4TN3
Image Processing

Digital Image Fundamentals

McMaster University

Digital Image Fundamentals

- Elements of visual perception
- Image sensing and acquisition
- Sampling and quantization
- Relationship between pixels

The Human Visual System (HVS)

– A true measure of image processing quality is how well the image appears to the observer.

– The HVS is very complex and is not understood well in a complete sense. However, many of its properties can be identified and used to our advantage.

Structure of Human Eye

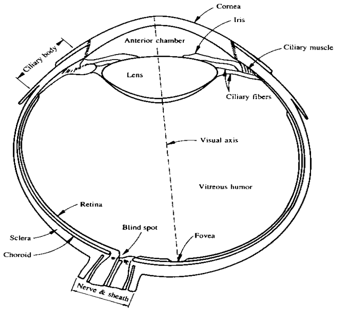
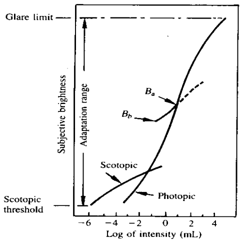


Image formation in the eye

- Lens is flexible and its refraction is controlled by its thickness.
- Thickness is controlled by the tension of muscles.
- Focus on distance objects: lens is relatively flattened, refractive power is minimum.
- Focus on near objects: lens is thicker, refractive power is maximum
- Perception takes place by excitation of receptors which transform radiant energy into electrical impulses that are decoded by the brain.

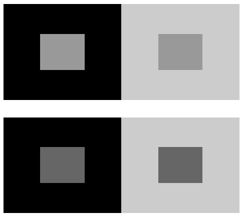
Brightness & Intensity

- The dynamic range of light intensity to which eye can adapt is enormous.
- Brightness is a logarithmic function of light intensity.
- HVS cannot operate over the entire range simultaneously. It accomplishes large variations due to ***brightness adaptation.***



Brightness & Intensity

- Relationship between brightness and intensity is not a simple function!



Brightness & Intensity

Mach Band Effect

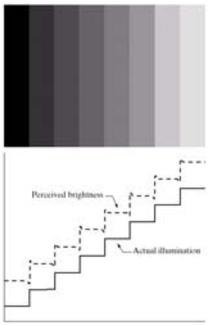


FIGURE 2.7 (a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.

Image sensing and acquisition

- If a sensor can be developed that is capable of detecting energy radiated by a band of the EM spectrum, we can image events in that band.
- Image is generated by energy of the illumination source reflected (natural scenes) or transmitted through objects (X-ray).
- A sensor detects the energy and converts it to electrical signals.
- Sensor should have a material that is responsive to the particular type of energy being detected.

A simple image model

- The image magnitude depends on:
  1. The amount of source illumination incident on the scene, i(x,y)
  2. The amount of illumination reflected by the objects in the scene, r(x,y)

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

(x,y): coordinates
Total absorption: r(x,y)=0
Total reflection: r(x,y)=1

Sampling & Quantization

- Computer processing: image f(x,y) must be digitized both spatially and in amplitude
- Digitization in spatial coordinates: sampling
- Digitization in amplitude: quantization
- Image: $[f(i,j)]_{NxM}$
- What should be the values of N, M and the number of gray levels G?
- Normally: $N=2^n$, $M=2^m$, $G=2^k$

Sampling & Quantization

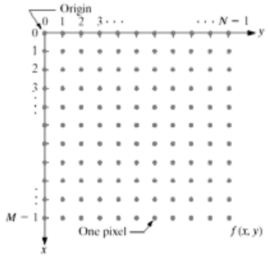


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Sampling & Quantization

- Number of bits required to store the image: N x M x k.
- The more the values of N,M and G, the better approximation of a continuous image.
- Storage and processing requirements increase as well.

Effects of Reducing Spatial Resolution

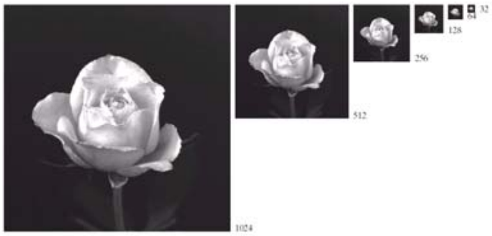


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Effects of Reducing Spatial Resolution

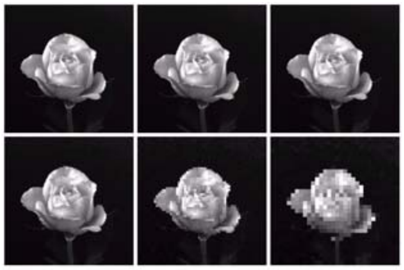


FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

Effects of Reducing Gray Levels

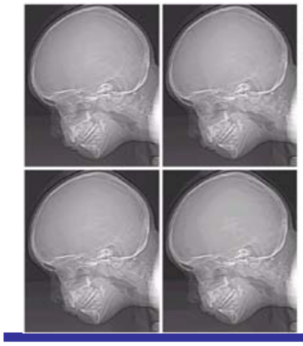
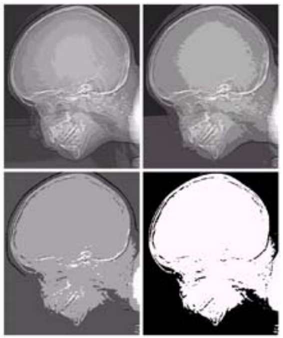


FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

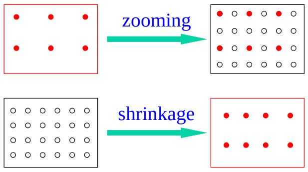
Effects of Reducing Gray Levels

FIGURE 2.21 (*Continued*) (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)



Zooming and Shrinkage

- Zooming: increasing the resolution (size) of an image.
- Shrinkage: decreasing the resolution of an image.



Zooming

- Pixel replication: interpolated pixel in the enlarged image is set to the gray-level of its nearest pixel in the original image.
- Bilinear interpolation: interpolated pixel in the enlarged image is set to the average its four nearest pixels in the original image.

Zooming: example

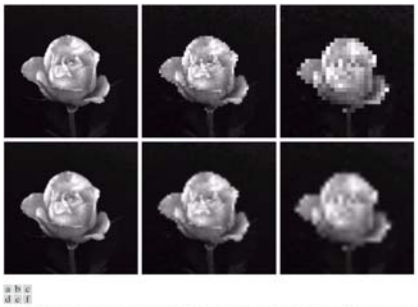
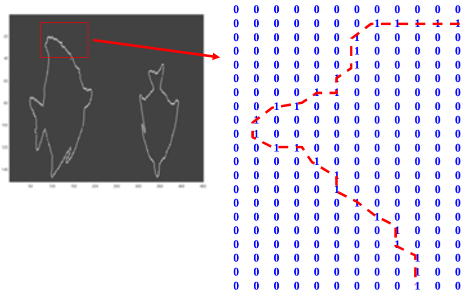


FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

Shrinkage

- Shrinkage by an integer number can be done by deleting some of the rows and columns of the image.
- Shrinkage by a non-integer factor can be done as the inverse of zooming.

Relationship between pixels



0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	1	1	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	1	0	0

Relationship between pixels

- Neighbors
- Adjacency
- Path
- Connectivity
- Region
- Boundary
- Distance

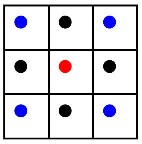
Basic relationships between pixels

- A pixel p at coordinates (x,y) has four horizontal and vertical neighbors:

  $N_4(P)=\{(x+1,y), (x-1,y),(x,y+1),(x,y-1)\}$
- The four diagonal neighbors of P

  $N_D(P)=\{(x+1,y+1), (x-1,y-1),(x-1,y+1),(x+1,y-1)\}$
- The eight point neighbors of P

  $N_8(P)=N_4(P) U N_D(P)$

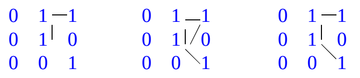


Adjacency

- Two pixels are adjacent if they are neighbors and their gray levels are similar
- V: set of gray levels
- Similar gray level means that the gray levels of both pixels belong to set V
- Exp:
  - Binary images: V={1}
  - Gray level image: V={32,33, …,63,64}

Adjacency

- 4-adjacency: Two pixels p and q with values from V are 4-adjacent if q is in $N_4(p)$
- 8-adjacency: Two pixels p and q with values from V are 8-adjacent if q is in $N_8(p)$
- 4-adjacency: broken paths
- 8-adjacency: multiple paths

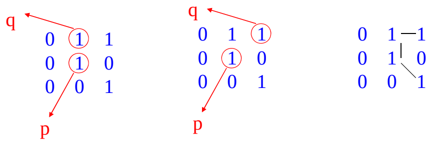


Adjacency

- m-adjacency: Two pixels p and q with values from V are m-adjacent if:

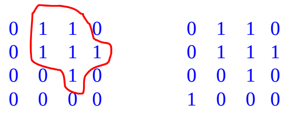
  q is in $N_4(p)$ or

  q is in $N_D(p)$ and the intersection of $N_4(p)$ and $N_4(q)$ has no pixels with values in V.



Region

- R: a subset of pixels in an image.
- R is called a region if every pixel in R is connected to any other pixel in R.
- Boundary (border or contour) of a region: set of pixels in the region that have one or more neighbors that are not in R.



Connected Components

Distance measures

- For pixels p,q, and z with coordinates (x,y), (s,t) and (v,w), respectively, D is a distance functions if:

$$D(p,q) \geq 0$$

$$D(p,q) = D(q,p)$$

$$D(p,z) \leq D(p,q) + D(q,z)$$

$$D_e = [(x-s)^2 + (y-t)^2]^{1/2}$$

Distance measures

- D_4 distance

$$D_4(p,q) = |x-s| + |y-t|$$

- D_8 distance

$$D_8(p,q) = \max\{|x-s|, |y-t|\}$$

Pixel values			D_4 distances			D_8 distances		
0	1	1	2	1	2	1	1	1
0	①	0	1	0	1	1	0	1
0	0	1	2	1	2	1	1	1

End of Lecture

Distance measures

- D_m distance: length of the shortest m-path between two pixels
- D_4, D_8 distance between p and q are independent of the pixels along the path
- D_m depends on the value of the pixels between p and q

$$\begin{matrix} 0 & 0 & \textcircled{1} \\ 1 & 1 & 0 \\ \textcircled{1} & 0 & 0 \end{matrix} \qquad \begin{matrix} 0 & 0 & \textcircled{1} \\ 0 & 1 & 0 \\ \textcircled{1} & 0 & 0 \end{matrix}$$

D_m=3 D_m=2

Linear & Non-linear operations

- H: an operator whose inputs and outputs are images
- H is linear if for any two images f and g and any two scalars a and b

H(af+bg)=aH(F)+bH(g)