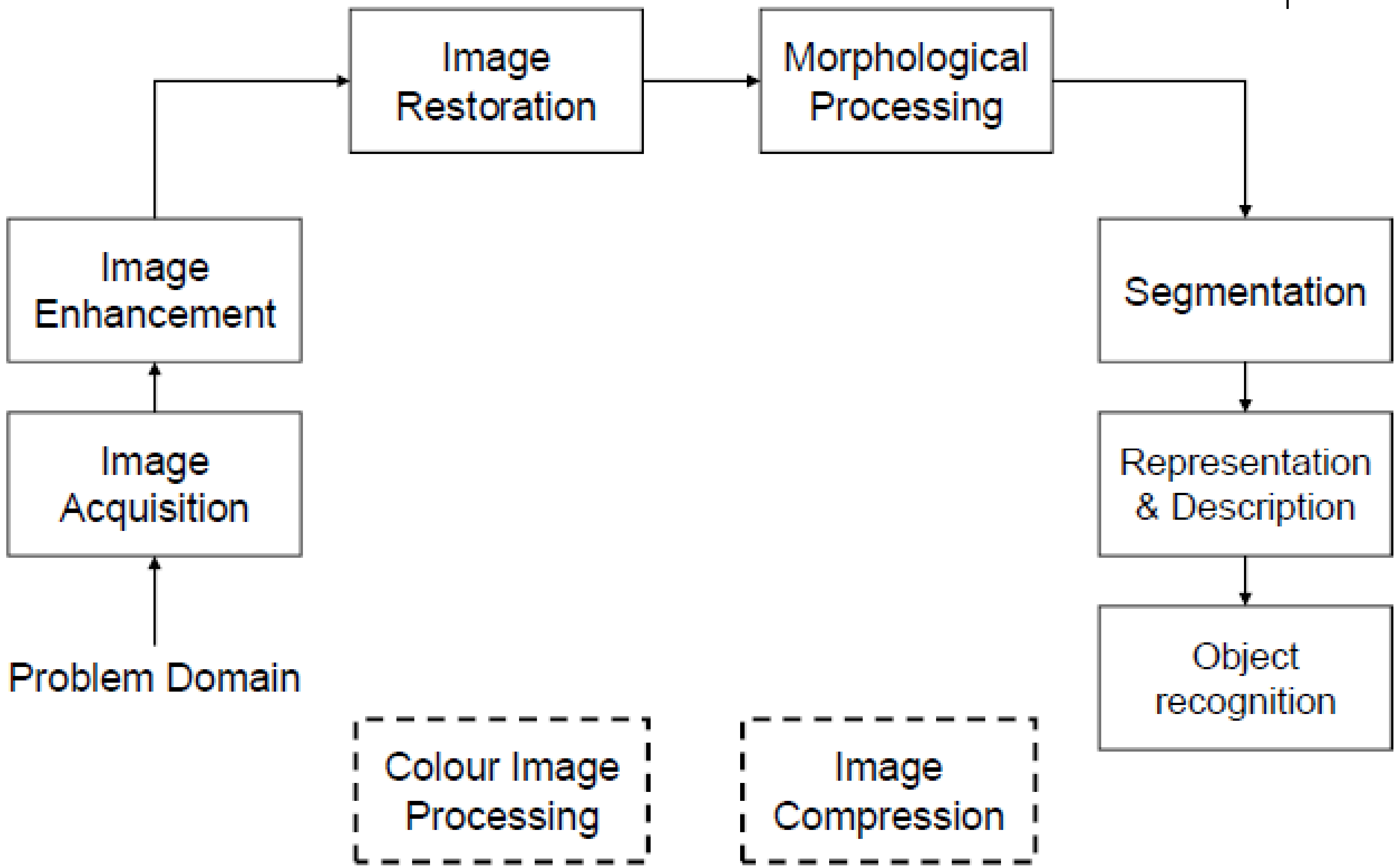
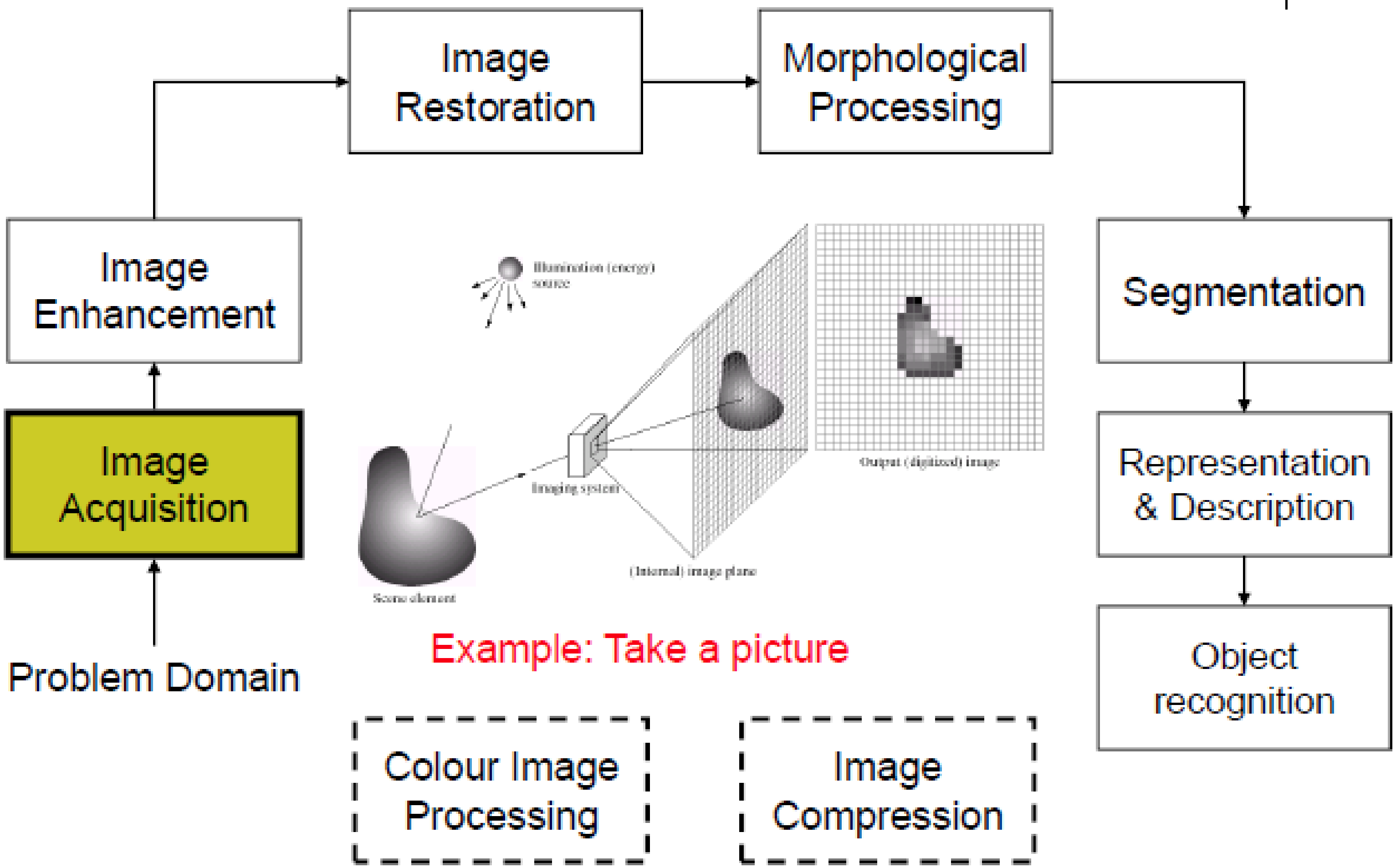
Key Stages in Digital Image Processing



Key Stages in Digital Image Processing: Image Aquisition



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

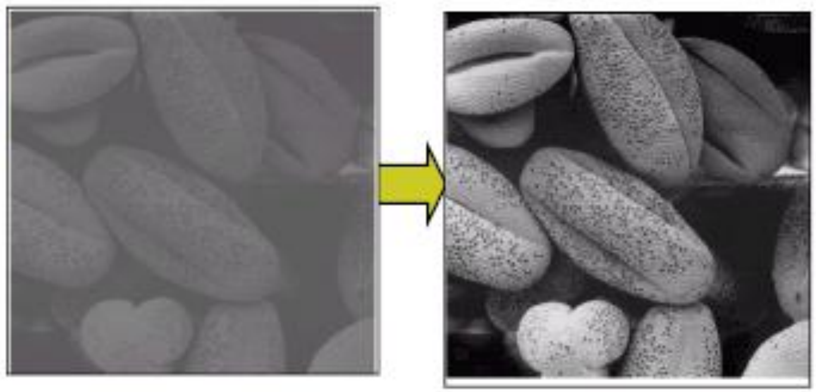
Key Stages in Digital Image Processing: Image Enhancement

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Restoration

Morphological Processing

Image Enhancement



Segmentation

Image Acquisition

Representation & Description

Problem Domain

Example: Change contrast

Object recognition

Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Image Restoration

Problem Domain

Image Acquisition

Image Enhancement

Image Restoration

Morphological Processing

Segmentation

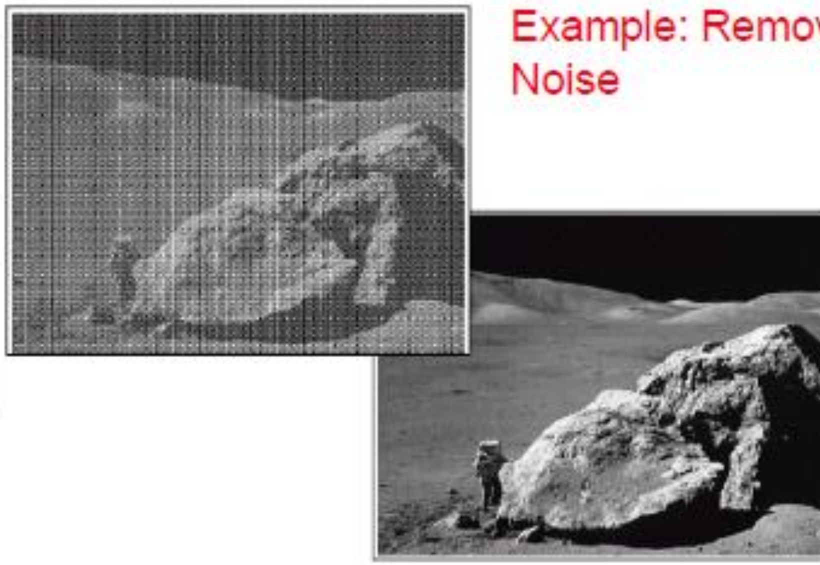
Representation & Description

Object recognition

Colour Image Processing

Image Compression

Example: Remove Noise



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Morphological Processing

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Restoration

Morphological Processing

Extract attributes useful for describing image

Image Enhancement

Image Acquisition

Problem Domain

Segmentation

Representation & Description

Object recognition

Colour Image Processing

Image Compression

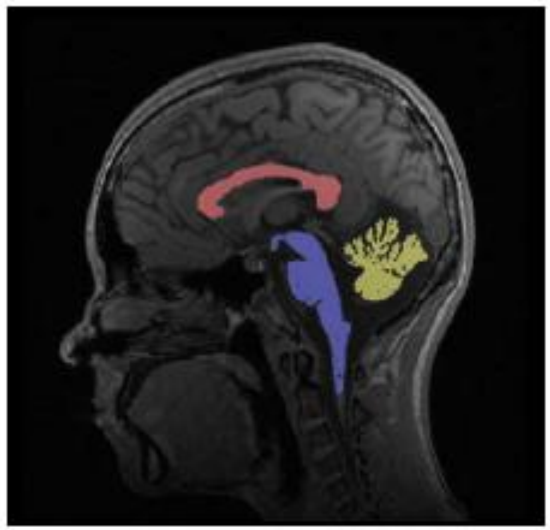
Key Stages in Digital Image Processing: Segmentation

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Problem Domain → Image Acquisition → Image Enhancement → Image Restoration → Morphological Processing → Segmentation → Representation & Description → Object recognition

Colour Image Processing

Image Compression



Divide image into constituent parts

Key Stages in Digital Image Processing: Object Recognition

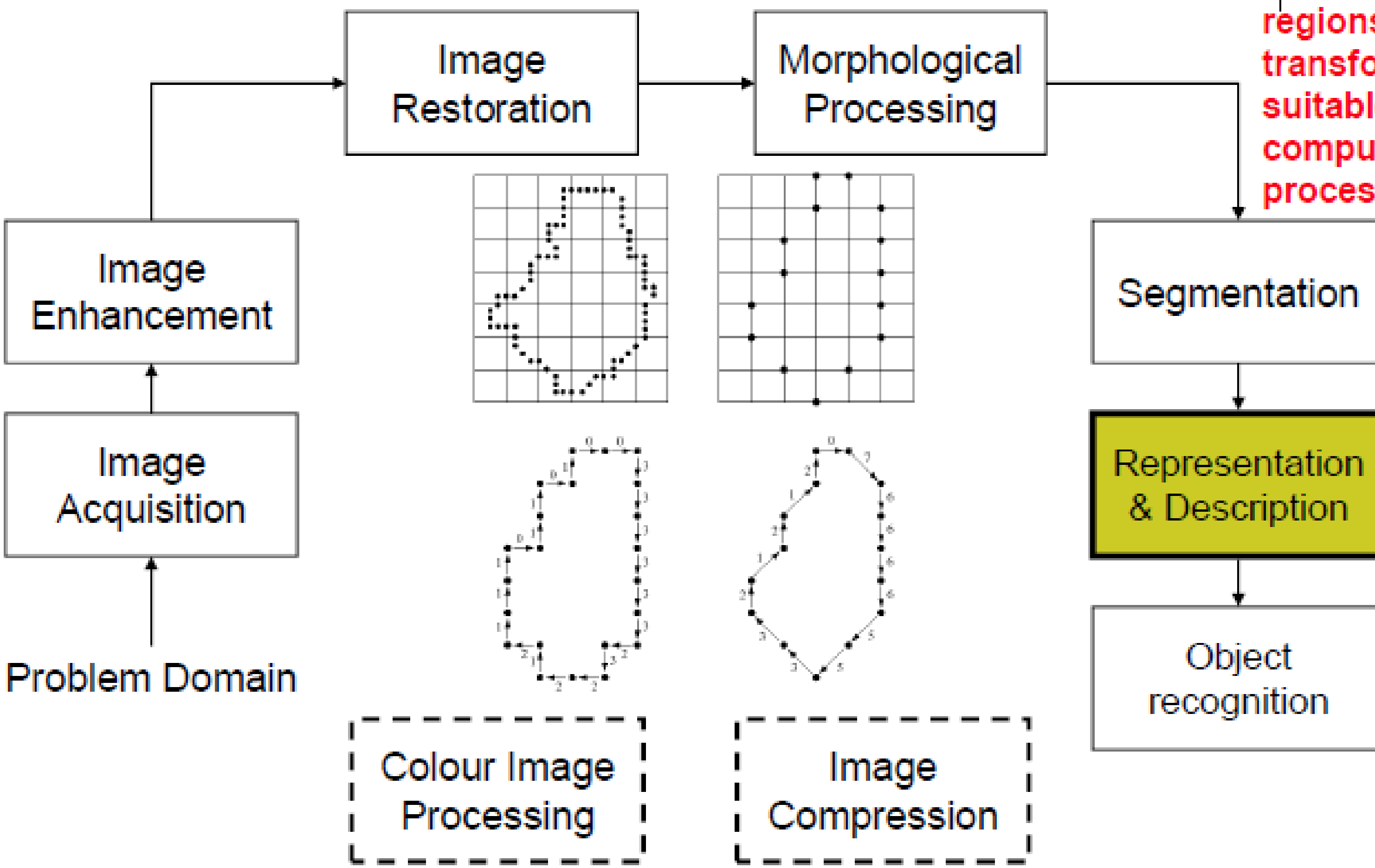


Image regions transformed suitable for computer processing

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Representation & Description

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Problem Domain

Image Acquisition

Image Enhancement

Image Restoration

Morphological Processing

Segmentation

Representation & Description

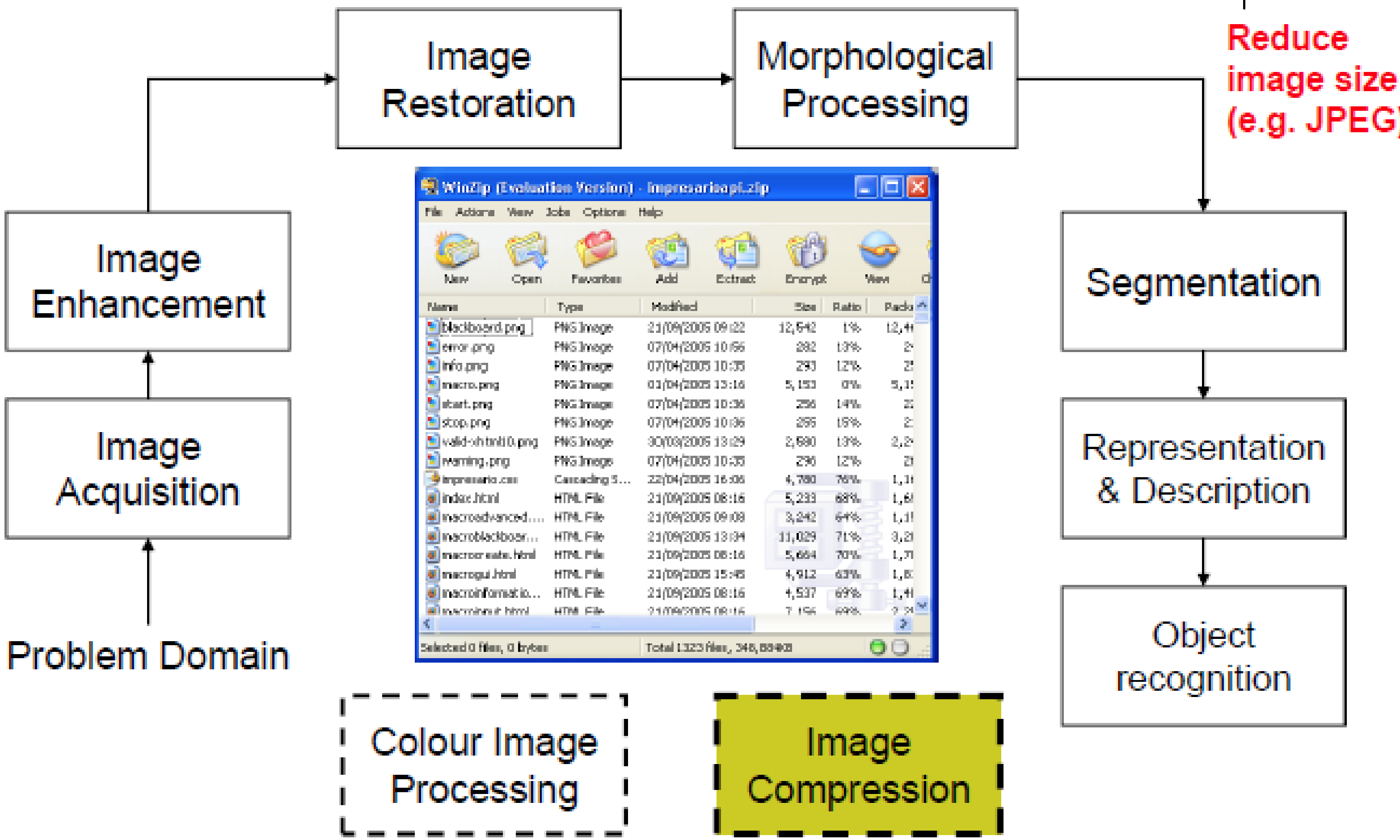
Object recognition

Finds & Labels objects in scene (e.g. motorbike)

Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Image Compression

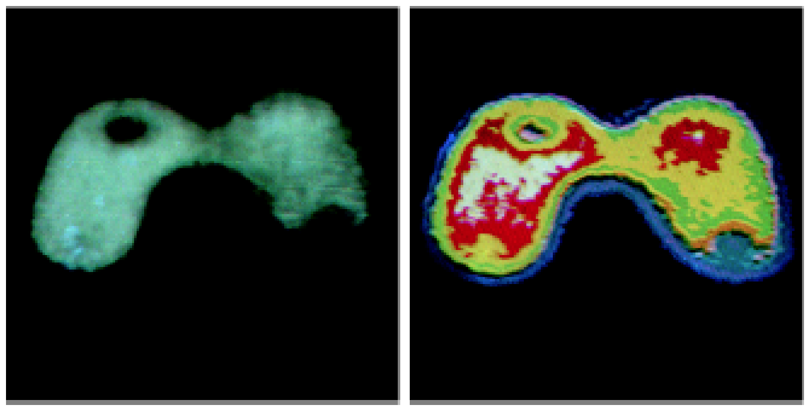


Key Stages in Digital Image Processing: Colour Image Processing

Image Restoration

Morphological Processing

Image Enhancement



Segmentation

Image Acquisition

Representation & Description

Object recognition

Problem Domain

Consider color images (color models, etc)

Colour Image Processing

Image Compression

Table 1.1 Common image formats and their associated properties

Acronym	Name	Properties
GIF	Graphics interchange format	Limited to only 256 colours (8 bit); lossless compression
JPEG	Joint Photographic Experts Group	In most common use today; lossy compression; lossless variants exist
BMP	Bit map picture	Basic image format; limited (generally) lossless compression; lossy variants exist
PNG	Portable network graphics	New lossless compression format; designed to replace GIF
TIF/TIFF	Tagged image (file) format	Highly flexible, detailed and adaptable format; compressed/uncompressed variants exist

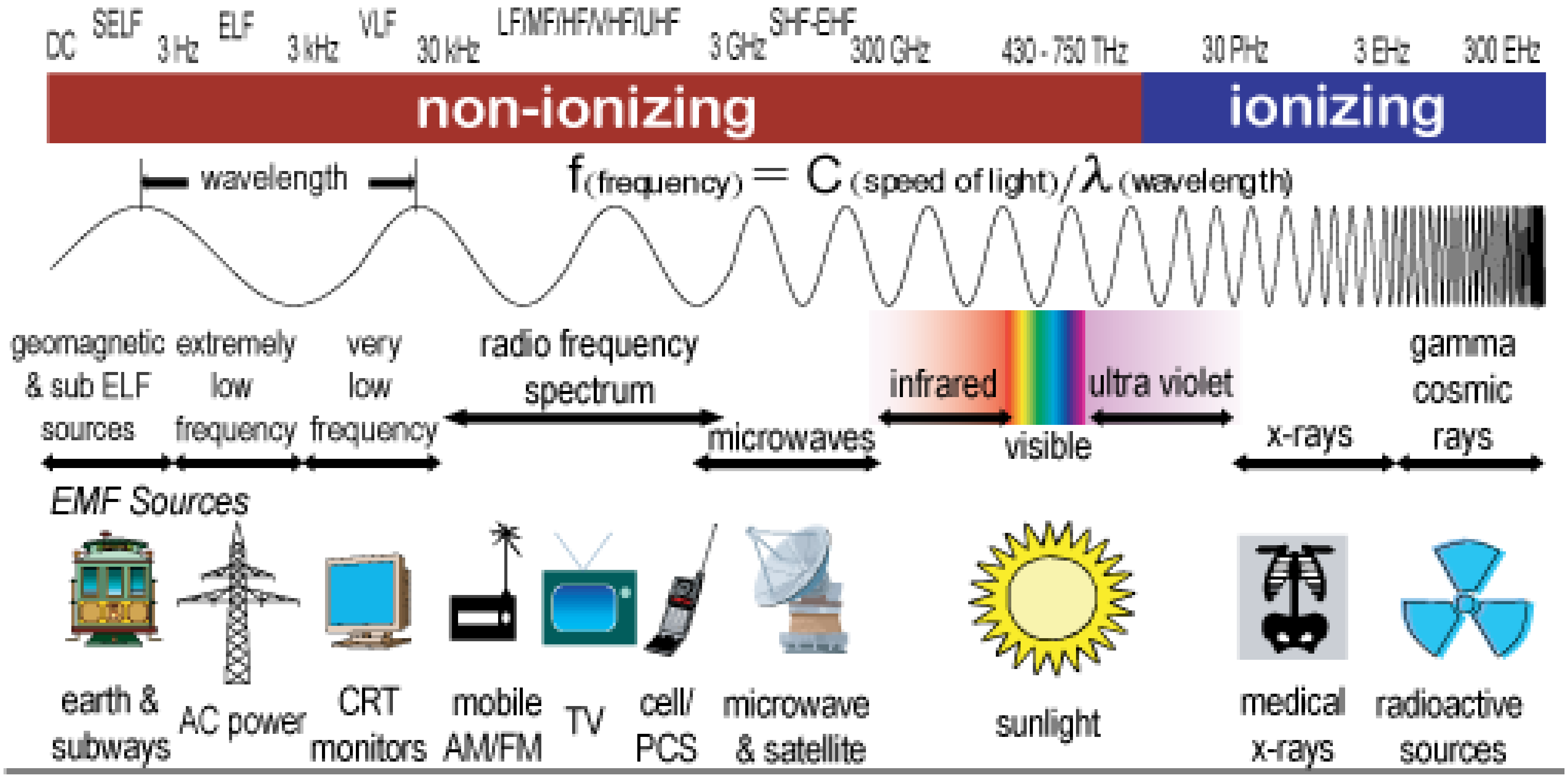
How is an image formed?

Image s can be formalized as a mathematical model comprising a functional representation of the scene (the object function o) and that of the capture process (the point spread function (PSF) p).

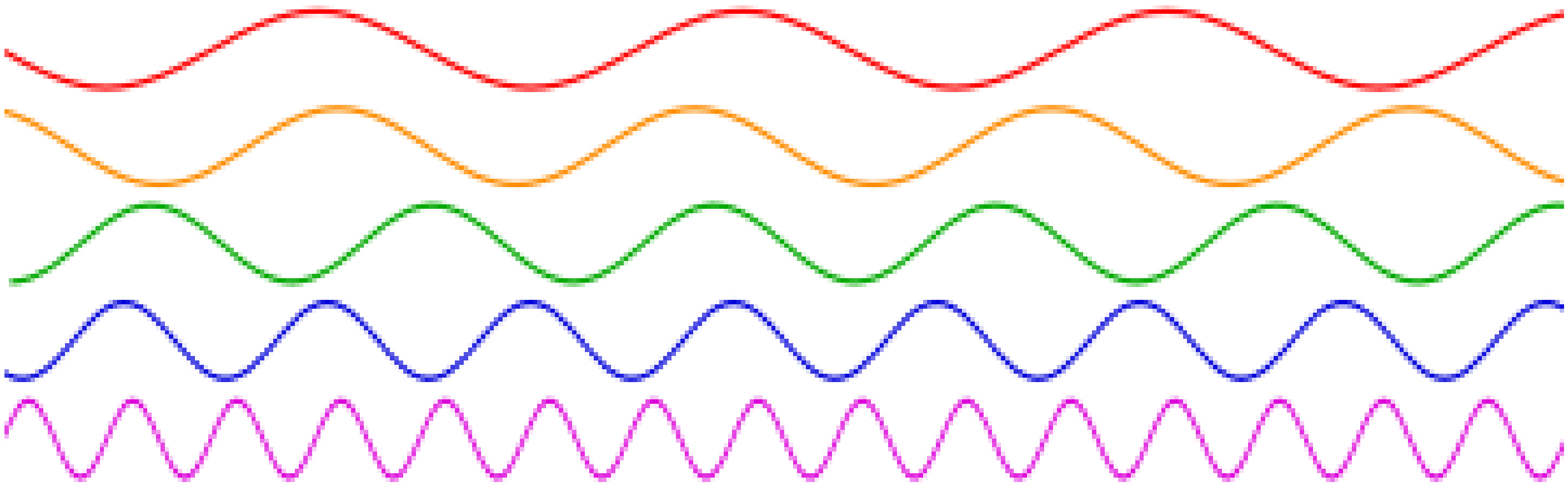
$$\text{Image} = \text{PSF} * \text{object function} + \text{noise}$$
$$s = p * o + n$$

- The **point spread function (PSF)** describes the response of an imaging system to a point source or point object.
- **Object function :** This describes the object (or scene) that is being imaged (its surface or internal structure, for example) and the way light is reflected from that structure to the imaging instrument.
- **Noise** : This is a nondeterministic function which can, at best, only be described in terms of some statistical noise distribution (e.g. Gaussian).
- **Convolution operator :** * A mathematical operation which convolves one function with another.

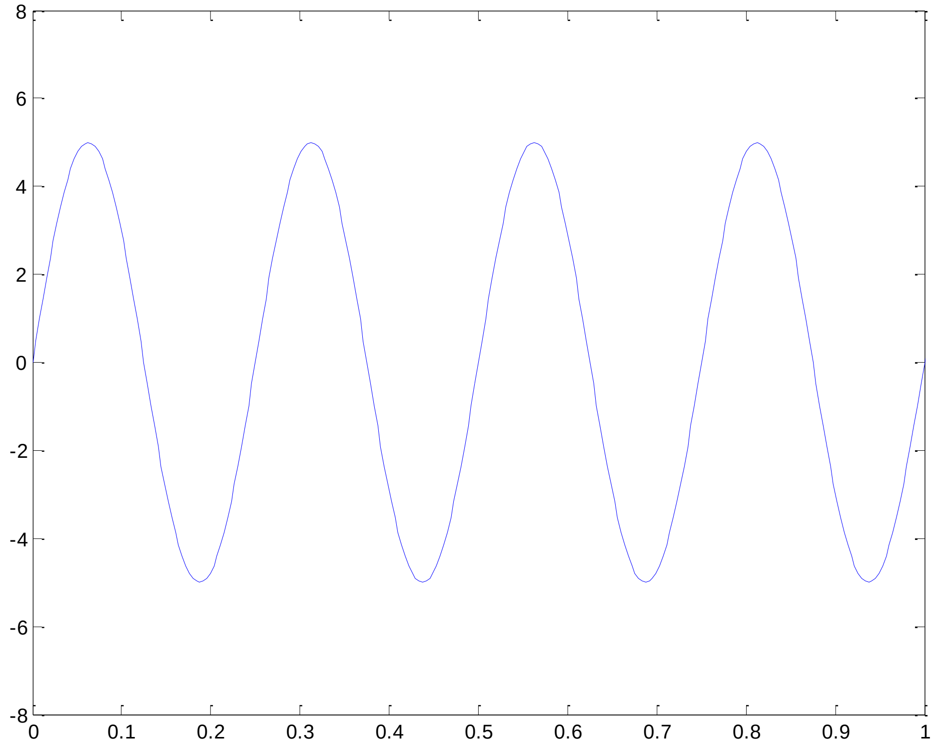
THE ELECTROMAGNETIC SPECTRUM



Gigahertz (GHz) 10-9 Terahertz (THz) 10-12 Petahertz (PHz) 10-15 Exahertz (EHz) 10-18 Zettahertz (ZHz) 10-21 Yottahertz (YHz) 10-24



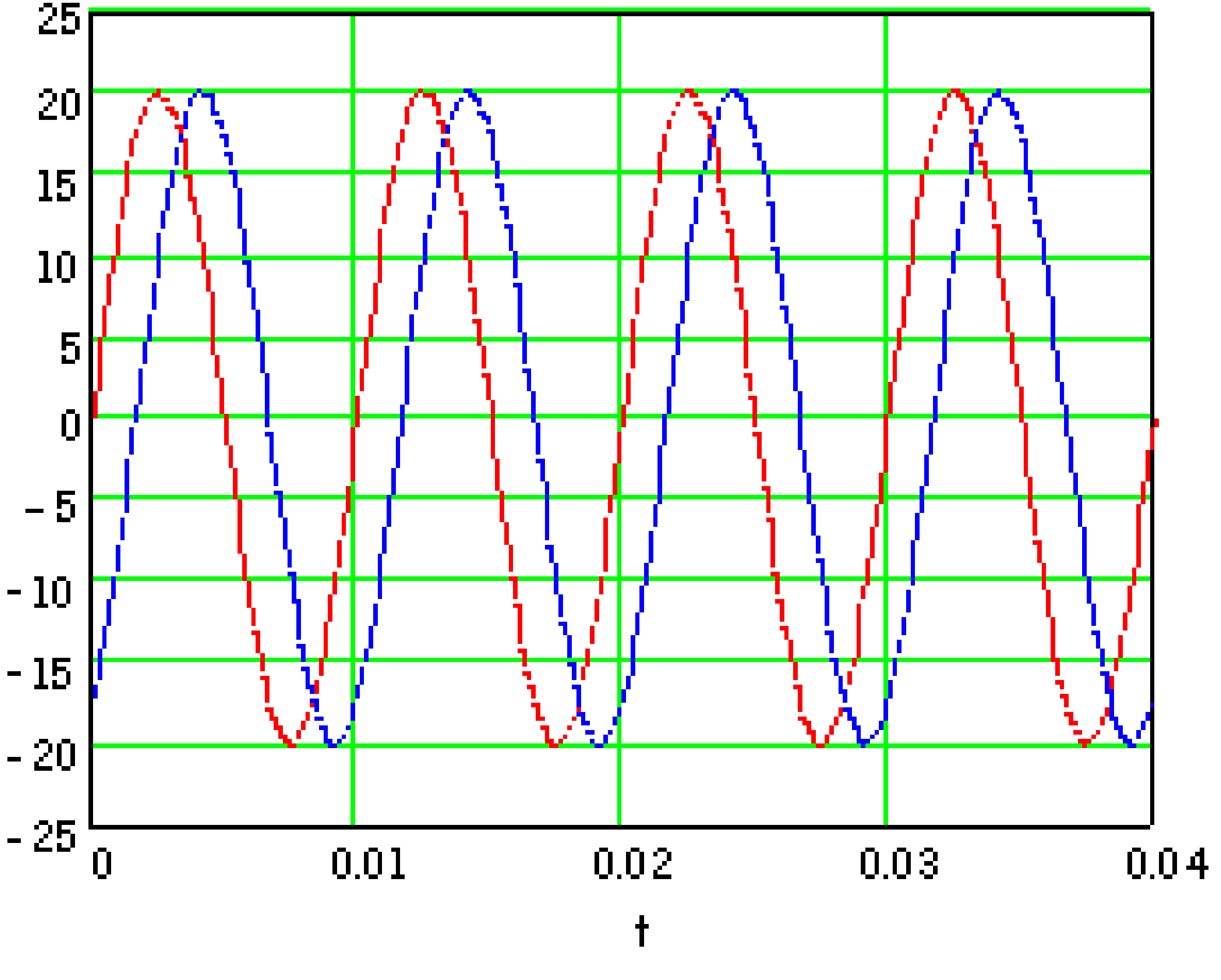
A sine wave



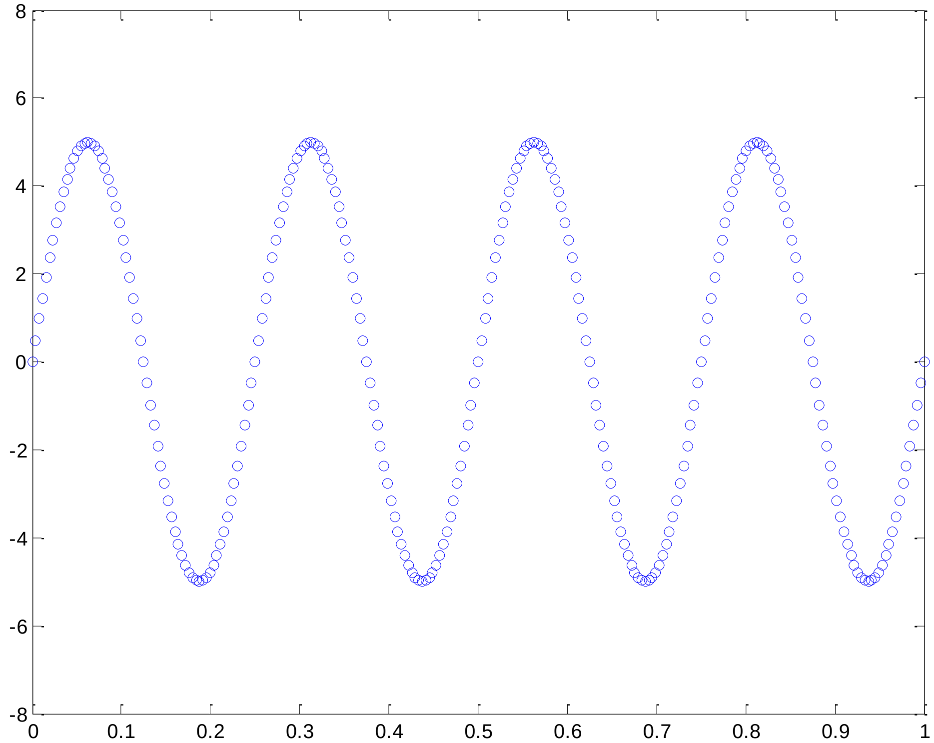
seconds

Amplitude = 5

Frequency = 4 Hz


25
20
15
10
5
0
- 5
- 10
- 15
- 20
- 25
0
0.01
0.02
0.03
0.04
t

A sine wave signal



seconds

$5*\sin(2\pi 4t)$

Amplitude = 5

Frequency = 4 Hz

Sampling rate = 256 samples/second

Sampling duration = 1 second

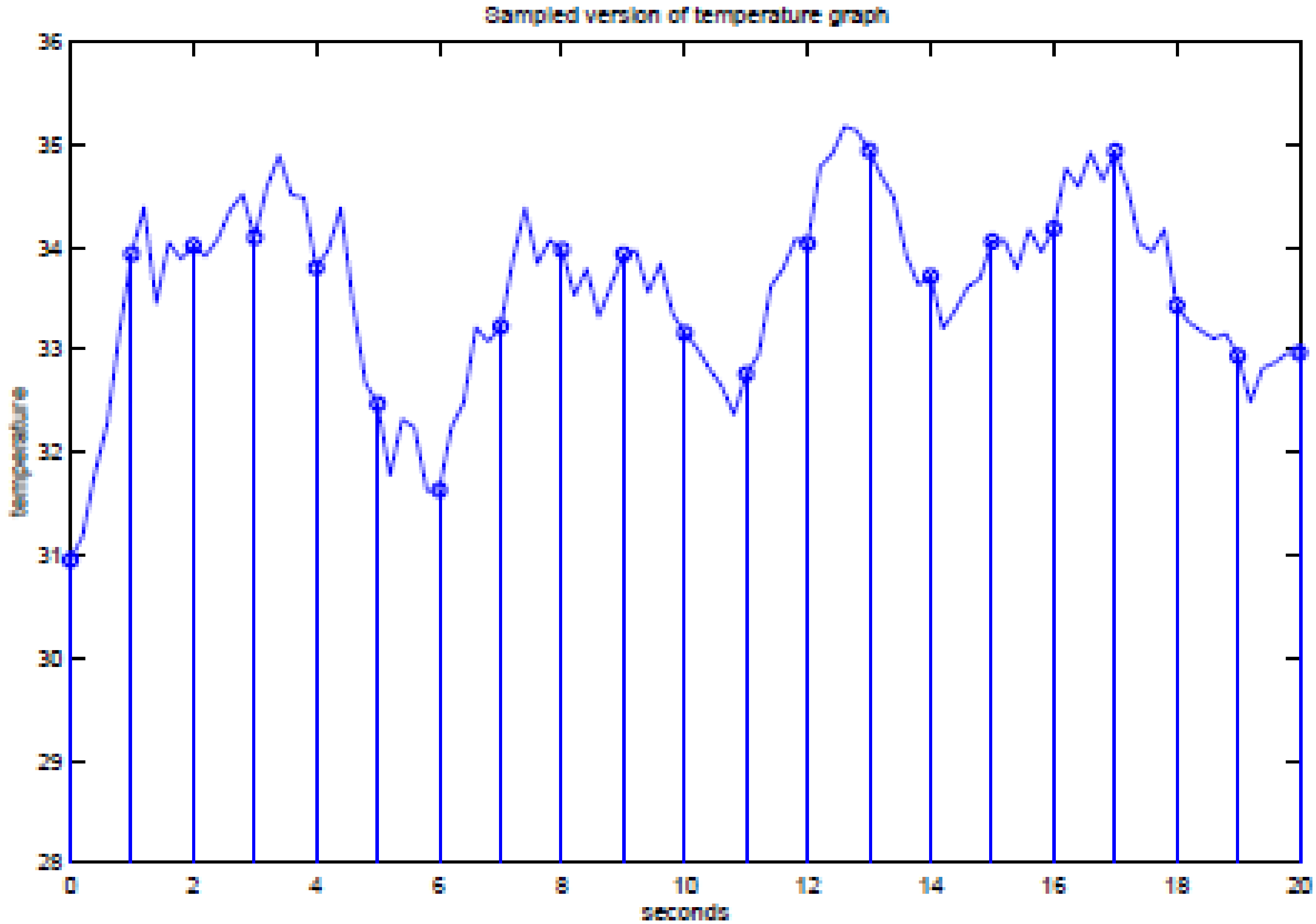


Figure 5.1: Sampling an analog signal.

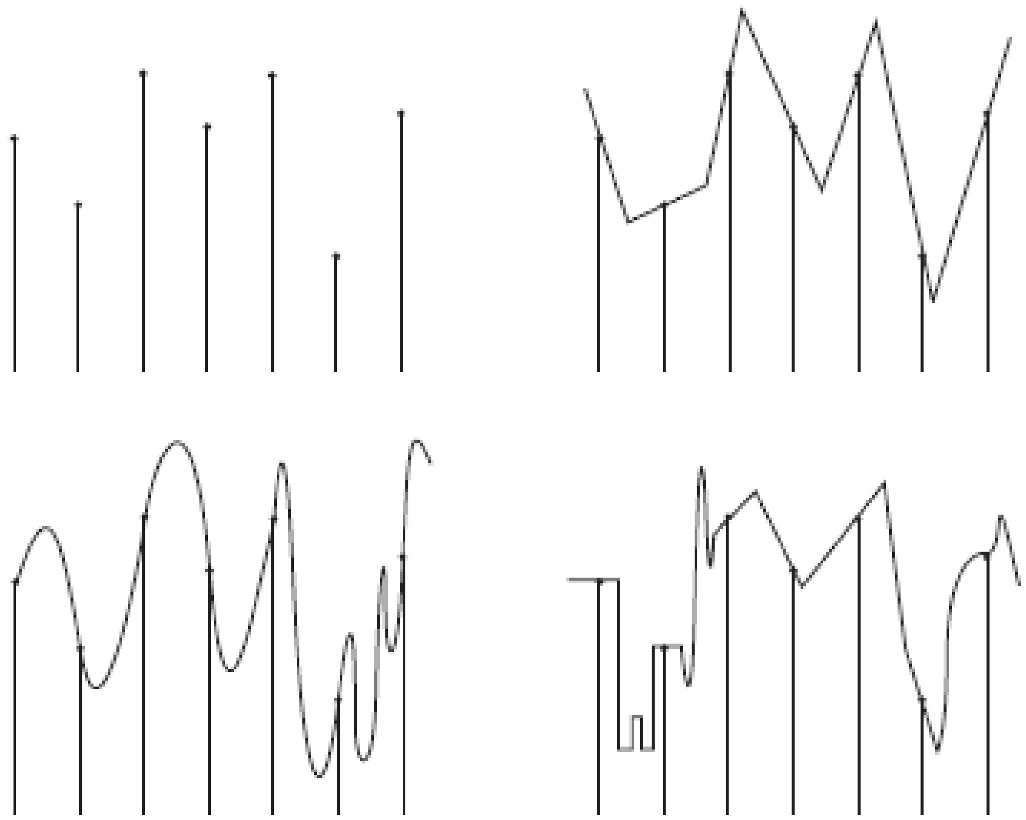


Figure 5.2: Possible continuous-time functions corresponding to samples.

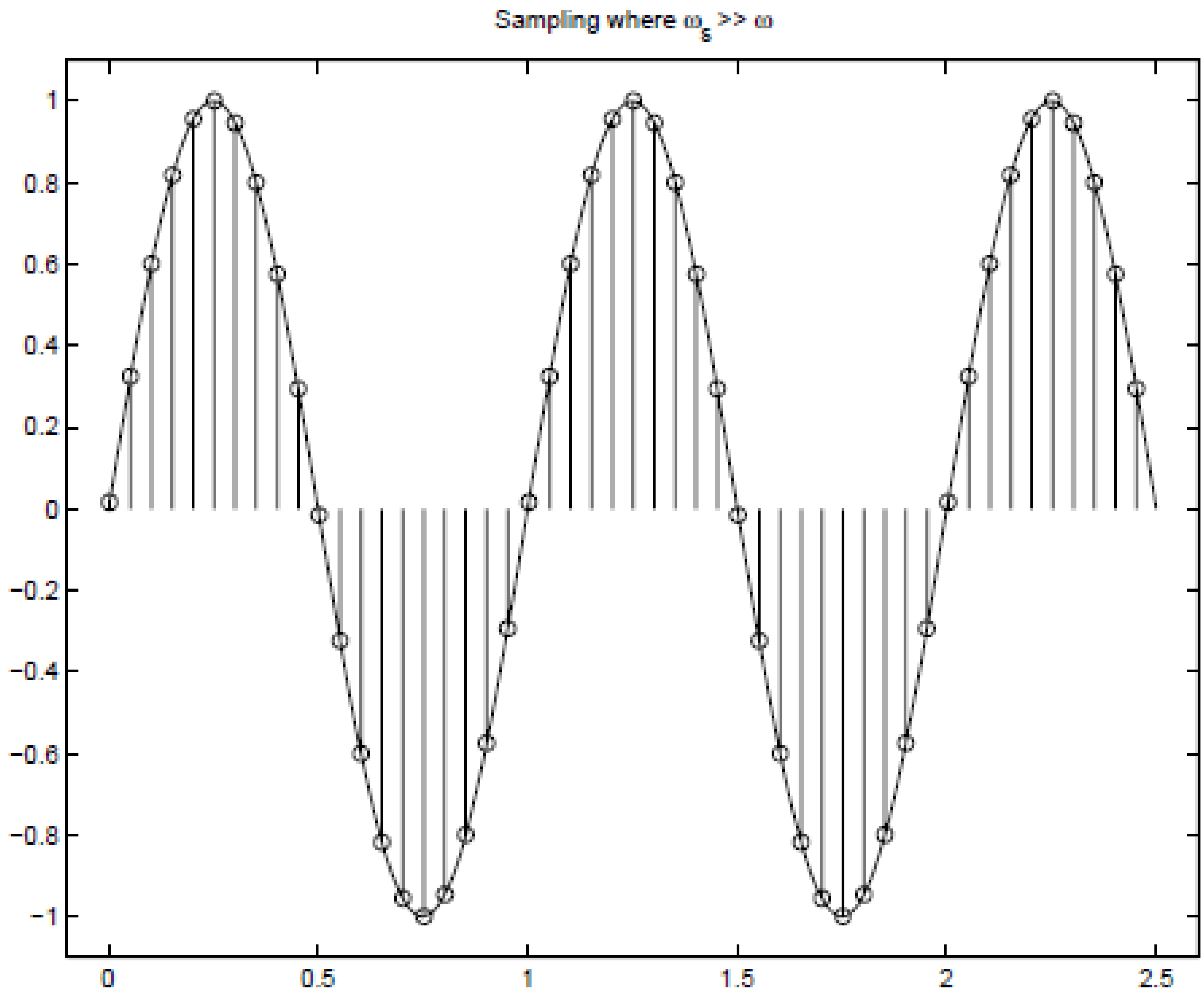


Figure 5.6: Sampling a sinusoid at a high rate.

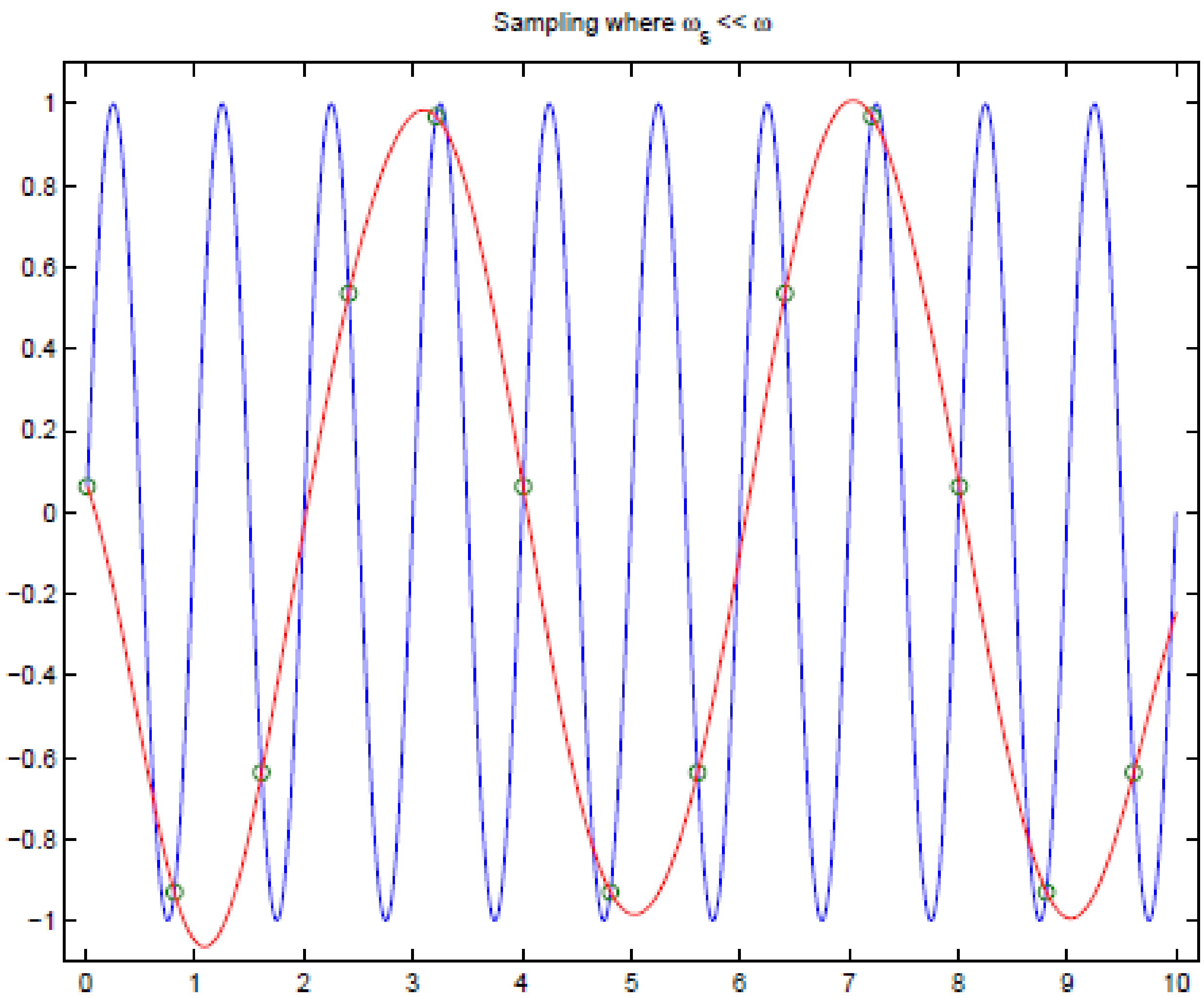
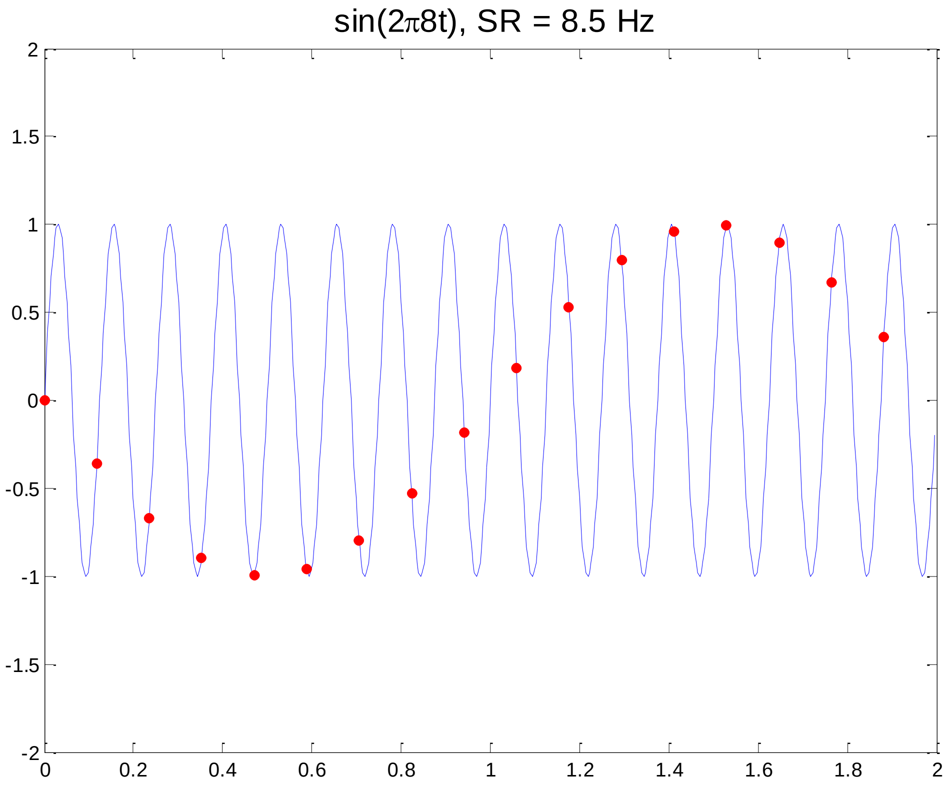


Figure 5.7: Sampling a sinusoid at too slow of a rate.

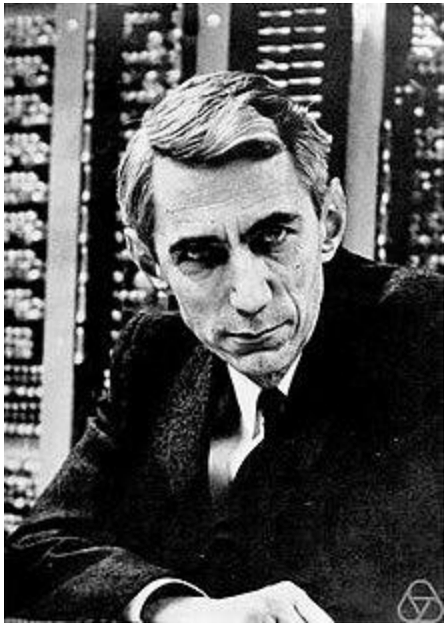
An undersampled signal



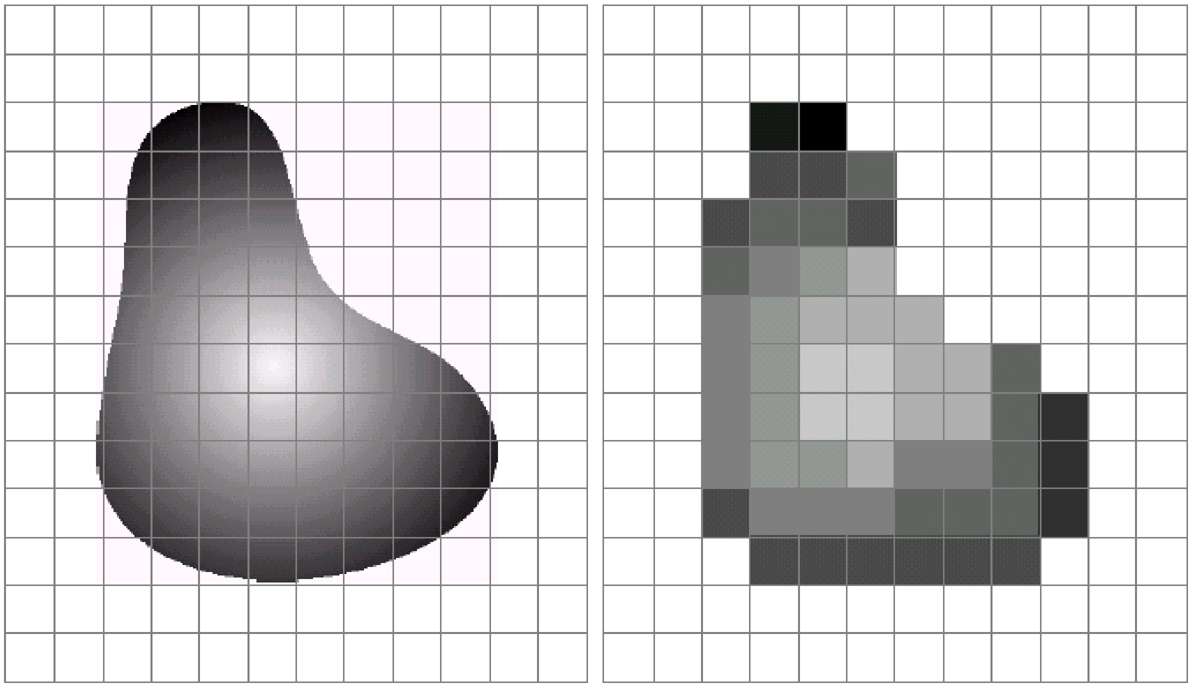
$$\text{sampling interval} \le \frac{1}{\text{Nyquist frequency}}$$

$$\text{Nyquist frequency} = 2 \times (\text{Maximum frequency in image})$$

Harry Nyquist



Claude Shannon



a b

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

a b

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

the imaging sample rate (or pixel) size should be 1/2 the size of the smallest object you wish to record.

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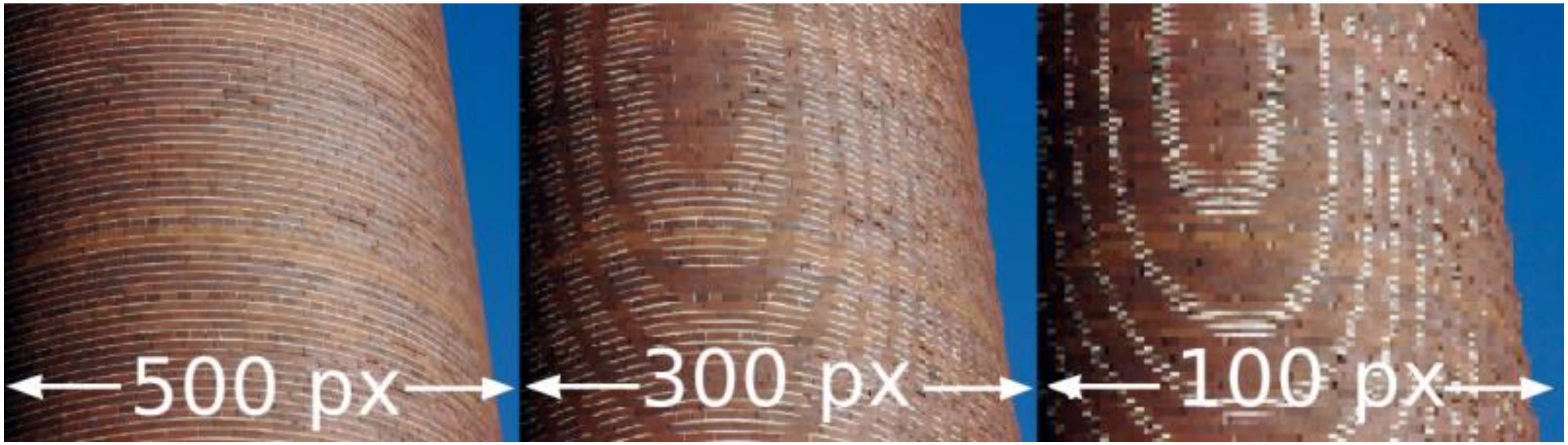
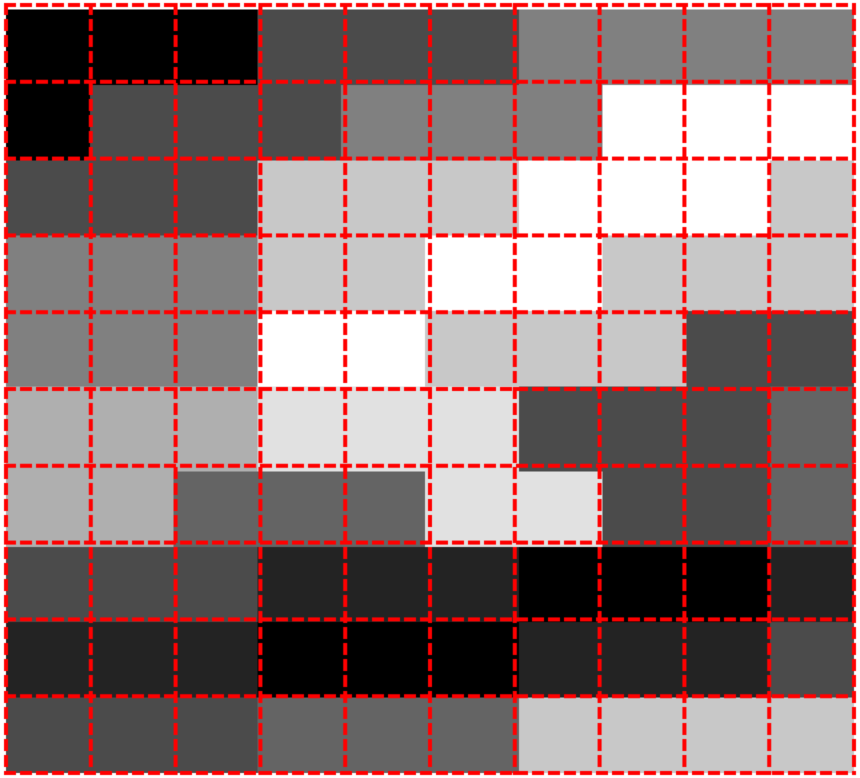


•Alaising is a phenomenon observed when the sample interval is not sufficiently brief to capture the higher range of frequencies in a signal.

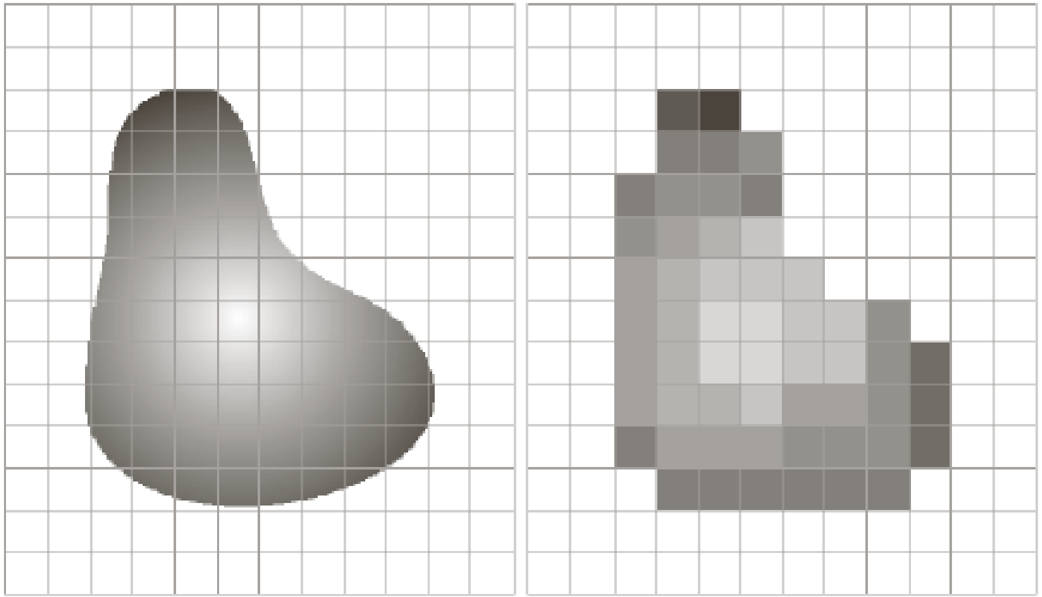
•Aliasing can happen in space, as well as in time. When the pixels in this image are larger than half the width of the bricks, we see these beautiful curved artifacts.



0	0	0	75	75	75	128	128	128	128
0	75	75	75	128	128	128	255	255	255
75	75	75	200	200	200	255	255	255	200
128	128	128	200	200	255	255	200	200	200
128	128	128	255	255	200	200	200	75	75
175	175	175	225	225	225	75	75	75	100
175	175	100	100	100	225	225	75	75	100
75	75	75	35	35	35	0	0	0	35
35	35	35	0	0	0	35	35	35	75
75	75	75	100	100	100	200	200	200	200

- Digitalization of an analog signal involves two operations:
  - Sampling, and
  - Quantization.
- Both operations correspond to a discretization of a quantity, but in different domains.

- Sampling corresponds to a discretization of the space. That is, of the domain of the function, into $f : [1, \ldots, N] \times [1, \ldots, M] \longrightarrow \mathbb{R}^m$.



a b

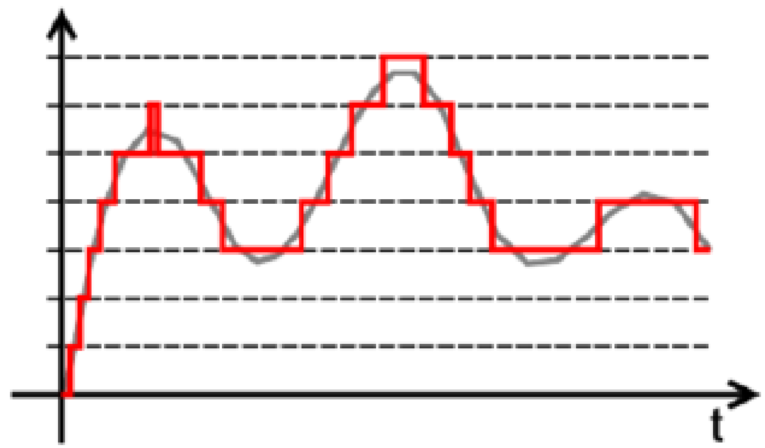
FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

- Thus, the image can be seen as matrix,

$$f = \begin{bmatrix} f(1,1) & f(1,2) & \cdots & f(1,M) \\ f(2,1) & f(2,2) & \cdots & f(2,M) \\ \vdots & \vdots & \ddots & \vdots \\ f(N,1) & f(N,2) & \cdots & f(N,M) \end{bmatrix}.$$

- The smallest element resulting from the discretization of the space is called a pixel (picture element).
- For 3-D images, this element is called a voxel (volumetric pixel).

- Quantization corresponds to a discretization of the intensity values. That is, of the co-domain of the function.



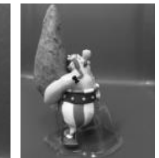
- After sampling and quantization, we get $f : [1, \ldots, N] \times [1, \ldots, M] \longrightarrow [0, \ldots, L]$.

Sampling

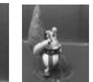
1024

512

256



128



64

32

Sampling


1024

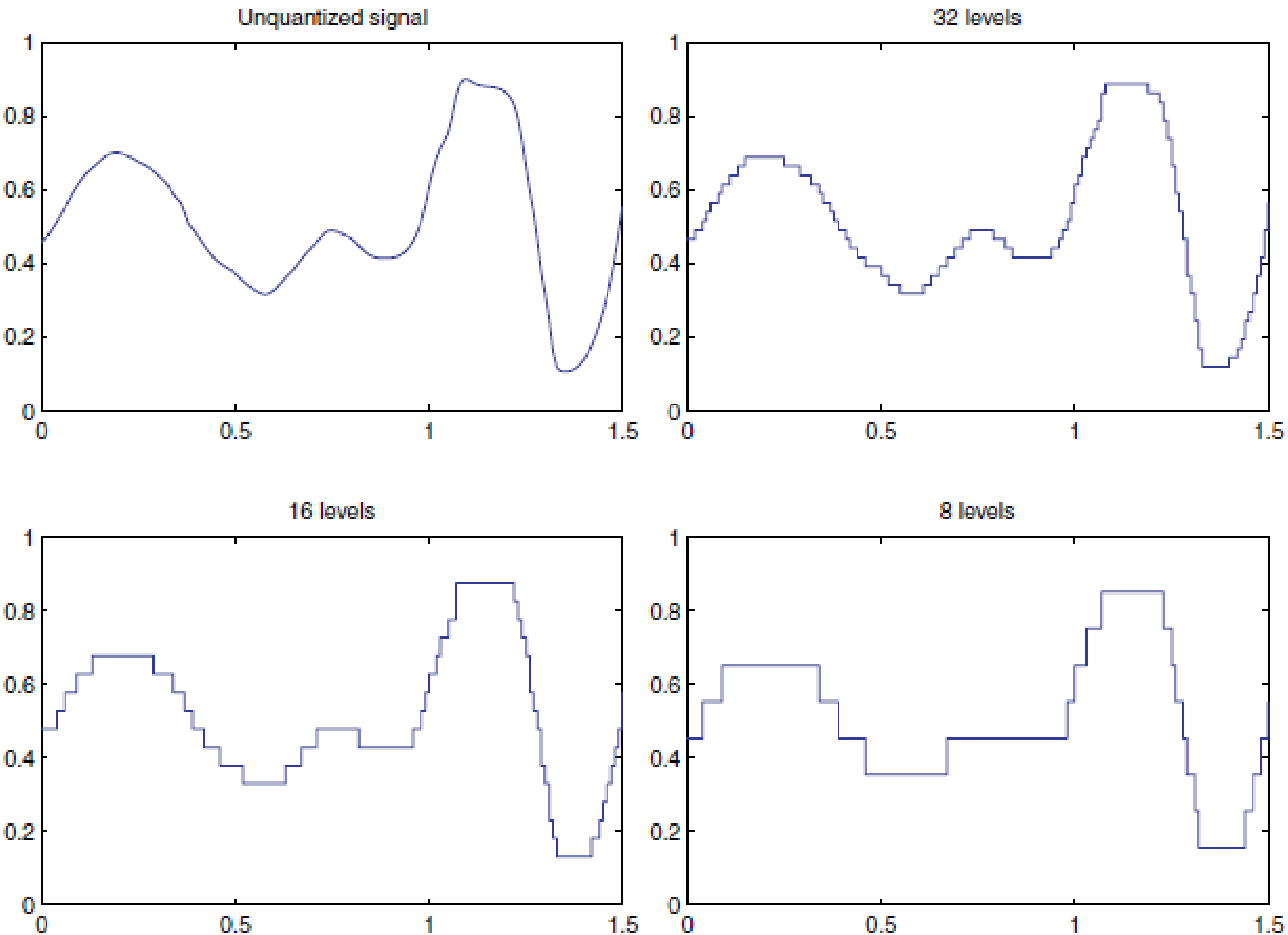

512


256


128


64


32



Unquantized signal
32 levels
16 levels
8 levels
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5

Quantization

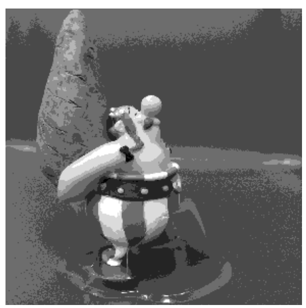
8-bit

7-bit

6-bit

5-bit

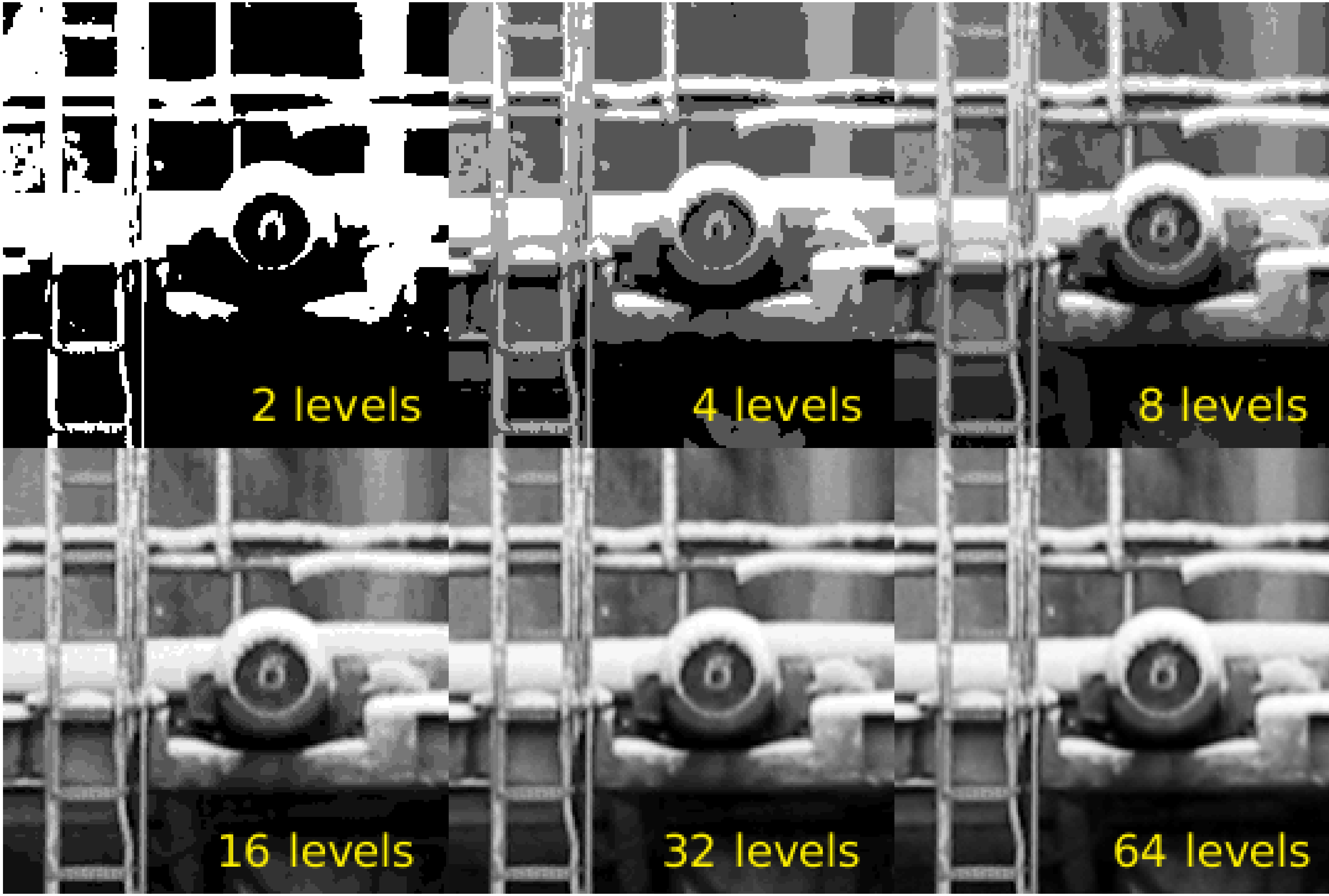
4-bit



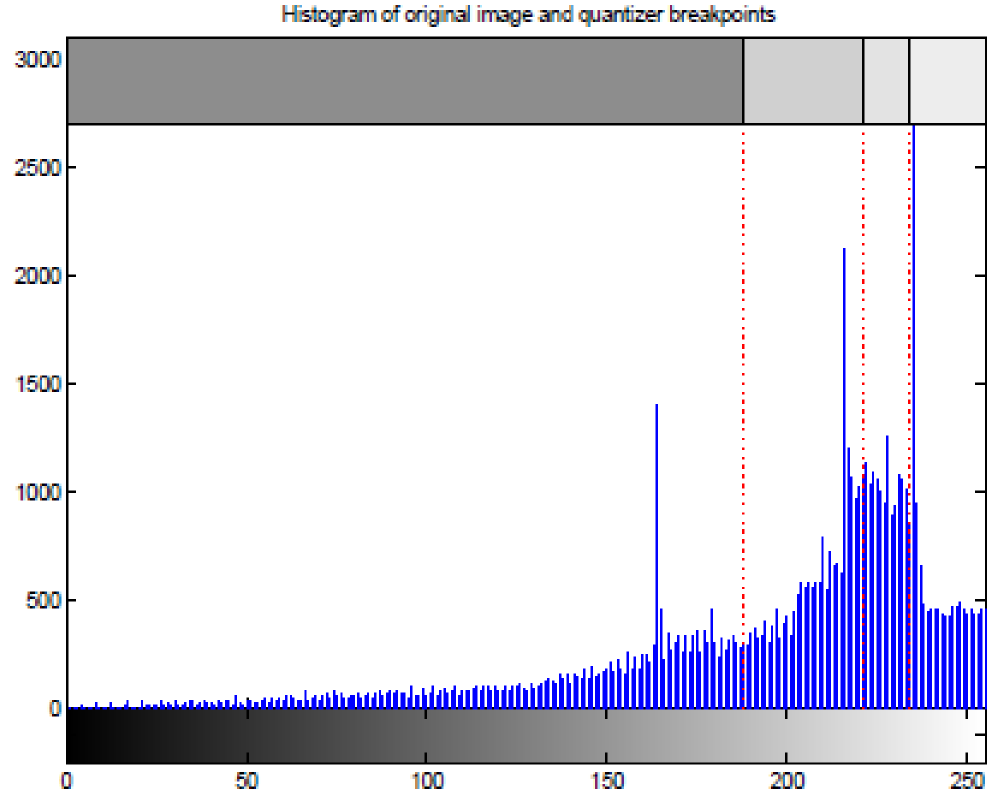
3-bit

2-bit

1-bit


2 levels
4 levels
8 levels
16 levels
32 levels
64 levels

(a)



(b)

Figure 5.15: (a) Original image. (b) Image histogram.

(a) (b)

Figure 5.16: (a) Uniformly quantized image. (b) Non-uniformly quantized image

Matrix form

$$
\begin{bmatrix}
f(0,0) & f(0,1) & \ldots & f(0,N-1) \\
f(1,0) & f(0,1) & \ldots & f(1,N-1) \\
 & & \ldots & \\
 & & \ldots & \\
f(M-1,0) & f(M-1,1) & \ldots & f(M-1,N-1)
\end{bmatrix}_{MxN}
$$

bits to store the image = M x N x k
gray level = 2^k

- We can think of an **image** as a function, *f*, from R^2 to R:
  - $f(x, y)$ gives the **intensity** at position (x, y)

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

- A color image is just three functions pasted together. We can write this as a "vector-valued" function:

$$f(x,y) = \begin{bmatrix} r(x,y) \\ g(x,y) \\ b(x,y) \end{bmatrix}$$