



SI100 – Introduction to Information Science and Technology

Signal & Image

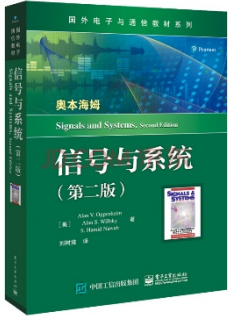
郑锐 Zheng Rui (助理教授/研究员)

上海科技大学信息科学与技术学院

E-mail: zhengrui@shanghaitech.edu.cn

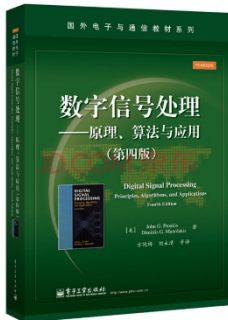
地址：信息学院大楼3号楼426

Reference book



Signal and System, 2nd Edition

AUTHORS: Alan V. Oppenheim, Alan S. Willsky, S. Hamid Nawab



Digital Signal Processing - Principles, Algorithms and Application, 4th Edition

AUTHORS: John G. Proakis, Dimitris G. Manolakis



Digital Image Processing, 3rd Edition

AUTHOR: Rafael C. Gonzalez & Richard E. Woods

Example : Ref: SS Ch1.1-1.2, DSP Ch1.1-1.2

Outline

➤ **Week 1-2 : Signal Acquisition & Processing**

- Definition, Types, Acquisition, ADC, LTI system, Convolution, Noise;

➤ **Week 3-4 : Frequency Domain & Spectrum**

- Sampling, DFT, Frequency spectrum, Filtering,

➤ **Week 5-6 : Concept of Digital Image**

- Image characteristics, Basic operation, Interpolation, Color;

➤ **Week 7-8 : Digital image processing**

- Enhancement, Filtering, Segmentation

Goal

- To know the definition of digital signal and image;
- To understand time/space/frequency domain
- To know some basic operations
- To be able to apply the common processing method

Assessment

➤ Homework (70%)

- Content: digital signal (50%); digital image(50%).
- Optional (20%) : more difficult, no Q&A

➤ Quiz (30%)

➤ Programming language

- Python;
- Matlab (optional)

➤ 学术规范

- 独立完成作业和Quiz
- 如发现作业抄袭，第一次抄袭与被抄袭者该次作业零分；第二次抄袭与被抄袭者该次作业零分，总成绩减半计入
- 如发现Quiz作弊，第一次本次quiz计零分；第二次本次quiz计零分，总成绩减半计入；三次以上总成绩计零分

Why to learn

Commonly known

sound

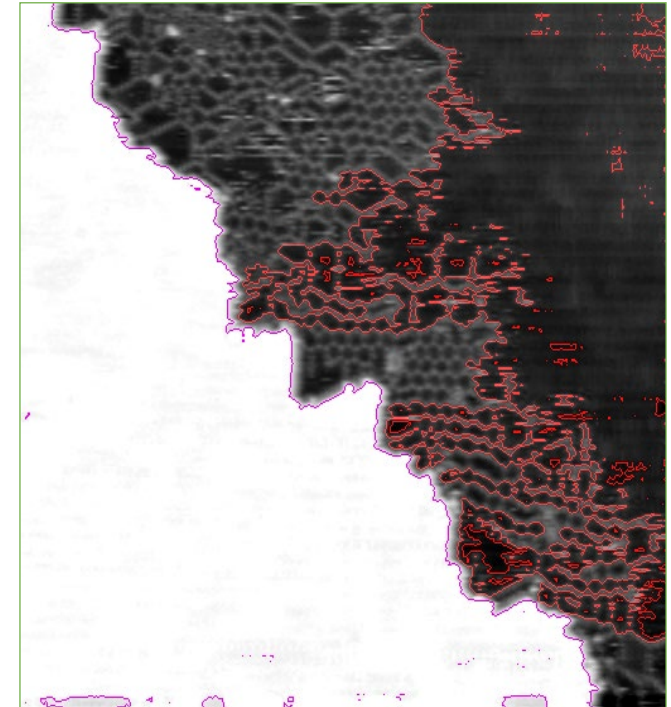
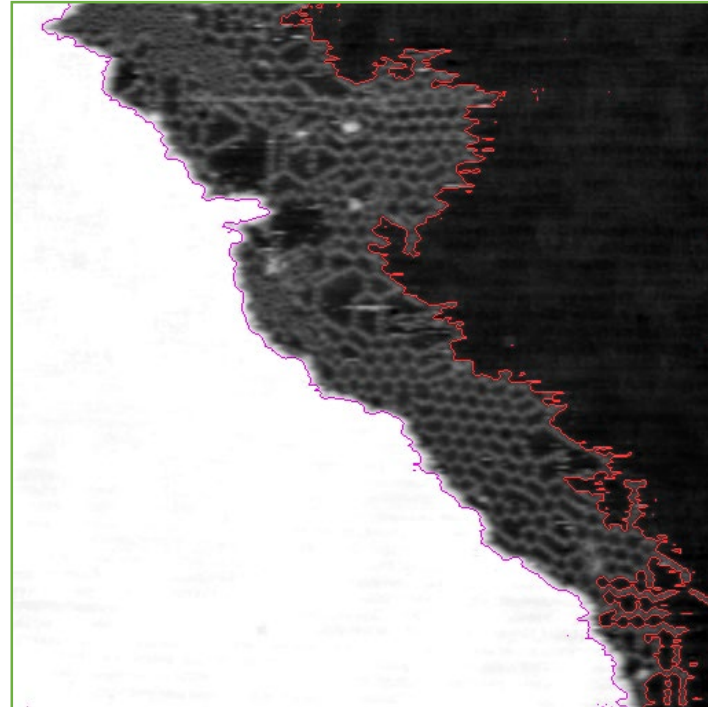
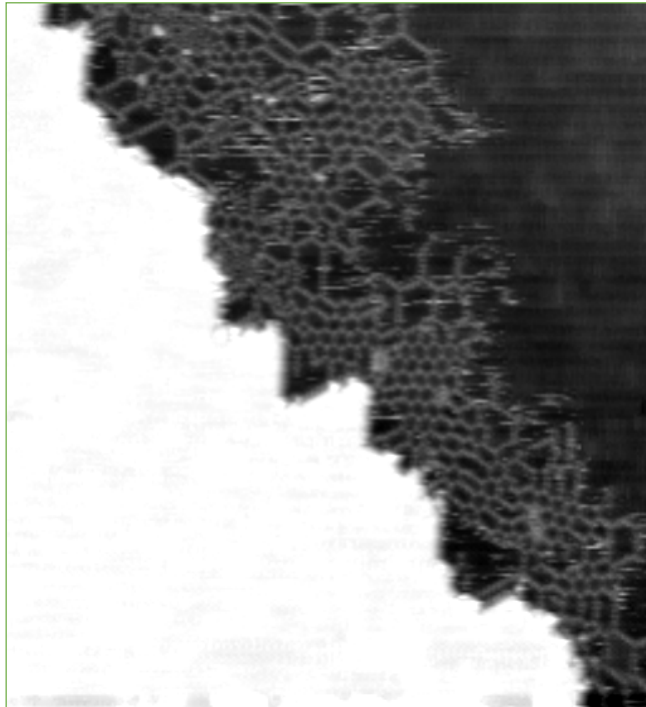


Photo



Why to learn

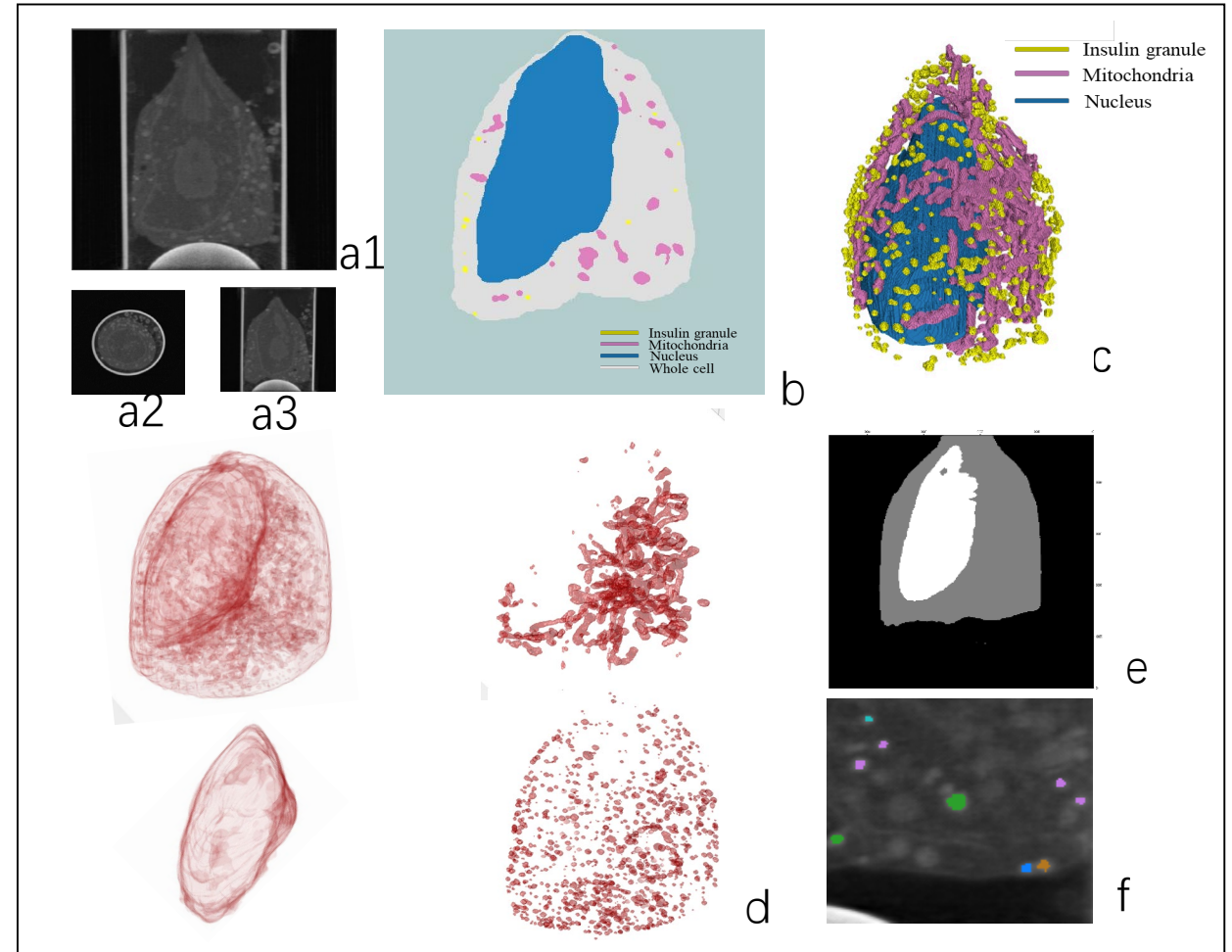
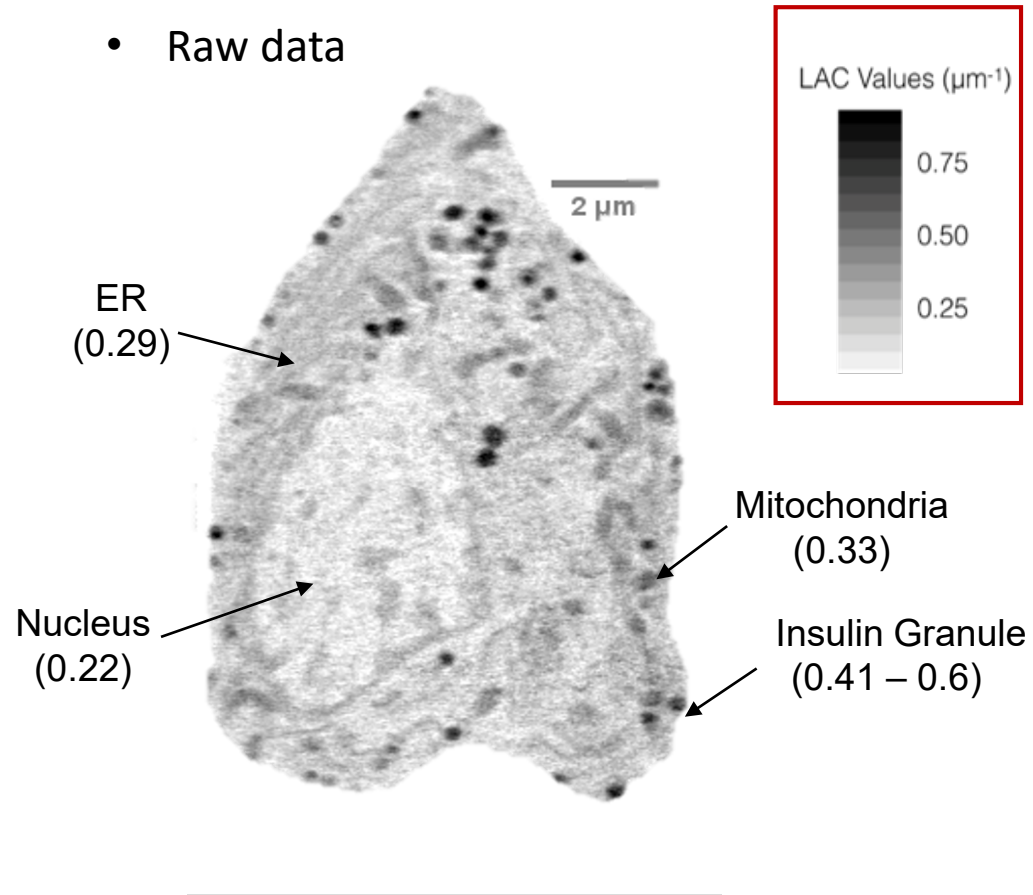
STM (scanning tunneling microscope) Image Processing



Why to learn

Soft X-ray tomography (SXT)

- Raw data



Part 1 – Signal Acquisition

This lecture will cover:

- Introduction to the **signal acquisition system**
- **Sensor** – *from events to electronics*
- What is the **signal** ?
- **ADC** – *from analog to digital*
- Introduction to **digital signal processing**
 - Linear time-invariant (LTI) system
 - Convolution
 - Degradation of system

From Real to Virtual

- Acquisition (采集)
 - electrical signal
 - Non-electric signal
- Processing (处理)
 - Analog processing
 - Analog to digital converter (A/D)
 - Digital signal processing
- Output (输出)
 - Display
 - Storage
 - Transmission
- Control (控制)
 - Calibration
 - Control & Feedback

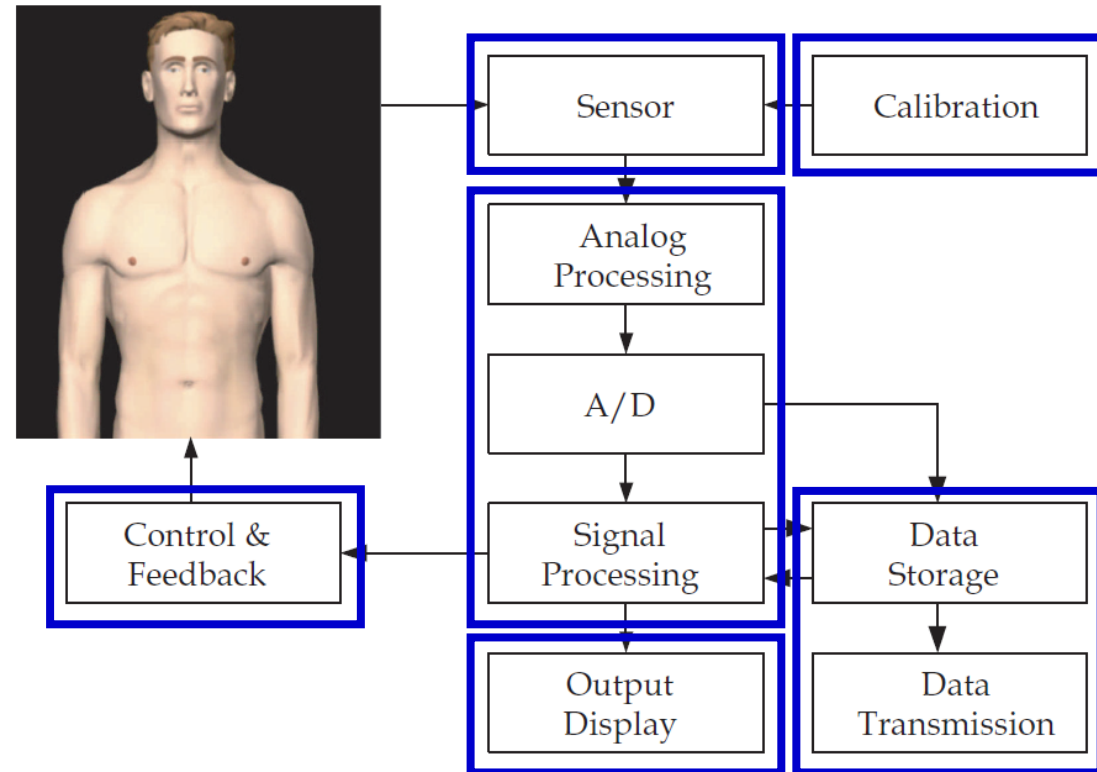


FIGURE 2.1: Basic instrumentation systems using sensors to measure a signal with data acquisition, storage and display capabilities, along with control and feedback.

Sensor (传感器)

- A device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics.
- Electrodes (电极) and transducers (换能器) are often grouped together and termed **sensors**.
- Sensor Classifications
 - Electrical sensors
 - Physical sensors
 - Chemical sensors
 - Biosensors

Implantable, wearable, wireless sensors, etc.

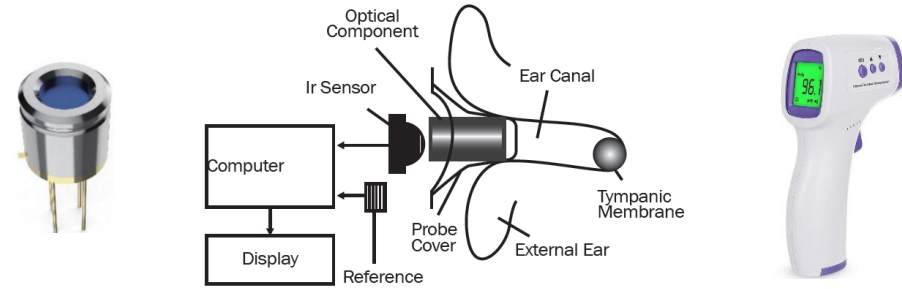


Fig 1. Infrared thermometer

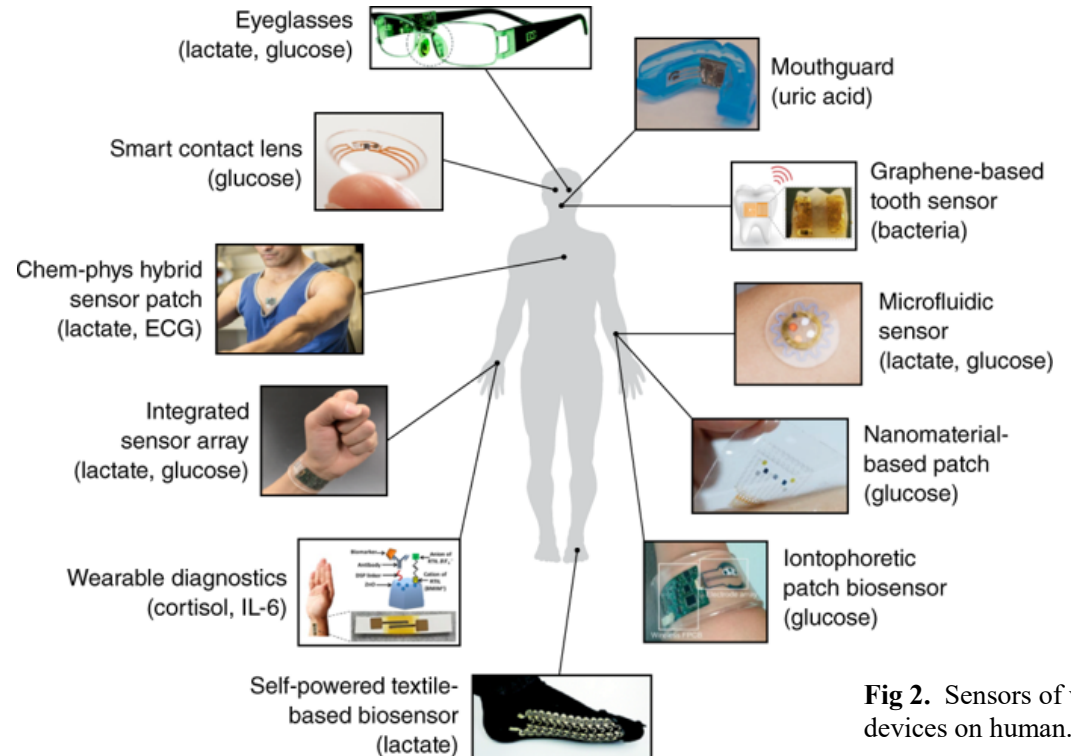


Fig 2. Sensors of wearable devices on human.

Signal

➤ What is a signal?

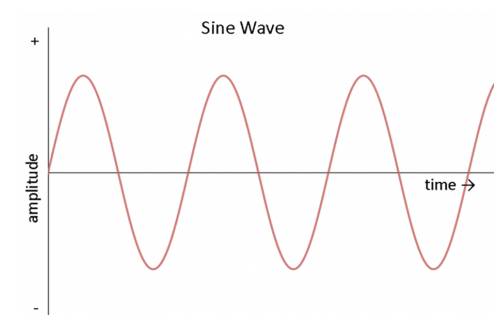
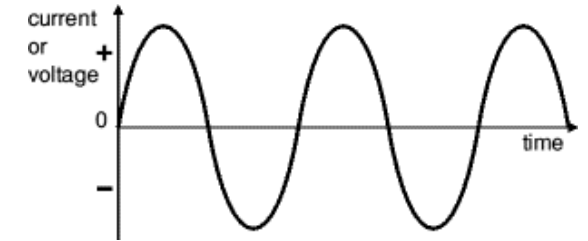
- **In Real World** - the change with independent parameters such as time, distance, position, temperature, pressure, etc.
- **In Mathematics** – a functions of one or more independent variables.

➤ Characterization

- **Amplitude(幅值)** - the value of a signal at a specific value of the variable.
- **Waveform(波形)** – the variation of the amplitude as a function of the variable.

➤ Classifications

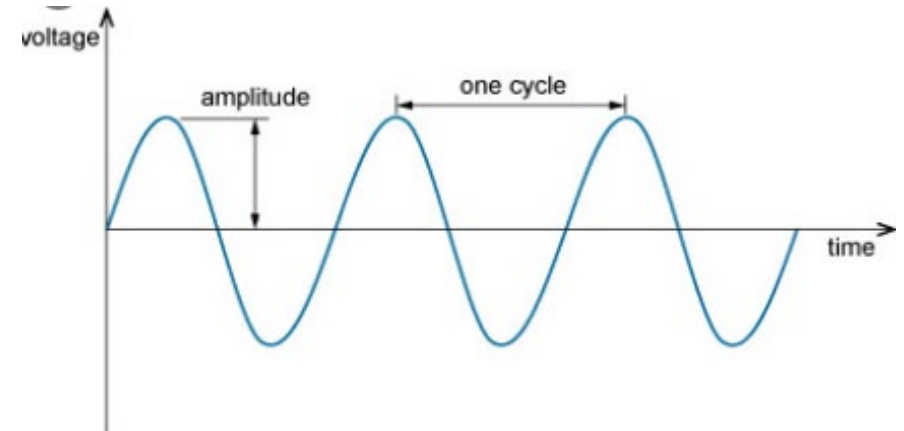
- Deterministic vs Random: *a completely specified function or not*
- Continuous vs Discrete: *depending on the independent variable*
- Real-valued vs Complex-valued : *depending on the function defining the signal*
- 1-D vs. M -D: *1 independent variable or M independent variables*
- Single-channel vs. M -channel: *1 amplitude or M amplitudes*
- etc.



Deterministic vs Random

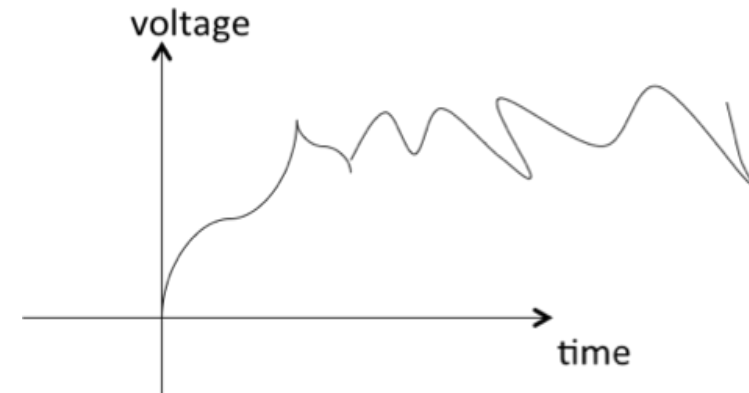
➤ **Deterministic signal (确定信号)**

- no uncertainty with respect to its value at any instant of time or variables
- In mathematics, a completely specified function defined by one or more independent variables



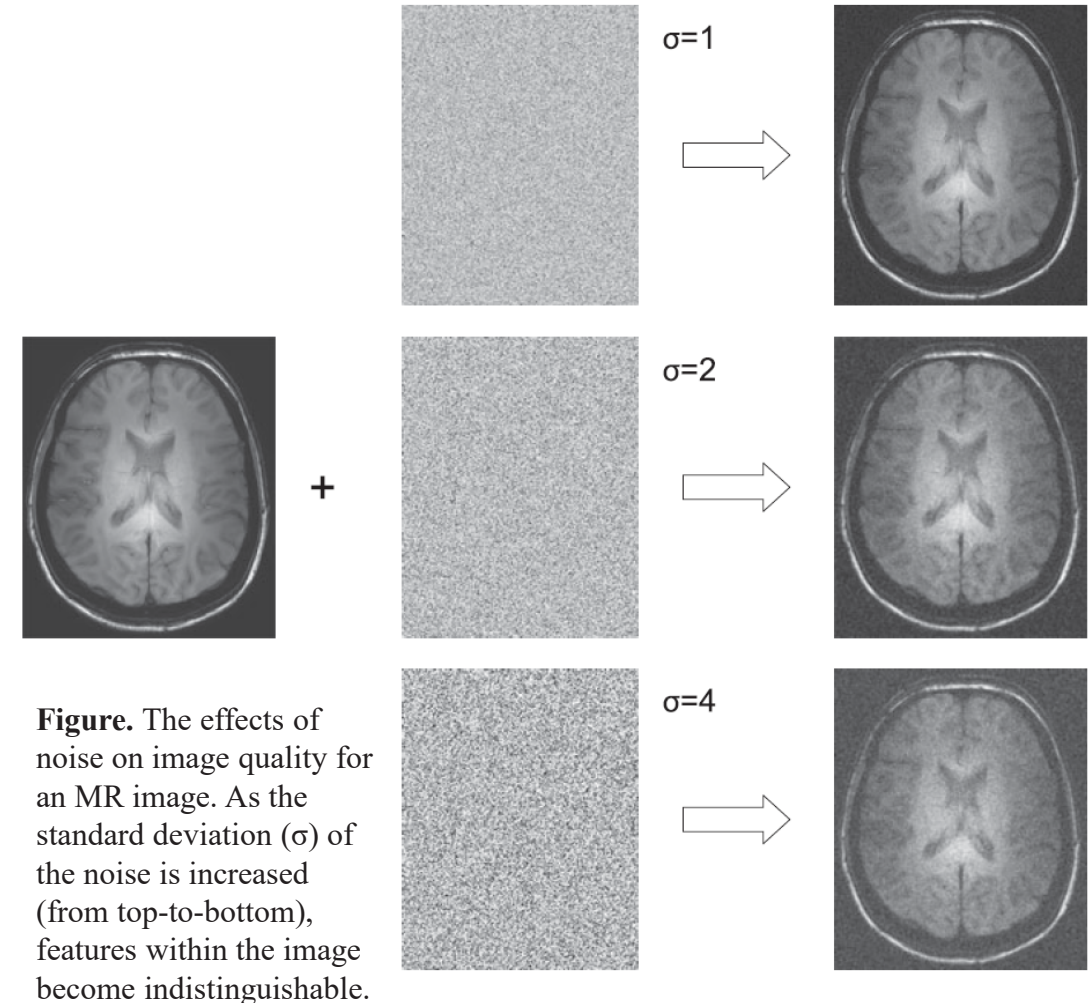
➤ **Random/Stochastic signal (随机信号)**

- influenced by a number of uncontrolled factors
- cannot be described by a mathematical equation and modelled in probabilistic terms



Noise

- **Definition:** any recorded signal not related to the actual signal that one is trying to measure.
- **Properties**
 - Mostly random;
 - Mostly independent of input variables;
 - Mean is zero, quantitative measure of noise is conventionally the standard deviation.
- **Classification**
 - **Distribution properties** - characteristics of noise
 - ✓ Gaussian, Rayleigh, Gamma, Exponential, Impulse...
 - **Frequency properties** – frequency content of noise
 - ✓ White noise
 - ✓ Periodic noise



Gaussian Noise (高斯噪声)

Image intensity of noise at each pixel

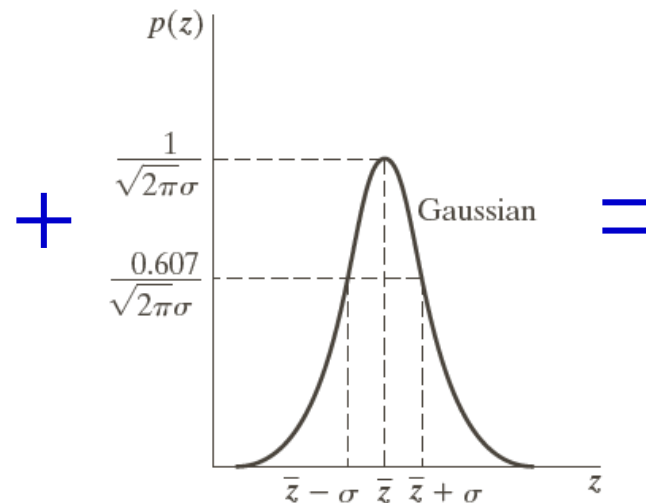
Mathematical distribution:
$$p(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(z-\bar{z})^2}{2\sigma^2}}$$

$\bar{z}$: mean (average) σ : standard deviation σ^2 : variance

Signal



Noise

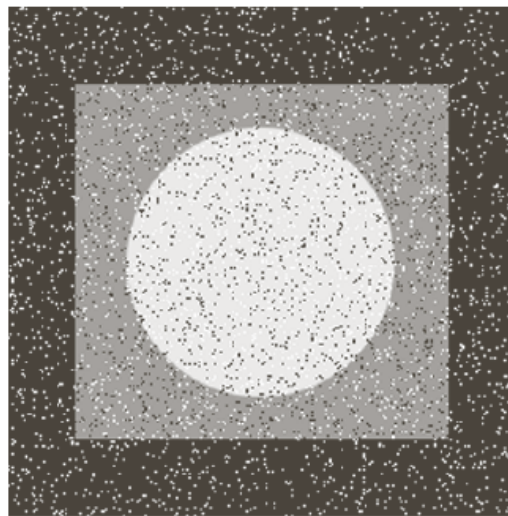
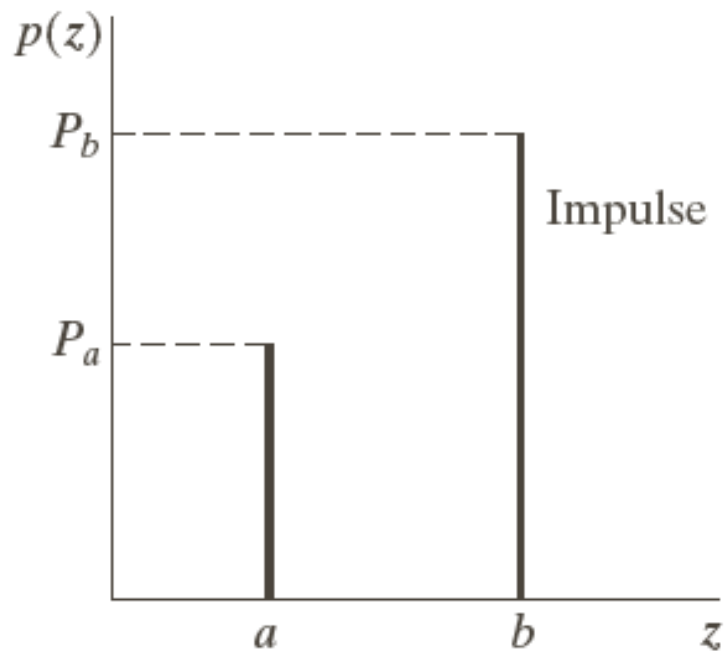


Impulse (salt-and-pepper) Noise (脉冲/椒盐噪声)

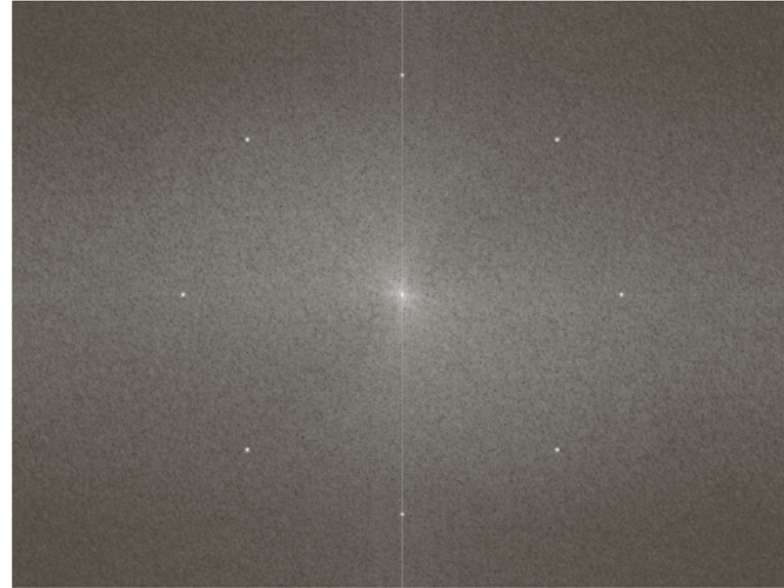
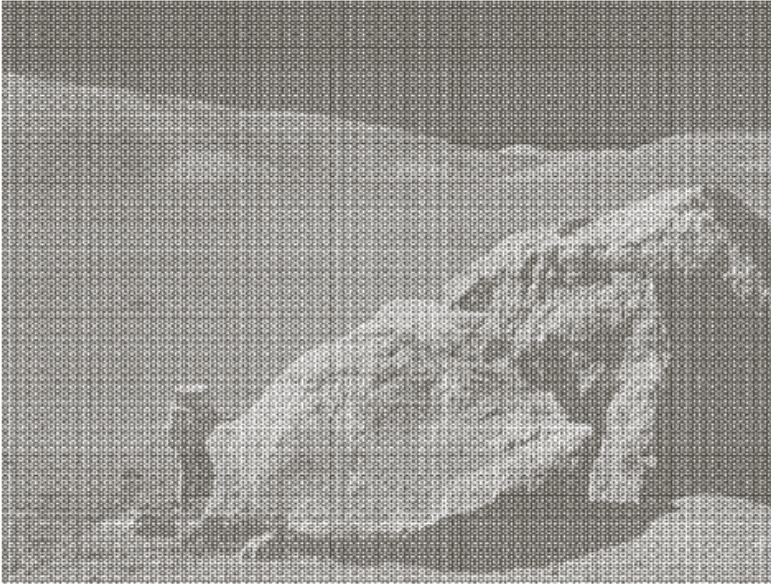


Impulse (salt-and-pepper) Noise (脉冲/椒盐噪声) :

$$p(z) = \begin{cases} P_a, & \text{for } z = a \\ P_b, & \text{for } z = b \\ 1 - P_a - P_b, & \text{otherwise} \end{cases}$$



Periodic Noise (周期噪声)

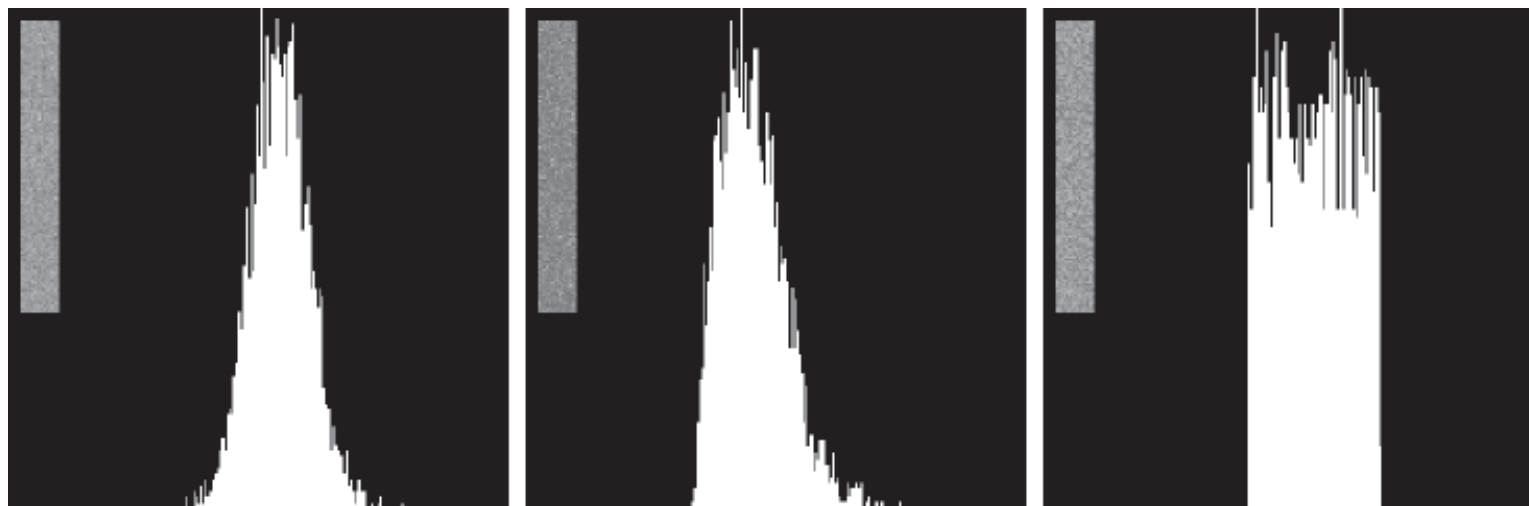


Estimation of Noise Parameter (噪声参数估计)



$$\text{Mean: } \bar{z} = \sum_{i=0}^{L-1} z_i P_s(z_i)$$

$$\text{Variance: } \sigma^2 = \sum_{i=0}^{L-1} (\bar{z} - z_i)^2 P_s(z_i)$$



a b c

FIGURE 5.6 Histograms computed using small strips (shown as inserts) from (a) the Gaussian, (b) the Rayleigh, and (c) the uniform noisy images in Fig. 5.4.

Signal-to-noise ratio (SNR)

- To compare the level of a desired signal to the level of background noise
- **Signal-to-noise ratio (SNR, 信噪比)**

$$\text{SNR} = \sqrt{\frac{P_s}{P_n}} = \sqrt{\frac{E(S^2)}{\sigma^2}} = \frac{\sqrt{E(S^2)}}{\sigma}$$

Where

P_s : Power density spectrum of signal

P_n : Power density spectrum of noise

E : Autocorrelation functions

- Increase SNR by factor of $\sqrt{N}$ by repeating scan numbers (Averaging)

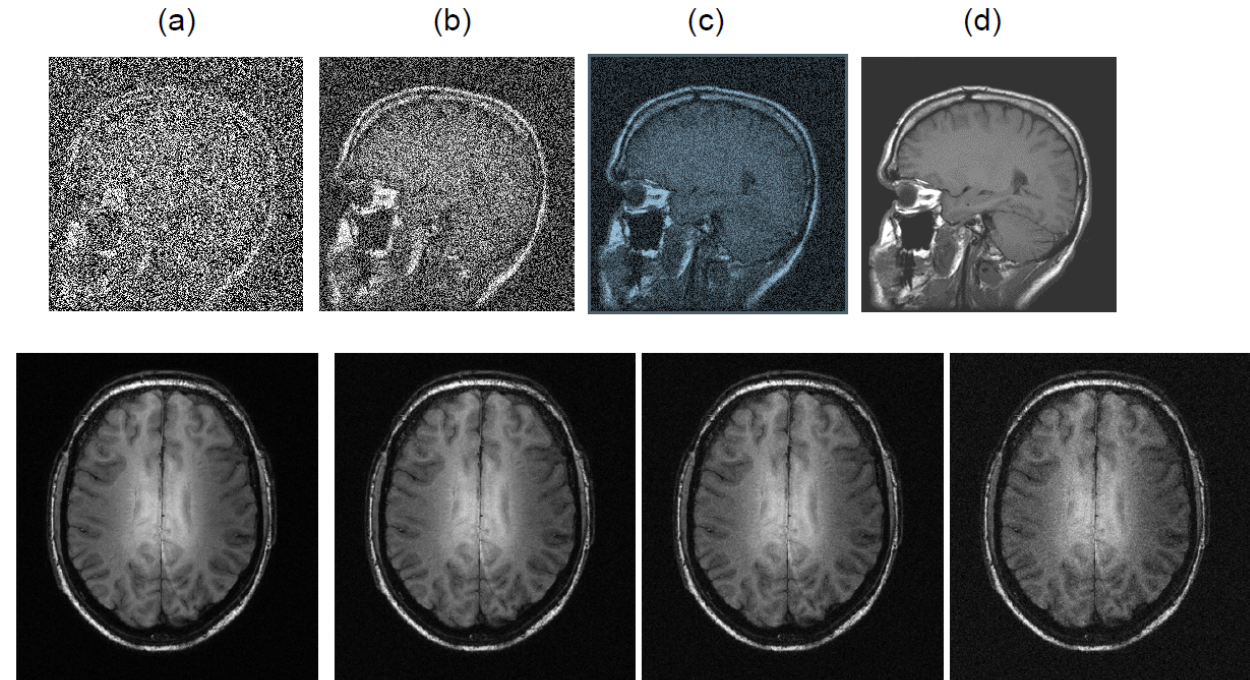
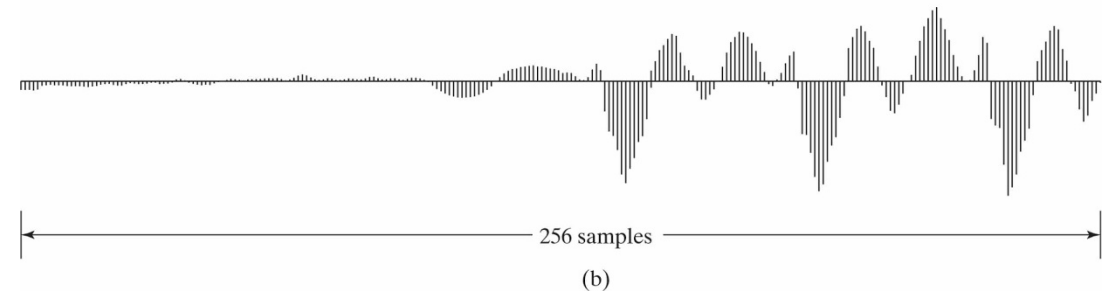
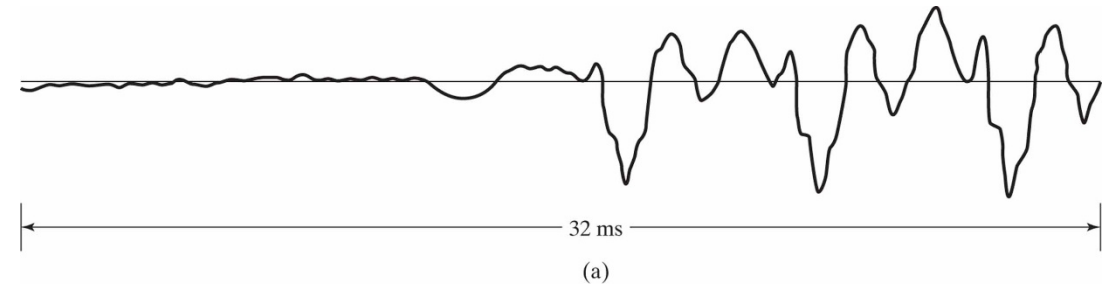


Figure. Signal averaging to improve the image SNR. (a) MR image acquired in a single scan, (b) two identical scans averaged together, (c) four scans, and (d) sixteen scans.

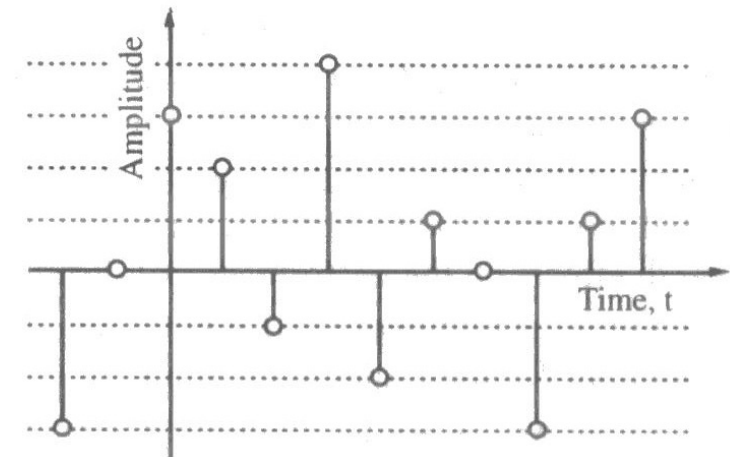
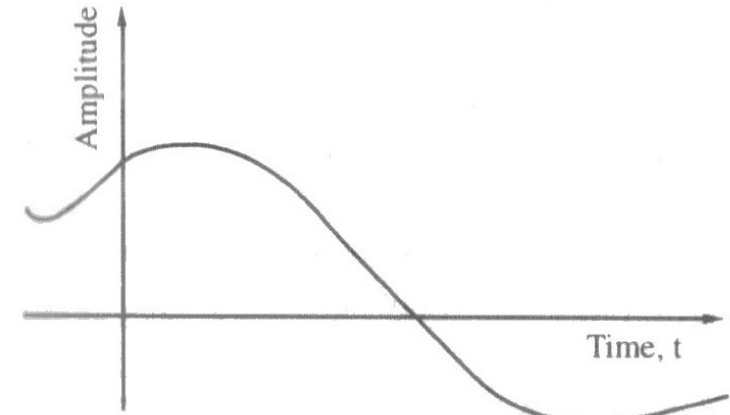
Continuous vs Discrete

- If the independent variable is continuous, the signal is called a **continuous signal** (连续信号)
 - defined at **every instant** of time
- If the independent variable is discrete, the signal is called a **discrete signal** (离散信号)
 - defined at **discrete instants** of time
 - **not defined** in between the time instants



Analog vs Digital

- Analog signal
 - **Continuous-time** signal with **continuous-valued** amplitude
 - Most of the natural signals are analog
- Digital signal
 - **Discrete-time** signal with **discrete-valued** amplitude
 - A digital signal is a **quantized sampled**-data signal



From Analog to Digital

➤ Sampling (采样/取样/抽样)

- Digitizing in the **independent variables**:

$$x[n] = \sum_{k=-\infty}^{\infty} x[k]\delta[n-k]$$

- Resolution: sampling rate/frequency/interval...

$$\text{sampling frequency} = \frac{1}{\text{sampling interval}}$$

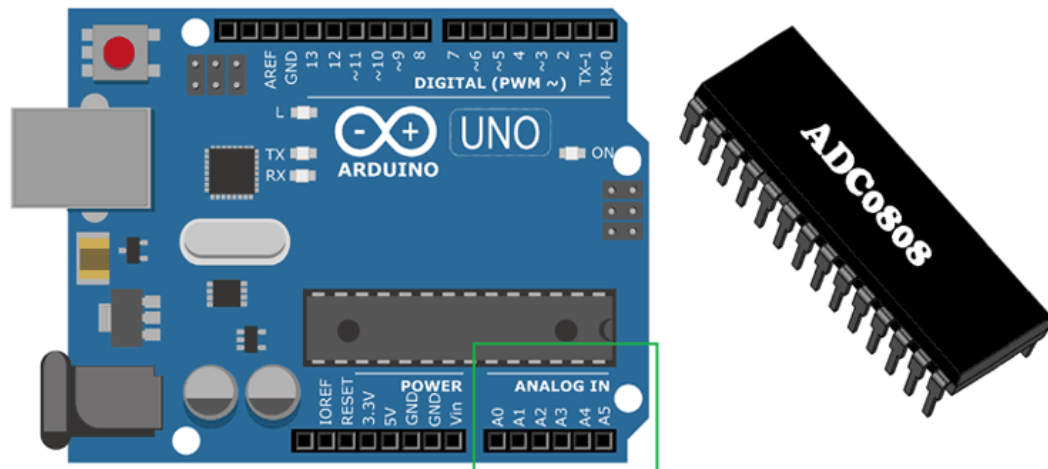
➤ Quantization (量化)

- Digitizing in the **amplitude** : by the different level
- Resolution: bit/level/measuring unit...

➤ Analog-to-Digital Converter (A/D, ADC)

ADC

- A system that converts an analog signal into a digital signal;
- The output is relative amplitudes;
- Typically the digital output is a two's complement binary number that is proportional to the input.



Ref: DSP Ch1.4, Ch6.1-6.3

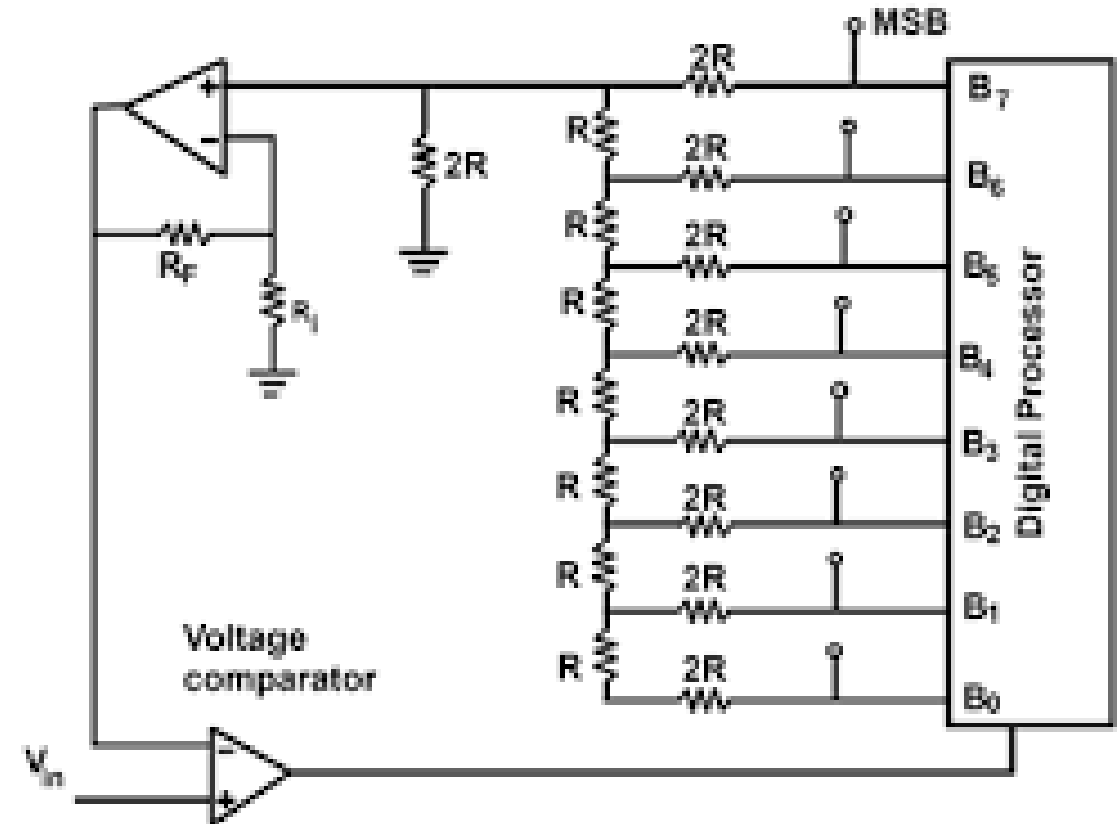


Figure. Successive Approximate ADC.

ADC

➤ Dynamic Range (动态范围)

- Amplitude level
- Measured in bits : $N \text{ bits} \sim 2^N \text{ levels (dB)}$
- Resolution: difference between levels, related to the input range

➤ Quantization Error (量化误差)

- The difference between the true analogue input signal and the digitized output.
- Lie between 0 and $\pm 1/2$ of the ADC resolution

➤ Bandwidth(带宽)

➤ Signal to Noise Ratio(SNR, 信噪比)

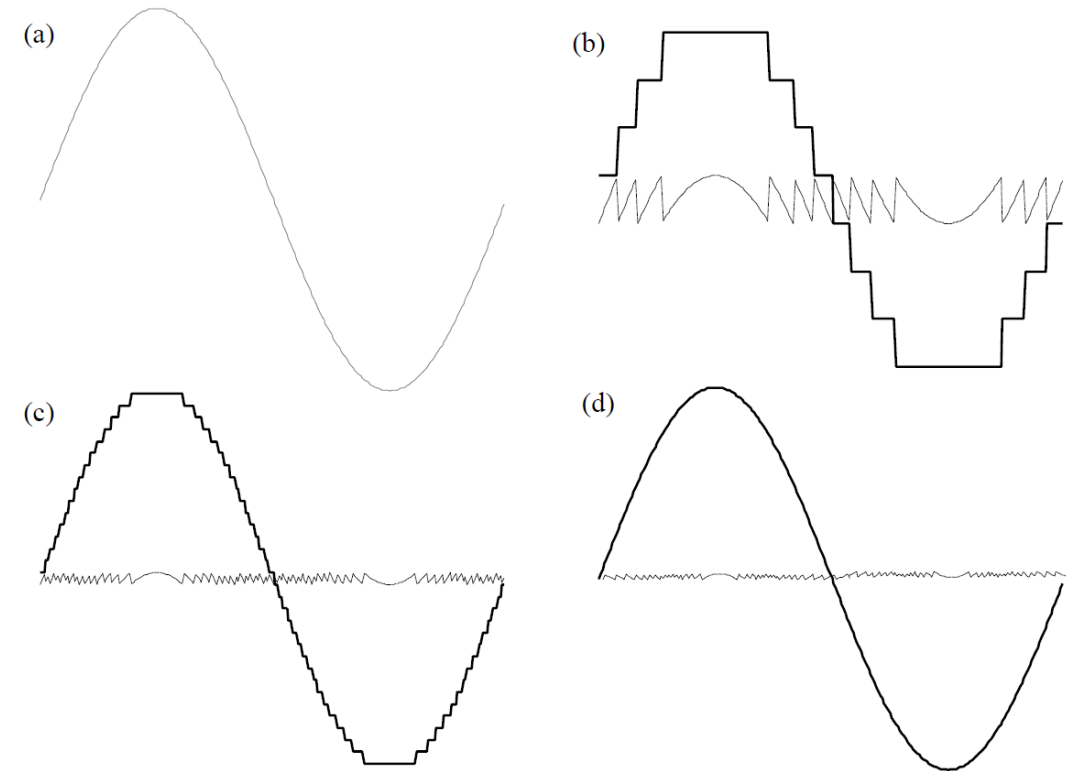


Figure. Dynamic range and quantization error. (a) The analogue sinusoidal signal which is to be digitized. (b) The signal recorded by a 3-bit ADC (dark line) and the quantization error (dashed line). (c) Corresponding plot for a 5-bit ADC, and (d) a 6-bit ADC.

Digital Signal Processing

➤ Objectives

- Signal analysis
 - ✓ the measurement of signal properties
 - ✓ Speech recognition, feature detection, tracking, etc...
- Signal filtering
 - ✓ the transformation of signals
 - ✓ Noise removal, image enhancement, etc...

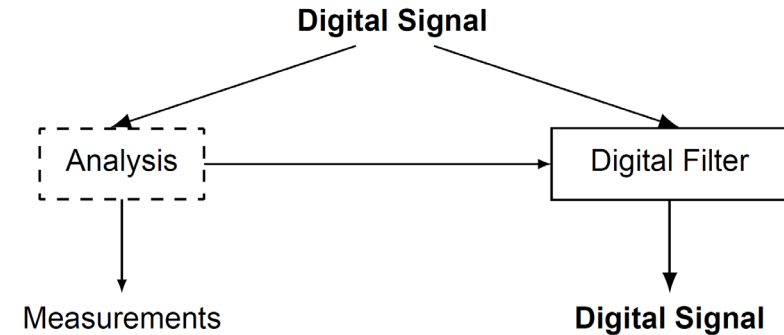


Figure. The objective of signal processing

➤ Advantages

- Flexibility in parameter change
- Insensitive to component tolerances, aging, environmental conditions, EM interference, et. al.
- Reproducibility, reusability
- Digital storage is easy and cheap
- Digital information can be encrypted for security
- Price/performance and reduced time-to-market
- ...

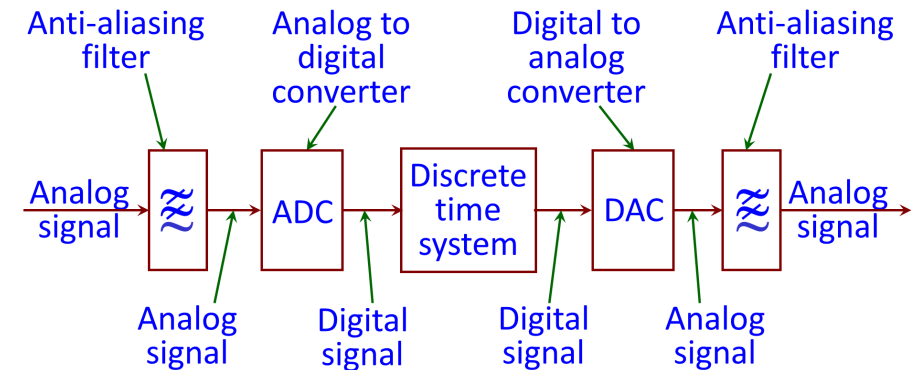


Figure. Block diagram of a digital signal processing system

Digital Signal Processing

➤ Linear time-invariant (LTI) system (线性时不变系统)

If $y[n] = T\{x[n]\}$

- Linearity: superposition & homogeneity

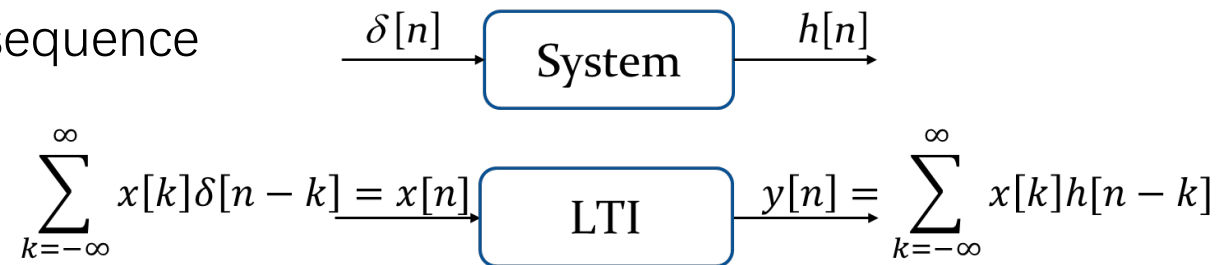
$$T\{a_1x_1[n] + a_2x_2[n]\} = a_1y_1[n] + a_2y_2[n]$$

- Time invariance: for a specified input, the output is independent of the time the input is being applied

$$y[n - n_0] = T\{x[n - n_0]\} \quad \text{for all integer } n_0$$

➤ Impulse response (冲激响应)

- the response of a system to a unit impulse sequence
- completely characterizes an LTI system



Convolution (卷积)

- To calculate the output from the applying system

$$x[n] \longrightarrow \boxed{\text{LTI}} \longrightarrow y[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k] = x[n] * h[n]$$

n: variable, k:constant

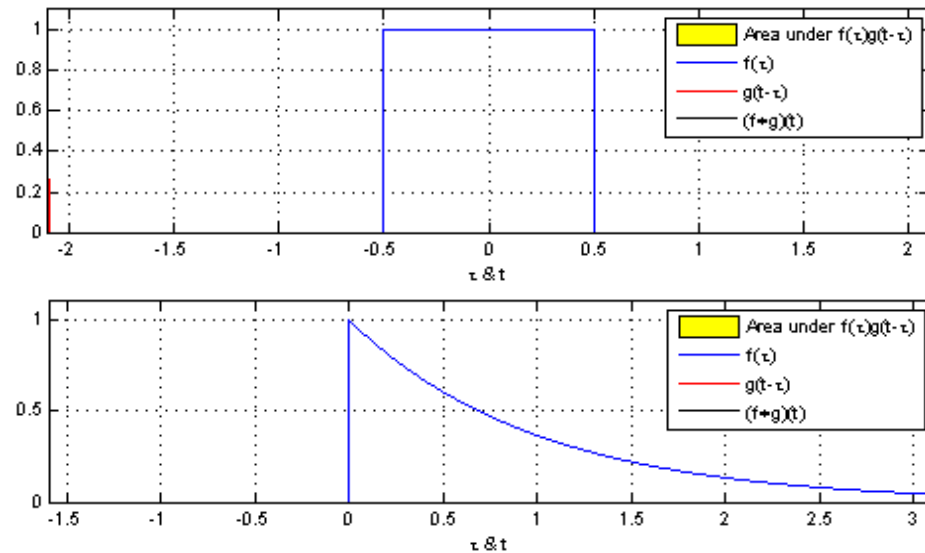


Figure. Demonstration of convolution for a continuous signal

Property	Convolution
Commutative	$f \star g = g \star f$
Associative	$f \star (g \star h) = (f \star g) \star h$
Distributive	$f \star (g + h) = (f \star g) + (f \star h)$

Figure. Some fundamental properties of convolution.

Degradation (退化)

➤ In the ideal case :

$$y(n) = x(n) \star h(n)$$



where

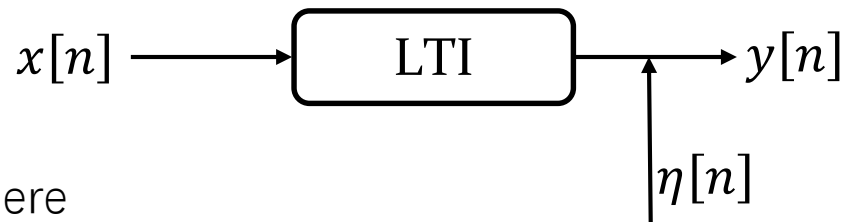
$x(n)$: the input signal

$h(n)$: the impulse response of a LTI system

$y(n)$: the output signal

➤ In the real case :

$$y(n) = x(n) \star h(n) + \eta(n)$$



where

$\eta(n)$: additive noise term

