BIL 719 - Computer Vision
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Texture

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Previously on BIL 719

• Spatial filtering
  - Box filter
  - Gaussian filters
  - Median filter
  - Unsharp masking

• Frequency domain
  - Fourier transform
  - Convolution theorem
  - Filtering in frequency domain
  - Gabor filters

• Edge detection
  - Image gradients
  - Derivative of Gaussian filters
  - The Canny edge detector

Some announcements

• Project proposals due on March 12
  - A half page proposal (the research topic to be investigated and a list of related major papers)

• Programming Assignment 1 will be also out next week!

Paper presentations

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What defines a texture?

Includes: more regular patterns

Includes: more random patterns

Slide credit: K. Grauman
What is texture?

- Regular or stochastic patterns caused by bumps, grooves, and/or markings

Images: B. Freeman and A. Torralba

Texture and Material

Texture and Orientation

Texture and Scale
Texture-related tasks

• Shape from texture
  – Estimate surface orientation or shape from image texture

• Texture segmentation/classification
  – Analyze, represent texture
  – Group image regions with consistent texture

• Texture synthesis
  – Generate new texture patches/images given some examples

Shape from texture

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

When are two textures similar?

All these images are different instances of the same texture. We can differentiate between them, but they seem generated by the same process.
Texture Analysis

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

Texture Synthesis

Given a finite sample of some texture, the goal is to synthesize other samples from that same texture – The sample needs to be "large enough"
What kind of response will we get with an edge detector for these images?

Images from Malik and Perona, 1990

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]

Pre-attentive texture discrimination

Textons, the elements of texture perception, and their interactions
Bela Julesz
Bell Laboratories, Murray Hill, New Jersey 07974, U.S.A.

Research with texture pairs having identical second-order statistics has revealed that the pre-attentive texture discrimination system cannot globally process third- and higher-order statistics, and that discrimination is the result of a few local conspicuous features, called textons. It seems that only the fine-order statistics of these textons have perceptual significance, and the relative phase between textons cannot be perceived without detailed scrutiny of focal attention.

Slide credit: B. Freeman and A. Torralba
Julesz - Textons

Textons: fundamental texture elements.

Textons might be represented by features such as terminators, corners, and intersections within the patterns...

“We note here that simpler, lower-level mechanisms tuned for size may be sufficient to explain this discrimination.”
Texture Segmentation

- 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
    - Mean, standard deviation
    - Histogram
    - Histogram of “prototypical” feature occurrences

Texture representation: example

- original image
- derivative filter responses, squared

Texture representation: example

- original image
- derivative filter responses, squared
Texture representation: example

original image

derivative filter responses, squared

statistics to summarize patterns in small windows

(mean d/dx value) (mean d/dy value)

| Win. #1 | 4 | 10 |
| Win. #2 | 18 | 7 |
| Win. #9 | 20 | 20 |

Dimension 1 (mean d/dx value)
Dimension 2 (mean d/dy value)

Windows with primarily horizontal edges
Windows with small gradient in both directions
Windows with primarily vertical edges

Both
Texture representation: example

Original image

Derivative filter responses, squared

Visualization of the assignment to texture "types"

Statistics to summarize patterns in small windows

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Distance reveals how dissimilar texture from window a is from texture in window b.
Texture representation: window scale

- We’re assuming we know the relevant window size for which we collect these statistics.

Possible to perform scale selection by looking for window scale where texture description not changing.

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

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

$\Sigma = \begin{bmatrix} 9 & 0 \\ 0 & 9 \end{bmatrix}$
$\Sigma = \begin{bmatrix} 16 & 0 \\ 0 & 9 \end{bmatrix}$
$\Sigma = \begin{bmatrix} 10 & 5 \\ 5 & 5 \end{bmatrix}$
Filter bank
We can form a feature vector from the list of responses at each pixel.

You try: Can you match the texture to the response?

Representing texture by mean abs response
$d$-dimensional features

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

Euclidean distance ($L_2$)

Example uses of texture in Computer 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
- Texture segmentation/classification
  - Analyze, represent texture
  - Group image regions with consistent texture
- 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

Texture synthesis

• 2 group of works:
  1. Parametric approaches
  2. Non-parametric approaches (example-based)

Method 1: Copy Block(s) of Pixels

Basic idea
1. Compute statistics of input texture (e.g., histogram of edge filter responses)
2. Generate a new texture that keeps those same statistics

One idea: Build Probability Distributions

• D. J. Heeger and J. R. Bergen. Pyramid-based texture analysis/synthesis. In SIGGRAPH '95.
One idea: Build Probability Distributions

But it (usually) doesn’t work

- Probability distributions are hard to model well

Input

Synthesized

Markov Chains

- A sequence of random variables $x_1, x_2, ..., x_t$
- $x_t$ is the state of the model at time $t$

\[
\begin{align*}
&x_1 \rightarrow x_2 \rightarrow x_3 \rightarrow x_4 \rightarrow x_5 \\
\end{align*}
\]

- Markov assumption: each state is dependent only on the previous one
  - dependency given by a conditional probability:

\[
p(x_t|\mathbf{x}_{t-1})
\]

- The above is actually a first-order Markov chain
- An N'th-order Markov chain: $p(\mathbf{x}_t|\mathbf{x}_{t-1}, \ldots, \mathbf{x}_{t-N})$

Efros & Leung Algorithm

- Assuming Markov property, compute $P(p|N(p))$
  - Building explicit probability tables infeasible
  - Instead, we search the input image for all similar neighborhoods
  - That’s our pdf for $p$
  - To sample from this pdf, just pick one match at random

Markov Chain Example: Text

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

\[
p(dog|a) = ?
\]
Markov Chain Example: Text

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

$X_t - 1$ $p(X_t | X_{t-1})$

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 $p(x_t | x_{t-1}, \ldots, x_{t-(n-1)})$

2. Given words $x_1, x_2, \ldots, x_{k-1}$
   - compute $x_k$ by sampling from $p(x_t | x_{t-1}, \ldots, x_{t-(n-1)})$

WE NEED TO EAT CAKE

Text synthesis

• 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"


Texture Synthesis [Efros & Leung, ICCV 99]

Can apply 2D version of text synthesis

Texture corpus
(sample)

Output
Texture synthesis: Intuition

Before, we inserted the next word based on existing nearby words...

Now we want to insert **pixel intensities** based on existing nearby pixel values.

Distribution of a value of a pixel is conditioned on its neighbors alone.

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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 neighbourhood match might not be present, so find the **best** matches using **SSD error** and randomly choose between them, preferring better matches with higher probability

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Neighborhood Window

Varying Window Size
Growing Texture

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

Slide credit: A. Efros

Synthesis results

- french canvas
- rafia weave

Slide credit: A. Efros

Synthesis results

- white bread
- brick wall

Slide credit: A. Efros

Homage to Shannon

Slide credit: A. Efros
Failure Cases

Growing garbage

Verbatim copying

Hole Filling

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
• Not the same as multi-scale!
Random placement of blocks

Neighboring blocks constrained by overlap

Minimal error boundary cut

Input texture

Block B1

Block B2

Block B1

Block B2

Minimal error boundary

overlapping blocks

vertical boundary

overlap error

min. error boundary

Slide credit: A. Efros
Failures  
(Chernobyl Harvest)

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
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