信號與系統
Signals & Systems

Spring 2026

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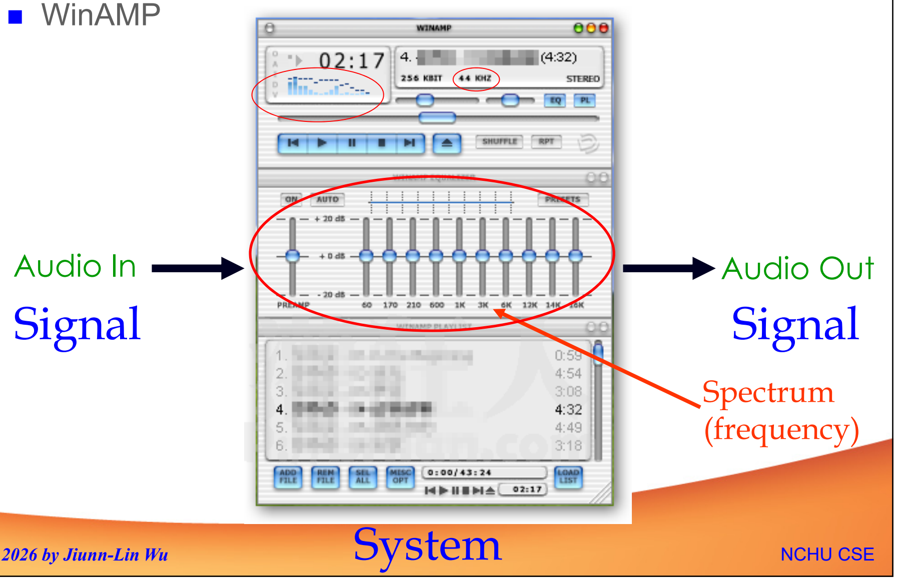
國立中興大學

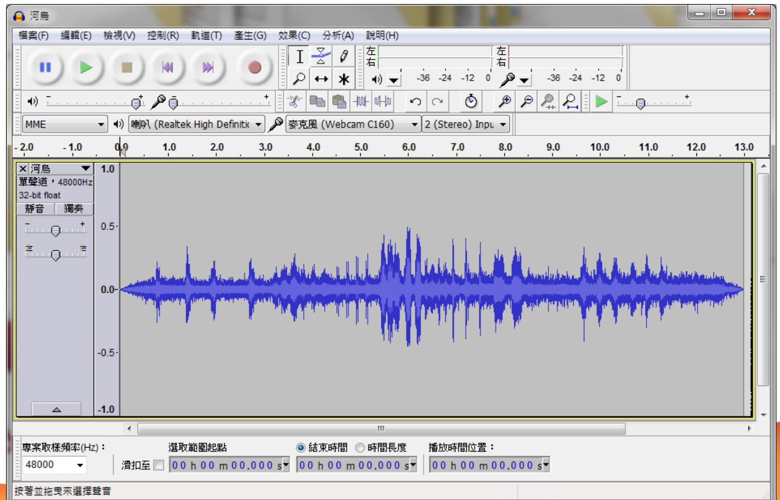
Signals & Systems

- WinAMP

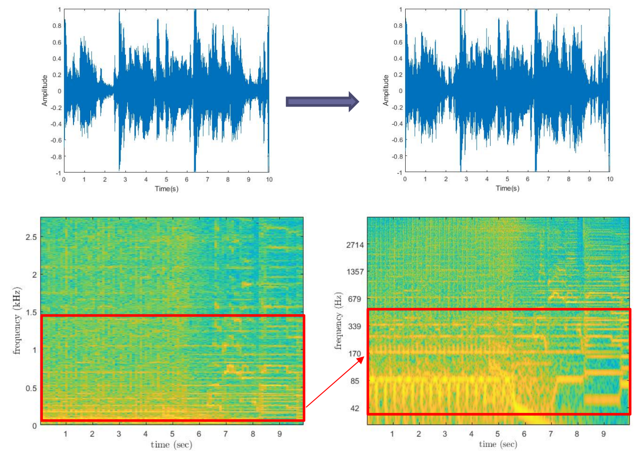


Signal Processing in Frequency Domain

- Audacity-Noise Removal / Vocal Removal



Spectrogram-Short Time Fourier Transform



(a) (b)

The spectrogram of an audio. (a) with STFT (b) with CQT

Fourier Series

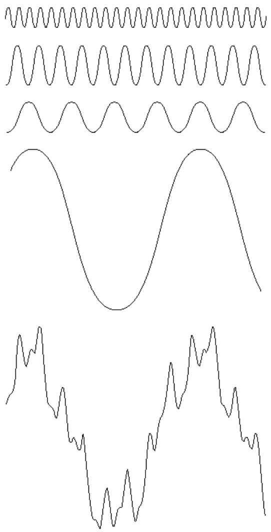


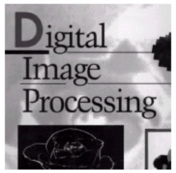
FIGURE 4.1 The function at the bottom is the sum of the four functions above it. Fourier's idea in 1807 that periodic functions could be represented as a weighted sum of sines and cosines was met with skepticism.

Signals & Systems

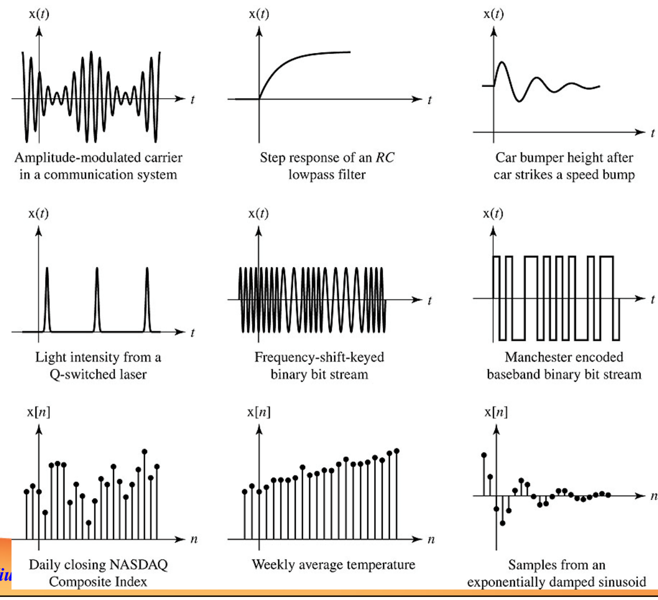
- A fundamental class for *Digital Signal Processing*.
- **Sampling** – Convert **analog** signals to **discrete-time** signal.
- **Fourier Transform** – **Frequency** domain representation.
- **Filtering/Convolution**

A Signal

- A signal is a function of one or more variables, which conveys information on the nature of some physical phenomena.
- Examples
  - f (t) : a voice signal, a music signal
  - f (x , y) : an image signal, a picture →
  - f (x , y , t): a video signal
  - : a sequence of data (n: integer)
  - : a bit stream (b:1 or 0)
  - continuous-time, discrete-time
  - analog, digital
- Human Perceptible/ Machine Processed

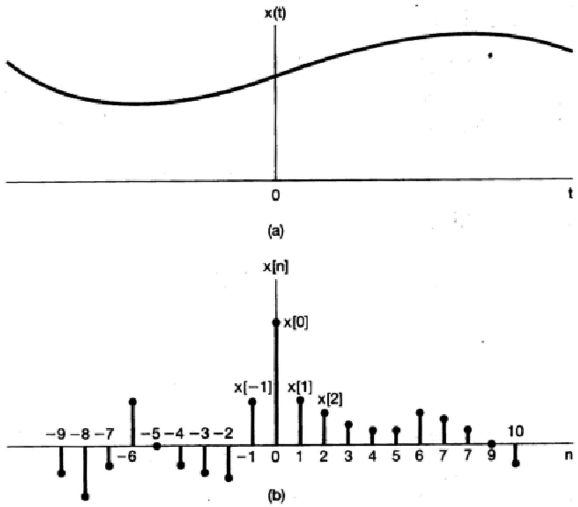


A Signal



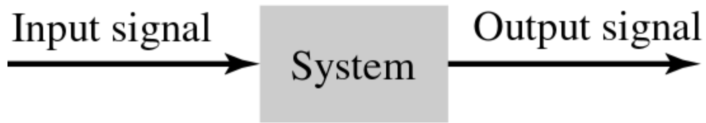
A Signal

- continuous-time and discrete-time signals



A System

- An entity that manipulates one or more signals to accomplish some function, including yielding some new signals.
  - Block diagram representation of a system.



- Examples
  - an electric circuit
  - a telephone handset
  - a PC software receiving pictures from Internet
  - a TV set
  - a computer with some software handling some data

A System

- Interconnection of two systems

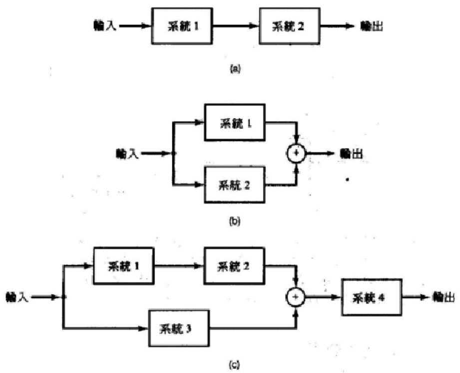
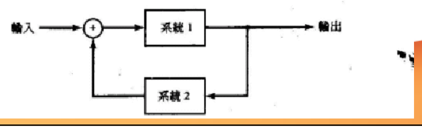
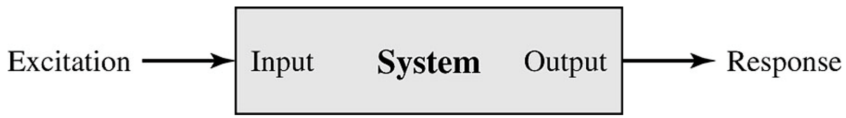


圖 1.42 兩個系統的相互連結：(a)串聯；(b)並聯；(c)串-並聯連接

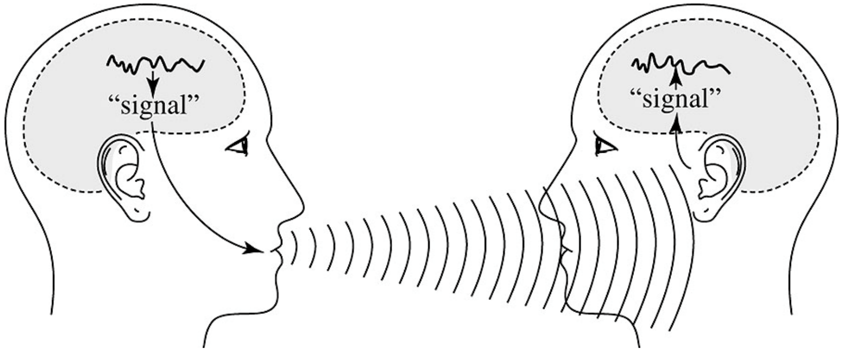


Signals & Systems

- Is about using mathematical techniques to help describe and analyze systems which process signals.
- Signals are variables that carry information.
- Systems process input signals to produce output signals.



Signals & Systems



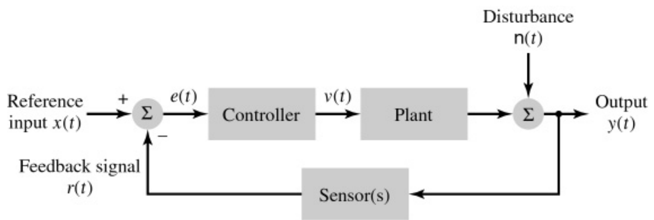
Examples of Signals/Systems

- Communication Systems

  - The transmitter changes the message signal into a form suitable for transmission over the channel.
  - The receiver processes the channel output (i.e., the received signal) to produce an estimate of the message signal.
- Computers
- Signal Processing Systems
  - Software systems processing the signal by computation/ memory.
  - Examples: audio enhancement systems, image processing systems, video compression systems, voice recognition/ synthesis systems, array signal processors, equalizers, etc.

Examples of Signals/ Systems

- Control Systems
  - Close-loop/ feedback control systems



  - Example: aircraft landing systems, satellite stabilization systems, robot arm control systems, etc.

Examples of Signals/ Systems-Imaging Model

- High-Resolution Image Reconstruction

  from Multiple Differently Exposed Images

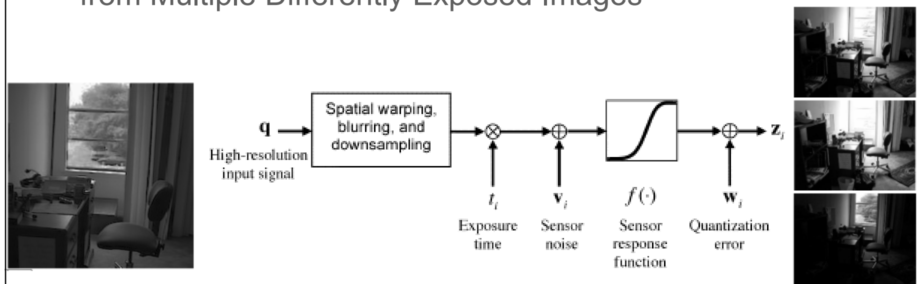
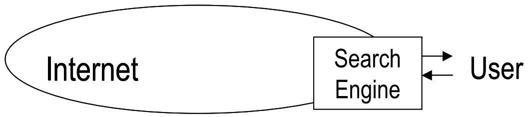


Fig. 1. Proposed super-resolution algorithm uses an imaging model that includes dynamic range and spatial domain effects.

Examples of Signals/ Systems

- Information Retrieval Systems



- Other Systems
  - Remote sensing systems, biomedical signal processing systems manufacturing systems, computer-aided-design systems, mechanical systems, chemical process systems, etc.

Scope of The Course

- Those Signals/ Systems Operated by Electricity, in Particular by Software and Computers, with Extensive Computation and Memory, for Information and Control Primarily.
- Analytical Framework to Handle Such Signals/ Systems.
- Mathematical Description/ Representation of Such Signals/ Systems.
- Language and Tools to Solve Problems with Such Signals/ Systems.
- Closely Related to: Communications, Signal Processing, Computers, Networks, Control, Biomedical Engineering, Circuits, Chips, EM Waves, etc.

Course Outline

- 1. Signals and Systems
  - Continuous-Time and Discrete-Time Signals
  - Exponential and Sinusoidal Signals
  - The Unit Impulse and Unit Step Functions
  - Basic System Properties
    - Linearity
    - Time Invariance
- 2. Linear Time-invariant Systems
  - Properties of Linear Time-Invariant Systems
  - Convolution Sum and Convolution Integral
- 3. Fourier Series & Fourier Transform
  - Properties of Fourier Series (Transform)
  - Fourier Series (Transform) and LTI Systems
  - Filtering
  - Convolution Property

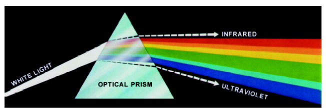


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Course Outline

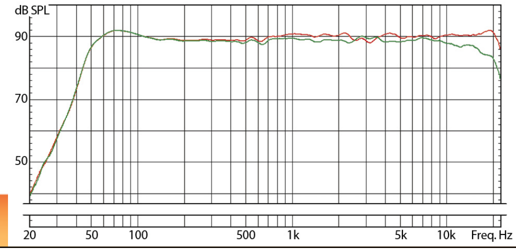
- 4. Discrete Fourier Transform (DFT)
  - Properties of DFT
  - Convolution Property
- 5. Time/ Frequency Characterization of Signals/ Systems
  - Magnitude-Phase Representation
- 6. Sampling & Sampling Theorem
  - Sampling of Discrete-Time Signals
  - The Effect of Undersampling: Aliasing
- 7. Communication Systems
- 8. Laplace Transform
  - Properties of Laplace Transform
  - Analysis and Characterization of LTI Systems Using the Laplace Transform

Course Outline

- 9. Z-Transform
  - The Region of Convergence of the z-Transform
  - The Inverse z-Transform
  - Properties of z-transform
  - Analysis and Characterization of LTI Systems Using the z-Transform
- 10. Linear Feedback Systems
  - Root-Locus Analysis of Linear Feedback Systems
  - The Nyquist Stability Criterion
  - Gain and Phase Margins

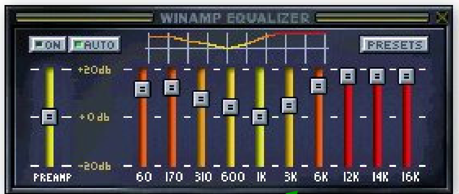
Signals & Systems

- Frequency Response (speaker)
  - Frequency response may well be one of the most misunderstood and frequently abused speaker specifications that any consumer has to deal with. It describes the range of frequencies or musical tones a component can reproduce.
  - A graph of the amplitude of a vibration versus the frequency of the vibration is called a system's frequency response. A good speaker should have a frequency response that is as "flat" as possible, meaning it reproduces frequencies at the same volume at which they were recorded.



Signals & Systems

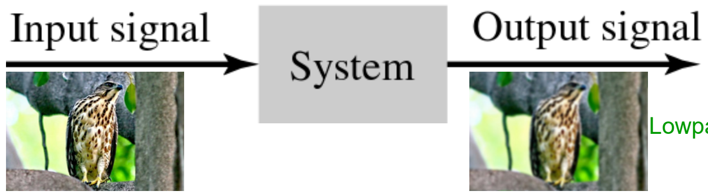
- Audio Equalizer
  - Audio equalizers are devices used for boosting and cutting predetermined frequency ranges or bands.
  - Every stereo system, including some portable systems as well as professional stereo systems typically has an equalizer to equalize the audio data.
  - An audio equalizer typically will adjust the energy levels of the audio data in one or more different frequency bands in order to change the characteristics of the audio data.



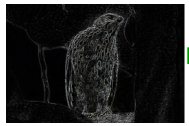
Spectrum (frequency domain)

Signals & Systems

- Image filtering



Lowpass Fileter



Highpass Fileter

- Filtering in the **time** domain

$$y(t) = h(t) * x(t)$$

- Filtering in **frequency** domain

$$Y = H \cdot X$$

convolution

- Sampling theorem

A Model of the Image Degradation/Restoration Process

- If H is a *linear, position-invariant* process, then the degraded image is given in the *spatial domain* by

$$g(x,y) = h(x,y) * f(x,y) + \eta(x,y)$$

- The model in an equivalent *frequency domain* representation is:

$$G(u,v) = H(u,v)F(u,v) + N(u,v)$$

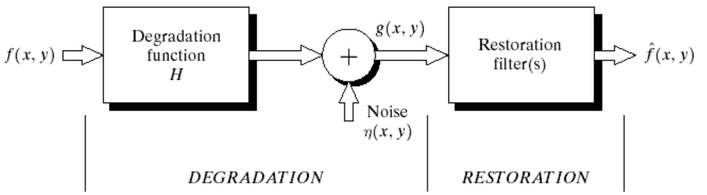


FIGURE 5.1 A model of the image degradation/ restoration process.

Deconvolution - Mnimum MSE (Wiener) Filtering

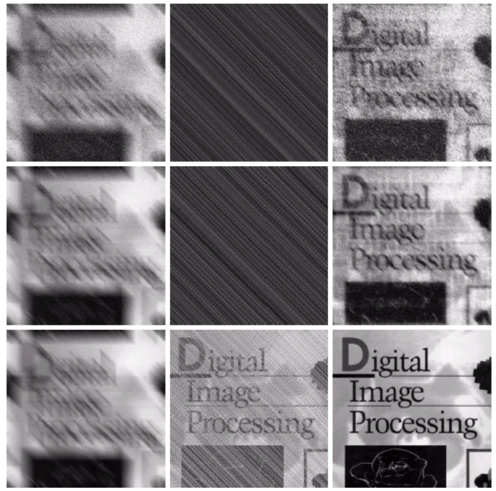


FIGURE 5.29 (a) Image corrupted by motion blur and additive noise. (b) Result of inverse filtering. (c) Result of Wiener filtering. (d)–(f) Same sequence, but with noise variance one order of magnitude less. (g)–(i) Same sequence, but noise variance reduced by five orders of magnitude from (a). Note in (h) how the deblurred image is quite visible through a "curtain" of noise.

Image Restoration

- High-Resolution Image Reconstruction From Multiple Differently Exposed Images

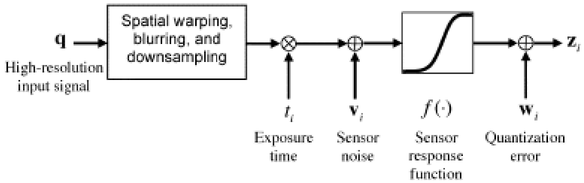


Fig. 1. Proposed super-resolution algorithm uses an imaging model that includes dynamic range and spatial domain effects.

$$\mathbf{z}_i = f(t_i \mathbf{H}_i \mathbf{q} + \mathbf{v}_i) + \mathbf{w}_i, \qquad i = 1, \ldots, N$$

Fourier Transform (Duality)

- Time Domain Frequency Domain

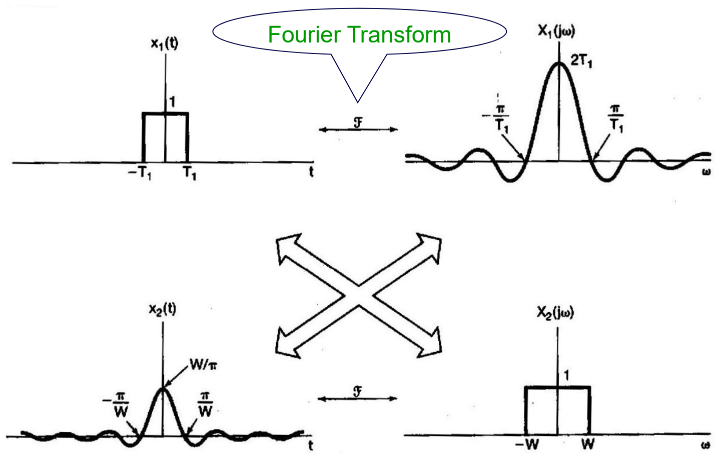
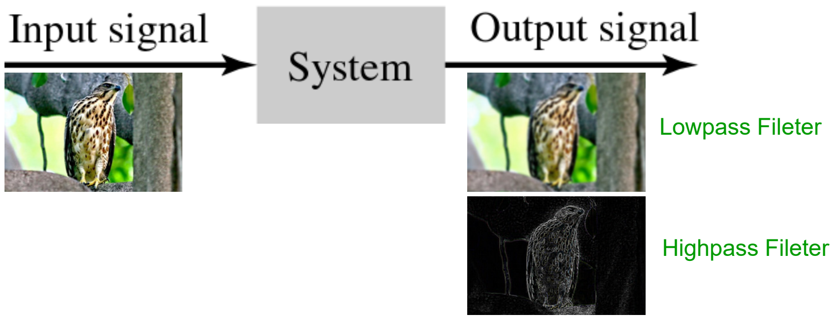


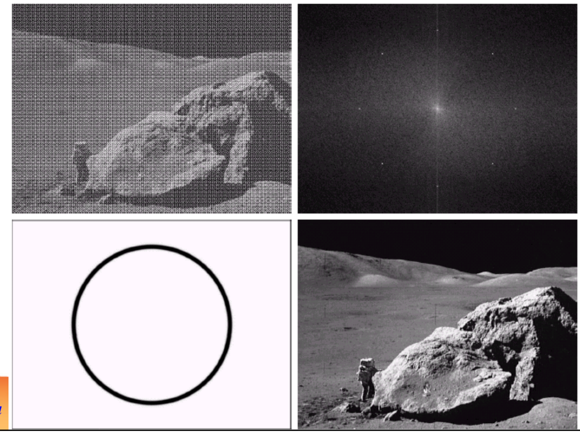
圖 4.17 (4.36)和 (4.37)式的傅立葉轉換對之間的關係

Highpass and Lowpass Filtering



Periodic Noise Reduction by Freq. Domain Filtering

- One of the principle applications of bandreject filtering is for noise removal in applications where the general location of the noise components in the frequency domain is approximately known.



a b
c d

FIGURE 5.16 (a) Image corrupted by sinusoidal noise. (b) Spectrum of (a). (c) Butterworth bandreject filter (white represents 1). (d) Result of filtering. (Original image courtesy of NASA.)

Discrete-Time Processing of CT Signals

- The discrete-time signal processing can be implemented with a general or special-purpose computer, with microprocessors, or with any of the variety of devices that are specifically oriented toward discrete-time signal processing.

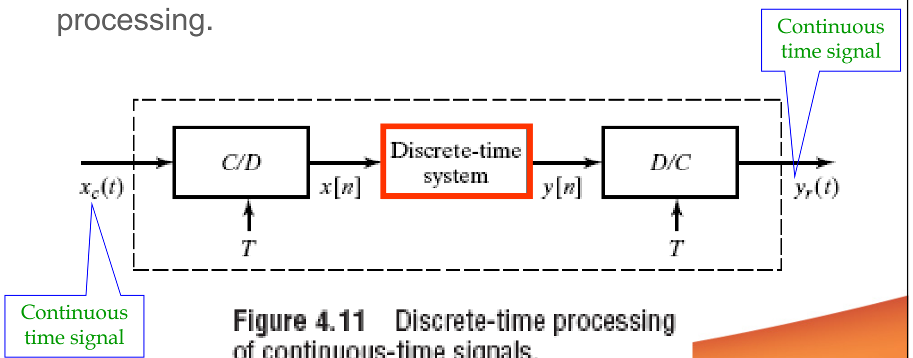


Figure 4.11 Discrete-time processing of continuous-time signals.

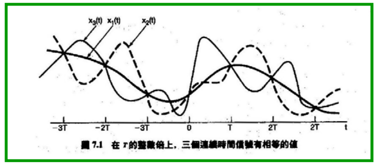
Sampling Theorem

Sampling Theorem:
Let $x(t)$ be a band-limited signal with $X(j\omega) = 0$ for $|\omega| > \omega_M$. Then $x(t)$ is uniquely determined by its samples $x(nT)$, $n = 0, \pm1, \pm2, \ldots$, if

$$\omega_s > 2\omega_M,$$

where

$$\omega_s = \frac{2\pi}{T}.$$



Given these samples, we can reconstruct $x(t)$ by generating a periodic impulse train in which successive impulses have amplitudes that are successive sample values. This impulse train is then processed through an ideal lowpass filter with gain T and cutoff frequency greater than ω_M and less than $\omega_s - \omega_M$. The resulting output signal will exactly equal $x(t)$.

Aliasing

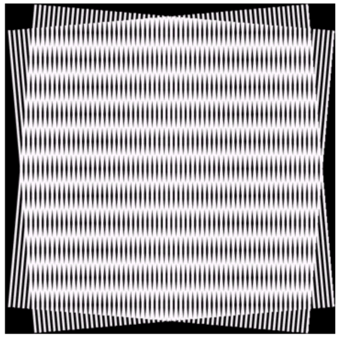


FIGURE 2.24 Illustration of the Moiré pattern effect.

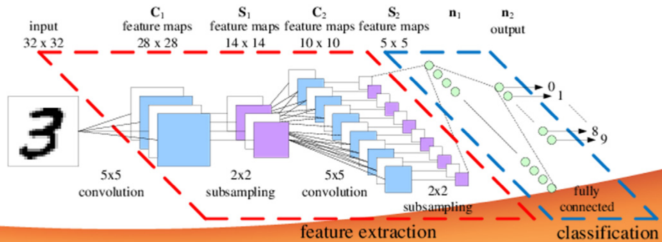
Aliasing

a b c

FIGURE 4.17 Illustration of aliasing on resampled images. (a) A digital image with negligible visual aliasing. (b) Result of resizing the image to 50% of its original size by pixel deletion. Aliasing is clearly visible. (c) Result of blurring the image in (a) with a 3 × 3 averaging filter prior to resizing. The image is slightly more blurred than (b), but aliasing is not longer objectionable. (Original image courtesy of the Signal Compression Laboratory, University of California, Santa Barbara.)

Deep Convolutional Neural Networks

- Convolutional neural networks are deep artificial neural networks that are used primarily to classify images (e.g. name what they see), cluster them by similarity (photo search), and perform object recognition within scenes.
- They are algorithms that can identify faces, individuals, street signs, tumors, platypuses and many other aspects of visual data.



Text/ Reference Books and Lecture Notes

- Textbook:
  - "Signals & Systems", by Oppenheim & Willsky, 2nd Ed. 1997, (Pearson, 高立)
  - "Signals & Systems", by S. Haykin & B. Van Veen, 2nd Ed., 2002, (John Willey & Sons, 滄海)
- Reference:
  - "Signals and Systems: Analysis Using Transform Methods and MATLAB", by M.J. Roberts, 2003, (McGrawHill 東華)
- Lecture Notes:
  - Available before the day of class.

Grading

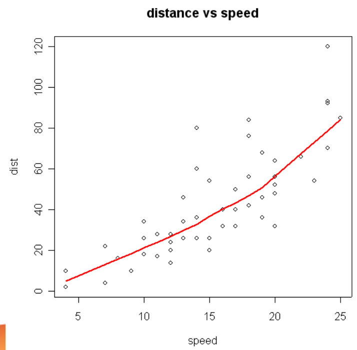
- HW (and MATLAB Problems) 30%
- Midterm 35%
- Final 35%

Comparison with Matlab and C++

功能	R	Matlab	C++
Learning	Easy	Easy	Difficult
變數宣告	No	No	Yes
Compiler	Interpreted	Interpreted	Compiler
效能			Very good, Fast
科學函式庫	套件(Packages)	Toolboxes	使用OpenCV
費用	Free (包含RStudio)	付費(Expensive)	OpenCV is free
Graphics	Very Good	Very Good	需用第三方元件
向量化運算	Good	Very Good	
統計分佈與分析	Excellent		
工程計算(影像處理)		Excellent	Excellent
讀取外部資料檔案	Excellent (資料庫)	CSV文字檔	
自訂函式	Good	Good	Excellent
建議使用場合	統計分析	快速驗證科學演算法與繪圖	須高效能處理的程式

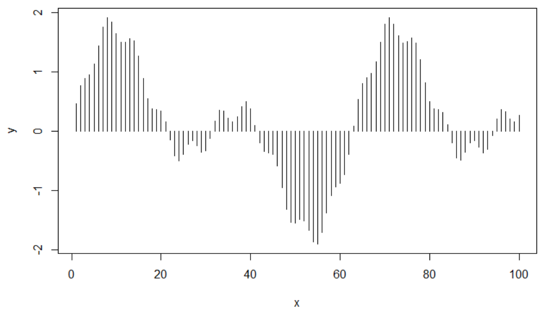
R Language

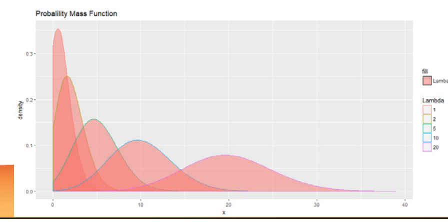
- Software for ***Statistical Data Analysis***
- Programming Environment
- Interpreted Language
- Data Storage, Analysis, Graphing
- Free and Open Source Software
- *Applications*
  - *Machine Learning*
  - *Regression and Classification*
  - *Big Data*
  - *Data Mining*



R語言於統計分析與深度學習的應用

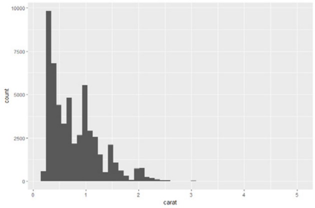
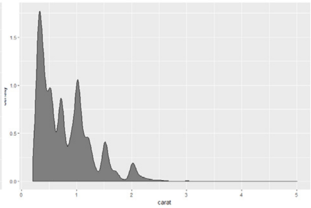
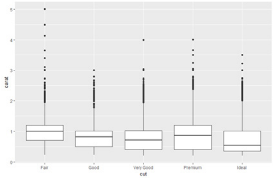
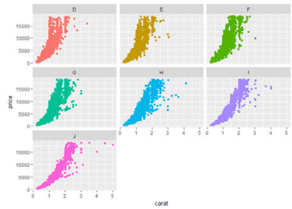
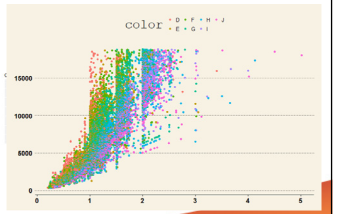
- 統計繪圖
- 機率分佈
- 基礎統計
- 線性模型(迴歸)
- 資料分群
- 深度學習





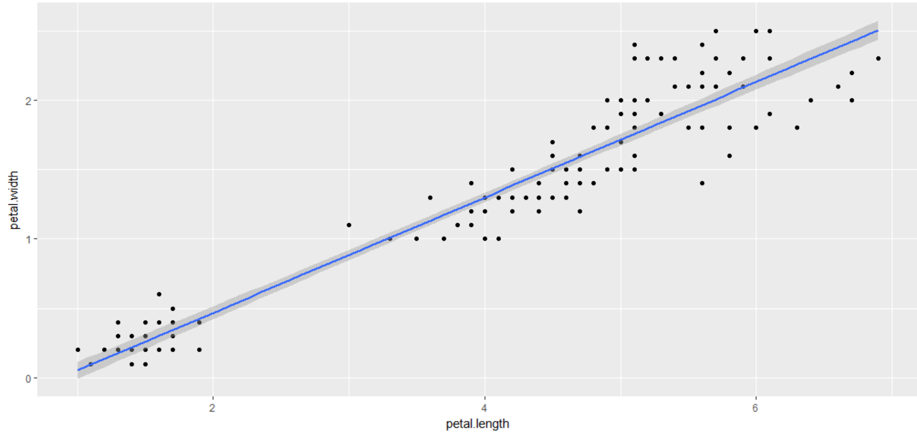
統計繪圖

- 直方圖
- 散佈圖
- 箱型圖
- ggplot2套件
  - ggthemes

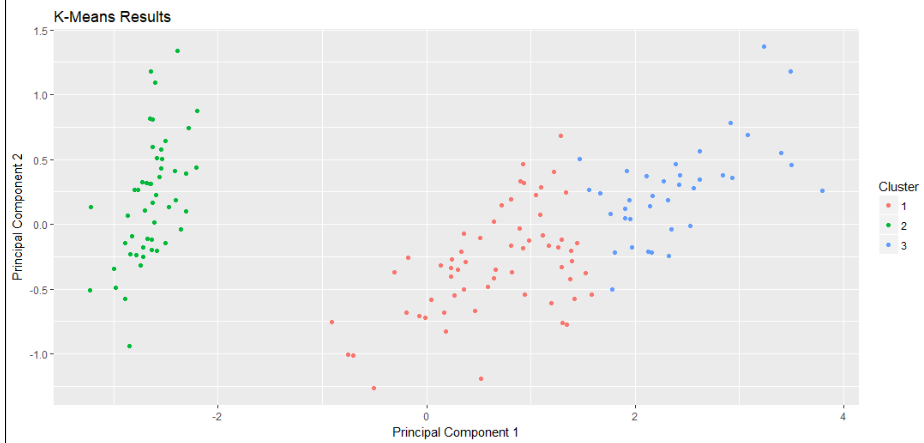
線性迴歸

- lm()



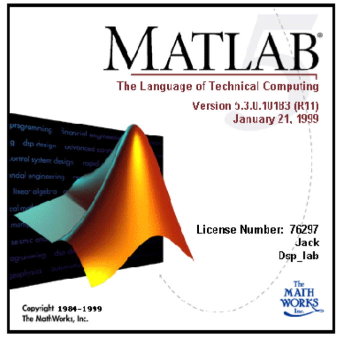
資料分群

- K-means



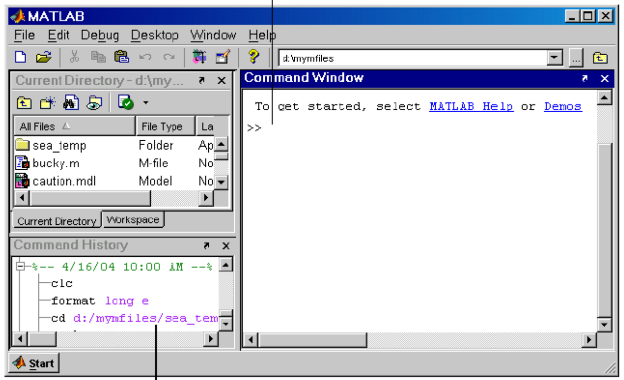
MATLAB

- MATLAB == MATrix LABoratory
- The language of technical computing
  - Computation
  - Visualization
  - Programming
- Applications
  - Math and computation
  - Algorithm development
  - Data acquisition
  - Modeling, simulation, and prototyping
  - Data analysis, exploration, and visualization
  - Scientific and engineering graphics
  - Application development, including graphical user interface building



MATLAB Desktop

Enter MATLAB functions at the Command Window prompt.



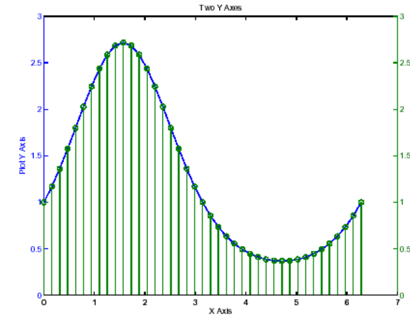
The Command History maintains a record of the MATLAB functions you ran.

Visualization

Plotting Tools and MATLAB Commands

You can enable the plotting tools on any graph, even if you created it using MATLAB commands. For example, suppose you create the following graph.

```
t = 0:pi/20:2*pi;
y = exp(sin(t));
plotyy(t,y,t,y,'plot','stem')
xlabel('X Axis')
ylabel('Plot Y Axis')
title('Two Y Axes')
```

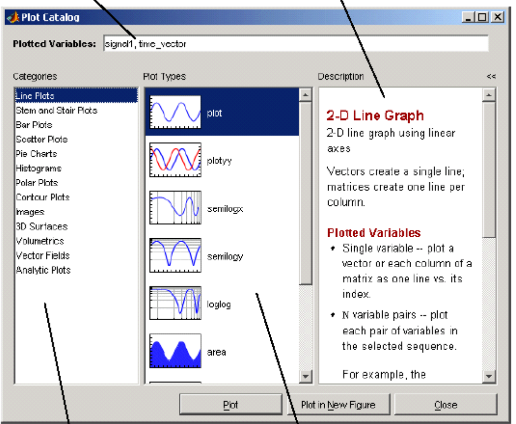


Visualization

MATLAB displays the Plot Catalog with the selected variables ready to plot, once you select a plot type.

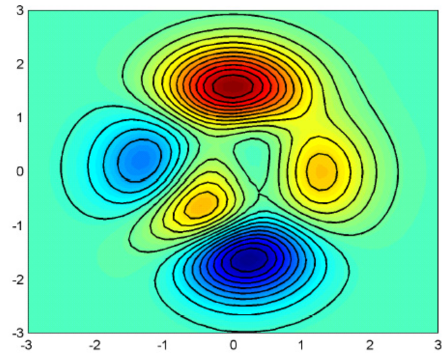
Specify variables to plot.

See a description of each plot type.



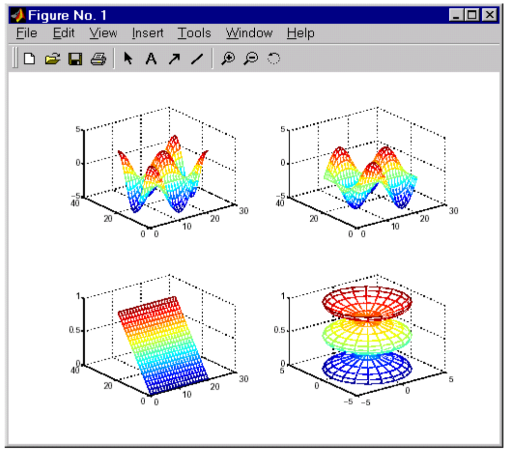
Select a category of graphs and then choose a specific type.

Visualization



Visualization

```
t = 0:pi/10:2*pi;
[X,Y,Z] = cylinder(4*cos(t));
subplot(2,2,1); mesh(X)
subplot(2,2,2); mesh(Y)
subplot(2,2,3); mesh(Z)
subplot(2,2,4); mesh(X,Y,Z)
```



Programming

- Flow Control
  - Use flow control constructs including if, switch and case, for, while, continue, and break.
- Other Data Structures
  - Work with multidimensional arrays, cell arrays,
  - character and text data, and structures.
- Scripts and Functions
  - Write scripts and functions, use global variables, pass string arguments to functions, use eval to evaluate text expressions, vectorize code, preallocate arrays, reference functions using handles, and use functions that operate on functions.