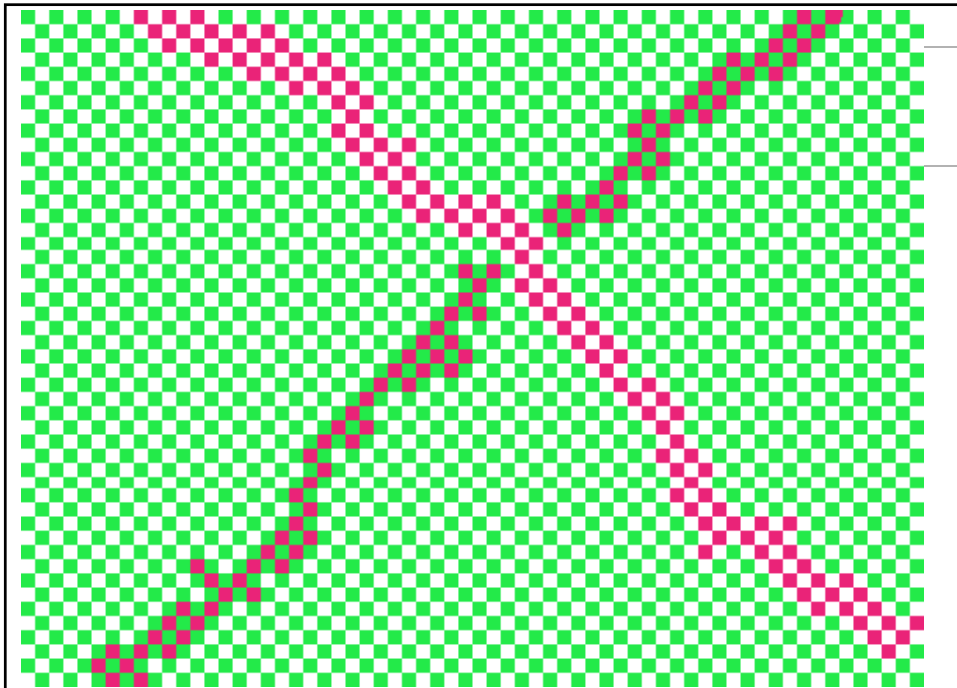




Butterfly Nebula: Gas heated at 36000 F and traveling at 600 000 miles/hr (earth-moon in 24 min!) from a dying star (used to be 5xsun) . Image was captured on 27 July 2009 by a Wide Field Camera (ultraviolet and visible light) onborad Hubble telescope. 2.1
Ref.: http://www.nasa.gov/mission_pages/hubble/multimedia/ero/index.html



<http://www.grand-illusions.com/square.htm>

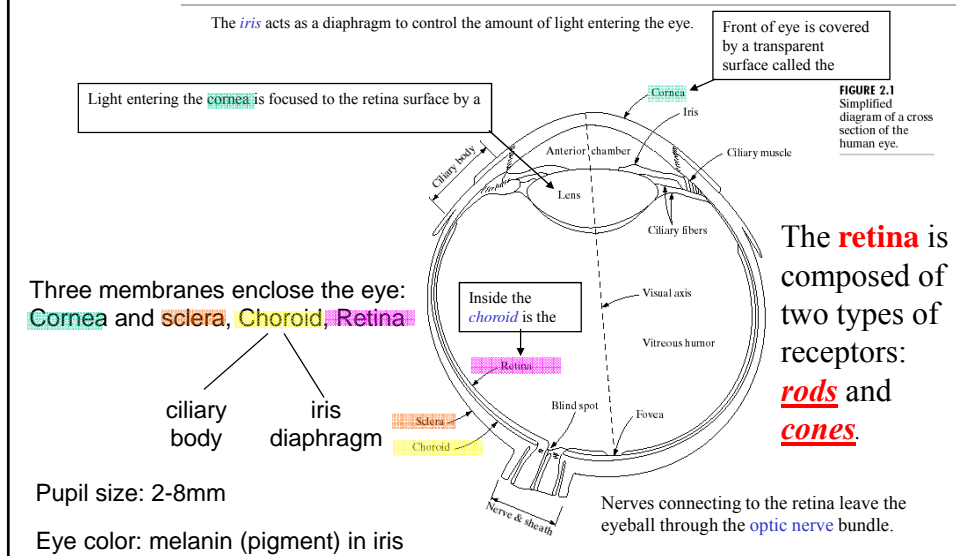
Chapter 2: Digital Image Fundamentals

Outline

- Elements of Visual Perception
- Light and the Electromagnetic Spectrum
- Image Sensing and Acquisition
- Sampling and Quantization

2.3

Chapter 2: Digital Image Fundamentals Structure of the Human Eye



Chapter 2: Digital Image Fundamentals

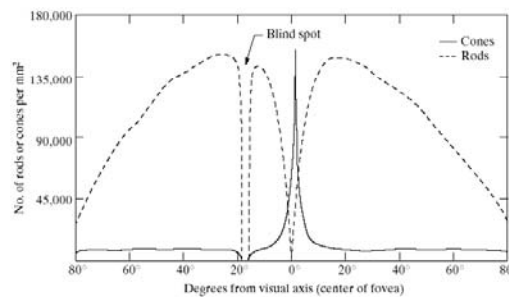


FIGURE 2.2
Distribution of rods and cones in the retina.

The distribution of rods and cones is radially symmetric wrt the **fovea** (central portion of the retina), except at the **blind spot** which includes no receptors.

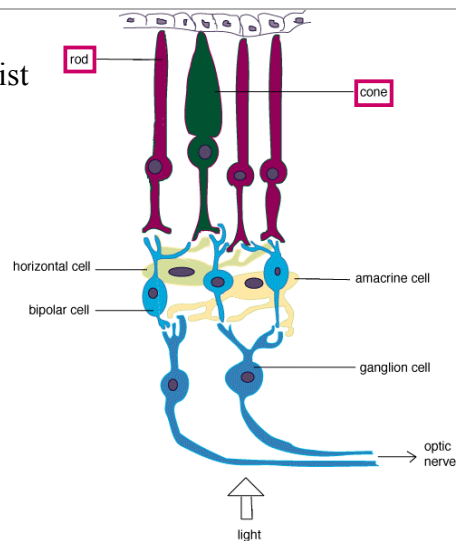
Cones are responsible for **photopic** (color or bright-light) vision; while **rods** are for **scotopic** (dim-light) vision.

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. This is easily achievable with medium resolution CCD imaging chip of size 5mm x 5mm!

Structure of the Retina

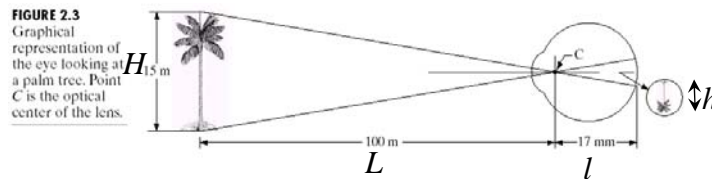
Light receptors in the retina consist of two types: *rods* and *cones*.

Rods are long slender receptors, 75~150 million, and cones are shorter and thicker, 6~7 million.



Chapter 2: Digital Image Fundamentals

How's an object seen at the back of the eye?



The focal length (distance bet center of the lens and the retina) varies from 17 mm to 14 mm (as the refractive power of the lens increases from its minimum to its maximum). Recall that $H/L = h/l$

Perception takes place by the relative excitation of light receptors, which transform radiant energy into electrical impulses that are ultimately decoded by the brain.

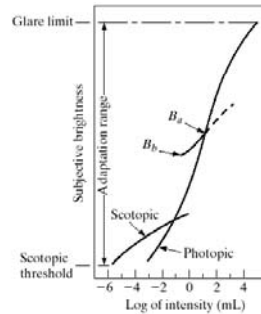
2.7

Chapter 2: Digital Image Fundamentals

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.

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



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 (0.001, 0.1) millilambert¹ (-3 to -1 mL in the log scale).²

- ¹Johann H. Lambert 1777, German Physicist,
- ² see <http://www.cns.nyu.edu/~msl/courses/2223/notes.2.pdf>

2.8

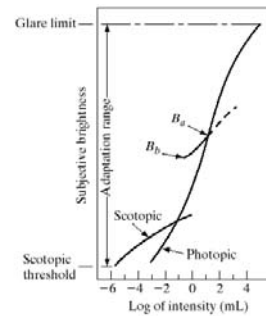
Chapter 2: Digital Image Fundamentals

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.

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 loses its meaning as it raises the adaptation level higher than B_a .

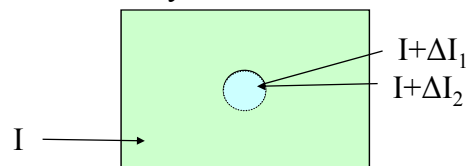


2.9

Chapter 2: Digital Image Fundamentals

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.



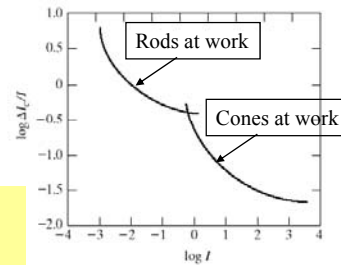
The results should move from "no perceivable change" to "perceived change". The fraction $\Delta I_c / I$ for which ΔI_c produces "just perceivable change" is called the **Weber ratio**.

2.10

Chapter 2: Digital Image Fundamentals

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 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.

2.11

Chapter 2: Digital Image Fundamentals

Perceived brightness is NOT a simple function of intensity.

Example 1: Mach bands

The reflected light intensity from each strip is uniform over its width and differs from its neighbors by a constant amount; nevertheless, the virtual appearance is that transitions at each bar appear **brighter on the left side and darker on the right side** (scalloped bands).

The Mach band* effect can be used to estimate the impulse response of the visual system.

*Mach 1906.

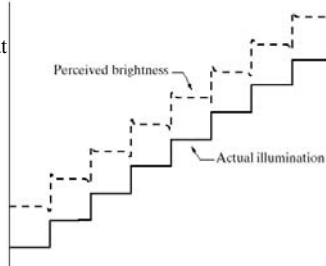
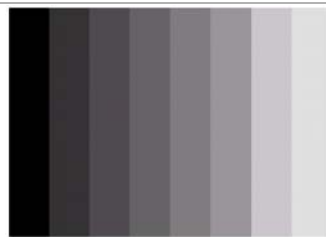


FIGURE 2.7
 (a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.

Chapter 2: Digital Image Fundamentals

Example 2: Simoultaneous Contrast

Each small square is actually the same intensity, but because of different intensities of the surrounding, the small squares do not appear equally bright.



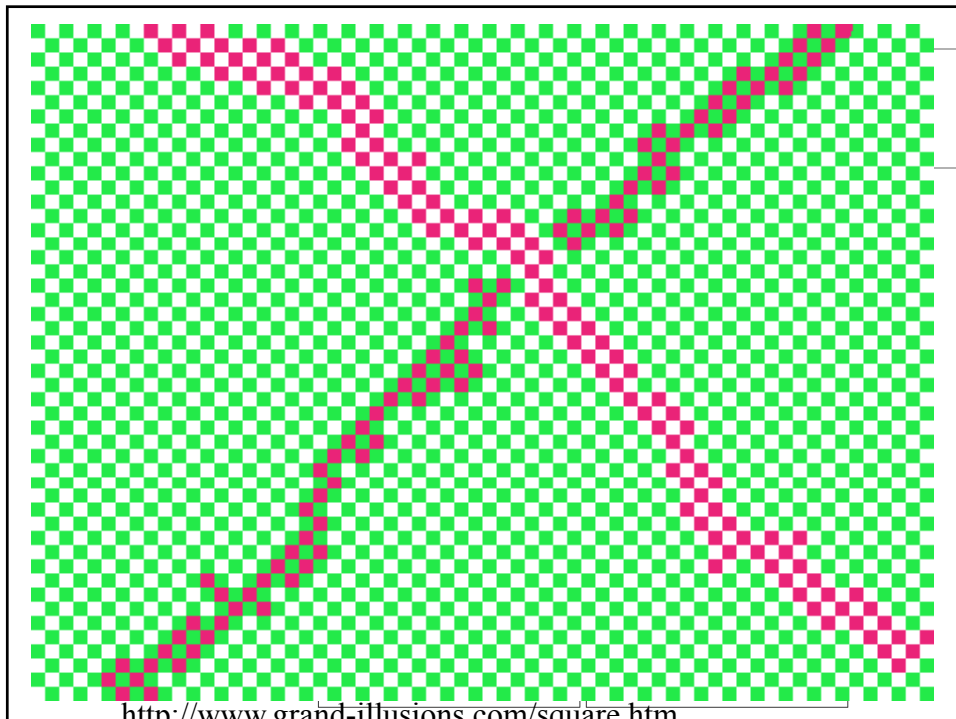
a b c

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.

Example 3: Metameric Pairs

Any two objects which appear equally bright, even though, their intensities are different are called metameric pairs.

2.13



Chapter 2: Digital Image Fundamentals

Other optical illusions

<http://www.optillusions.com/>

[http://video.google.com/videoplay?docid=6330601890396636382
&q=nice+video](http://video.google.com/videoplay?docid=6330601890396636382&q=nice+video)

2.15

Chapter 2: Digital Image Fundamentals

Definition:

Light is an electromagnetic radiation which, by stimulation, arouses a sensation on the visual receptors making sight possible.

Sir Isaac Newton (1666) discovered that when a beam of sunlight is passed through a glass prism, the emerging beam of light is not white but consists instead of a continuous spectrum of colors ranging from **violet** to **red**. This is called the **visible** region of the spectrum, see next figure.

2.16

Chapter 2: Digital Image Fundamentals The Electromagnetic Spectrum

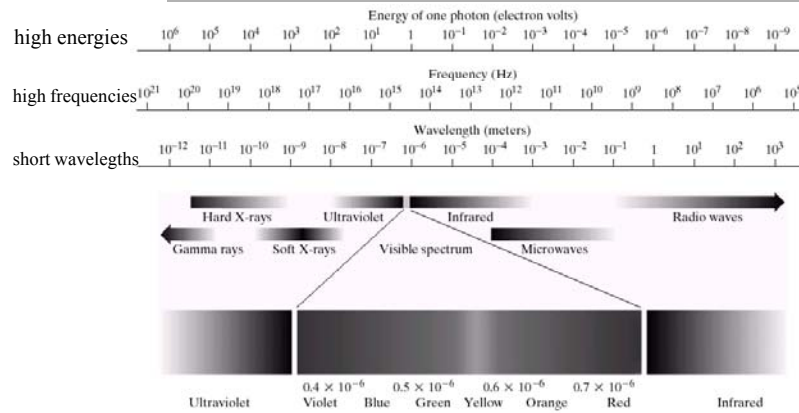


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

2.17

Chapter 2: Digital Image Fundamentals

The electromagnetic spectrum can be expressed in terms of **wavelength** (λ), **frequency** (ν), or **energy** (E). Recall that

$$\lambda = c/\nu$$

where c is the speed of light (2.998×10^8 m/s).

The energy of the various components is given by:

$$E = h\nu$$

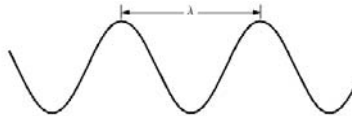
where h is Planck's constant ($6.62606891 \times 10^{-34}$ Joule-seconds (or $\text{m}^2\text{kg/s}$)). E is measured in electron-volt.

2.18

Chapter 2: Digital Image Fundamentals

Electromagnetic waves can be visualized as propagating sinusoidal waves of varying wavelengths (λ) or as a stream of massless particles, each traveling in a wavelike pattern and moving at the speed of light. Each massless particle contains a certain amount (or bundle) of energy. Each bundle of energy is called a **photon**.

FIGURE 2.11
Graphical
representation of
one wavelength.



λ is measured in meters (or km for radio waves), microns (visible) or nanometers (for X-ray).

2.19

Image Sensing and Acquisition

The types of images we're interested in are generated by the combination of an "illumination" source and the reflection or absorption of energy from the "scene" being imaged.

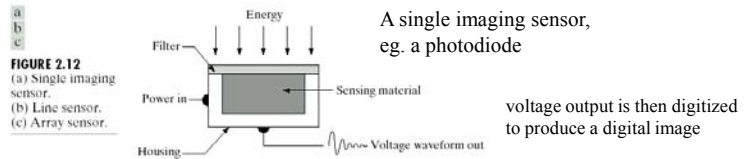
Exception: stained glass which transmits light
Rather than reflecting or absorbing it!

"Illumination" includes visible light, radar, infrared, X-ray, or ultrasound.

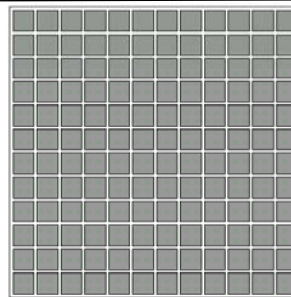
"Scene" may be a familiar 3D object, underground, human internal organs.

2.20

How to transform illumination energy into digital images?



An array sensor



2.21

Chapter 2: Digital Image Fundamentals

Generating a 2-D image using a single sensor.

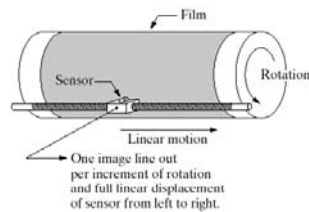
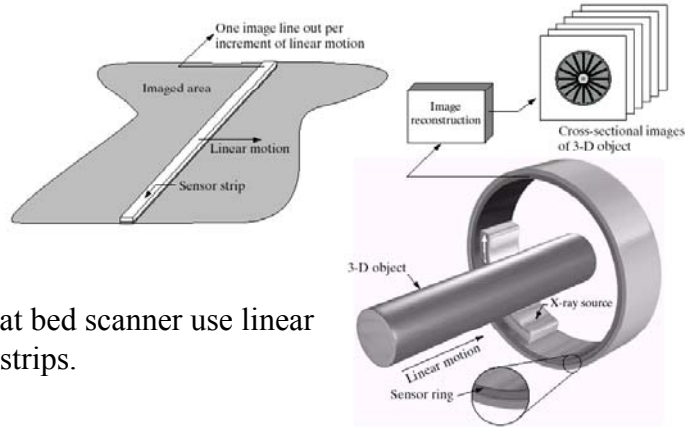


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

This type of mechanical digitizers is called a microdensitometer and is used in high-precision scanning (but slow).

2.22

Image Acquisition Using Sensor Strips



most flat bed scanner use linear sensor strips.

circular sensor strips are used, e.g. in medical and industrial imaging to produce cross-sectional "slice" images of 3-D objects.

2.23

Some Digital Cameras



24 February 2009 – The world's smallest and lightest creative D-SLR with built-in **image stabilization** has finally arrived! The new Olympus E-620 combines the technical sophistication required by pros with easy-to-use functions desired by hobbyists. As a result, ambitious photographers everywhere can now take creativity to a whole new level. Outfitted with a custom 7-point Twin **autofocus** system, the E-620 provides consistent focus, as well as a generous **12.3 Megapixel High-Speed Live MOS**. Additionally, the Live View technology as well as the 2.7" free-angle HyperCrystal III LCD make framing every shot a cinch. In-camera Art Filters entice users to be artistic by allowing them to apply **stylish effects** at the touch of a button. Indeed, the E-620 is everything that makes Olympus Four Thirds Standard D-SLR cameras great. The latest addition to the E-System range offers creative and technological power – all rolled into one. The new model will be available for purchase at the end of April 2009.

Ref.: <http://www.cameratown.com/news/news.cfm/hurl/id/7238>

2.24

Some Digital Cameras



- 15.1 Megapixel APS-C CMOS sensor
- 6.3fps continuous shooting, max. burst 90 JPEGs with UDMA card
- DIGIC 4 processor
- ISO 100-3200, expandable to 12800
- 9-point wide area AF
- 3.0" Clear View VGA LCD with Live View mode & Face Detection Live AF
- Magnesium alloy body, with environmental protection
- EOS Integrated Cleaning System
- HDMI connection for high quality viewing and playback on a High Definition TV
- Full compatibility with Canon EF and EF-S lenses and EX-series Speedlites

2.25

Some Digital Cameras

Main Features

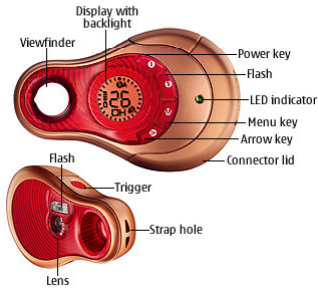
- 7x Zoom-NIKKOR lens
- Sure Grip with reassuring fit to capture all those precious moments
- 12.0 effective megapixels for high-resolution images
- 2.7-in. high-resolution LCD monitor
- High performance image sensor shift VR image stabilization
- Motion Detection for sharp, steady results
- High Sensitivity up to ISO 6400*
- Sport Continuous Mode for high-speed capture settings
- Scene Auto Selector provides quick, carefree picture-taking in a variety of situations
- Smart Portrait System ? Face-priority AF, Smile Mode, Blink Proof and In-Camera Red-Eye Fix
- Quick Retouch for the best balance of contrast and saturation
- D-Lighting adds detail and optimizes exposure to rescue underexposed images



Ref.:
<http://imaging.nikon.com/products/imaging/lineup/digitalcamera/coolpix/s630/index.htm>

2.26

Some Digital Cameras



VGA 640 x 480 resolution
 Three file sizes for images:
 P=Photo: max 60 kB
 H=Higher quality: max 32 kB
 L=Lower quality: typical 15 kB

Integrated Digital Camera
 5 mega-pixel, (2592 x 1944 pixels), Carl Zeiss
 –optical lens
 MPEG-4 VGA –video recording (up to 30 f/s)
 8GB hard-disk inside!

2.27

Some Digital Cameras

Miniature Digital Camera - Keychain
 640x480 Digital Camera USB

<http://www.compuvisor.com/mike64dicaus.html>



2.28

One of the smallest digital cameras



The Cubik is the world's smallest megapixel digital camera. Its 1.3 million pixel CMOS captures images at 1280x1024. Its on-board 16mb RAM stores 50 1280x1024 or 99 640x512 low-res pictures. You can even capture a 90 second movie (no sound, though). Although not as small as the Spyz, the Cubik is small enough to fit unobtrusively into your pocket.

The Cubik also works as a webcam.

<http://www.dynamism.com/cubik/index.shtml>

2.29

The SpyZ Digital Camera



- The SpyZ, our original micro-digital camera, is about the size of a Zippo lighter, and features an aluminum chassis (blue or silver) and a loop for a keychain. The **350,000 pixel CCD** takes **640x480** photos on internal flash memory. (Up to 26 photos.) The camera then connects directly to your computer's USB port (mini-USB to USB cable is included). While connected, you can also use it as a webcam for videoconferencing. In digital camera mode, it runs on one AAA battery; in webcam mode, it draws power from the USB port.

<http://www.dynamism.com/spyz/index.shtml>

2.30

Chapter 2: Digital Image Fundamentals

Principles of Image Acquisition, Sampling and Quantization

2.31

A Simple Image Model

- Image: a 2-D light-intensity function $f(x,y)$
- The value of f at $(x,y) \rightarrow$ the intensity (brightness) of the image at that point
- $0 < f(x,y) < \infty$

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A Simple Image Formation Model

Consider the monochrome case, e.g., black and white images

Represent the spectral intensity distribution of the image by a continuous function $f(x,y)$, *i.e.*, for fixed value of (x,y) , $f(x,y)$ is proportional to the grey level of the image at that point.

Of course,

$$\text{(black)} \quad 0 \leq f(x,y) \leq f_{max} \quad \text{(white)}$$

Why such limits?

Lower bound is because light intensity is a real positive quantity (recall that intensity f is proportional to $|E|^2$, where E is the electric field).

Upper bound is due to the fact that in all practical imaging systems, the physical system imposes some restrictions on the maximum intensity level of an image, e.g., film saturation and cathode ray tube phosphor heating.

Intermediate values between 0 and f_{max} are called shades of gray varying from black to white.

2.33

Digital Image Acquisition

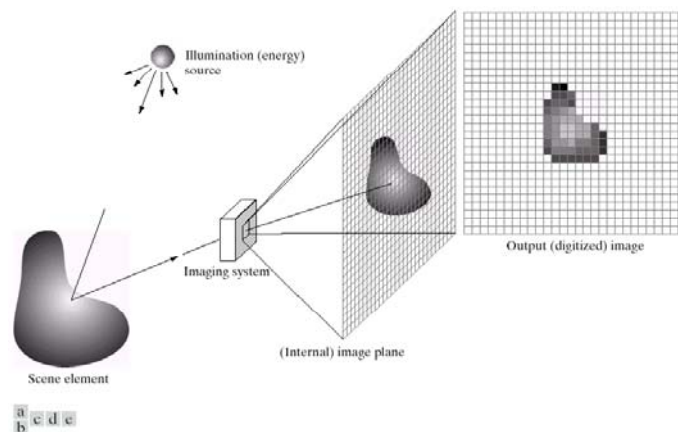


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

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A Simple Image Model

- Nature of $f(x,y)$:
 - The amount of source light incident on the scene being viewed
 - The amount of light reflected by the objects in the scene

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A Simple Image Model

- Illumination & reflectance components:
 - Illumination: $i(x,y)$
 - Reflectance: $r(x,y)$
 - $f(x,y) = i(x,y) \cdot r(x,y)$
 - $0 < i(x,y) < \infty$
 and $0 < r(x,y) < 1$
 (from total absorption to total reflectance)

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A Simple Image Model

- Sample values of $r(x,y)$:
 - 0.01: black velvet
 - 0.93: snow
- Sample values of $i(x,y)$:
 - 9000 foot-candles: sunny day
 - 1000 foot-candles: cloudy day
 - 0.01 foot-candles: full moon

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A Simple Image Model

- Intensity of a monochrome image f at (x_0, y_0) :
gray level l of the image at that point

$$l=f(x_0, y_0)$$

- $L_{\min} \leq l \leq L_{\max}$
 - Where L_{\min} : positive
 - L_{\max} : finite

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Digital Image

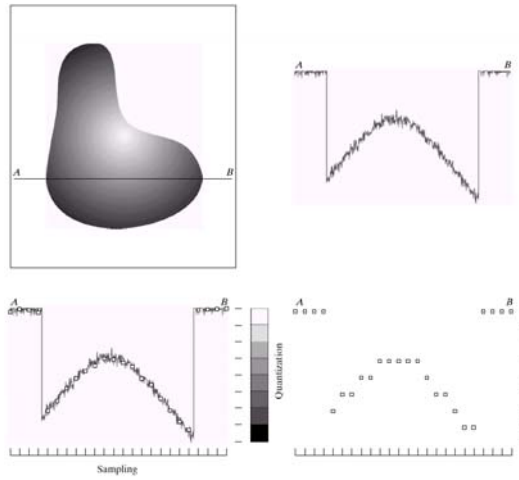


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling and Quantization

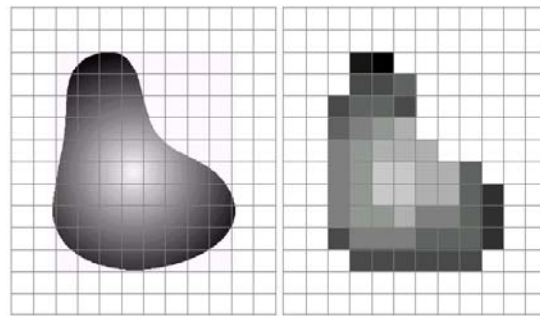


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

A Digital Image

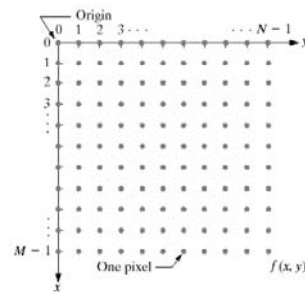
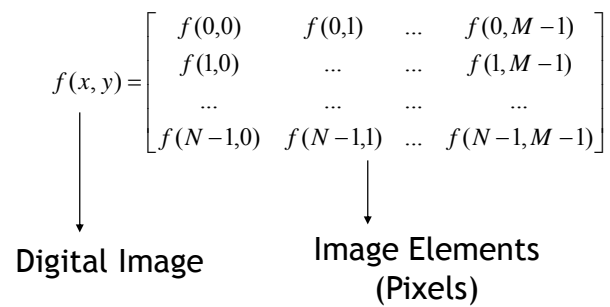


FIGURE 2.18
Coordinate convention used in this book to represent digital images.

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Sampling & Quantization



stop

Sampling & Quantization

- Important terms for future discussion:
 - Z : set of real integers
 - R : set of real numbers

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Sampling & Quantization

- Sampling: partitioning xy plane into a grid
 - the coordinate of the center of each grid is a pair of elements from the Cartesian product $Z \times Z$ (Z^2)
- Z^2 is the set of all ordered pairs of elements (a,b) with a and b being integers from Z .

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Sampling & Quantization

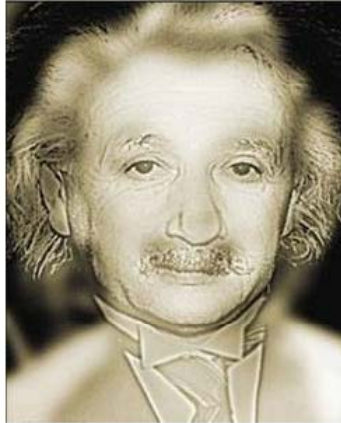
- $f(x,y)$ is a digital image if:
 - (x,y) are integers from Z^2 and
 - f is a function that assigns a gray-level value (from R) to each distinct pair of coordinates (x,y) [quantization]
- Gray levels are usually integers
 - then Z replaces R

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Sampling & Quantization

- The digitization process requires decisions about:
 - values for N,M (where $N \times M$: the image array)
 - and
 - the **number** of discrete gray levels allowed for each pixel.

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Sampling & Quantization

- Usually, in DIP these quantities are integer powers of two:

$$N=2^n \quad M=2^m \quad \text{and} \quad G=2^k$$

↓
number of gray levels

- Another assumption is that the discrete levels are equally spaced between 0 and $L-1$ in the gray scale.

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Examples

1 MP (mega-pixel)

1/4 MP

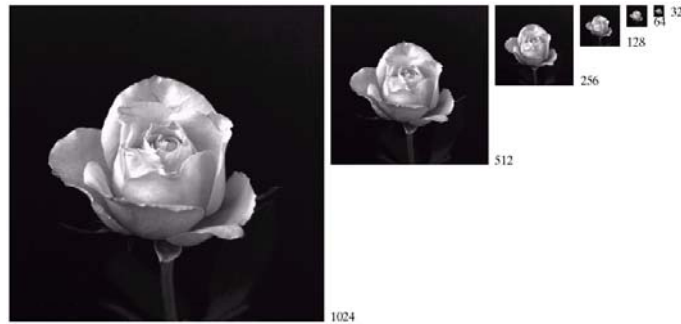
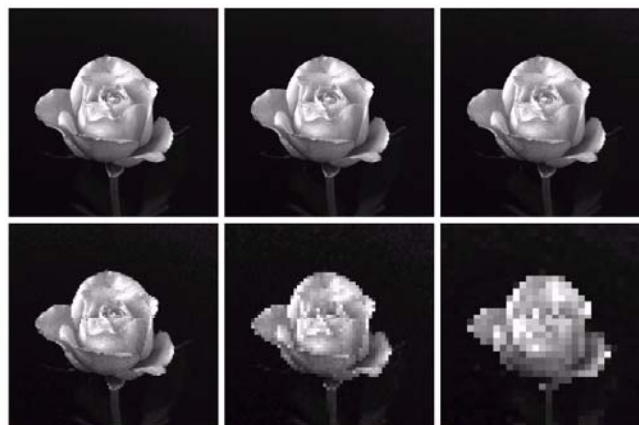


FIGURE 2.19 A 1024×1024 , 8-bit image subsampled down to size 32×32 pixels. The number of allowable gray levels was kept at 256.

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Examples



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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Examples

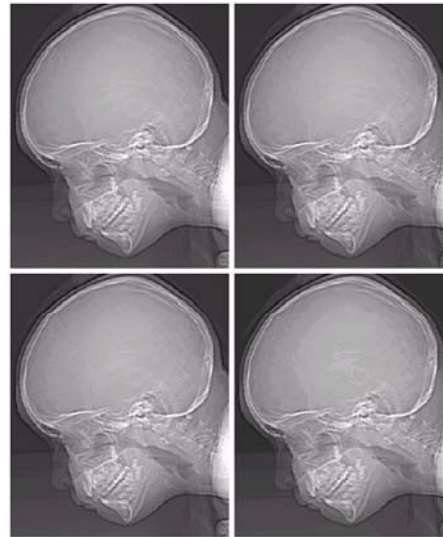


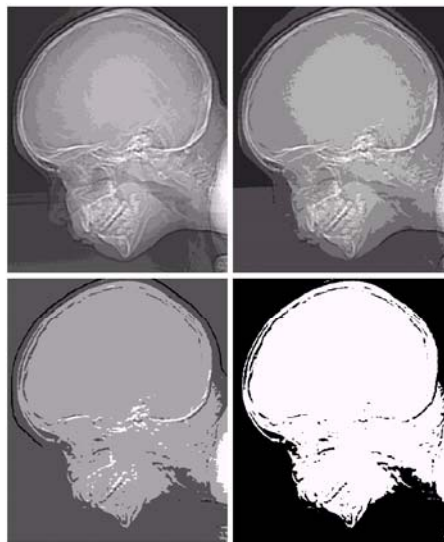
FIGURE 2.21
 (a) 452×374 ,
 256-level image.
 (b)–(d) Image
 displayed in 128,
 64, and 32 gray
 levels while
 keeping the
 spatial resolution
 constant.

8-bit	7-bit
6-bit	5-bit

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Examples

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



4-bit	3-bit
2-bit	1-bit

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Sampling & Quantization

- If b is the number of bits required to store a digitized image then:
 - $b = N \times M \times k$ (if $M=N$, then $b=N^2k$)

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Chapter 2: Digital Image Fundamentals

The number of bits required to store an image is $b=M \times N \times k$ and when $M=N$, b becomes N^2k .

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

Ex. 8-bit images of size 1024 by 1024 and higher require a significant storage space!

How do these parameters (N and k) affect the image?

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Sampling & Quantization

- How many samples and gray levels are required for a good approximation?
 - Resolution (the degree of discernible detail) of an image depends on the number of samples (spatial resolution, e.g. 300 dpi) and the number of gray levels (intensity resolution, e.g. 8-bit).
 - i.e. the more these parameters are increased, the closer the digitized array approximates the original image.

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STOP

Sampling & Quantization

- How many samples and gray levels are required for a good approximation? (cont.)
 - **But:** storage & processing requirements increase rapidly as a function of N , M , and k

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Sampling & Quantization

- Different versions (images) of the same object can be generated through:
 - Varying N, M numbers
 - Varying k (number of bits)
 - Varying both

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Example 1: Spatial Resolution: we keep k constant at 8 bits and we vary N from 1024 to 32.

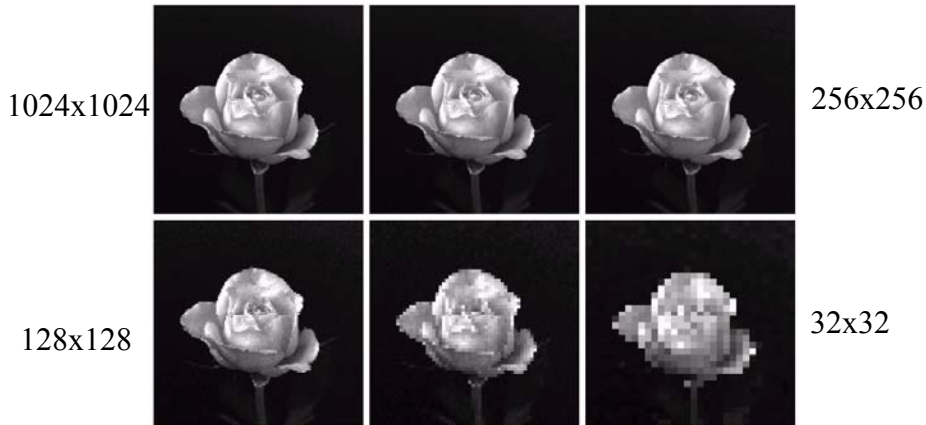


FIGURE 2.19 A 1024×1024 , 8-bit image subsampled down to size 32×32 pixels. The number of allowable gray levels was kept at 256.

How? The original 1024 by 1024 image is subsampled by removing every other column and every other row to produce the 512 by 512 image.

Image Resampling:

To visualize the difference, we up-sample (by duplication) to the original size of 1024 by 1024.



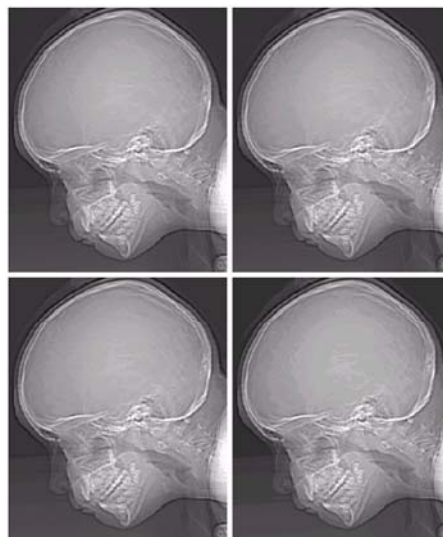
a b c
d e f

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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Example 2: we keep the image size constant at 452×374 and reduce the number of gray levels L from 256 to 2 (i.e. reduce k from 8 to 1)

64 levels



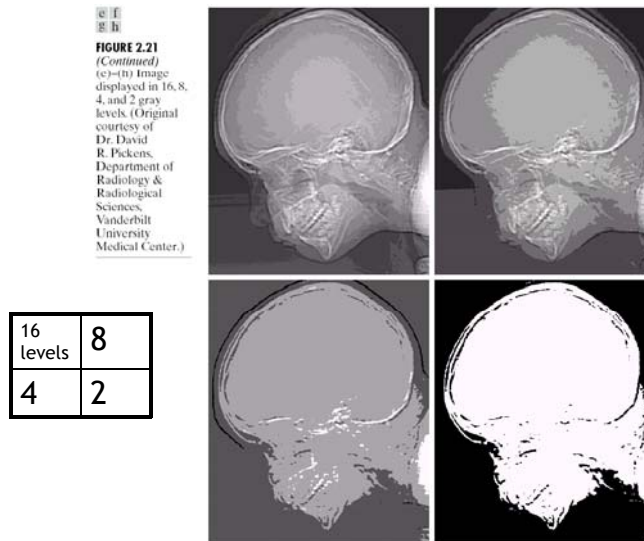
a b
c d

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.

in this 32-level image, note the appearance of very fine ridge-like structures in the areas of smooth gray levels, e.g. skull.

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Due to insufficient number of gray levels, this artifact is more visible below and it is called **false contouring**.



Sampling & Quantization

Example 3: what happens when we vary both N and k?

Isopreference curves (in the Nk plane)

- Each point: image having values of N and k equal to the coordinates of this point
- Points lying on an isopreference curve correspond to images of equal subjective quality.

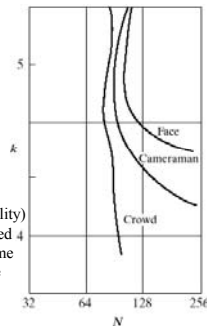


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Isopreference [Huang 1965] curves are plotted in the Nk -plane, where each point represents an image having values of N and k equal to the coordinates of that point.

Points lying on an isopreference curve correspond to images of **equal subjective quality**.

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



Comments:

1. Isopreference curves tend to shift right and upward (i.e. better image quality)
2. In images with a large amount of details, only a few gray levels are needed
3. In the other two image categories, the perceived quality remained the same in some intervals in which N was increased but k actually decreased! (more contrast in the image is perhaps preferred by some people!)

Sampling & Quantization

- Conclusions:
 - Quality of images increases as N & k increase
 - Sometimes, for fixed N , the quality improved by decreasing k (increased contrast)
 - For images with large amounts of detail, few gray levels are needed

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Nonuniform Sampling & Quantization

- An adaptive sampling scheme can improve the appearance of an image, where the sampling would consider the characteristics of the image.
 - i.e. fine sampling in the neighborhood of sharp gray-level transitions (e.g. boundaries)
 - Coarse sampling in relatively smooth regions
- **Considerations:** boundary detection, detail content

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Nonuniform Sampling & Quantization

- Similarly: nonuniform quantization process
- In this case:
 - few gray levels in the neighborhood of boundaries
 - more in regions of smooth gray-level variations (reducing thus false contours)

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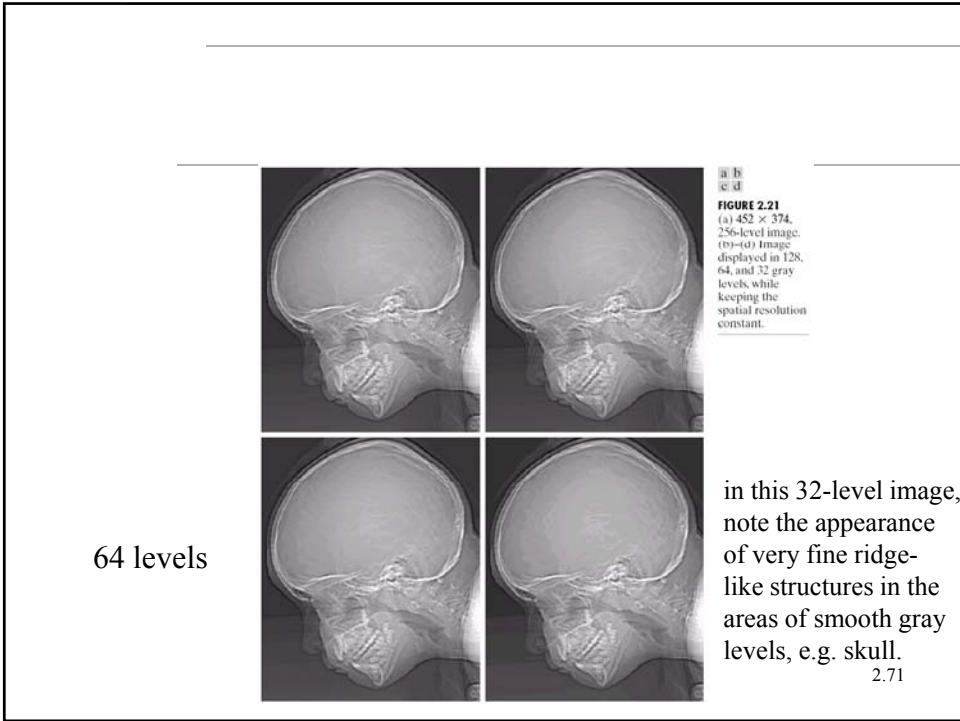
Contouring Effect

- If the number of quantization levels is not sufficient, contouring can be seen in the image.
- Contouring starts to become visible at 6 bits/pixel.
- Quantization should attempt to keep the quantization contours below the visible level.

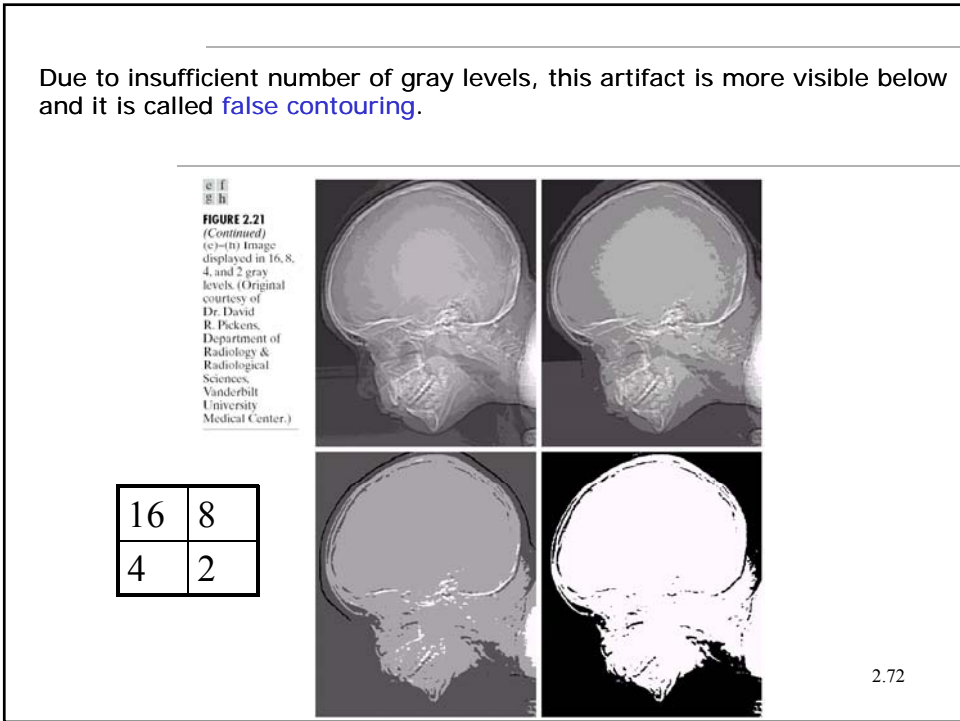
To reduce this effect:

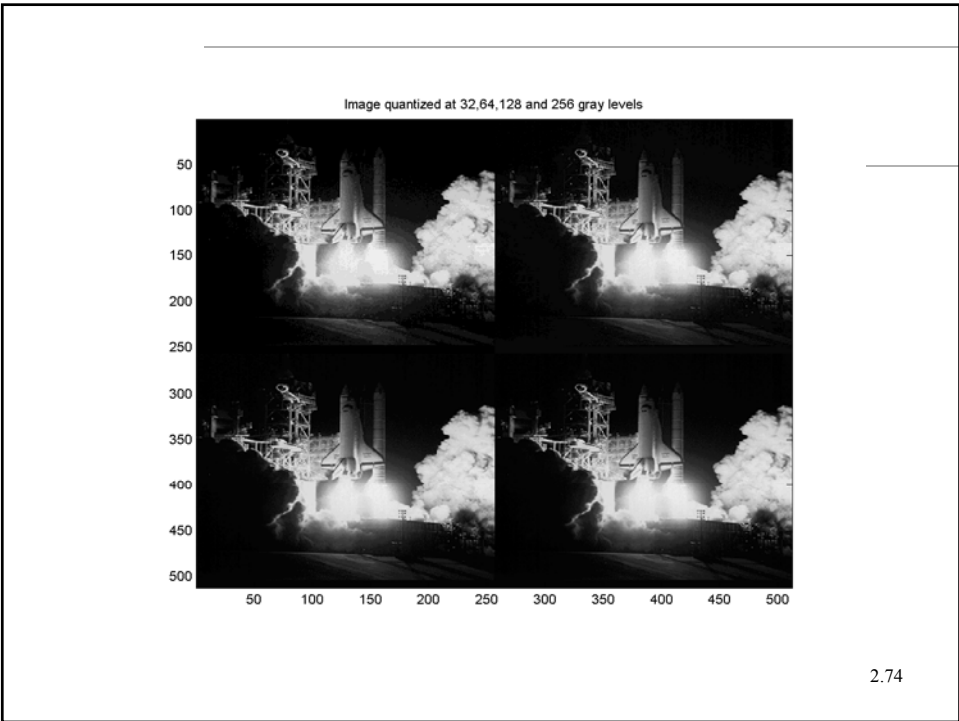
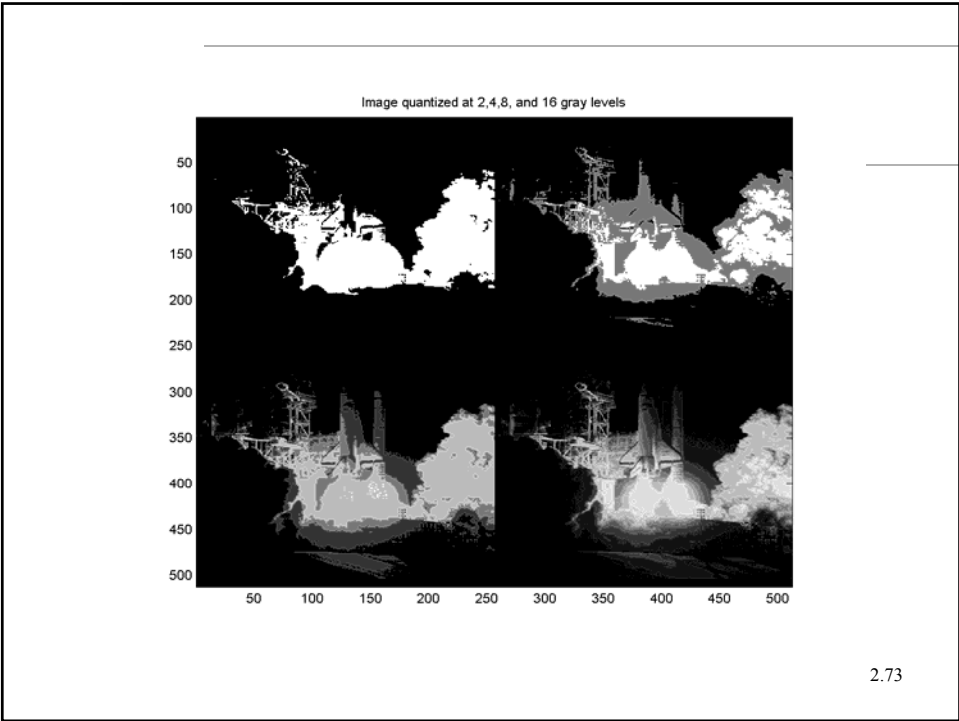
- Contrast Quantization,
- Dithering.

2.70



Due to insufficient number of gray levels, this artifact is more visible below and it is called **false contouring**.





Aliasing in Digital Images: Moiré Patterns

The effects of aliased frequencies can be seen under the right conditions in the form of so-called Moiré patterns.

A Moiré pattern caused by a break up of the periodicity is seen below as a 2-D sinusoidal (aliased) waveform running in a vertical direction.

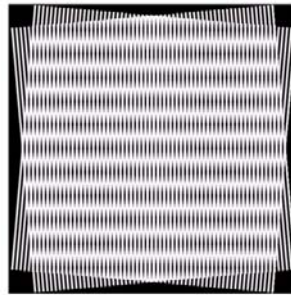


FIGURE 2.24 Illustration of the Moiré pattern effect.

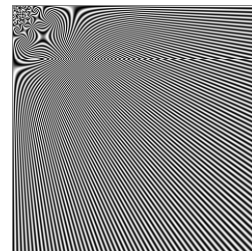
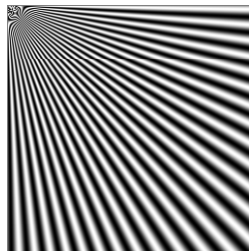
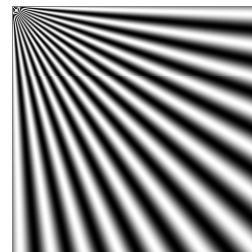
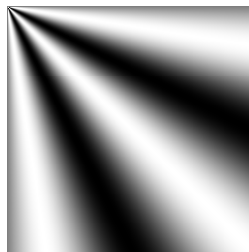
2.75

Moiré Patterns (cont'd)

Aliasing manifests itself through high-frequency components masquerading as low-frequency ones.

In images, it appears as low-frequency patterns scattered throughout the image.

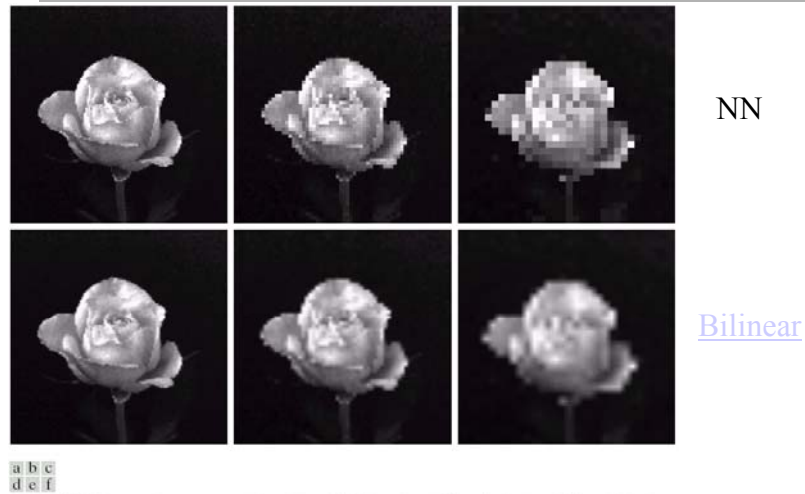
These patterns are called *Moiré* patterns.



2.76

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Image Zooming: NN vs Bilinear Interpolation



abc
def

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.

2.77

Another example: <http://www.drowview.com/learn/?key=interpolation>

High Dynamic Range Imaging



Q: Can we generate a HDR image (16bpp) by a standard camera?
A: Yes, adjust the exposure and fuse multiple LDR images together

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Towards Gigapixel



Mega-pel \longrightarrow Giga-pel

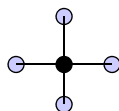
Photographers and artists have manually or semi-automatically stitched hundreds of mega-pel pictures together to demonstrate how a giga-pel picture looks like \rightarrow **the power of pixels**

<http://triton.tpd.tno.nl/gigazoom/Delft2.htm>

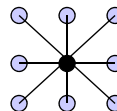
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Commonly-used Terminology

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 p is in the set $N_4(q)$

8-adjacency: p, q are 8-adjacent if p is in the set $N_8(q)$

Note that if p is in $N_{4/8}(q)$, then q must be also in $N_{4/8}(p)$

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Common Distance Definitions

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)

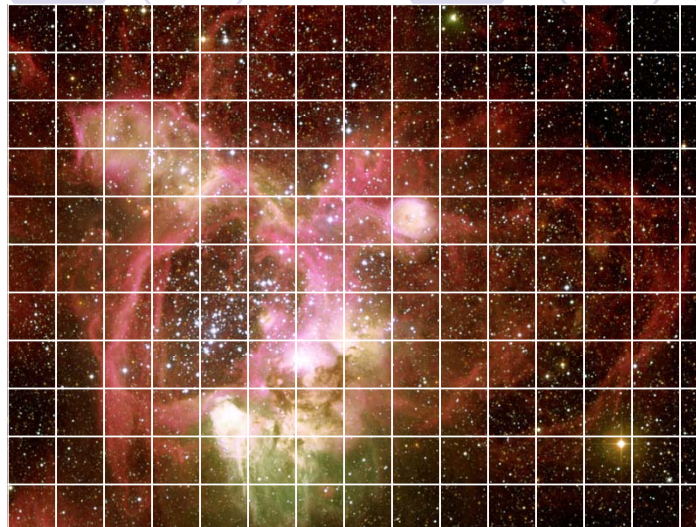
4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

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

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Block-based Processing



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

a b c

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

2.83