



Digital Image Processing

Lecture #5

Ming-Sui (Amy) Lee

[Announcement]

- **Class Information**

- **Homework #2**

- Due at **11:59 am on Apr. 12, 2016**

[Announcement]

- **Seminar Talk**

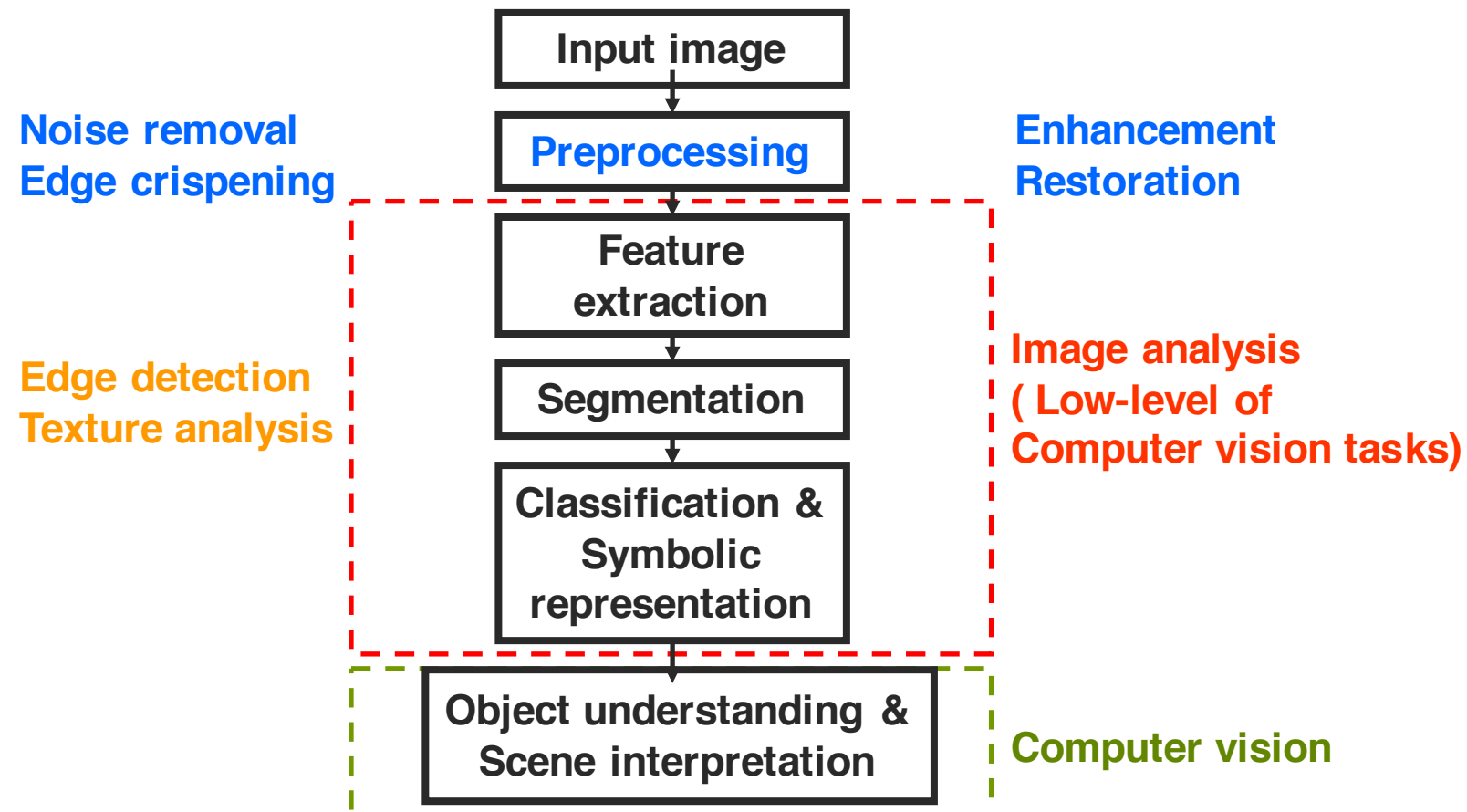
- **“Recreational Graphics: Applications in Life, Art, and Entertainment”**
 - **03/25 02:20~03:30 p.m. @ 徳田館 R103**
 - **Prof. Hung-Kuo Chu (James)**
 - **Department of Computer Science,
National Tsing Hua University**



Texture Analysis

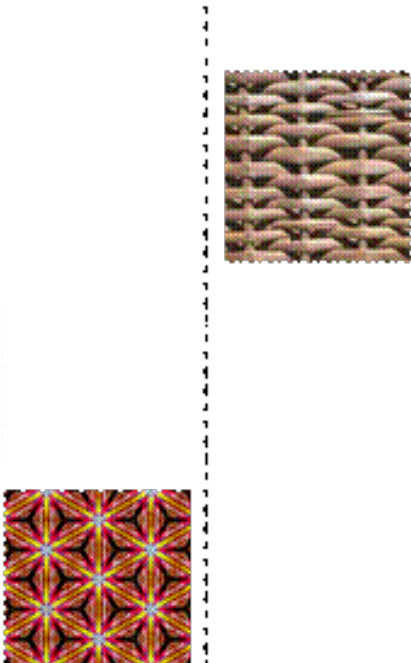
Texture Analysis

■ Image analysis and its applications



[Texture Analysis]

- What is texture?



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)



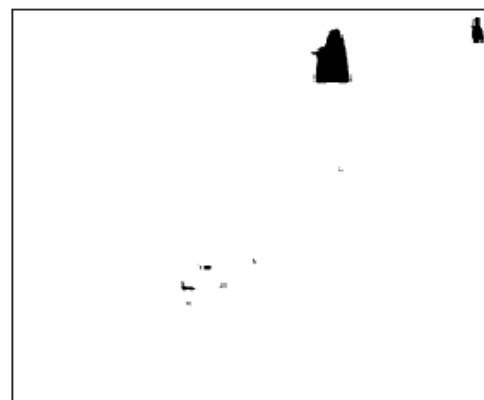
(a)



(b)



(c)

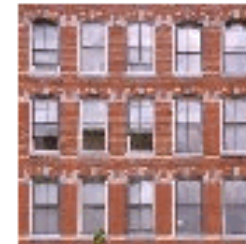
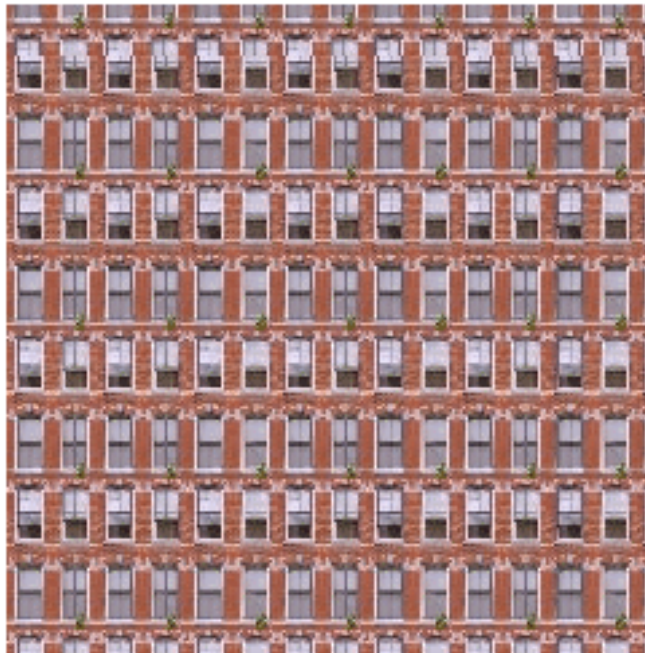


(d)

(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

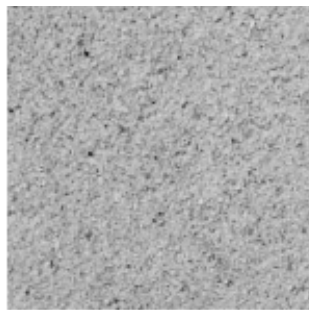
[Texture Analysis]

- **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

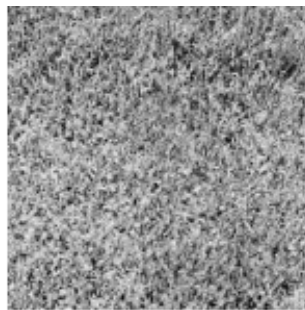
Texture Analysis

■ Autocorrelation Methods

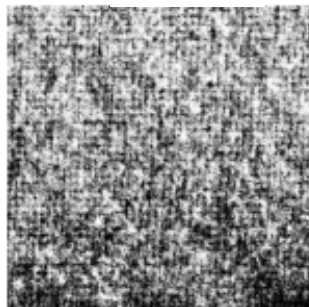
- Treat the texture pattern as a 2D random process, denoted as $F(x,y)$
- Statistical approach



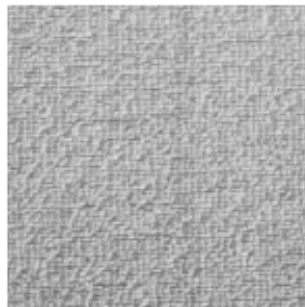
Sand



Grass



Wool



Raffia

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

Texture Analysis

■ Decorrelation Methods

○ 2D whitening filter

- Special type of decorrelation operator



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

○ Spatially decorrelated

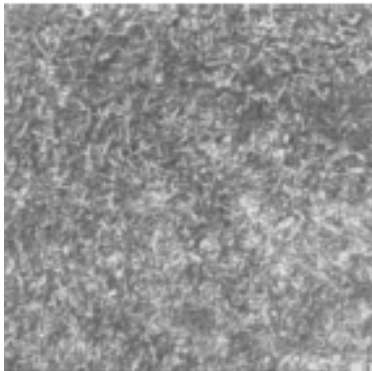
- Form histogram as its feature

Texture Analysis

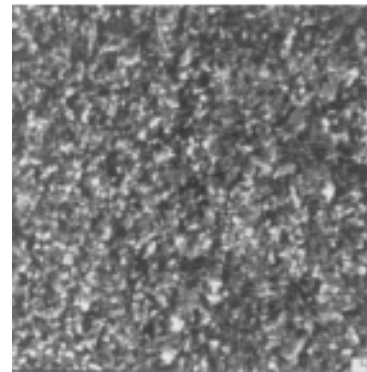
- **Dependency Matrix Method**
 - Joint probability
 - Also called Co-occurrence method

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

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



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

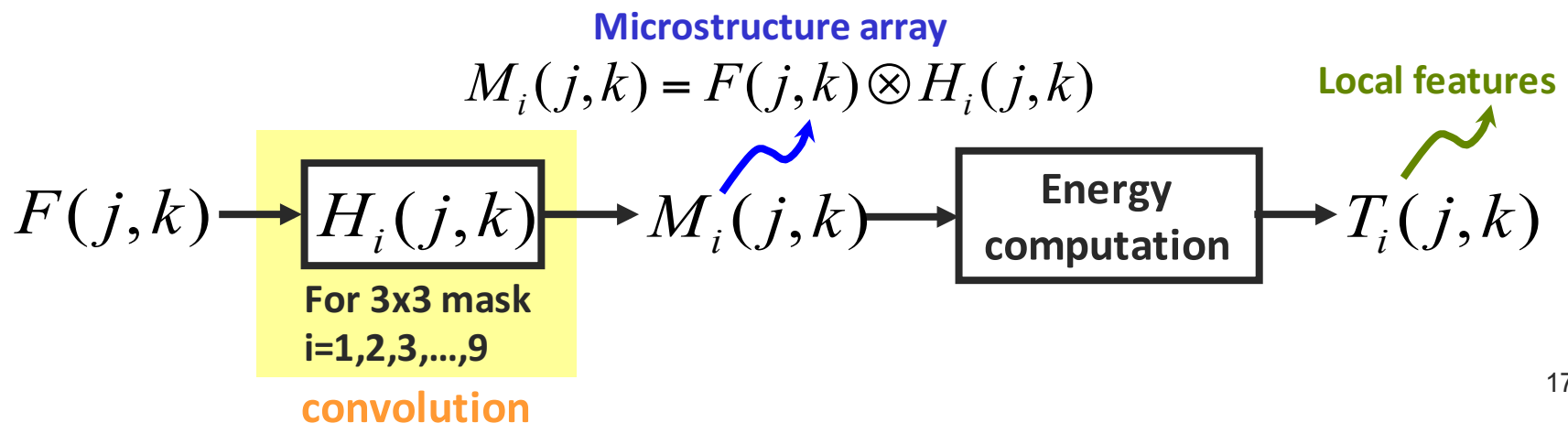
○ Micro-structure (Multi-channel) method

■ Emphasize the microstructure of the texture

■ Two steps

○ step 1: Convolution

○ step 2: Energy computation



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)

$H_i(j,k)$

for 3x3 mask,
 $i=1,2,3,\dots,9$

for 5x5 mask,
 $i=1,2,3,\dots,25$

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 **tensor product** of the 1D horizontal and vertical masks

$$L_3 = \frac{1}{6} \begin{bmatrix} 1 & 2 & 1 \end{bmatrix}$$

Local averaging

$$E_3 = \frac{1}{2} \begin{bmatrix} -1 & 0 & 1 \end{bmatrix}$$

Edge detector
(1st-order gradient)

$$S_3 = \frac{1}{2} \begin{bmatrix} 1 & -2 & 1 \end{bmatrix}$$

spot detector
(2nd-order gradient)

■ E.g.

$$L_3^T \otimes E_3 = \frac{1}{6} \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \otimes \frac{1}{2} \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} = \frac{1}{12} \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad \text{Laws 2}^{19}$$

[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

$$L_3 = \frac{1}{6} \begin{bmatrix} 1 & 2 & 1 \end{bmatrix}$$

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

Kronecker Delta 

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

→ Low-pass filter

Texture Analysis

■ Laws' Method

○ Micro-structure impulse response arrays

- Examine the frequency response of L_3 , E_3 , and S_3

$$E_3 = \frac{1}{2} \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \quad h[n] = \frac{1}{2} (-\delta[n-1] + \delta[n+1])$$

$$H(\omega) = (-e^{-j\omega} + e^{j\omega}) = 2j \sin \omega \quad \rightarrow \text{Bandpass filter}$$

$$S_3 = \frac{1}{2} \begin{bmatrix} 1 & -2 & 1 \end{bmatrix} \quad h[n] = \frac{1}{2} (\delta[n-1] - 2\delta[n] + \delta[n+1])$$

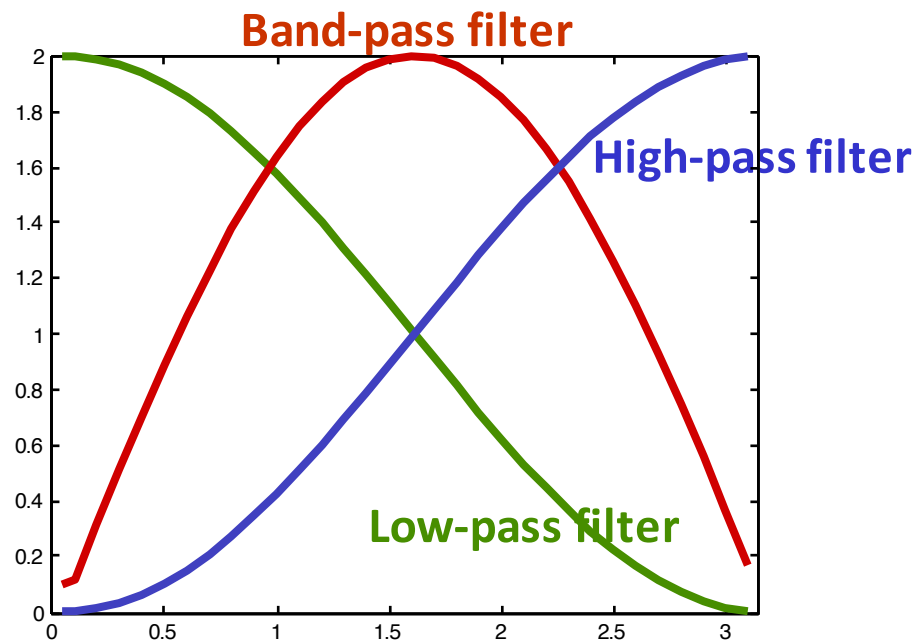
$$H(\omega) = \frac{1}{2} (e^{-j\omega} - 2 + e^{j\omega}) = \cos \omega - 1 \quad \rightarrow \text{High-pass filter}$$

Texture Analysis

■ Laws' Method

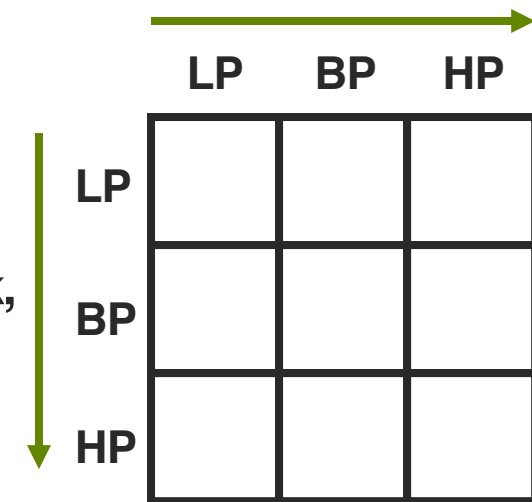
○ Micro-structure impulse response arrays

- Examine the frequency response of L_3 , E_3 , and S_3



$$H_i(j, k)$$

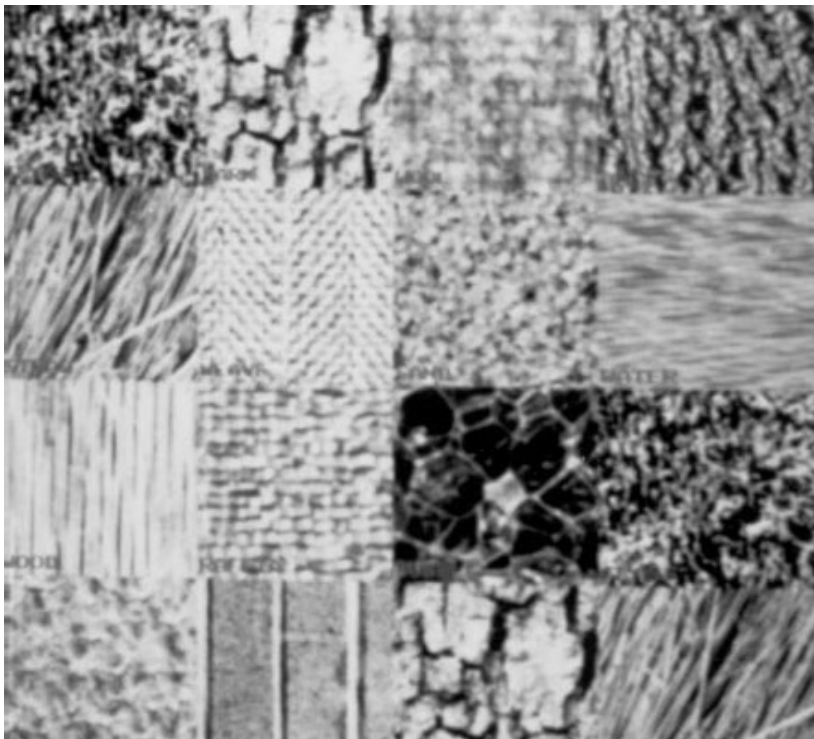
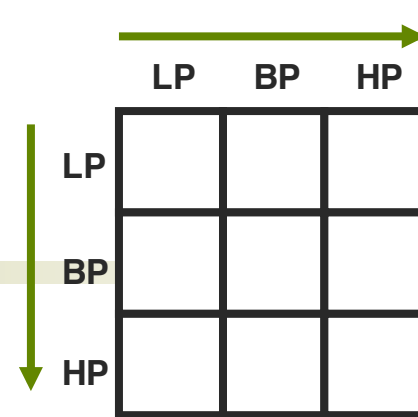
for 3x3 mask,
 $i=1,2,3,\dots,9$



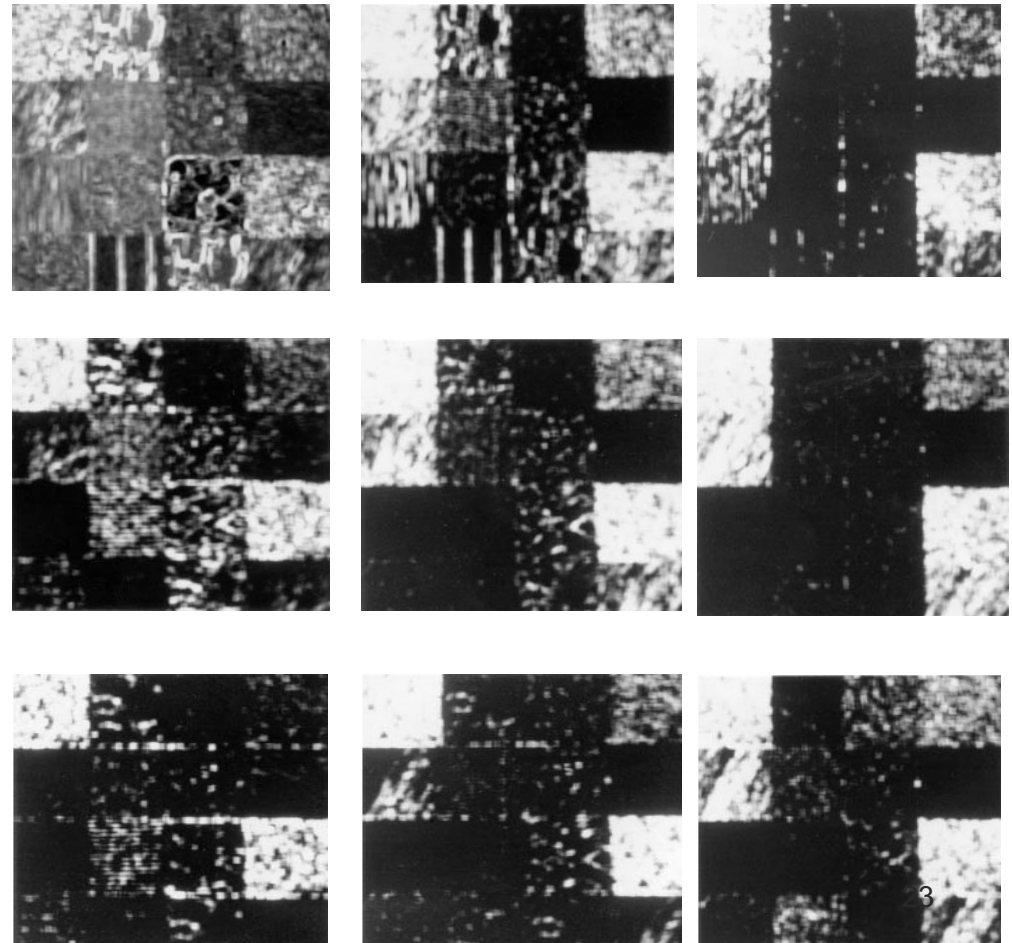
// Multi-channel method //

[Texture Analysis]

■ Example



original image



[Texture Analysis]

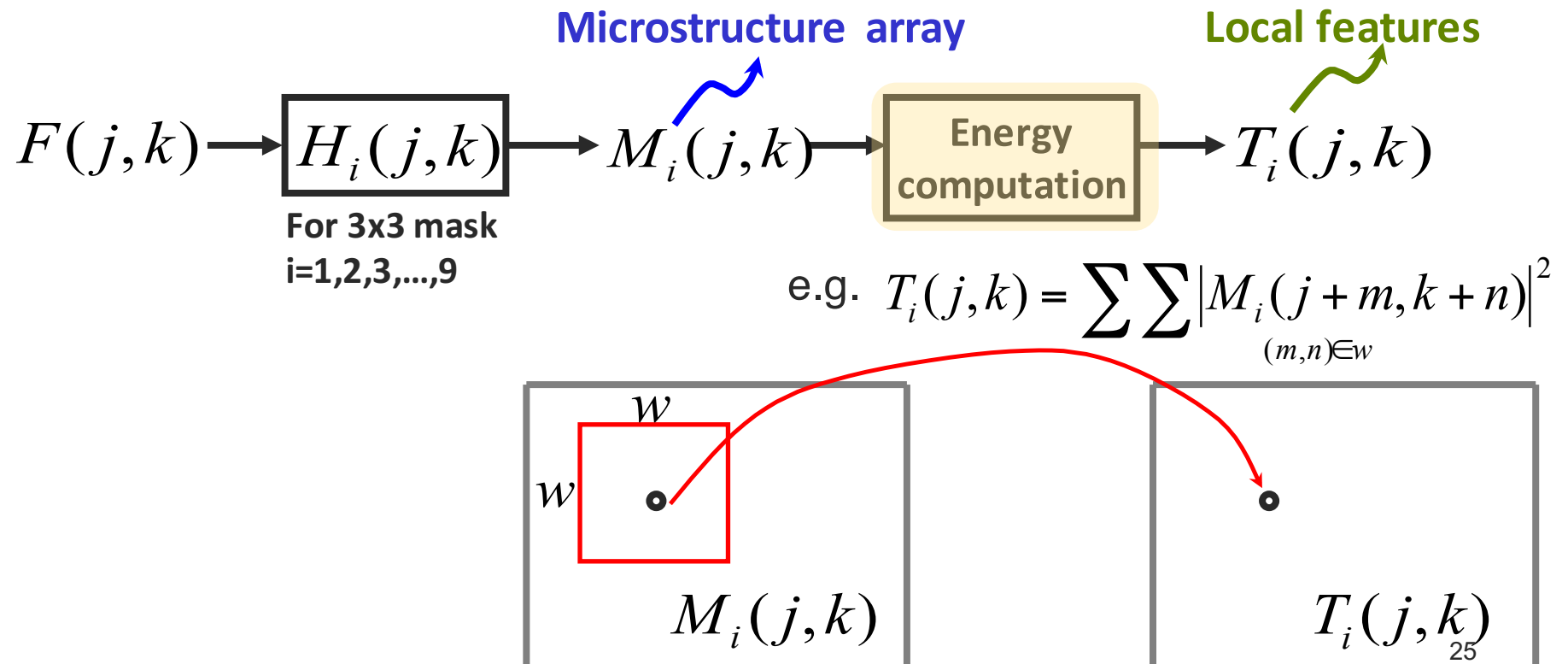
■ Laws' Method

- **//Step 2//** Energy Computation $T_i(j, k)$
 - Extract features over a window that has a few cycles of the repetitive texture
 - How to choose the window size?
 - Global/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



[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, $T_1, T_2, T_3, \dots, T_9$
How do we do texture classification?
 - Two cases
 - Each input is homogeneous
 - 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

$textureA \rightarrow T_{A1}, T_{A2}, T_{A3}, \dots T_{A9}$

$textureB \rightarrow T_{B1}, T_{B2}, T_{B3}, \dots T_{B9}$

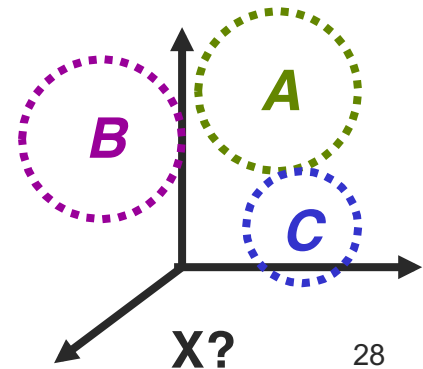
$textureC \rightarrow T_{C1}, T_{C2}, T_{C3}, \dots T_{C9}$



- Texture space \rightarrow 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

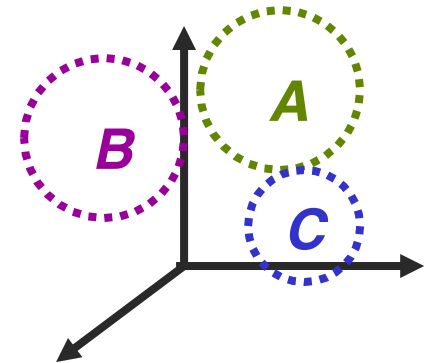
○ More discriminating power

○ 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



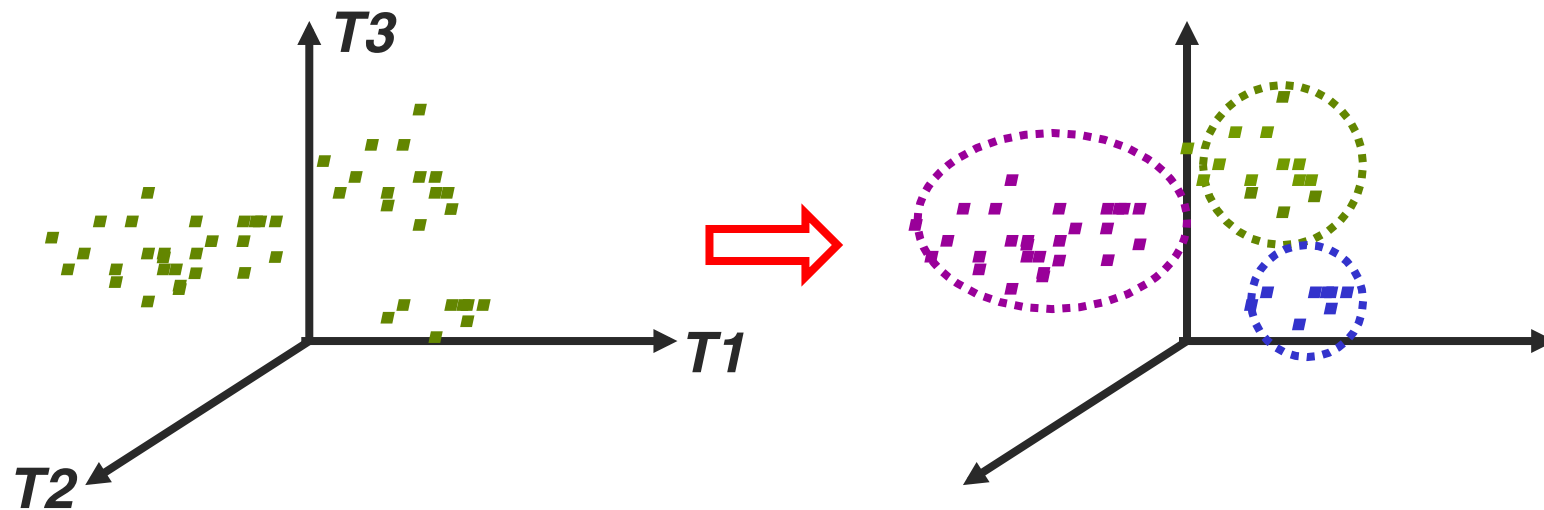
- K-means algorithm

- 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

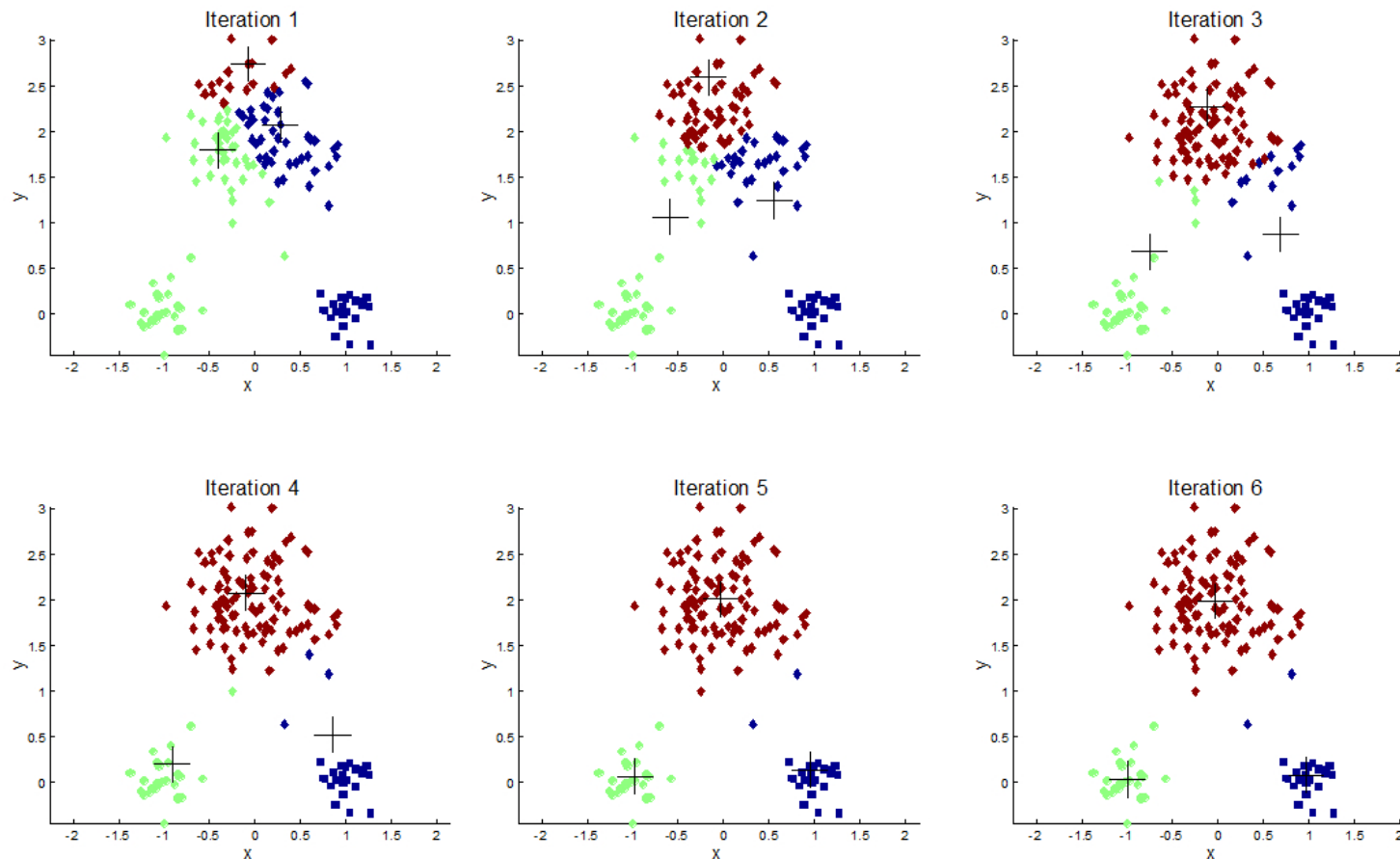
- Do the following iterations

- // 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 criteria**

- 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