DIGITAL IMAGE PROCESSING: DIGITAL IMAGING FUNDAMENTALS

Contents

- This lecture will cover:
  - Examples of fields that use Digital Image Processing
  - Pixel Interpolation methods
  - Distribution of rods and cones around fovea
  - Scotopic and Photopic curves.
  - Isopreference Curves
  - Commonly–used Terminology
    - Pixel neighbors, and adjacency

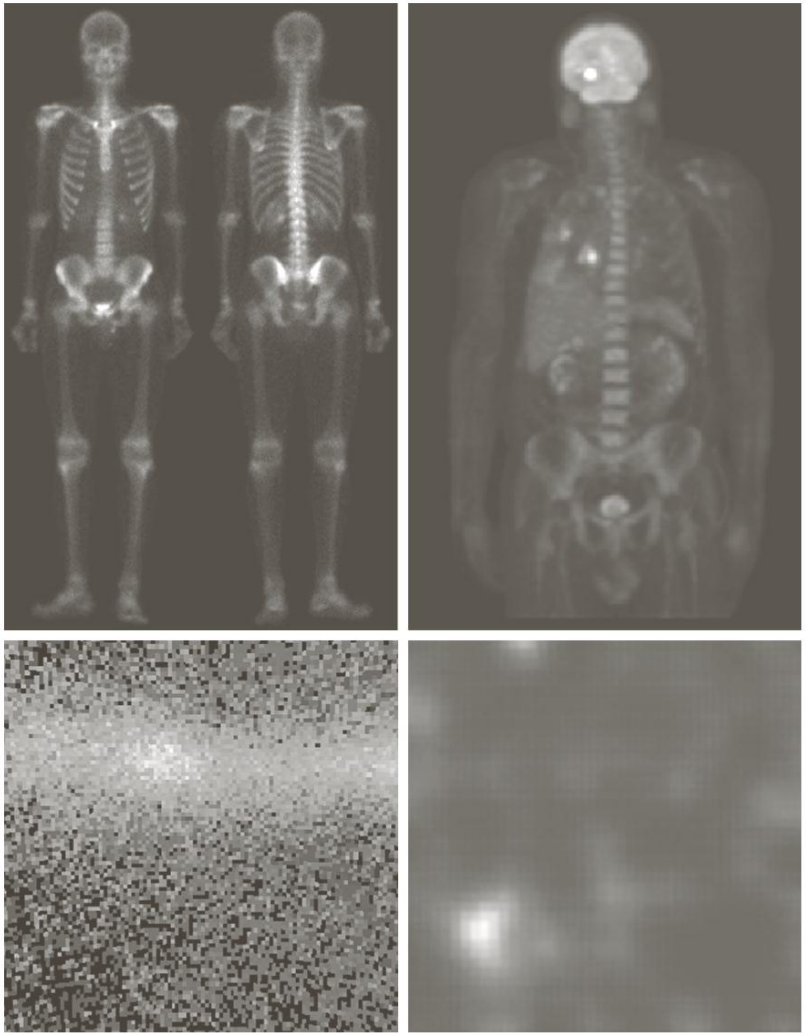
Examples of fields that use Digital Image Processing - **Gamma-Ray Imaging**

- Major uses of G-R Imaging are in **nuclear medicines** and **astronomical observations**
- In nuclear medicines, patients are injected with radioactive isotope that emits gamma rays
- Images are produced from emissions collected by a detector
- Images of this type are used to locate sites of bone pathology
- Gamma rays are detected and tomographic image is created

Examples of fields that use Digital Image Processing

Gamma-Ray Imaging

- G-R imaging is also used for astronomical observations
- Here the source of Gamma radiation is **natural** in contrast to the nuclear medicines



a b
c d

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of Michigan.)

Examples of fields that use Digital Image Processing X-Ray Imaging

- X-ray imaging has a widespread medical and industrial usage
- Digital radiographic images can be obtained by allowing X-rays pass through a patient onto an X-ray film
- Different ways to acquire X-ray images; depending on application
- Angiography relies on X-ray contrast enhancement radiography
- X-ray imaging is also used in Computerized Axial Tomography (CAT) scans
- Similarly, X-ray imaging is also used in industry to examine manufacturing flaws in various components

Examples of fields that use Digital Image Processing **Ultraviolet Imaging**

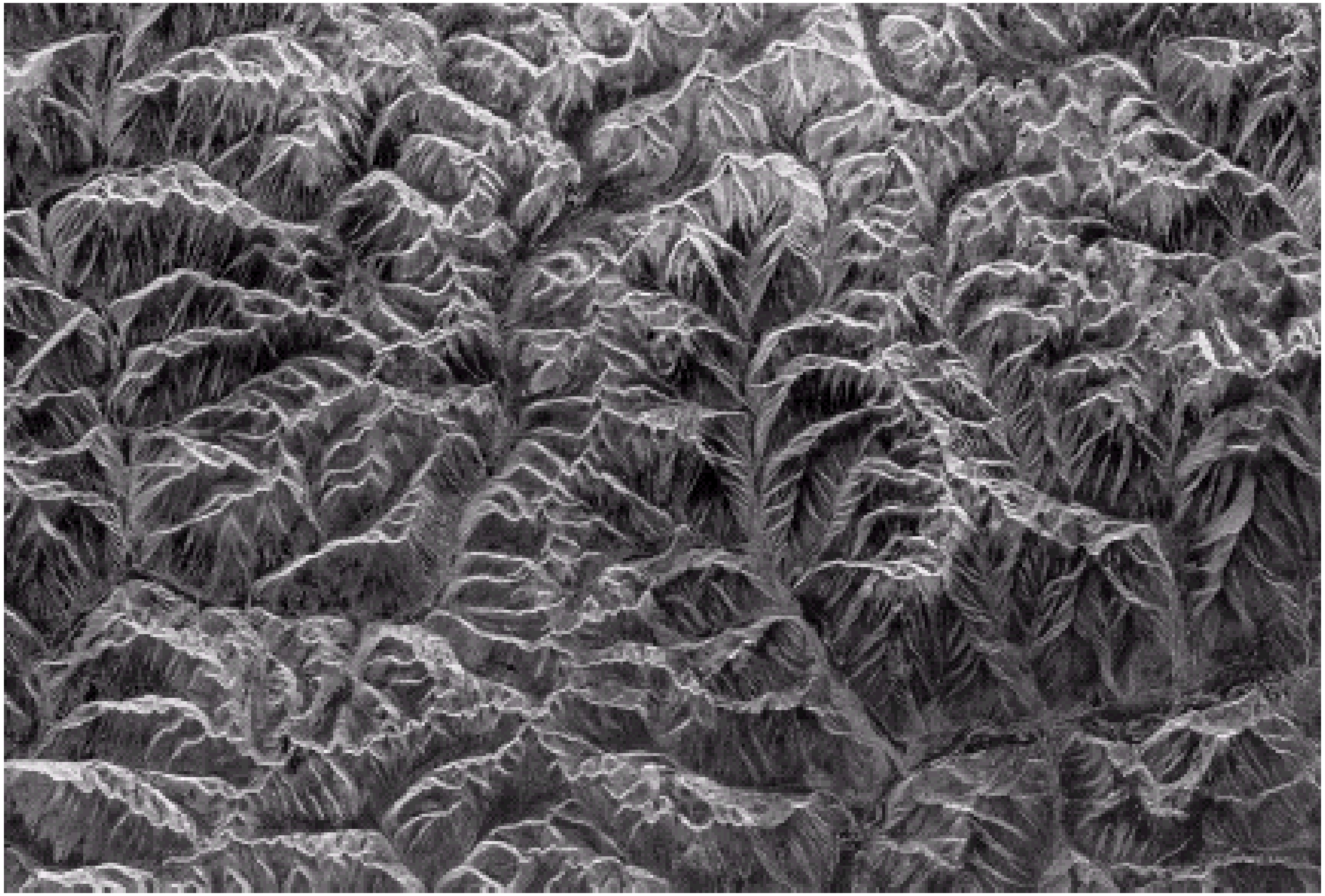
- Ultraviolet imaging is used in fluorescence microscopy
- The basic idea of fluorescence microscopy is to stain the components with dyes
- Fluorescent dyes, also known as fluorophores or fluorochromes, are molecules that absorb UV light and after a short delay emit light in the visible band
- The delay between absorption and emission is negligible, generally on the order of nanoseconds

Examples of fields that use Digital Image Processing Imaging in Microwave band

- The dominant application of imaging in the Microwave band is radar
- Traditional radar sends directional pulses and detects the presence of an object by analyzing the portion of the energy reflected from the object back to the radar station
- Imaging radar attempts to form a picture of the object as well
- It is capable to collect imaging data regardless of ambient lighting conditions
- Imaging using this method is **not interfered with objects like clouds** that normally interferes with images in the visual band

Examples of fields that use Digital Image Processing Imaging in Microwave band

FIGURE 1.16
Spaceborne radar image of mountains in southeast Tibet. (Courtesy of NASA.)



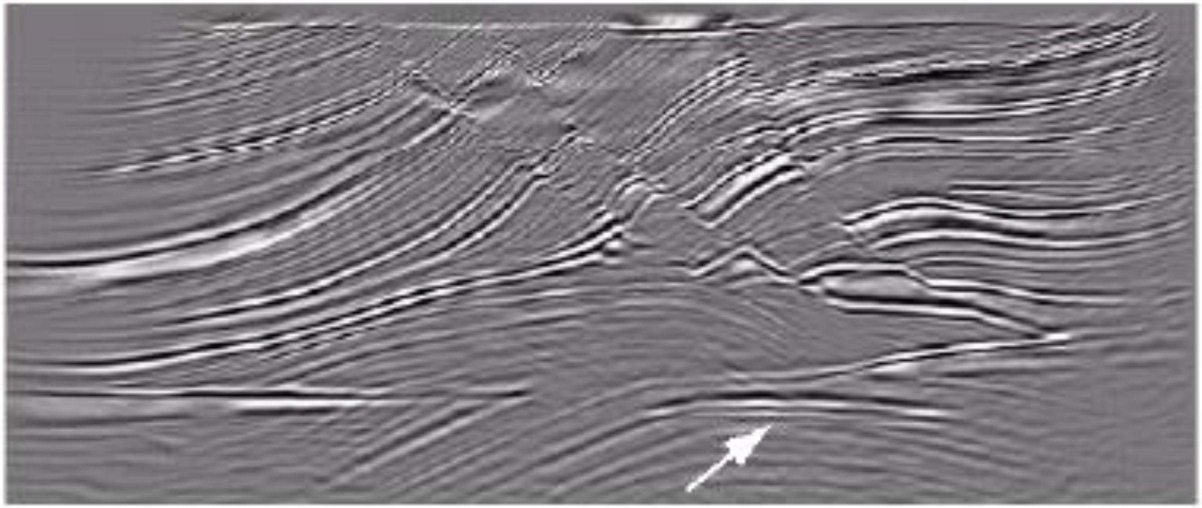
Examples of fields that use Digital Image Processing **Ultrasound Imaging**

- An ultrasound system transmits high-frequency sound pulses into a body
- The sound waves travel into the body and are reflected back to a probe
- The distance between the probe and the object which reflected the waves is determined by the speed of sound in human tissue and the time of each echo return
- The ultrasound system makes a two dimensional image using the distances and the intensity of the echoes

Mineral and oil exploration

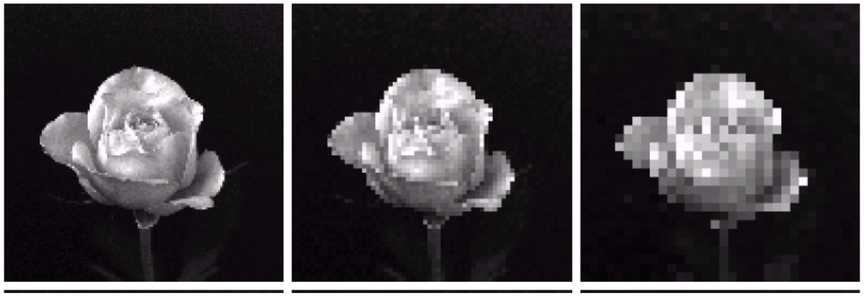
- Use of large truck and large flat steel plate.
- The plate is pressed on the ground by the truck and the truck is vibrated

FIGURE 1.19 Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)



Oversampling - zooming

- Zooming: **creation of new pixel locations** and **assignment of gray levels** to those locations
- Nearest neighbour interpolation:
  - Resizing a 500 x 500 pixel to a 1.5 times larger image (750 x 750)
  - Mark a 750 x 750 grid on the original (500 x 500) image
  - Start assigning gray levels to the smaller (new) pixels based on the gray level value of the closest neighbour in the original image
  - After the assignment, expand the new image to the actual size
  - Nearest neighbour interpolation causes checkerboard effect



Bilinear interpolation

- Known's:

$$f(x1, y1) \quad f(x1, y2) \quad f(x2, y1) \quad f(x2, y2)$$

- Unknown: $f(x, y)$

x_1, y_2		x_2, y_2
	x,y	
x_1, y_1		x_2, y_1

$$f(x,1) = \frac{x_2 - x}{x_2 - x_1} f(1,1) + \frac{x - x_1}{x_2 - x_1} f(2,1)$$

$$f(x,2) = \frac{x_2 - x}{x_2 - x_1} f(1,2) + \frac{x - x_1}{x_2 - x_1} f(2,2)$$

$$f(x,y) = \frac{y_2 - y}{y_2 - y_1} f(x,1) + \frac{y - y_1}{y_2 - y_1} f(x,2)$$

- Effect of Bilinear interpolation is much better than nearest neigbour

Distribution of rods and cones

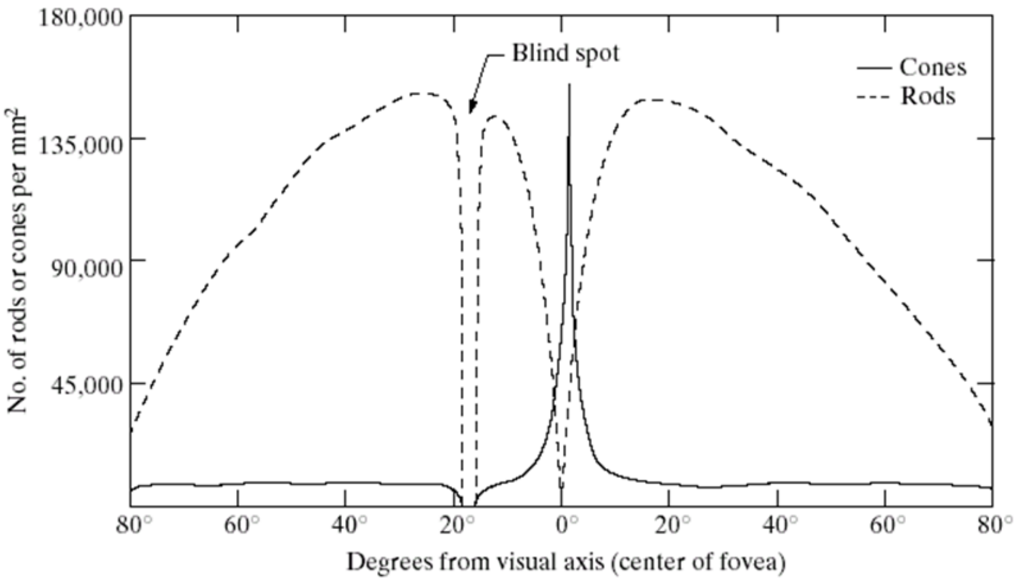


FIGURE 2.2 Distribution of rods and cones in the retina.

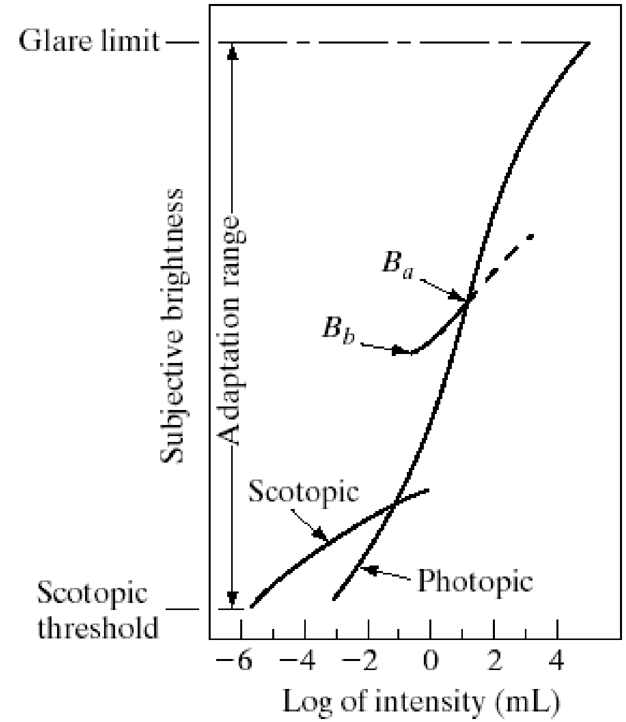
The distribution of rods and cones is radially symmetric wrt the fovea (central portion 2.5 of the retina), except at the blind spot which includes no receptors. Cones are responsible for photopic (color or bright-light) vision; while rods are for Scotopic (dim-light) vision.
Fovea area in the retina is circular with 1.5 mm in diameter where most of the cones are concentrated with 150,000 cones/mm2.

Brightness Adaptation and Discrimination

- Human eye can adapt to an enormous range (in the order of 10^{10}) of light intensity levels, from scotopic threshold to the glare limit.
- **Subjective brightness** (i.e. perceived intensity) is a logarithmic function of the light intensity incident on the eye.
- In photopic vision alone, the range is about 10^{6} (-2 to 4 in the log scale).
- The transition from scotopic to photopic vision is gradual over the range

  3 to -1 mL in the log scale.
- The visual system is not able to operate over such a huge range simultaneously, instead, it changes its overall sensitivity. This phenomena is called brightness adaptation.

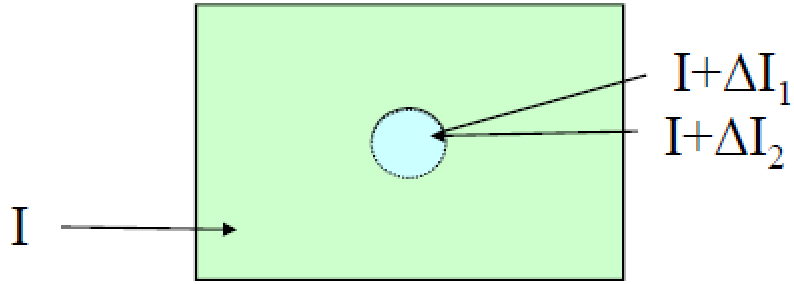
FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.



- For example, if the eye is adapted to brightness level B_a, the short intersecting curve represents the range of subjective brightness perceived by the eye.
- The range is rather restricted, i.e. below level B_b , all stimuli are perceived as indistinguishable blacks.
- The upper part of the curve (dashed line) is not restricted, but when extended too far, it looses its meaning as it raises the adaptation level higher than B_a

Experiment for brightness discrimination:

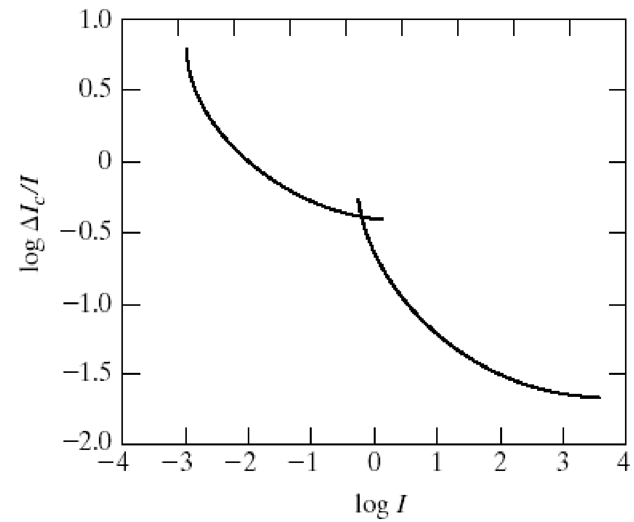
- Look at a flat, uniformly illuminated large area, e.g. a large opaque glass illuminated from behind by a light source with intensity I. Add an increment of illumination ΔI, in the form of a short duration flash as a circle in the middle. Vary ΔI and observe the result.



- The results should move from "no perceivable change" to "perceived change". The fraction $\Delta I_c/I$ for which Δi_c produces "just perceivable change" is called the Weber ratio.

Weber Ratio

FIGURE 2.6
Typical Weber ratio as a function of intensity.



- A small Weber ratio indicates "good" brightness where a small percentage change in illumination is discriminable. On the other hand, a large Weber ratio represents "poor" brightness discrimination indicating that a large percentage change in intensity is needed.
- The curve shows that brightness discrimination is poor (large Weber ratio) at low level of illumination, and it improves significantly (Weber ratio decreases) as background illumination increases.
- The two branches illustrate the fact that at low levels of illumination, vision is carried out by the rods, whereas at high levels (showing better discrimination), cones are at work.

Sampling & Quantization

- The digitization process requires decisions about:
  - – values for N,M (where N x M: the image array)

and

  - – the number of discrete gray levels L allowed for each pixel, where $L=2^k$
- If b is the number of bits required to store a digitized image then:
  - $b = N \times M \times k$ (if M=N, then $b=N^2k$)

Sampling & Quantization

- Number of bits (**b**) required to store an **M** by **N** image with **L** gray levels: **b= MxNxk** or **b=N²k** (when M=N)

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

- Different versions (images) of the same object can be generated through:
  - – Varying N, M numbers
  - – Varying k (number of bits)
  - – Varying both
- – But: storage & processing requirements increase rapidly as a function of N, M, and k
- **Question:** what happens when we vary both N and k?

Isopreference Curves

- Isopreference curves (in the Nk plane)
  - – Each point: image having values of N and k equal to the coordinates of this point 64
  - – Points lying on an isopreference curve correspond to images of equal subjective quality.

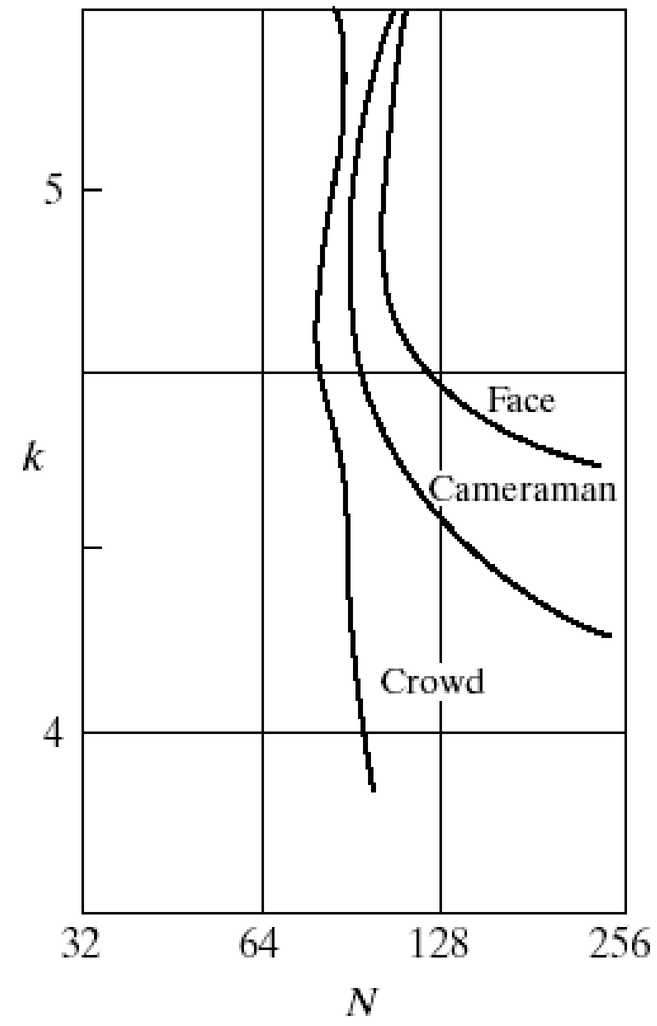
low level detail | medium level detail | high level detail

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.)

Isopreference Curves

- **Comments:**
  - In images with a large amount of details, only limited variation in number of Gray levels is possible.
  - In images with low and medium amount of details are more flexible in varying the Gray levels and resolution.



Exercise

A high-definition T.V. (HDTV) generates images with a resolution of 1125 horizontal interlaced lines (where every other line is painted on the tube face in each of two fileds, each field being $1/60^{th}$ of a second in duration). The width to height ratio of the images is 16:9.

A company has designed an image capture system that generates digital images from HDTV images. Each pixel in the recorded image is represented by 24 bits (three bytes – 8 bits each for red, green and blue).

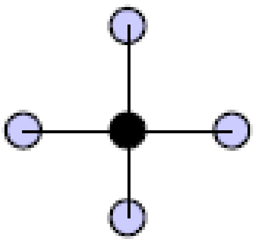
How many bits would it take to store a 2 hours long HDTV program?

Exercise

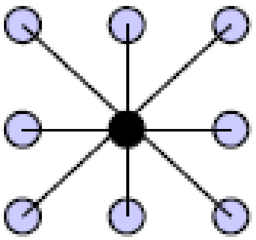
- The width to height ratio is 16/9 and the resolution in the horizontal direction is 1125 lines
- Resolution in the vertical direction (1125)x(16/9) = 2000 pixels per line
- Size of full frame= 2000 x 1125 pixels
- 1/60 of second interlaced video makes a full frame in every 1/30 of a second
- The image capture system records, 8bit image every 1/30 sec for each of the red, green, and blue component
- Full frame takes 24 bits per pixel
- Total number of pixels in each frame (image)= 1125x2000
- Total bits in each frame (image) = 1125x2000x24
- Number of such frames in 1 second= 30 frames
- For a 2-hours (7200 sec) program, the number of bits required are: (1125)(2000)(24)(30)(7200) = 1.166×10^{13} bits (i.e., about 1.5 terrabytes)

Commonly–used Terminology

- Neighbors of a pixel $p=(i,j)$



$N_4(p)=\{(i-1,j),(i+1,j),(i,j-1),(i,j+1)\}$



$N_8(p)=\{(i-1,j),(i+1,j),(i,j-1),(i,j+1),$
$(i-1,j-1),(i-1,j+1),(i+1,j-1),(i+1,j+1)\}$

Adjacency

- 4-adjacency: p,q are 4-adjacent if q is in the set N4(p)/ND(p)
- 8-adjacency: p,q are 8-adjacent if q is in the set N8(p)
- Note that if p is in N4/8(q), then q must be also in N4/8(p)
- M-adjacency: either q is in N4(p) or q is in ND(p) but
  - N4(p) and N4(q) have no adjucent pixels.

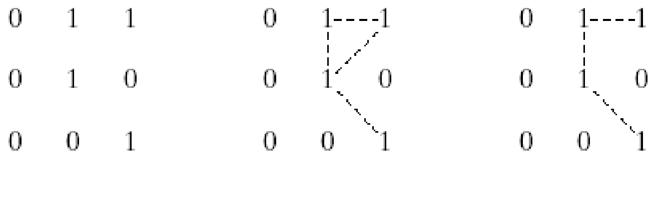


FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

Common Distance Measures

- For p(x,y) and q(s,t)
  - $D_e(p,q) = [(x-s)^2+(y-t)^2]^{1/2}$
  - $D_4(p,q) = |x-s|+|y-t|$
  - $D_8(p,q) = \max(|x-s|,|y-t|)$

Euclidean distance
(2-norm)

$2\sqrt{2}$	$\sqrt{5}$	2	$\sqrt{5}$	$2\sqrt{2}$
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
2	1	0	1	2
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
$2\sqrt{2}$	$\sqrt{5}$	2	$\sqrt{5}$	$2\sqrt{2}$

D_4 distance
(city-block distance)

4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

D_8 distance
(checkboard distance)

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2