Digital Image Processing

Lecture #5

Ming-Sui (Amy) Lee

Course Information

- Following Schedule

03/28	Lecture 4	05/16	Lecture 8
04/04	溫書假	05/23	Lecture 9
04/11	Lecture 5 hw3	05/30	Lecture 10
04/18	Lecture 6	06/06	Lecture 11
04/25	Midterm	06/13	Demo
05/02	Lecture 7	06/20	Demo
05/09	Proposal hw4	06/27	Final Package Due

- Midterm Exam
  - Apr. 25, 2018

Texture Analysis

Texture Analysis

- **Image analysis and its applications**

Noise removal
Edge crispening

Enhancement
Restoration

Edge detection
Texture analysis

Image analysis
(Low-level of
Computer vision tasks)

分析一張圖片的內容，分析他有哪些東西

Computer vision

Input image
↓
Preprocessing
↓
Feature extraction
↓
Segmentation
↓
Classification & Symbolic representation
↓
Object understanding & Scene interpretation

4

Texture Analysis

- **What is texture?**

http://architecturehell.wordpress.com/
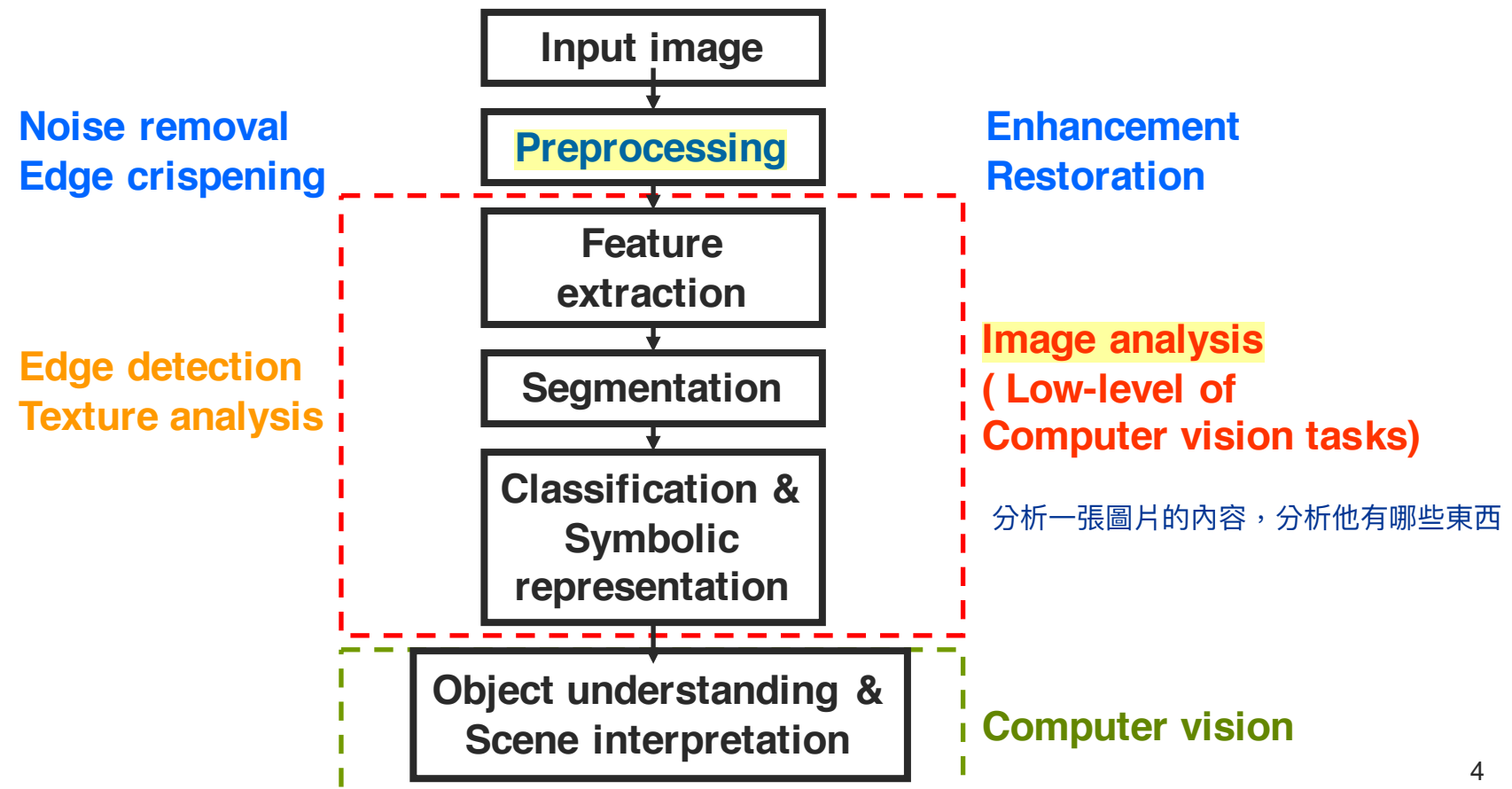
Texture Analysis

- **What is texture?**
  - No mathematical definition
  - Two dimensional arrays of variations
  - Semi-regular structured patterns of object
  - E.g. Surfaces such as sand, grass, wool, cloth, leaves, etc.

Texture Analysis

- **Why texture analysis?**
  - **People started to be interested in late 50's and early 60's**
    - **Analyze aerial images / texture patches**
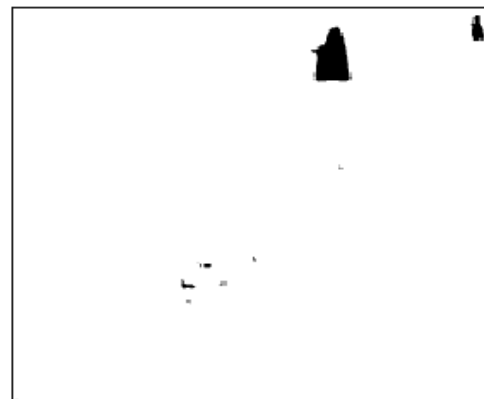
Texture Analysis
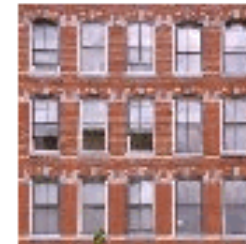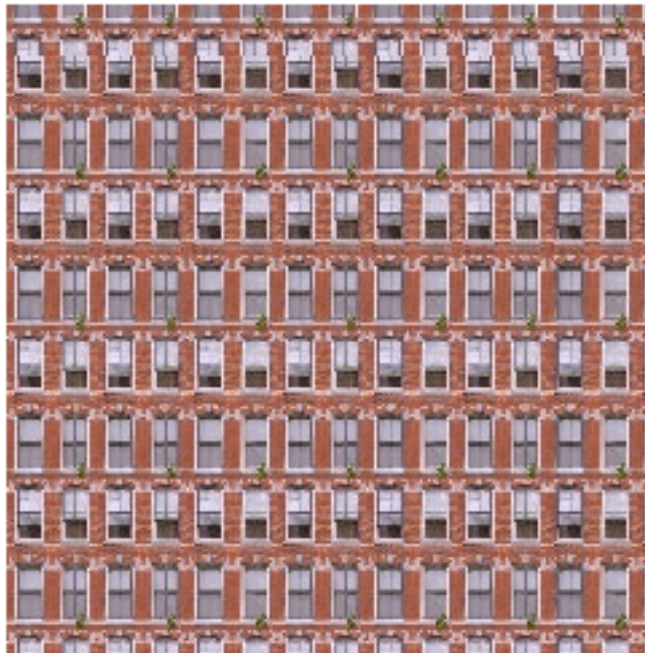
- **Example (an aerial image)**

(a) Aerial photo (b)Field (c) Residential area (d) Vegetation area

Texture Analysis

- **Example (Texture Synthesis)**

Texture Analysis

- **History of texture analysis**
  - Fourier Spectral Methods
  - Edge Detection Methods
  - Autocorrelation Methods
  - Decorrelation Methods
  - Dependency Matrix Method

Texture Analysis

- **Fourier Spectral Methods**
  - ○ **Right direction but incomplete development**
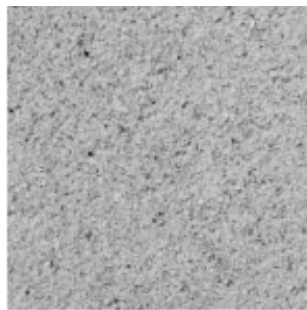 - ○ **No continuous work for a long while**
- **Edge Detection Methods**
  - ○ **Edge detection**
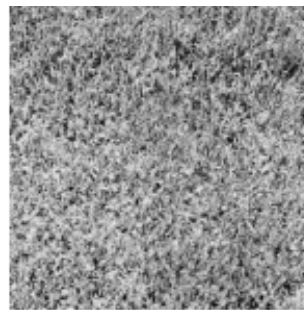 - ○ **Use edge density and orientation as texture features**

Texture Analysis

- **Autocorrelation Methods**
  - Treat the texture pattern as a 2D random process, denoted as F(x,y)
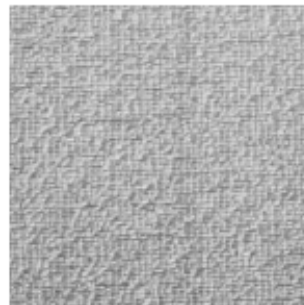 - Statistical approach

Sand

Grass

Wool

Raffia

$$E\{F(x, y)F(x - \Delta x, y - \Delta y)\}$$

shift

Texture Analysis

- **Decorrelation Methods**
  - **2D whitening filter**
    - Special type of decorrelation operator

$$\text{input} \longrightarrow \boxed{\begin{array}{c} \textbf{2D} \\ \textbf{whitening} \\ \textbf{filter} \end{array}} \longrightarrow \sigma^2$$

$$\hat{W}(j,k) = F(j,k) \otimes H_W(j,k)$$

whitening filter

  - **Spatially decorrelated**
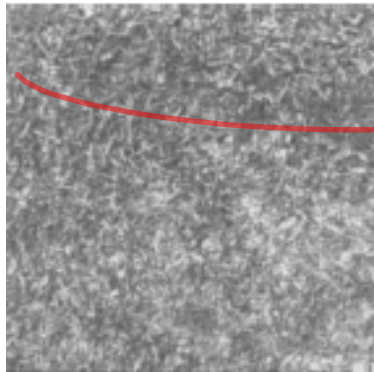   - Form histogram as its feature

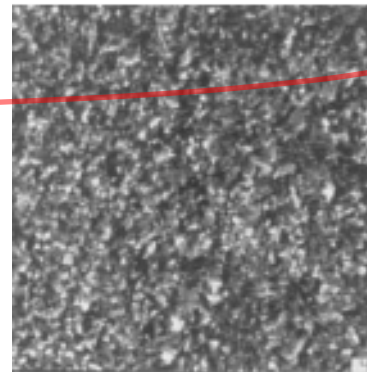# Texture Analysis

- **Dependency Matrix Method**
  - ○ **Joint probability**
  - ○ **Also called Co-occurrence method**

$$P(a,b \mid j,k,\Delta j, \Delta k)$$

$$= \text{Prob}\{F(j,k) = a, F(j - \Delta j, k - \Delta k) = b, 0 \leq a,b \leq L-1\}$$

Grass

Ivy

Texture Analysis

- **History of texture analysis**
  - Fourier Spectra methods
  - Edge Detection Methods
  - Autocorrelation Methods
  - Decorrelation Methods
  - Dependency Matrix Method

  → Not successful!!

Texture Analysis

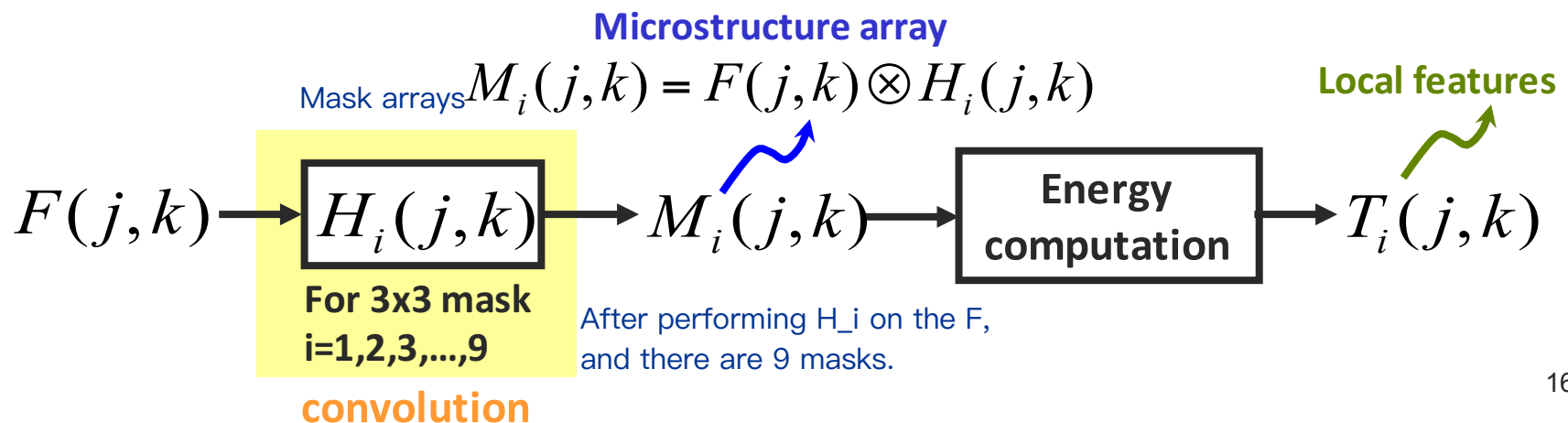- **Laws' Method** 卷積
  - **Micro-structure (Multi-channel) method**
    - Emphasize the microstructure of the texture
    - Two steps
      - step 1: Convolution
      - step 2: Energy computation

Microstructure array

Mask arrays $M_i(j,k) = F(j,k) \otimes H_i(j,k)$

Local features

$$F(j,k) \rightarrow \boxed{H_i(j,k)} \rightarrow M_i(j,k) \rightarrow \boxed{\begin{array}{c}\textbf{Energy}\\\textbf{computation}\end{array}} \rightarrow T_i(j,k)$$

For 3x3 mask i=1,2,3,…,9

After performing H_i on the F, and there are 9 masks.

convolution

Texture Analysis

- ## Laws' Method

  - ### //Step 1// Convolution $M_i(j,k) = F(j,k) \otimes H_i(j,k)$

    - **Micro-structure** impulse response **arrays (a basis set)**

      一個 dynamic system 會對 signal 做的事情

$H_i(j,k)$

for 3x3 mask,
i=1,2,3,…,9

for 5x5 mask,
i=1,2,3,…,25

How to choose
the mask size?

$$\frac{1}{36}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$
Laws 1

$$\frac{1}{12}\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$
Laws 2

$$\frac{1}{12}\begin{bmatrix} -1 & 2 & -1 \\ -2 & 4 & -2 \\ -1 & 2 & -1 \end{bmatrix}$$
Laws 3

$$\frac{1}{12}\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$
Laws 4

$$\frac{1}{4}\begin{bmatrix} 1 & 0 & -1 \\ 0 & 0 & 0 \\ -1 & 0 & 1 \end{bmatrix}$$
Laws 5

$$\frac{1}{4}\begin{bmatrix} -1 & 2 & -1 \\ 0 & 0 & 0 \\ 1 & -2 & 1 \end{bmatrix}$$
Laws 6

$$\frac{1}{12}\begin{bmatrix} -1 & -2 & -1 \\ 2 & 4 & 2 \\ -1 & -2 & -1 \end{bmatrix}$$
Laws 7

$$\frac{1}{4}\begin{bmatrix} -1 & 0 & 1 \\ 2 & 0 & -2 \\ -1 & 0 & 1 \end{bmatrix}$$
Laws 8

$$\frac{1}{4}\begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix}$$
Laws 9

Texture Analysis

- **Laws' Method**
  - ○ **Micro-structure impulse response arrays**
    - **Generated by the <mark>tensor product</mark> of the 1D horizontal and vertical masks**

$$L_3 = \frac{1}{6}[1 \quad 2 \quad 1] \qquad E_3 = \frac{1}{2}[-1 \quad 0 \quad 1] \qquad S_3 = \frac{1}{2}[1 \quad -2 \quad 1]$$

Local averaging   **Edge detector**   **spot detector**
(1st-order gradient)   **(2nd–order gradient)**

- **E.g.**

$$L_3^T \otimes E_3 = \frac{1}{6}\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \otimes \frac{1}{2}[-1 \quad 0 \quad 1] = \frac{1}{12}\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

Laws 2[18]

Texture Analysis

- **Laws' Method**
  - **Micro-structure impulse response arrays**
    - **1979 → 1984,1986 mathematical analysis of Laws' filters**
    - **Examine the frequency response of** L_3, E_3, and S_3

$$L_3 = \frac{1}{6}[1 \quad 2 \quad 1]$$

Kroneckor Delta

$$h[n] = \frac{1}{6}\left(\delta[n-1] + 2\delta[n] + \delta[n+1]\right) \qquad \delta[n] = \begin{cases} 1 & n = 0 \\ 0 & otherwise \end{cases}$$

$$H(\omega) = \frac{1}{6}\left(e^{-j\omega} + 2 + e^{j\omega}\right) = \frac{2}{6}(1 + \cos\omega)$$

→ Low-pass filter

Texture Analysis

- **Laws' Method**
  - Micro-structure impulse response arrays
    - Examine the frequency response of $L_3, \ E_3, \ and \ S_3$

$$E_3 = \frac{1}{2}[-1 \ \ 0 \ \ 1] \qquad h[n] = \frac{1}{2}\left(-\delta[n-1] + \delta[n+1]\right)$$

$$H(\omega) = \left(-e^{-j\omega} + e^{j\omega}\right) = 2j\sin\omega \qquad \rightarrow \textbf{Bandpass filter}$$

$$S_3 = \frac{1}{2}[1 \ \ -2 \ \ 1] \ h[n] = \frac{1}{2}\left(\delta[n-1] - 2\delta[n] + \delta[n+1]\right)$$
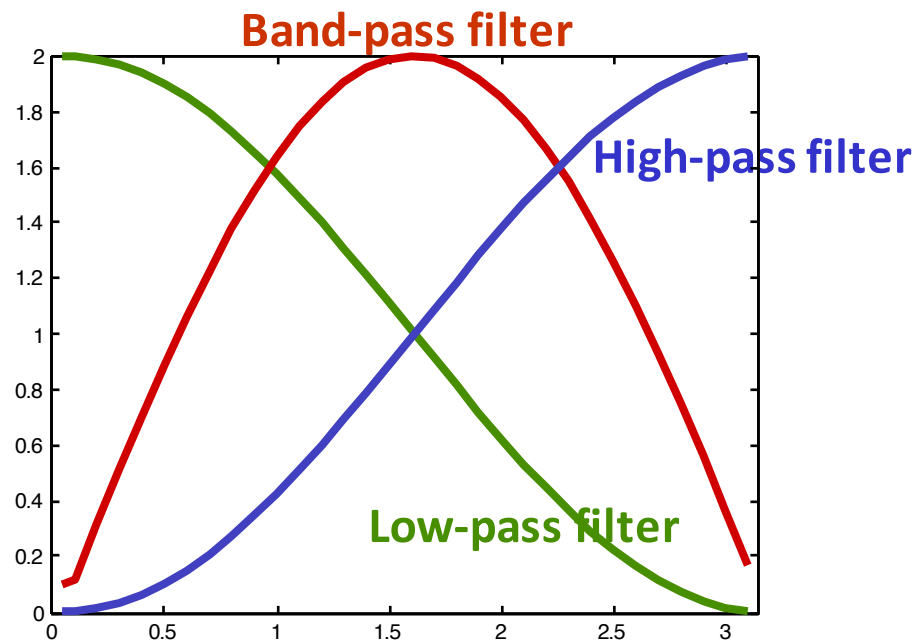
$$H(\omega) = \frac{1}{2}\left(e^{-j\omega} - 2 + e^{j\omega}\right) = \cos\omega - 1 \ \rightarrow \textbf{High-pass filter}$$
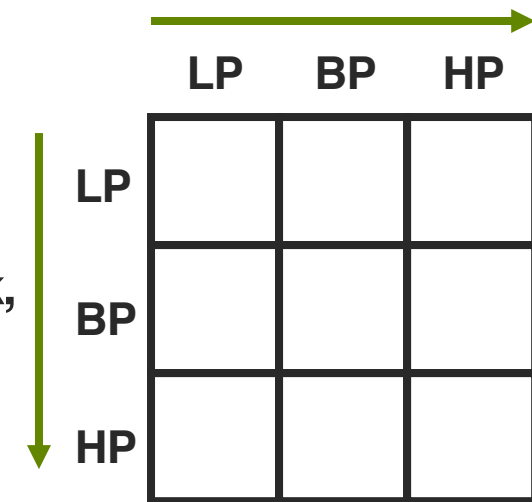
Texture Analysis

- ## Laws' Method

  - ○ **Micro-structure impulse response arrays**

    - ■ **Examine the frequency response of** $L_3, \quad E_3, \quad and \quad S_3$

Band-pass filter

High-pass filter

Low-pass filter

$$H_i(j,k)$$

for 3x3 mask, i=1,2,3,…,9

	LP	BP	HP
LP			
BP			
HP			

// Multi-channel method //

Texture Analysis

- **Example**
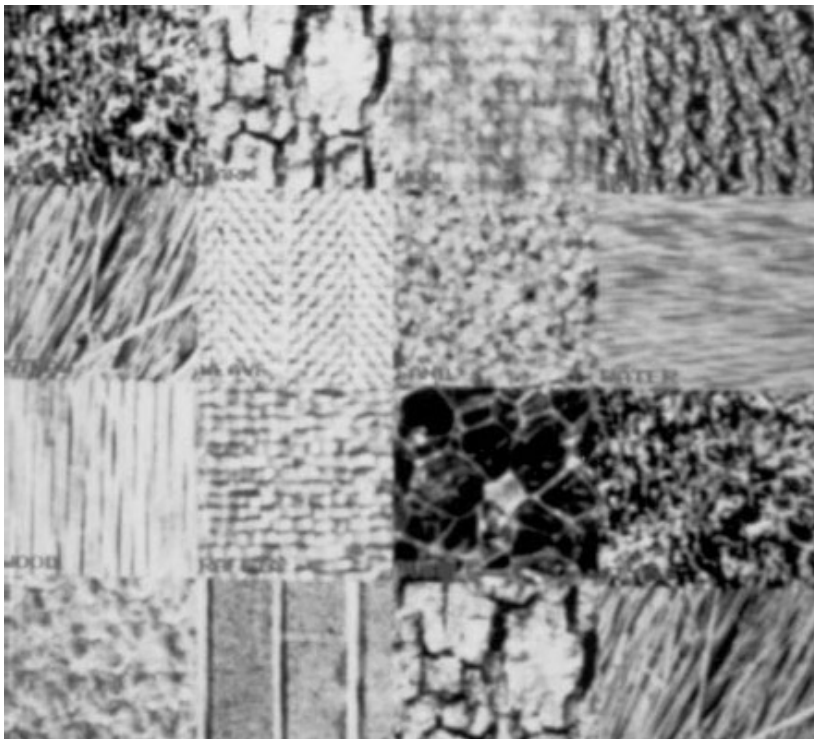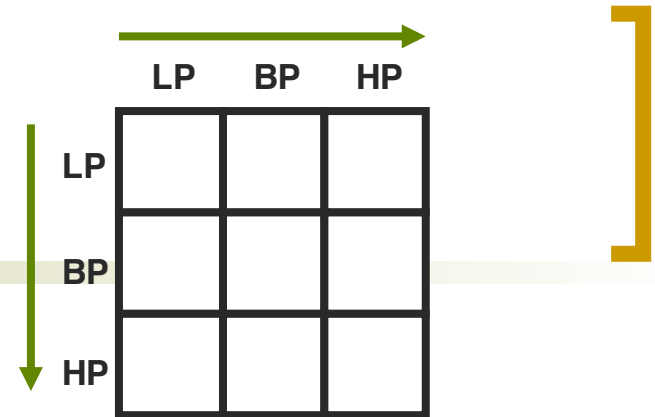
original image
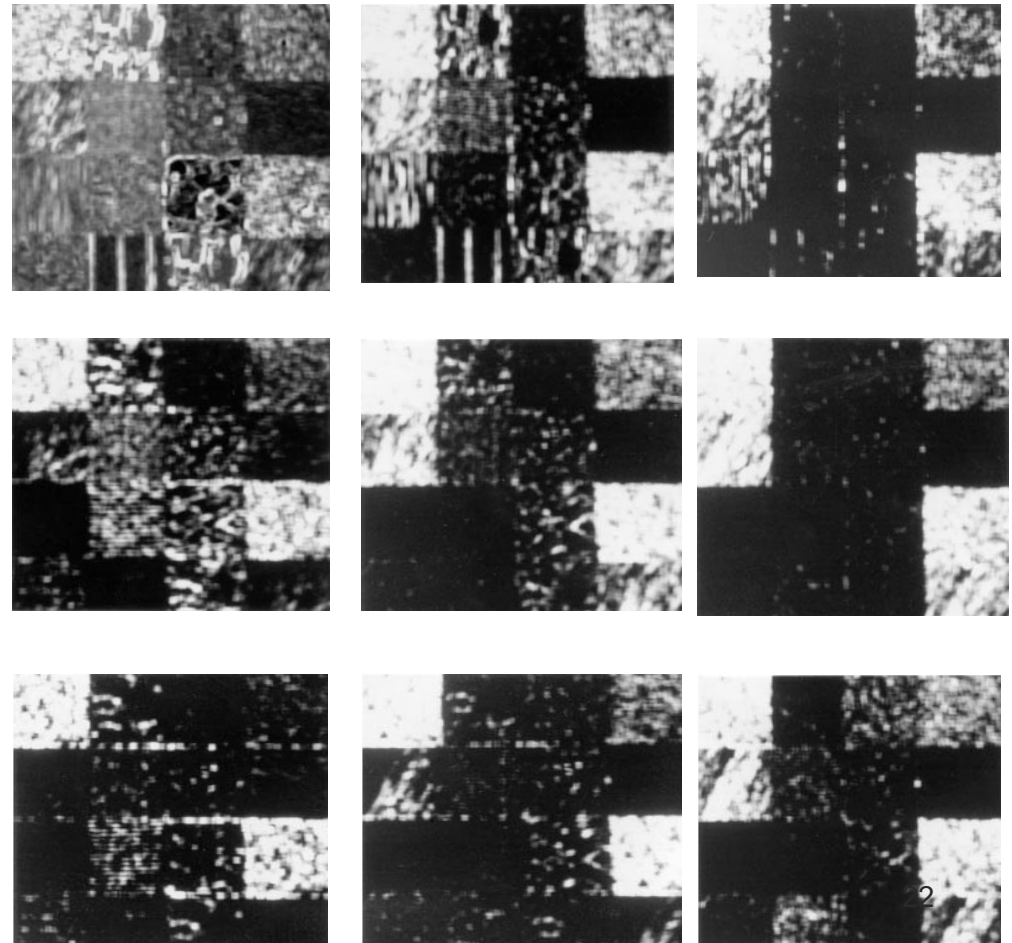
Texture Analysis

- **Laws' Method**
  - **//Step 2//** **Energy Computation** $T_i(j,k)$
    - **Extract features over a window that has <u>a few cycles of the repetitive texture</u>**
    - **How to choose the window size?**
    - 整張算出一個 feature ■ **<u>Global</u>/local energy computation**
    - **9 energy features correspond to the energy in the 9 subbands. We use the energy distribution in these 9 subbands to differentiate different texture types**
    - **Features**
      - **Mean, standard deviation, energy, smoothness etc.**

Texture Analysis

- **Laws' Method**
  - **//Step 2// Energy Computation**

Microstructure array　　　　**Local features**

$$F(j,k) \longrightarrow \boxed{H_i(j,k)} \longrightarrow M_i(j,k) \longrightarrow \boxed{\begin{array}{c}\text{Energy}\\\text{computation}\end{array}} \longrightarrow T_i(j,k)$$

For 3x3 mask
i=1,2,3,…,9

對每個點，開一個 window
最好能包含幾個重複 pattern

function 可換

e.g. $T_i(j,k) = \sum\sum_{(m,n)\in w} \left|M_i(j+m, k+n)\right|^2$

w

w

$M_i(j,k)$　　　　　$T_i(j,k)$

24
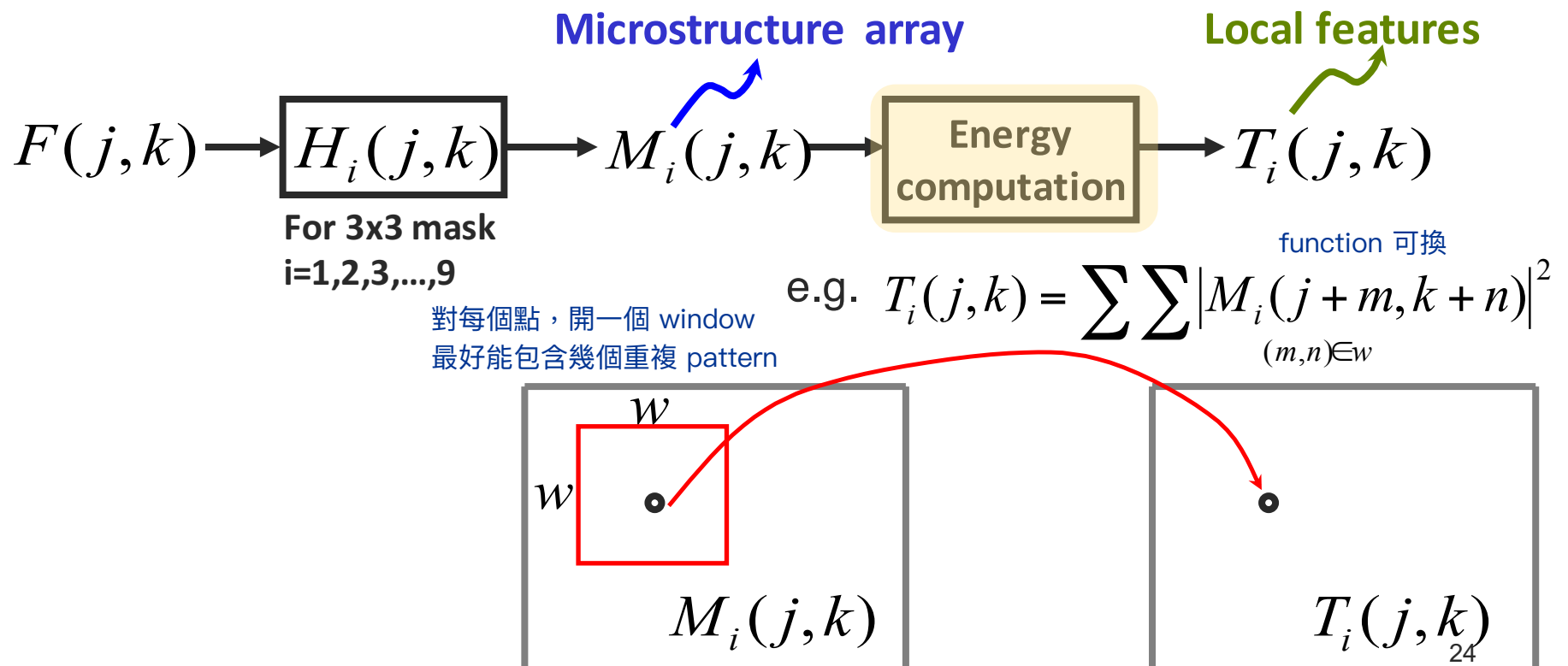
Texture Analysis

- **Notes for Laws' method**
  - How to choose the mask size? $H_i(j,k)$
  - Fixed subband structure vs
    Dynamic subband structure
  - How to choose the window size for energy computation?
    - For texture analysis, window size is usually set to be 13x13 or 15x15

Texture Analysis

- **Texture classification/segmentation**
  - Given 9 feature sets, $T_1, \; T_2, \; T_3, \cdots \; T_9$

    How do we do texture classification?

  - **Two cases**
    - **Each input is homogeneous** 每個 input 的 texture 都是類似的
    - **Single input consists of more than one texture**

  - **Two approaches**
    - **Supervised texture classification**
    - **Un-supervised texture classification**

Texture Analysis

- **Texture classification**

  - **Supervised texture classification**

    - **For each given texture type**

      $$textureA \rightarrow T_{A1}, \ T_{A2}, \ T_{A3}, \cdots \ T_{A9}$$
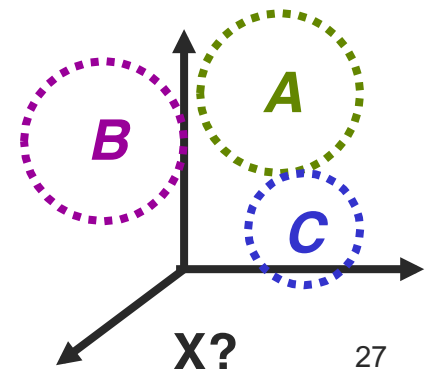 $$textureB \rightarrow T_{B1}, \ T_{B2}, \ T_{B3}, \cdots \ T_{B9}$$
      $$textureC \rightarrow T_{C1}, \ T_{C2}, \ T_{C3}, \cdots \ T_{C9}$$

    - **Texture space → 9 dimensional**

    - **Given texture X**

      Use nearest neighbor classification rule

Texture Analysis

- **Texture classification**
  - Feature space dimension reduction
    - Not considering all 9 features equally
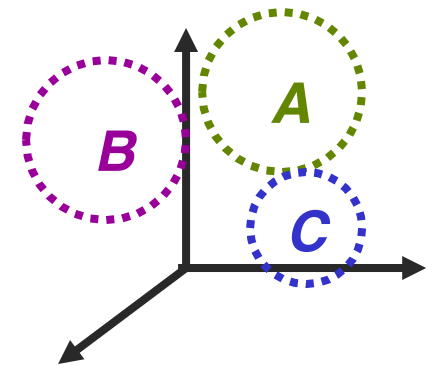   - More important feature
      - More discriminating power
      - Weighted more
    - Less important feature
      - Weighted less
      - Taken out from the feature set

Texture Analysis

- **Texture classification**
  - **Un-supervised texture classification**
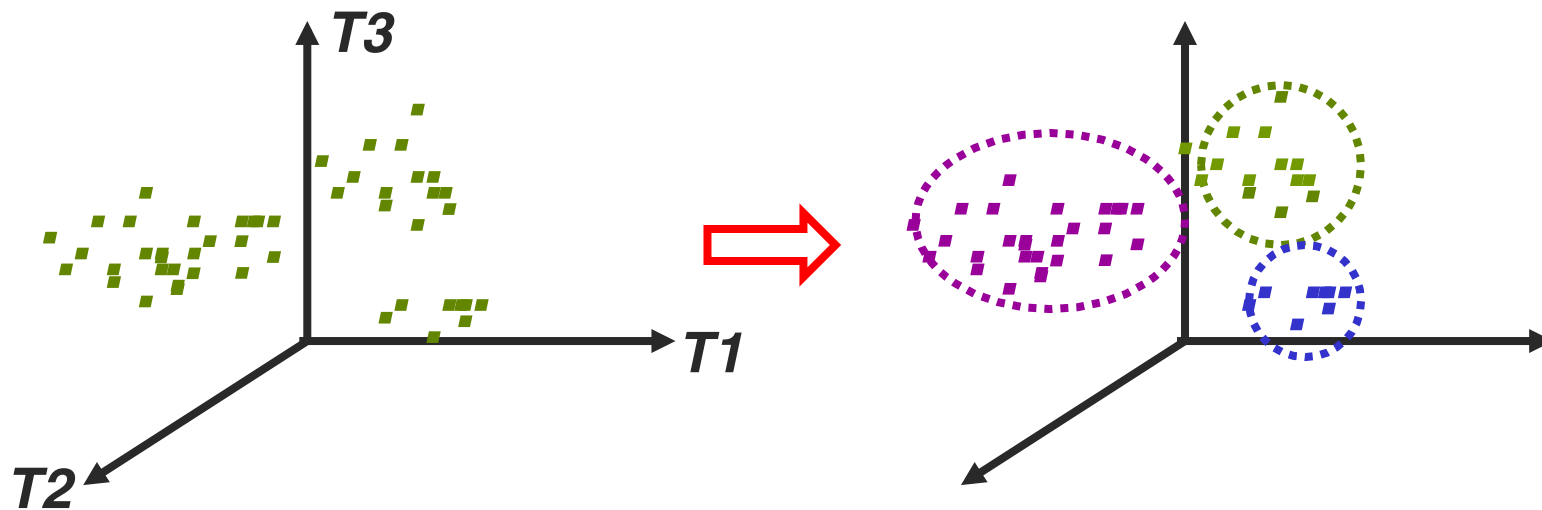   - **For several texture patches**

$$\square\ \square\ \square\ \square\ \square\ \square\ \square\ \square \quad ? \quad \begin{array}{l} A \\ B \\ C \end{array}$$

  - **K-means algorithm**
    - **The famous tool to handle unsupervised classification problem**

Texture Analysis

- **K-means algorithm**
  - K=3

  - **Good classification**
    - Inter-clustering →
    - Intra-clustering →

Texture Analysis

- **K-means algorithm**
  - **Two issues**
    - **How to choose k?**

      depends on the inter-cluster and intra-cluster statistical analysis OR by the problem set-up (domain knowledge)

    - **Given k, how to do the clustering?**
      - **// Initialization //**
        - **Select k vectors as the initial centroids**
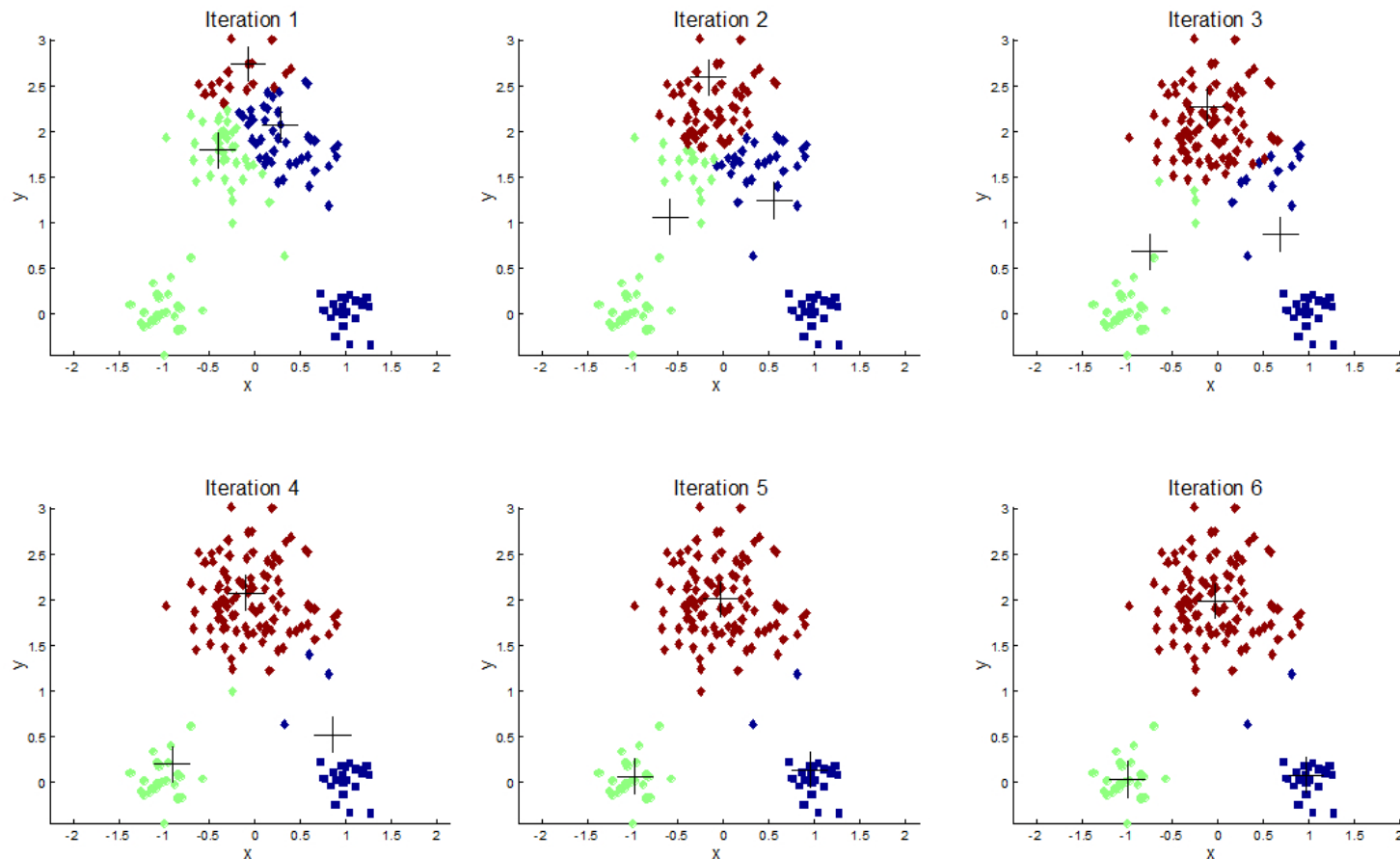   - **Do the following iterations**
      - **// step1 // Form k clusters using the NN rule**
      - **// step2 // re-compute the centroid of each cluster**

Texture Analysis

- **K-means algorithm demo**

Texture Analysis

- **Texture classification**
  - ○ **Two criterions**
    - If pixels belong to the same type of texture, their associated feature vectors are close to each other in the feature space
    - Pixels belong to the same texture type should be close to each other in the space domain

  - ○ **What is a good segmentation result?**
    - Regions of a segment should be homogeneous w.r.t. some properties (i.e. feature vectors are close to each other in the feature space)
    - Region interior should be simple and without many holes
    - Boundaries of each segment should be simple, not ragged