ICT2403 – Graphics and Image Processing

Digital Image Fundamentals 1

K.A.S.H. Kulathilake
Ph.D., M.Phil., MCS, B.Sc.(Hons.)IT, SEDA(UK)
Senior Lecturer
Department of Computing
Rajarata University of Sri Lanka
kule@as.rjt.ac.lk

Learning Outcomes

- At the end of this lecture, you should be able to;
  - describe the energy and the EM spectrum.
  - describe image acquisition methods.
  - discuss image formation model.
  - express sampling and quantization.
  - define dynamic range and image representation.

Light and the EM Spectrum

- The EM spectrum can be expressed in the terms of wavelength (λ), frequency (ν) or energy.
- Wavelength (λ) and frequency (ν) are related as;

$$\lambda = c / \nu$$

  – where c is the speed of light ($2.998 * 10^8$ m/s)

Light and the EM Spectrum (Cont…)

- The energy of the various components of the EM spectrum is given by the expression;

$$E = h\nu$$

  - where h is Planck's constant (6.626176×10^{-34} joule-seconds).
- Frequency is measured in Hertz (Hz), with 1Hz being equal to one cycle of a sinusoidal wave per second.
- The commonly used unit of energy is the electron-volt.

Light and the EM Spectrum (Cont…)

- Electromagnetic waves are conceptually sinusoidal and formation of different wave lengths.
- It can be thought of as a stream of massless particles, each travelling in a wave like pattern and moving at the speed of light.
- Each massless particle contains a certain amount of energy and a bundle of energy is known as **photon**.
- **Energy is proportional to the frequency.**
- **Therefore, for higher frequency bands in EM spectrum carries more energy per photon and lower frequency bands in EM spectrum carries lower energy per photon.**

Light and the EM Spectrum - Light

- Light is the particular type of EM radiation that can be visible and sense by the human eye.
- The visible band of the EM spectrum spans the range from approximately 0.43 micrometer (violet) to about 0.79 micrometer (red).
- The color spectrum divided into six broad regions; violet, blue, green, yellow, orange and red.
- No color ends abruptly, but rather each range blends smoothly into the next.
- **The colors that human perceive in an object are determine by the nature of the light reflected from the object.**

Light and the EM Spectrum - Achromatic Light

- The light that is void of color is called **achromatic** or **monochromatic light**.
- The only attribute of such light is its intensity, or amount.
- The term **gray level** generally is used to describe monochromatic intensity because it ranges from black to gray and finally to white.

Light and the EM Spectrum - Chromatic Light

- Chromatic light spans the EM energy spectrum from approximately 0.43 to 0.79 micrometers.
- Three basic quantities are used to describe the quality of a chromatic light source; radiance, luminance and brightness.
  - **Radiance** is a total amount of energy that flows from the light source, and it is usually measured in Watts (W).
  - **Luminance** measure in lumen (lm), gives the measure of the amount of energy and observer perceives from light source.
  - **Brightness** is a subjective descriptor of light perception that is particularly impossible to measure.

Image Sensing & Acquisition

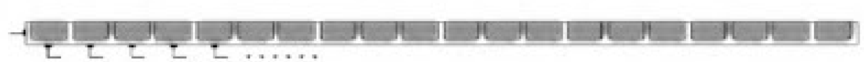
- Most of the images are generated by the combination of <u>an illumination source</u> and <u>the reflection or absorption of energy</u> from that source by the elements of the scene being imaged.
- The illumination may originate from a source of EM energy such as radar, infrared, X-ray system or from less traditional sources, such as ultrasound or computer-generated illumination pattern.

Image Sensing & Acquisition (Cont…)

- Depending on the nature of the source, illumination energy is **reflected from**, or **transmitted through**, objects.
  - As an example, we can say light reflected from planer surface and X ray transmitted through the human body to construct the images.
- In some applications, the reflected or transmitted energy is focused on to a **photo converter**, which **converts the energy into a visible light**.
  - Electron microscopy and some applications on Gamma imaging (single-photon emission computed tomography (SPECT))use this approach.

Image Sensing & Acquisition (Cont…)

- There are three principle sensor arrangements used to transform illumination energy into digital images.
  - Single imaging sensor
  - Line sensor
  - Array sensor



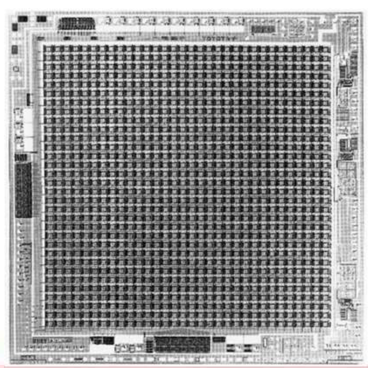
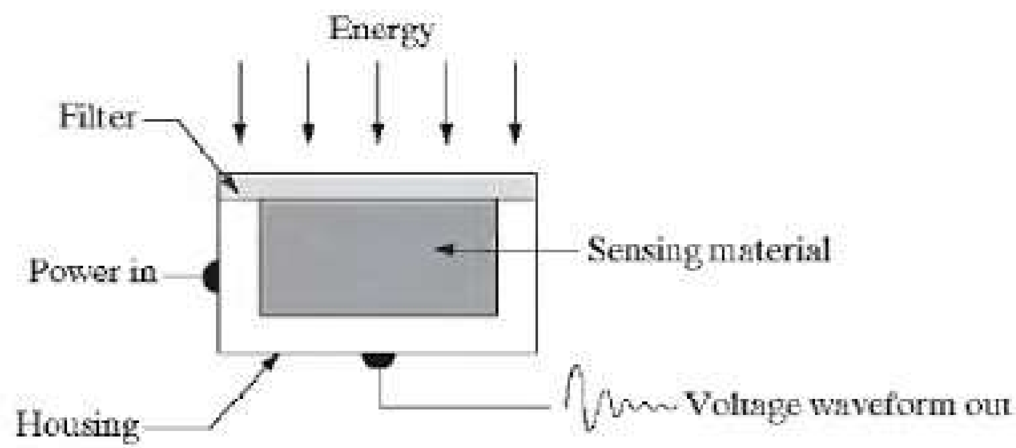


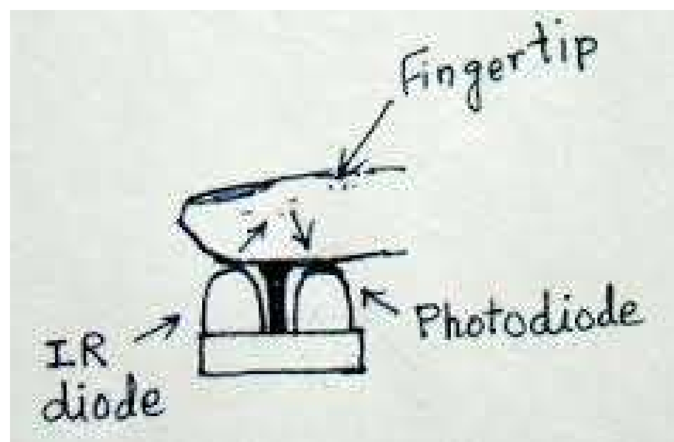
Image Sensing & Acquisition (Cont…)

- **Sensor process**
  - Incoming energy is transformed into a voltage by the combination of input electrical power and a sensor material that is responsive to the particular type of energy being detected.
  - The output voltage waveform is the response of the sensor(s), and a digital quantity is obtained from each sensor by digitizing its response.

Image Sensing & Acquisition (Cont…)

- **Image acquisition using a single sensor**
  - Most familiar sensor of this type is the photodiode, which is constructed of silicon materials and whose output voltage waveform is proportional to light.
  - The use of a filter in front of a sensor improves selectivity.
  - In order to generate a 2D image using a single sensor, there has to be relative displacements in both the *x* and *y* directions between the sensor and the area to be imaged.





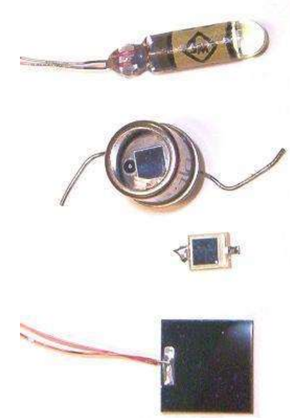


Image Sensing & Acquisition (Cont…)

- Image Acquisition using Sensor Strips
  - The sensor strip provides imaging elements in one direction.
  - Motion perpendicular to the strip provides imaging in the other direction.
  - This is the type of arrangement used in most flat bed scanners.

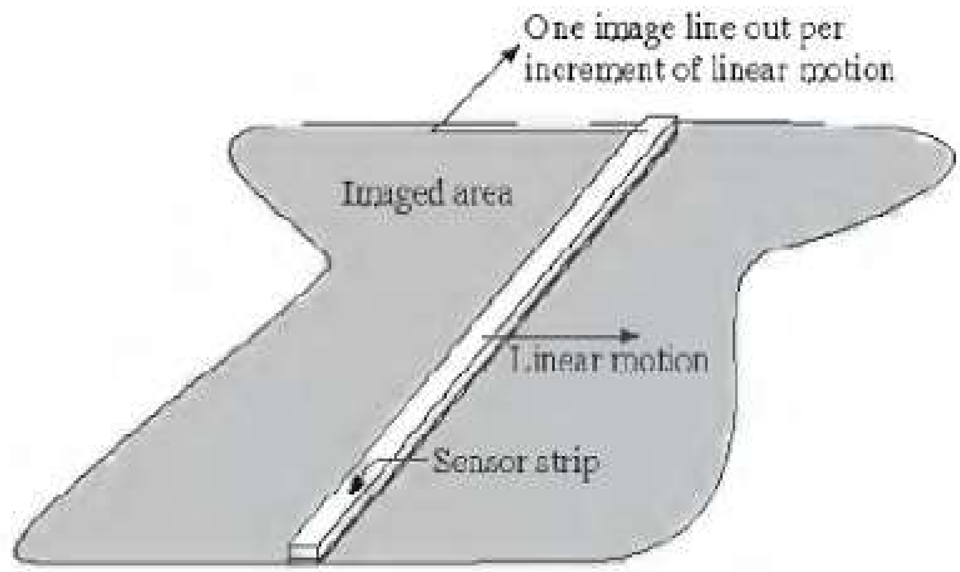


Image Sensing & Acquisition (Cont…)

- Sensor strips mounted in a ring configuration are used in medical and industrial imaging to obtain cross sectional images of 3D objects.
- CAT, MRI and PET imaging are used this concept to produce images.
- Images are not obtained directly from the sensors by motion alone, they require extensive processing.
- A 3D digital volume consisting of stacked images is generated as the object is moved in a direction perpendicular to the sensor ring.

Image Sensing & Acquisition (Cont…)

- <u>Image Acquisition using Sensor Arrays</u>
  - Numerous electromagnetic and some ultrasonic sensing devices frequently are arranged in array format.
  - This is also found in digital cameras.
  - The response of each sensor is proportional to the **integral of the light energy** (the cumulative sum or total of the light energy) projected on to the surface of the sensor.
  - The key advantage of 2D sensor array is it can be obtained the complete image by focusing the energy pattern onto the surface of the array.
  - Motion is not necessary in this method.

Image Sensing & Acquisition (Cont…)

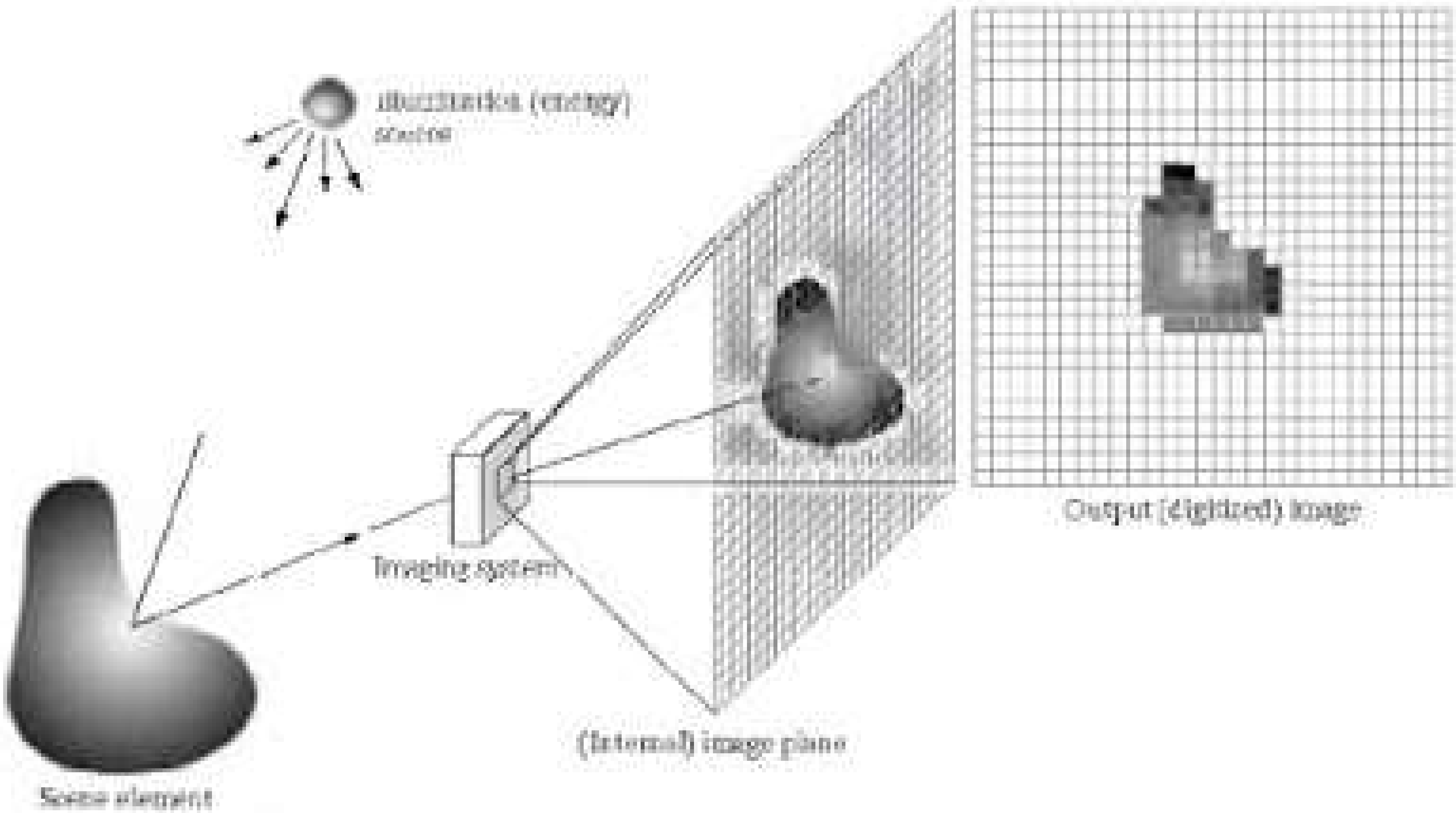


Image Formation Model

- We can denote images by two dimensional function of the form ***f(x,y).***
- The value or amplitude of the *f* at spatial coordinates *(x,y)* is a positive scalar quantity whose physical meaning is determined by the source of the image.
- When an image is generated from a physical process, its values are proportional to energy radiated by a physical source (electromagnetic waves).
- As a consequence, *f(x,y)* must be non-zero and finite; that is, $0 < f(x,y) < \infty$

Image Formation Model (Cont...)

- The function $f(x,y)$ may be characterized by two components;
  - **Illumination** – The amount of source illumination incident on the scene being viewed - $\boldsymbol{i(x,y)}$.
  - **Reflectance** – The amount of illumination reflected by the objects in the scene - $\boldsymbol{r(x,y)}$.
- The two functions combine as a product to form $f(x,y)$.

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

Where; $0 < i(x,y) < \infty$ *and* $0 < r(x,y) < 1$ (0 – total absorption, 1 – total reflectance)

- The nature of $i(x,y)$ is determined by the illumination source, and $r(x,y)$ is determined by the characteristics of the imaged objects.

Image Formation Model (Cont…)

- We call the intensity of a monochrome image at any coordinates (x_n, y_n) the gray level (l) of the image at that point.

  That is; $l = f(x_0, y_0)$

- It is evident that l lies in the range; $L_{min} < l < L_{max}$
- In theory, the only requirement of L_{min} is that it be positive, and on L_{max} that it be finite.
- In practice $L_{min} = i_{min}\ r_{min}$ and $L_{max} = i_{max}\, r_{max}$
- The interval $[L_{min}, L_{max}]$ is called the **GRAY SCALE**.
- Common practice is to shift this interval numerically to the interval [0, L-1], where l=0 is considered black and l = L-1 is considered white on the gray scale.
- All the **intermediate values are shades of gray** varying from black to white.

Image Sampling & Quantization

- **Why?**
  - The output of most sensors is a continuous voltage waveform whose amplitude and spatial behaviors are related to the physical phenomenon being sensed.
  - To create a digital image, we need to convert the continuous sensed data into digital form.
  - This involves two processes; **Sampling and Quantization.**

Image Sampling & Quantization (cont…)

- An image may be continuous with respect to the *x* and *y* coordinates and also an amplitude.
- To convert image to digital form, we have to sample the function in both coordinates and in amplitude.
- Digitizing the coordinate values is called **Sampling**.
- Digitizing the amplitude values is called **Quantization**.

Image Sampling & Quantization (cont…)

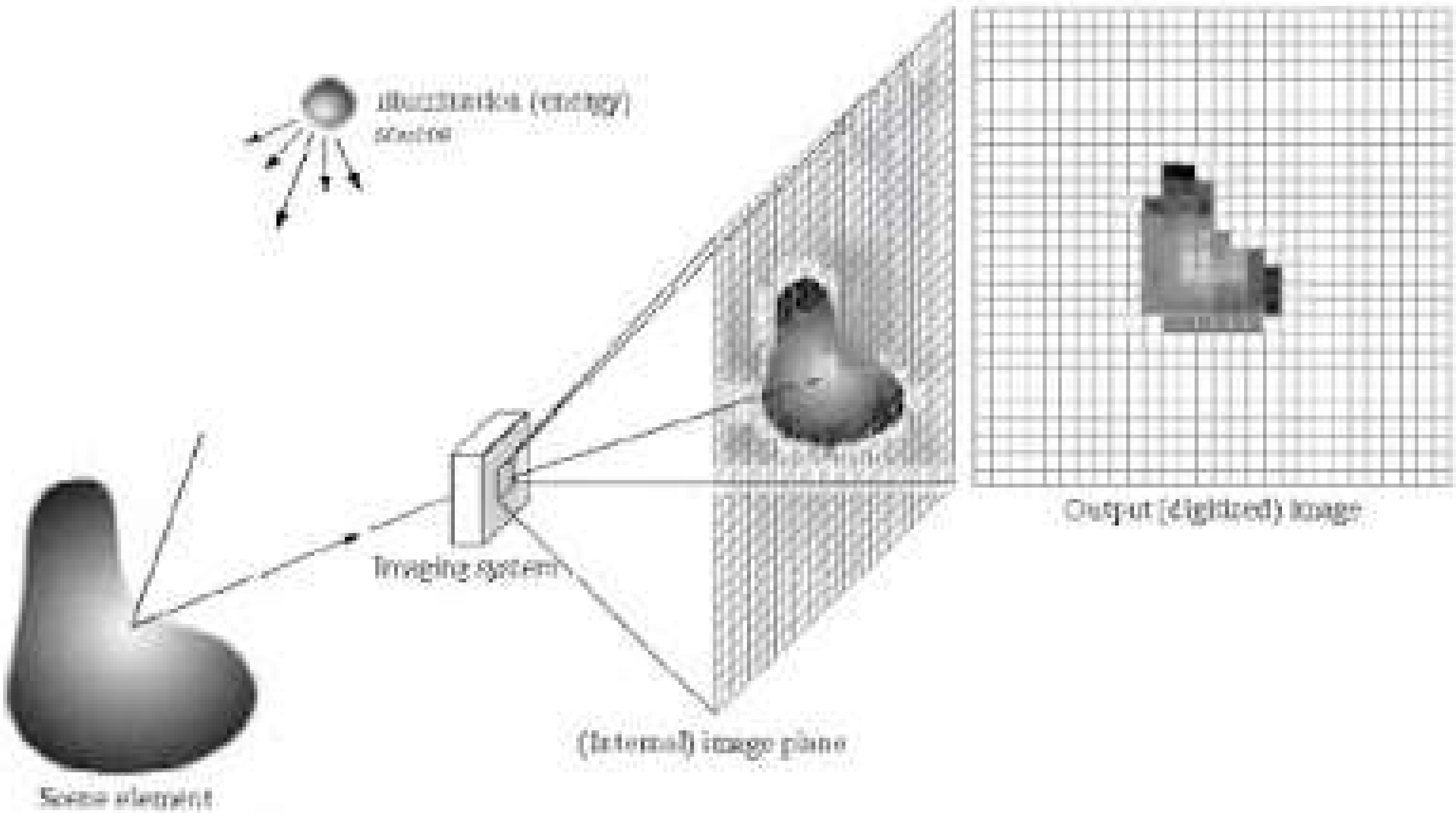
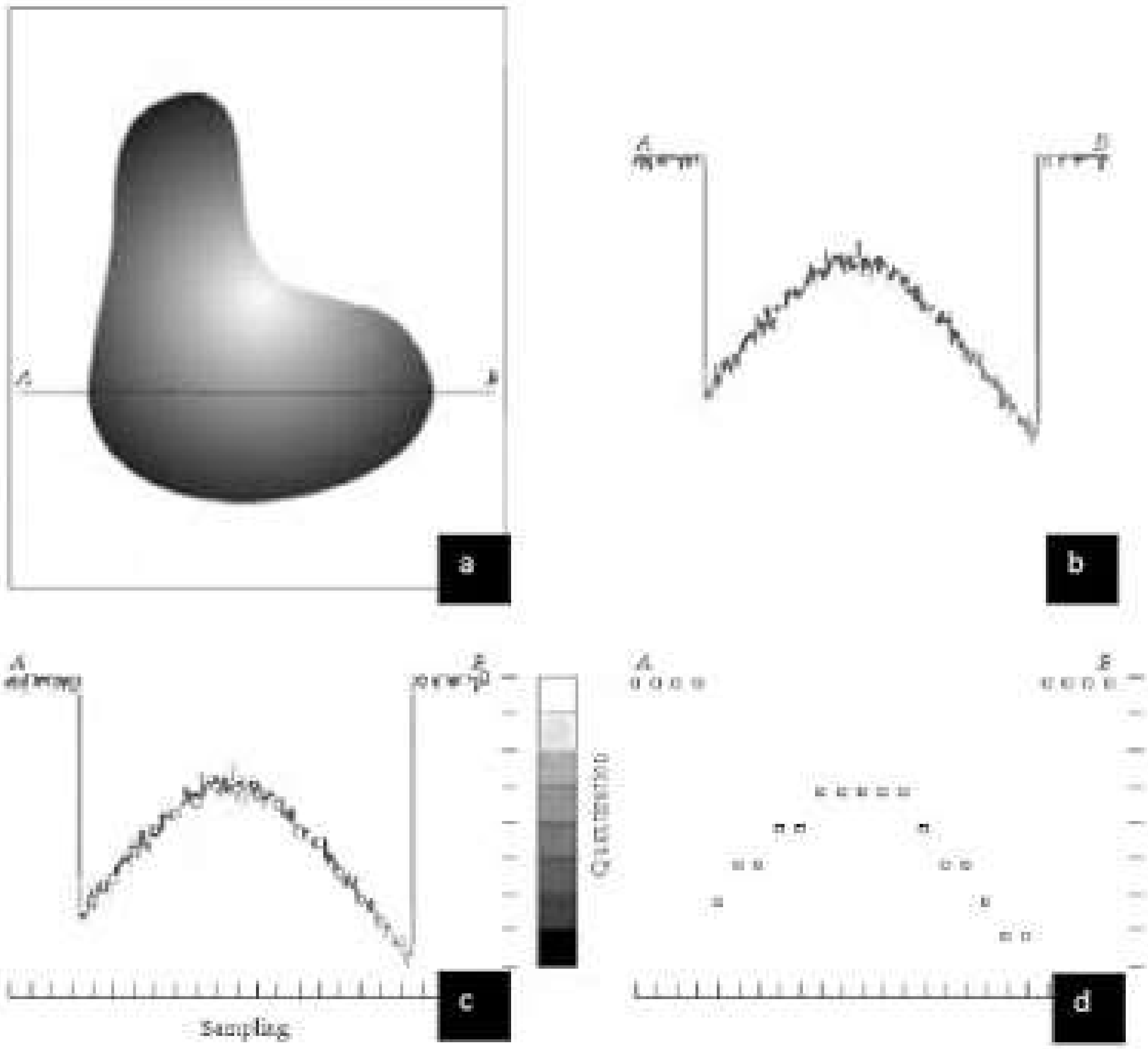


Image Sampling & Quantization (cont…)



Generating a digital image

a: continuous image

b: a scan line from A to B in the continuous image, used to illustrate the concept of sampling and quantization

c: Sampling and Quantization

d: Digital scan line

Image Sampling & Quantization (cont…)

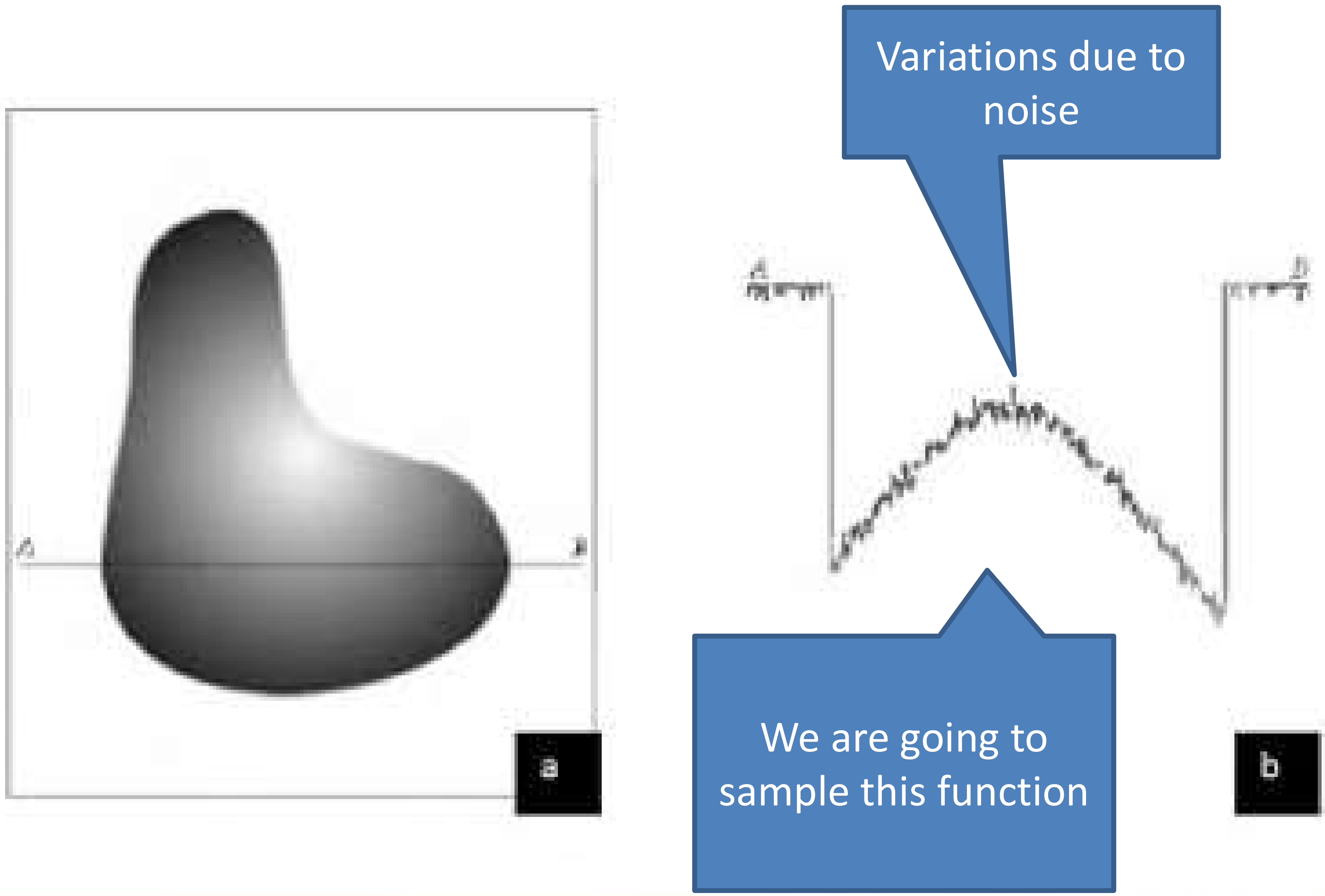


Image Sampling & Quantization (cont…)

- **Sampling**
  - To sample this function, we take equally spaced samples alone line AB.
  - The location of each sample is given by a vertical thick mark in the bottom part of the figure.

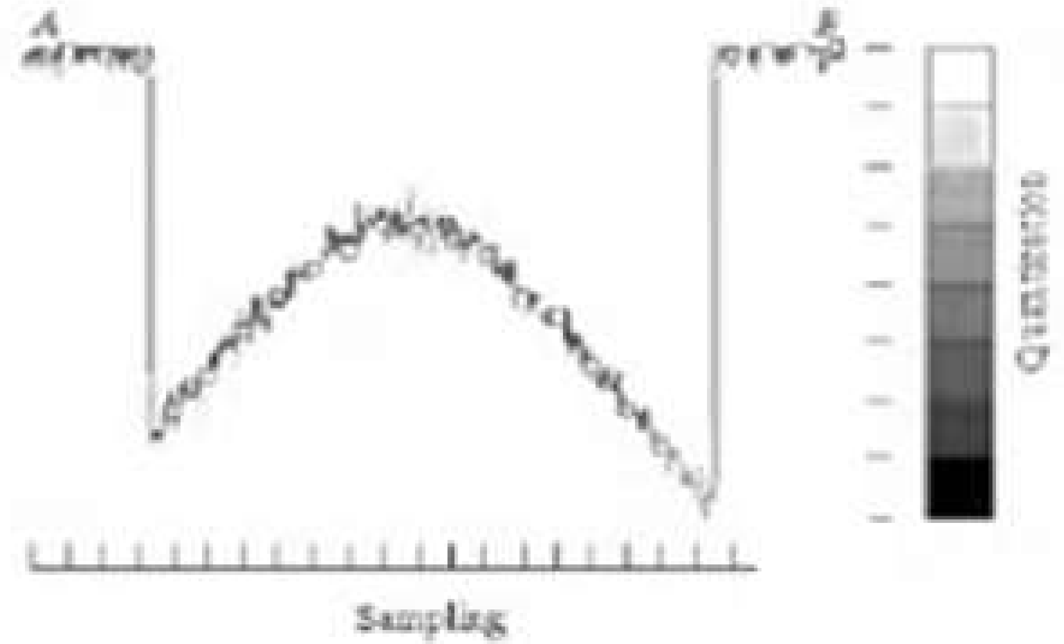


Image Sampling & Quantization (cont…)

- The set of these discrete locations gives the sampled functions.
- However, the values of samples still span (vertically) a continuous range of gray level values.

Image Sampling & Quantization (cont…)

- **Quantization**
  - In order to form a digital function, the gray level values must be converted (quantized) into direct quantities.
  - The right side of figure shows the gray level scale divided into eight discrete levels, ranging from black to white.
  - The vertical thick marks indicate the specific values assigned to each of the eight gray levels.

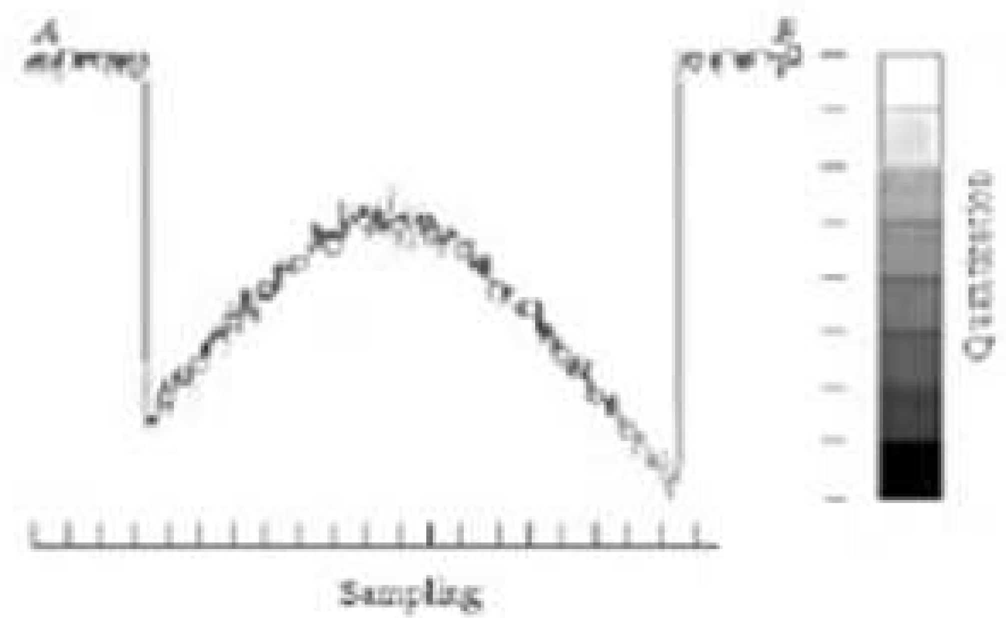
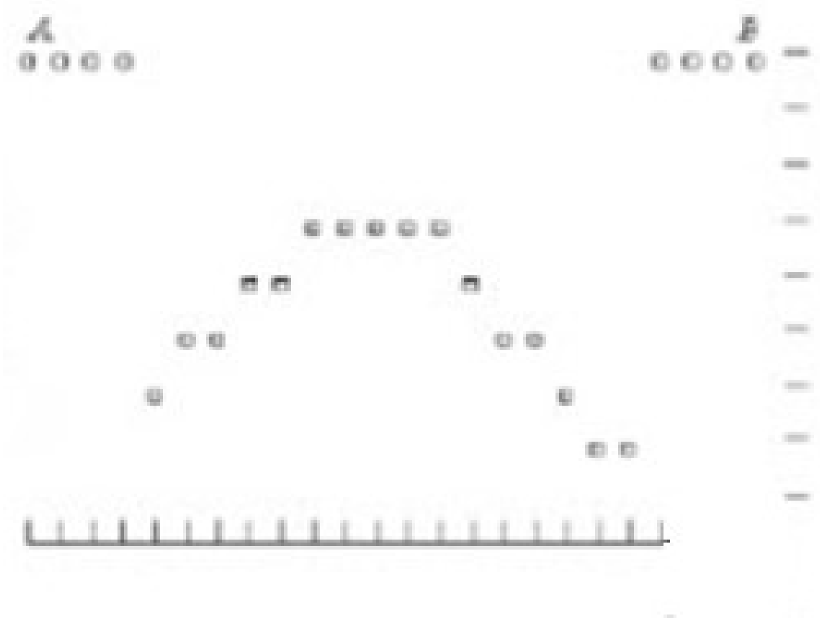


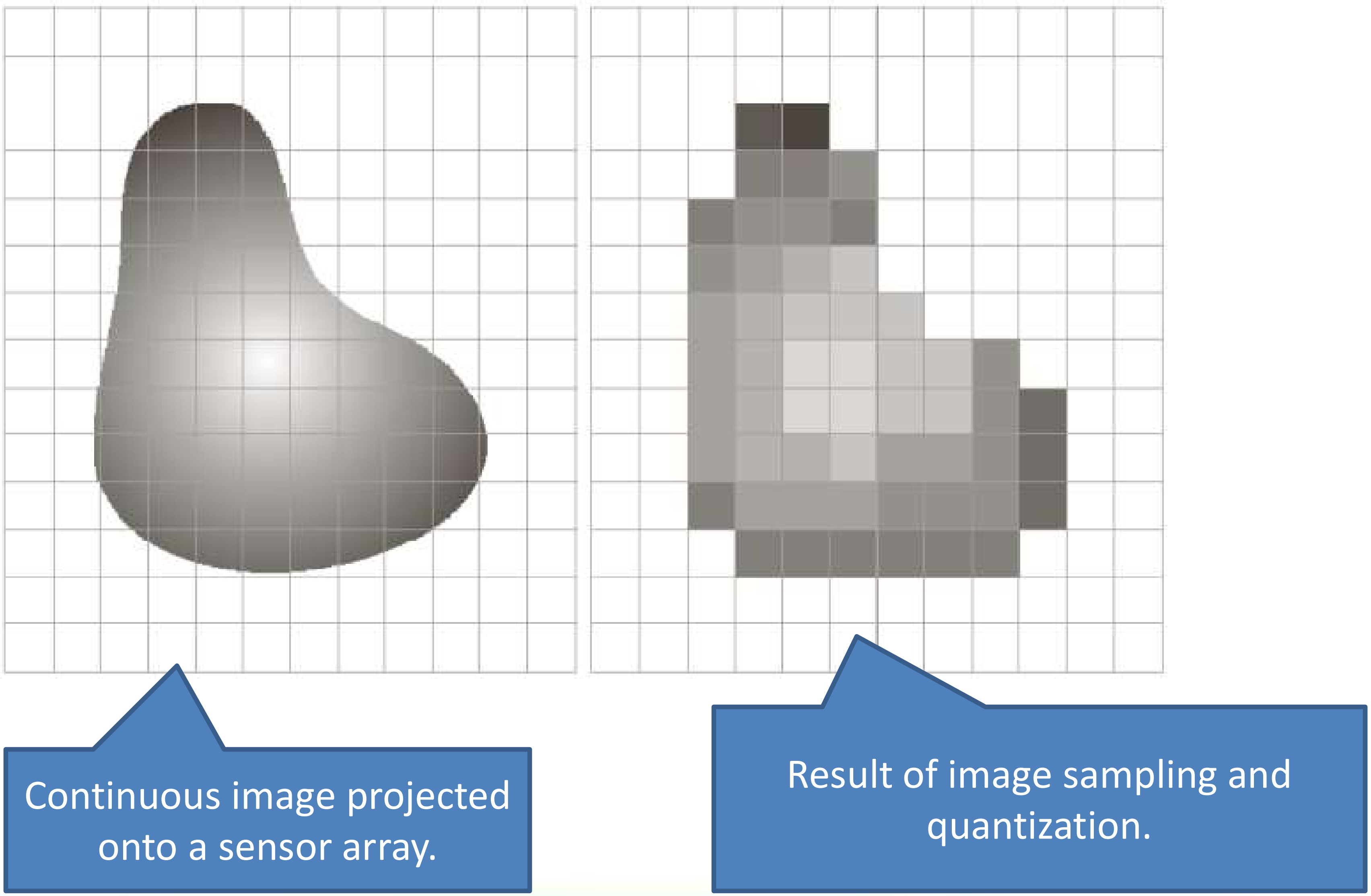
Image Sampling & Quantization (cont…)

- The continuous gray levels are quantized simply by assigning one of the eight discrete gray levels to each sample.
- The assignment is made depending on the vertical proximity of a sample to a vertical thick mark.



Starting at the top of the image and carrying out this procedure line by line produces a two dimensional digital image.

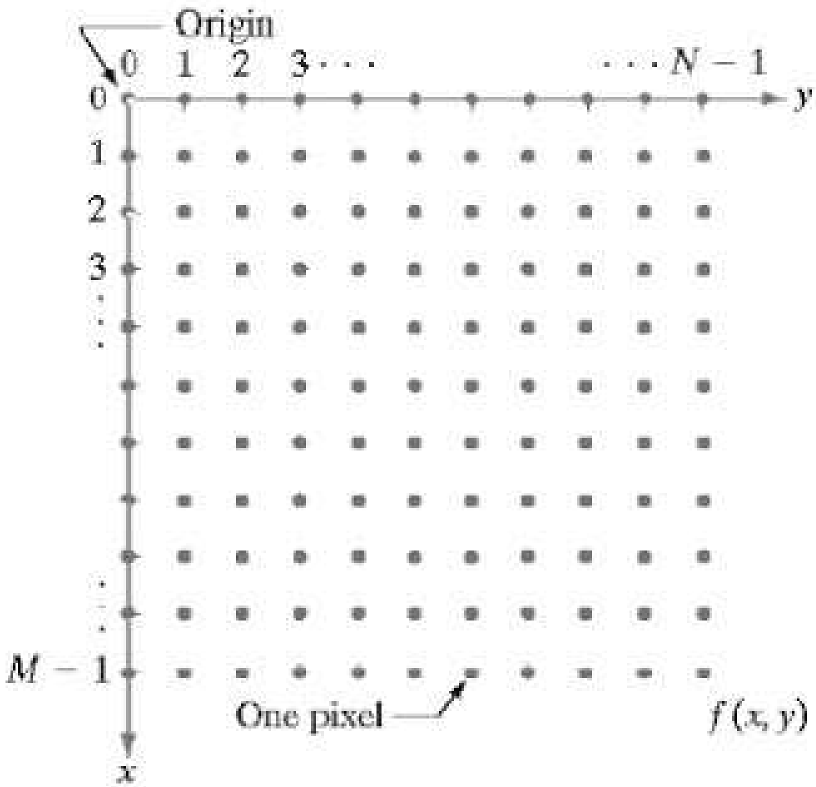
Image Sampling & Quantization (cont…)



Representing Digital Images

- The result of sampling and quantization is a matrix of real numbers.
- **Assume that an image *f(x,y)*is sampled and so that the resulting digital image has *M* rows and *N* columns.**
- **The values of the coordinates *(x,y)* now become discrete quantities.**

Representing Digital Image (cont...)



- We can denote the values of the coordinates at the origin are *(x,y) = (0,0)*.
- It is important to keep in mind that the notation *(0,1)* is used to signify the first sample along the first row and so on.
- It does not mean that these are the actual values of physical coordinates when the image was sampled

Representing Digital Image (cont…)

- We can write the complete *M * N* digital image in the following compact matrix form.

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

Representing Digital Image (cont…)

- The digitization process requires decisions about values for *M, N* and for the *L* number of discrete gray levels allowed for each pixel.
- *M* and *N* should be positive integers.
- However due to **<u>processing, storage</u>** and **<u>sampling hardware considerations</u>**, the number of gray levels typically is the integer power of 2 as expressed below;

$$L = 2^k$$

- We assume that the discrete levels are equally spaced and that they are integers in the interval [0, L-1].

Representing Digital Image (cont…)

- The number of *b* of bits required to store a digitized image is

$$b = M * N * k$$

$$b = N^2 * k \quad when\ M{=}N$$

- Example: If N = 32 and L = 256, what is the value of b?
  - If L = 256 then k = 8 because $L = 2^k$
  - Then b = 32 * 32 * 8 = 8192 bits
- When an image can have 2^k gray levels, it is common practice to refer to the image as a "**k bit image**".
- For example an image with 256 possible gray level values called 8 bit image.

Representing Digital Image (cont…)

- **Dynamic Range**
  - **The lowest and highest intensity levels that a system can represent is denoted as dynamic range.**
  - This can be further explained as **Contrast.**
  - When an appreciable number of pixels exhibit this property, the image will have high contrast.
  - Conversely, an image with low dynamic range tends to have a dull, washed out gray look.

Representing Digital Image (cont…)

Reference

- Chapter 02 of Gonzalez, R.C., Woods, R.E., Digital Image Processing, 3rd ed. Addison-Wesley Pub.

Learning Outcomes Revisit

- Now, you should be able to;
  - describe the energy and the EM spectrum.
  - describe image acquisition methods.
  - discuss image formation model.
  - express sampling and quantization.
  - define dynamic range and image representation.

Next Lecture – Digital Image Fundamentals – II

QUESTIONS ?