Overview of Digital Signal Processing (DSP)

Signal:

- Anything that conveys information, e.g.,
  - Speech
  - Electrocardiogram (ECG) (心電圖)
  - Radar pulse
  - DNA sequence
  - Stock price
  - Code division multiple access (CDMA) signal
  - Image
  - Video

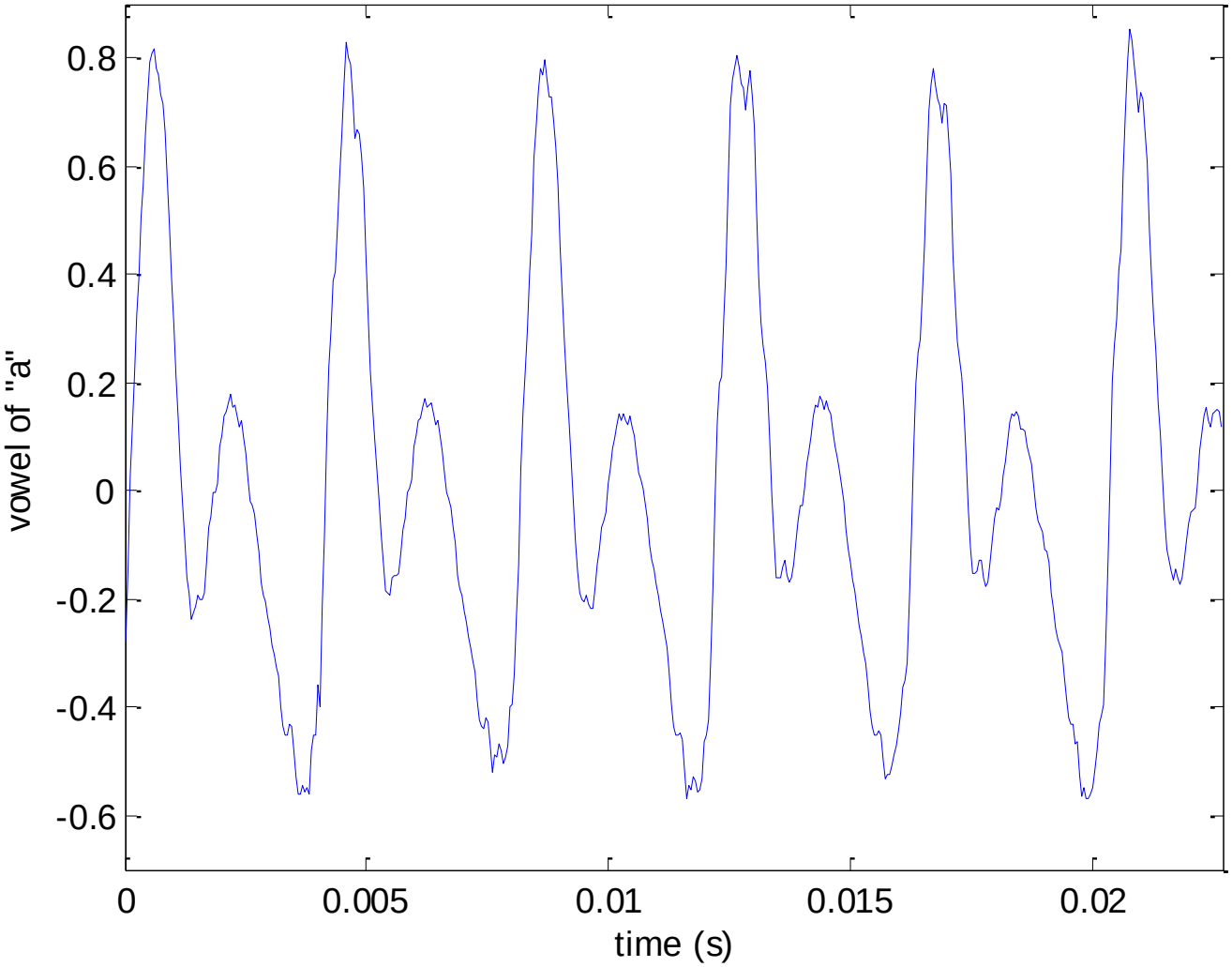

Fig.1.1: Speech

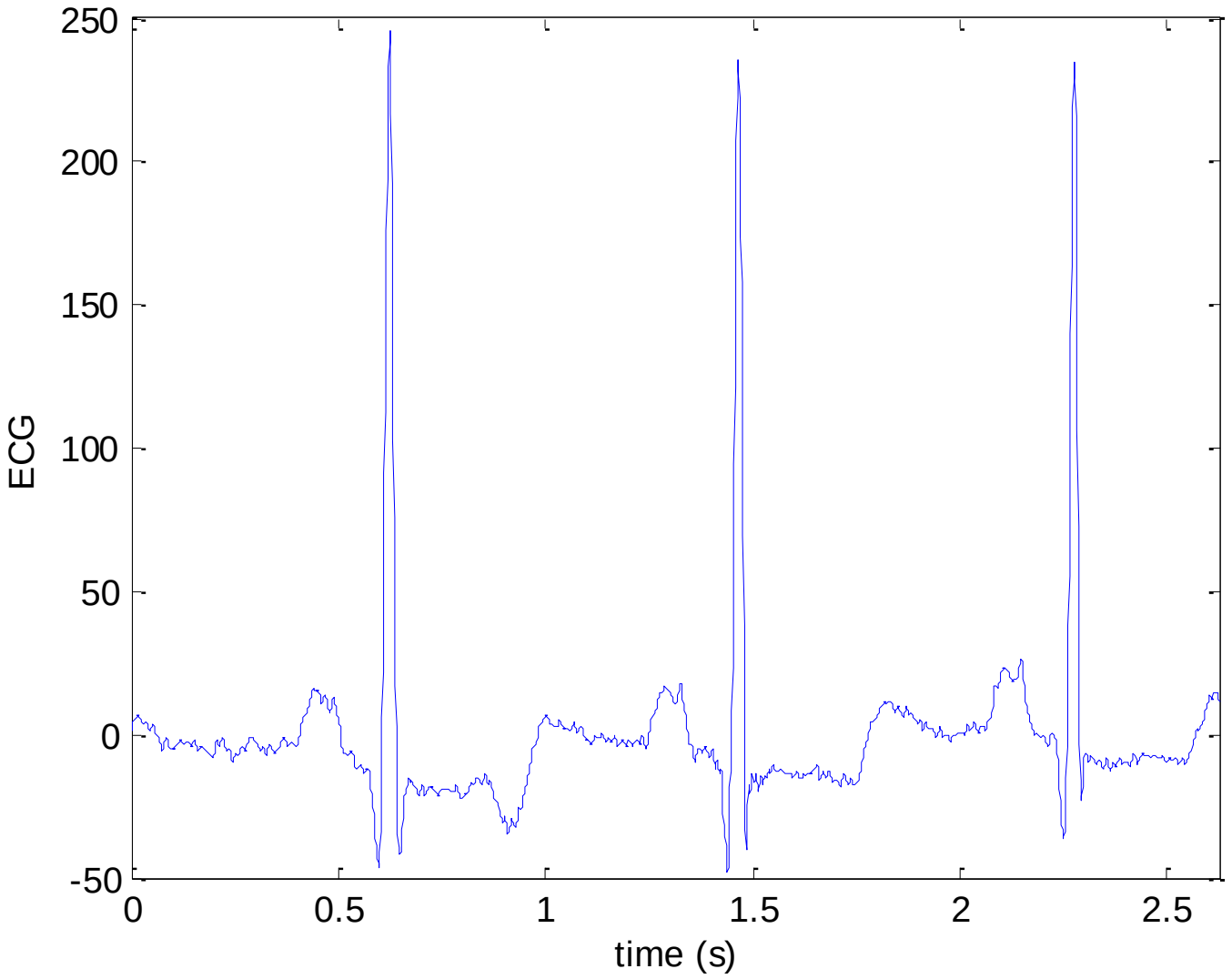

Fig.1.2: ECG

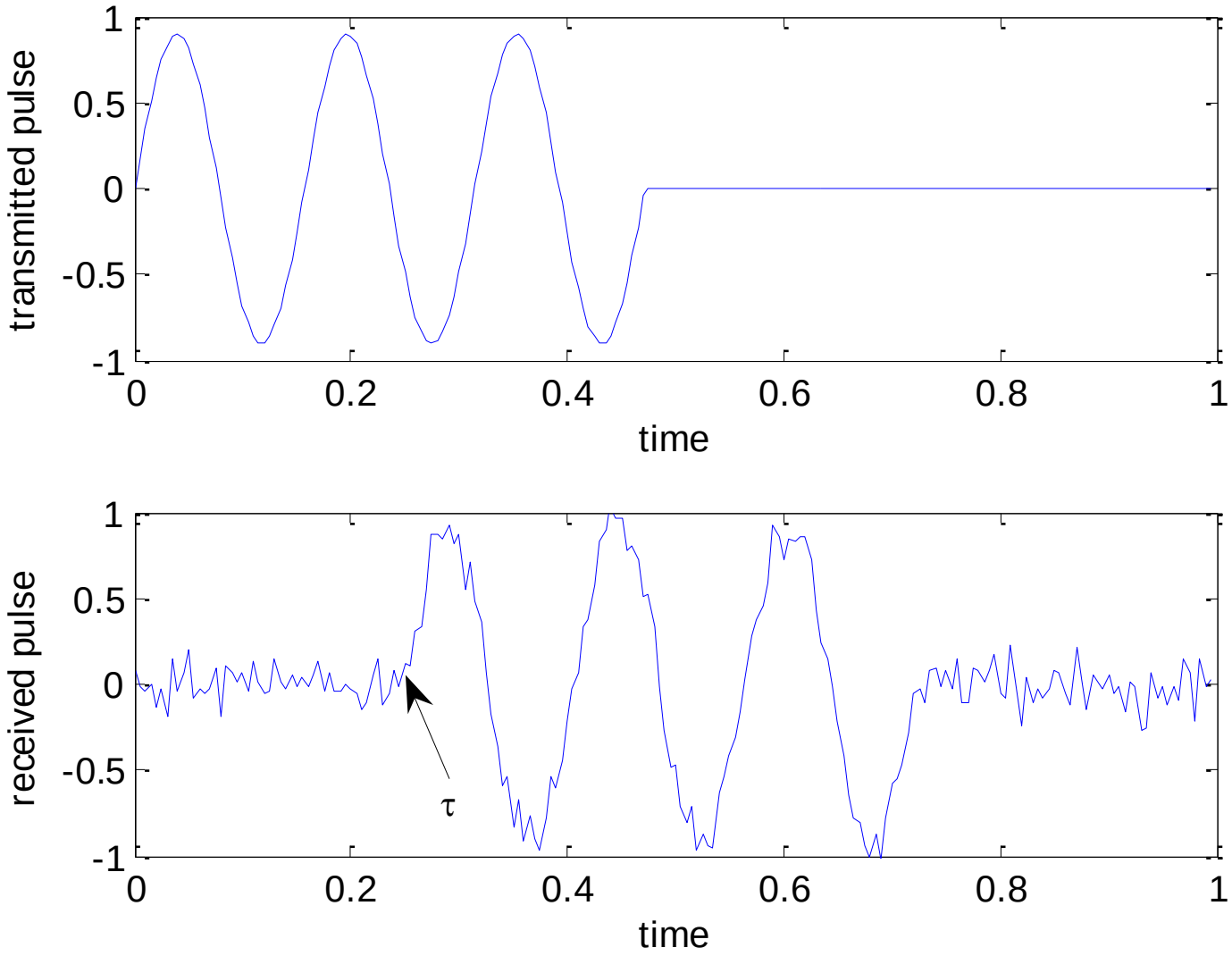

Fig.1.3: Transmitted & received radar waveforms

Radar transceiver sends a 1-D sinusoidal pulse at time 0

It then receives echo reflected by an object at a range of R

Reflected signal is noisy and has a time delay of τ which corresponds to round trip propagation time of radar pulse

Given the signal propagation speed, denoted by c, τ is simply related to R as:

$$\tau = \frac{2R}{c} \tag{1.1}$$

As a result, the radar pulse contains the object range information

- Can be a function of one, two or three independent

variables, e.g., speech is 1-D signal, function of time; image is 2-D, function of space; wind is 3-D, function of latitude, longitude and elevation

- 3 types of signals that are functions of time:
  - Continuous-time (analog) $x(t)$: defined on a continuous range of time t, amplitude can be any value
  - Discrete-time $x(nT)$: defined only at discrete instants of time $t = \cdots -T, 0, T, 2T, \cdots$, amplitude can be any value
  - Digital (quantized) $x_Q(nT)$: both time and amplitude are discrete, i.e., it is defined only at $t = \cdots -T, 0, T, 2T, \cdots$ and amplitude is confined to a finite set of numbers

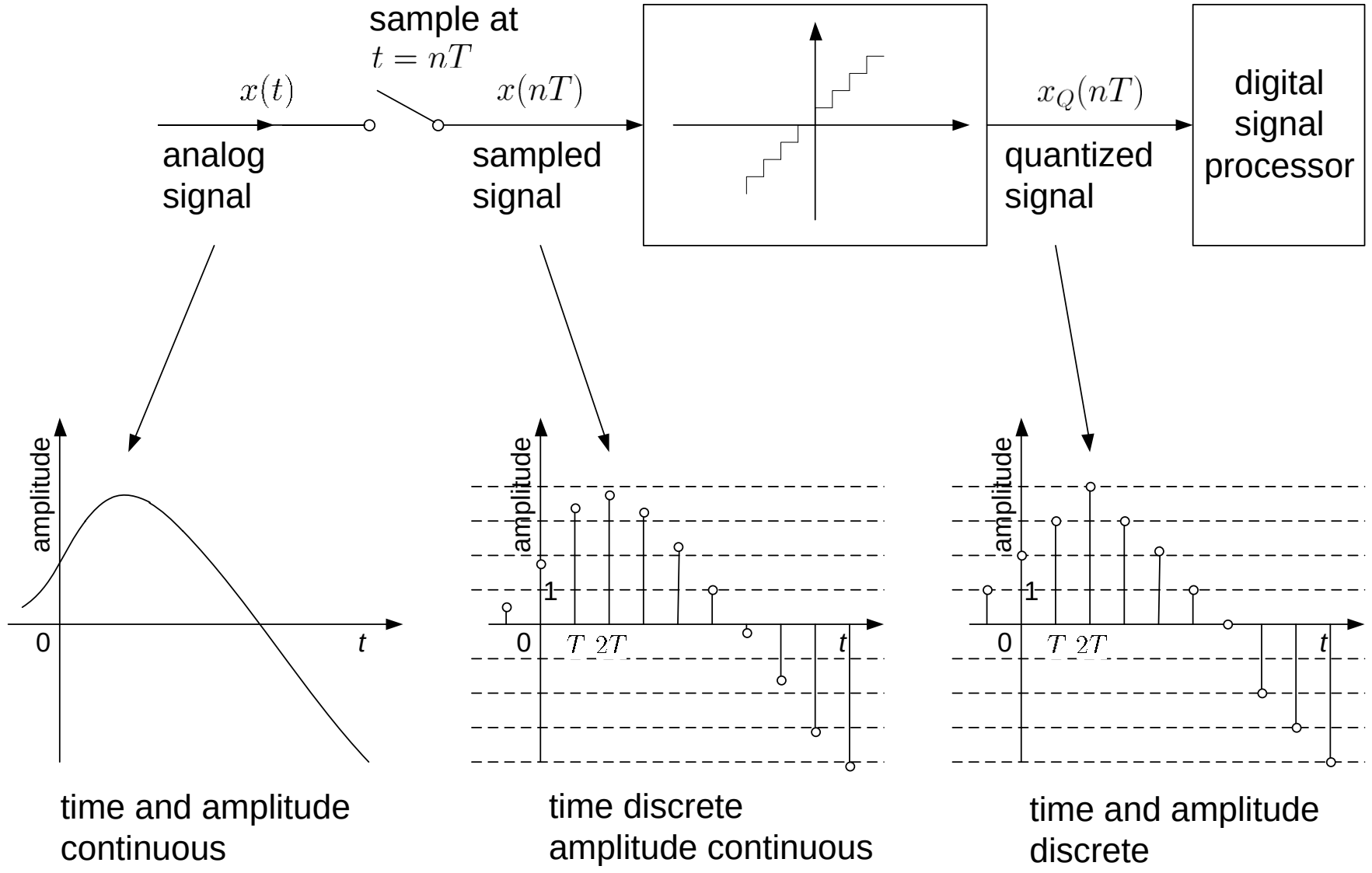

Fig. 1.4: Relationships between $x(t)$, $x(nT)$ and $x_Q(nT)$

$x(nT)$ at $n = 0$ is close to 2 and $x_Q(0) = 2$

$x(nT) \in (3, 4)$ at $n = 1$ and $x_Q(T) = 3$

Using 4-bit representation, $x_Q(0) = 0010$ and $x_Q(T) = 0011$, and in general, the value of $x_Q(nT)$ is restricted to be an integer between -8 and 7 according to the two's complement representation.

In DSP, we deal with $x_Q(nT)$ as it corresponds to computer-based processing. Throughout the course, it is assumed that discrete-time signal = digital signal, or the quantizer has infinite resolution

System:

- Mathematical model or abstraction of a physical process that relates input to output, e.g.,
  - Grading system: inputs are coursework and examination marks, output is grade
  - Squaring system: input is 5, then the output is 25
  - Amplifier: input is $\cos(\omega t)$, then output is $10\cos(\omega t)$
  - Communication system: input to mobile phone is voice, output from mobile phone is CDMA signal
  - Noise reduction system: input is a noisy speech, output is a noise-reduced speech
  - Feature extraction system: input is $\cos(\omega t)$, output is ω
- Any system that processes digital signals is called a digital system, digital filter or digital (signal) processor

Processing:

- Perform a particular function by passing a signal through system

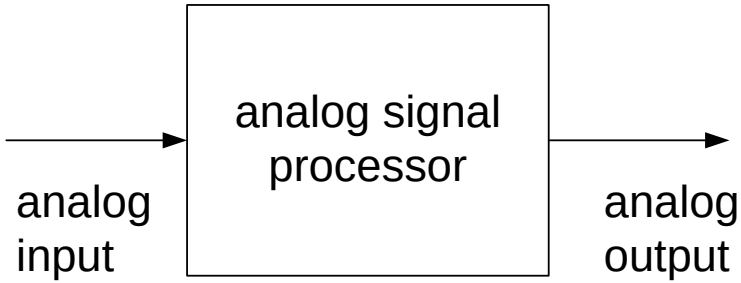

Fig.1.5: Analog processing of analog signal

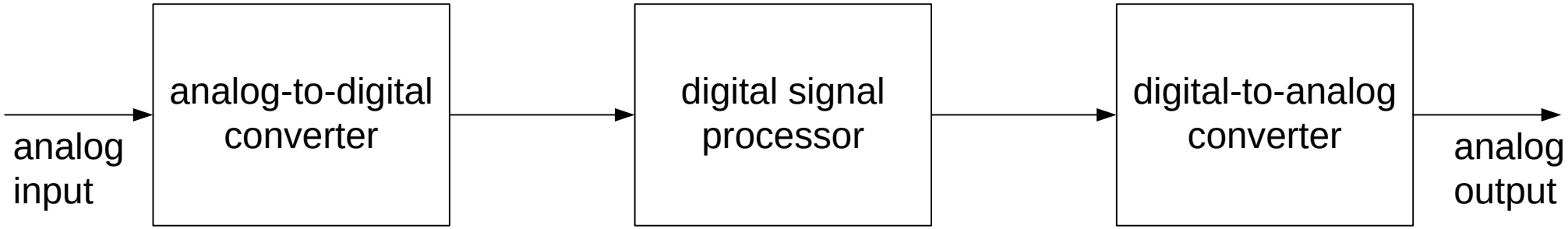

Fig.1.6: Digital processing of analog signal

Can you identify the systems in Fig.1.4 and Fig.1.6? What are they?

Advantages of DSP over Analog Signal Processing

- Allow development with the use of PC, e.g., MATLAB
- Allow flexibility in reconfiguring the DSP operations simply by changing the program
- Reliable: processing of 0 and 1 is almost immune to noise and data are easily stored without deterioration
- Lower cost due to advancement of VLSI technology
- Security can be introduced by encrypting/scrambling
- Simple: additions and multiplications are main operations

DSP Application Areas

- Speech
  - Compression (e.g, LPC is a coding standard for compression of speech data)
  - Synthesis (computer production of speech signals, e.g., text-to-speech engine by Microsoft)
  - Recognition (e.g., PCCW's 1083 telephone number enquiry system)
  - Enhancement (e.g., noise reduction for a noisy speech)
- Audio
  - Compression (e.g., MP3 is a coding standard for compression of audio data)

- Generation of music by different musical instruments such as piano, cello, guitar and flute using computer
- Song with low-cost electronic piano keyboard quality
- Automatic music transcription (writing a piece of music down from a recording)

- Image and Video
  - Compression (e.g., JPEG and MPEG is are coding standards for image and video compression, respectively)
  - Recognition such as face, palm and fingerprint

- Enhancement

- Construction of 3-D objects from 2-D images
- Animation, e.g., “Avatar (阿凡達)”

- Communications: encoding and decoding of digital communication signals
- Astronomy: finding the periods of orbits
- Biomedical Engineering: medical care and diagnosis, analysis of ECG, electroencephalogram (EEG), nuclear magnetic resonance (NMR) data
- Bioinformatics: DNA sequence analysis
- Finance: algorithmic trading system design