Texture

- D. Forsythe and J. Ponce
- Computer Vision modern approach
- Chapter 9
- (Slides D. Lowe, UBC)

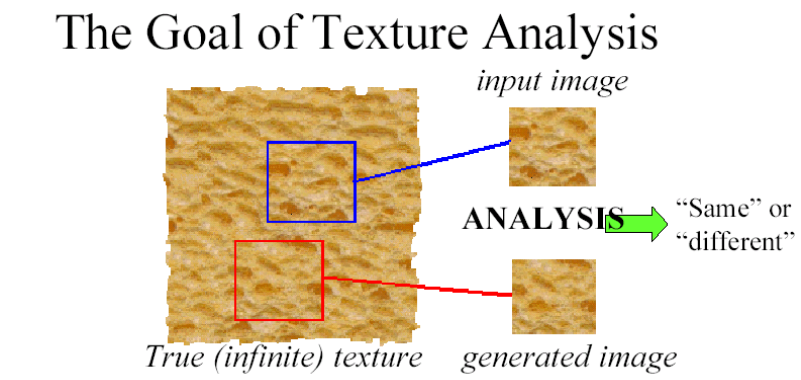
Previously

- Edges, contours, feature points, patches (templates)
- Color features
- Useful for matching, recognizing objects
- Image based retrieval
- How to characterize, recognize regions characterized by their texture

Texture

- **Key issue**: How do we represent texture?
- Depends of the scale: large leaf – object, many small leaves – foliage, texture
- Textures: grass, pebbles, hair, trees, bark, tigers, zebras, cheetahs
- **Topics:**
  - Texture segmentation
  - Texture-based matching
  - Texture synthesis
    - Can be based on simpler representations than analysis
  - Shape from texture (we will skip)

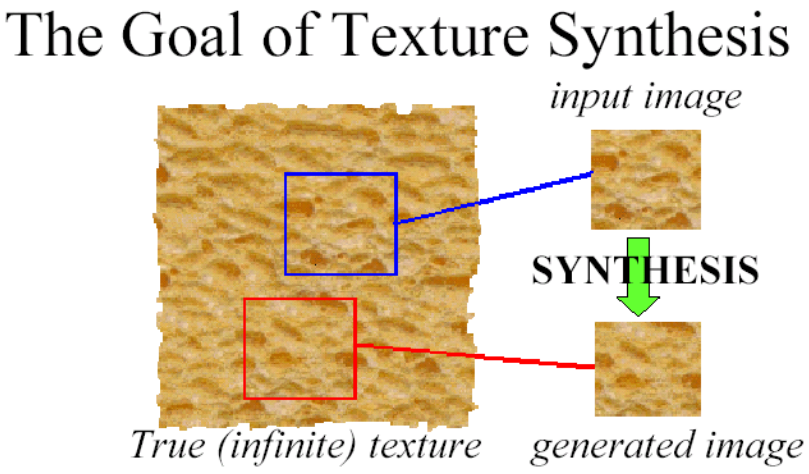
Objectives: 1) Discrimination/Analysis



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

Slide credit: Freeman

2) Synthesis



Slide credit: Freeman

Representing textures

Observation: textures are made up of sub-elements, repeated over a region with similar statistical properties

Texture representation:

- find the sub-elements, and represent their statistics

- What filters can find the sub-elements?
  - Human vision suggests spots and oriented filters at a variety of different scales
- What statistics?
  - Mean of each filter response over region
  - Other statistics can also be useful

Human texture perception

Bergen and Adelson, Nature 1988

Learn size-tuned filter responses.

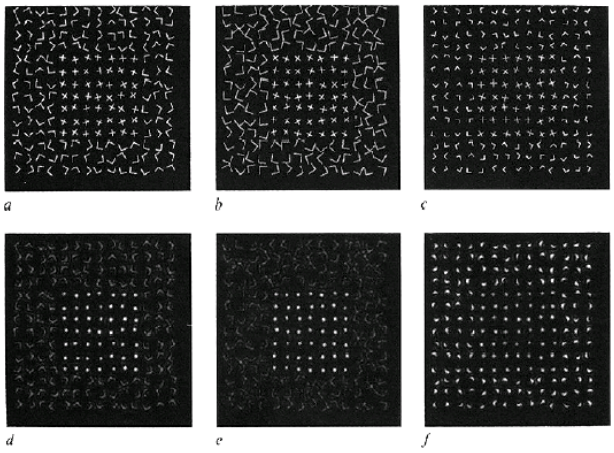
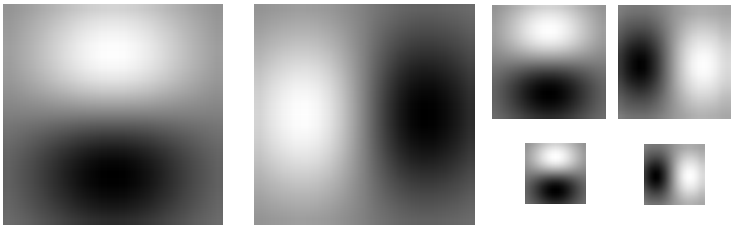


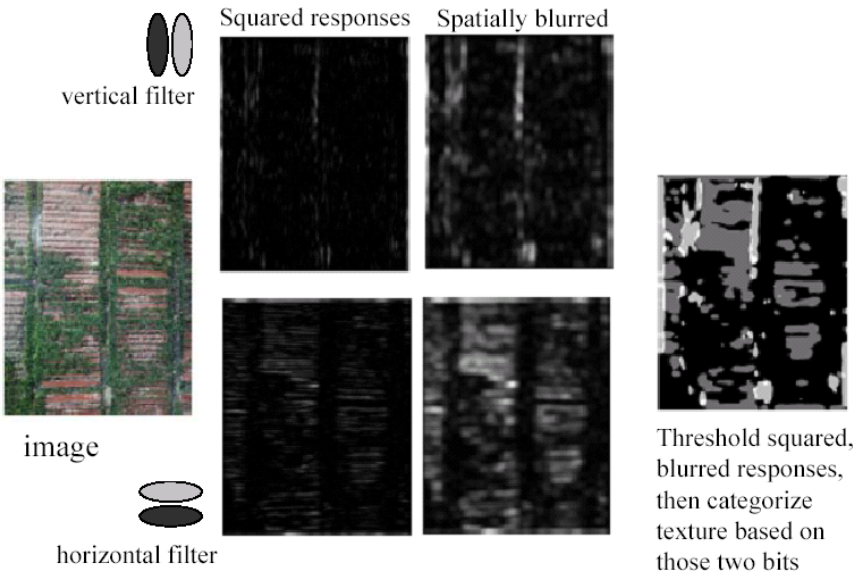
Fig. 1 *Top row*, Textures consisting of Xs within a texture composed of Ls. The micropatterns are placed at random orientations on a randomly perturbed lattice. *a*, The bars of the Xs have the same length as the bars of the Ls. *b*, The bars of the Ls have been lengthened by 25%, and the intensity adjusted for the same mean luminance. Discriminability is enhanced. *c*, The bars of the Ls have been shortened by 25%, and the intensity adjusted for the same mean luminance. Discriminability is impaired. *Bottom row*: the responses of a size-tuned mechanism *d*, response to image *a*; *e*, response to image *b*; *f*, response to image *c*.

Derivative of Gaussian Filters

Measure the image gradient and its direction at different scales (use a pyramid).



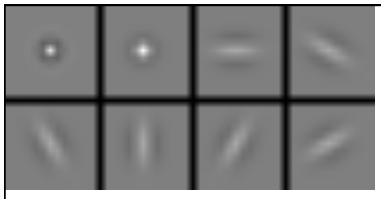
Convolving with filter bank – convolving with bar filter will measure ‘barriness” at the point
Convolving with spot filter will measure “spottiness”



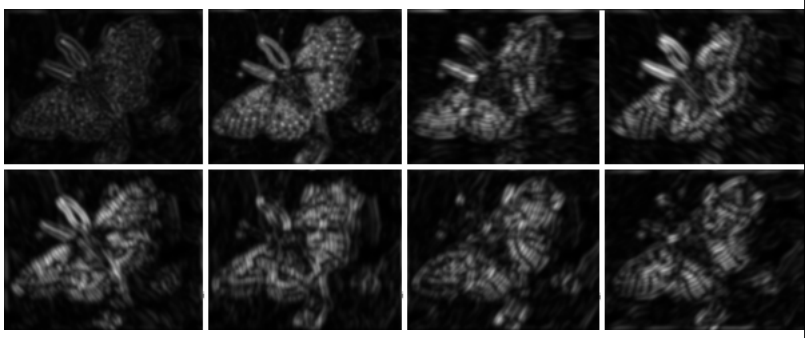
- Blurring – to spatially integrate – get the mean
- Classification – to 4 classes – outputs of horizontal, vertical, both or neither are large

Extracting structure with filter banks

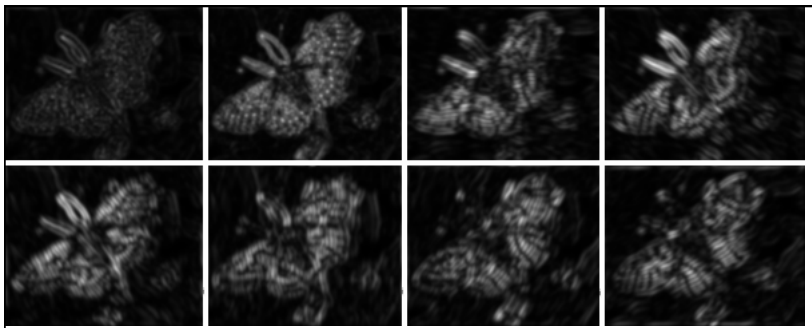
- Convolution with a filter – response is strong at places where the image structure looks similar to the filter
- Use multiple filters – to detect different types of image structures
- Commonly used filter bank – combination of bars and spots at different scale and orientation

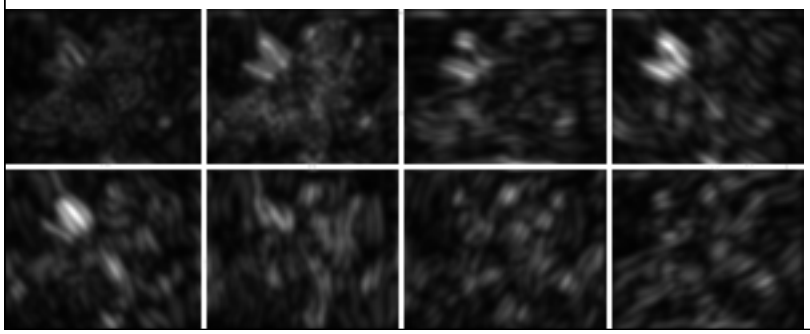


Add more oriented filters
(Malik & Perona, 1990)



Shown are absolute values of the filter responses



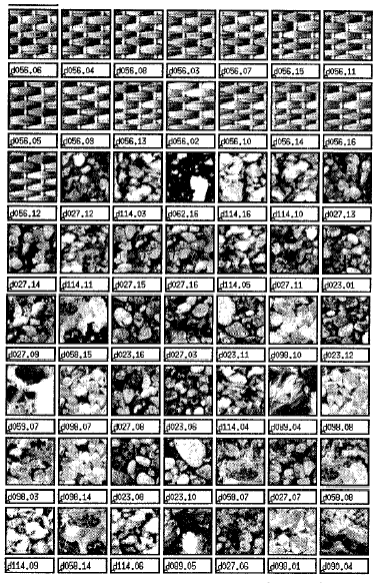


Texture representation

- Given set of responses of filter banks
- Compute some statistics of the distribution of texture elements (e.g. flower field – many yellow spots)
- Zebra – many vertical bars
- Need to choose the scale over which the distribution of filter outputs is computed – see previous example
- What statistics to collect ? (e.g. just consider mean of squared outputs)
- Mean and standard deviation of the filter outputs
- What if the outputs are correlated (e.g. spots and bars) … cabbage field example

Application: Texture-based Image Matching

Query image



Decreasing response vector similarity

Ordered list of best matches

from Forsyth & Ponce

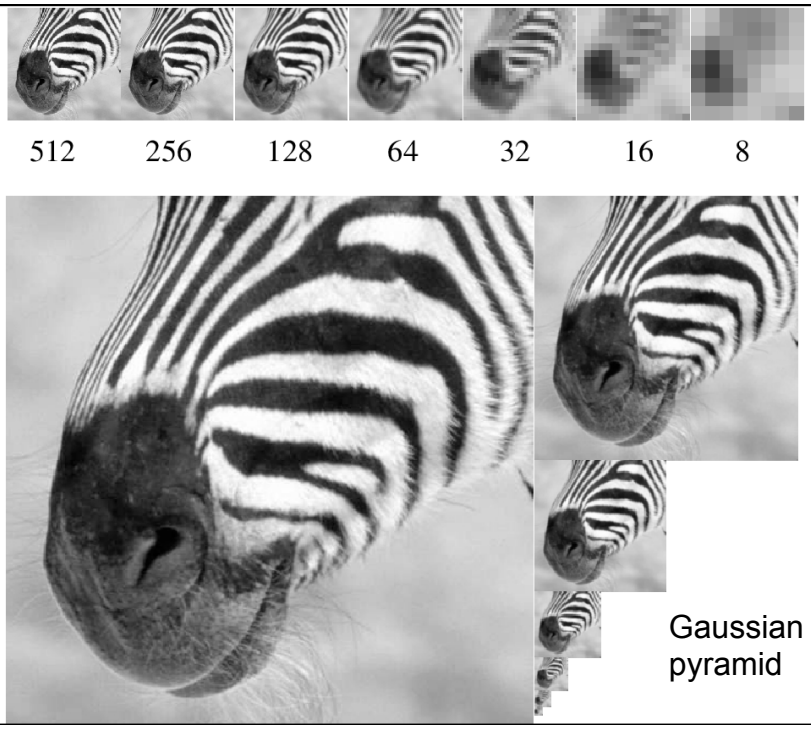
Analysis using pyramids

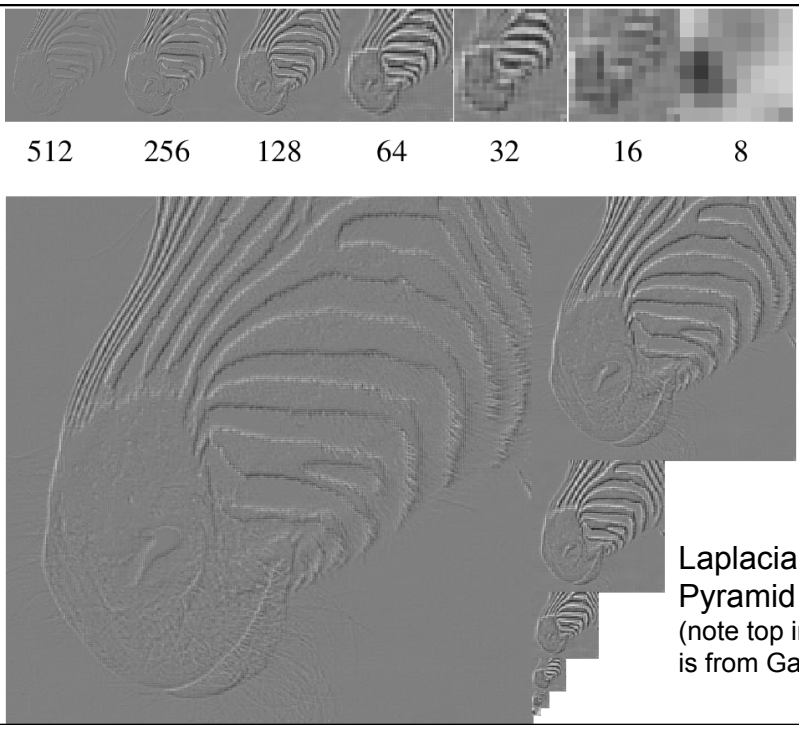
- Choice of scale is important – how large of the neighborhood should I choose

- Analysis and synthesis using oriented pyramids
- Gaussian and Laplacian Pyramid
- Gaussian pyramid highly redundant
- Laplacian pyramid – approximated by differences of Gaussians
- Obtain image from Laplacian Pyramid – recover Gaussian and get the final resolution

The Laplacian Pyramid

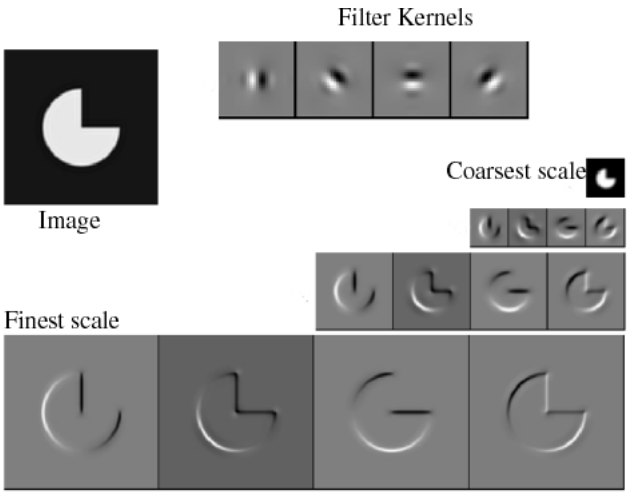
- **Building a Laplacian pyramid:**
  - Create a Gaussian pyramid
  - Take the difference between one Gaussian pyramid level and the next (before sub-sampling)
- **Properties**
  - Also known as the difference-of-Gaussian function, which is a close approximation to the Laplacian
  - It is a band pass filter - each level represents a different band of spatial frequencies
- **Reconstructing the original image:**
  - Reconstruct the Gaussian pyramid starting at top layer


512
256
128
64
32
16
8
Gaussian pyramid


512
256
128
64
32
16
8
Laplacian Pyramid
(note top image is from Gaussian)

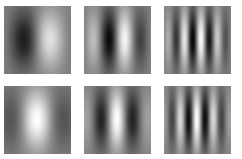
Oriented pyramids

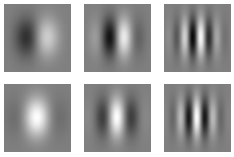
- Laplacian pyramid is orientation independent
- Apply an oriented filter to determine orientations at each layer
- This represents image information at a particular scale and orientation.



Reprinted from "Shiftable MultiScale Transforms," by Simoncelli et al., IEEE Transactions on Information Theory, 1992, copyright 1992, IEEE

Alternative: Gabor filters





Gabor filters: Product of a Gaussian with sine or cosine

Top row shows anti-symmetric (or odd) filters, bottom row the symmetric (or even) filters.

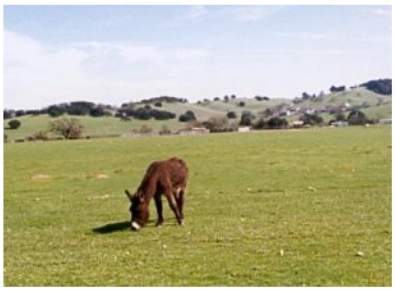
No obvious advantage to any one type of oriented filters.

Final texture representation

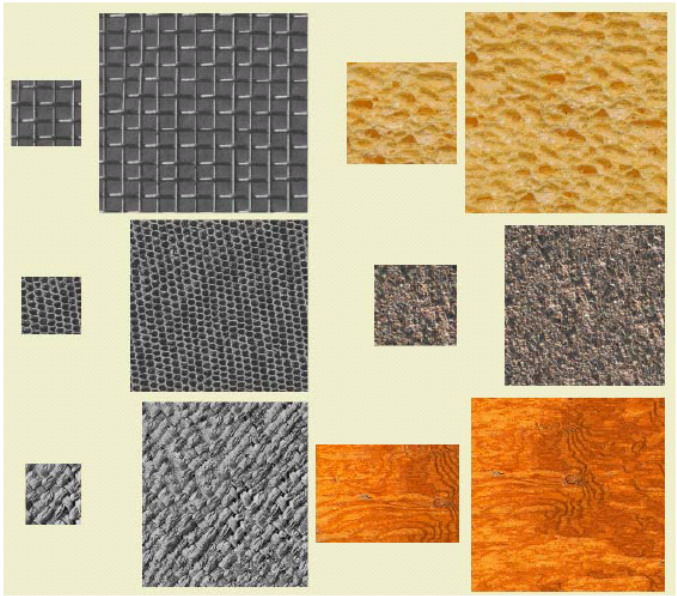
- Form a Laplacian and oriented pyramid (or equivalent set of responses to filters at different scales and orientations).
- Square the output (makes values positive)
- Average responses over a neighborhood by blurring with a Gaussian
- Take statistics of responses
  - Mean of each filter output
  - Possibly standard deviation of each filter output
  - or quantized the outputs (texton)

Texture Synthesis

- Application
- Texture synthesis for rendering
- How to obtain/generate a texture map reconstruction
- Hole filling



Efros and Leung



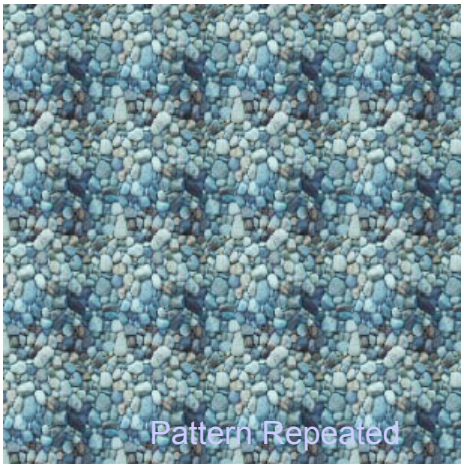
The texture synthesis problem

Generate new examples of a texture.

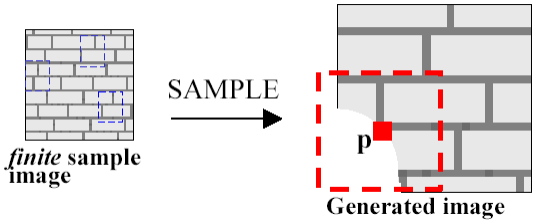
- **Original approach:** Use the same representation for analysis and synthesis
  - This can produce good results for random textures, but fails to account for some regularities
- **Recent approach:** Use an image of the texture as the source of a probability model
  - This draws samples directly from the actual texture, so can account for more types of structure
  - Very simple to implement
  - However, depends on choosing a correct distance parameter

This is like copying, but not just repetition

Photo



Efros and Leung method

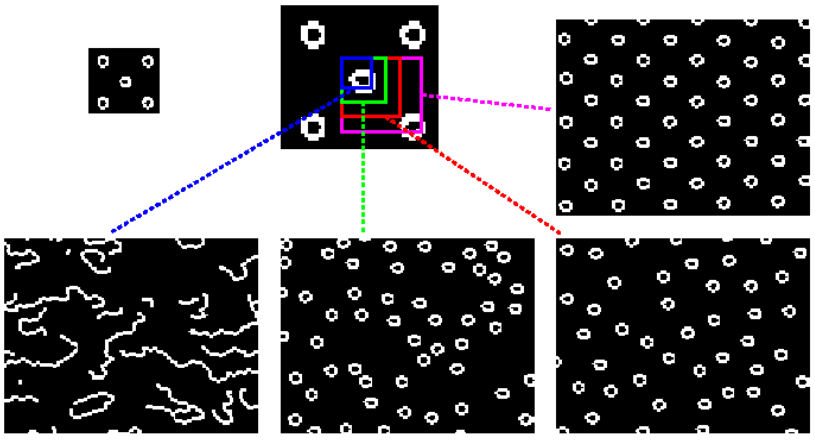


- For each new pixel **p** (select **p** on boundary of texture):
  - Match a window around **p** to sample texture, and select several closest matches
    - Matching minimizes sum of squared differences of each pixel in the window (Gaussian weighted)
    - Give zero weight to empty pixels in the window
  - Select one of the closest matches at random and use its center value for **p**
  - Size and shape of the neighborhood matter

Initial conditions for growing texture

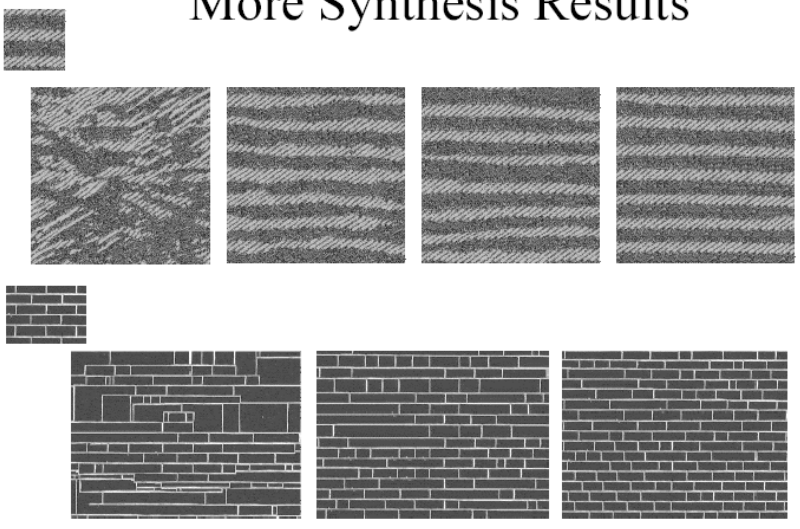
- If no initial conditions are specified, just pick a patch from the texture at random
- To fill in an empty region within an existing texture:
  - Grow away from pixels that are on the boundary of the existing texture

Window size parameter

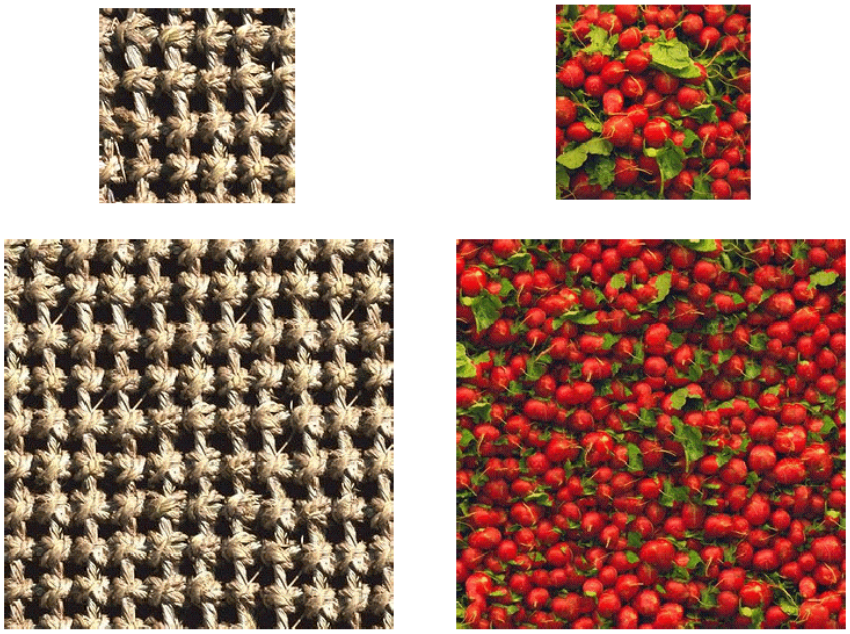


http://www.cs.berkeley.edu/~efros/research/NPS/efros-iccv99.ppt

More Synthesis Results



http://www.cs.berkeley.edu/~efros/research/NPS/efros-iccv99.ppt



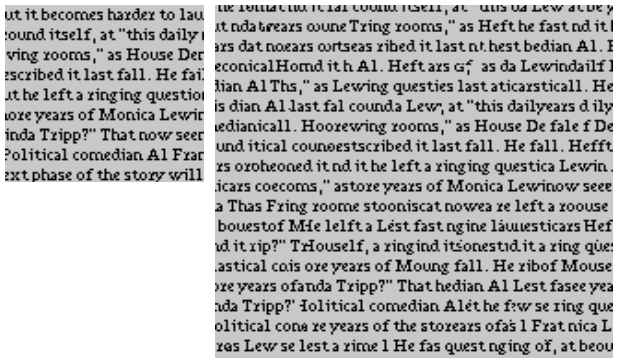
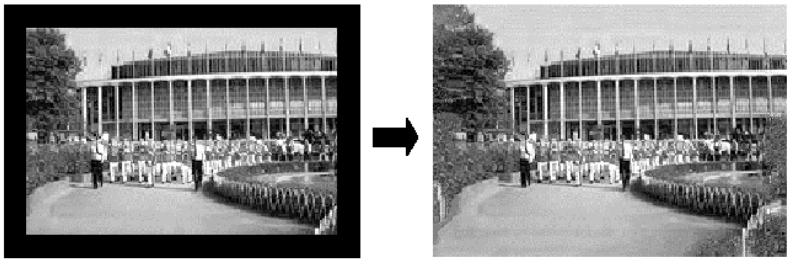


Figure from Texture Synthesis by Non-parametric Sampling, A. Efros and T.K. Leung, Proc. Int. Conf. Computer Vision, 1999 copyright 1999, IEEE

Failures




Image Extrapolation



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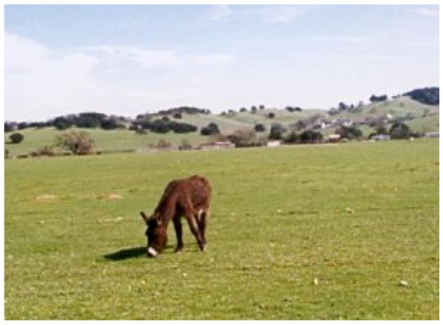
http://www.cs.berkeley.edu/~efros/research/NPS/efros-iccv99.ppt

Further issues in texture synthesis

- How to improve efficiency
- Use fast nearest-neighbor search
- How to select region size automatically
- How to edit textures to modify them in natural ways

Texture synthesis

Task:
Make the donkey vanish



Fill in black region using texture from white box

```
% Holefill.m
> clear; tic;

% Change patchL to change the patch size used (patch size is  2*patchL+1)

> patchL = 10;
> patchSize = 2 * patchL + 1;
> randomPatchSD = 1;  % Standard deviation for random patch selection
> showResults = 1;
% Read input image

> im = double(imread('donkey.jpg'))/255;
> [imRows, imCols, imBands] = size(im);

% Define hole and texture regions. This will use regions.mat if it exists,
%   but otherwise will allow the user to select the regions.

> fid = fopen('regions.mat');
> if (fid ~= -1)                        % file exists read regions from disk
>  disp('Loading regions');
>  fclose(fid);
>  load 'regions.mat' fillRegion textureRegion
>  else                                  % file does not exist
>  disp('Select fill region');        % User define fill region
>  fillRegion = roipoly(im);
>  disp('Select texture region');  % User define texture region
>  textureRegion = roipoly(im);
>   save 'regions.mat' fillRegion textureRegion; % Save regions to disk
> end; % else
```

```
> if (fid ~= -1)                        % file exists read regions from disk
>    disp('Loading regions');
>    fclose(fid);
>    load 'regions.mat' fillRegion textureRegion
> else                                  % file does not exist
>    disp('Select fill region');        % User define fill region
>    fillRegion = roipoly(im);
>    disp('Select texture region');  % User define texture region
>    textureRegion = roipoly(im);
>     save 'regions.mat' fillRegion textureRegion; % Save regions to disk
>  end; % else
```

```
> % Perform the hole filling
> while (nFill > 0)
>   disp(sprintf('Number of pixels remaining = %i', nFill));

>  % Set TODORegion to pixels on the boundary of fillRegion
>  TODORegion = fillRegion - imerode(fillRegion, [0,1,0;1,0,1; 0,1,0]);
>  [iTODO, jTODO] = find(TODORegion);
>  nTODO = length(iTODO);
>
>  while(nTODO > 0)
>    % Pick a random pixel from the TODORegion
>    r = rand;
>    pix = ceil(r * nTODO);
>      …
>     % Compute masked SSD of TODOPatch and textureIm
>     ssdIm = ComputeSSD(TODOPatch, patchL, TODOMask, textureIm,     texImRows,
texImCols, imBands);
```

```
> % Randomized selection of one of the best texture patches
>    [ssdImRows, ssdImCols] = size(ssdIm);
>    [sortVal, sortIndex] = sort(ssdIm(:));
>    r = abs(random('Normal', 0, randomPatchSD));
>    selectIndex = ceil(r);
>    selectIndex = max(1, min(ssdImRows * ssdImCols, selectIndex));

> …
>    selectPatch = textureIm(iSelectRange, jSelectRange, :);
>
>    % Copy patch into hole
>    imHole = CopyPatch(iPatchCentre, jPatchCentre, imHole, imRows, imCols, imBands,
selectPatch, patchL, TODOMask);
>
>  end; % while nTODO > 0
```

```
> % Output results
> if (showResults)
>  figure;
>  imshow(imHole0);
>  hold on;
>  line([jTextureMin, jTextureMax], [iTextureMin, iTextureMin], 'color', 'w');
>  line([jTextureMin, jTextureMax], [iTextureMax, iTextureMax], 'color', 'w');
>  line([jTextureMin, jTextureMin], [iTextureMin, iTextureMax], 'color', 'w');
>  line([jTextureMax, jTextureMax], [iTextureMin, iTextureMax], 'color', 'w');
>
>  figure;  imshow(im);
>  figure;
>  imshow(imHole);
>end; % if showResults
> imwrite(imHole, 'holefill.jpg');
> toc
```