



Recap of Monday

• Linear filtering (convolution)

$$h[m,n] = \sum_{k,l} f[k,l] I[m-k,n-l]$$

- Not a matrix multiplication
- Sum over Hadamard product
- Can smooth, sharpen, translate (among many other uses)
- Be aware of details for filter size, extrapolation, cropping





 $\frac{1}{9}$



James Hays

Sobel filter visualization

• What happens to negative numbers?

- For visualization:
 - Shift image + 0.5
 - If gradients are small, scale edge response

>> I = im2double(imread('luke.jpg')); >> h = imfilter(I, fspecial('sobel'));



imshow(h); imshow(h + 0.5);





h(:,:,1) < 0 h(:,:,1) > 0



Think-Pair-Share

* = Convolution operator





Η















NON-LINEAR FILTERS

Median filters

- Operates over a window by selecting the median intensity in the window.
- 'Rank' filter as based on ordering of gray levels
 E.G., min, max, range filters









h[.,.]

0	10	20	30	30		
			?			

 $h[m,n] = \sum f[k,l] I[m+k,n+l]$ k.l

Credit: S. Seitz



Image filtering - mean



1	1	1	1
- -	1	1	1
1	1	1	1

h[.,.]

0	10	20	30	30		
			50			

 $h[m,n] = \sum_{k,l} f[k,l] I[m+k,n+l]$

Credit: S. Seitz

Median filter?

I[.,.]

h[.	• •	•	
-----	-----	---	--

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	0	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	0	0	0	0	0	0	0
0	0	90	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0



Median filters

- Operates over a window by selecting the median intensity in the window.
- What advantage does a median filter have over a mean filter?

Noisy Jack – Salt and Pepper



Mean Jack – 3 x 3 filter



Very Mean Jack – 11 x 11 filter



Noisy Jack – Salt and Pepper



Median Jack – 3 x 3



Very Median Jack – 11 x 11



Median filters

- Operates over a window by selecting the median intensity in the window.
- What advantage does a median filter have over a mean filter?
- Is a median filter a kind of convolution?

Median filters

- Operates over a window by selecting the median intensity in the window.
- What advantage does a median filter have over a mean filter?
- Is a median filter a kind of convolution?

Secret: Median filtering is sorting.



Salvador Dali, 1976

Today's Class

- Spatial frequency
- Fourier transform and frequency domain
 - Frequency view of filtering
 - Hybrid images
 - Sampling
- Reminder: Textbook

- Today's lecture covers material in 3.4

Why does a lower resolution image still make sense to us? What information do we lose?



Image: http://www.flickr.com/photos/igorms/136916757/

Slide: Hoiem

Hybrid Images



 A. Oliva, A. Torralba, P.G. Schyns, <u>"Hybrid Images,"</u> SIGGRAPH 2006

Why do we get different, distance-dependent interpretations of hybrid images?



Slide: Hoiem

Sampling

Why does a lower resolution image still make sense to us? What do we lose?





Image: http://www.flickr.com/photos/igorms/136916757/

Subsampling by a factor of 2



Throw away every other row and column to create a 1/2 size image

Sampling and aliasing



Aliasing problem

• 1D example (sinewave):



Aliasing problem

• 1D example (sinewave):



Aliasing problem

- Sub-sampling may be dangerous....
- Characteristic errors may appear:
 - "car wheels rolling the wrong way in movies"
 - "checkerboards disintegrate in ray tracing"
 - "striped shirts look funny on color television"
 - Moiré patterns



Aliasing in graphics



Source: A. Efros





The blue and green colors are actually the same http://blogs.discovermagazine.com/badastronomy/2009/06/24/the-blue-and-the-green/

Aliasing and Moiré patterns



Gong 96, 1932, Claude Tousignant, Musée des Beaux-Arts de Montréal

Videos

Aliasing in video

Imagine a spoked wheel moving to the right (rotating clockwise). Mark wheel with dot so we can see what's happening.

If camera shutter is only open for a fraction of a frame time (frame time = 1/30 sec. for video, 1/24 sec. for film):



Without dot, wheel appears to be rotating slowly backwards! (counterclockwise)

Nyquist-Shannon Sampling Theorem

- When sampling a signal at discrete intervals, the sampling frequency must be $\ge 2 \times f_{max}$
- f_{max} = max frequency of the input signal
- This will allows to reconstruct the original perfectly from the sampled version



How to fix aliasing?

Solutions?

Better sensors

Solutions:

• Sample more often

Anti-aliasing

Solutions:

• Sample more often

- Get rid of all frequencies that are greater than half the new sampling frequency
 - Will lose information
 - But it's better than aliasing
 - Apply a smoothing (low pass) filter



256x256 128x128 64x64 32x32 16x16



Forsyth and Ponce 2002

Algorithm for downsampling by factor of 2

- 1. Start with image(h, w)
- 2. Apply low-pass filter

im_blur = imfilter(image, fspecial('gaussian', 7, 1))

3. Sample every other pixel

im_small = im_blur(1:2:end, 1:2:end);

Subsampling without pre-filtering



1/2

1/4 (2x zoom)

1/8 (4x zoom)

Subsampling with Gaussian pre-filtering



Gaussian 1/2

G 1/4

G 1/8

Image Pyramids



Project 1 function: vis_hybrid_image.m

Why do we get different, distance-dependent interpretations of hybrid images?



Clues from Human Perception

• Early processing in humans filters for orientations and scales of frequency.



Early Visual Processing: Multi-scale edge and blob filters

Campbell-Robson contrast sensitivity curve

Perceptual cues in the mid-high frequencies dominate perception.



Frequency increase (log) ———

Application: Hybrid Images

When we see an image from far away, we are effectively subsampling it!





A. Oliva, A. Torralba, P.G. Schyns, SIGGRAPH 2006

Hays



Salvador Dali

"Gala Contemplating the Mediterranean Sea, which at 30 meters becomes the portrait of Abraham Lincoln", 1976

Salvador Dali invented Hybrid Images?



Salvador Dali

"Gala Contemplating the Mediterranean Sea, which at 30 meters becomes the portrait of Abraham Lincoln", 1976

