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# TEXTURE

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# Texture?

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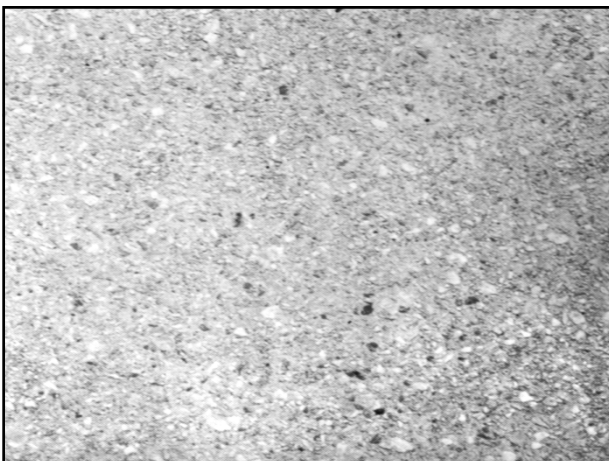
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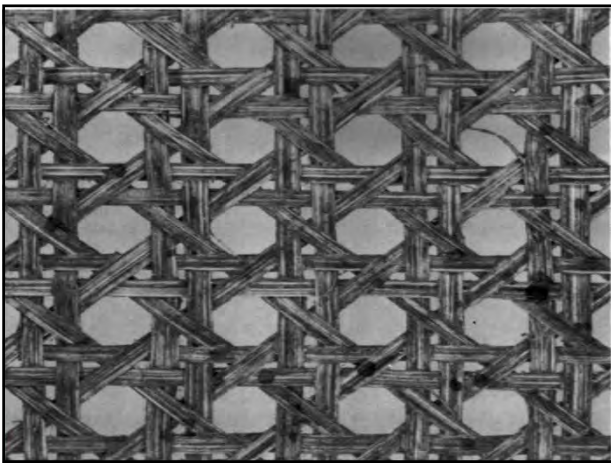
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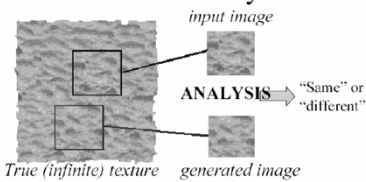
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 **Issues in Texture Analysis**

**Discrimination**

The Goal of Texture Analysis



Compare textures and decide if they're made of the same "stuff".

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Issues in Texture Analysis

**Synthesis**

*True (infinite) texture*      *input image*      **SYNTHESIS**      *generated image*

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Aspects of texture

- Size or granularity (sand versus pebbles versus boulders)
- Directionality (stripes versus sand)
- Random or regular (sawdust versus woodgrain; stucko versus bricks)
- Concept of texture elements (texel) and spatial arrangement of texels

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What is Texture?

- Something that repeats with variation.
- Must separate what repeats and what stays the same.
- Model as repeated trials of a random process
  - The probability distribution stays the same.
  - But each trial is different.
  - This may be true (eg., pile of objects)
  - Or not really (tile floor).

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Pre-attentive texture discrimination

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Pre-attentive texture discrimination

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Pre-attentive texture discrimination

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Bela Julesz, "Textons, the Elements of Texture Perception, and their Interactions". Nature 290: 91-97. March, 1981.

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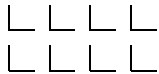
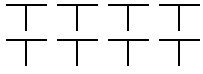
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Julesz

- Textons: analyze the texture in terms of statistical relationships between fundamental texture elements, called "textons".
- It generally required a human to look at the texture in order to decide what those fundamental units were...

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Texture Description

**Statistical**

**Structured**

**Spectral**

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Statistical Texture Description

- Co-occurrence Matrices
- Edge Frequencies
- Laws Texture Measures
- Fractal texture
- Wavelet Domain (Multiscale, Gabor)
- Markov Random Fields

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## Simple Description

- Each pixel independent, identically distributed (iid).
- Examples:
  - Region of constant intensity.
  - Gaussian noise pattern.
  - Speckled pattern

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## Simple Description

- Compare sample distributions (histograms).
  - Divide intensities into discrete ranges.
  - Count how many pixels in each range.

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## Edge Density and Direction

- Use an edge detector as the first step in texture analysis.
- The number of edge pixels in a fixed-size region tells us how busy that region is.
- The directions of the edges also help characterize the texture

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Co-occurrence Matrix Features

A co-occurrence matrix is a 2D array C in which

- Both the rows and columns represent a set of possible image values
- $C_d(i,j)$  indicates how many times value  $i$  co-occurs with value  $j$  in a particular spatial relationship  $d$ .
- The spatial relationship is specified by a vector  $d = (dr,dc)$ .

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Co-occurrence Matrix Features

1	1	0	0
1	1	0	0
0	0	2	2
0	0	2	2
0	0	2	2
0	0	2	2

gray-tone image

1

$d = (3,1)$

0	1	0	3
1	2	0	2
2	0	0	1

$C_d$

co-occurrence matrix

From  $C_d$  we can compute  $N_d$ , the normalized co-occurrence matrix, where each value is divided by the sum of all the values.

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Co-occurrence Features

What do these measure?

$$Energy = \sum_i \sum_j N_d^2(i,j) \quad (7.7)$$

$$Entropy = - \sum_i \sum_j N_d(i,j) \log_2 N_d(i,j) \quad (7.8)$$

$$Contrast = \sum_i \sum_j (i-j)^2 N_d(i,j) \quad (7.9)$$

$$Homogeneity = \sum_i \sum_j \frac{N_d(i,j)}{1+|i-j|} \quad (7.10)$$

$$Correlation = \frac{\sum_i \sum_j (i-\mu_i)(j-\mu_j) N_d(i,j)}{\sigma_i \sigma_j} \quad (7.11)$$

where  $\mu_i, \mu_j$  are the means and  $\sigma_i, \sigma_j$  are the standard deviations of the row and column sums.

Energy measures uniformity of the normalized matrix.

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**Laws' Texture Energy Features**

- Signal-processing-based algorithms use texture filters applied to the image to create filtered images from which texture features are computed.
- The Laws Algorithm
  - **Filter** the input image using texture filters.
  - **Compute texture energy** by summing the absolute value of filtering results in local neighborhoods around each pixel.
  - **Combine features** to achieve rotational invariance.

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**Law's texture masks (1)**

$$\begin{array}{l}
 L5 \text{ (Level)} = [ 1 \ 4 \ 6 \ 4 \ 1 ] \\
 E5 \text{ (Edge)} = [ -1 \ -2 \ 0 \ 2 \ 1 ] \\
 S5 \text{ (Spot)} = [ -1 \ 0 \ 2 \ 0 \ -1 ] \\
 R5 \text{ (Ripple)} = [ 1 \ -4 \ 6 \ -4 \ 1 ]
 \end{array}$$

- (L5) (Gaussian) gives a center-weighted local average
- (E5) (gradient) responds to row or col step edges
- (S5) (LOG) detects spots
- (R5) (Gabor) detects ripples

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**Law's texture masks (2)**

Creation of 2D Masks

- 1D Masks are "multiplied" to construct 2D masks:  
mask E5L5 is the "product" of E5 and L5 -

$$\begin{array}{c}
 E5 \\
 \begin{bmatrix} -1 \\ -2 \\ 0 \\ 2 \\ 1 \end{bmatrix}
 \end{array}
 \times
 \begin{array}{c}
 L5 \\
 [ 1 \ 4 \ 6 \ 4 \ 1 ]
 \end{array}
 =
 \begin{array}{c}
 E5L5 \\
 \begin{bmatrix} -1 & -4 & -6 & -4 & -1 \\ -2 & -8 & -12 & -8 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 2 & 8 & 12 & 8 & 2 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix}
 \end{array}$$

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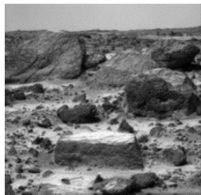
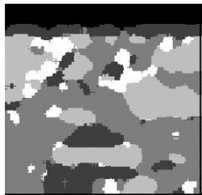
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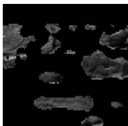
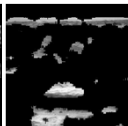
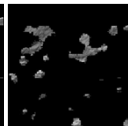
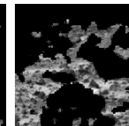
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## Texture Segmentation

MARS-Path Finder

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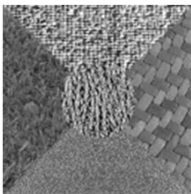

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## Texture Segmentation

BRODATZ Texture Album

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## Markov Models

- Captures local dependencies.
  - Each pixel depends on neighborhood.
  - Example, 1D first order model

$$\begin{aligned}
 P(p_1, p_2, \dots, p_n) &= \\
 &P(p_1) * P(p_2|p_1) * P(p_3|p_2, p_1) * \dots \\
 &= P(p_1) * P(p_2|p_1) * P(p_3|p_2) * P(p_4|p_3) * \dots
 \end{aligned}$$

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## Markov Model of printed Text

- From Shannon: "A mathematical theory of communication."
- Think of text as a 1D texture
- Choose next letter at random, based on previous letters.

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## 1D Markov Model

- Zero'th order:  
XFOML RXKHJFFJUJ ZLPWCFWKCYJ  
FFJEYVKCQSGHYD  
QPAAMKBZAACIBZIHJQD
- First order:  
OCRO HLI RGWR NMIELWIS EU LL  
NBNESEBYA TH EEI ALHENHTTPA  
OOBTTVA NAH BRI

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## 1D Markov Model

First order:  
OCRO HLI RGWR NMIELWIS EU LL  
NBNESEBYA TH EEI ALHENHTTPA  
OOBTTVA NAH BRI

Second order  
ON IE ANTSOUTINYS ARE T  
INCTORE T BE S DEAMY ACHIN D  
ILONASIVE TUCOOWE AT  
TEASONARE FUSO TIZIN ANDY  
TOBE SEACE CTISBE

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## 1D Markov Model

Second order

ON IE ANTSOUTINYS ARE T  
 INCTORE T BE S DEAMY ACHIN D  
 ILONASIVE TUCCOOWE AT  
 TEASONARE FUSO TIZIN ANDY  
 TOBE SEACE CTISBE

Third order

IN NO IST LAT WHEY CRATICT FROURE  
 BIRS GROCID PONDENOME OF  
 DEMONSTURES OF THE REPTAGIN IS  
 REGOACTIONA OF CRE.

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## Markov for Words

- First order:  
 REPRESENTING AND SPEEDILY IS AN GOOD APT  
 OR COME CAN DIFFERENT NATURAL HERE HE  
 THE A IN CAME THE TO OF TO EXPERT GRAY  
 COME TO FURNISHES THE LINE MESSAGE HAD  
 BE THESE.
- Second order:  
 THE HEAD AND IN FRONTAL ATTACK ON AN  
 ENGLISH WRITER THAT THE CHARACTER OF  
 THIS POINT IS THEREFORE ANOTHER METHOD  
 FOR THE LETTERS THAT THE TIME OF WHO  
 EVER TOLD THE PROBLEM FOR AN  
 UNEXPECTED.

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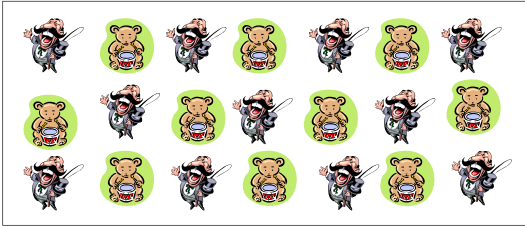
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## Structural Texture

- Structural approach: a set of texels in some regular or repeated pattern



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**Structural Texture Rules**

S → aS

"a" is a basic pattern (TEXEL)

S → aaaaaS, results in:

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"a" ... Circle Right  
 "b" ... Circle Down  
 "c" ... Circle Left

aaabccbaa ..... 3 x 3 Circles

Texel

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