Texture Synthesis

- Texture has spatially repeating patterns
- It lacks the full range of complexity of photographic imagery, but makes a good starting point for study of image-based techniques

Examples:
- Radishes
- Rocks
- Yogurt

The Challenge

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

Some History

- Stochastic textures
  - [Heeger & Bergen,'95]
  - [DeBonet,'97]
  - [Portilla & Simoncelli,'98]
- Structured textures
  - [Liu,'04]
- Both
  - [Efros & Leung,'99]
  - [Efros & Freeman,'01]
  - [Kwatra,'05]

Statistical modeling of texture

- Assume stochastic model of texture (Markov Random Field)
- Stationarity: the stochastic model is the same regardless of position

Examples:
- Stationary texture
- Non-stationary texture
Statistical modeling of texture

- Assume stochastic model of texture (Markov Random Field)
- Stationarity: the stochastic model is the same regardless of position
- Markov property: p(pixel | rest of image) = p(pixel | neighborhood)

Motivation from Language

- Shannon (1948) proposed a way to generate English-looking text using N-grams
  - Assume a Markov model
  - Use a large text to compute probability distributions of each letter given N–1 previous letters
  - Starting from a seed repeatedly sample the conditional probabilities to generate new letters
  - One can use whole words instead of letters too

Mark V. Shaney (Bell Labs)

- Results (using alt.singles corpus):
  - “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.”
- Notice how well local structure is preserved!
  - Now let’s try this in 2D...

Efros & Leung Algorithm

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Efros & Leung Algorithm

- Assume Markov property, sample from P(p|N(p))
  - Building explicit probability tables infeasible
  - Instead, we search the input image for all sufficiently similar neighborhoods and pick one match at random

Finding matches

- Sum of squared differences (SSD)

\[ \left| \begin{array}{c} \text{original pixel} \\ \text{replaced pixel} \end{array} \right|^2 \]
Finding matches

- Sum of squared differences (SSD)
  - Gaussian-weighted to make sure closer neighbors are in better agreement

\[ || \mathbf{f} \ast (\mathbf{f} - \mathbf{g}) ||^2 \]

Implementation Details

- Initialization
  - Start with a few rows of white noise and grow in scanline order
  - Start with a “seed” in the middle and grow outward in layers
- Sampling
  - Random sampling from the set of candidates vs. picking the best candidate

Synthesis Results

- french canvas
- raffia weave

More Results

- white bread
- brick wall

Homage to Shannon

Varying Window Size
### Varying Window Size

Increasing window size

### Failure Cases

- Growing garbage
- Verbatim copying

### Hole Filling and Extrapolation

- Grow in “onion skin” order
  - Within each “layer”, pixels with most neighbors are synthesized first
  - Normalize error by the number of known pixels
  - If no close match can be found, the pixel is not synthesized until the end

### Hole Filling

### Summary

- The Efros & Leung algorithm
  - Very simple
  - Surprisingly good results

- Problems?
Accelerating texture synthesis
- Indexed similarity search
- Coherence
- Multiresolution
- Patches

Indexed Similarity Search
- Perform fast approximate nearest neighbor search using spatial search structure
  - tree-structured vector quantization (TSVQ)
  - kd-tree

Indexed Similarity Search
- Perform fast approximate nearest neighbor search using e.g. tree-structured vector quantization
  - Use all neighborhoods of the exemplar texture to build a tree-structured codebook
  - To find a match for a new neighborhood, follow the tree in best-first order (at each level, choose child codeword closest to the query)
  - Example running times from the paper:
    - Exhaustive search: 360 sec
    - Building codebook: 22 sec, synthesis: 7.5 sec
  - Shortcomings?

Wei00

Indexed Similarity Search
- Can degrade quality (blur)

Wei00

Coherence
- Use original position of already synthesized neighborhood pixels to create a “short list” of candidates for the current pixel

Ashikhmin01

Coherence

Ashikhmin01
Multiresolution

- For textures with large-scale structures, use a Gaussian pyramid to reduce required neighborhood size

Multiresolution

- For textures with large-scale structures, use a Gaussian pyramid to reduce required neighborhood size
  - Low-resolution image is synthesized first
  - For synthesis at a given pyramid level, the neighborhood consists of already generated pixels at this level plus all neighboring pixels at the lower level

Multiresolution

- Example:

Multiresolution

- Results

Multiresolution

Random

Oriented

Regular

Semi-regular

Multiresolution
**Patch-Based Synthesis**

- Copy patches of pixels rather than pixels
- Observation: neighbor pixels are highly correlated
  - Exactly the same as Efros & Leung but $P(B|N(B))$
  - Much faster: synthesize all pixels in a block at once

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**Chaos Mosaic**

- Process: 1) tile input image; 2) pick random blocks and place them in random locations 3) Smooth edges
- Of course, doesn’t work for structured textures

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**Image Quilting [Efros & Freeman]**

- Regularly arranged patches

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**Algorithm**

- Pick size of block and size of overlap
- Synthesize blocks in raster order
- Search input texture for block that satisfies overlap constraints (above and left)
- Paste new block into resulting texture
  - use dynamic programming to compute minimal error boundary cut
Random placement of blocks

Neighboring blocks constrained by overlap

Minimal error boundary cut

Input texture

B1 B2

B1 B2

B1 B2

Minimal error boundary

overlapping blocks

vertical boundary

\[ \text{overlap error} \]

\[ \text{min. error boundary} \]

Efros01
Summary

- Texture synthesis
  - create new samples of a given texture

- Non-parametric methods
  - Copy samples from input based on neighborhood similarity

- Acceleration techniques
  - Multiresolution
  - Indexing
  - Coherence
  - Patches