CSI 4133 Computer Methods in Picture Processing and Analysis

Fall 2024

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The first digital images

FIGURE 1.1 A digital picture produced in 1921 from a coded tape by a telegraph printer with special typefaces. (McFarlane.) [References in the bibliography at the end of the book are listed in alphabetical order by authors' last names.]

FIGURE 1.2 A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice. (McFarlane.)

www.imageprocessingbook.com

The first digital images

FIGURE 1.3
Unretouched cable picture of Generals Pershing (right) and Foch, transmitted in 1929 from London to New York by 15-tone equipment. (McFarlane.)

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The first picture of the moon

FIGURE 1.4
The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

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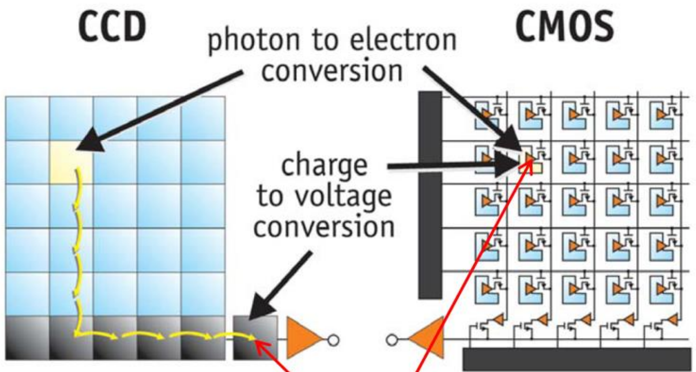
Introduction to image capture with cameras

- Components of a camera:
  - Lens: focuses light onto the sensor
  - Image sensor: converts light into electrical signals (CCD or CMOS sensors)
  - Aperture: controls the amount light entering the camera
  - Shutter: regulates how long the sensor is exposed to light
  - Viewfinder/display: provides a preview of the captured scene

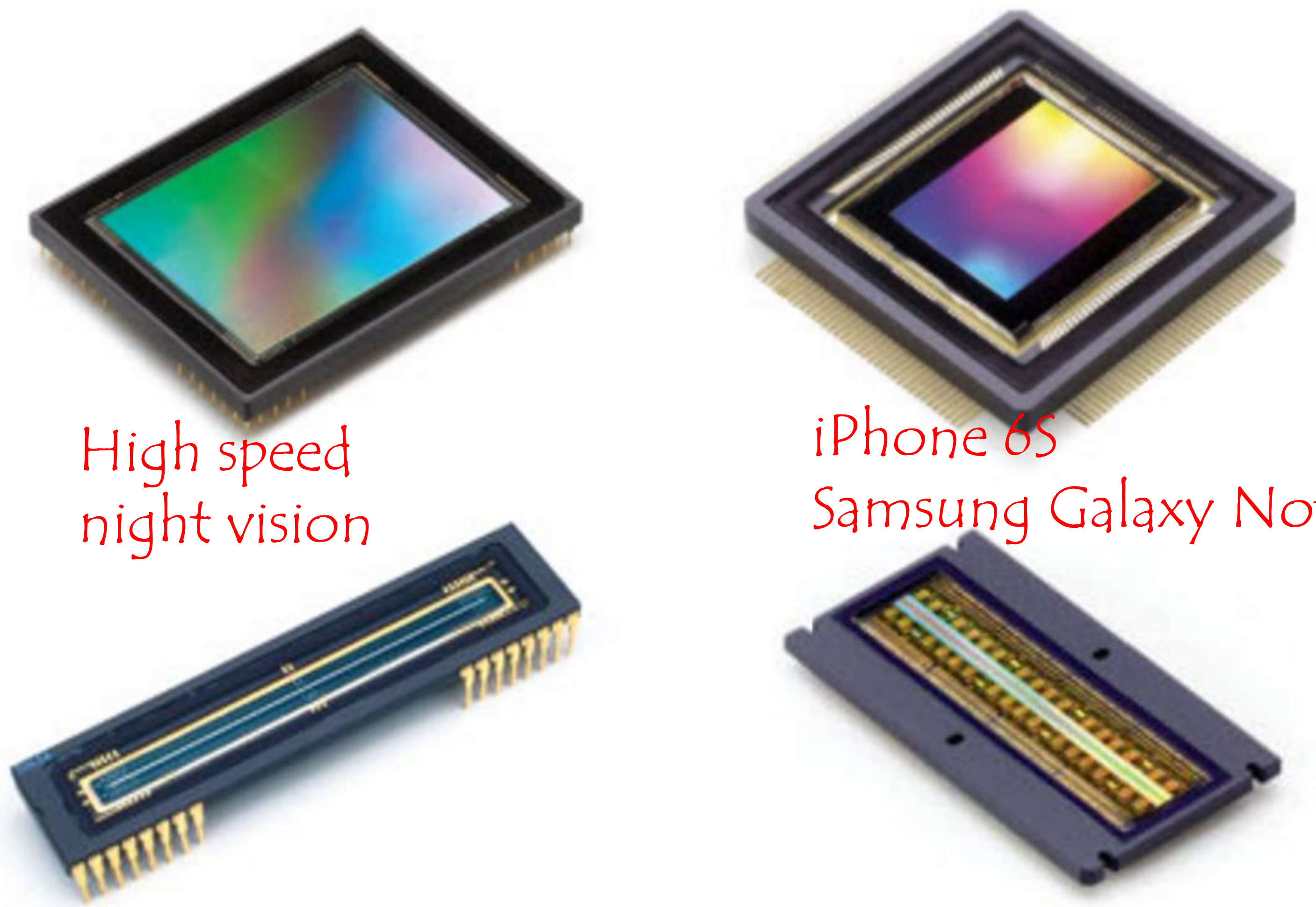
CCD vs. CMOS



CCDs move photogenerated charge from pixel to pixel and convert it to voltage at an output node. CMOS imagers convert charge to voltage inside each pixel.

- CCD (Charge-Coupled Device) and CMOS (Complementary Metal-Oxide-Semiconductor) sensors are both types of image sensors used in digital cameras and other imaging devices. They convert light into electrical signals to create images.
- CCD
  - Advantages:
    - Generally provide high-quality images with low noise.
    - Have high sensitivity and good performance in low light.
  - Disadvantages:
    - Usually consume more power than CMOS sensors.
    - Tend to be more expensive and slower in terms of data transfer rates.
- CMOS
  - Advantages:
    - More power-efficient and generally less expensive to produce.
    - Faster readout speeds, which is beneficial for capturing high-speed action and video.
  - Disadvantages:
    - Historically had higher noise levels compared to CCDs, though advances have significantly improved this.
    - May have lower light sensitivity compared to CCDs in some cases, though this varies by model and technology

https://www.gatan.com/ccd-vs-cmos



Teledyne DALSA CCD (left) and CMOS (right) image sensors

Image formation process

- Light entry: light from the scene enters the camera through the lens
- Focus: the lens focuses the light onto the image sensor, determining which parts of the scene are sharp
- Exposure: the amount of light hitting the sensor is controlled by the aperture, shutter speed, and ISO
- Digital conversion: the image sensor converts light into electrical signals, forming a digital image

Importance of optical parameters

- Exposure: brightness and darkness of an image
- Sharpness: how much of the scene is in focus
- Perspective: how objects appear in relation to each other in terms of size and distance
- Distortion: how straight lines and shapes are rendered in the image

Camera types

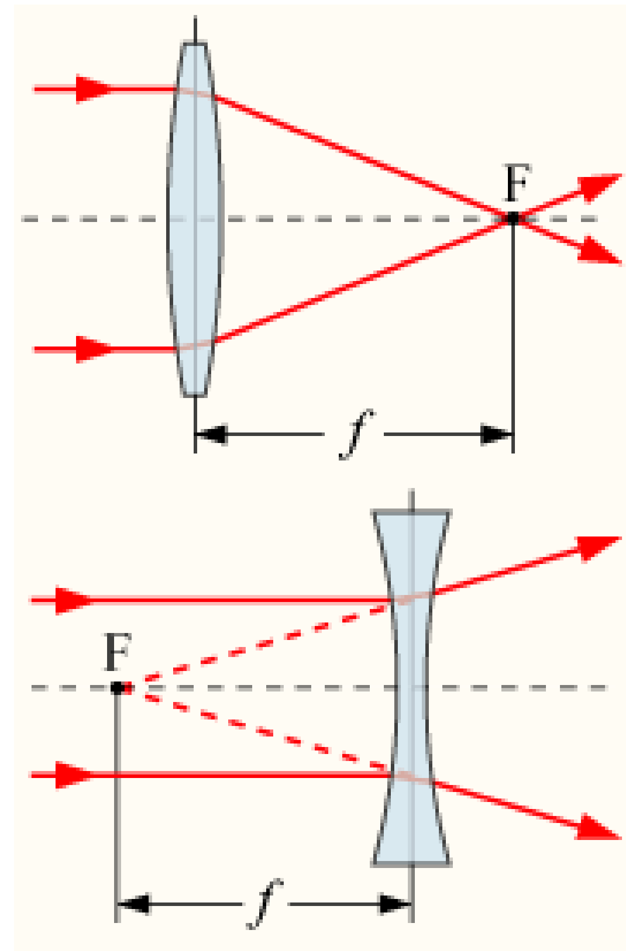
- DSLR: Digital Single-Lens Reflex cameras with interchangeable lenses, typically used in professional photography.
- Mirrorless: Compact and lightweight, offering features like fast autofocus.
- Smartphone Cameras: Highly portable with advanced software-driven photography capabilities.

Focal length

- Definition: Distance between the lens and the image sensor when the subject is in focus
- Effects on image:
  - Shorter focal lengths = wider field of view (FOV)
  - Longer focal lengths = narrower FOV
- Examples: 18mm (wide-angle) vs. 200mm (telephoto)

Focal length

- The focal point F and focal length *f* of
  - A positive (convex) lens
    - a converging lens
    - *f* is positive
  - A negative (concave) lens
    - A diverging lens
    - *f* is nagative

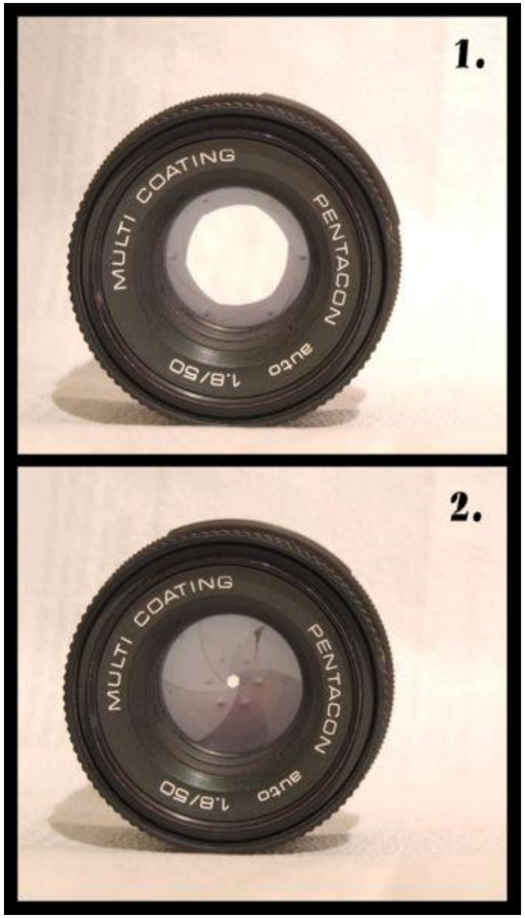


Focal length

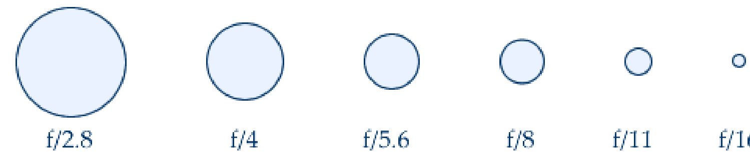
- A measure of how strongly it focuses or diverges light. A system with a shorter focal length has greater optical power than one with a long focal length
  - Myopic – too much power so light if focused in front of the retina (e.g., the focal length of the lens is too short)
  - Hyperopic – too little power so when the eye is relaxed, light is focused behind the retina (e.g., the lens’ focal length is too long)

Aperture

- In optics, an **aperture** is a hole or an opening through which light is admitted.
- The iris diaphragm, behind the lens, controls the lens opening.
- A lens with a wider maximum aperture lets in more light.
- Since the wide aperture lets in so much light, the shutter doesn't have to stay open as long.



f-number



- The *f*-number (f/#) is N and is given by N=f/D
  - Where f is the focal length
  - D is the diameter of the entrance pupil
- If the focal length is 16 times the pupil diameter, the *f*-number is *f*/16, or N=16
- The greater the *f*-number, the less light per unit area reaches the image plane of the system

f/32

f/5

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f-number of human eyes

- The f-number of the human eye varies from about *f*/8.3 in a very brightly lit place to about *f*/2.1 in the dark.
    - According to the *incoming* rays of light (what we actually see), the focal length of the eye is a bit longer, resulting in maximum f-number of *f*/3.2.

Maximum aperture

- Definition: the largest possible lens opening through which light can pass
- Aperture and f-stop: f/2.8, f/5.6, f/16 (lower f-stop = larger aperture)
- Impact on exposure: larger aperture = more light

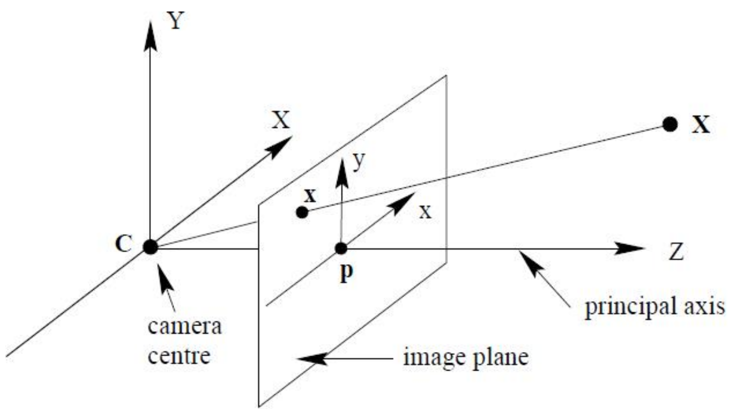
Field of view (FOV)

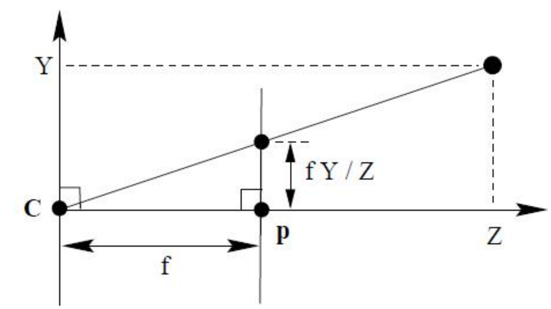
- Definition: the extent of the observable world seen through the camera at a given time
- Dependence on focal length and sensor size
- Example: narrow FOV in telephoto lenses, wide FOV in wide-angle lenses
- Typical sensor sizes for modern cameras are:
  - 1/4 in. (2.4mm x 3.2mm)
  - 1/3 in. (3.6mm x 4.8mm)
  - 1/2 in. (4.8mm x 6.4mm)
  - 2/3 in. (6.6mm x 8.8mm)
  - 1 in. (9.6mm x 12.8mm)

Pin-hole camera model

- Concept: simplified model where light passes through a small aperture (pinhole)
- No lens, only a single point projection
- Introduction to the perspective projection used in modern cameras
- Mathematical model

Pin-hole camera model





The simplest camera model is pinhole model which decribes the mathematical relationship of the projection of points in 3d-space onto a image plane. Let the centre of projection be the origin of a Euclidean coordinate system, and the plane $Z = f$, which is called the *image plane* or *focal plane*. Under pinhole camera model, a point in space with coordinates $(X, Y, Z)^T$ is mapped to the point on the image plane $(\frac{fX}{Z}, \frac{fY}{Z}, f)^T$ using triangles as shown in Figure 1. Ignoring the final image coordinate, the central projection mapping from 3d world space to 2d image coordinates is,

$$(X, Y, Z)^T \longrightarrow (\frac{fX}{Z}, \frac{fY}{Z})^T \tag{1}$$

https://hedivision.github.io/Pinhole.html

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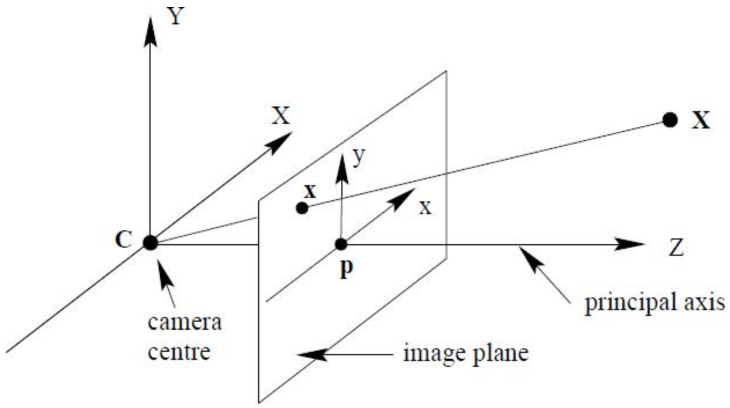
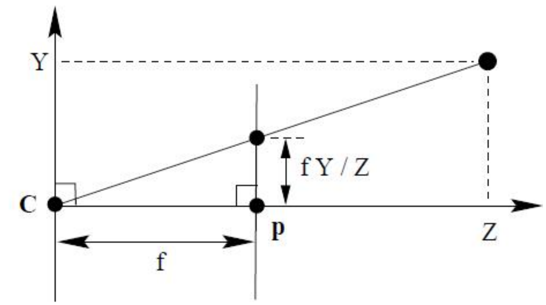
Pin-hole camera model

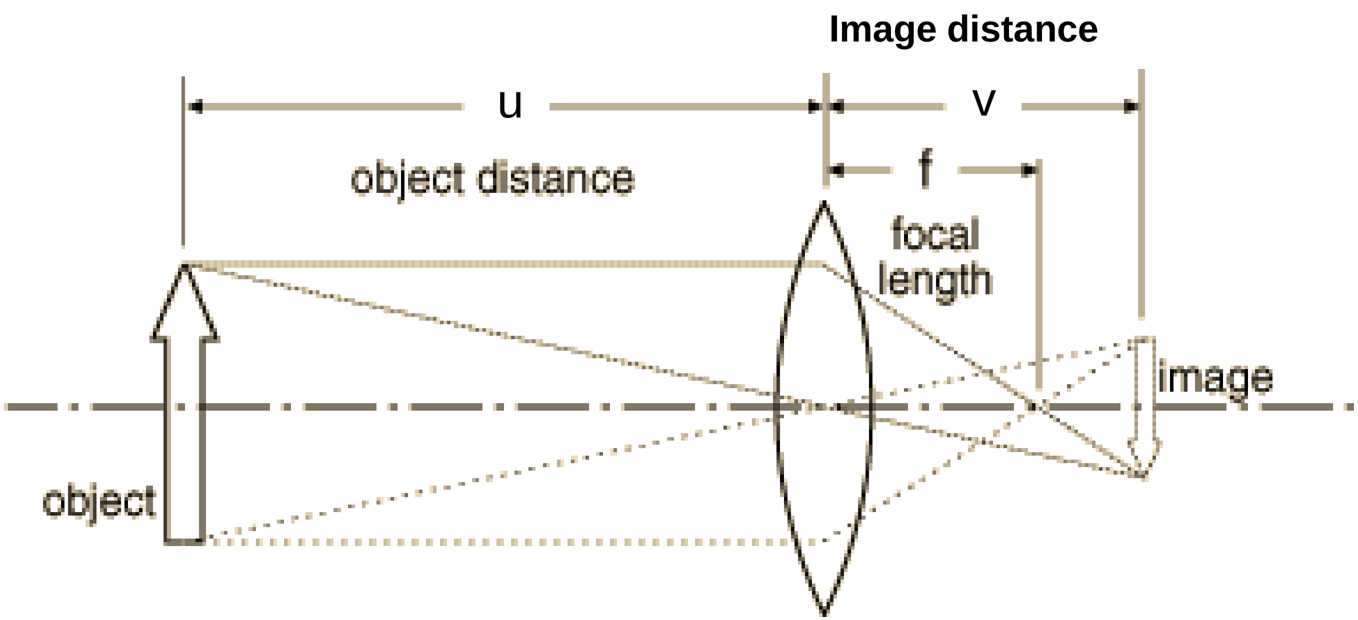




- If ℓx and ℓy are the horizontal and vertical pixel sizes and if (uo, vo) is the pixel coordinate of the image plane center, then the image of point (X, Y, Z) in pixels is:

$$x = \frac{f}{\ell x}\frac{X}{Z} + uo \qquad y = \frac{f}{\ell y}\frac{Y}{Z} + vo$$

Magnification



$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

magnification: $m = \dfrac{image\_size}{object\_size} = \dfrac{v}{u}$

$$m = \frac{f}{u - f}$$

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Focal length

- [Question]
  - A camera is looking to a tennis court from the top at a height of 25 meters. The objective is to detect and track the tennis balls. The dimension of the image sensor is 4mm x 4mm. The court is 36 meters long. What should be the focal length of the lens in order to completely see the court?
- Compute m
  - m = Image size / object size = 4mm/36m
- Compute f
  - u = 25m
  - v = mu
  - f = uv/(u+v)

Pixel resolution

- Definition: the number of pixels that make up an image, measured in width x height (e.g, 1920x1080)
- Impact on image detail and quality
- Relationship between sensor size and pixel density

Pixel resolution

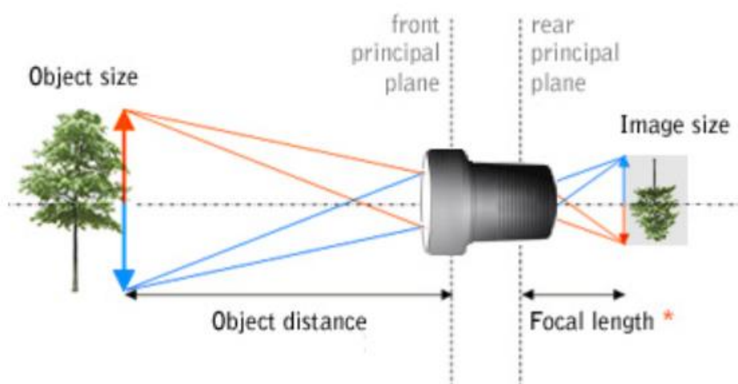
- [Question]
  - Following up from the previous question. The size of a tennis ball is 6cm, what should the resolution of the sensor (in pixels) be if we want the balls to be at least 10 pixels in diameter on the image?
- Compute image size for the ball:
  - Image size / object size = 4mm/36m = x/6cm
    - => x = 1/150 mm
  - x with 1/150 mm is 10 pixels, then how many pixels of object of 4mm
    - 6000 pixels

Focal length calculator

Focal Length Calculator

With this tool you can calculate the required focal length to take a picture of an object at a given distance in order to generate an image fitting on your sensor size.

Object size:	150	mm
Image size:		mm
Object distance:	0.2	m
	Calculate	
Magnification:		x
Focal length:		mm
Angle of view:		°



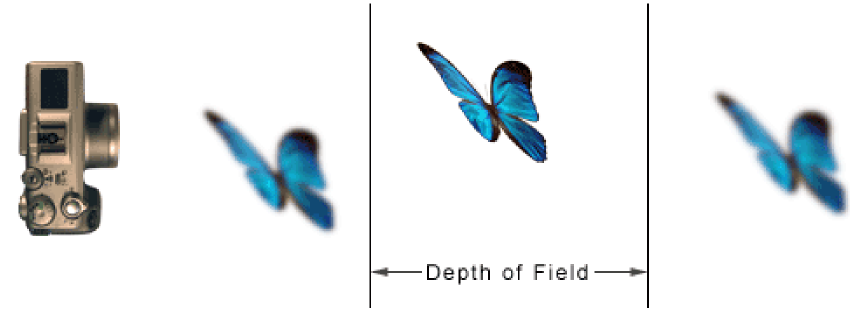
Of course, all distances are measured from the lens front and rear principal points respectively. **Too often, unfortunately, these points are not specified by the lens manufacturer: it's hard to guess their position, since they can be anywhere inside or outside the lens.** Anyway, the rear principal point is always one focal length ahead the sensor * **when the lens is focused at infinity.** The location of the front principal point cannot be neglected when using macro lenses.

https://www.lensation.de/calculator.html

Lens types

- **Normal Lens**: Similar to the human eye's FOV (50mm focal length)
- **Wide-Angle Lens**: Short focal length (<35mm), wide FOV, used in landscapes
- **Telephoto Lens**: Long focal length (>70mm), narrow FOV, used in distant subjects like wildlife
- **Specialized Lenses**: Macro (close-up), Fisheye (extreme wide-angle with distortion)

Depth of field



- Definition: The distance between the nearest and farthest objects that are in sharp focus
- Factors affecting DOF:
  - Aperture size: Larger aperture = shallower DOF
  - Focal length: Longer focal length = shallower DOF
  - Distance to subject
- Applications: Portrait vs. Landscape photography

http://en.wikipedia.org/wiki/Depth_of_field

Shutter speed

- Definition: Duration for which the camera sensor is exposed to light
- Impact on motion blur:
  - Fast shutter speeds (1/1000s) freeze motion
  - Slow shutter speeds (1/30s) capture motion blur
- Trade-off with exposure and ISO
  - Photographers must achieve a balance between shutter speed, aperture, and ISO to properly expose an image.
  - ISO refers to the sensitivity of the camera sensor to light
    - A lower ISO value (e.g., ISO 100) makes the sensor less sensitive to light, producing cleaner images with less noise
    - A higher ISO value (e.g., ISO 3200) increases sensitivity, allowing for better performance in low-light situations, but it introduces more digital noise
  - A fast enough shutter speed to avoid blur, an aperture that controls depth of field, and an ISO that minimizes noise while achieving proper brightness

Photo-taking tips

- With a short focal length, you have to be close to your subject for a close-up
- With a long focal length, you can be far away and still get a close-up

Wide Angle
Focal Length: 28mm

Standard
Focal Length: 75mm

Telephoto
Focal Length: 200mm

Applications

- **Action Shots (e.g., Sports, Wildlife):**
  - **Goal**: Freeze fast-moving subjects like athletes or animals.
  - **Shutter Speed**: Use a **fast shutter speed** (e.g., 1/1000s or faster) to freeze the motion without blur.
  - **Aperture**: A **wider aperture** (e.g., f/2.8) allows more light to compensate for the fast shutter speed.
  - **ISO**: Depending on lighting, increase the **ISO** (e.g., ISO 800-1600) to ensure proper exposure without introducing motion blur.
- **Effect**: The subject is sharp and frozen in motion, with possibly a shallow depth of field to separate the subject from the background.

Applications

- **Low-Light Photography (e.g., Night Scenes, Indoor Events):**
  - **Goal**: Capture a bright image in low-light conditions while avoiding noise and motion blur.
  - **Shutter Speed**: Use a **slow shutter speed** (e.g., 1/30s or slower) to allow more light to reach the sensor.
  - **Aperture**: A **wide aperture** (e.g., f/1.8 or f/2.8) helps gather as much light as possible.
  - **ISO**: Increase the **ISO** (e.g., ISO 1600 or higher), but be cautious to avoid too much digital noise.
- **Effect**: The image is well-exposed in dim conditions, though some noise might appear if the ISO is very high. If the shutter speed is too slow, motion blur may occur unless the camera is stabilized.

Applications

- **Portrait Photography (e.g., Headshots, Close-ups):**
  - **Goal**: Achieve a sharp focus on the subject with a blurred background (bokeh effect).
  - **Shutter Speed**: Use a moderate **shutter speed** (e.g., 1/125s) to ensure sharpness in the subject while avoiding any unintended motion blur.
  - **Aperture**: Use a **wide aperture** (e.g., f/1.8 or f/2.8) to create a **shallow depth of field**, isolating the subject from the background.
  - **ISO**: Use a **low ISO** (e.g., ISO 100 or 200) to avoid noise, since ample light is typically available.
- **Effect**: The subject is sharp with the background beautifully blurred, creating a flattering separation between the subject and the environment.

Applications

- **Landscape Photography:**
  - **Goal**: Capture as much detail as possible across a wide depth of field (everything from the foreground to background in focus).
  - **Shutter Speed**: Use a **slower shutter speed** (e.g., 1/30s or slower), especially when using a narrow aperture, to allow more light in.
  - **Aperture**: Use a **narrow aperture** (e.g., f/11 or f/16) to achieve a **deep depth of field**, where everything from foreground to background is sharp.
  - **ISO**: Use a **low ISO** (e.g., ISO 100) to maintain image quality with minimal noise.
- **Effect**: The entire scene is sharp and detailed, with minimal noise and maximum focus from foreground to background.

Applications

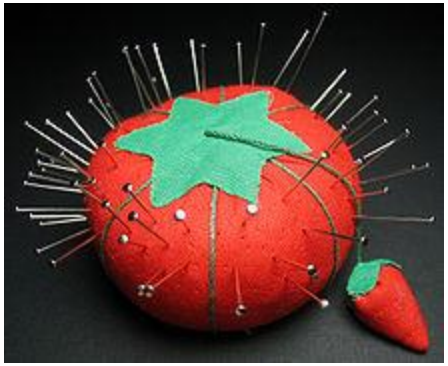
- **Panning Shots (e.g., Moving Cars, Bicycles):**
  - **Goal**: Capture the sense of motion by blurring the background while keeping the subject in focus.
  - **Shutter Speed**: Use a **moderate shutter speed** (e.g., 1/30s to 1/60s) to allow the background to blur while panning with the subject.
  - **Aperture**: Use a moderate aperture (e.g., f/5.6) to allow enough light in while controlling the depth of field.
  - **ISO**: Adjust the **ISO** (e.g., ISO 400) depending on lighting conditions to maintain proper exposure.
- **Effect**: The subject is relatively sharp, while the background shows motion blur, creating a sense of speed and action.

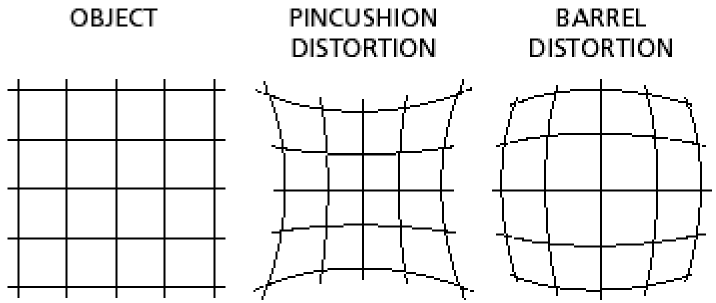
Applications

- **Long-Exposure Photography (e.g., Light Trails, Star Trails, Waterfalls):**
  - **Goal**: Capture movement over time, such as flowing water or light trails.
  - **Shutter Speed**: Use a **very slow shutter speed** (e.g., several seconds to minutes) to capture the motion of the subject (e.g., smooth water or star trails).
  - **Aperture**: Use a **narrow aperture** (e.g., f/8 to f/16) to avoid overexposure during the long exposure.
  - **ISO**: Use a **low ISO** (e.g., ISO 100) to reduce noise, since the long exposure already gathers a lot of light.
- **Effect**: Moving elements in the scene (like water, cars, or stars) appear as smooth or streaked, while stationary objects remain sharp.

Optical distortions

- Caused by lens shape
  - **Barrel Distortion**: Straight lines bow outward (common in wide-angle lenses)
  - **Pincushion Distortion**: Straight lines bend inward (common in telephoto lenses)
  - **Chromatic Aberration**: Color fringes around high-contrast edges
  - **Vignetting**: Darkening of the image towards the edges





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Barrel distortion

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Pincushion distortion

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Ultra-wide angle

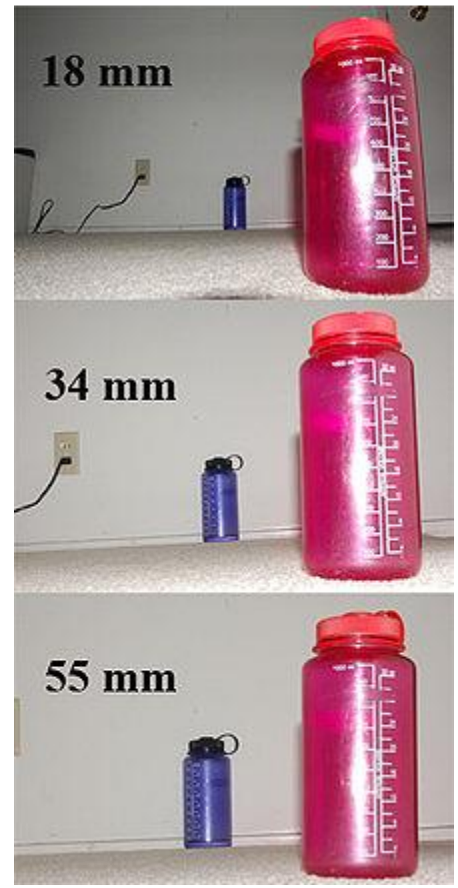
- Ultra-wide angle lenses
  - Larger depth of field (DOF)
- Fisheye lenses
  - With curvilinear barrel distortion
- Rectilinear lenses
  - Designed so that straight lines will render straight (uncurved)
  - Lack the extreme distortion that is characteristic of a fisheye lens

Ultra-wide angle

- Curvilinear (above) and rectilinear (below) image.
- this example has been rectilinear-corrected by software
- high quality wide-angle lenses are built with optical rectilinear correction.

How focal length affects perspective

- 18mm (ultra wide-angle), 34mm (wide-angle), and 55mm (normal lens) at identical field size achieved by different camera-subject distances.
- Notice that the shorter the focal length and the wider the angle of view, perspective distortion and size differences change.



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Optical distortions

- **Vignetting** is another type of defect in an optical system in which the amount of incoming light at the edges of an image is reduced

http://en.wikipedia.org/wiki/Vignetting

Image capture

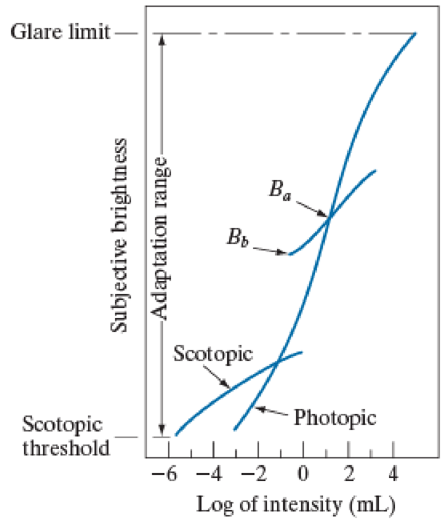
- Radiance
  - The total amount of energy that flows from a light source (W)
- Luminance
  - The amount of energy an observer receives from a source (lm)
- Brightness
  - Subjective descriptor of light perception
- Reflectance
  - The fraction of radiant energy that is reflected from a surface

Radiance vs. luminance

- light emitted from a source operating in the far infrared region of the spectrum could have significant energy (radiance), but an observer would hardly perceive it; its luminance would be almost zero

Brightness

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



<u>Photopic vision:</u> Vision under well-lit conditions, which provides for color perception, and which functions primarily due to cone cells in the eye.

<u>Scotopic vision:</u> Monochromatic vision in very low light, which functions primarily due to rod cells in the eye.

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Image capture

- To capture an image, luminance must be converted in voltage (and vice-versa for display)

Transferring images

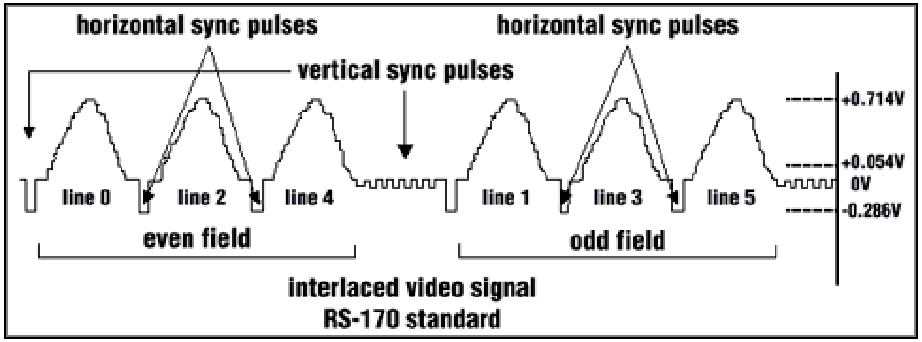
- An image is captured, transmitted and displayed in a path similar to text on a page: line by line, from top to bottom.
- When serializing an image (for transmission or storage), it is read line-by-line.
  1. **Interlace**
  2. **Progressive** or **non-interlaced scanning**

Serializing an image

- For a constant reading speed,
    1. Increase the number of lines (image resolution) which reduce the frame rate (and cause temporal aliasing).
    2. Increase the frame rate which reduce the number of line per frame (vertical aliasing).
- The tradeoff solution is to read the image in two passes, even lines first, then odd lines after: interlaced scanning. This is what is done under the NTSC television standard (in North America).

Interlaced scanning

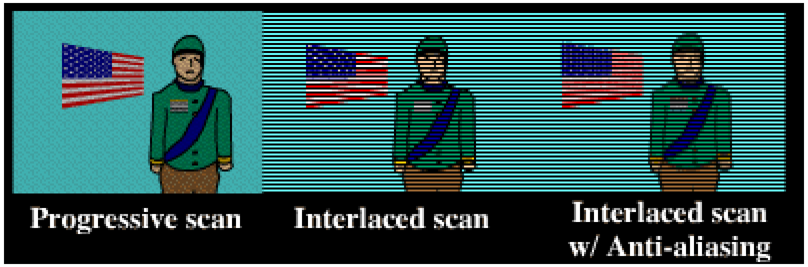
- The difficulty with such decomposition is that the image must be written (on a display device) the same way it has been read (by a camera): a synchronization signal must be added.



from: http://zone.ni.com/devzone/devzoneweb.nsf/Opendoc?openagent&BB087524D4052C9E8625685E0080301B

Interlace

- **Interlace** is a technique of improving the picture quality of a video transmission without consuming any extra bandwidth. It was invented by RCA engineer Randall Ballard in the late 1920s.
    - used for most standard definition TVs, and the 1080i HDTV broadcast standard



Progressive

- **Progressive** or **non-interlaced scanning** is any method for displaying, storing or transmitting moving images in which the lines of each frame are drawn in sequence
  - LCD, micromirror (DLP), or plasma displays, CRT computer monitors. (Other CRT-type displays, such as televisions, typically use interlacing.)
  - It is also becoming increasingly common in high-end television equipment, which is often capable of performing deinterlacing so that interlaced video can still be viewed.

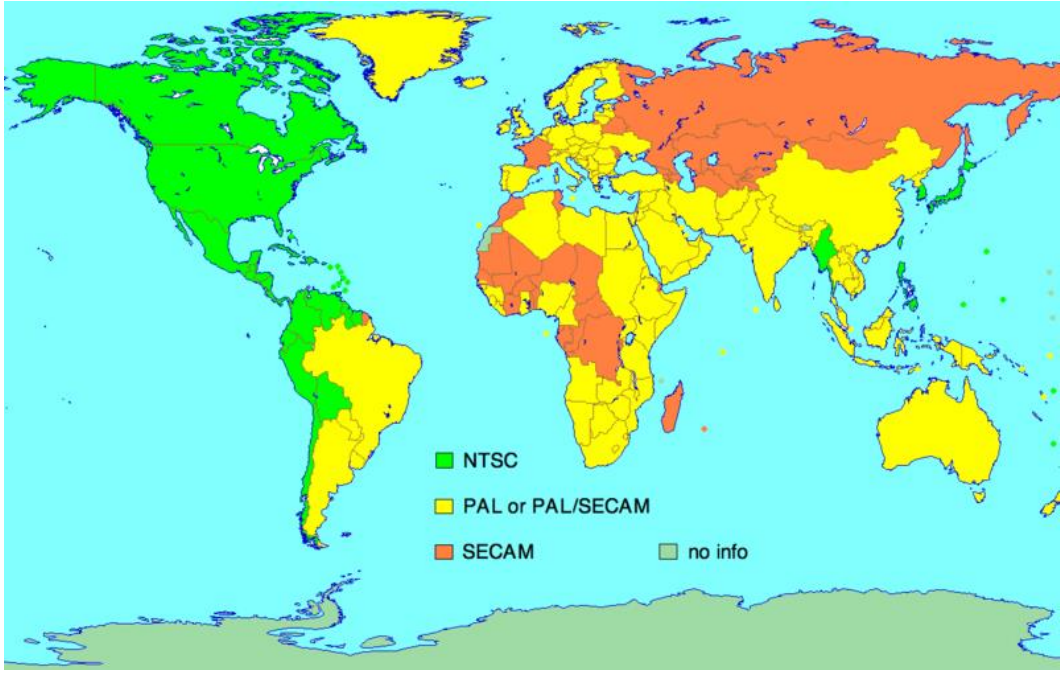
Sampling and digitization

- NTSC (1941):
  - the analog television system in use in Canada, Japan, South Korea, the United States
  - Total number of lines: 525
  - Number of active lines: 483
  - Aspect ratio: 4:3
  - Line frequency: 15.75KHz
  - Field frequency: 59.94Hz
  - Bandwidth (monochrome): 4.2MHz
- CCIR601 (1986):
  - Number of pixels per line: 720
  - Transmission rate (color): 216Mb/s

Required sampling frequency	Format	Pixels/line
13.5 MHz	CCIR601 (NTSC/PAL)	720
12.27 MHz	NTSC Square Pixel	640
14.75 MHz	PAL Square Pixel	768

Video standard

- “PAL" system
  - a 625-line/50 Hz (principally European) television system
- "NTSC" system
  - a 525-line/60 Hz (principally North American/Central American/Japanese)
- DVDs are labelled as either "PAL" or "NTSC" (referring informally to the line count and frame rate) even though technically neither of them have encoded PAL or NTSC composite colour.



Digital camera interfaces

- IEEE1394:
  - developed by Apple under the name FireWire, adopted by Sony that calls it iLINK. To connect machines to external peripherals. It is a hardware and software specification. Hot pluggable, support daisy chaining. Data rate of 100, 200 and 400Mbps. Non-proprietary, licensing is open.
- USB 2.0:
  - standard for PC I/O. Can run at up to 480Mbps (compared to 12Mbps for USB1.1). Multiple devices are connected through hub.
- CameraLink:
  - standard developed by camera and frame grabber manufacturers. It is a system application of the ChannelLink standard developed by National Semiconductor and that can run at 2.38Gbps over a distance of 10m. Multiple cameras can be connected, easy synchronization. Require complex specialized hardware.

Image sensing elements

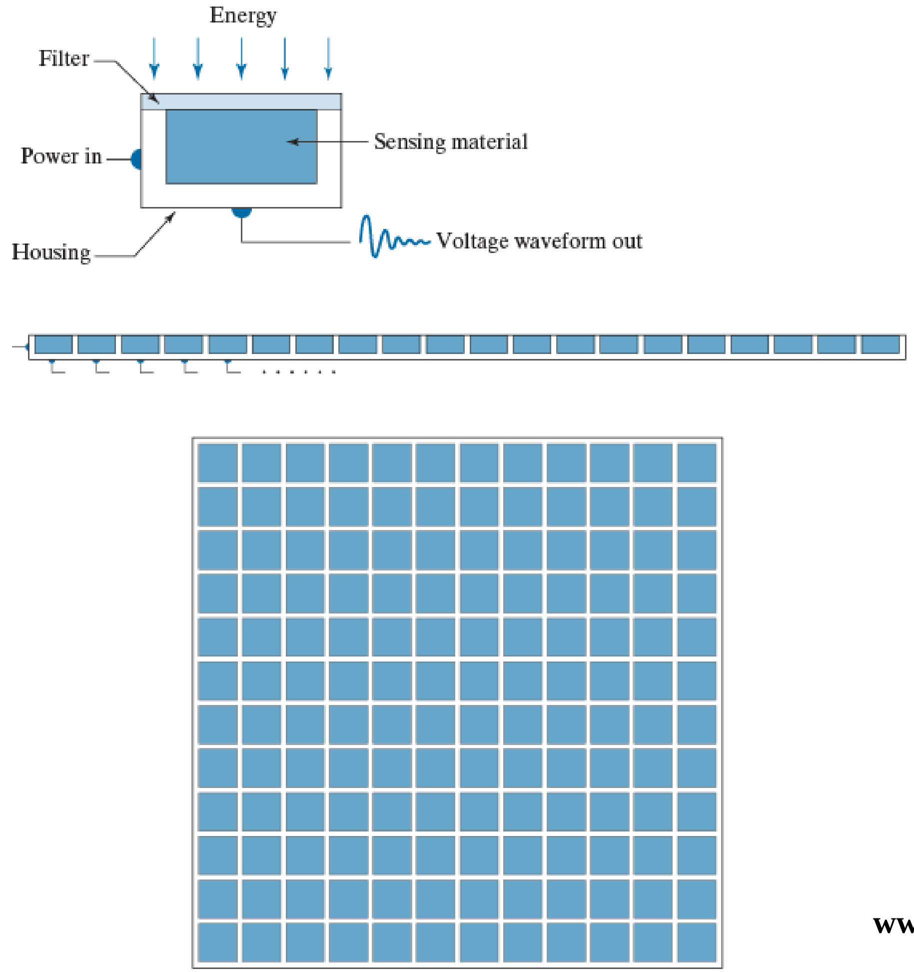


FIGURE 2.12
(a) Single sensing element.
(b) Line sensor.
(c) Array sensor.

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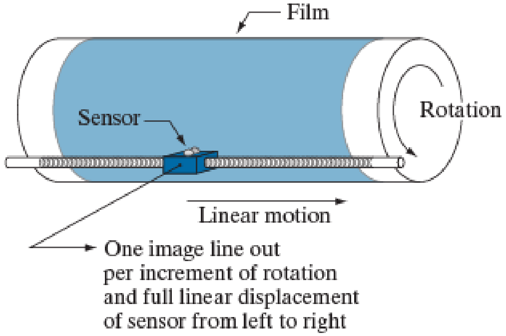
Single sensing element

FIGURE 2.13 Combining a single sensing element with mechanical motion to generate a 2-D image.



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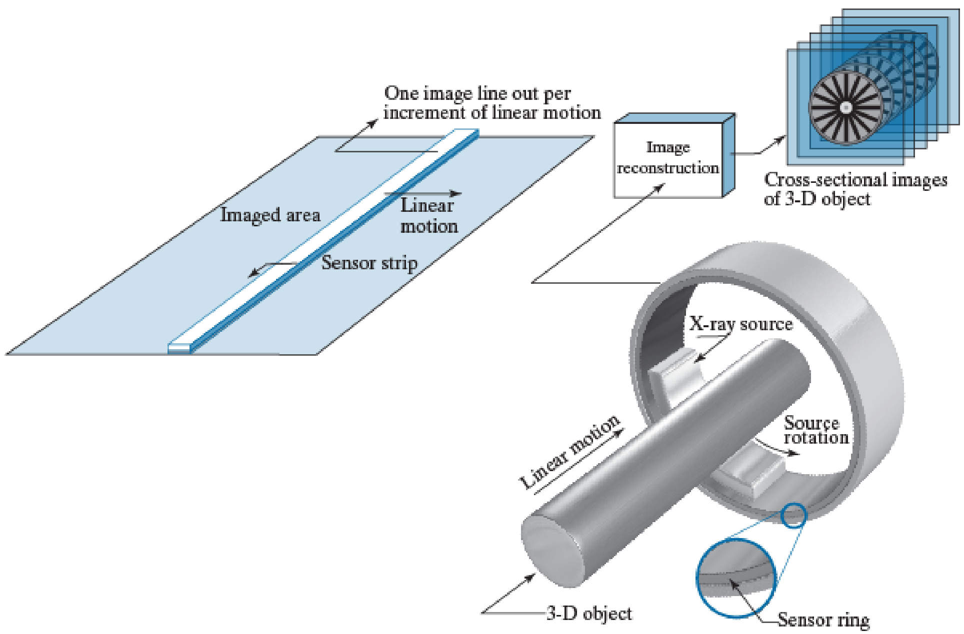
Linear and circular sensors



a b

FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

Digital image acquisition process

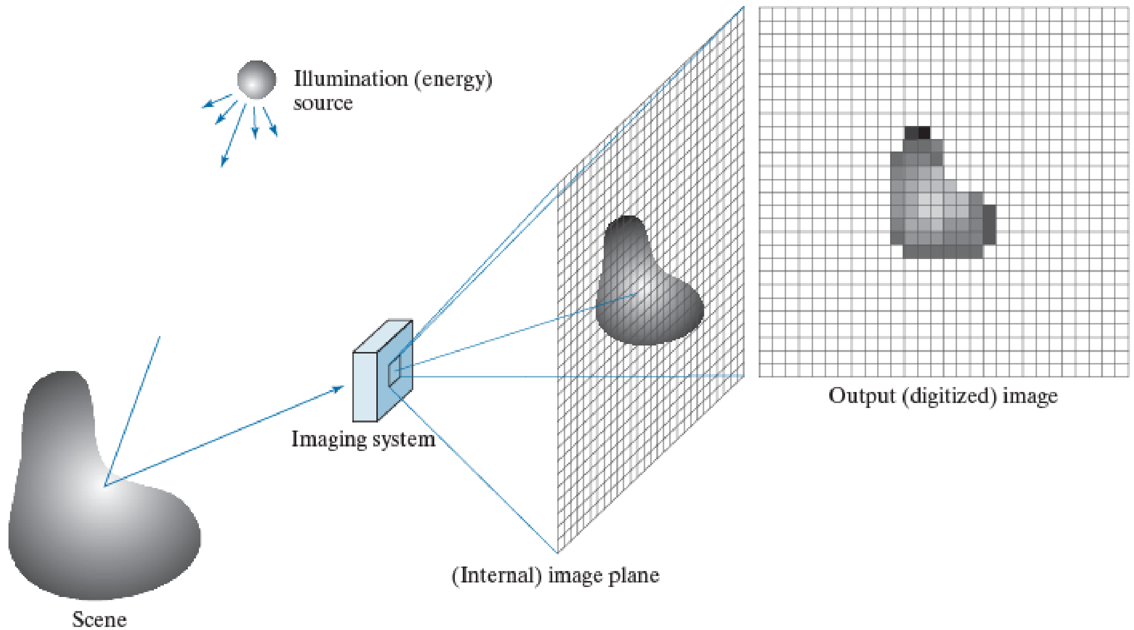


FIGURE 2.15 An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

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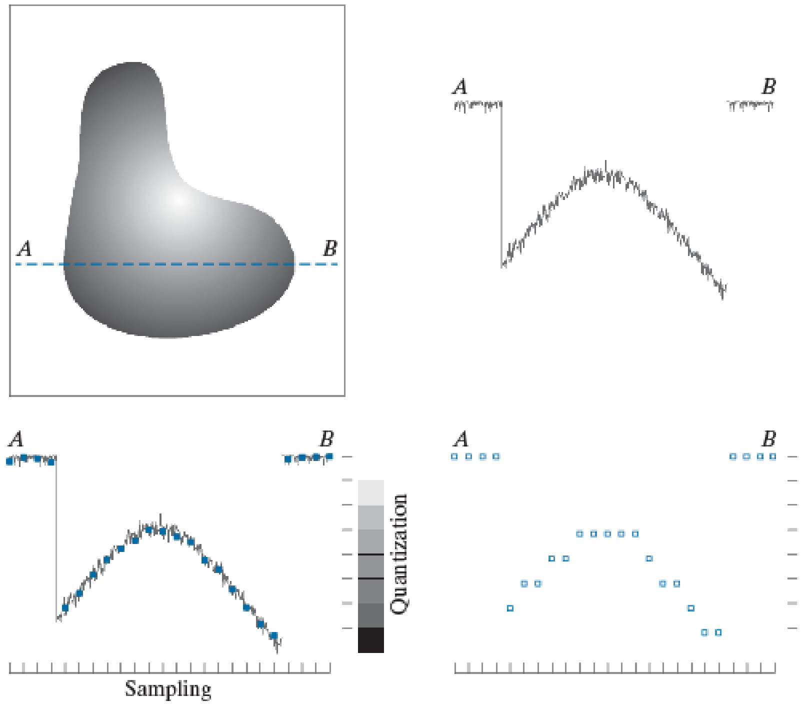
Sampling and digitization

- In order to be read by a computer, such signal must be sampled and digitized.
- **Sampling**:
  - obtaining a sequence of instantaneous values that are read at regular intervals.
- Digitization (**Quantization**):
  - converting a continuous range of values to a finite number of symbols. Usually a monochrome image is digitized using 256 levels (8 bits).

Sampling and quantization

a b
c d

FIGURE 2.16
(a) Continuous image. (b) A scan line showing intensity variations along line AB in the continuous image. (c) Sampling and quantization. (d) Digital scan line. (The black border in (a) is included for clarity. It is not part of the image).



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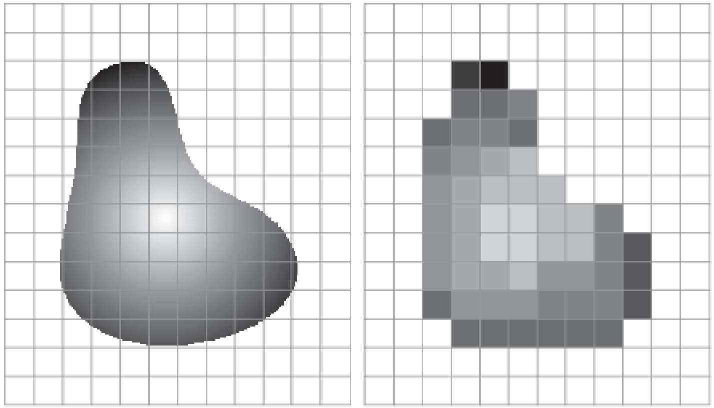
Sampling and quantization



a b

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

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Sampling and quantization

FIGURE 2.21 Number of megabytes required to store images for various values of N and k.

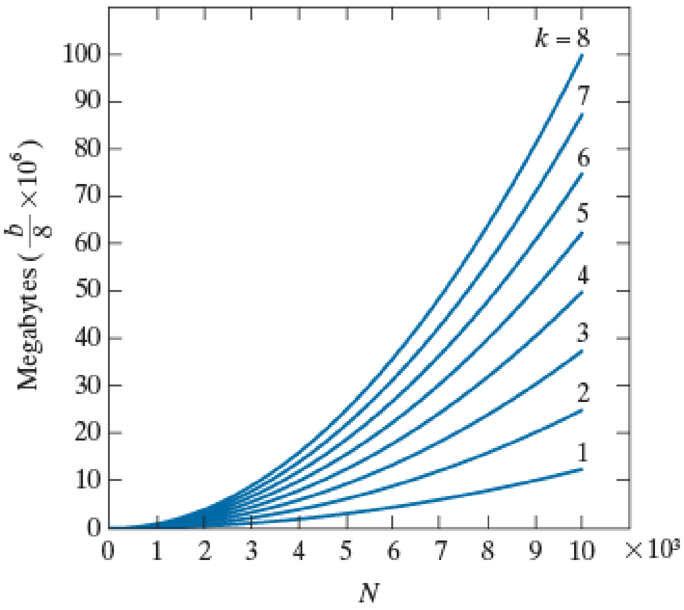

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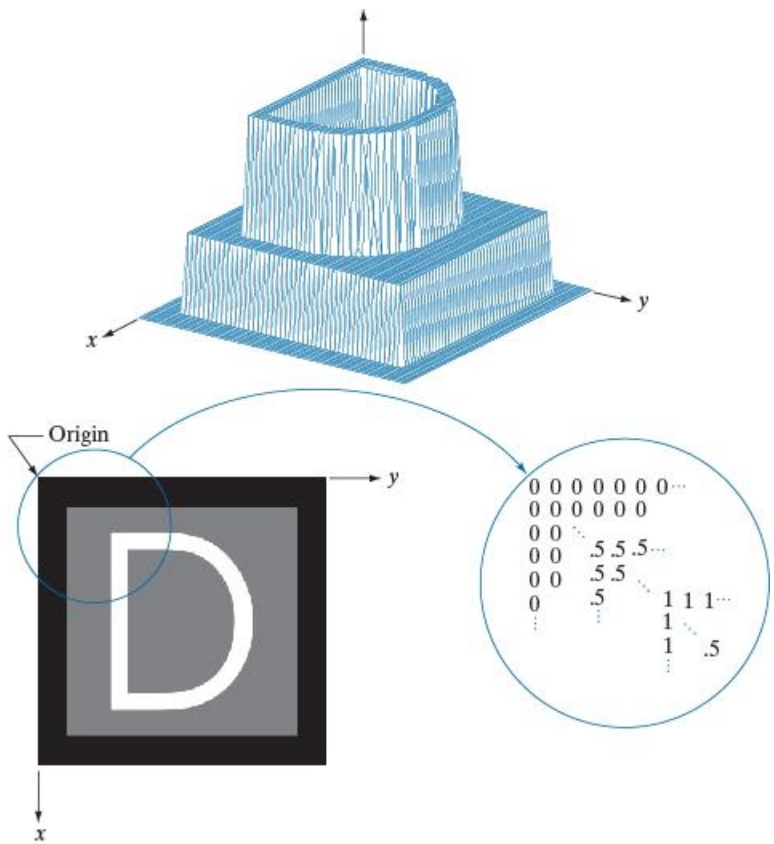
Image plotting/representation

a
b c

FIGURE 2.18
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array. (c) Image shown as a 2-D numerical array. (The numbers 0, .5, and 1 represent black, gray, and white, respectively.)



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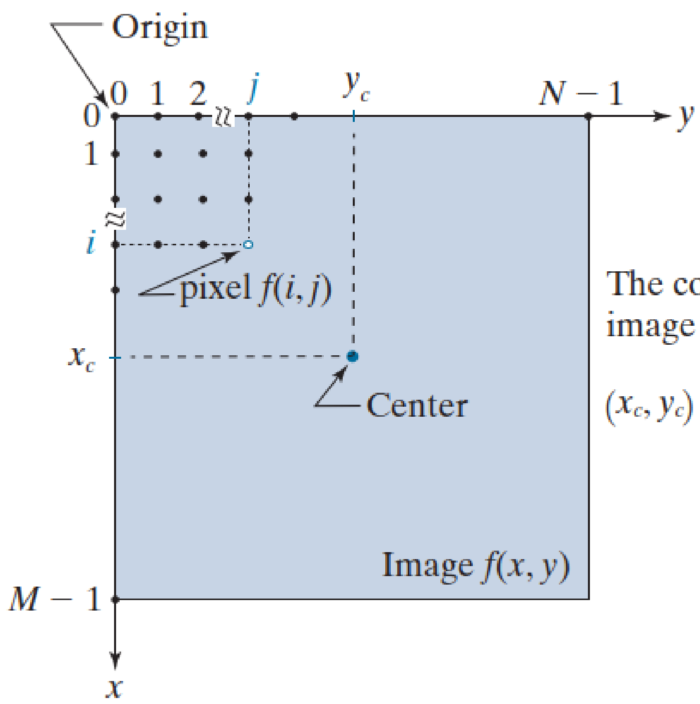
Coordinate convention

FIGURE 2.19 Coordinate convention used to represent digital images. Because coordinate values are integers, there is a one-to-one correspondence between x and y and the rows (r) and columns (c) of a matrix.



The coordinates of the image center are

$$(x_c, y_c) = \left(\text{floor}\left(\frac{M}{2}\right), \text{floor}\left(\frac{N}{2}\right)\right)$$

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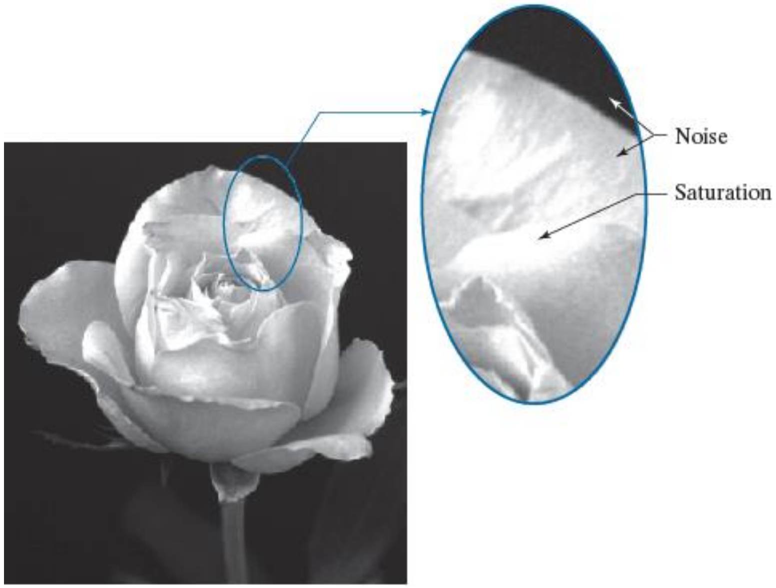
Image saturation and noise

FIGURE 2.20
An image exhibiting saturation and noise. Saturation is the highest value beyond which all intensity values are clipped (note how the entire saturated area has a high, constant intensity level). Visible noise in this case appears as a grainy texture pattern. The dark background is noisier, but the noise is difficult to see.



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Column scanning

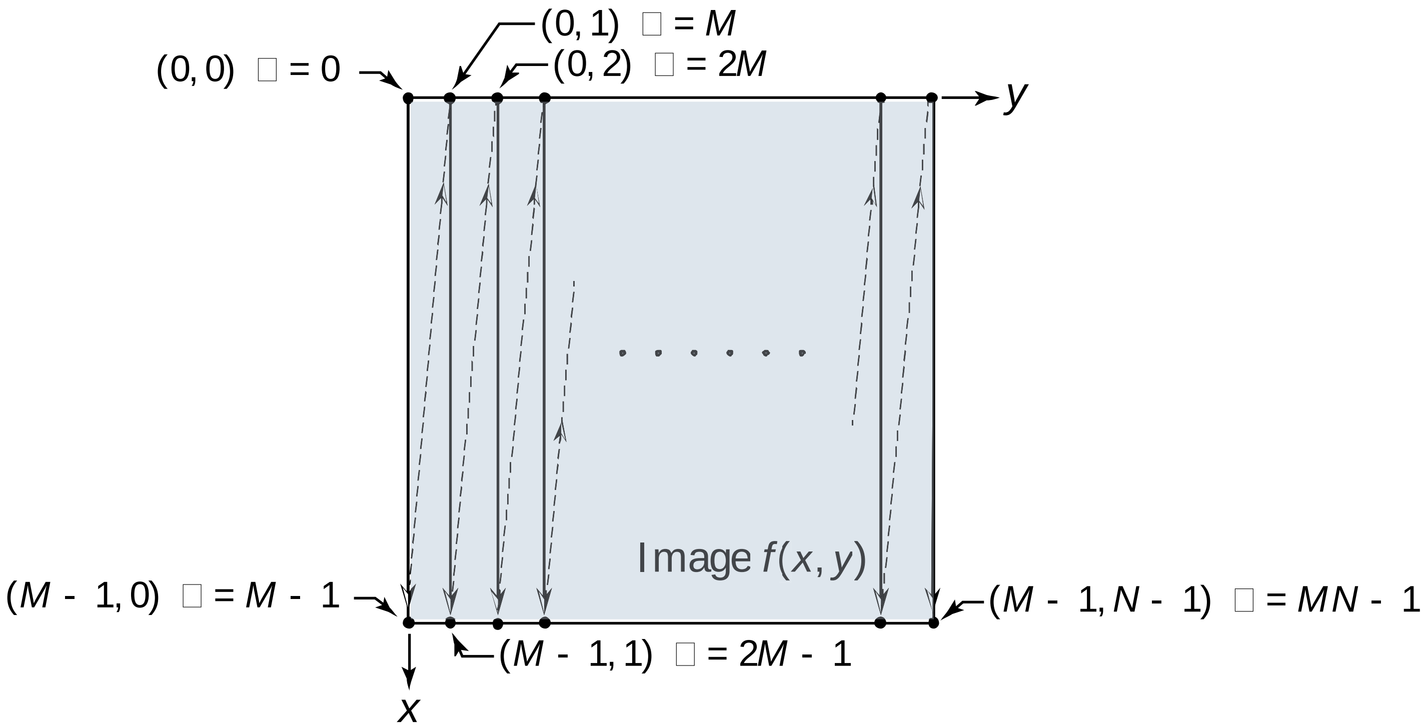

FIGURE 2.22 Illustration of column scanning for generating linear indices. Shown are several 2-D coordinates (in parentheses) and their corresponding linear indices.

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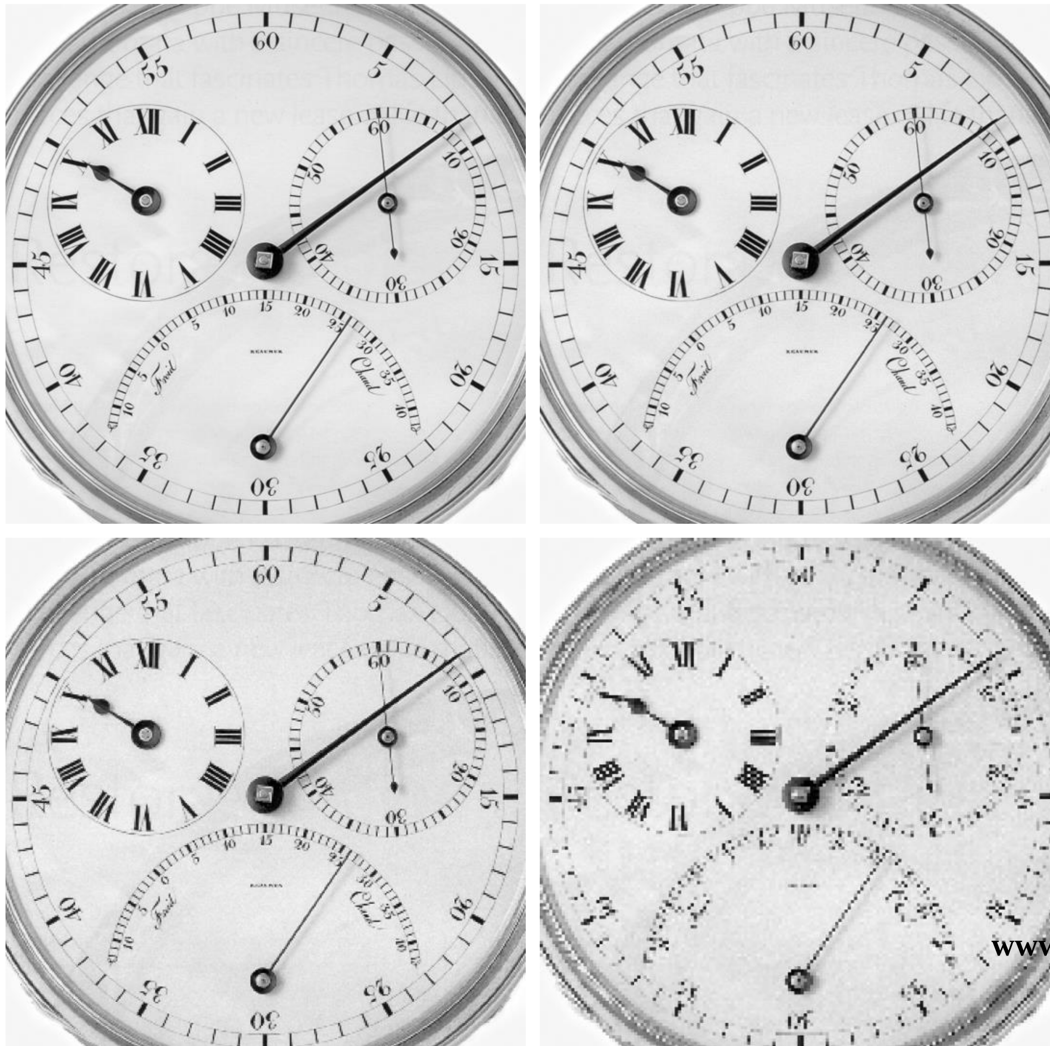
Sampling

a b
c d

FIGURE 2.23
Effects of reducing spatial resolution. The images shown are at:
(a) 930 dpi,
(b) 300 dpi,
(c) 150 dpi, and
(d) 72 dpi.



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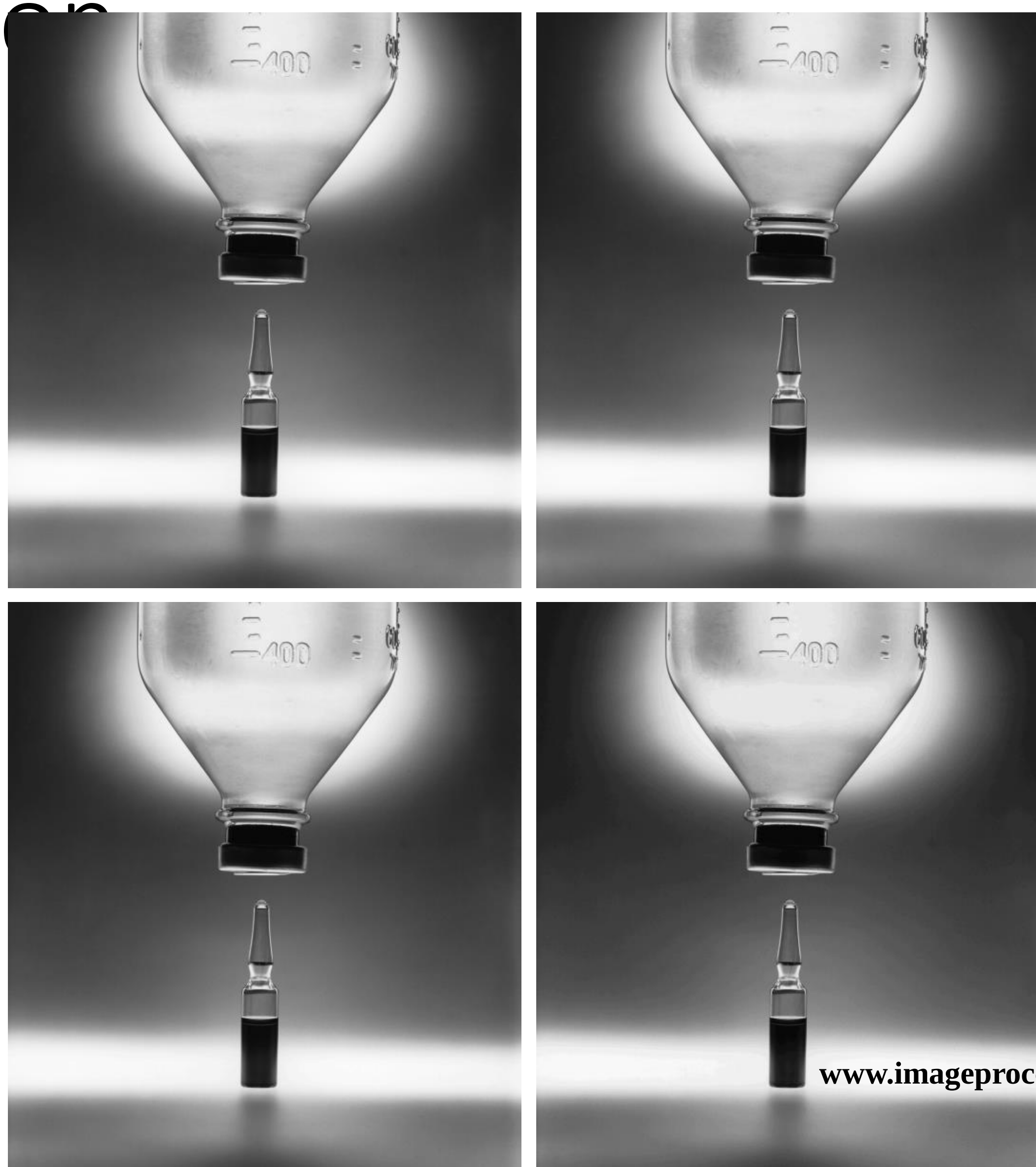
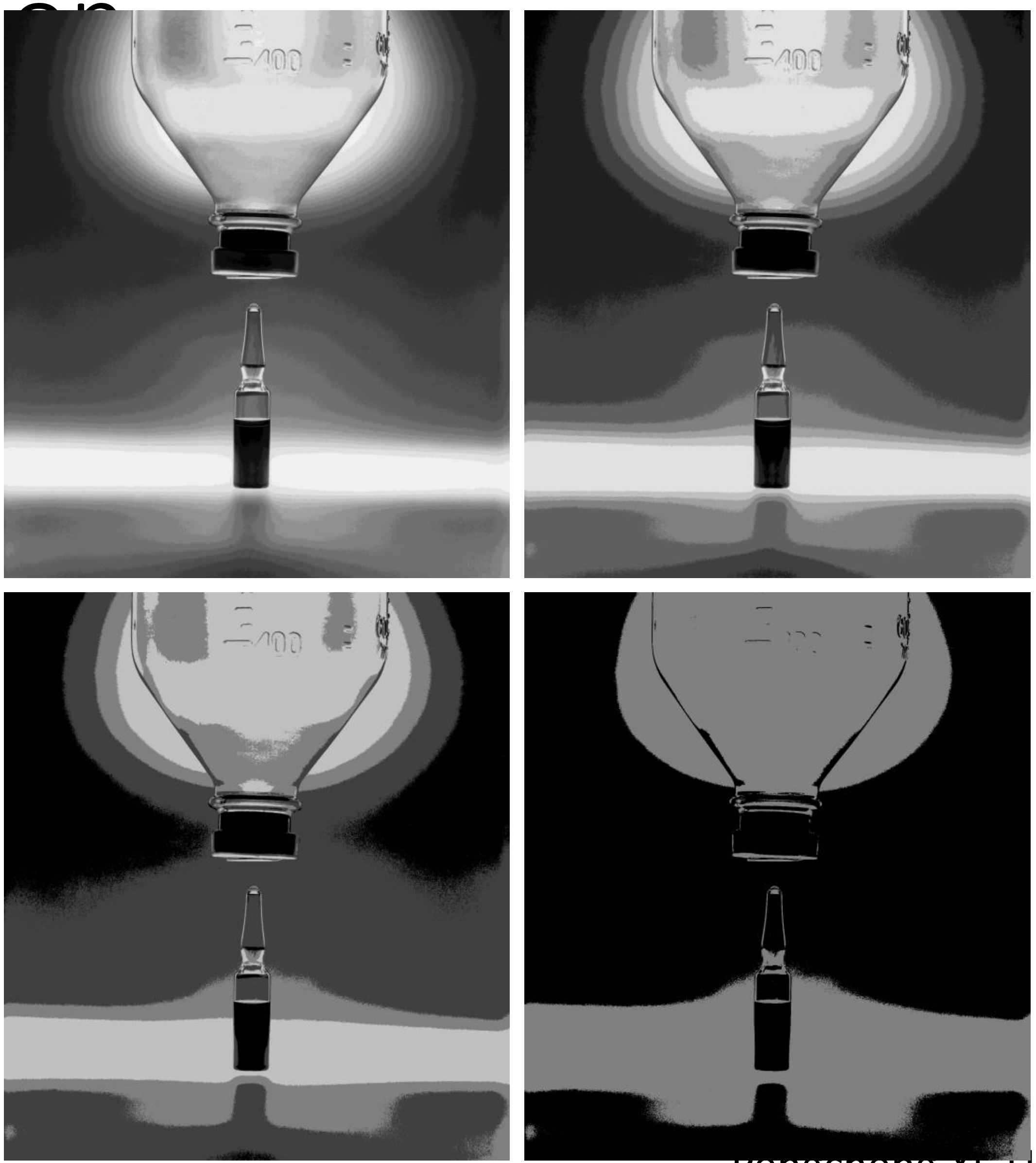
Quantization



a b
c d

FIGURE 2.24
(a) 2022 × 1800, 256-level image. (b)-(d) Image displayed in 128, 64, and 32 intensity levels, while keeping the image size constant. (Original image courtesy of the National Cancer Institute.)

Quantization



e f
g h

FIGURE 2.24 (*Continued*) (e)-(h) Image displayed in 16, 8, 4, and 2 intensity levels. (Original image courtesy of the National Cancer Institute.)

Sampling and digitization

- What if we vary N and k together?

a b c

FIGURE 2.25 (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.)

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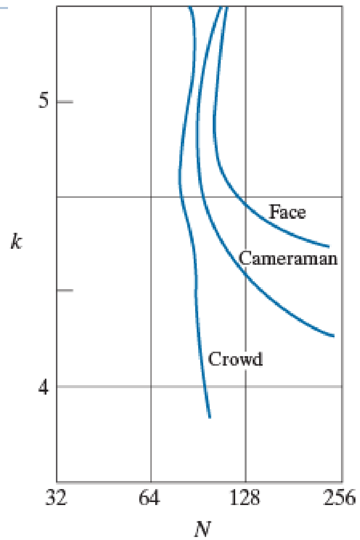
Sampling and digitization

- Isopreference curves
    - for images with a large amount of detail only a few gray levels may be needed.
    - in some intervals in which the spatial resolution was increased, but the number of gray levels actually decreased.
        - The most likely reason for this result is that a decrease in k tends to increase the apparent contrast of an image, a visual effect that humans often perceive as improved quality in an image.

FIGURE 2.26 Representative isopreference curves for the three types of images in Fig. 2.25.



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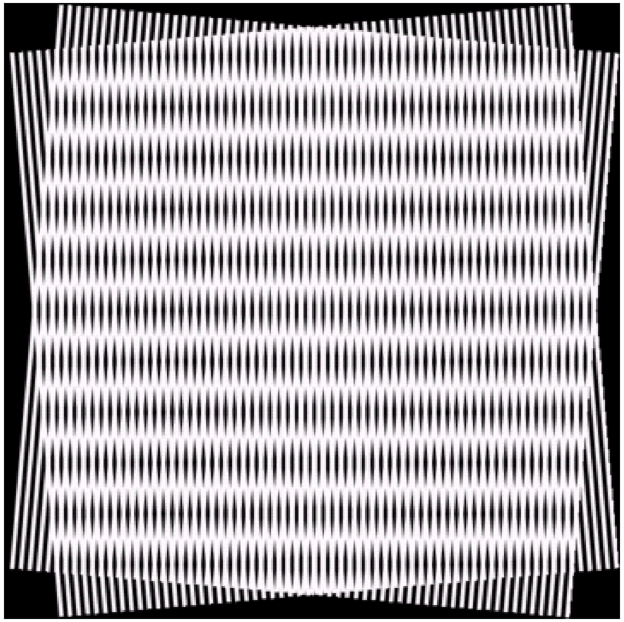
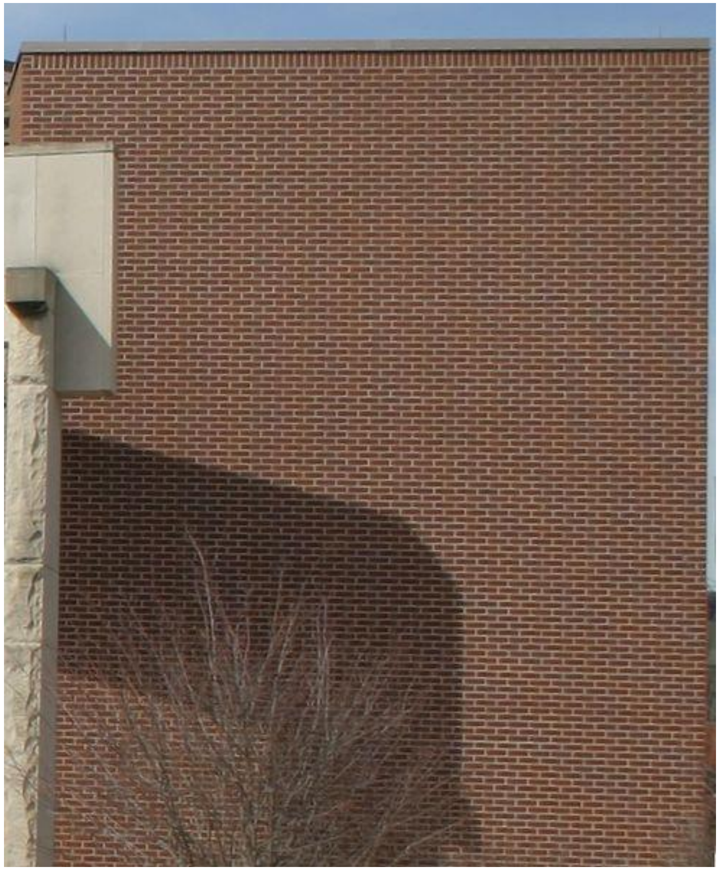
Sampling and aliasing

- Shannon sampling theorem
  - if the function is sampled at a rate equal to or greater than twice its highest frequency, it is possible to recover completely the original function from its samples.
- If the function is *undersampled*, then a phenomenon called *aliasing* corrupts the sampled image.
- The corruption is in the form of additional frequency (*aliased frequencies)* components being introduced into the sampled function



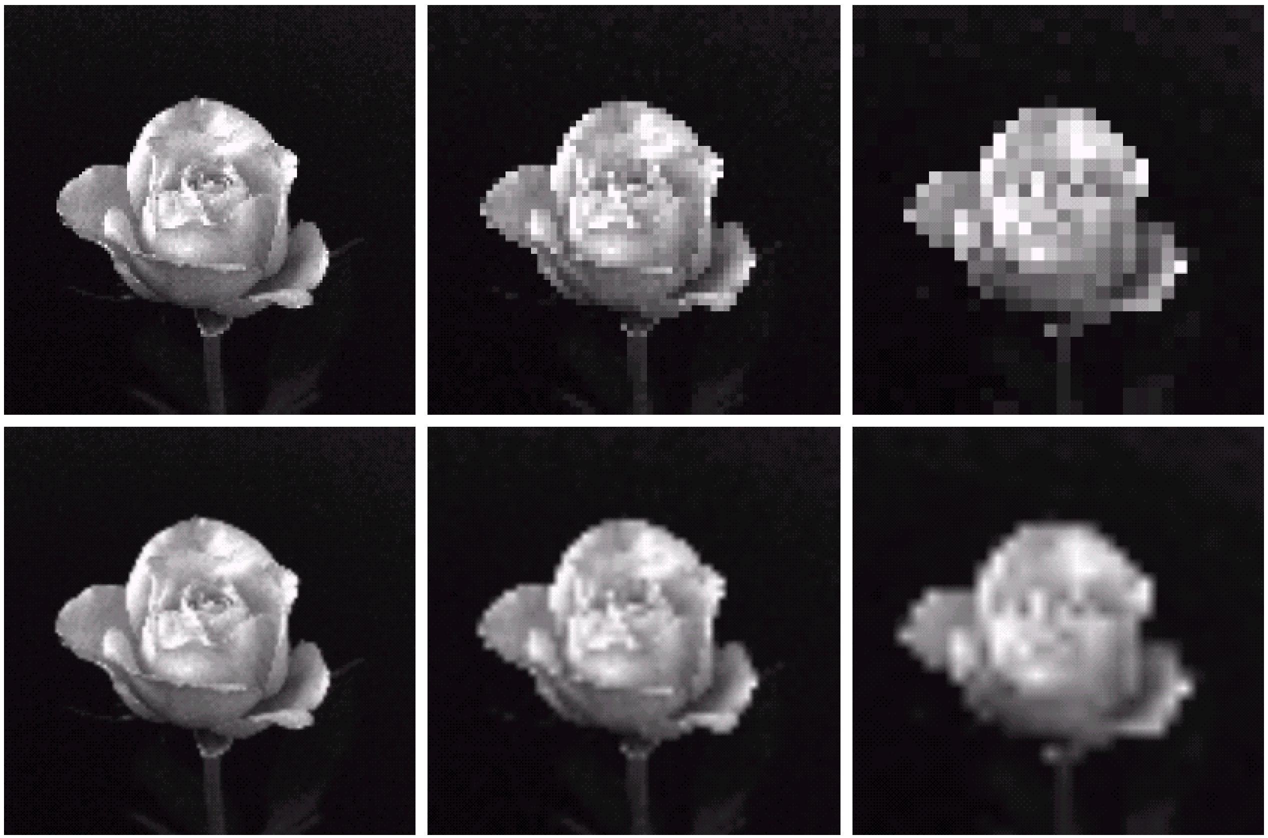
llustration of the Moiré pattern effect.

Moiré pattern example



- A moiré pattern formed by incorrectly down sampling the image left

Sampling and interpolation



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.

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