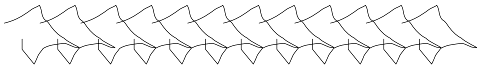
Texture

Texture is a description of the spatial arrangement of color or intensities in an image or a selected region of an image.

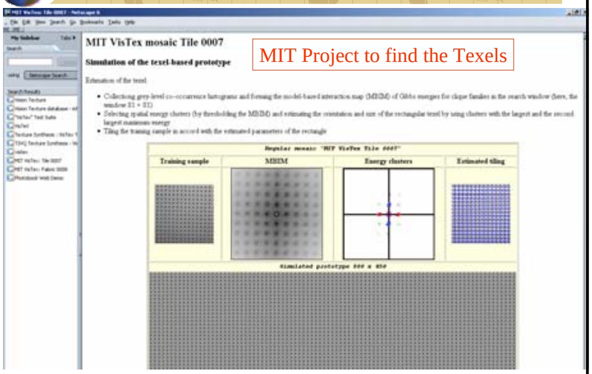
Structural approach: a set of texels in some regular or repeated pattern

Problem with Structural Approach

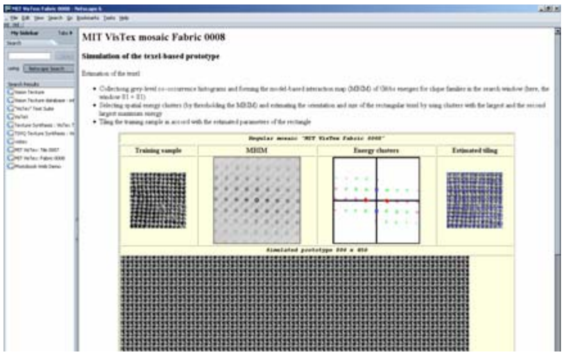
How do you decide what is a texel?



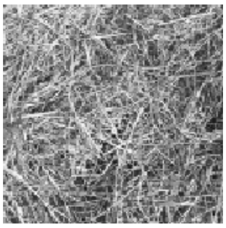
Ideas?



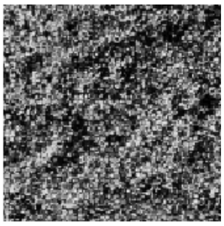
MIT Project to find the Texels



Natural Textures from VisTex



grass



leaves

What/Where are the texels?

The Case for Statistical Texture

- Segmenting out texels is difficult or impossible in real images.
- Numeric quantities or statistics that describe a texture can be computed from the gray tones (or colors) alone.
- This approach is less intuitive, but is computationally efficient.
- It can be used for both classification and segmentation.

Some Simple Statistical Texture Measures

1. 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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Two Edge-based Texture Measures

1. edgeness per unit area

$F_{edgeness}$ = |{ p | gradient_magnitude(p) ≥ threshold}| / N

where N is the size of the unit area

2. edge magnitude and direction histograms

F_{magdir} = ($H_{magnitude}$, $H_{direction}$)

where these are the normalized histograms of gradient magnitudes and gradient directions, respectively.

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Original Image	Frei-Chen Edge Image	Thresholded Edge Image

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Local Binary Partition Measure

- For each pixel p, create an 8-bit number b_1 b_2 b_3 b_4 b_5 b_6 b_7 b_8, where b_i = 0 if neighbor i has value less than or equal to p's value and 1 otherwise.
- Represent the texture in the image (or a region) by the histogram of these numbers.

Neighbor positions: 1 2 3 (top row), 8 (left), 4 (right), 7 6 5 (bottom row)

100	101	103
40	50	80
50	60	90

→ 1 1 1 1 1 1 0 0

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Fids (Flexible Image Database System) is retrieving images similar to the query image using LBP texture as the texture measure and comparing their LBP histograms

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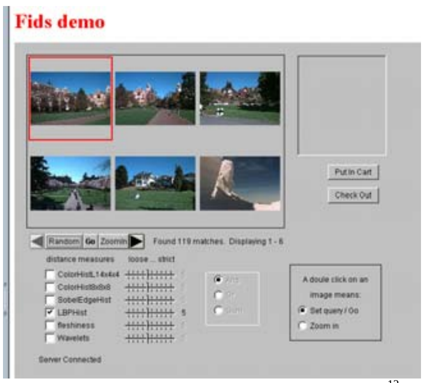
Low-level measures don't always find semantically similar images.



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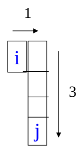
1	1	0	0
1	1	0	0
0	0	2	2
0	0	2	2
0	0	2	2
0	0	2	2

gray-tone image



d = (3,1)

	0	1	2
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 μ_i, μ_j are the means and σ_i, σ_j are the standard deviations of the row and column sums.

Energy measures uniformity of the normalized matrix.

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But how do you choose d?

- This is actually a critical question with **all** the statistical texture methods.
- Are the "texels" tiny, medium, large, all three …?
- Not really a solved problem.

Zucker and Terzopoulos suggested using a χ^2 statistical test to select the value(s) of d that have the most structure for a given class of images. See transparencies.

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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)

L5	(Level)	= [	1	4	6	4	1	]
E5	(Edge)	= [	-1	-2	0	2	1	]
S5	(Spot)	= [	-1	0	2	0	-1	]
R5	(Ripple)	= [	1	-4	6	-4	1	]

- (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 –

$$\underset{\text{E5}}{\begin{bmatrix}-1\\-2\\0\\2\\1\end{bmatrix}} \times \underset{\text{L5}}{\begin{bmatrix}1 & 4 & 6 & 4 & 1\end{bmatrix}} = \underset{\text{E5L5}}{\begin{bmatrix}-1 & -4 & -6 & -4 & -1\\-2 & -8 & -12 & -8 & -1\\0 & 0 & 0 & 0 & 0\\2 & 8 & 12 & 8 & 2\\1 & 4 & 6 & 4 & 1\end{bmatrix}}$$

9D feature vector for pixel

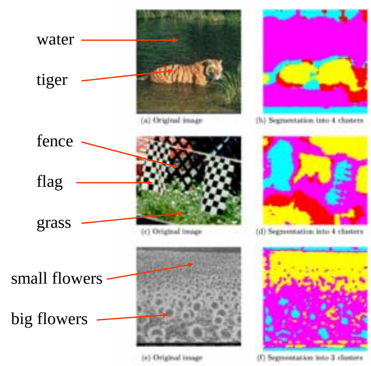
- Subtract mean neighborhood intensity from pixel
- Dot product 16 5x5 masks with neighborhood
- 9 features defined as follows:

L5E5/E5L5	L5S5/S5L5
L5R5/R5L5	E5E5
E5S5/S5E5	E5R5/R5E5
S5S5	S5R5/R5S5
R5R5	

Features from sample images

Table 7.2: Laws texture energy measures for major regions of the images of Figure 7.8.

Region	E5E5	S5S5	R5R5	E5L5	S5L5	R5L5	S5E5	R5E5	R5S5
Tiger	168.1	84.0	807.7	553.7	354.4	910.6	116.3	339.2	257.4
Water	68.5	36.9	366.8	218.7	149.3	459.4	49.6	159.1	117.3
Flags	258.1	113.0	787.7	1057.6	702.2	2056.3	182.4	611.5	350.8
Fence	189.5	80.7	624.3	701.7	377.5	803.1	120.6	297.5	215.0
Grass	206.5	103.6	1031.7	625.2	428.3	1153.6	146.0	427.5	323.6
Small flowers	114.9	48.6	289.1	402.6	241.3	484.3	73.6	158.2	109.3
Big flowers	76.7	28.8	177.1	301.5	158.4	270.0	45.6	89.7	62.9
Borders	15.3	6.4	64.4	92.3	36.3	74.5	9.3	26.1	19.5



Is there a neighborhood size problem with Laws?

Autocorrelation function

- Autocorrelation function can detect repetitive paterns of texels
- Also defines fineness/coarseness of the texture
- Compare the dot product (energy) of non shifted image with a shifted image

$$\rho(dr, dc) = \frac{\sum_{r=0}^{N}\sum_{c=0}^{N} I[r,c]I(r+dr,c+dc]}{\sum_{r=0}^{N}\sum_{c=0}^{N} I^2[r,c]} = \frac{I[r,c] \circ I_d[r,c]}{I[r,c] \circ I[r,c]}$$

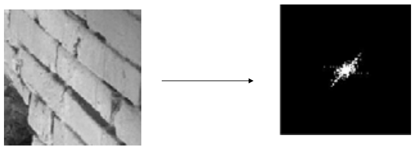
Interpreting autocorrelation

- Coarse texture → function drops off slowly
- Fine texture → function drops off rapidly
- Can drop differently for r and c
- Regular textures → function will have peaks and valleys; peaks can repeat far away from [0, 0]
- Random textures → only peak at [0, 0]; breadth of peak gives the size of the texture

Fourier power spectrum

- High frequency power → fine texture
- Concentrated power → regularity
- Directionality → directional texture

Fourier example



What else?

- Gabor filters (we’ve been using)
- Wold decomposition
- Global Signatures (CANDID)
- DOOG filter
- Second Moment Matrix (Belongie and Malik)
- 3D Textons (Leung and Malik)

etc.