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?
Natural Textures from VisTex

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.

Two Edge-based Texture Measures

1. edgeness per unit area

\[
F_{\text{edgeness}} = \frac{|\{ p \mid \text{gradient\_magnitude}(p) \geq \text{threshold}\}|}{N}
\]

where \(N\) is the size of the unit area

2. edge magnitude and direction histograms

\[
F_{\text{magdir}} = (H_{\text{magnitude}}, H_{\text{direction}})
\]

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

How would you compare two histograms?
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.

\[
\begin{array}{ccccccccc}
100 & 101 & 103 & 40 & 50 & 80 & 50 & 60 & 90 \\
8 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8
\end{array}
\]

\[11111100\]
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 $d = (dr,dc)$.

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.

Co-occurrence Features

What do these measure?

- Energy measures uniformity of the normalized matrix.
- Entropy
- Contrast
- Homogeneity
- Correlation

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 $\chi^2$ statistical test to select the value(s) of $d$ that have the most structure for a given class of images. See transparencies.
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.

Law’s texture masks (1)

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

9D feature vector for pixel

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

\[
\begin{array}{c}
L5E5/E5L5 \\
L5R5/R5L5 \\
E5S5/E5S5 \\
S5S5 \\
R5R5
\end{array}
\]
Features from sample images

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

<table>
<thead>
<tr>
<th>Region</th>
<th>R0.05</th>
<th>S0.05</th>
<th>R0.10</th>
<th>S0.10</th>
<th>R0.15</th>
<th>S0.15</th>
<th>R0.20</th>
<th>S0.20</th>
<th>R0.25</th>
<th>S0.25</th>
<th>R0.30</th>
<th>S0.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tiger</td>
<td>16.4</td>
<td>13.3</td>
<td>15.2</td>
<td>14.8</td>
<td>15.4</td>
<td>15.4</td>
<td>16.5</td>
<td>16.4</td>
<td>17.2</td>
<td>17.3</td>
<td>18.0</td>
<td>18.1</td>
</tr>
<tr>
<td>Water</td>
<td>12.5</td>
<td>10.3</td>
<td>11.8</td>
<td>11.8</td>
<td>12.0</td>
<td>12.0</td>
<td>12.8</td>
<td>12.8</td>
<td>13.8</td>
<td>14.1</td>
<td>14.9</td>
<td>15.1</td>
</tr>
<tr>
<td>Flags</td>
<td>25.6</td>
<td>20.7</td>
<td>25.7</td>
<td>23.0</td>
<td>25.2</td>
<td>24.4</td>
<td>25.4</td>
<td>25.4</td>
<td>26.5</td>
<td>26.8</td>
<td>27.8</td>
<td>28.0</td>
</tr>
<tr>
<td>Fence</td>
<td>17.8</td>
<td>17.7</td>
<td>17.2</td>
<td>16.9</td>
<td>17.5</td>
<td>17.0</td>
<td>18.0</td>
<td>17.9</td>
<td>19.0</td>
<td>18.9</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Grass</td>
<td>28.8</td>
<td>24.1</td>
<td>32.9</td>
<td>28.6</td>
<td>32.6</td>
<td>29.0</td>
<td>33.8</td>
<td>30.3</td>
<td>35.7</td>
<td>33.6</td>
<td>37.5</td>
<td>35.6</td>
</tr>
<tr>
<td>Small flowers</td>
<td>16.9</td>
<td>14.6</td>
<td>20.1</td>
<td>16.8</td>
<td>21.9</td>
<td>17.8</td>
<td>25.4</td>
<td>20.0</td>
<td>29.6</td>
<td>22.9</td>
<td>29.0</td>
<td>23.9</td>
</tr>
<tr>
<td>Big flowers</td>
<td>65.7</td>
<td>52.4</td>
<td>77.4</td>
<td>64.4</td>
<td>86.4</td>
<td>64.4</td>
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<td>62.6</td>
<td>116.4</td>
<td>68.4</td>
<td>127.5</td>
<td>69.0</td>
</tr>
</tbody>
</table>

Autocorrelation function

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

\[ \rho(dr, dc) = \sum_{x=0}^{N} \sum_{y=0}^{N} f(x) \cdot f(x+dr, y+dc) \]
\[ \sum_{x=0}^{N} \sum_{y=0}^{N} f(x)^2 \cdot f(y)^2 \]

Interpreting autocorrelation

- Coarse texture \( \rightarrow \) function drops off slowly
- Fine texture \( \rightarrow \) function drops off rapidly
- Can drop differently for \( r \) and \( c \)
- Regular textures \( \rightarrow \) function will have peaks and valleys; peaks can repeat far away from \( [0, 0] \)
- Random textures \( \rightarrow \) only peak at \( [0, 0] \); breadth of peak gives the size of the texture
Fourier power spectrum
- High frequency power $\rightarrow$ fine texture
- Concentrated power $\rightarrow$ regularity
- Directionality $\rightarrow$ directional texture

What else?
- Gabor filters
- Wold decomposition
- Global Signatures (CANDID)
- Second Moment Matrix (Belongie paper)
- DOOG filter
- etc.

Fourier example