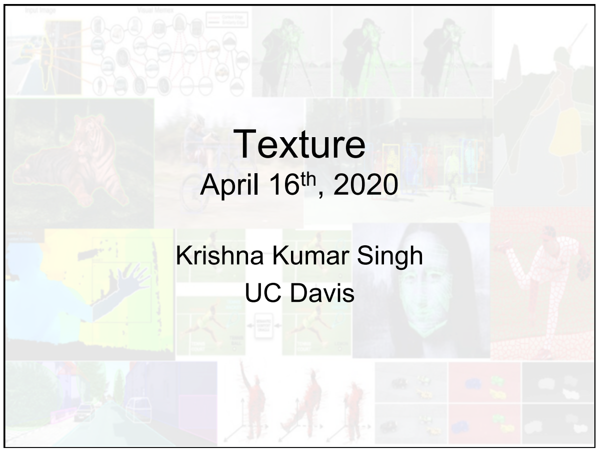


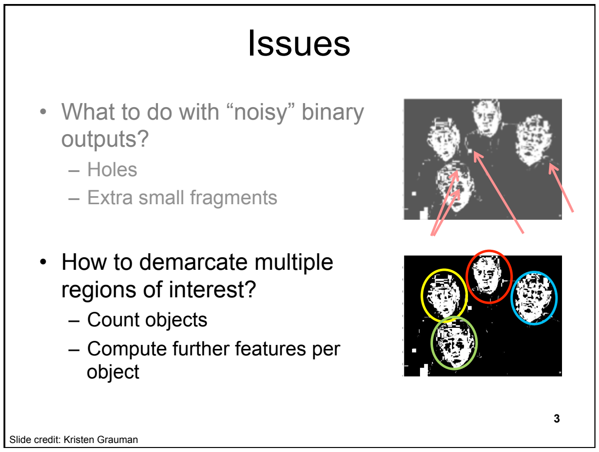
Texture

April 16th, 2020

Krishna Kumar Singh
UC Davis

Review: last time

- 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”



Issues

- What to do with “noisy” binary outputs?
  - Holes
  - Extra small fragments
- How to demarcate multiple regions of interest?
  - Count objects
  - Compute further features per object

Slide credit: Kristen Grauman

Connected components

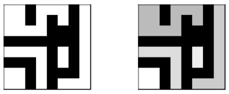
- Identify distinct regions of “connected pixels”

1	1	0	1	1	1	0	1
1	1	0	1	0	1	0	1
1	1	1	1	0	0	0	1
0	0	0	0	0	0	0	1
1	1	1	1	0	1	0	1
0	0	0	1	0	1	0	1
1	1	0	1	0	0	0	1
1	1	0	1	0	1	1	1

a) binary image

1	1	0	1	1	1	0	2
1	1	0	1	0	1	0	2
1	1	1	1	0	0	0	2
0	0	0	0	0	0	0	2
3	3	3	3	0	4	0	2
0	0	0	3	0	4	0	2
5	5	0	3	0	0	0	2
5	5	0	3	0	2	2	2

b) connected components labeling

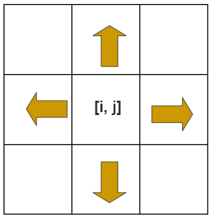


c) binary image and labeling, expanded for viewing

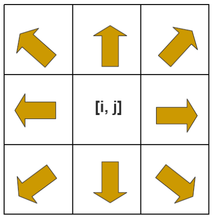
`>> L = bwlabel(BW,conn)`

Connectedness

- Defining which pixels are considered neighbors



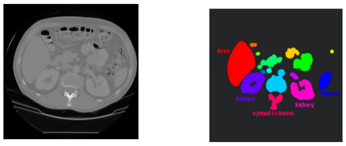
4-connected



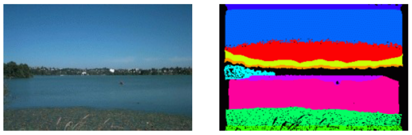
8-connected

Slide credit: Chaitanya Chandra

Connected components



connected components of 1’s from thresholded image



connected components of cluster labels

Slide credit: Pinar Duygulu

Region properties

- Given connected components, can compute simple features per blob, such as:
  - Area (num pixels in the region)
  - Centroid (average x and y position of pixels in the region)
  - Bounding box (min and max coordinates)

Slide credit: Kristen Grauman

Binary image analysis: basic steps (recap)

- Convert the image into binary form
  - Thresholding
- Clean up the thresholded image
  - Morphological operators
- Extract separate blobs
  - Connected components
- Describe the blobs with region properties

Slide credit: Kristen Grauman

Matlab

- `L = bwlabel (BW,8);`
- `STATS = regionprops(L,PROPERTIES) ;`
  - `'Area'`
  - `'Centroid'`
  - `'BoundingBox'`
  - `'Orientation'`, …
- `IM2 = imerode(IM,SE);`
- `IM2 = imdilate(IM,SE);`
- `IM2 = imclose(IM, SE);`
- `IM2 = imopen(IM, SE);`

Slide adapted from Kristen Grauman

Binary images

- Pros
  - Can be fast to compute, easy to store
  - Simple processing techniques available
  - Lead to some useful compact shape descriptors
- Cons
  - Hard to get “clean” silhouettes
  - Noise common in realistic scenarios
  - Can be too coarse of a representation

Slide credit: Kristen Grauman

Summary

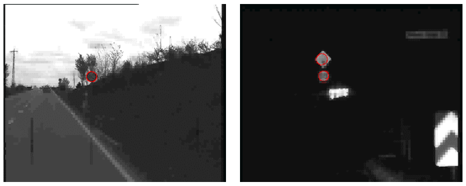
- Operations, tools

Derivative filters
Smoothing, morphology
Thresholding
Connected components
Matching filters
Histograms

- Features, representations

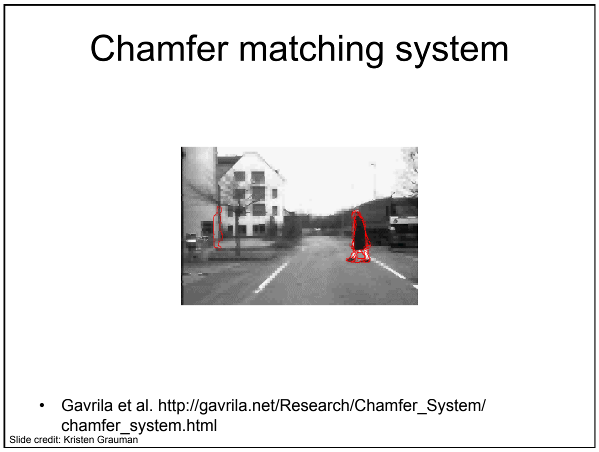
Edges, gradients
Blobs/regions
Local patterns
Textures (next)
Color distributions

Chamfer matching system



- Gavrila et al. http://gavrila.net/Research/Chamfer_System/chamfer_system.html

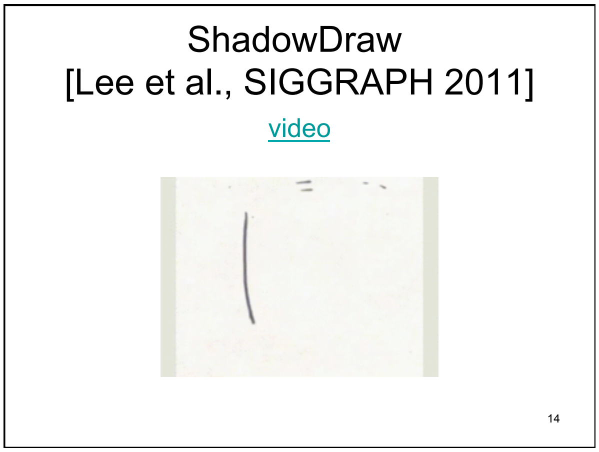
Slide credit: Kristen Grauman



Chamfer matching system

- Gavrila et al. http://gavrila.net/Research/Chamfer_System/chamfer_system.html

Slide credit: Kristen Grauman



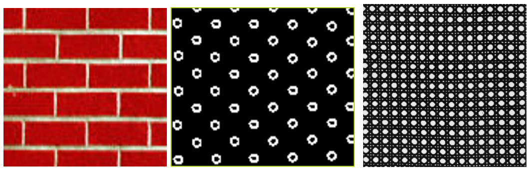
ShadowDraw
[Lee et al., SIGGRAPH 2011]

video

Today: Texture

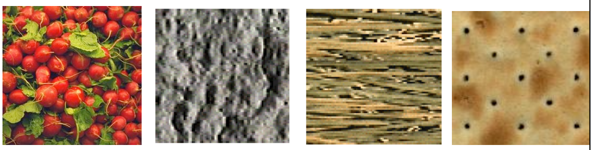
What defines a texture?

Includes: more regular patterns



Slide credit: Kristen Grauman

Includes: more random patterns

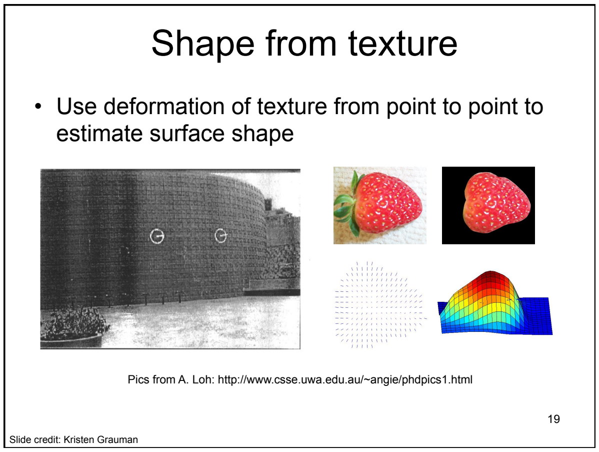


Slide credit: Kristen Grauman

Texture-related tasks

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

Slide credit: Kristen Grauman

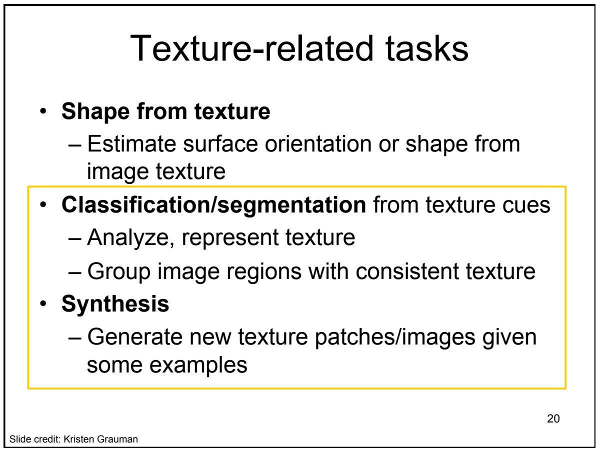


Shape from texture

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

Pics from A. Loh: http://www.csse.uwa.edu.au/~angie/phdpics1.html

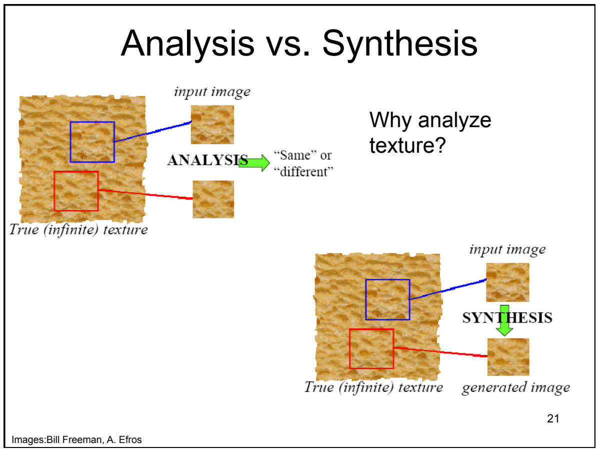
Slide credit: Kristen Grauman



Texture-related tasks

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

Slide credit: Kristen Grauman



Analysis vs. Synthesis

Why analyze texture?

Images:Bill Freeman, A. Efros

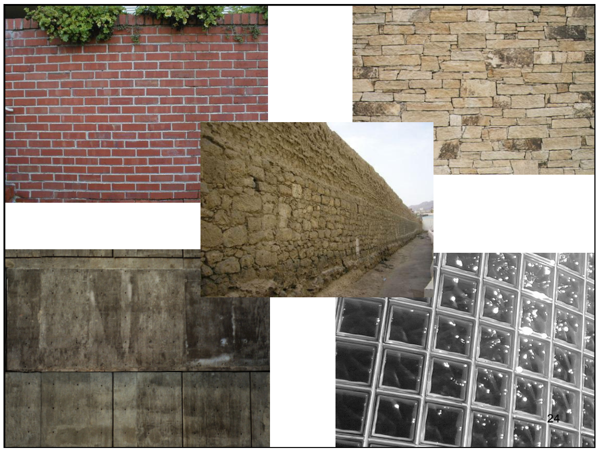
Image credit: D. Forsyth

Why analyze texture?

Importance to perception:

- Often indicative of a material’s properties

Slide credit: Kristen Grauman

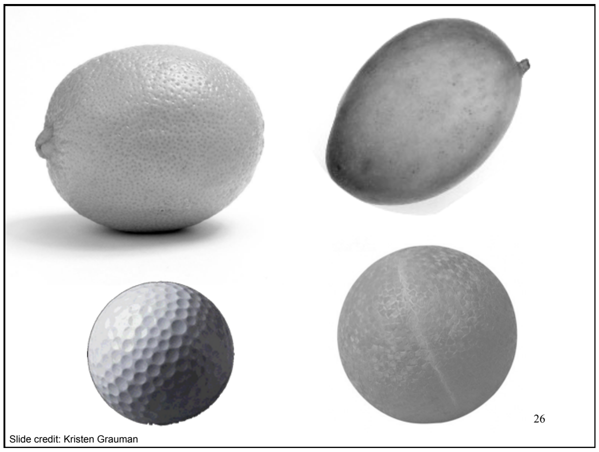


Why analyze texture?

Importance to perception:

- Often indicative of a material's properties
- Can be important appearance cue, especially if shape is similar across objects

Slide credit: Kristen Grauman



Slide credit: Kristen Grauman

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 boundaries and texture

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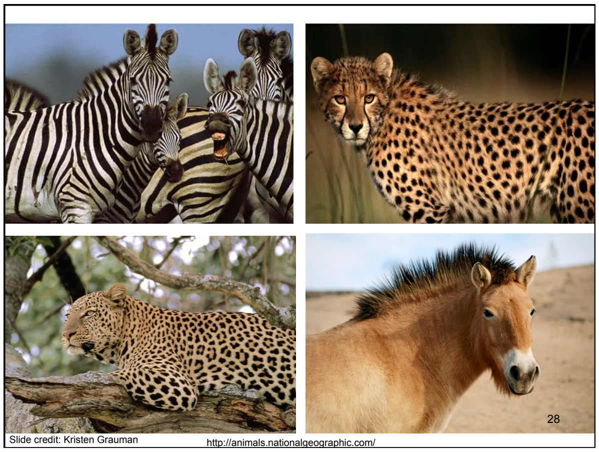


Slide credit: Kristen Grauman

http://animals.nationalgeographic.com/

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 boundaries and texture

Technically:

- Representation-wise, we want a feature one step above “building blocks” of filters, edges.

Slide credit: Kristen Grauman

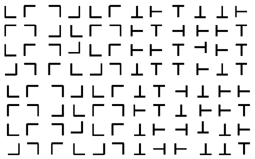
Images from Malik and Perona, 1990

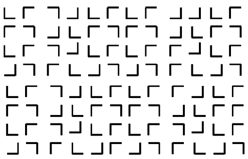
Psychophysics of texture

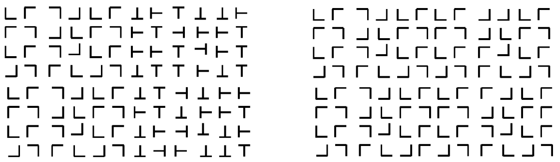
- Some textures distinguishable with *preattentive* perception – without scrutiny, eye movements [Julesz 1975]

Same or different?

Slide credit: Kristen Grauman







Capturing the local patterns with image measurements

[Bergen & Adelson, *Nature* 1988]

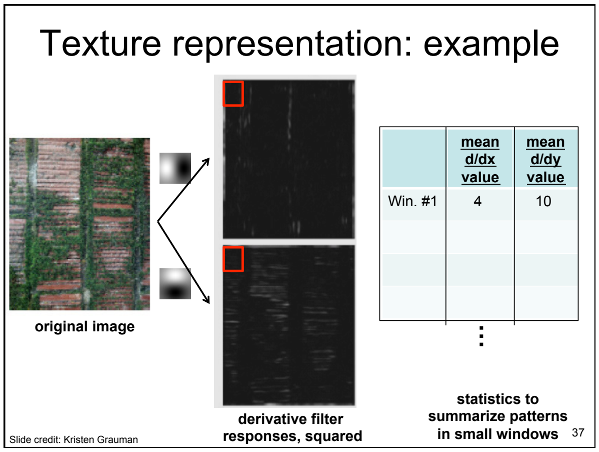
Scale of patterns influences discriminability

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

Slide credit: Kristen Grauman



Texture representation: example

	mean d/dx value	mean d/dy value
Win. #1	4	10

⋮

statistics to summarize patterns in small windows

Slide credit: Kristen Grauman

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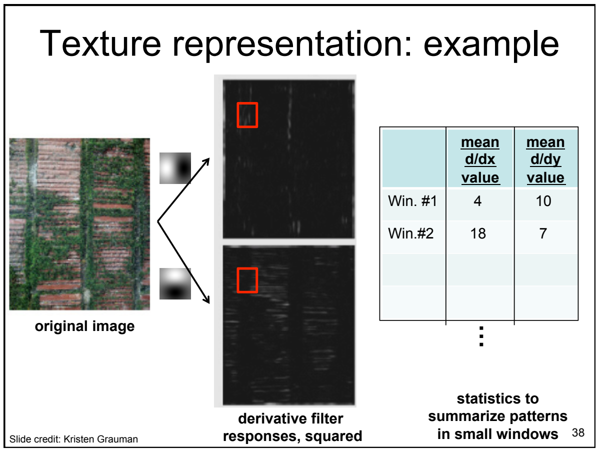

Texture representation: example

	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7

⋮

statistics to summarize patterns in small windows

Slide credit: Kristen Grauman

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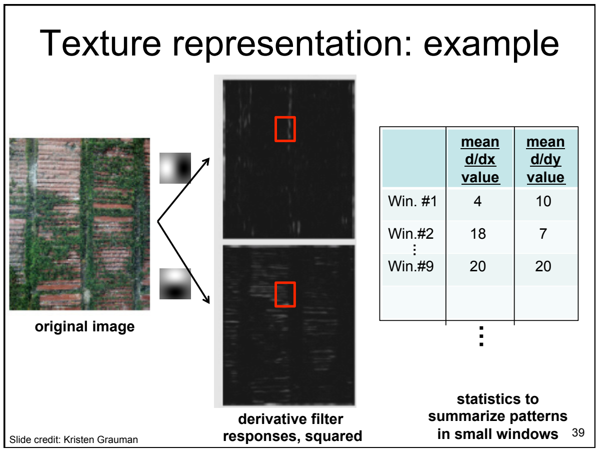

Texture representation: example

	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2 ⋮	18	7
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

Slide credit: Kristen Grauman

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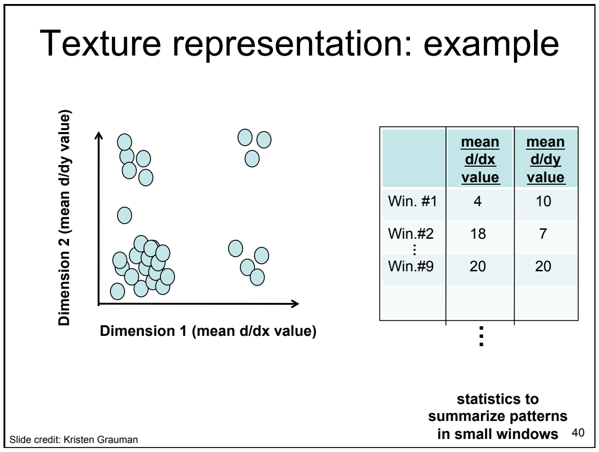


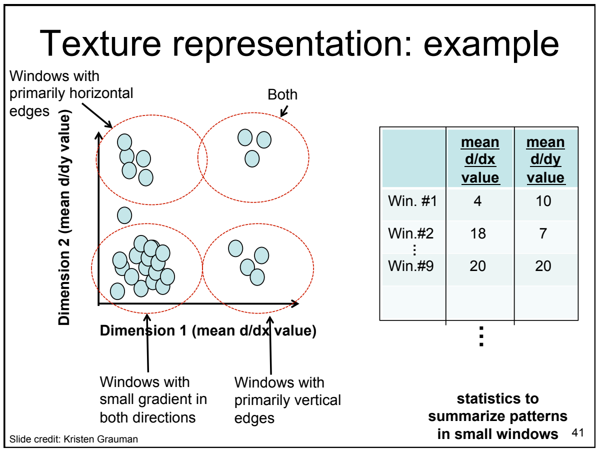
Texture representation: example

	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

Slide credit: Kristen Grauman



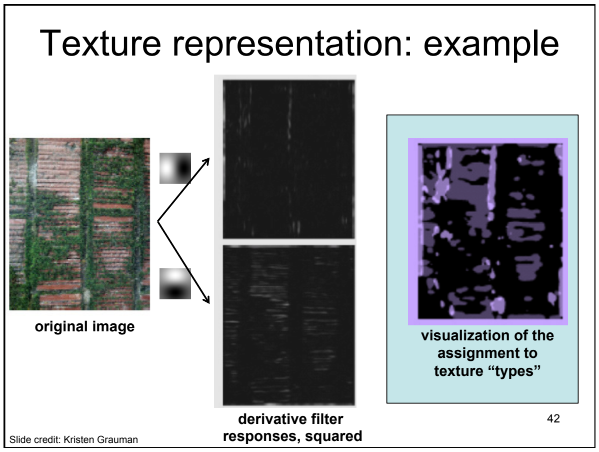
Texture representation: example

	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

Slide credit: Kristen Grauman



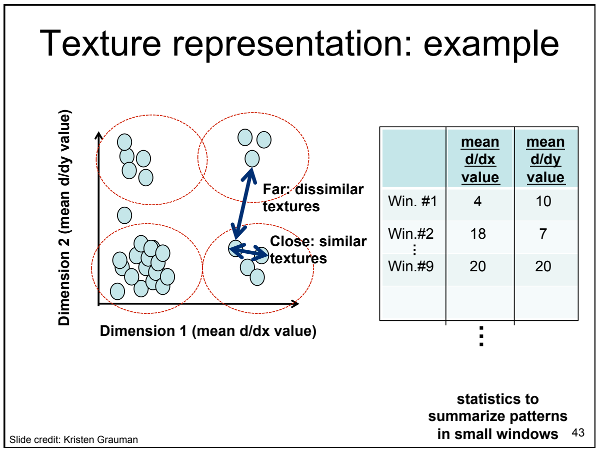
Texture representation: example

original image

derivative filter responses, squared

visualization of the assignment to texture "types"

Slide credit: Kristen Grauman



Texture representation: example

	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2 ⋮	18	7
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

Slide credit: Kristen Grauman

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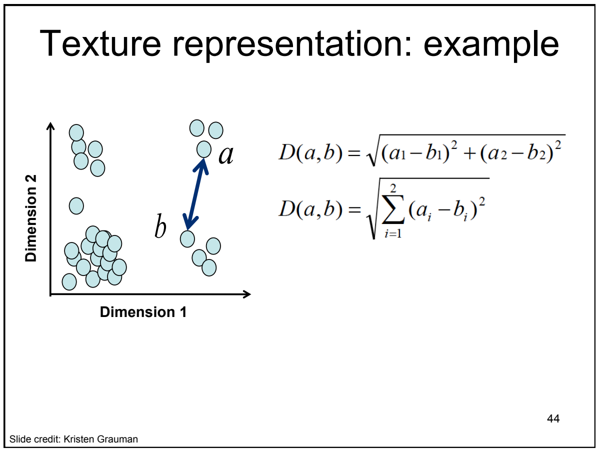

Texture representation: example

$$D(a,b)=\sqrt{(a_1-b_1)^2+(a_2-b_2)^2}$$

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

Slide credit: Kristen Grauman

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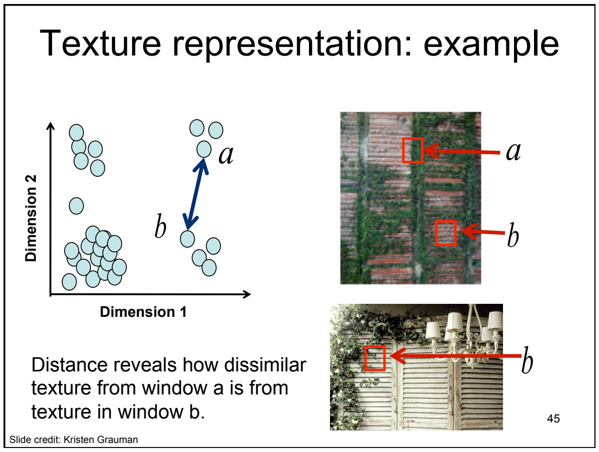

Texture representation: example

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

Slide credit: Kristen Grauman

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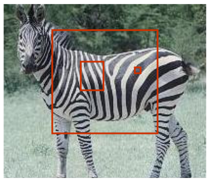
Texture representation: window scale

- The window size (i.e., scale) for which we collect these statistics is important.



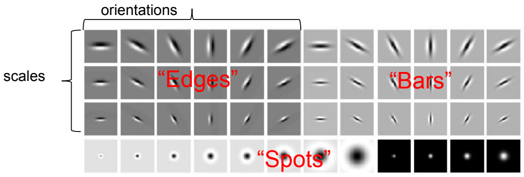
Possible to perform scale selection by looking for window scale where texture description not changing.

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

Slide credit: Kristen Grauman

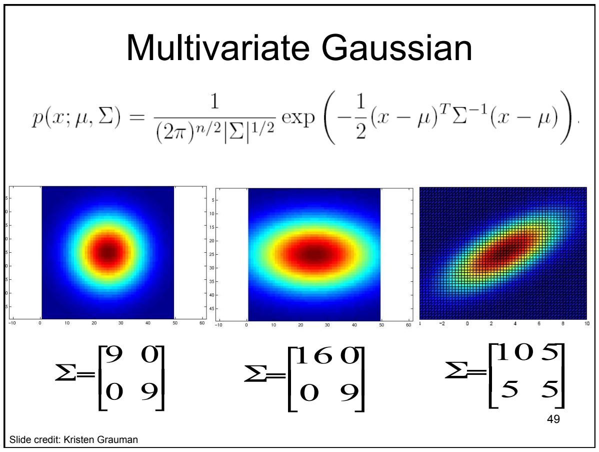
Filter banks



- 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

Slide credit: Kristen Grauman

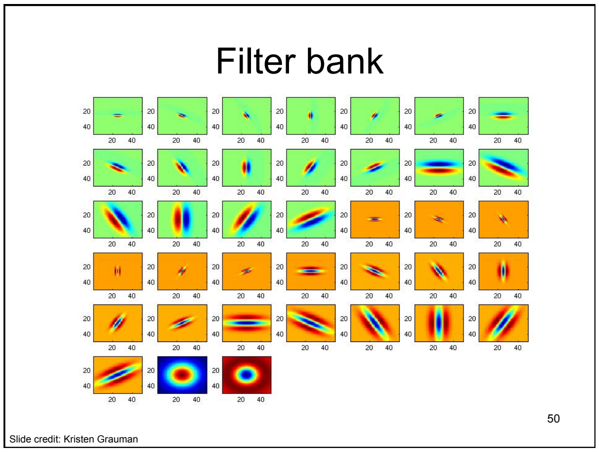


Multivariate Gaussian

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

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

Slide credit: Kristen Grauman

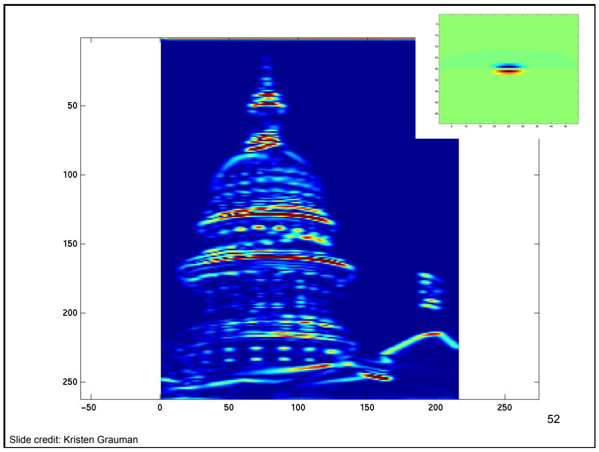


Filter bank

Slide credit: Kristen Grauman

Image from http://www.texasexplorer.com/austincap2.jpg

Slide credit: Kristen Grauman



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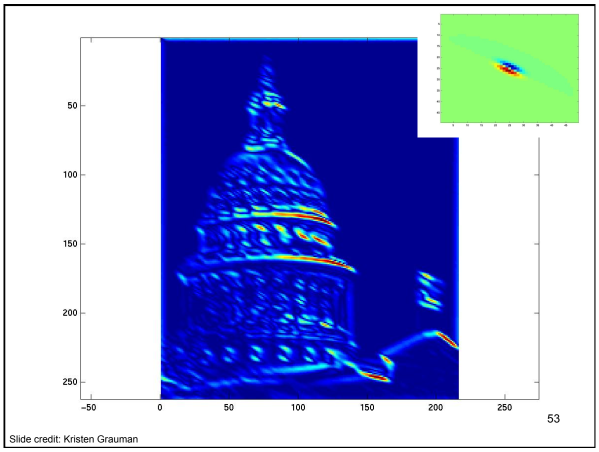

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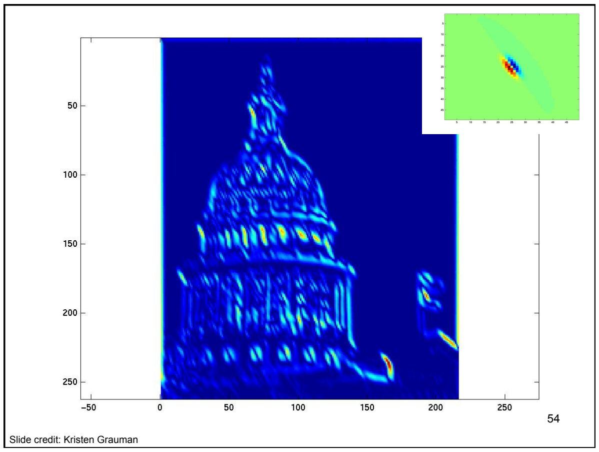

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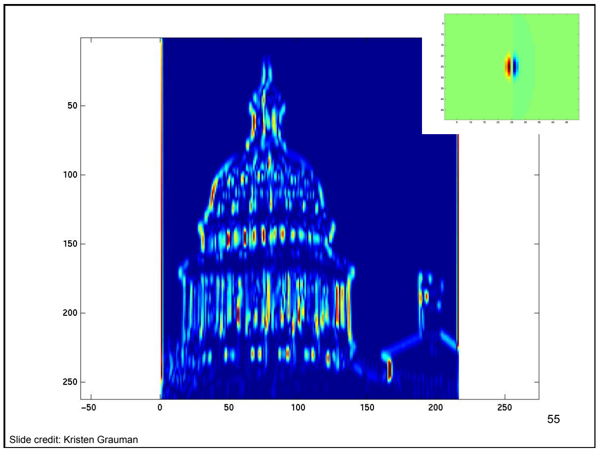

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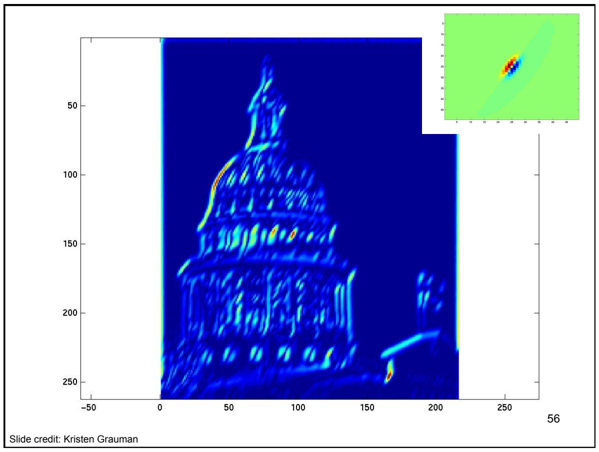
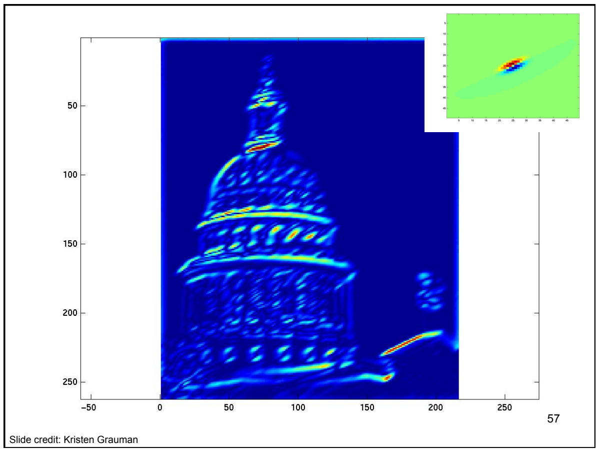


Slide credit: Kristen Grauman



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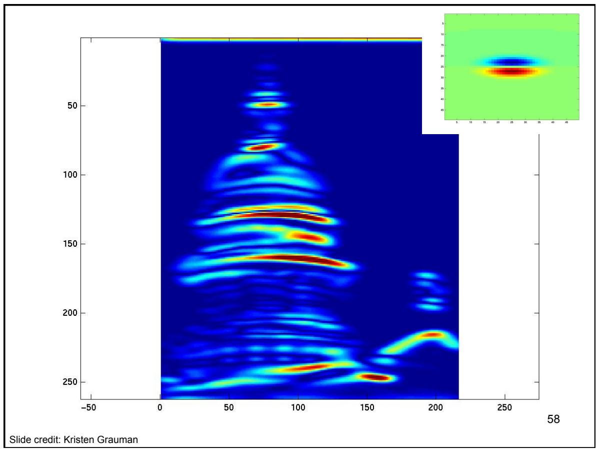
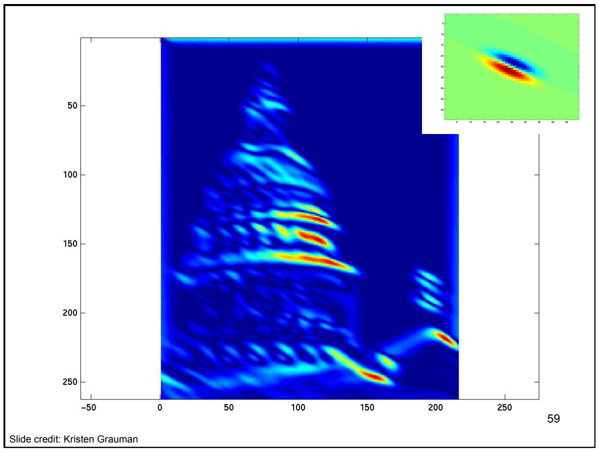


Slide credit: Kristen Grauman



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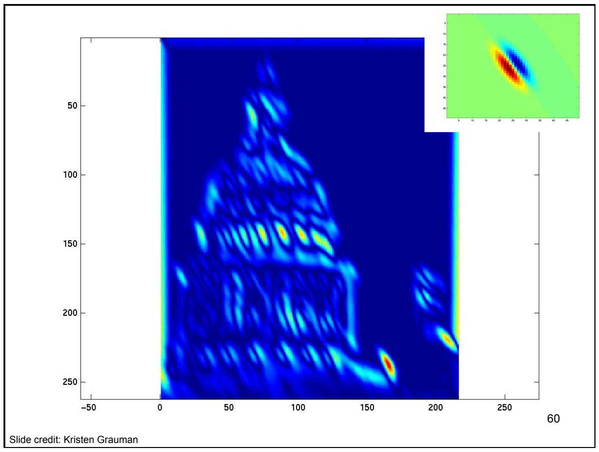

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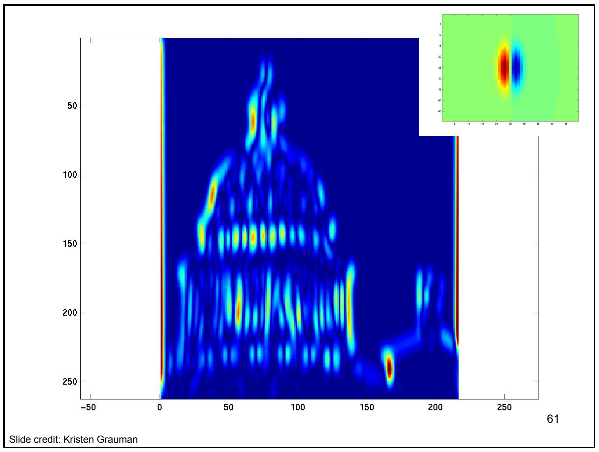

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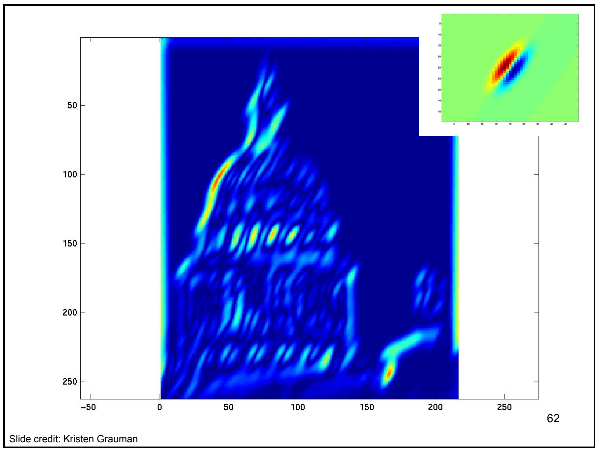
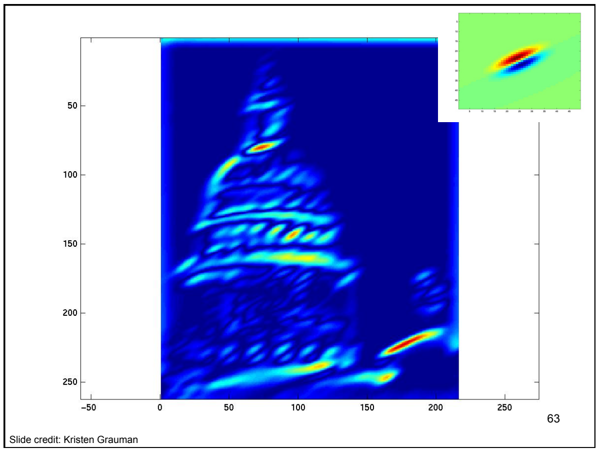


Slide credit: Kristen Grauman



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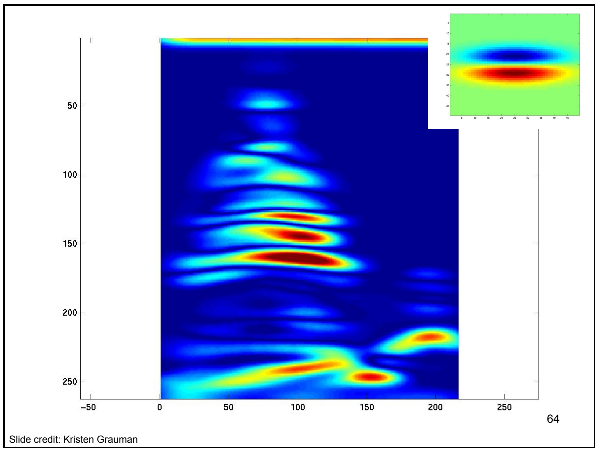

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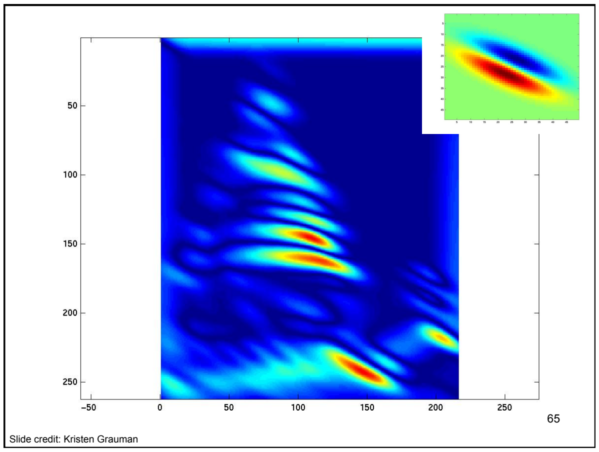
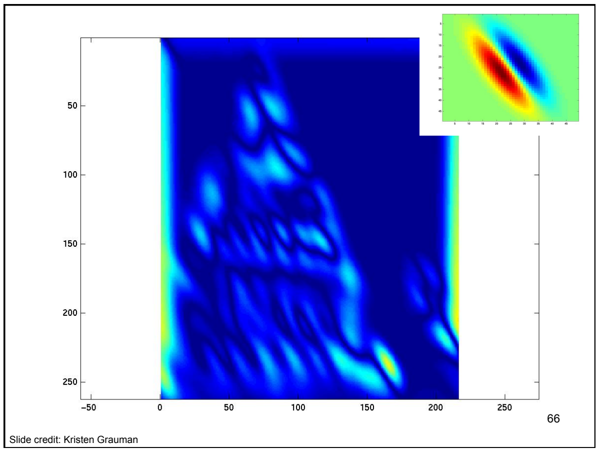
Slide credit: Kristen Grauman



65

Slide credit: Kristen Grauman



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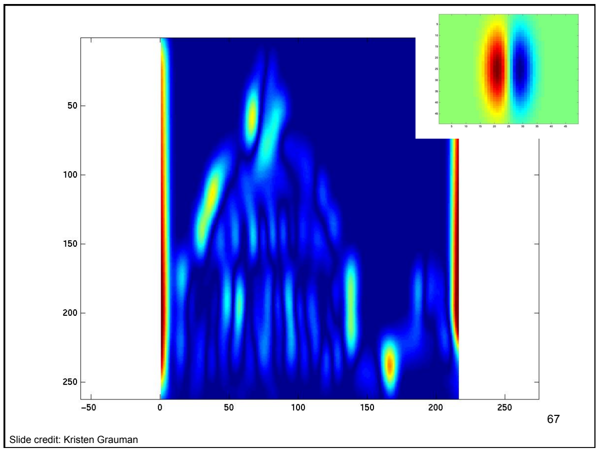

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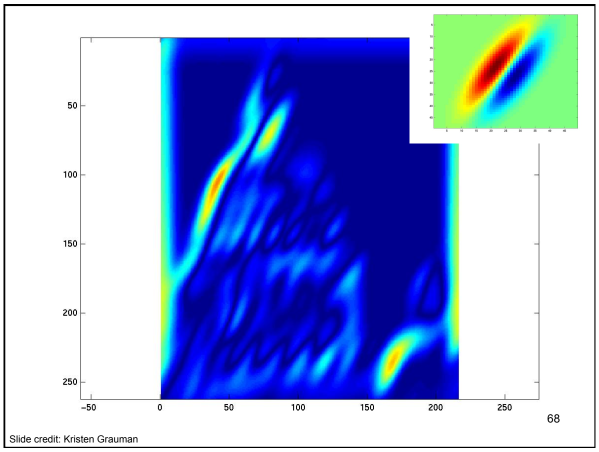

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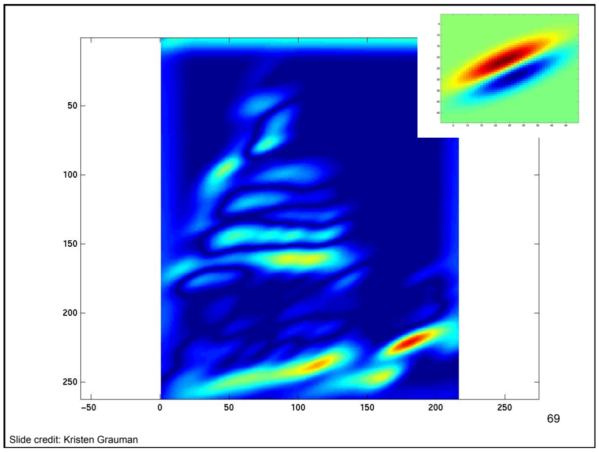

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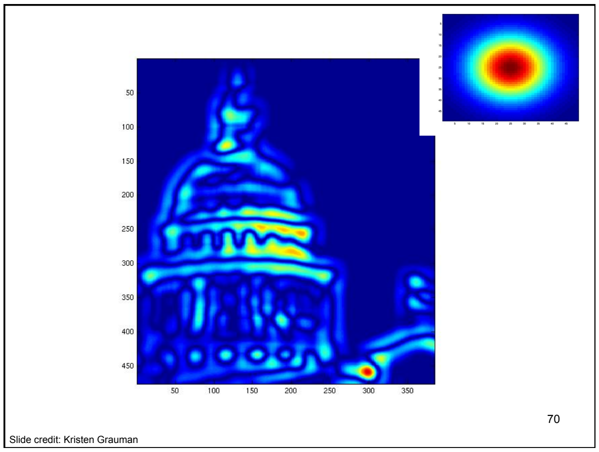

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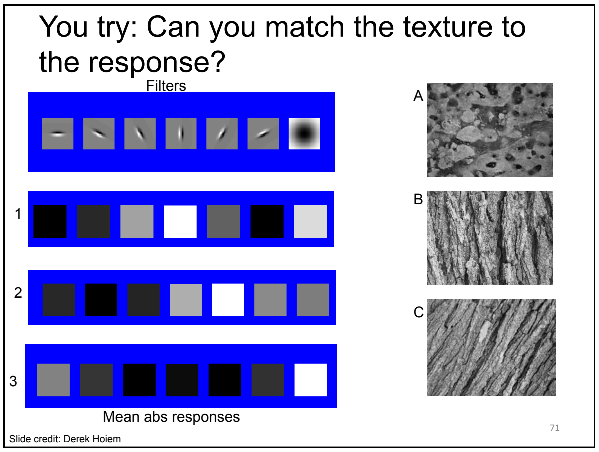
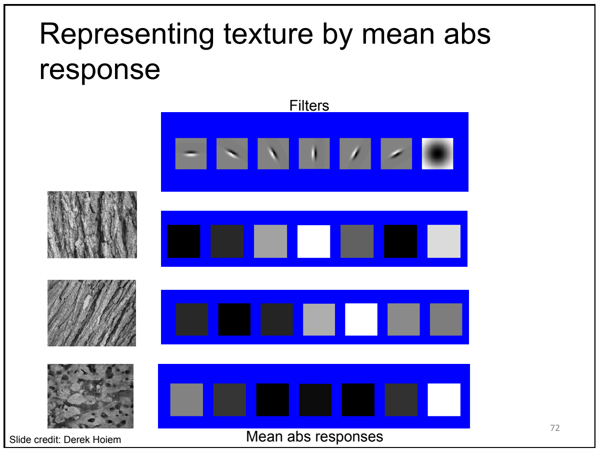


You try: Can you match the texture to the response?

Mean abs responses

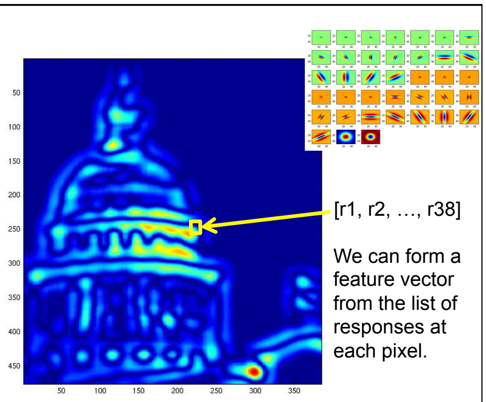
Slide credit: Derek Hoiem



Representing texture by mean abs response

Mean abs responses

Slide credit: Derek Hoiem



[r1, r2, …, r38]

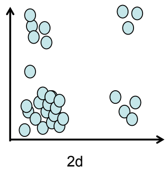
We can form a feature vector from the list of responses at each pixel.

Slide credit: Kristen Grauman

d-dimensional features

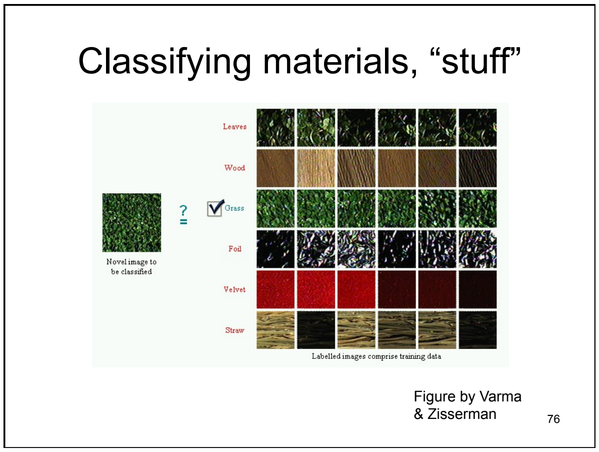
$$D(a,b) = \sqrt{\sum_{i=1}^{d} (a_i - b_i)^2}$$

Euclidean distance (L_2)



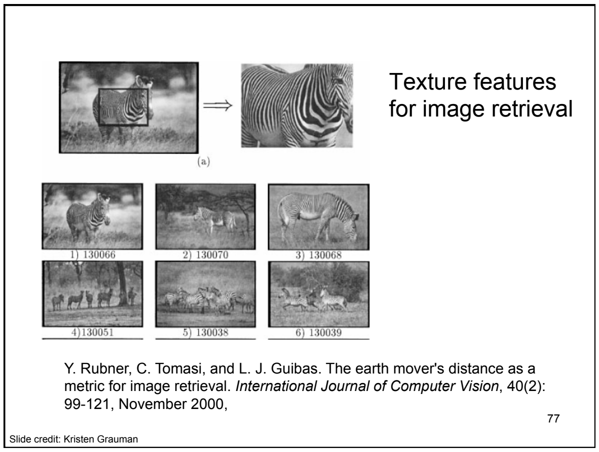
Slide credit: Kristen Grauman

Example uses of texture in vision: analysis



Classifying materials, “stuff”

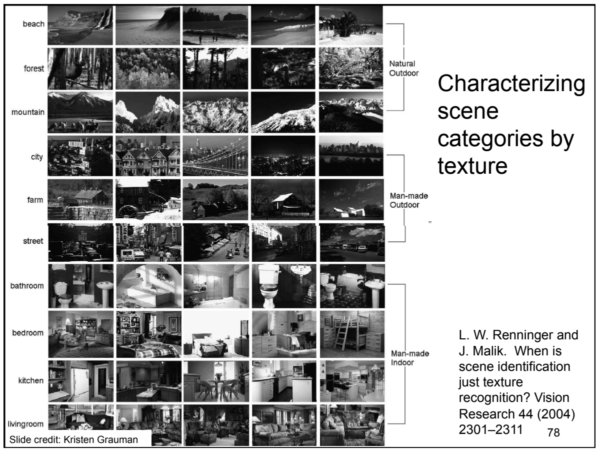
Figure by Varma & Zisserman



Texture features for image retrieval

Y. Rubner, C. Tomasi, and L. J. Guibas. The earth mover's distance as a metric for image retrieval. *International Journal of Computer Vision*, 40(2): 99-121, November 2000,

Slide credit: Kristen Grauman



Characterizing scene categories by texture

L. W. Renninger and J. Malik. When is scene identification just texture recognition? Vision Research 44 (2004) 2301–2311

Slide credit: Kristen Grauman

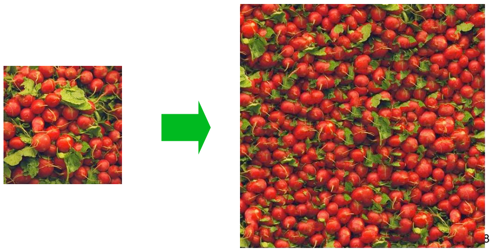
Texture-related tasks

- **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

Slide credit: Kristen Grauman

Texture synthesis

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

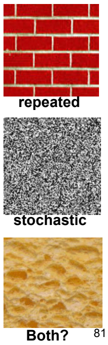


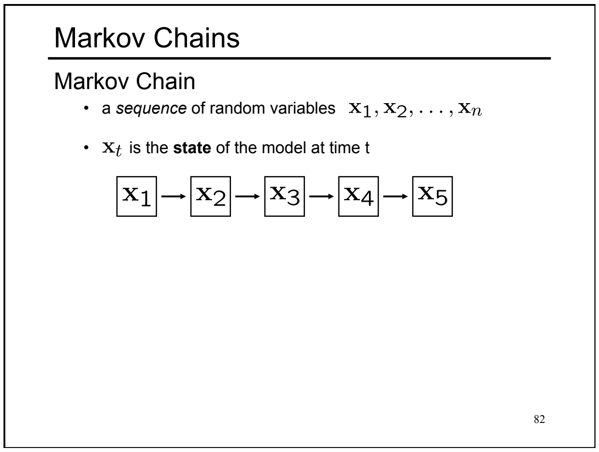
Slide credit: Kristen Grauman

The Challenge

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

Alexei A. Efros and Thomas K. Leung, "Texture Synthesis by Non-parametric Sampling," Proc. International Conference on Computer Vision (ICCV), 1999.



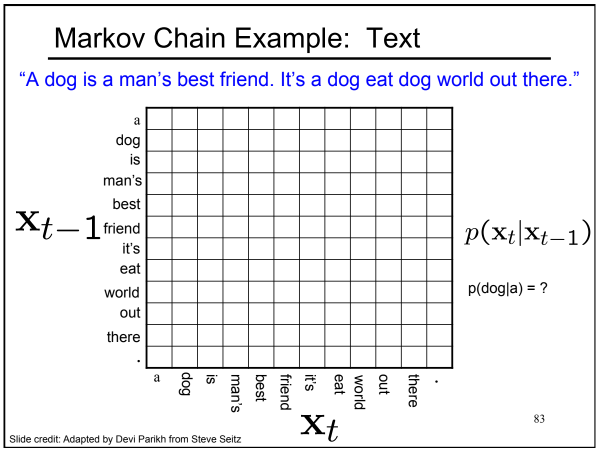


Markov Chains

Markov Chain

- a *sequence* of random variables $\mathrm{x}_1, \mathrm{x}_2, \ldots, \mathrm{x}_n$
- x_t is the **state** of the model at time t

$$\boxed{\mathrm{x}_1} \rightarrow \boxed{\mathrm{x}_2} \rightarrow \boxed{\mathrm{x}_3} \rightarrow \boxed{\mathrm{x}_4} \rightarrow \boxed{\mathrm{x}_5}$$



Markov Chain Example: Text

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

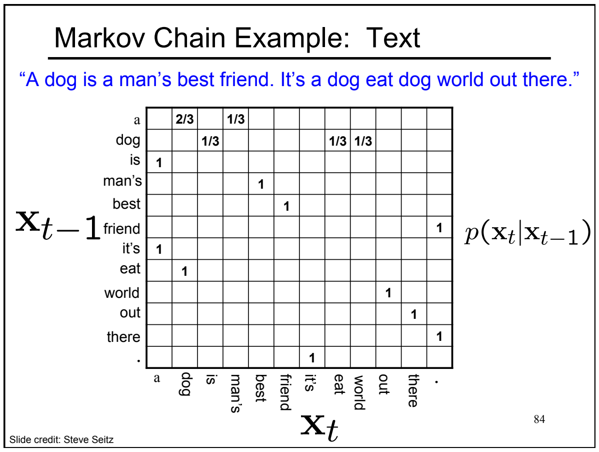
x_{t-1} (rows), x_t (columns)

	a	dog	is	man's	best	friend	it's	eat	world	out	there	.
a												
dog												
is												
man's												
best												
friend												
it's												
eat												
world												
out												
there												
.												

$p(\mathrm{x}_t|\mathrm{x}_{t-1})$

p(dog|a) = ?

Slide credit: Adapted by Devi Parikh from Steve Seitz



Markov Chain Example: Text

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

x_{t-1} (rows), x_t (columns)

	a	dog	is	man's	best	friend	it's	eat	world	out	there	.
a		2/3		1/3								
dog			1/3					1/3	1/3			
is	1											
man's					1							
best						1						
friend												1
it's	1											
eat		1										
world										1		
out											1	
there												1
.							1					

$p(\mathrm{x}_t|\mathrm{x}_{t-1})$

Slide credit: Steve Seitz

Text synthesis

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

Most basic algorithm

1. Build probability histogram/table
   - find all blocks of N consecutive words/letters in training documents
   - compute probability of occurrence $p(\mathbf{x}_t|\mathbf{x}_{t-1},\ldots,\mathbf{x}_{t-(n-1)})$

WE NEED TO EAT CAKE

Slide credit: Steve Seitz

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"*

Dewdney, “A potpourri of programmed prose and prosody” *Scientific American,* 1989.

Slide from Alyosha Efros, ICCV 1999

Markov Random Field

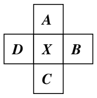
A Markov random field (MRF)

- generalization of Markov chains to two or more dimensions.

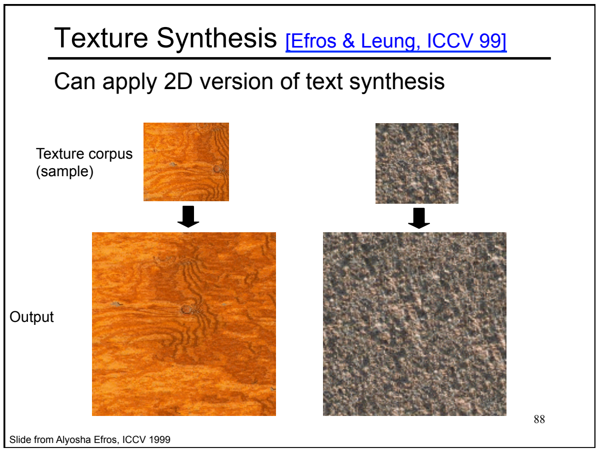
First-order MRF:

- probability that pixel *X* takes a certain value given the values of neighbors *A*, *B*, *C*, and *D*:

$$P(\mathrm{X}|\mathrm{A},\mathrm{B},\mathrm{C},\mathrm{D})$$



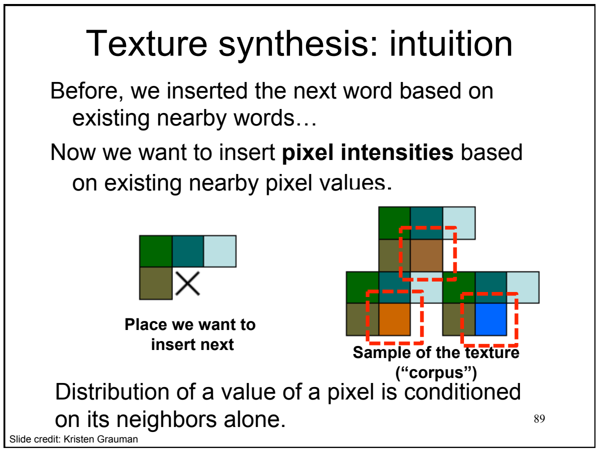
Slide credit: Steve Seitz



Texture Synthesis [Efros & Leung, ICCV 99]

Can apply 2D version of text synthesis

Slide from Alyosha Efros, ICCV 1999



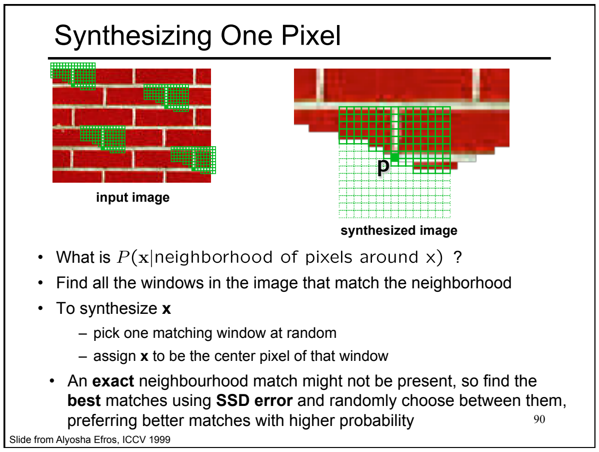
Texture synthesis: intuition

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.

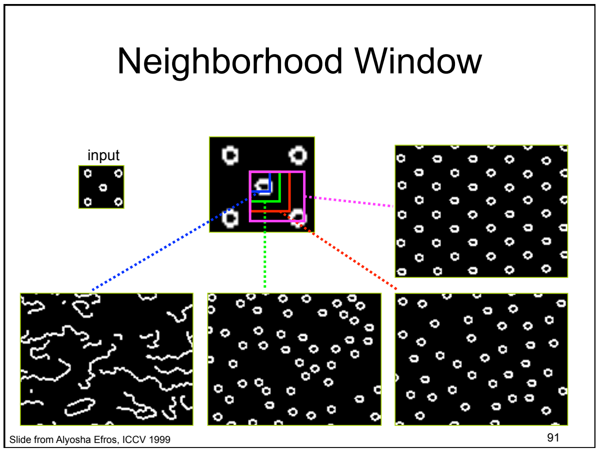
Slide credit: Kristen Grauman



Synthesizing One Pixel

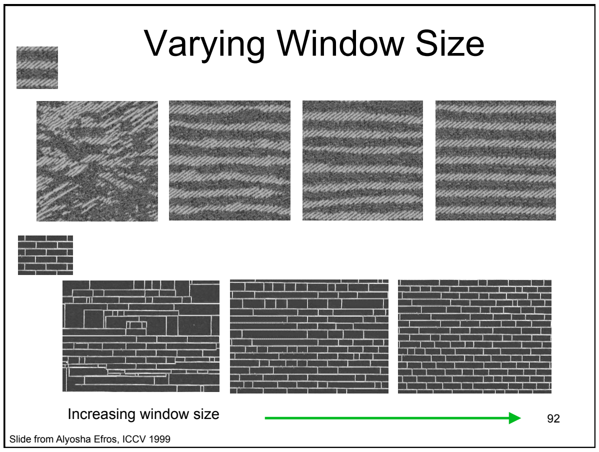
- What is $P(\mathrm{x}|\text{neighborhood of pixels around x})$?
- Find all the windows in the image that match the neighborhood
- To synthesize **x**
  - pick one matching window at random
  - assign **x** to be the center pixel of that window
- An **exact** neighbourhood match might not be present,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

Slide from Alyosha Efros, ICCV 1999



Neighborhood Window

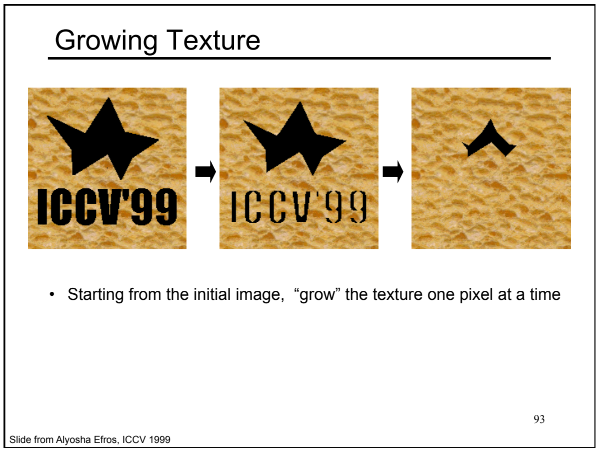
Slide from Alyosha Efros, ICCV 1999



Varying Window Size

Increasing window size

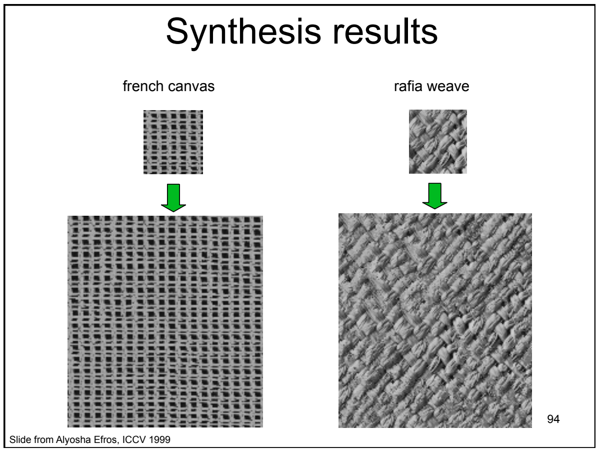
Slide from Alyosha Efros, ICCV 1999



Growing Texture

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

Slide from Alyosha Efros, ICCV 1999

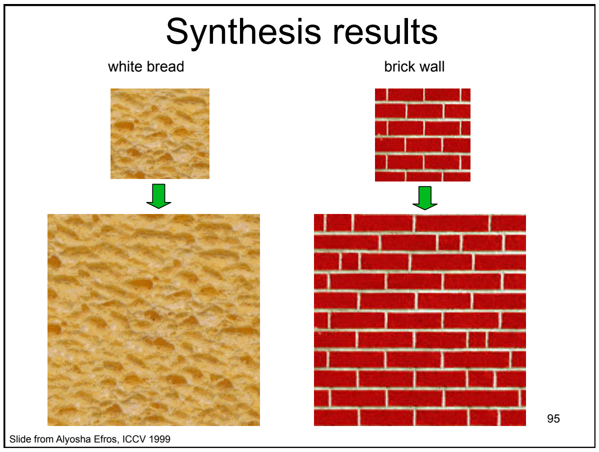


Synthesis results

french canvas

rafia weave

Slide from Alyosha Efros, ICCV 1999

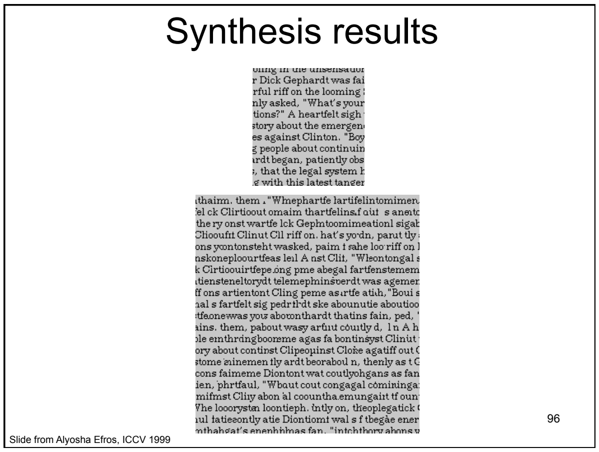


Synthesis results

white bread

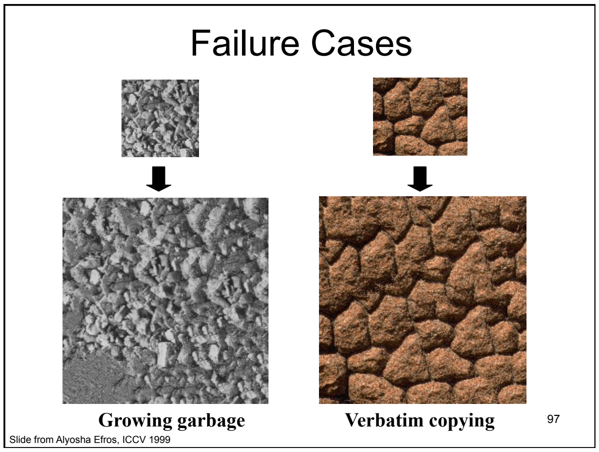
brick wall

Slide from Alyosha Efros, ICCV 1999



Synthesis results

Slide from Alyosha Efros, ICCV 1999

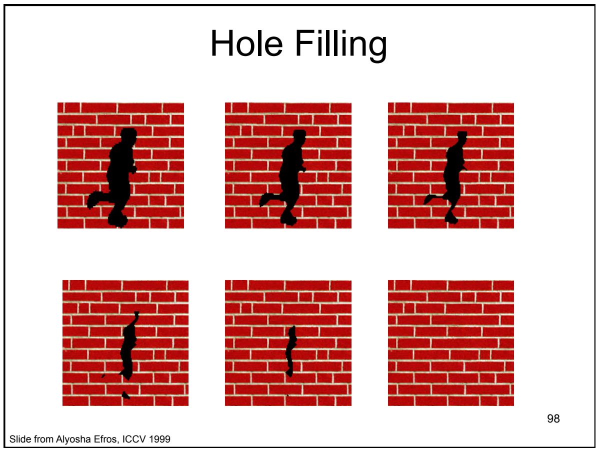


Failure Cases

Growing garbage

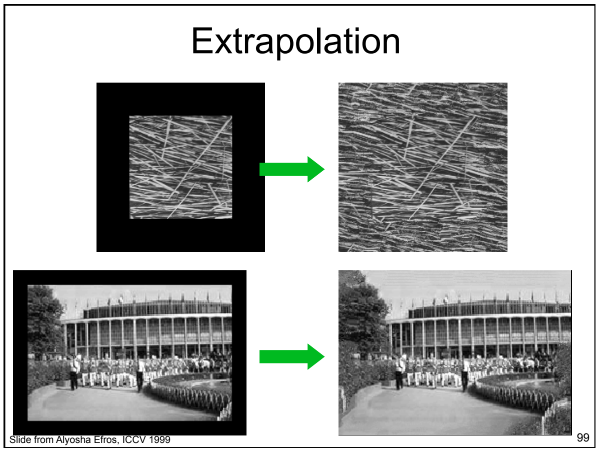
Verbatim copying

Slide from Alyosha Efros, ICCV 1999



Hole Filling

Slide from Alyosha Efros, ICCV 1999

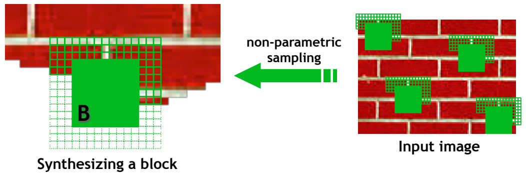


Extrapolation

Slide from Alyosha Efros, ICCV 1999

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

Image Quilting [Efros & Freeman 2001]

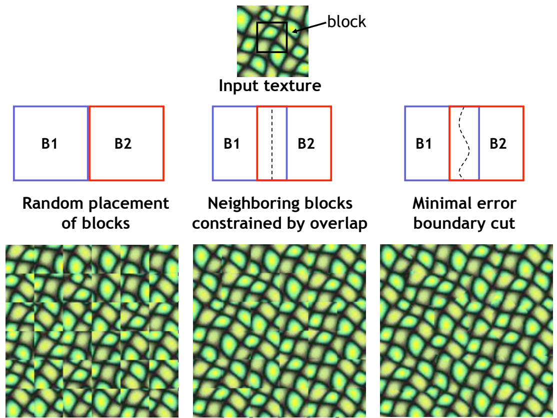


- Observation: neighbor pixels are highly correlated

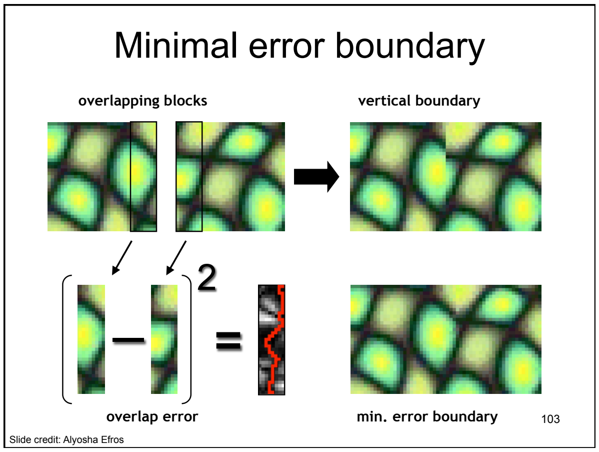
Idea: unit of synthesis = block

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

Slide credit: Alyosha Efros



Slide credit: Alyosha Efros



Minimal error boundary

Slide credit: Alyosha Efros

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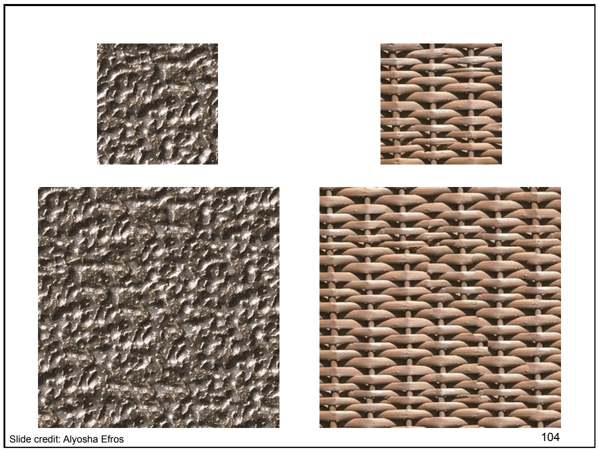

Slide credit: Alyosha Efros

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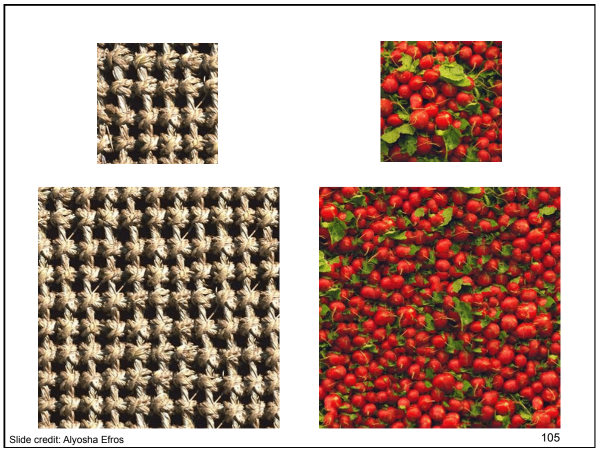

Slide credit: Alyosha Efros

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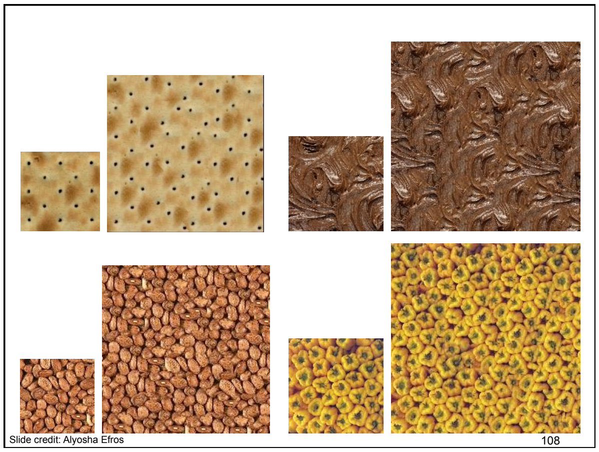
Slide credit: Alyosha Efros

Slide credit: Alyosha Efros

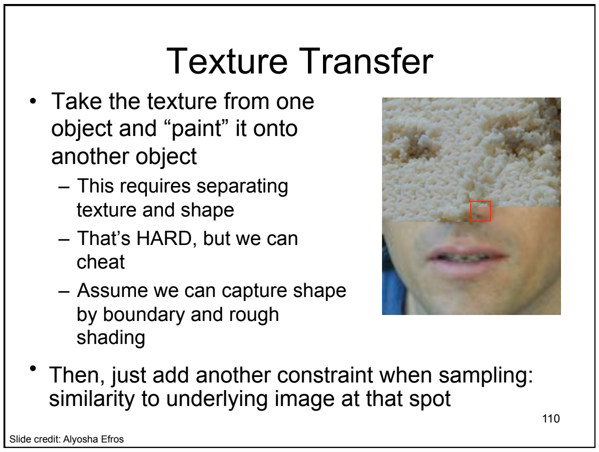


Slide credit: Alyosha Efros

Failures

(Chernobyl Harvest)

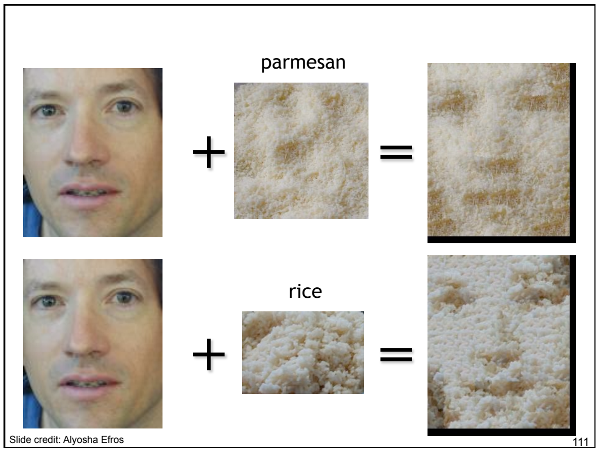
Slide credit: Alyosha Efros



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

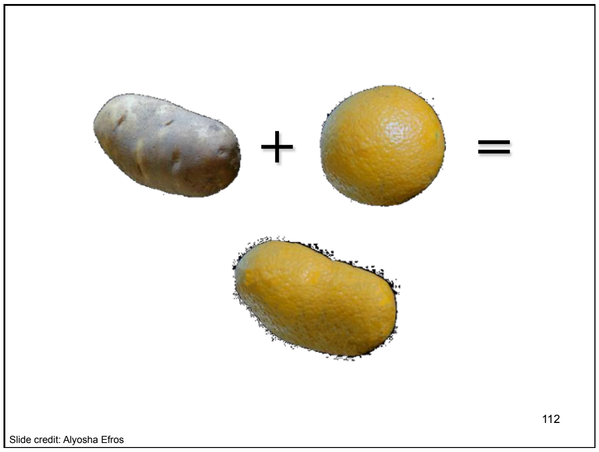
Slide credit: Alyosha Efros



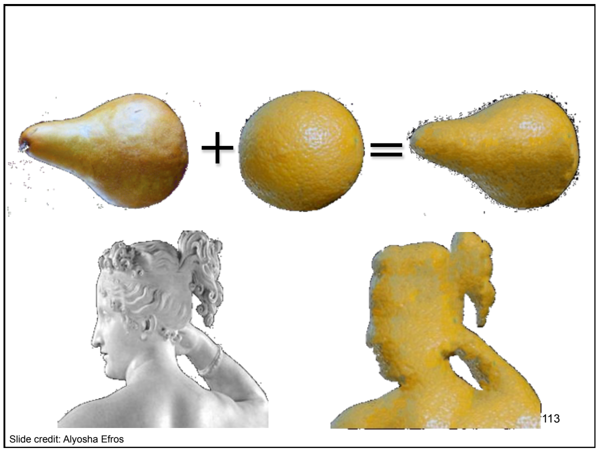
parmesan

rice

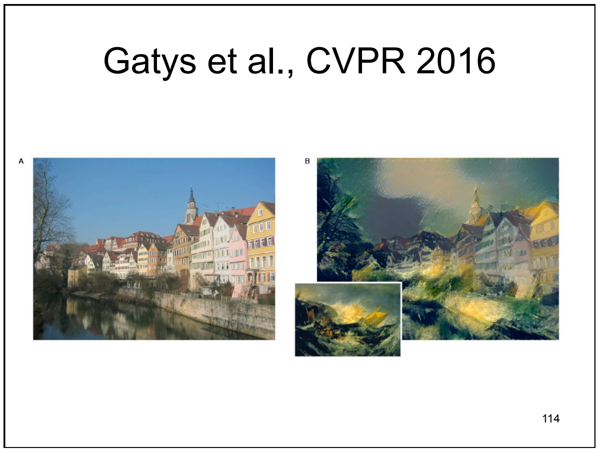
Slide credit: Alyosha Efros



Slide credit: Alyosha Efros

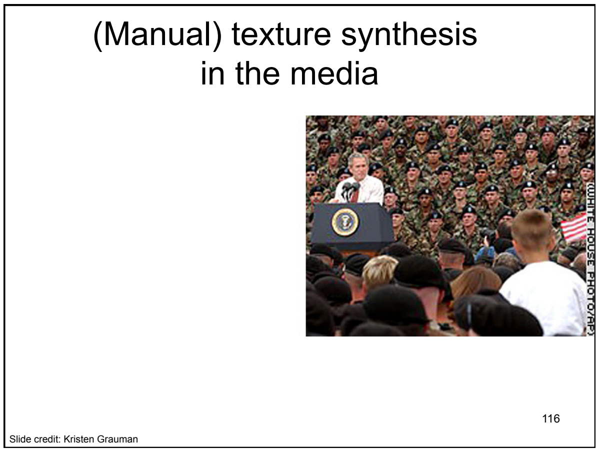


Slide credit: Alyosha Efros



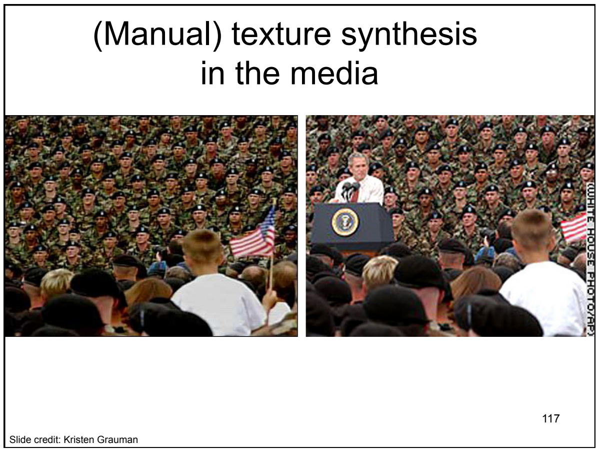
Gatys et al., CVPR 2016

Gatys et al., CVPR 2016



(Manual) texture synthesis in the media

Slide credit: Kristen Grauman



(Manual) texture synthesis in the media

Slide credit: Kristen Grauman

Slide credit: Kristen Grauman http://www.dailykos.com/story/2004/10/27/22442/878

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 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

Questions?

See you Tuesday!