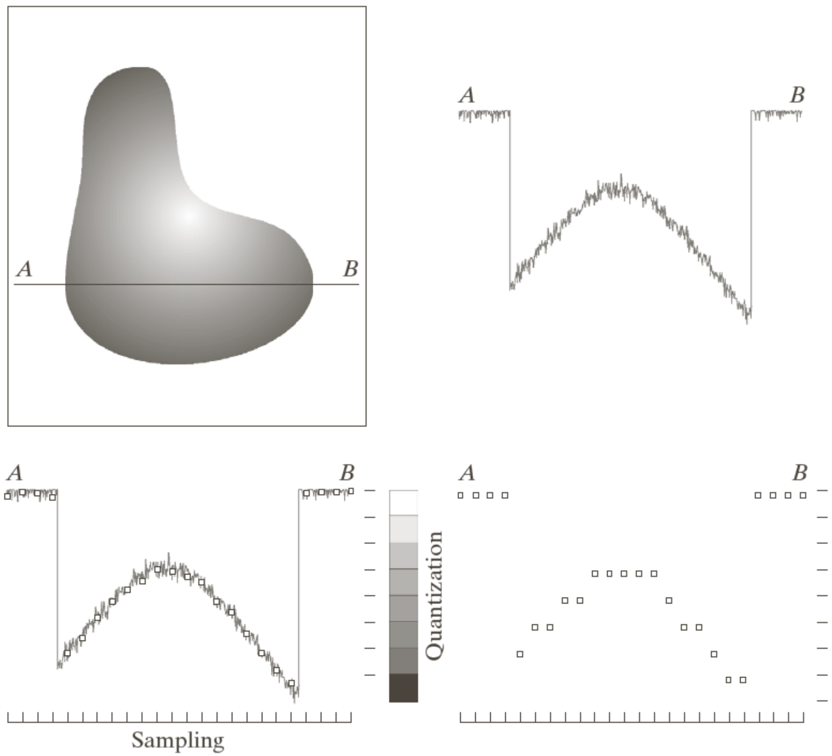
$L_{\min} < f(x,y) < L_{\max}$ **in practice**

where $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

i(x,y): **Sunlight: 10,000 lm/m^2 (cloudy), 90,000lm/m^2 clear day**
Office: 1000 lm/m^2

r(x,y): **Black velvet 0.01; white pall 0.8; 0.93 snow**

Image Sampling and Quantization



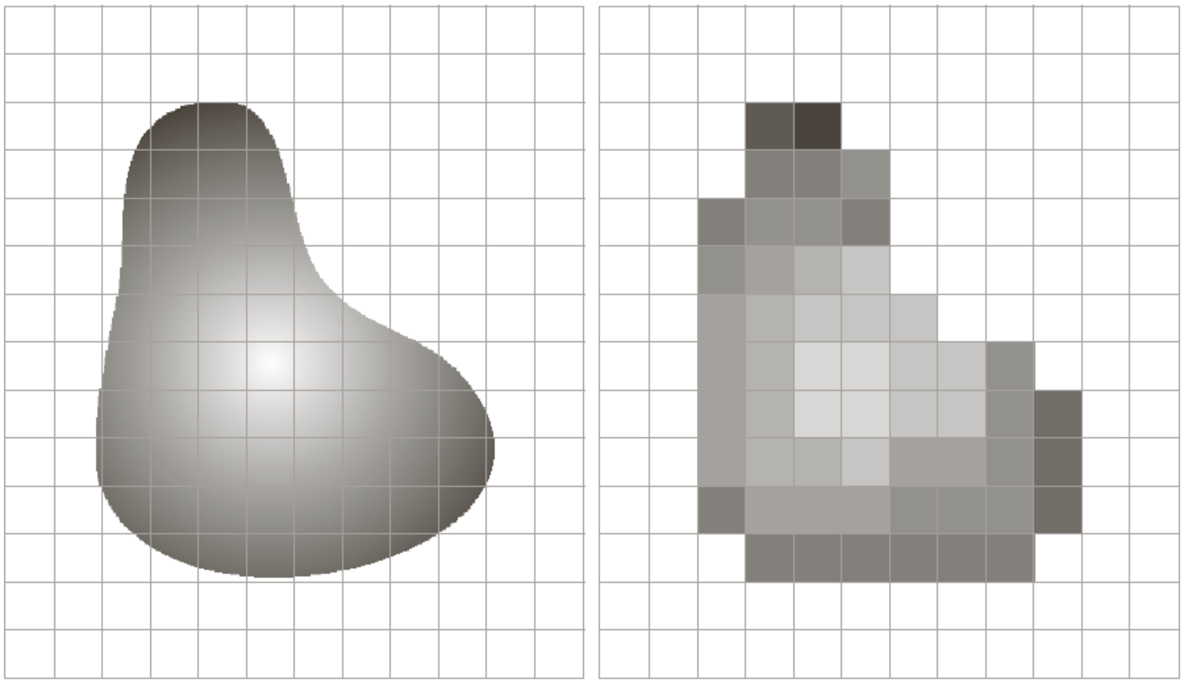
a b
c d

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



a b

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

CCD array

Dynamic Range

$L_{\min} < f(x,y) < L_{\max}$ **in practice**

where $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

$0 \le f(x,y) \le L-1$ **and** $L = 2^k$

Dynamic range/contrast ratio:

the ratio of the maximum detectable intensity level (saturation) to the minimum detectable intensity level (noise)

$$\frac{I_{max}}{I_{min}}$$

Representing Digital Images

(a)*: f*(*x*,*y*), *x*=0, 1, …, *M*-1, *y*=0,1, …, *N*-1

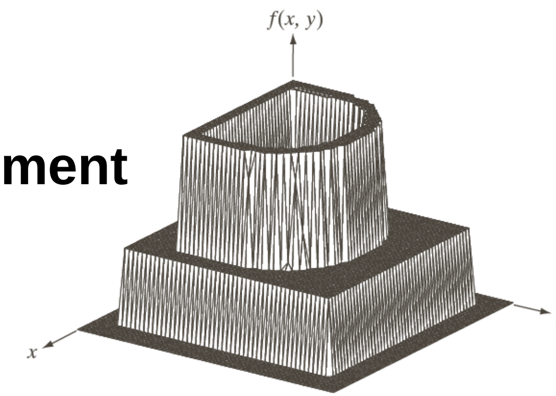
***x*, *y*: spatial coordinates → spatial domain**

(b): suitable for visualization

(c): processing and algorithm development

***x*: extend downward (rows)**

***y*: extend to the right (columns)**



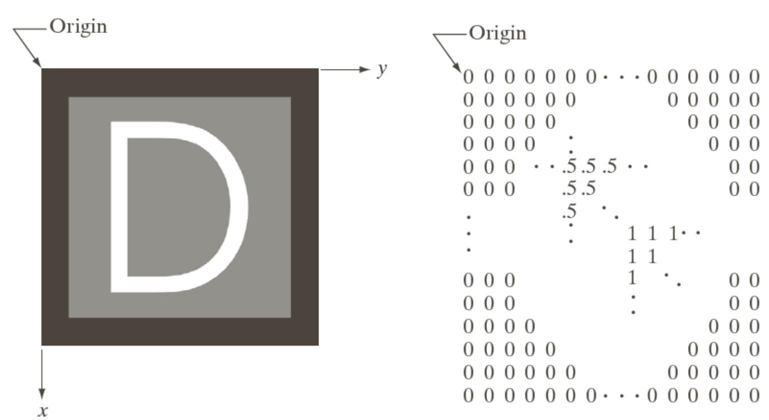
Number of bits storing the image

↑

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

a
b c

FIGURE 2.18
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array.
(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).



Store an Image

TABLE 2.1
Number of storage bits for various values of N and k.

N/k	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

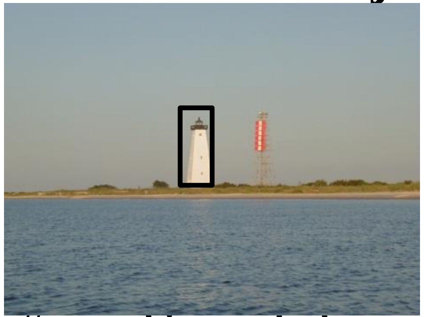
Spatial resolution: smallest discernible details

- # of line pairs per unit distance
- # of dots (pixels) per unit distance
  - Printing and publishing
  - In US, dots per inch (dpi)

Newspaper → magazines → book

Large image size itself does not mean high spatial resolution!

→ **Scene/object size in the image**



1280*960

http://www.shimanodealer.com/fishing_reports.htm

a b
c d

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Intensity Resolution

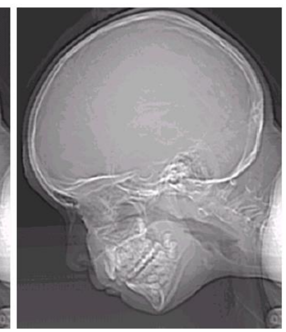
Intensity resolution

- Smallest discernible change in intensity levels
- Using the number of levels of intensities
- False contouring (banding) when *k* is small - undersampling

256

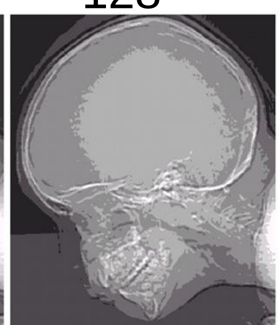
128

64

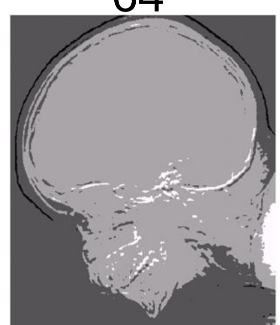


32

16



8



4

2

Isopreference Curves

a b c

FIGURE 2.22 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

Vary the spatial and intensity sampling simultaneously:

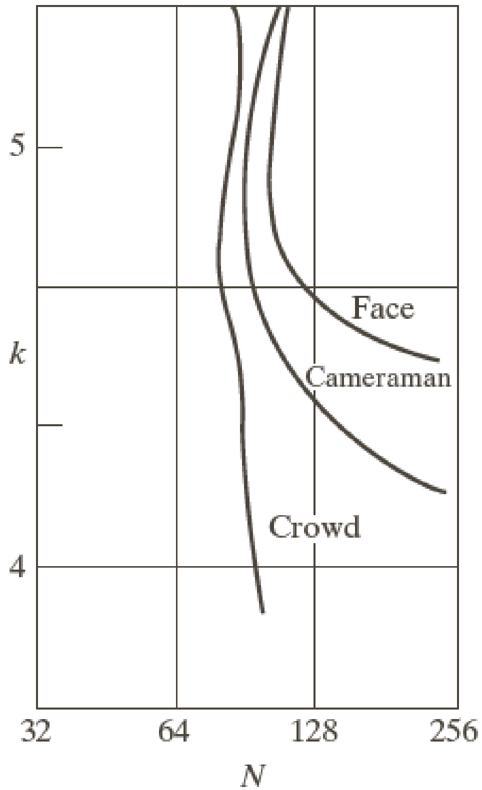
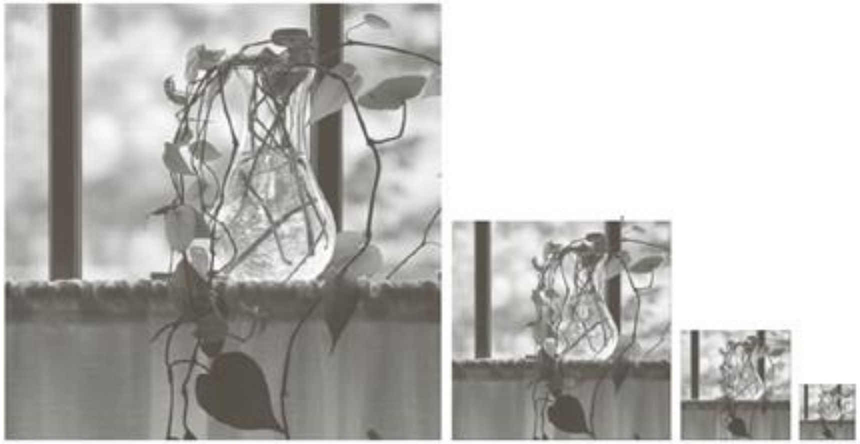


FIGURE 2.23 Typical isopreference curves for the three types of images in Fig. 2.22.

Image Resampling & Interpolation



Need to resample the image when

- Rescaling
- Geometrical transformation
- The output image coordinates are not discrete

Interpolation methods:

- Nearest neighbor
  - Fast and simple
  - Loss of sharpness
  - Artifacts (checkerboard)
- Bilinear
- Bicubic
  - Images are sharpest
  - Fine details are preserved
  - Slow

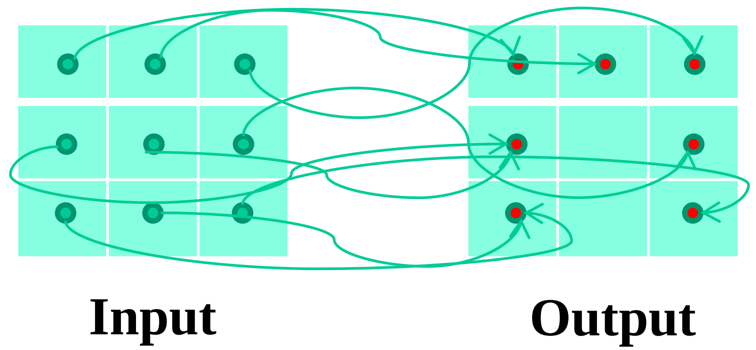
Image Resampling & Interpolation

a b c
d e f

FIGURE 2.24 (a) Image reduced to 72 dpi and zoomed back to its original size (3692 × 2812 pixels) using nearest neighbor interpolation. This figure is the same as Fig. 2.20(d). (b) Image shrunk and zoomed using bilinear interpolation. (c) Same as (b) but using bicubic interpolation. (d)–(f) Same sequence, but shrinking down to 150 dpi instead of 72 dpi [Fig. 2.24(d) is the same as Fig. 2.20(c)]. Compare Figs. 2.24(e) and (f), especially the latter, with the original image in Fig. 2.20(a).

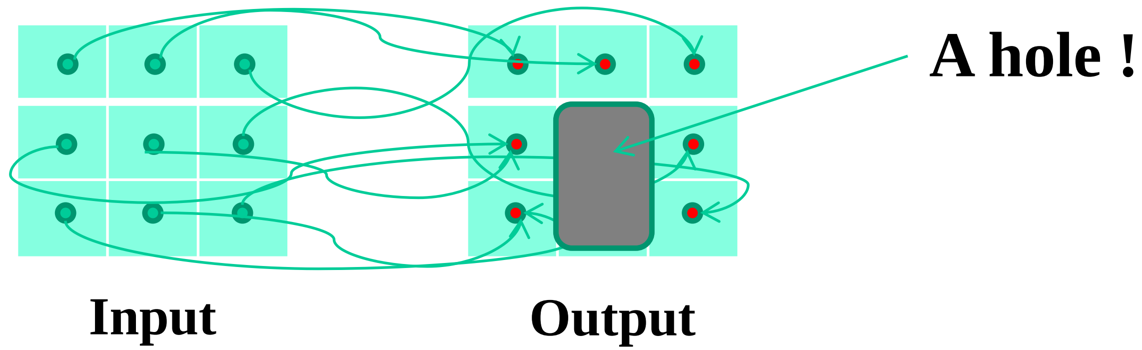
Image Resampling & Interpolation

Forward mapping



Issues on Image Resampling & Interpolation

Missing points in forward mapping



Solution: perform a backward mapping

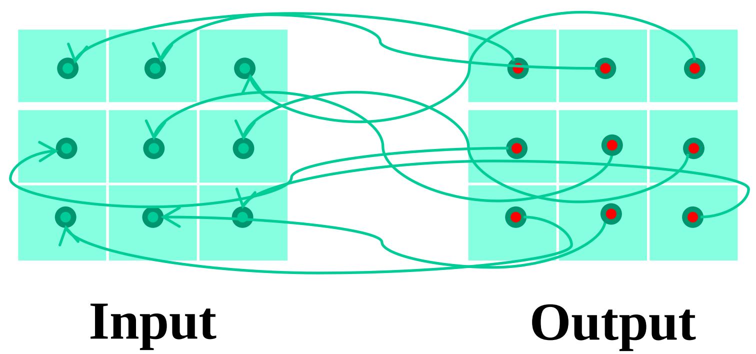
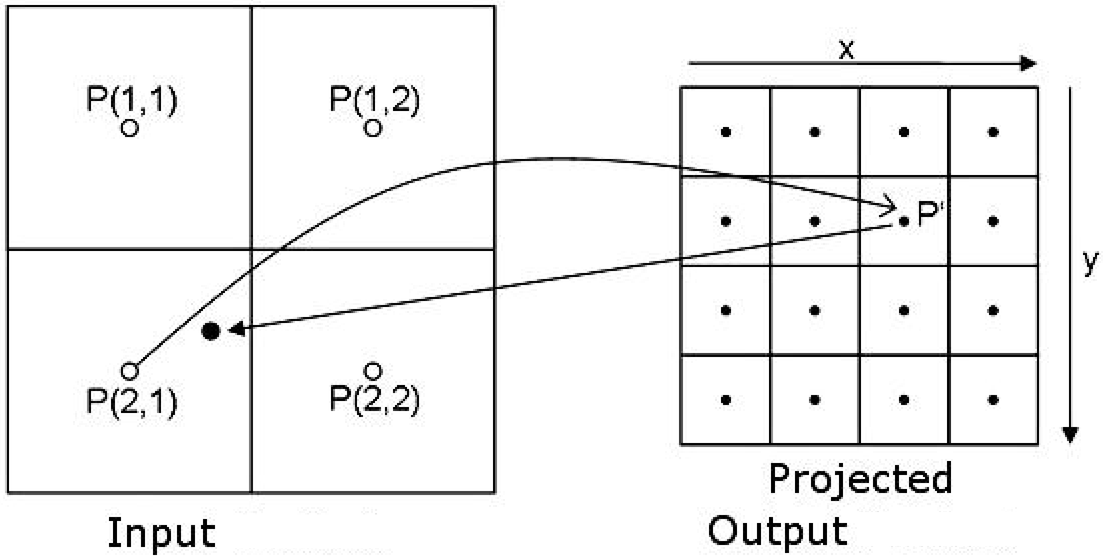


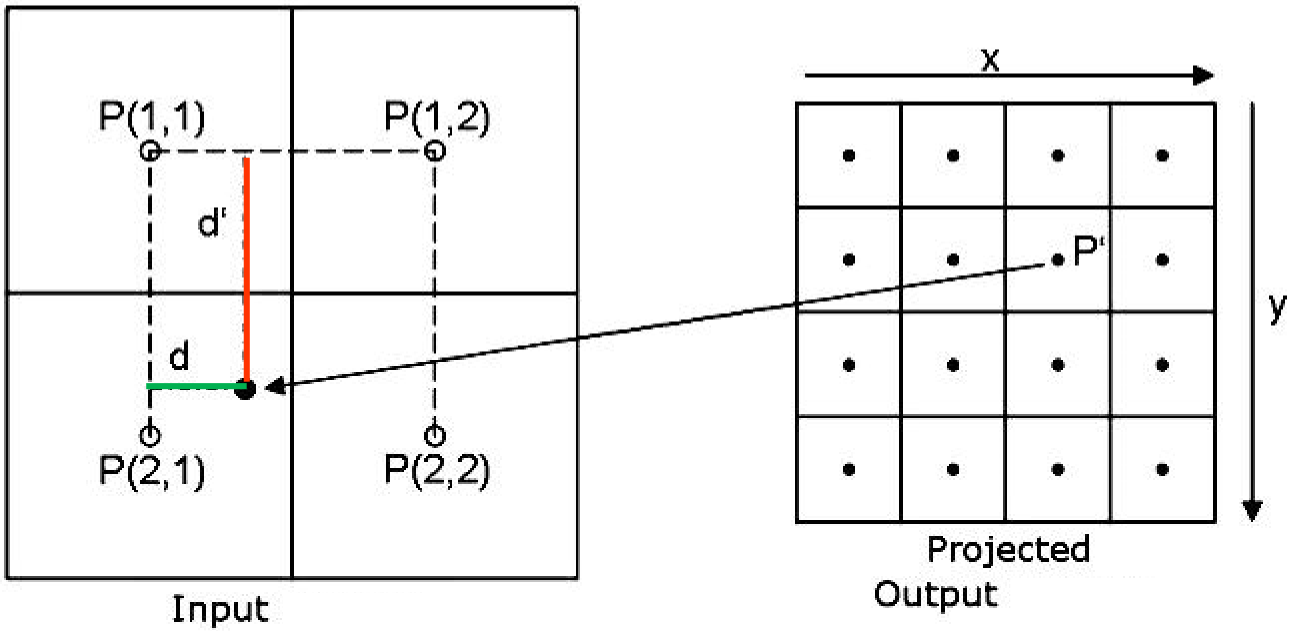
Image Interpolation – Nearest Neighbor



http://www.brockmann-consult.de/beam/doc/help/general/ResamplingMethods.html

Assign each pixel in the output image with the nearest neighbor in the input image.

Image Interpolation – Bilinear

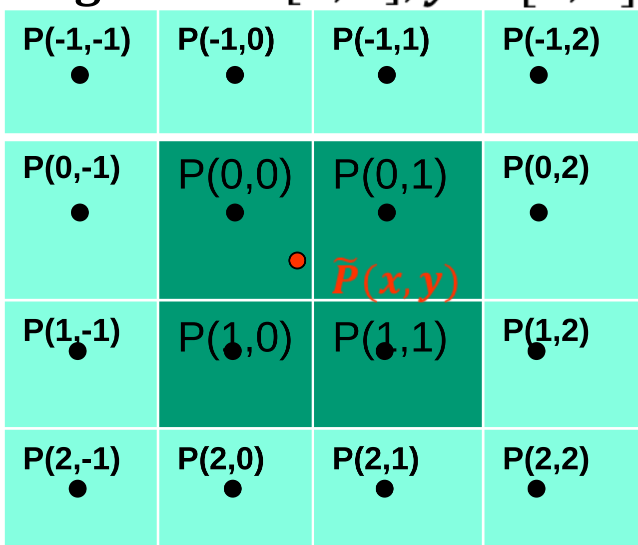


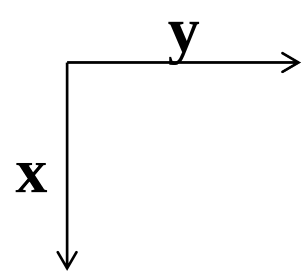
http://www.brockmann-consult.de/beam/doc/help/general/ResamplingMethods.html

$$\boldsymbol{P' = P(1,1)(1-d)(1-d') + P(1,2)d(1-d') + P(2,1) * d' * (1-d) + P(2,2)dd'}$$

Image Interpolation – Bicubic

If we know the intensity values, derivatives, and cross derivatives for the four corners (0,0), (0,1), (1,0), and (1,1), we can interpolate any point (x,y) in the region $x \in [0,1], y \in [0,1]$





$$\widetilde{P}(x,y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j$$

Need to solve the 16 coefficients