Advanced Digital Image Processing

Chapter 2: Digital Image Fundamental

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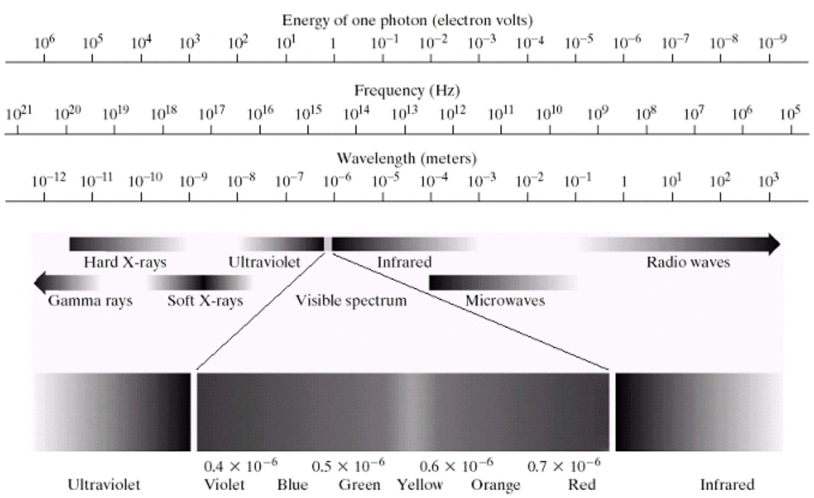
Outline

Electro-magnetic Spectrum



Light Attribute

Mono-chromatic (Achromatic) light

Described by Intensity or Gray level.

Chromatic light

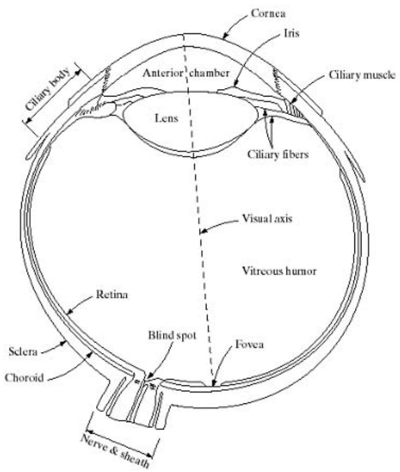
Described by three quantities,

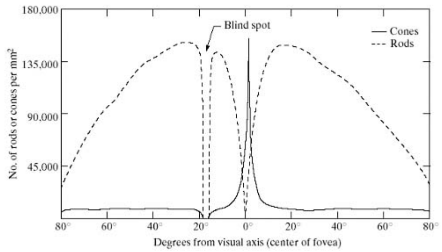
- ________: total amount of energy that flows from the light source
- _________: Measured in lumens(lm), a measure of the amount of energy an observer *perceives* from a light source.
- _________: a *subjective* descriptor of light perception that is practically impossible to measure.

Example

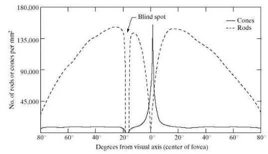
Far infrared light: Large radiance but almost zero luminance

Structures of the Human Eye





Two Classes of Receptors



______: 6 to 7 million.

- Located primarily in the center of the retina (fovea)
- resolve fine detail
- highly sensitive to color.
- cone vision, *photopic*, bright-light vision

_____: 75 to 150 million (larger)

- Radially symmetirc about the fovea (except blind spot)
- give a general, overall picture of field of view.
- not invovled in color vision but sensitive to low illumination.
- rod vision,*scotopic*,dim-light vision

Example of Receptors

Example

Sensitivity:
Why objects are in bright color in daylight, but colorless in moonlight?
Only rods are stimulated.

Example

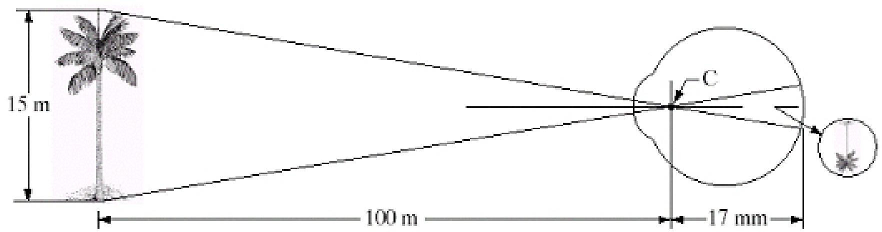
Density:

- 337,000 cones on fovea (1.5mm x 1.5mm)
  ie. cone density: 150,000 elements/mm^2
- CCD have this number of elements in a receptor array no larger than 5mm x 5mm.

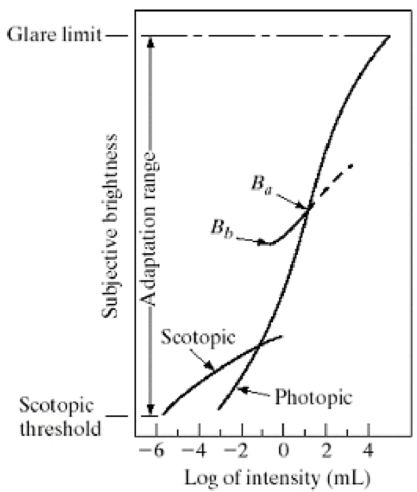
Image Formation in the Eye

Definition

____________ is the distance between the center fo the lens and the retina.



Brightness Adaptation

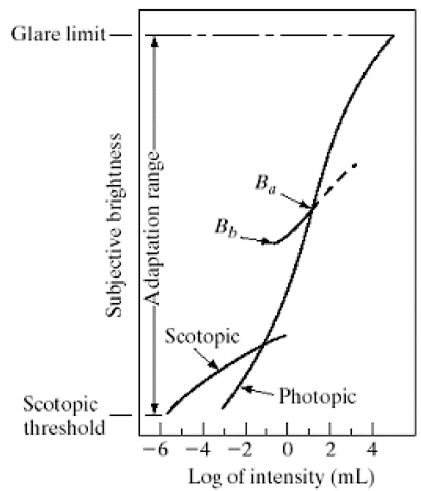


- Subjective brightness of HVS is a log function of light intensity
- HVS can adapt enormous range around 10^{10} from scotopic threshold to glare limit (10^6 for photopic)

Definition

________: HVS cannot operate over the range simultaneously. Rather, it accomplishes this large variation by changes in its overall sensitivity.

Brightness Adaptation

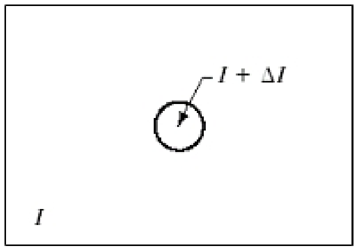


Example

Let ________ be at B_a

- The range below B_b is indistinquishable black.
- The (dashed) range above B_a is not restricted, but too high may change to new adapation level.
- The adaptation range is small compared with the total range

Bright Discrimination



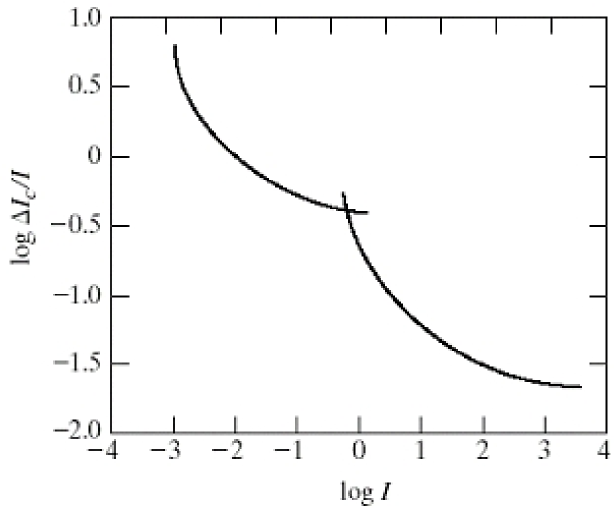
- Changing light at specific adaptation level
- $\triangle I$ in the form of a short-duration flash.

Definition

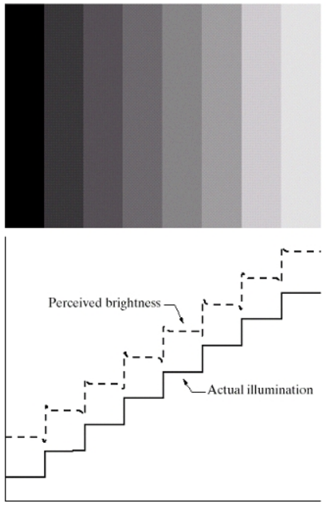
________ is the quantify $\triangle I/I$, where $\triangle I$ is the increment of illumination discriminable 50% of the time with background illumination I.

- Small Weber ratio ⇒ Good ________.

Chart of Weber Ratio



Mach Bands

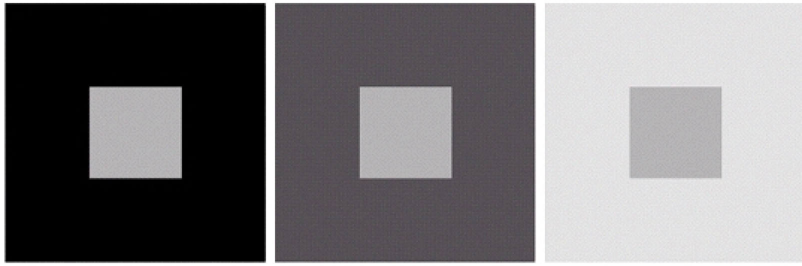


- The perceived brightness is not a simple function of intensity
- HVS undershoots or overshoots around the boundary of regions of different intensities.

Definition

The seemsingly scalloped bands are called ___________ (Ernst Mach, 1865)

Simultaneous Contrast

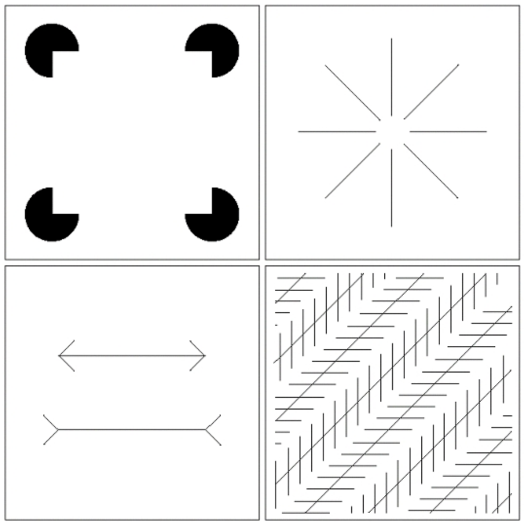


- The perceived brightness is not a simple function of intensity

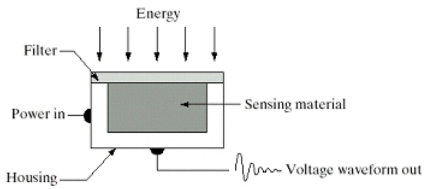
Definition

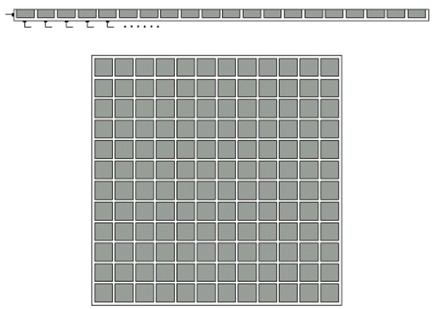
____________________: All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Optical Illusions

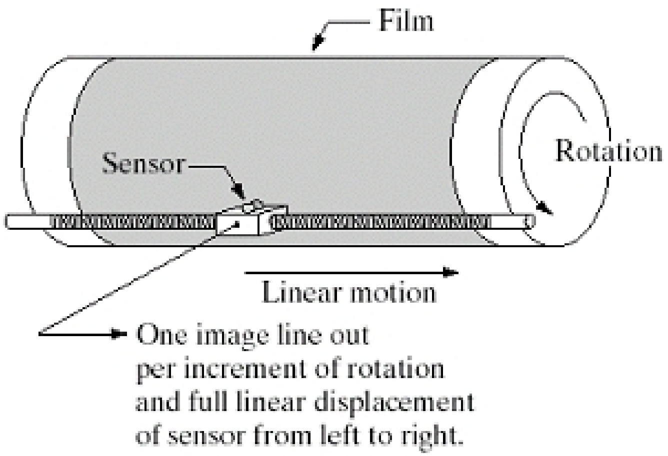


Line sensor and Array Sensor

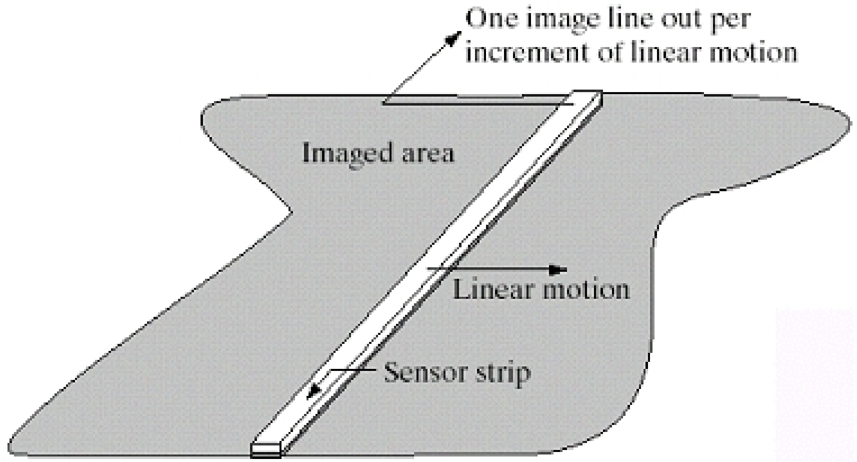




Single sensor



Line sensor strip



Circular sensor strip

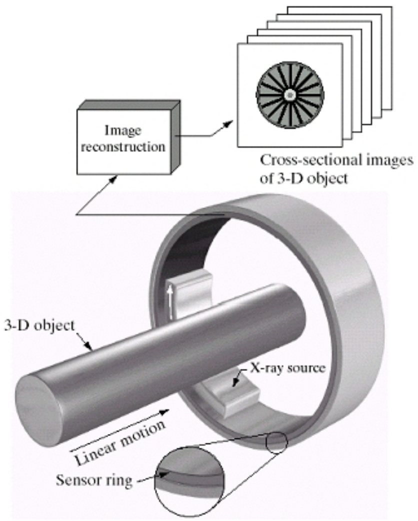
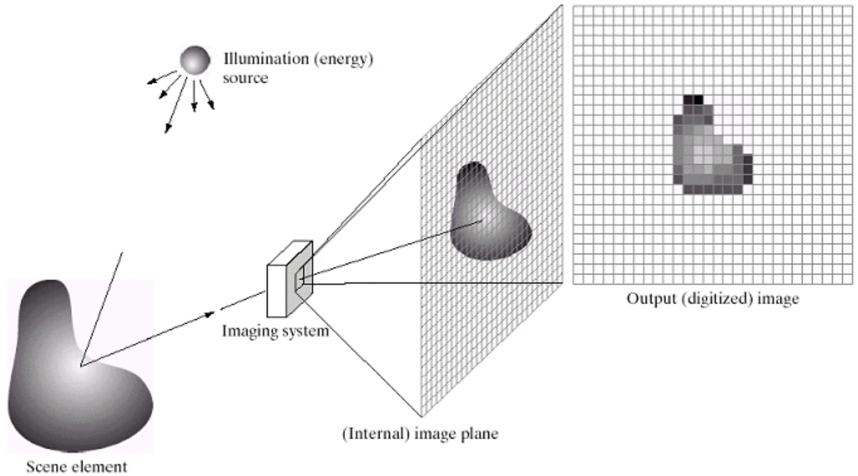


Image Acquisition by *Array* sensor



Monochromatic Image

- The values of image are proportional to energy radiated by a physical soucre (e.g., EM waves).
- Therefore, $0 < f(x,y) < \infty$
- $f(x,y) = i(x,y)r(x,y)$
  - $0 < i(x,y) < \infty$
    ________: Amount of source illumination incident on the scene being viewed.
    (sun: $90,000 lm/m^2$, clound: $10,000 lm/m^2$, full moon: $0.1 lm/m^2$, office: $1000 lm/m^2$)
  - $0 < r(x,y) < 1$
    ______________________: Amount of illumination relfected by the objects in the scene.
    (black velvet:0.01, stainless steel:0.65, snow:0.93)

Intensity (Gray Level)

Given the intensity l of an monochromatic image at (x_0, y_0),

$$l = f(x_o, y_o),$$
$$L_{min} \leq l \leq L_{max}$$

Definition

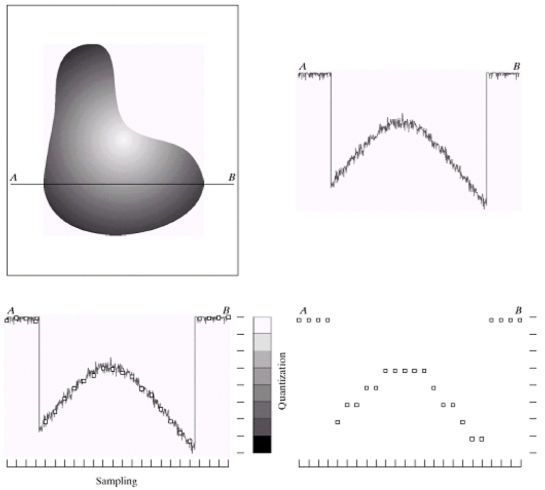
The interval $[L_{min}, L_{max}]$ is called the ________

Example

Common practice:

- $[0, L-1]$: (black $l = 0$, white $l = L-1$)
- Ex: For $[0, 255]$, gray scale $L = 256$

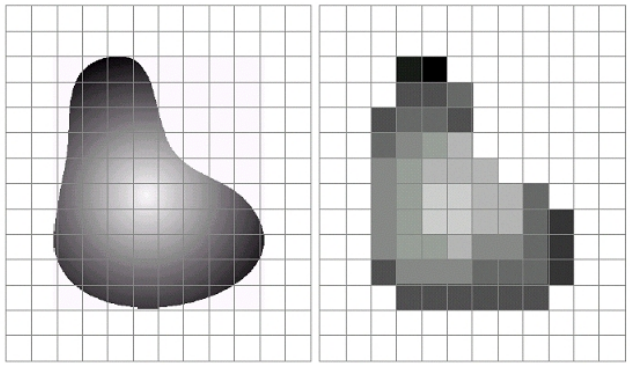
Sampling and Quantization



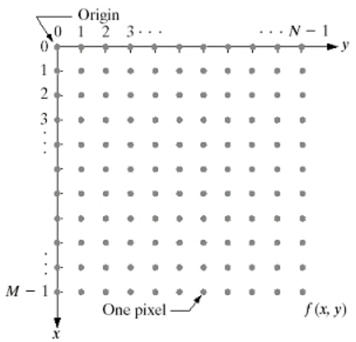
- ________: Digitizing the coordinate values of $f(x,y)$
- ________: Digitizing the amplitude values of $f(x,y)$

Sampling and Quantization

Continuous image projected onto a sensor array.



Digital Image Notation



- Assume an image $f(x, y)$ is sampled so that the resulting digital image has M rows and N columns ($M \times N$ digital image).
- Origin of coordinate $(x, y) = (0, 0)$. (x:row, y:column)
- Note: (x, y) is not the actual values of physical ocoordinates when the image was sampled.

$M \times N$ Digital Image

- $M \times N$ Digital Image = $M \times N$ Matrix

$$f(x,y) = \begin{pmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & \ddots & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{pmatrix}$$

- __________: image can have 2^k gray level. ($L = 2^k$)

Example

- __________: 256 possible gray-level.
- ________________: Black and white

- The number of bits required to store a digital image: $M \times N \times k$ bits.

Storage bits for $N \times N$ Digital Image

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

Definition

__________(width $2W$): consists of one line(width W) and its adjacent space(width W).

Definition

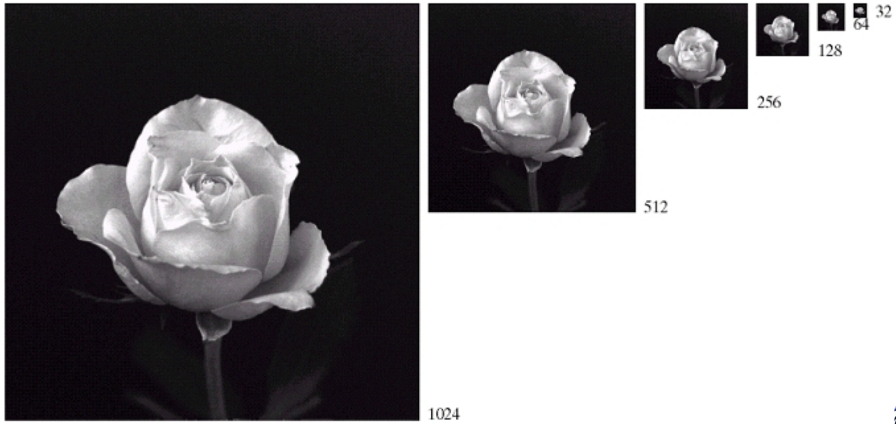
____________________ is the smallest number of discernible line pairs per unit distance;

Example

100 line pairs per millimeter, dpi., 1024x768 pixels.

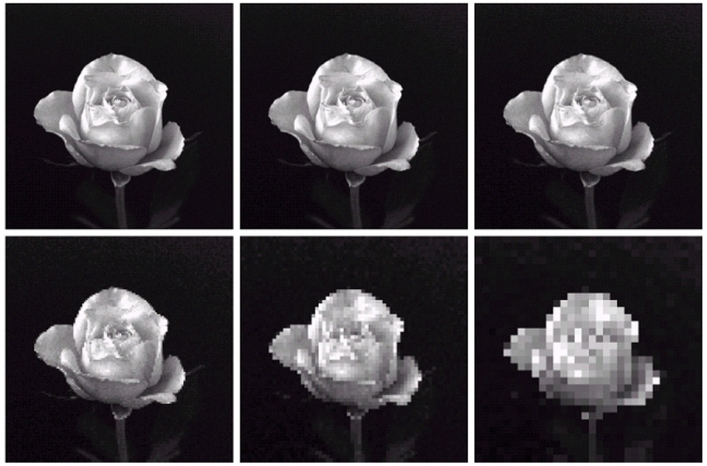
Spatial Resolution
Subsampling

A 1024×1024, 8-bits image subsampled down to size 32×32 pixels.



Spatial Resolution
Sampling Checkerboard

Resampled image: Sampling checkerboard



Gray-Level Resolution

Definition

________________ is the smallest discernible change in gray level. (subjective).

Example

8 bits/10 bits/12 bits/16 bits images.

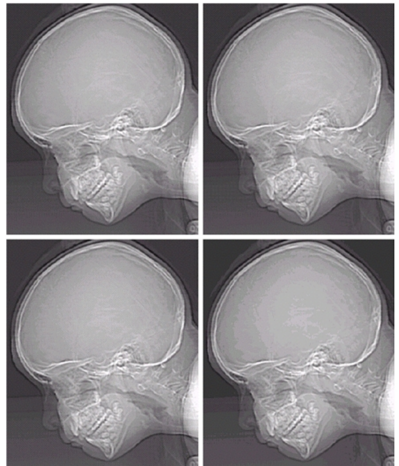
Example

L-level digital image of size $M \times N$:

- Spatial resolution: $M \times N$ pixels.
- Gray-level resolution: L levels.
- Reasonable smallest image free of objectionable sampling checkerboards/false contouring: $M, N = 256$ with $L = 64$.

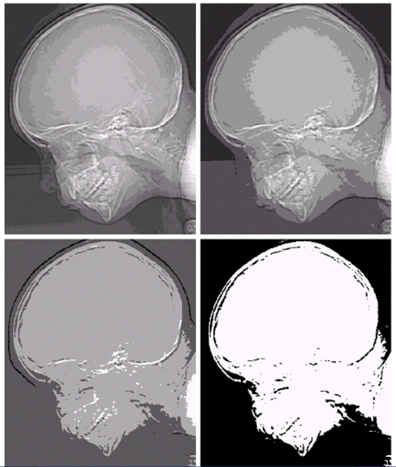
Gray-Level Resolution
False Contouring

452×374 image with 256/128/64/32 gray level



False Contouring
False Contouring

452×374 image with 16/8/4/2 gray level: False contouring

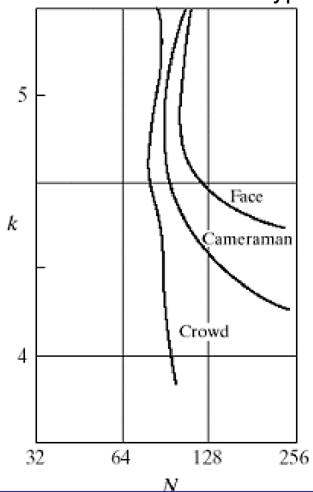


Isopreference curve
Image Details

Image with low/medium/high level of detail

Isopreference curve

Isopreference curves for the three types of images



Aliasing

Definition

____________ is the number of samples taken per unit distance. (in both spatial directions)

Definition

____________: twice the highest frequency of *band-limited* signal to avoid aliasing.

In practical, image is finite size, i.e., not band-limited signal, therefore,

____

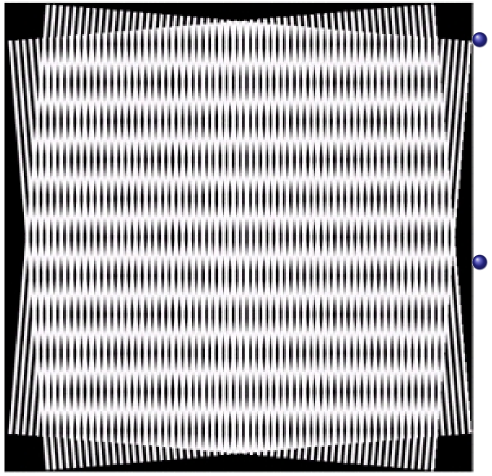
Tip

To sample an image, the principal approach for ____________ is to reduce its high-frequency components by blurring the image prior to sampling.

Resolution

Aliasing
Moire Patterns

Moire pattern effect



- Periodic function is one special case in which a function of infinite duration can be sampled over a finite interval without violating the sampling theorem.
- ___________: caused by a break-up of the periodicity, and produce a 2-D sinusoidal waveform(aliasing frequency) running in vertical direction.

Zooming and Shrinking

Zooming Digital Image

- Two steps:
  - The creation of new pixel locations.
  - The assignment of gray levels to those new locations.
- Two popular approaches:
  - ________________________
  - _________________

Zooming and Shrinking

Zooming
Nearest neighbor interpolation

Suppose that we want to enlarge a 500×500 image 1.5 times to 750×750.

- Shrinking and Laying an imaginary 750×750 grid over the original image.
- Looking for the cloest pixel in the original image and assign its gray level to the new pixel in the grid
- Expanding the grid to the original specified size.

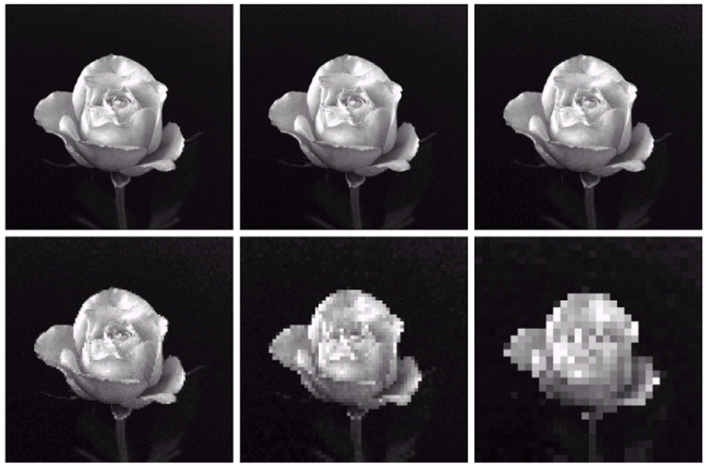
Example

_______________ is a special case of nearest neighbor interpolation when the zooming factor is an integer.

Zooming and Shrinking

Zooming
Nearest neighbor interpolation

zooming image by nearest neighbor intp(fast but checkerboard effect)



Zooming
Bilinear interpolation

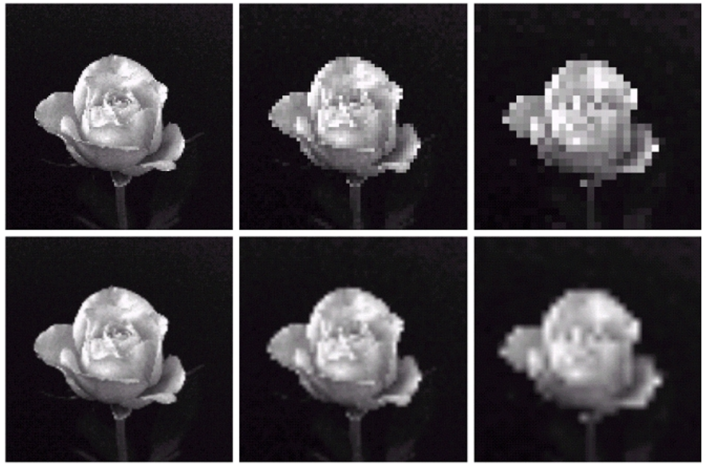
Using four nearest neighbors of a point (x', y') to interpolate $v(x', y')$.

$$v(x', y') = ax' + by' + cx'y' + d$$

where the a, b, c, d are determined from the four equations in four unknowns that can be written using the four nearest neighbors of point (x', y')

Zooming
Bilinear interpolation

Zooming image by bilinear interpolation



Shrinking Digital Image

Similar to Zooming

- Expand the grid to fit the original image
- Do gray-level nearest neighbor or bilinear interpolation.
- Shrink the grid back to its original size.

Example

________________ is a special case of nearest neighbor interpolation when the shrinking factor is an integer.

Tip

To reduce possilbe aliasing effects, it is a good idea to blur image slightly before shrinking it.

Neighbors of a Pixel

Definition

A pixel p at coordinates (x, y) has neighbors,

- ________________ $N_4(p)$: $(x+1, y), (x-1, y), (x, y+1), (x, y-1)$
- ________________ $N_D(p)$: $(x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1)$
- ________________ $N_8(p)$: $\{N_4(p), N_d(p)\}$

$N_4(p), N_D(p), N_8(p)$ may fall outside the image if (x, y) is on the border of the image.

Adjacency

Definition

Let V be the set of gray-level values used to define adjacency.

- binary image: $V \subset 0, 1$.
- 8-bit image $V \subset 0, 1, 2, 3, \ldots, 255$.

Example

For example, $V = \{1\}$ if referring to adjacency of pixels with value 1.

Adjacency of a pixel

Definition

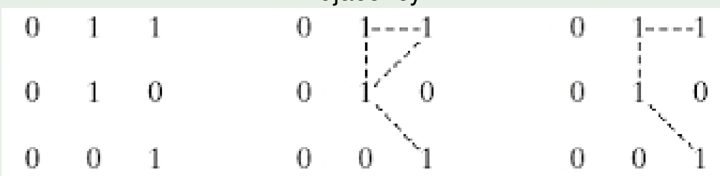
__________ is the neighborhood with similar gray-level:

- __________ Two pixels p and q with values from V are 4-adjacent if q is in $N_4(p)$.
- __________ Two pixels p and q with values from V are 8-adjacent if q is in $N_8(p)$.
- _______________ Two pixels p and q with values from V are m-adjacent
  - if q is in $N_4(p)$, *or*
  - if q is in $N_D(p)$ *and* $N_4(p) \cap N_4(q)$ has no pixels whose value are from V.

Adjacency of a pixel

Example

Adjacency



Adjacency of an image

Definition

____________________ if some pixel in S_1 is (4-,8-,m-)adjacent to some pixel in S_2.

Example

TBA

Digital Path

Definition

__________ from pixel p with coordinates (x, y) to pixel q with coordinates (s, t) is a sequence of distinct pixels with coordinates

$$p = (x, y) = (x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n) = (s, t) = q$$

- __________: n (not $n + 1$)
- __________: if $(x_0, y_0) = (x_n, y_n)$
- __________: depending on the type of adjacency specified.
- No ambiguity in the m-path.

Connectivity

Definition

Let S be a subset of pixels in an image.

- __________:
  Two pixels __________ if there exists a path between them consisting entirely of pixels *in* S.
- __________:
  For any pixel p in S, the set of pixels that are connected to it in S is called a __________.
- __________:
  If S only has one connected component, then S is called __________.

Region and Boundary

Definition

______: Let R be a subset of pixels in an image. We call R a ______ of the image if R is a connected set.

Definition

________________: The boundary of a region R is the set of pixels in the region that have one or more neighbors that are not in R.

Example

If R happens to be an entire image, the boundary of R is the pixels in the first and last rows and columns of the image.

Boundary versus Edge

Definition

______:

- Pixels with derivative values that exceed a preset threshold.
- Based on a measure of gray-level discontinuity at a point.

- Boundary:
  - Closed path
  - Global concept
- Edge:
  - May not be a closed path
  - Local concept

Distance
Euclidean Distance

For pixel p, q with coordinates $(x, y), (s, t)$.

Definition

____________________:

$$D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

Example

Equal distance: Disk

Light: Spectrum and Attribute | Eyes: Elements of Visual Perception | Image Sensing and Acquisition | Image Sampling and Quantization
Distance

Distance
D_4 Distance

For pixel p, q with coordinates $(x, y), (s, t)$.

Definition

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

Example

Equal distance: Diamond

$$\begin{array}{ccccc} & & 2 & & \\ & 2 & 1 & 2 & \\ 2 & 1 & 0 & 1 & 2 \\ & 2 & 1 & 2 & \\ & & 2 & & \end{array}$$

Light: Spectrum and Attribute | Eyes: Elements of Visual Perception | Image Sensing and Acquisition | Image Sampling and Quantization
Distance

Distance
D_8 Distance

For pixel p, q with coordinates $(x, y), (s, t)$.

Definition

______________: $D_8(p,q) = max(|x-s|, |y-t|)$

Example

Equal distance: Square

$$\begin{array}{ccccc} 2 & 2 & 2 & 2 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 1 & 0 & 1 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 2 \end{array}$$

Light: Spectrum and Attribute | Eyes: Elements of Visual Perception | Image Sensing and Acquisition | Image Sampling and Quantization
Distance

Distance
D_m Distance

Definition

______________:

- $D_m(p,q)$ the shortest m-path between the points
- The distance between two pixels will depend on the values of the pixels along the path and the values of their neighbors.

Example

Let $V = \{1\}$

$$\begin{array}{cccc} & & 0 & 1 \\ 0 & & 1 & \\ 1 & & & \end{array} \qquad \begin{array}{ccc} & 0 & 1 \\ 1 & 1 & \\ 1 & & \end{array} \qquad \begin{array}{ccc} & 1 & 1 \\ 0 & 1 & \\ 1 & & \end{array} \qquad \begin{array}{ccc} & 1 & 1 \\ 1 & 1 & \\ 1 & & \end{array}$$

$D_m(p,q) = 2$ $\quad$ $D_m(p,q) = 3$ $\quad$ $D_m(p,q) = 3$ $\quad$ $D_m(p,q) = 4$