CoE4TN3
Image Processing

Chapter 2: Digital Image Fundamentals

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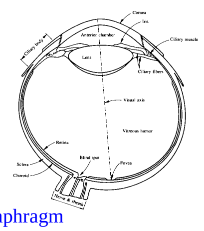
Digital Image Fundamentals

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

The Human Visual System (HVS)

- Why study the 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

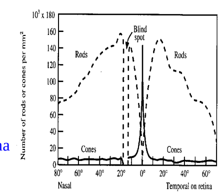


- Eye: Sphere, diameter of 20 mm
- Consists of 3 membranes:
  1. Cornea and sclera
  2. Choroid
  3. Retina
- Cornea: transparent
- Sclera: opaque, connected to cornea
- Choroid: network of blood vessels
- In front choroid is connected to iris diaphragm
- Iris: contracts or expands to control amount of light
- Pupil: central opening of iris, 2 to 8 mm in diameter

Structure of Human Eye

- Lens:
  - focuses light on retina
  - Contains 60% to 70% water
  - Absorbs 8% of visible light
  - High absorption in infrared and ultraviolet (can cause damage to eye)
- Retina: the inner most layer, covers the posteriori portion of eye
- When eye is properly focused, light of an object is imaged on the retina
- Light receptors are distributed over the surface of retina

- Retina contains light receptors: Cones & rods
  - Cones:
    - 6 to 7 million,
    - located mainly in central part of retina (fovea)
    - Sensitive to color,
    - Can resolve fine details because each one is connected to its nerve
    - Cone vision: photopic or bright-light
  - Rods:
    - 75 to 150 million,
    - No color vision, responsible for low-light vision,
    - Distributed a wide region on the retina
    - Rod vision: scotopic or dim-light



Human Eye

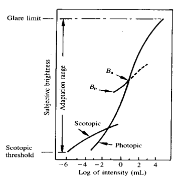
- Blind spot: a region of retina without receptors, optic nerves go through this part
- Fovea: a circular area of about 1.5 mm in diameter
- A comparison between eye (fovea) and a CCD camera:
  - Density of cones in fovea: 150,000 /mm^2
  - Number of cones: 337,000
  - A medium resolution CCD chip has the same number of elements in a 5mm x 5mm area.

Image formation in the eye

- Lens is flexible
- Refraction of lens is controlled by its thickness
- Thickness is controlled by the tension of muscles connected to the lens
- 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.

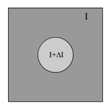
Brightness & Intensity

- The dynamic range of light intensity to which eye can adapt is enormous - on the order of *10^{10}*- from the scotopic threshold to the glare limit
- Brightness (intensity perceived by visual system) is a logarithmic function of light intensity.
- HVS can not operate over the entire range simultaneously. It accomplishes large variations due to ***brightness adaptation***



Weber Experiment

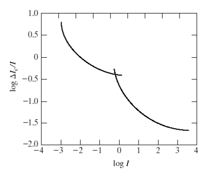
- To characterize the intensity discrimination properties of eye
- ΔI starts at zero and is increased slowly
- The observer is asked to indicate when the circle on the constant background becomes visible (just noticeable difference).
- The ratio $\Delta I/I$ is called the Weber ratio.
- Procedure is repeated for different values of I.



Weber Experiment

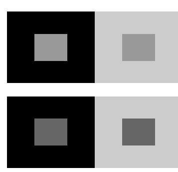
- Small values of $\Delta I/I$: good discrimination
- Large values of $\Delta I/I$: poor discrimination
- Low levels of illumination: high Weber ratio: poor discrimination
- In high levels of illumination, discrimination improves.

FIGURE 2.6 Typical Weber ratio as a function of intensity.



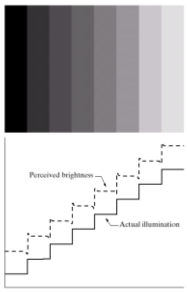
Intensity & Brightness

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



Intensity & Brightness

- Mach Band effect:
  Although the shades are constant, overshoot and undershoot are observed near the transition boundary.



a
b

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

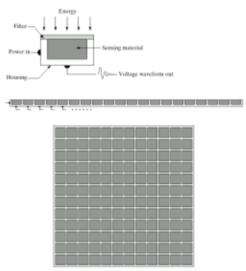
- If a sensor can be developed that is capable of detecting energy radiated by a band of the EM spectrum, we can image events in that band.
- Image is generated by energy of the illumination source reflected (natural scenes) or transmitted through objects (X-ray)
- A sensor detects the energy and converts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

Image sensing and acquisition

- Three principle sensor arrangements:
  1. Single imaging sensor
  2. Line sensor
  3. Array sensor

a
b
c

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



Single sensor

- Most familiar sensor of this type is photodiode
- In order to generate a 2-D image using a single sensor, there has to be relative displacement in both x and y directions between the sensor and the area to be imaged

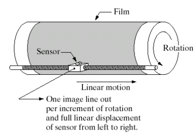
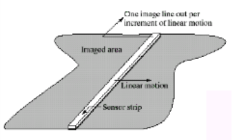


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

Sensor strips

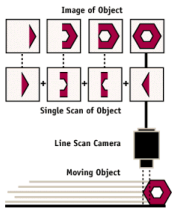
- Sensor elements are arranged in a line
- Strip provides imaging in one direction, and motion provides imaging in the other direction
- Used in scanners and airborne imaging
- Airborne imaging: imaging system is mounted on the aircraft which flies at a constant altitude over the area to be imaged



Sensor strips

- Sensor strips mounted in a ring configuration are used in medical and industrial imaging to obtain cross-sectional images of 3-D objects (CAT)
- Output of the sensors must be processed by reconstruction algorithms to transform the sensed data into meaningful cross-sectional images.

Line scan array



Sensor arrays

- This is the arrangement used on digital cameras
- Typical sensor for these cameras is the CCD array (Charge Coupled Devices)
- Since the sensor is two dimensional a complete image can be obtained
- Motion is not necessary

A simple image model

- The amount of light that enters the eye 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

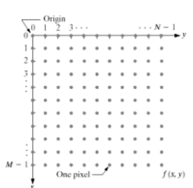


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Sampling & Quantization

- Number of bits required to store 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

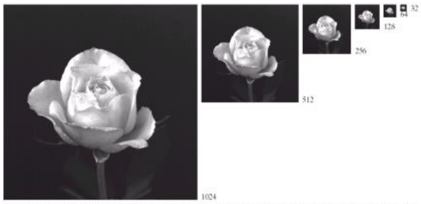


FIGURE 2.19 A 1024×1024, 8-bit image subsampled down to size 32×32 pixels. The number of allowable gray levels was kept at 256.

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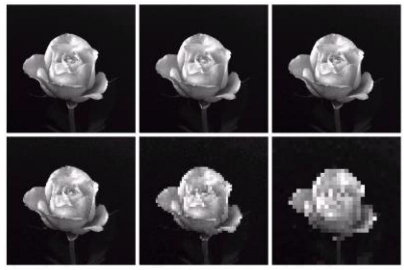
Effects of Reducing Spatial Resolution



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.

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Effects of Reducing Spatial Resolution

Effect of reducing spatial resolution: checkerboard pattern

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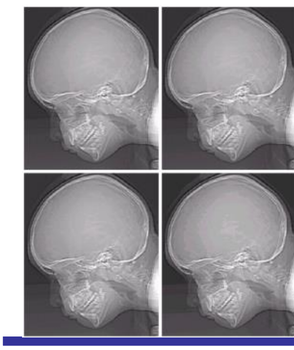
Effects of Reducing Gray Levels



a b
c d

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.

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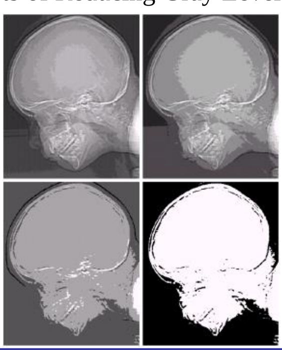
Effects of Reducing Gray Levels

e f
g h

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.)



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Effects of Reducing Gray Levels

- Effects of Reducing Gray Levels:
  - appearance of fine ridge-like structures in areas of smooth gray levels
- This effect is called false contouring

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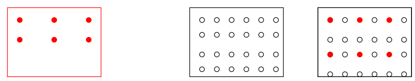
Zooming and Shrinkage

- Zooming: increasing the resolution (size) of an image
- Shrinkage: decreasing the resolution of an image
- Example of zooming: we have an image of 500x500 pixels and we want to enlarge it to 750x750
- Zooming has two steps: creation of new pixel locations and the assignment of gray levels to those locations

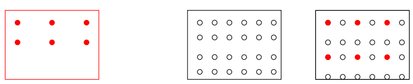
Zooming

- A simple way of zooming which works for increasing the size of an image by integer numbers is pixel replication
- Visualize assignment in zooming: the enlarged image is placed on the original image
- Gray level of each pixel in the enlarged image is set to the gray-level of its nearest pixel in the original image



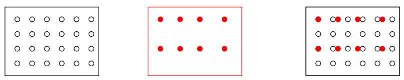
Zooming

- A more sophisticated way of accomplishing gray-level assignment is bilinear interpolation
- v(x’,y’)=ax’+by’+cx’y’+d
- The four coefficients are determined from the four equations in four known (four nearest neighbors of the point (x’,y’))

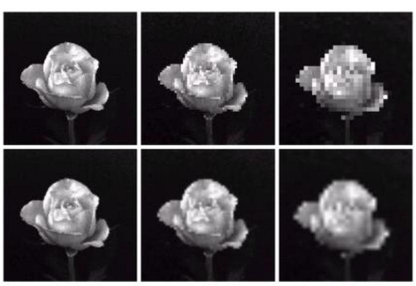


Shrinkage

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

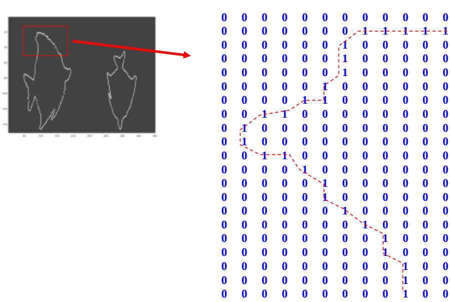


Zooming



a b c
d e f
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.

Relationship between pixels

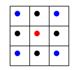


Relationship between pixels

- 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
  $N_8(P)=N_4(P) \cup N_D(P)$

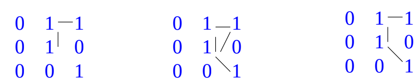


Adjacency

- 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}

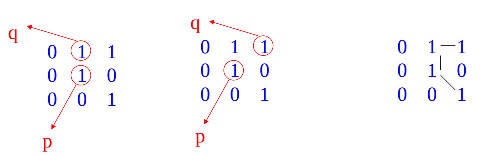
Adjacency

- 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.



Path

- A path from pixel p with coordinates (x,y) to pixel q with coordinates (s,t) is a sequence of distinct pixels with coordinates $(x_0,y_0),(x_1,y_1),\ldots,(x_n,y_n)$ where $(x_0,y_0)=(x,y)$, $(x_n,y_n)=(s,t)$, and points (x_i,y_i) and (x_{i-1},y_{i-1}) are adjacent for $1 \le i \le n$
- n is the length of the path
- We can have 4-, 8-, or m-paths depending on the type of adjacency specified.

Connectivity

- S: a subset of pixels in an image
- Two pixels p and q are said to be connected in S if there exists a path between them consisting entirely of pixels in S
- We can have 4-, 8-, or m-connectivity depending on the type of path specified.

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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

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

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

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Distance measures

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

$$D(p,q) \geq 0$$
$$D(p,q) = D(q,p)$$
$$D(p,z) \leq D(p,q) + D(q,z)$$

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

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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

0	1	1
0	1	0
0	0	1

D_4 distances

2	1	2
1	0	1
2	1	2

D_8 distances

1	1	1
1	0	1
1	1	1

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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

0	0	1
1	1	0
1	0	0

D_m=3

0	0	1
0	1	0
1	0	0

D_m=2

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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)

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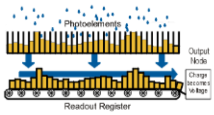
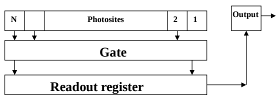
Line scan arrays

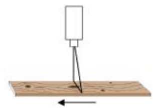
- A row of photosites forms the imaging device
- Charges of photosites are transferred to a readout register
- Readout register works similar to a shift register

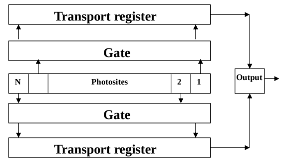




Line scan arrays

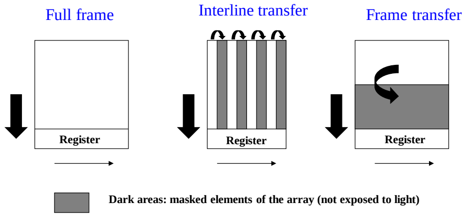
- While register is read, image capturing should stop
- Readout speed can be increased using more than one register
- A 2-D image is formed by relative motion between the scene and sensor





Area scan arrays

- Composed of 2-D array of CCD elements.
- Different methods to read the accumulated charge:



Color imaging with CCD

- Light is separated into red, green and blue components.
- Color filters or prism can be used to break light
- Each component is recorded by CCD