Announcements

• Reminder: A1 due this Friday

Review

• Edge detection:
  – Filter for gradient
  – Threshold gradient magnitude, thin

• Chamfer matching to compare shapes (in terms of edge points)

• Binary image analysis
  – Thresholding
  – Morphological operators to “clean up”
  – Connected components to find regions

Today: Texture

What defines a texture?

Includes: more regular patterns

Includes: more random patterns
Scale and texture

Texture-related tasks

- **Shape from texture**
  - Estimate surface orientation or shape from image texture

Shape from texture

- Use deformation of texture from point to point to estimate surface shape

Texture-related tasks

- **Shape from texture**
  - Estimate surface orientation or shape from image texture
- **Segmentation/classification** from texture cues
  - Analyze, represent texture
  - Group image regions with consistent texture
- **Synthesis**
  - Generate new texture patches/images given some examples

Analysis vs. Synthesis

Why analyze texture?
What kind of response will we get with an edge detector for these images?

Why analyze texture?
Importance to perception:
• Often indicative of a material's properties
• Can be important appearance cue, especially if shape is similar across objects
• Aim to distinguish between shape, boundaries, and texture

Technically:
• Representation-wise, we want a feature one step above "building blocks" of filters, edges.

Psychophysics of texture
• Some textures distinguishable with preattentive perception—without scrutiny, eye movements
  [Julesz 1975]

Same or different?
Capturing the local patterns with image measurements


Scale of patterns influences discriminability

Size-tuned linear filters

Texture representation

- Textures are made up of repeated local patterns, so:
  - Find the patterns
    - Use filters that look like patterns (spots, bars, raw patches...)
    - Consider magnitude of response
  - Describe their statistics within each local window, e.g.,
    - Mean, standard deviation
    - Histogram
    - Histogram of “prototypical” feature occurrences

Texture representation: example
Texture representation: example

original image

derivative filter responses, squared

statistics to summarize patterns in small windows

<table>
<thead>
<tr>
<th>Dimension 1 (mean d/dx value)</th>
<th>Dimension 2 (mean d/dy value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Win. #1</td>
<td>4 10</td>
</tr>
<tr>
<td>Win. #2</td>
<td>18 7</td>
</tr>
<tr>
<td>Win. #9</td>
<td>20 20</td>
</tr>
</tbody>
</table>

Windows with primarily horizontal edges

Windows with small gradient in both directions

Windows with primarily vertical edges

Both

visualization of the assignment to texture “types”
Texture representation: example

- Far, dissimilar textures
- Close, similar textures

Statistics to summarize patterns in small windows

Win. #1: 4, 10
Win. #2: 18, 7
Win. #9: 20, 20

Distance reveals how dissimilar texture from window a is from texture in window b.

Filter banks

- Our previous example used two filters, and resulted in a 2-dimensional feature vector to describe texture in a window.
  - x and y derivatives revealed something about local structure.
- We can generalize to apply a collection of multiple (d) filters: a "filter bank"
- Then our feature vectors will be d-dimensional.
  - still can think of nearness, farness in feature space

Filter banks

- What filters to put in the bank?
  - Typically we want a combination of scales and orientations, different types of patterns.

Matlab code available for these examples:
http://www.robots.ox.ac.uk/~vgg/research/texclass/filters.html
Multivariate Gaussian

\[ p(x; \mu, \Sigma) = \frac{1}{(2\pi)^{w/2}|\Sigma|^{1/2}} \exp\left(-\frac{1}{2}(x - \mu)^T \Sigma^{-1} (x - \mu)\right) \]

\[
\Sigma = \begin{bmatrix} 9 & 0 \\ 0 & 9 \end{bmatrix} \quad \Sigma = \begin{bmatrix} 16 & 0 \\ 0 & 9 \end{bmatrix} \quad \Sigma = \begin{bmatrix} 10 & 5 \\ 5 & 10 \end{bmatrix}
\]

Filter bank

Image from http://www.texasexplorer.com/austin_cap2.jpg

Showing magnitude of responses
You try: Can you match the texture to the response?

Representing texture by mean abs response
We can form a feature vector from the list of responses at each pixel.

\[ d\text{-dimensional features} \]

\[ D(a,b) = \sqrt{\sum_{i=1}^{d} (a_i - b_i)^2} \]

Euclidean distance (\(L_2\))

Example uses of texture in vision: analysis

Classifying materials, “stuff”

Texture features for image retrieval

Characterizing scene categories by texture


Segmenting aerial imagery by textures

Texture-related tasks

- Shape from texture
  - Estimate surface orientation or shape from image texture

- Segmentation/classification from texture cues
  - Analyze, represent texture
  - Group image regions with consistent texture

- Synthesis
  - Generate new texture patches/images given some examples

Texture synthesis

- Goal: create new samples of a given texture
- Many applications: virtual environments, hole-filling, texturing surfaces

The Challenge

- Need to model the whole spectrum: from repeated to stochastic texture


Markov Chains

Markov Chain

- a sequence of random variables $X_1, X_2, \ldots, X_n$
- $X_t$ is the state of the model at time $t$

$X_1 \rightarrow X_2 \rightarrow X_3 \rightarrow X_4 \rightarrow X_5$

Markov Chain Example: Text

"A dog is a man’s best friend. It’s a dog eat dog world out there."

$X_{t-1}$

$X_t$

Source: S. Seitz
Text synthesis

Create plausible looking poetry, love letters, term papers, etc.

Most basic algorithm

1. Build probability histogram
   - find all blocks of $N$ consecutive words/letters in training documents
   - compute probability of occurrence $p(x_i|x_{i-1}, \ldots, x_{i-(n-1)})$

   WE NEED TO EAT CAKE

Source: S. Seitz

Results:

- “As I've commented before, really relating to someone involves standing next to impossible.”
- “One morning I shot an elephant in my arms and kissed him.”
- “I spent an interesting evening recently with a grain of salt”


Synthesizing Computer Vision text

• What do we get if we extract the probabilities from a chapter on Linear Filters, and then synthesize new statements?

Check out Yisong Yue’s website implementing text generation: build your own text Markov Chain for a given text corpus. http://www.yisongyue.com/shaney/

Synthesized text

• This means we cannot obtain a separate copy of the best studied regions in the sum.
• All this activity will result in the primate visual system.
• The response is also Gaussian, and hence isn’t bandlimited.
• Instead, we need to know only its response to any data vector, we need to apply a low pass filter that strongly reduces the content of the Fourier transform of a very large standard deviation.
• It is clear how this integral exist (it is sufficient for all pixels within a $2k+1 \times 2k+1 \times 2k+1 \times 2k+1$ — required for the images separately.

Synthesized UTCS code of conduct

• You should be on the day your assignment is due.
• Remember that the work available to the bookstore, buy books, read them, and write some code without ever signing up for a class.
• In this document, a group of the grade will go down rather than up.
• To make this process work, you have made prior arrangements with the instructor.
• But remember that the instructor responded to such issues.

Synthesized UTCS code of conduct

• For example, don’t write to your instructor.
• For example, don’t write to your instructor.
• But, whenever you do in the field.
• Classes that use different exams each semester may have very different score distributions from one semester to the day your assignment is due.
• (It’s on the class to file a complaint about the grading of your work, you have the right to expect your instructor has read a lot of problems, and then chosen, from all of that material, 14 weeks of the one week from the time of preregistration.
Markov Random Field

A Markov random field (MRF)
- generalization of Markov chains to two or more dimensions.

First-order MRF:
- probability that pixel \( X \) takes a certain value given the values of neighbors \( A, B, C, \) and \( D \):

\[
P(X|A, B, C, D) \quad \begin{array}{c} A \ \ X \ \ B \\ \ C \end{array}
\]

Source: S. Seitz

Texture Synthesis [Efros & Leung, ICCV 99]
Can apply 2D version of text synthesis

Texture corpus (sample)
Output

Synthesizing One Pixel

- What is \( p(x|\text{neighborhood of pixels around } x) \)?
- Find all the windows in the image that match the neighborhood
- To synthesize \( x \)
  - pick one matching window at random
  - assign \( x \) to be the center pixel of that window
- An exact neighborhood match might not be present, so find the best matches using SSD error and randomly choose between them, preferring better matches with higher probability

Neighborhood Window

Varying Window Size
Growing Texture

- Starting from the initial image, "grow" the texture one pixel at a time

Synthesis results

- french canvas
- rafia weave

Synthesis results

- white bread
- brick wall

Failure Cases

- Growing garbage
- Verbatim copying

Hole Filling
Extrapolation

• The Efros & Leung algorithm
  – Simple
  – Surprisingly good results
  – Synthesis is easier than analysis!
  – …but very slow

Image Quilting [Efros & Freeman 2001]

• Observation: neighbor pixels are highly correlated

**Idea:** unit of synthesis = block

• Exactly the same but now we want $P(B | N(B))$
• Much faster: synthesize all pixels in a block at once

Minimal error boundary

overlapping blocks  ->  vertical boundary

overlapping error  =  min. error boundary

• Input texture
• Random placement of blocks
• Neighboring blocks constrained by overlap
• Minimal error boundary cut
Texture Transfer

- Take the texture from one object and “paint” it onto another object
  - This requires separating texture and shape
  - That’s HARD, but we can cheat
  - Assume we can capture shape by boundary and rough shading
- Then, just add another constraint when sampling: similarity to underlying image at that spot

(Manual) texture synthesis in the media
Summary

- Texture is a useful property that is often indicative of materials, appearance cues
- **Texture representations** attempt to summarize repeating patterns of local structure
- **Filter banks** useful to measure redundant variety of structures in local neighborhood
  - Feature spaces can be multi-dimensional
- Neighborhood statistics can be exploited to “sample” or **synthesize** new texture regions
  - Example-based technique

So far: features and filters

Transforming and describing images; textures, colors, edges

A. Zalesny et al., Realistic Textures for Virtual Anastylosis