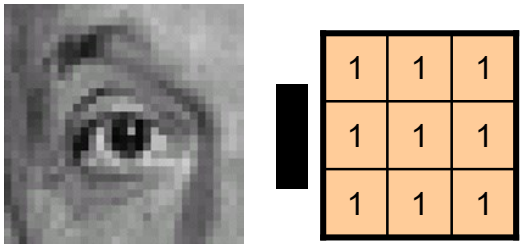
Recap

- 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, cropping

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

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

Image filtering - mean

$f[\cdot,\cdot]$

1	1	1
1	1	1
1	1	1

$I[.,.]$

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

$h[.,.]$

	0	10	20	30	30				
				?					

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

Credit: S. Seitz

Image filtering - mean

$f[\cdot,\cdot]$

1	1	1
1	1	1
1	1	1

$I[.,.]$

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

$h[.,.]$

	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?

$I[.,.]$

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

$h[.,.]$

				?					

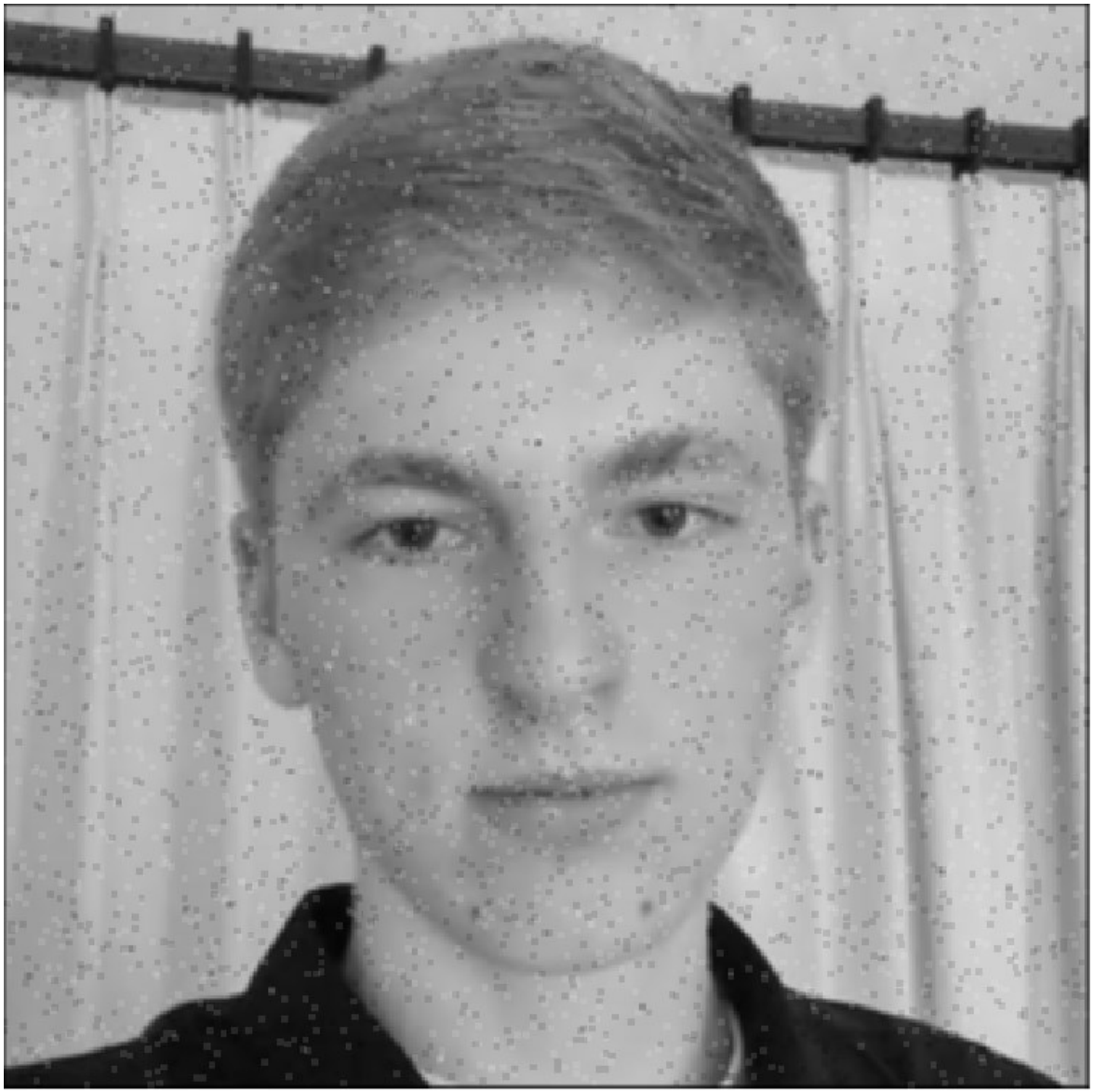
Credit: S. Seitz

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

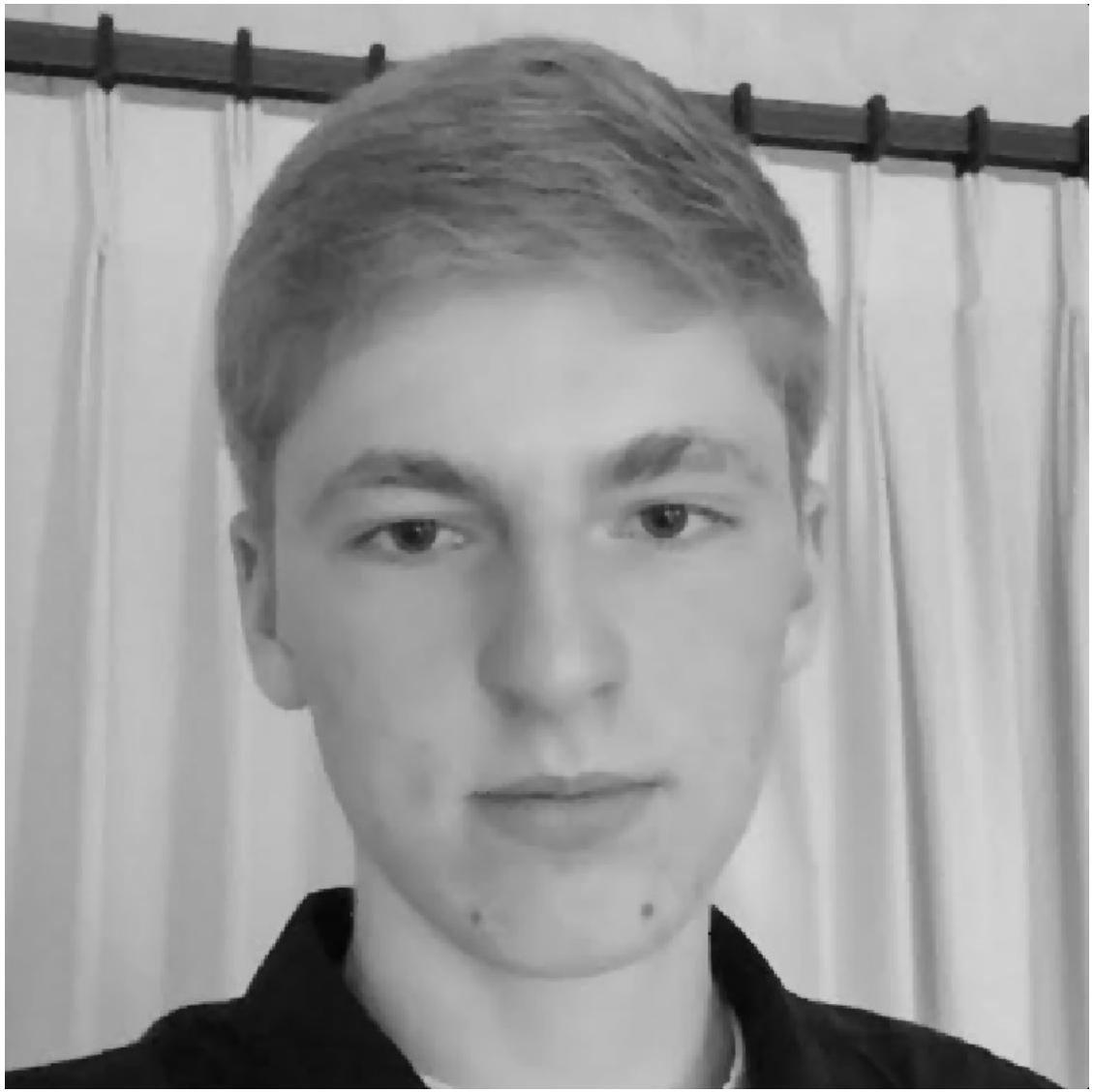
Mean Jack – 3 x 3 filter



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?

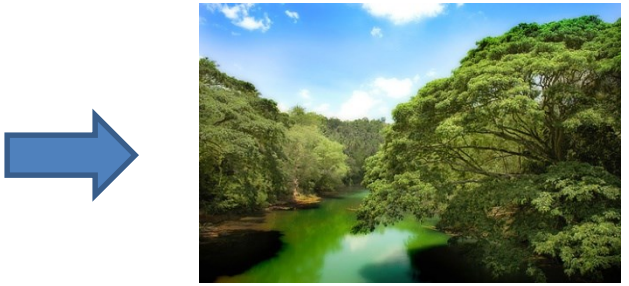
Secret: Median filtering is sorting.

Salvador Dali, 1976

In Frequency Domain

- Spatial frequency
- Fourier transform and frequency domain
  - Frequency view of filtering
  - Hybrid images
  - Sampling
- Reminder: Textbook
  - Today's lecture covers material in 3.4

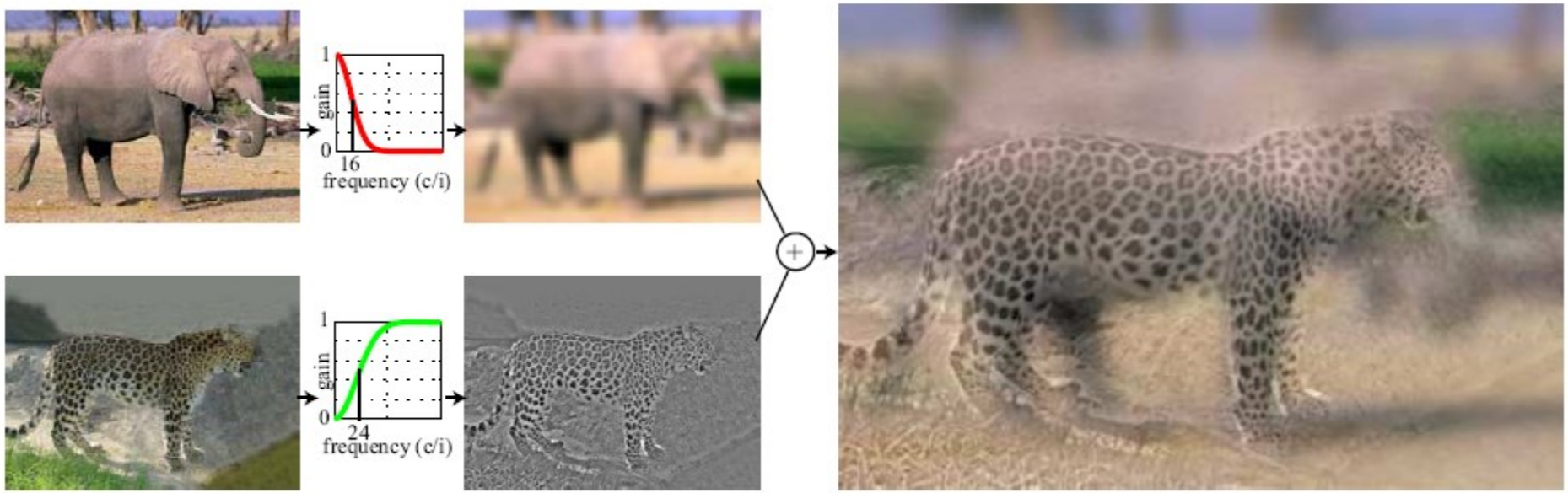
Why does a lower resolution image still make sense to us? What information do we lose?



Slide: Hoiem

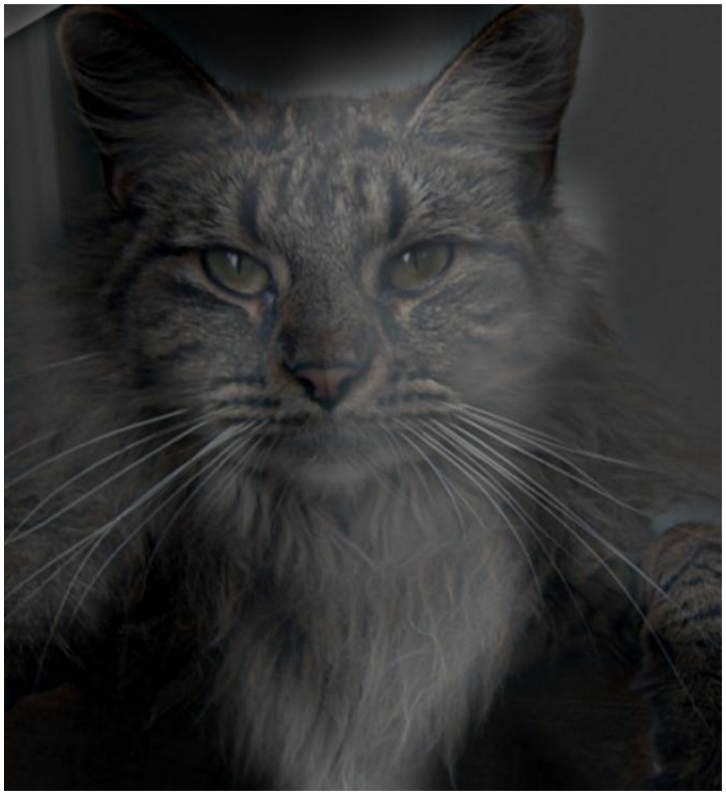
Image: http://www.flickr.com/photos/igorms/136916757/

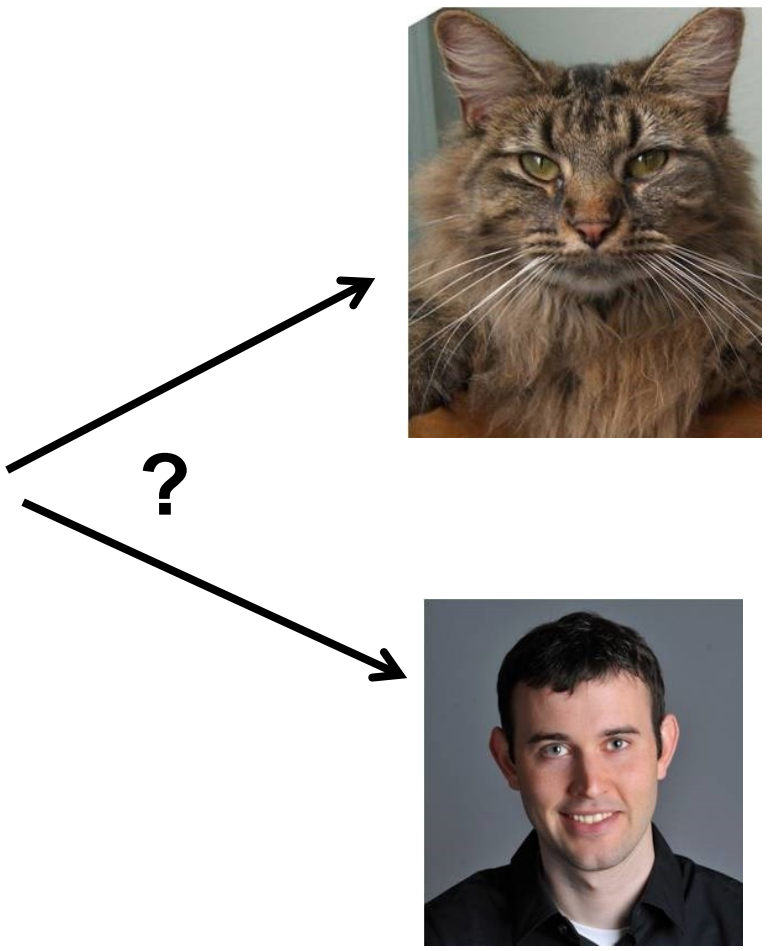
Hybrid Images



- A. Oliva, A. Torralba, P.G. Schyns, "Hybrid Images," SIGGRAPH 2006

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





Sampling

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

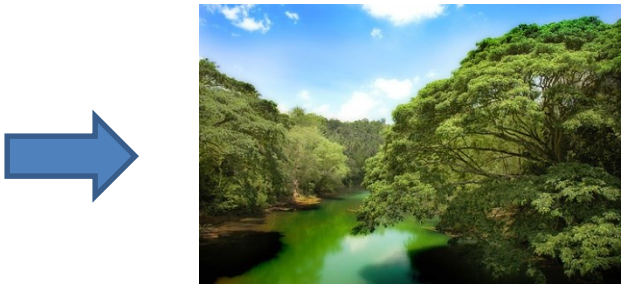
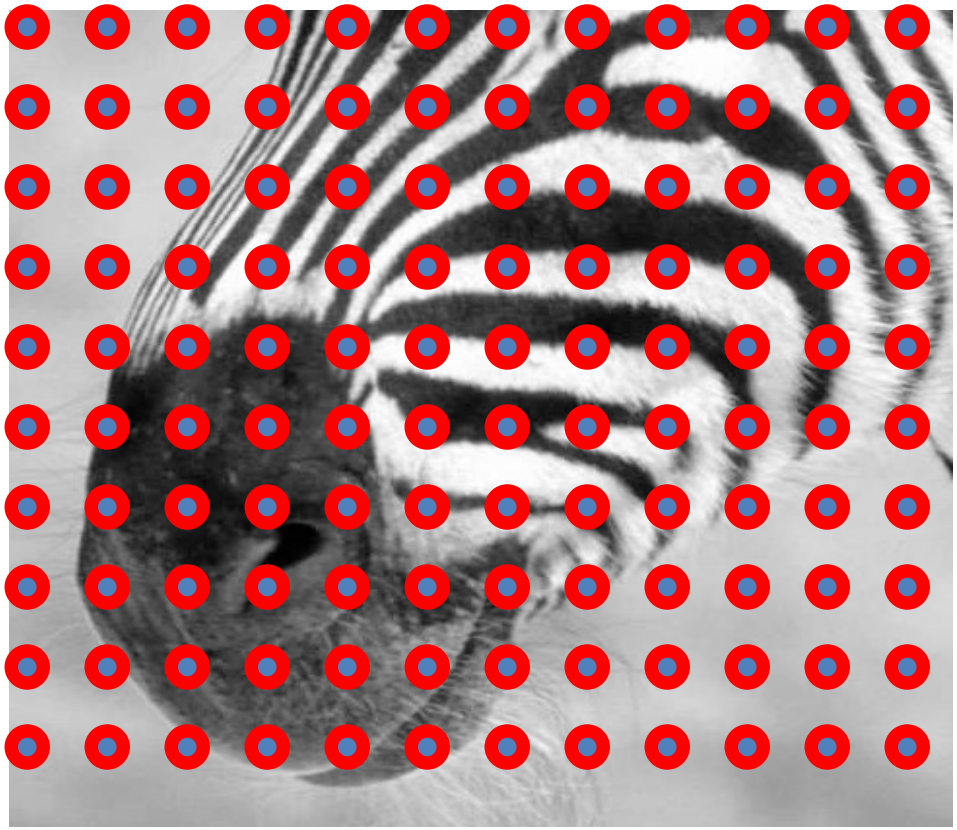


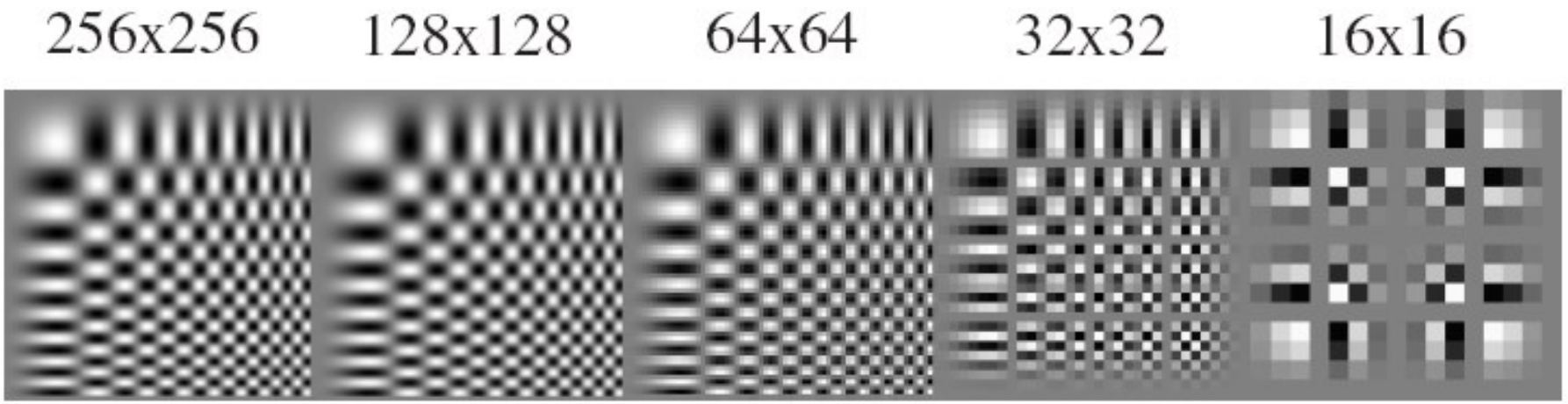
Image: http://www.flickr.com/photos/igorms/136916757/

Subsampling by a factor of 2



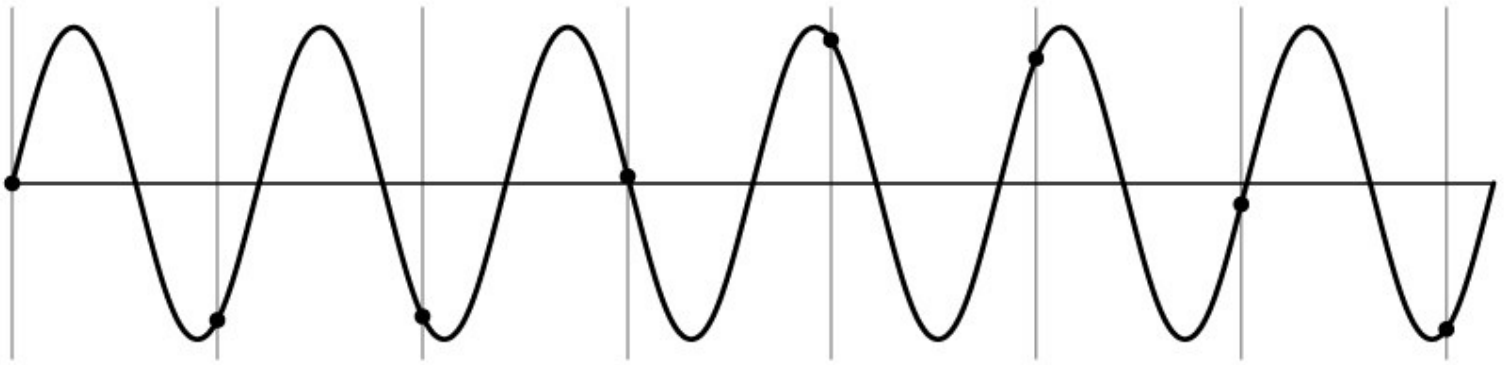
Throw away every other row and column to create a 1/2 size image

Sampling and aliasing （混叠）



Aliasing problem

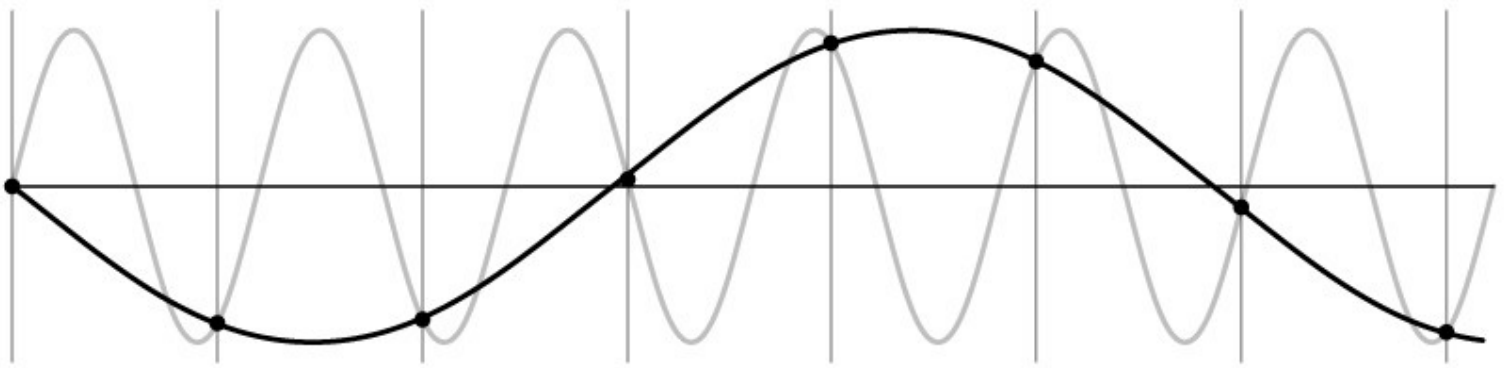
- 1D example (sinewave):



Source: S. Marschner

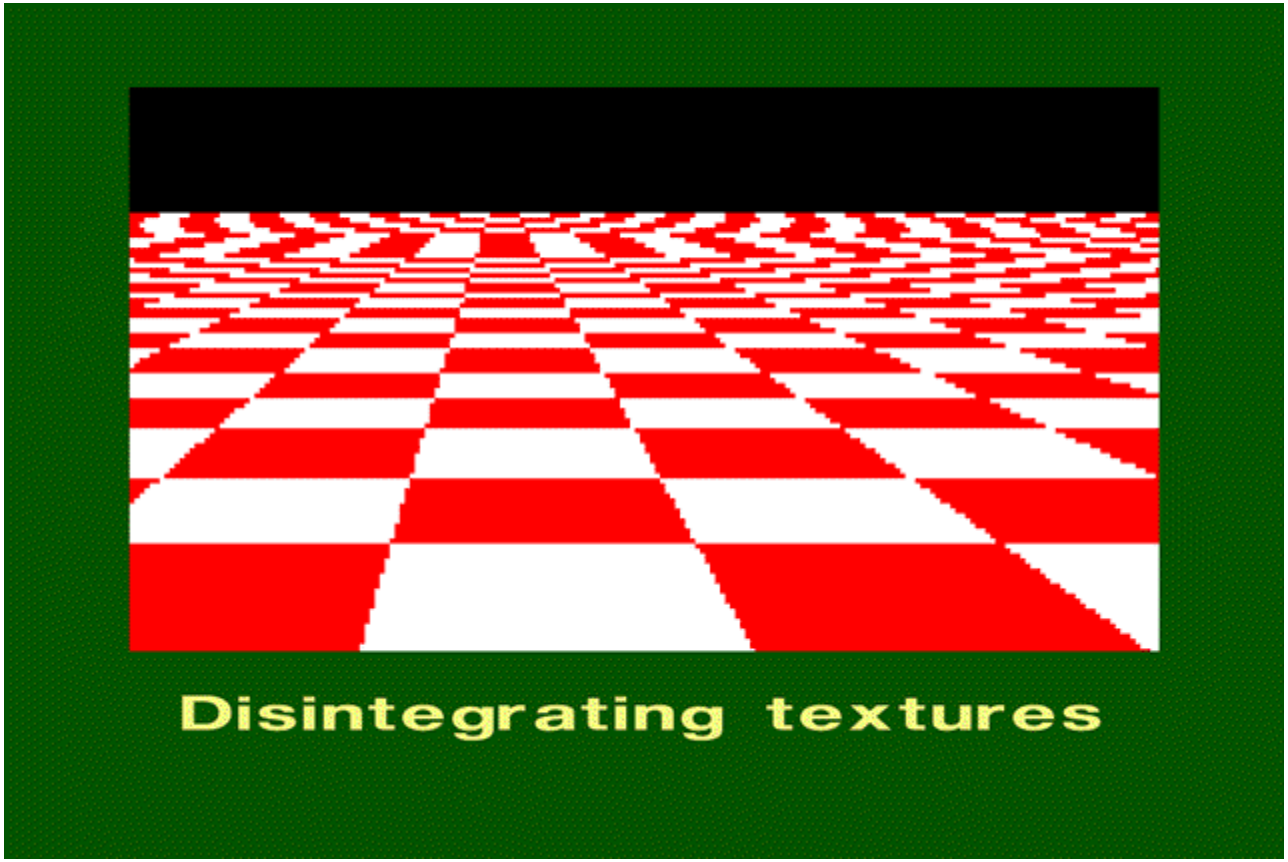
Aliasing problem

- 1D example (sinewave):



Source: S. Marschner

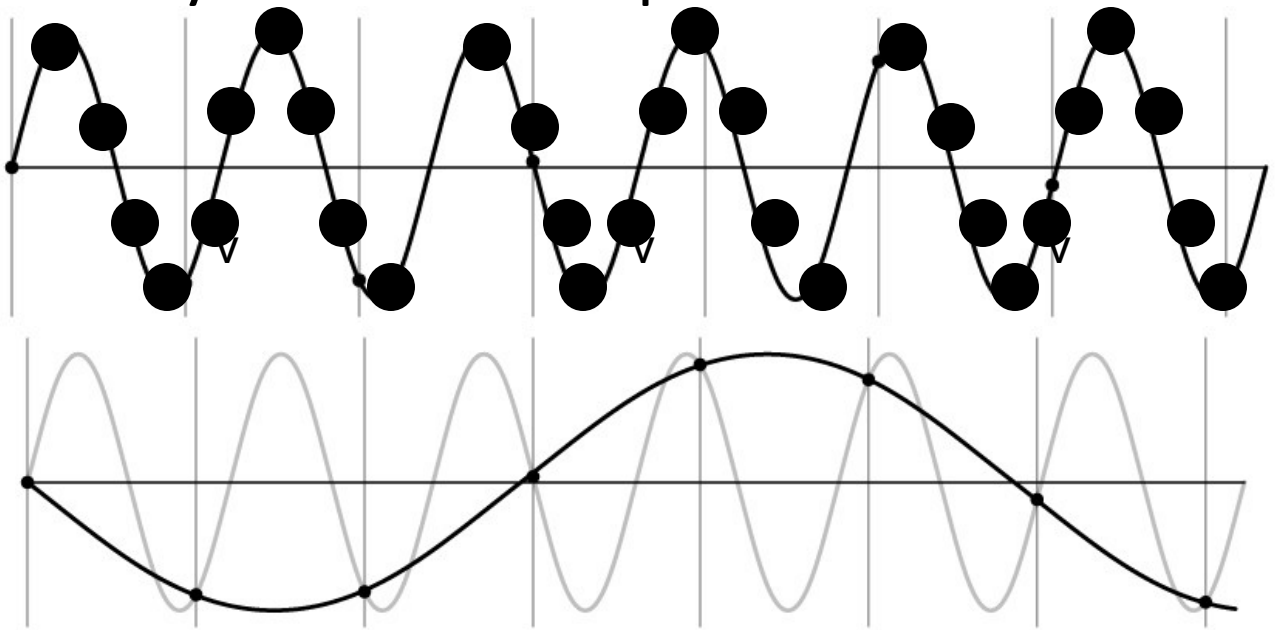
Aliasing in graphics



Source: A. Efros

Nyquist-Shannon Sampling Theorem

- When sampling a signal at discrete intervals, the sampling frequency must be $\geq 2 \times f_{max}$
- 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

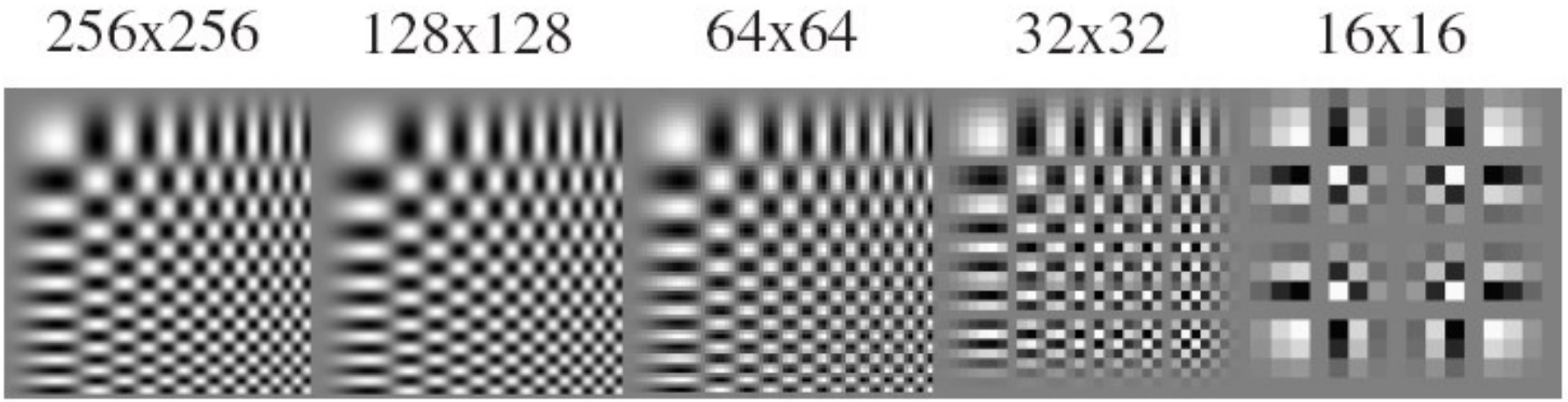
Anti-aliasing

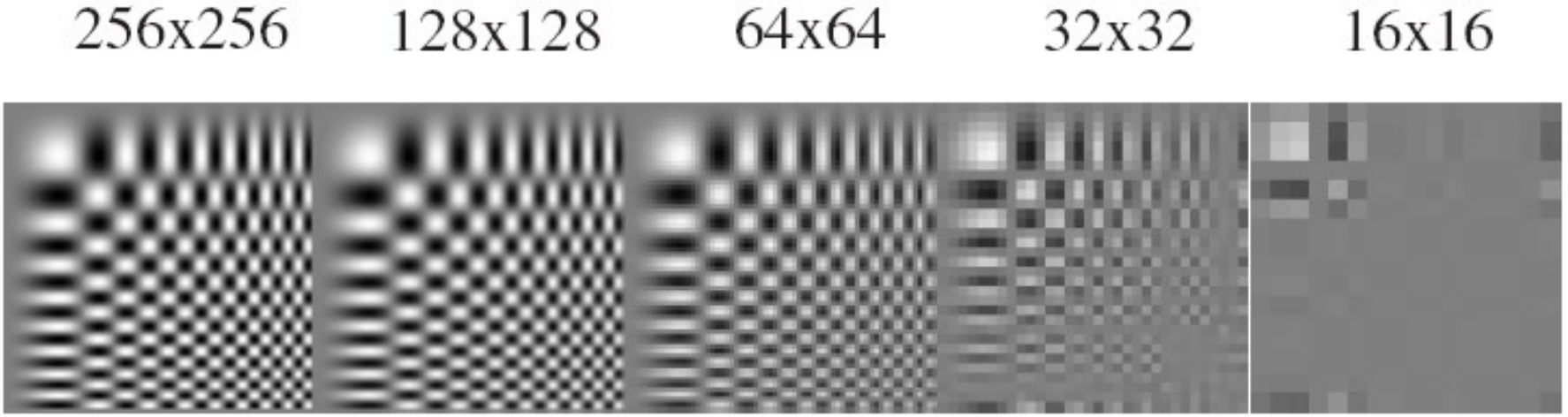
Solutions:

- 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

Anti-aliasing





Forsyth and Ponce 2002

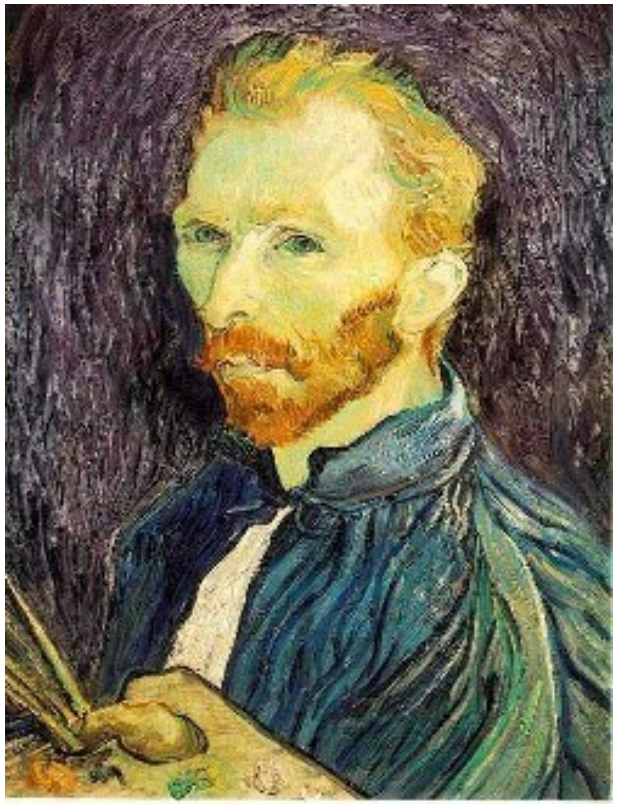
Algorithm for downsampling by factor of 2

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

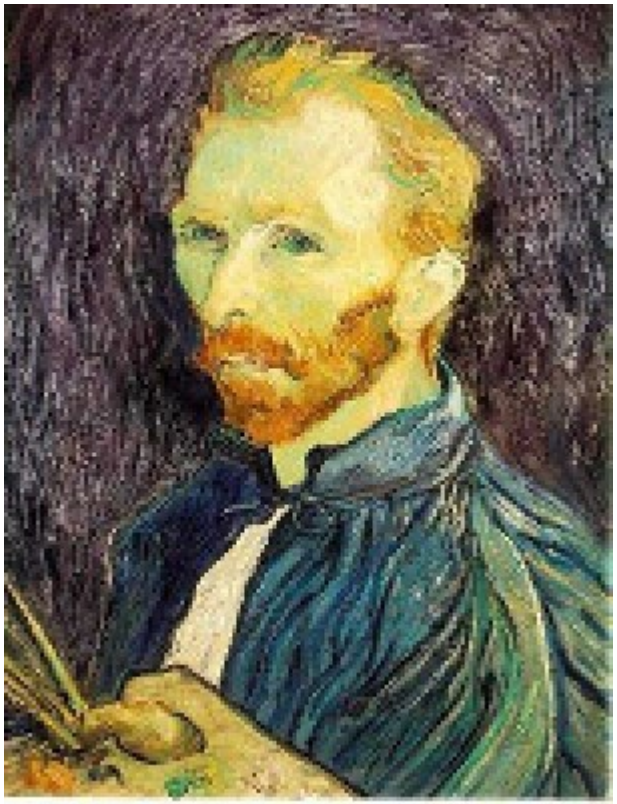
   im_blur = imfilter(image, fspecial('gaussian', 7, 1))
3. Sample every other pixel

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

Subsampling without pre-filtering



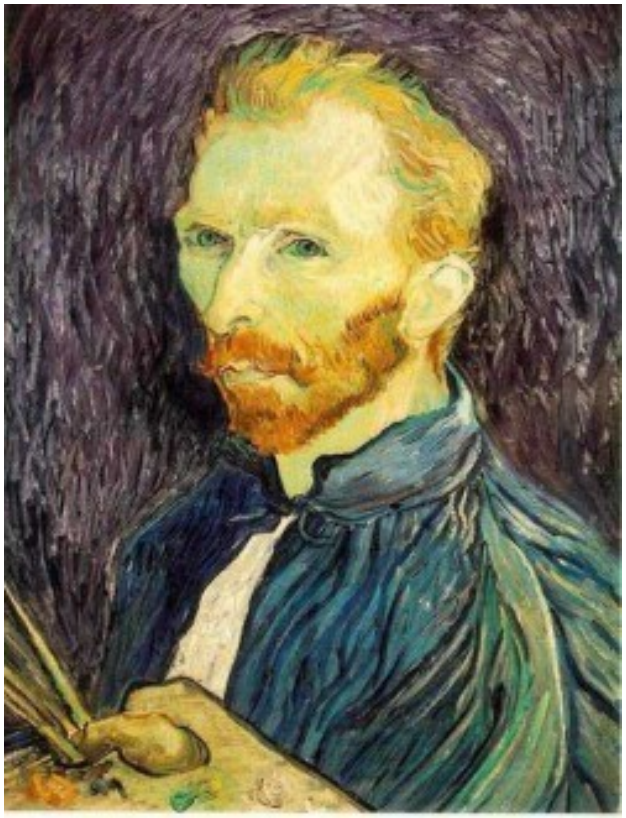
1/2



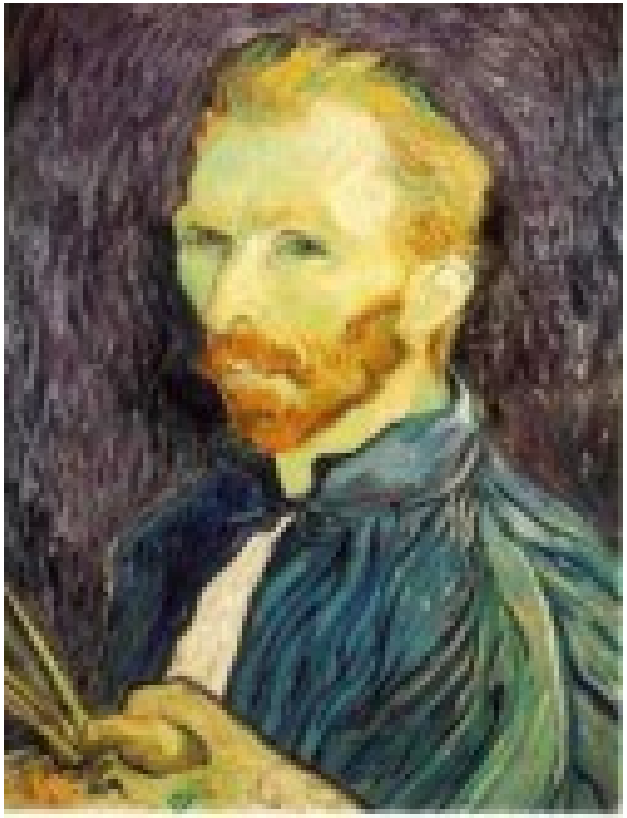
1/4 (2x zoom)

1/8 (4x zoom)

Subsampling with Gaussian pre-filtering



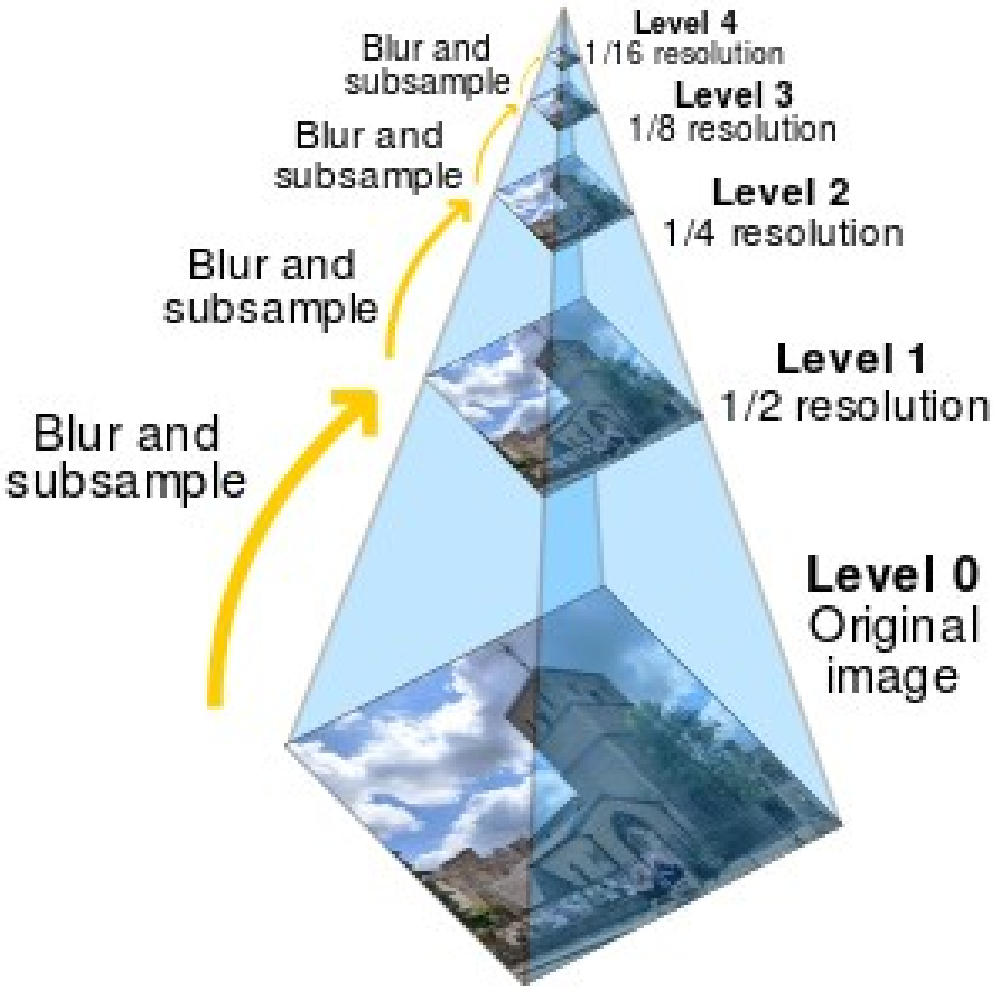
Gaussian 1/2



G 1/4

G 1/8

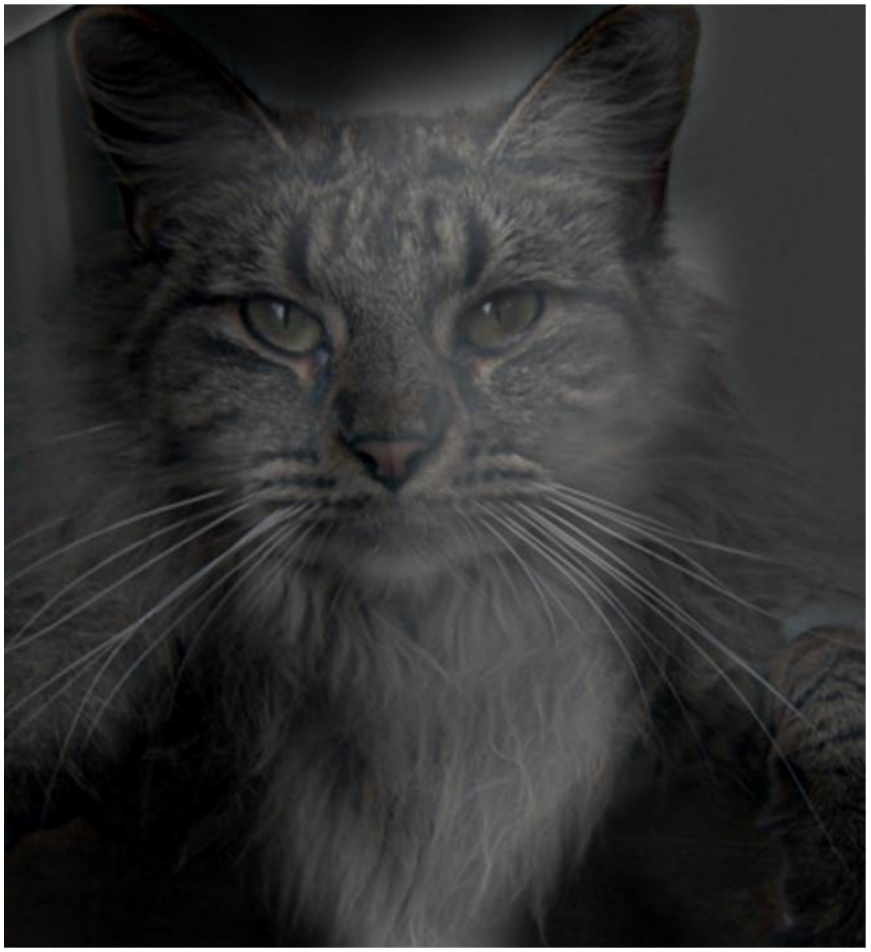
Image Pyramids



Project 1 function:
vis_hybrid_image.m

Wikipedia – Image Pyramids

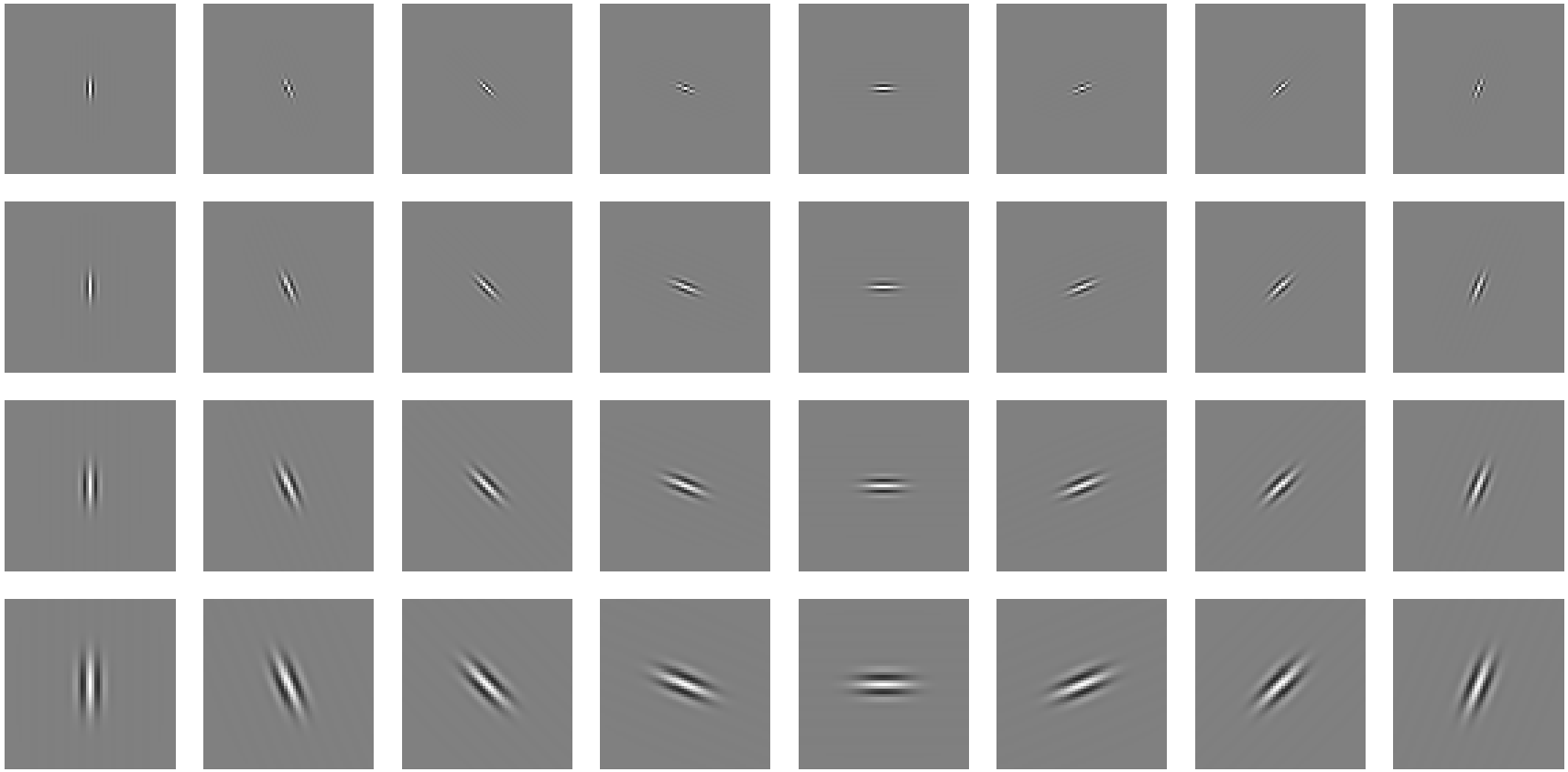
Why do we get different, distance-dependent interpretations of hybrid images?



?

Clues from Human Perception

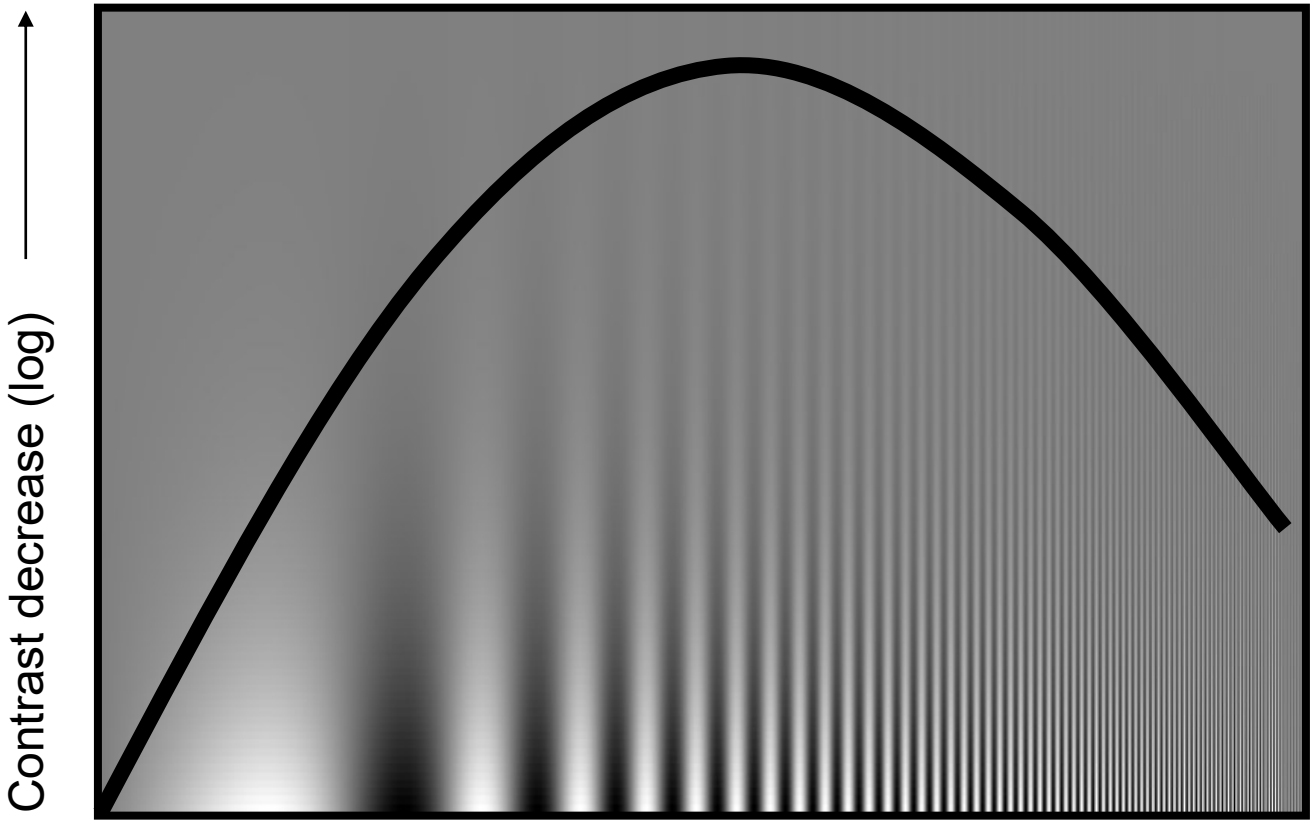
- Early processing in humans filters for orientations and scales of frequency.



Early Visual Processing: Multi-scale edge and blob filters

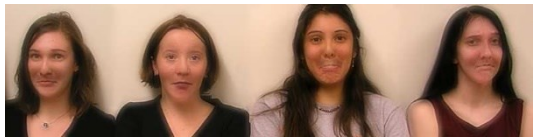
Campbell-Robson contrast sensitivity curve

Perceptual cues in the mid-high frequencies dominate perception.



Application: Hybrid Images

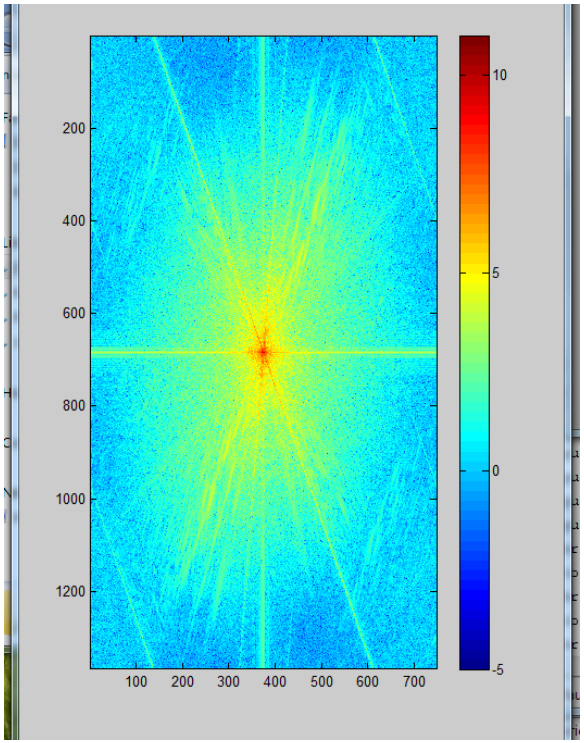
When we see an image from far away, we are effectively subsampling it!



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

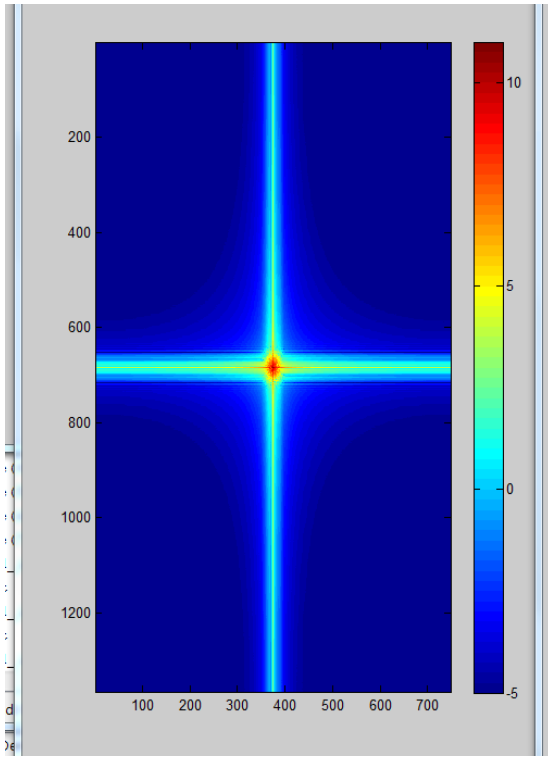
Hybrid Image in FFT

Hybrid Image



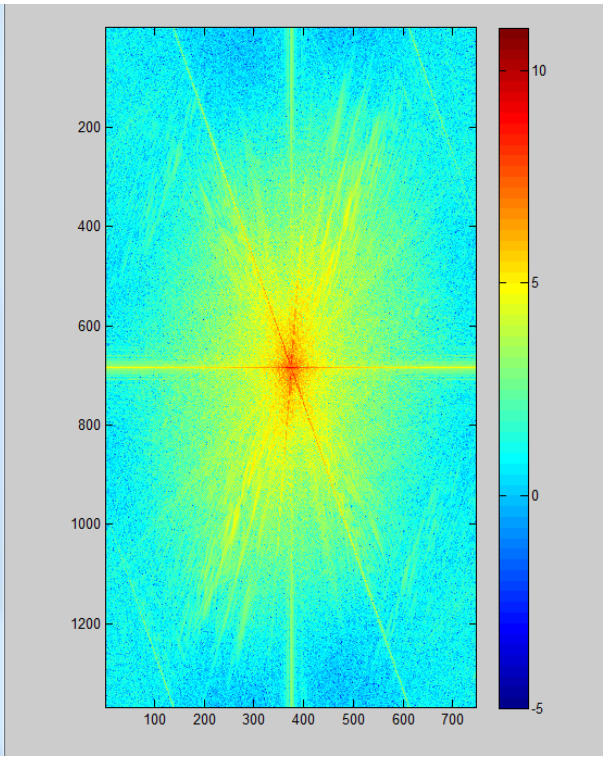
=

Low-passed Image



+

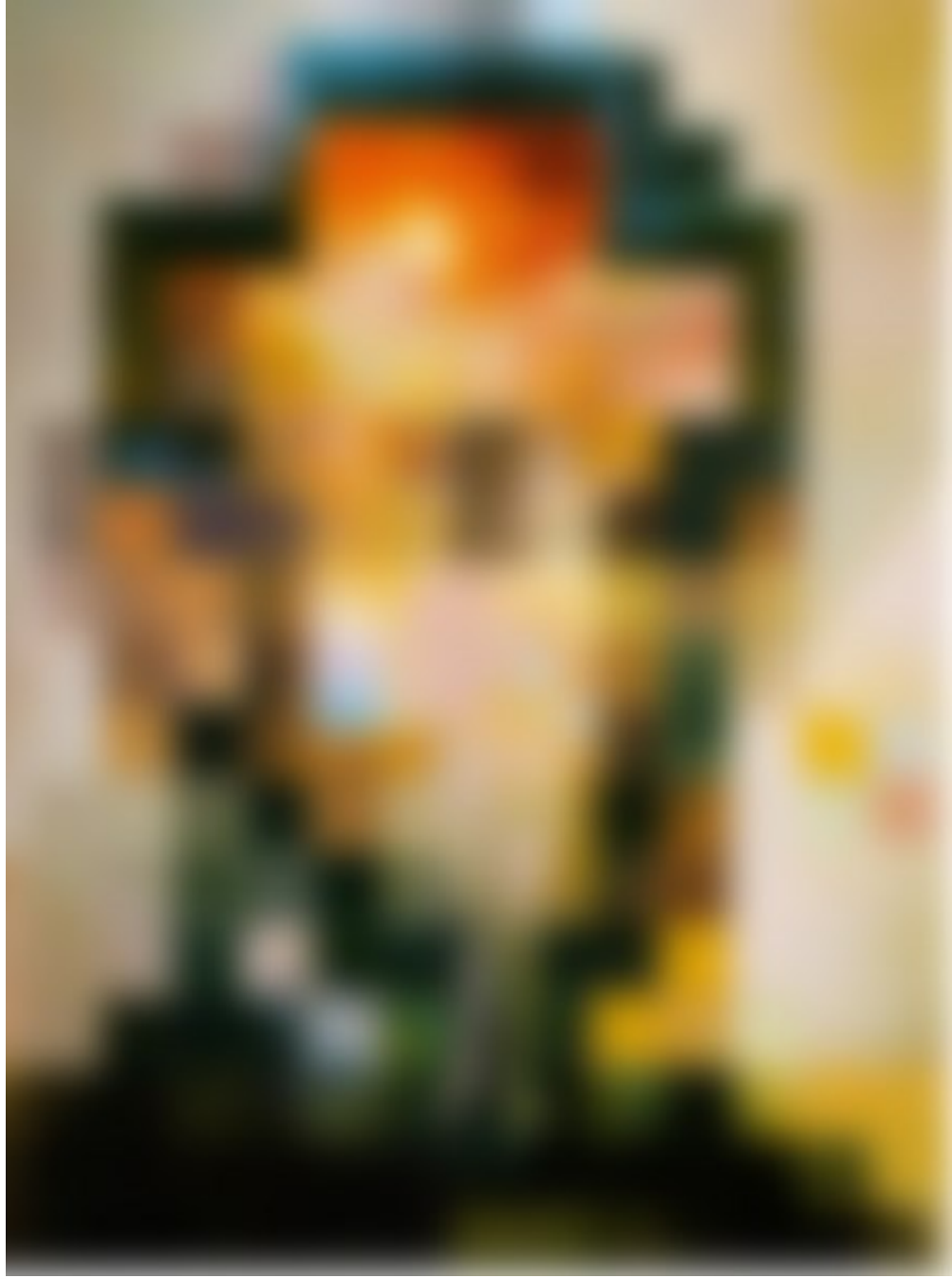
High-passed Image

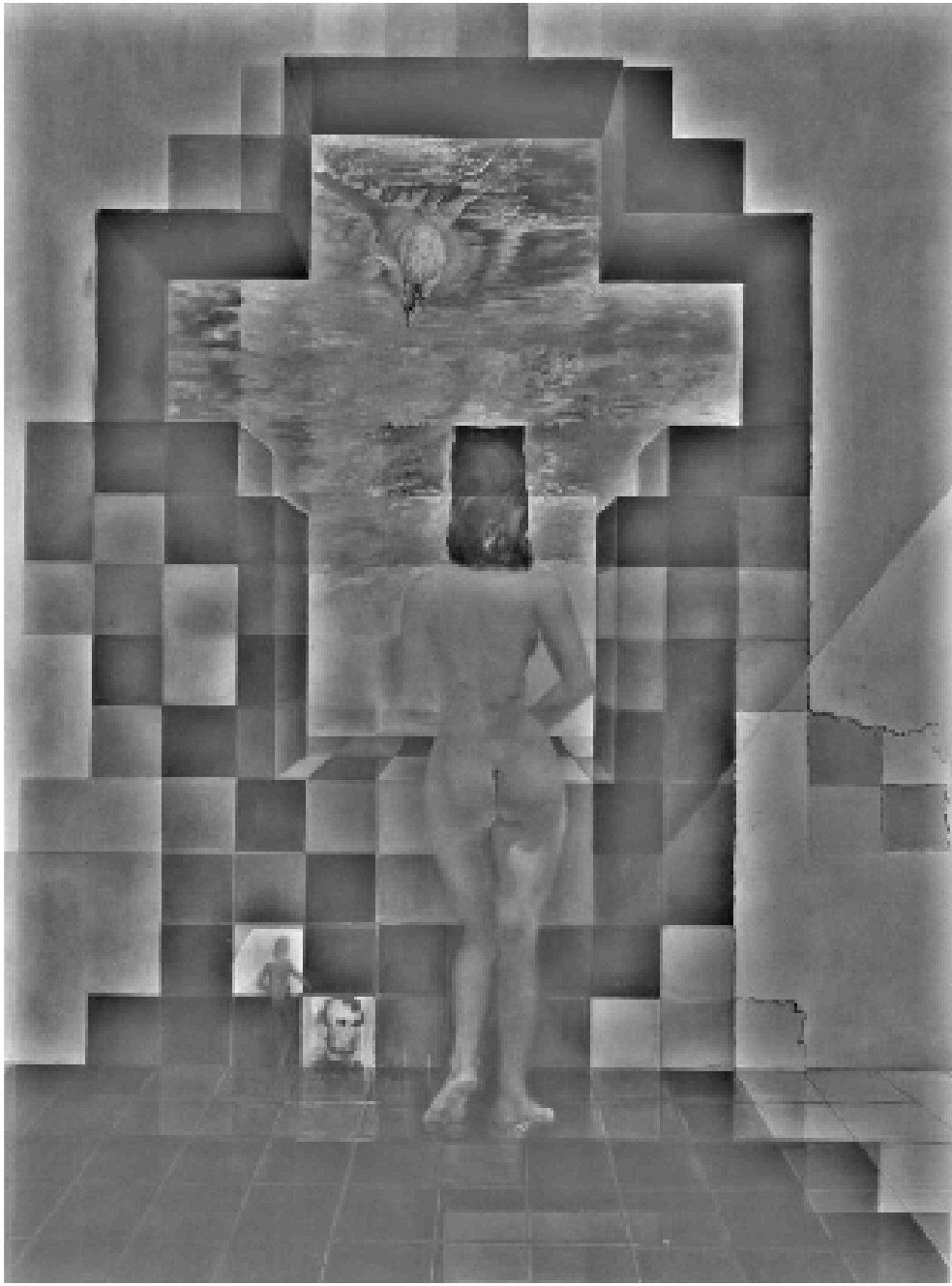


Salvador Dali
"Gala Contemplating the Mediterranean Sea, which at 30 meters becomes the portrait of Abraham Lincoln", 1976

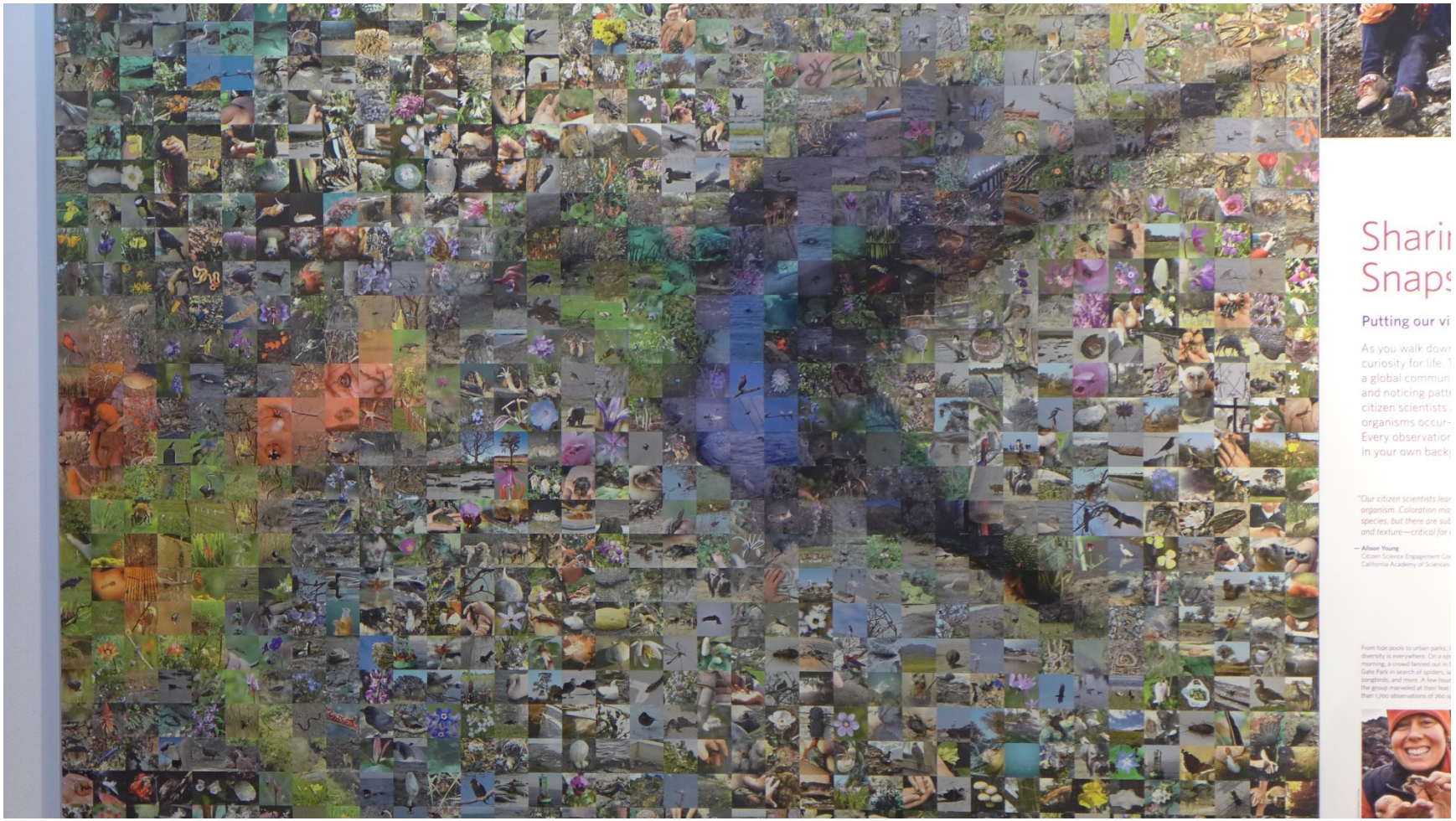
Salvador Dali invented Hybrid Images?

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






Ken-ichi Ueda
sodutchbaby
flapack
tueda
tsokrau
Mark Wilkinson
Ken-ichi Ueda
antonyw
flapack
Mark Wilkinson
annetanne
drew_avery
flapack
Mark Wilkinson


Sharin
Snaps
Putting our vi
As you walk down
curiosity for life.
a global commun
and noticing patt
citizen scientists
organisms occur
Every observation
in your own back
"Our citizen scientists lea
organism. Coloration ma
species, but there are sub
and texture—critical for
— Alison Young
Citizen Science Engagement Co
California Academy of Sciences
From tide pools to urban parks,
diversity is everywhere. On a sp
morning, a crowd fanned out in
Gate Park in search of spiders,
songbirds, and more. A few hou
the group marveled at their feat
than 1,700 observations of 260 s


Sharing
Snapshots
Putting our vision to work
As you walk down the street or visit a park, bring your curiosity for life. The Academy and iNaturalist are fostering a global community of ordinary people making observations and noticing patterns in the world around them. These citizen scientists are building a record of where and when organisms occur—data that helps protect Earth's biodiversity. Every observation matters. Who knows what you may find in your own backyard?


Sharing
Snapshots
Putting our vision to work


Seeing in
Color
Want to see the world differently? Try on another animal's eyes. Birds and bees see colors of light invisible to the human eye. Other animals detect only a few colors—dogs see shades of yellows, blues, and grays. Explore how every animal eye, from simple to complex, is built to pick up a certain slice of light.