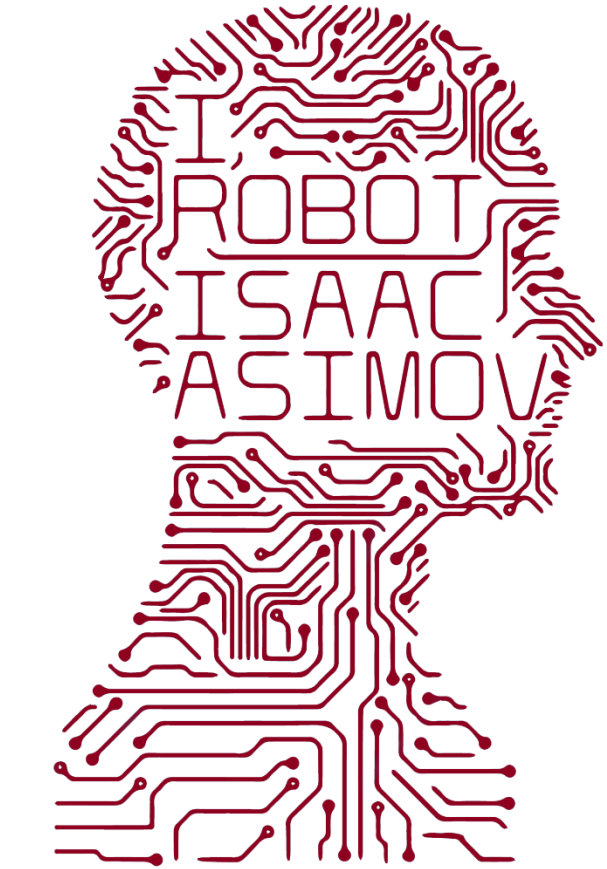
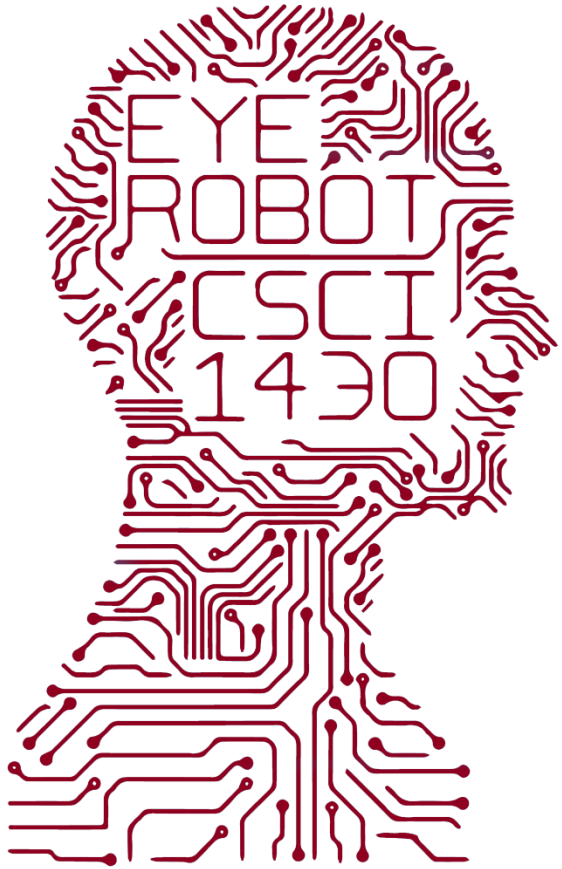


FUTURE VISION



COMPUTER VISION

Prismia.Chat https://tinyurl.com/y26ragof

Next Classes

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

Overview of today's lecture

- Image downsampling.
- Aliasing.
- Gaussian image pyramid.
- Laplacian image pyramid.
- Fourier series.
- Frequency domain.
- Fourier transform.
- Frequency-domain filtering.
- Revisiting sampling.

Slide credits

Most of these slides were adapted directly from:

- Kris Kitani (15-463, Fall 2016).

Some slides were inspired or taken from:

- Fredo Durand (MIT).
- Bernd Girod (Stanford University).
- James Hays (Georgia Tech).
- Steve Marschner (Cornell University).
- Steve Seitz (University of Washington).

Image downsampling

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

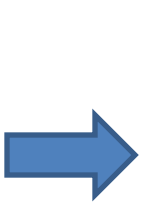
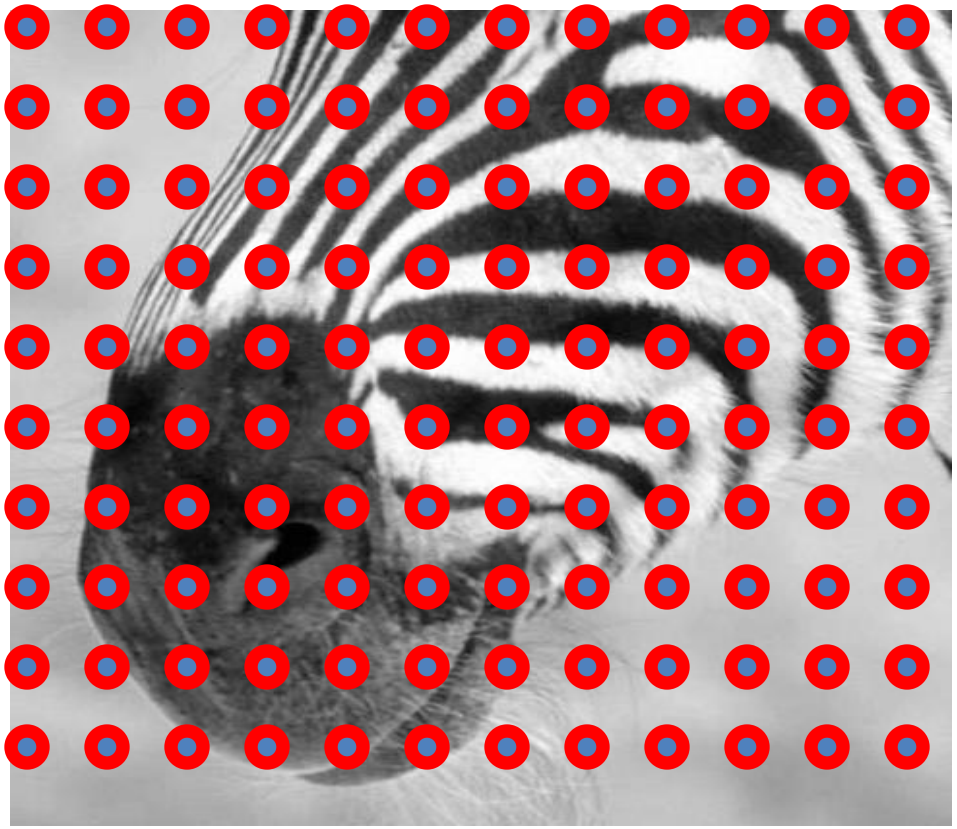


Image: http://www.flickr.com/photos/igorms/136916757/

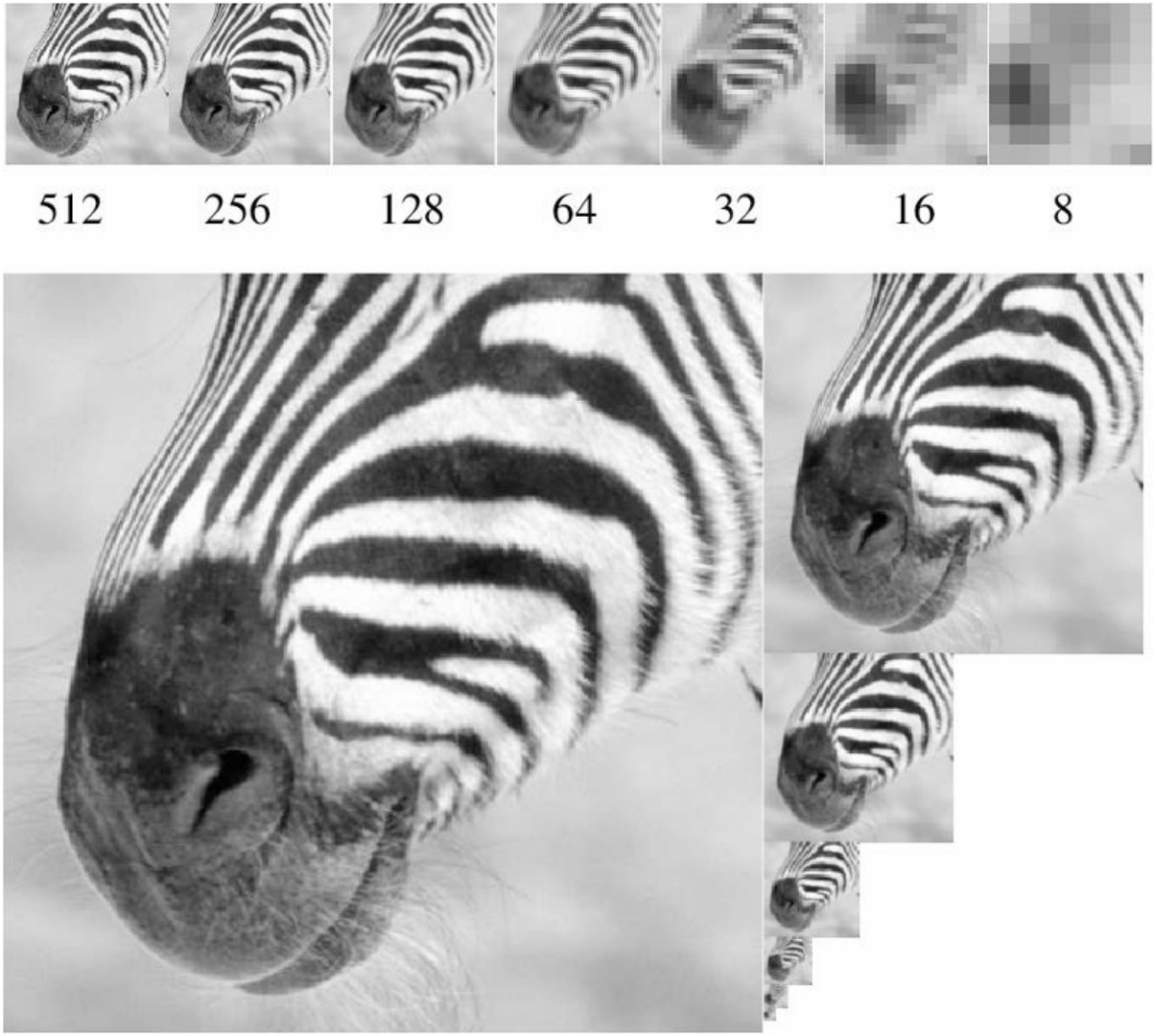
Slide: Hoiem

Making lower resolution images: Subsampling by a factor of 2



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

Figure from David Forsyth



A ‘bar’ in the big images is a hair on the zebra’s nose; in smaller images, a stripe; in the smallest, the animal’s nose

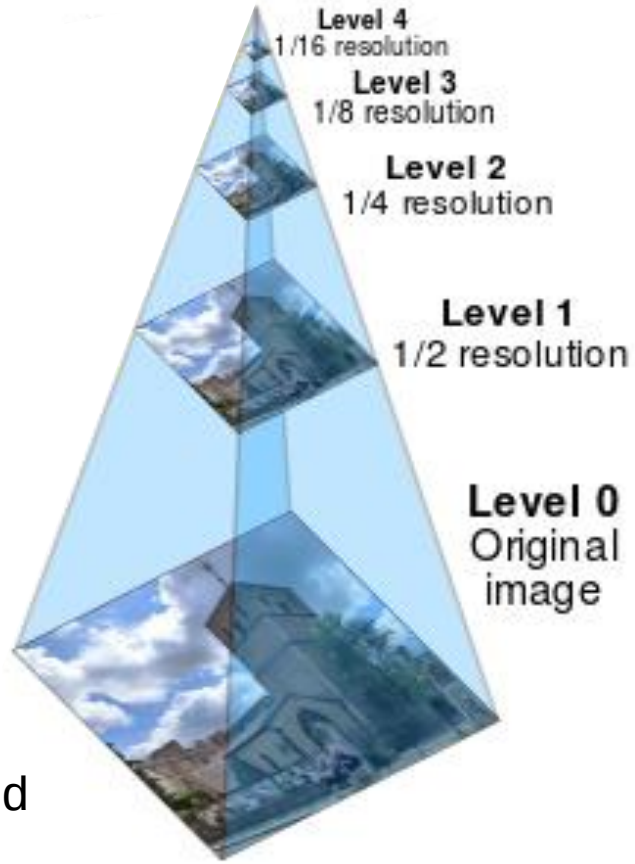


Image pyramid

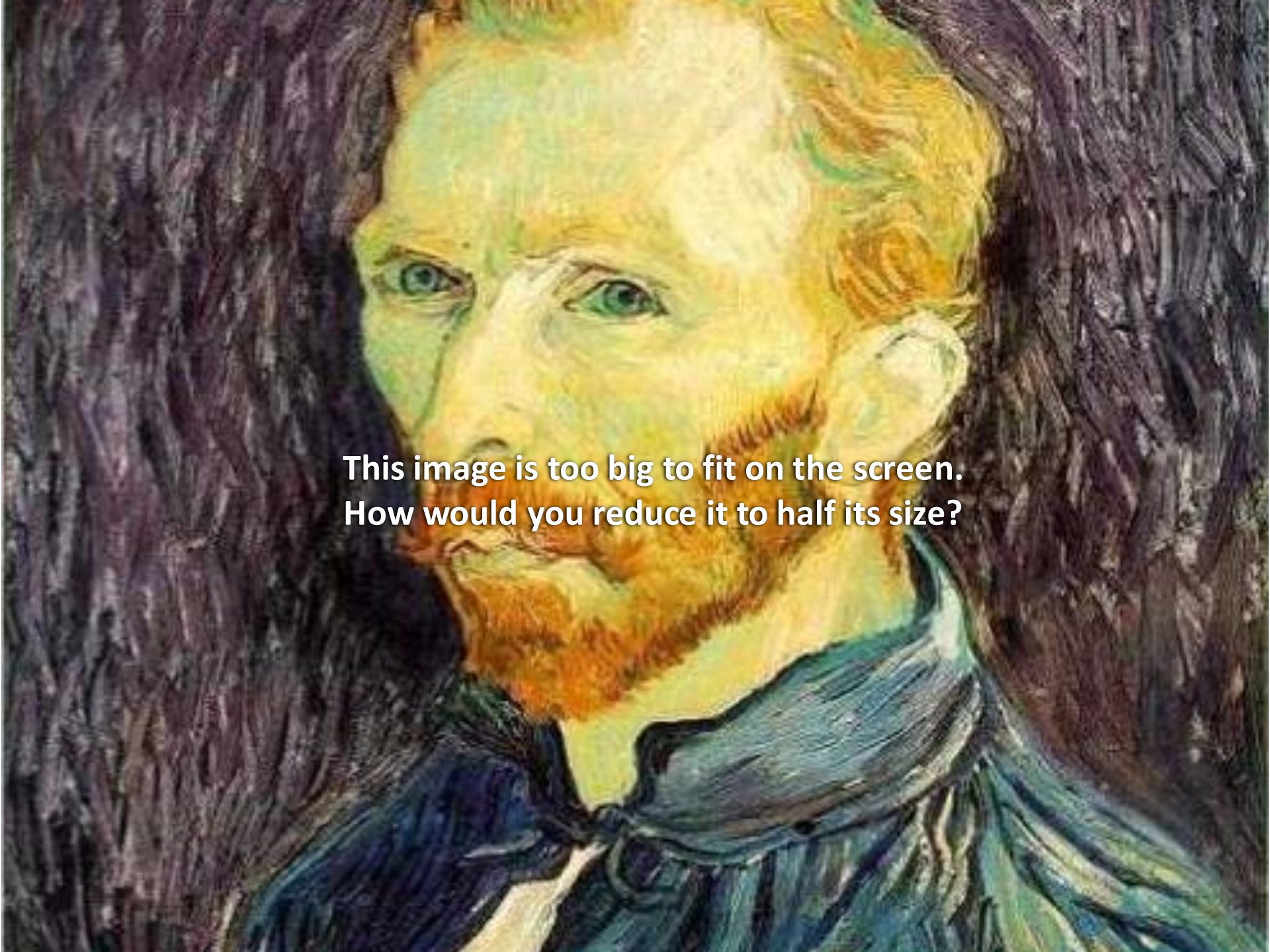
Algorithm for downsampling by factor of 2

1. Start with image of w x h
2. Sample every other pixel
   - im_small = image[::2, ::2]
3. To build a pyramid,
   repeat Steps 1 & 2
   until im_small is 1 pixel large.

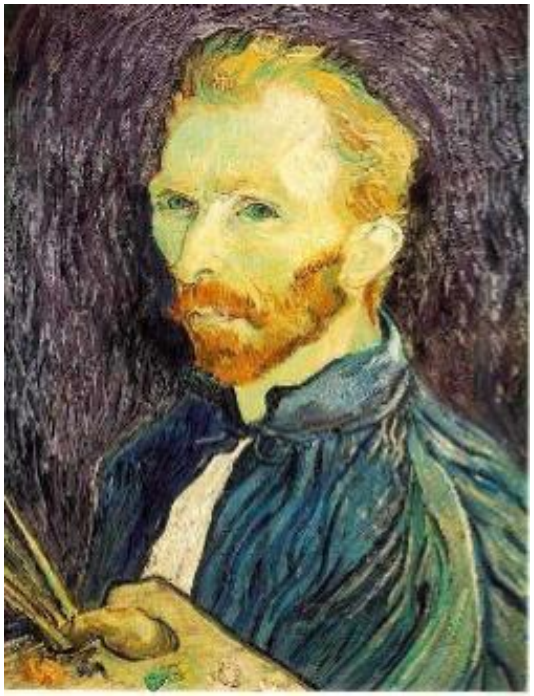
Numpy syntax:
::2 -> start at 0,
end at 'end',
increase every 2,
until the end.

e.g.,
0,2,4,6,…,w

(if w is not even, then this goes to w-1)


This image is too big to fit on the screen.
How would you reduce it to half its size?

Naïve image downsampling



1/2

Throw away half the rows and columns

delete even rows
delete even columns

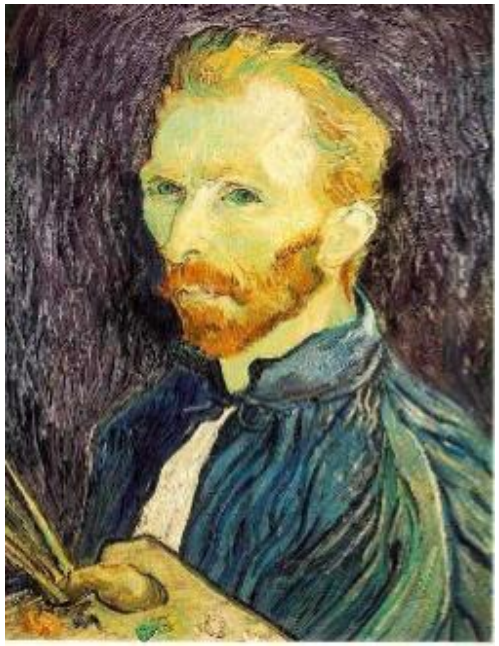
1/4

delete even rows
delete even columns

1/8

What is the problem with this approach?

Naïve image downsampling



1/2

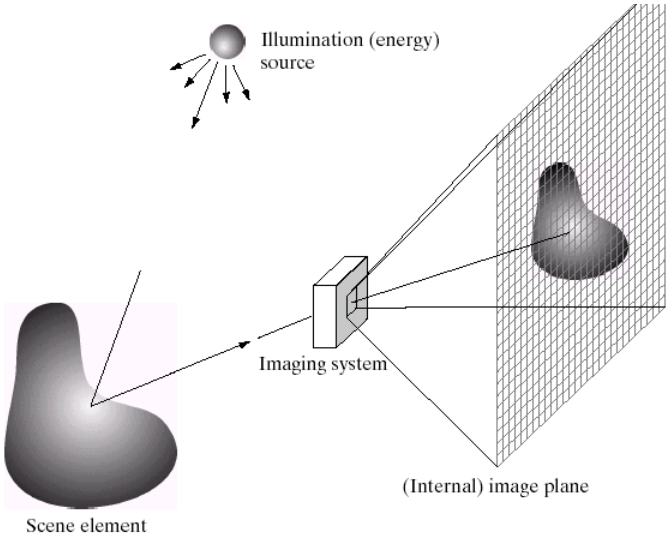
1/4 (2x zoom)

1/8 (4x zoom)

What is the 1/8 image so pixelated (and do you know what this effect is called)?

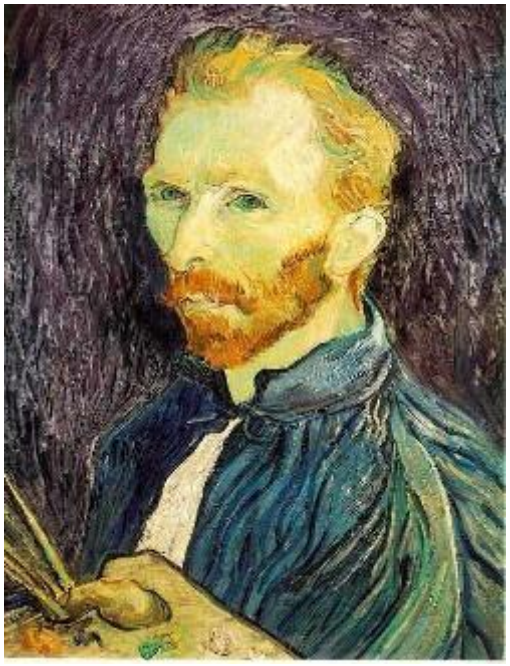
Aliasing

Reminder



Images are a *discrete*, or *sampled*, representation of a *continuous* world

Image sub-sampling

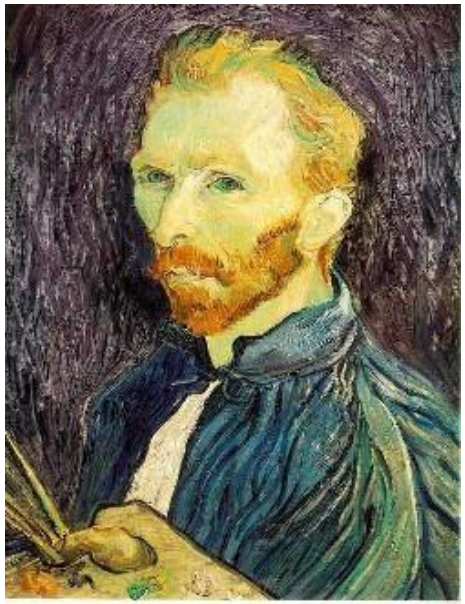


Throw away every other row and column to create a 1/2 size image.

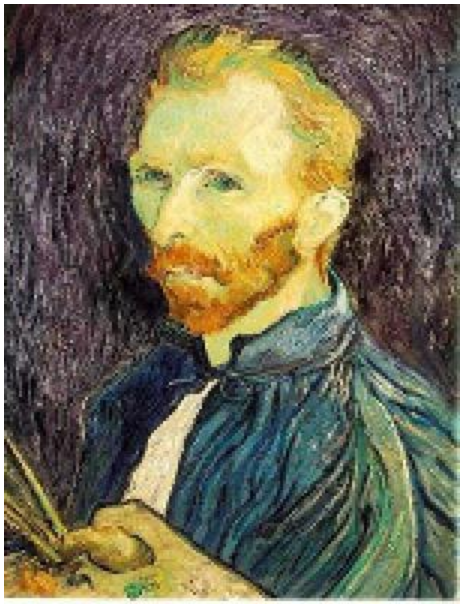
1/4

1/8

Subsampling without filtering



1/2



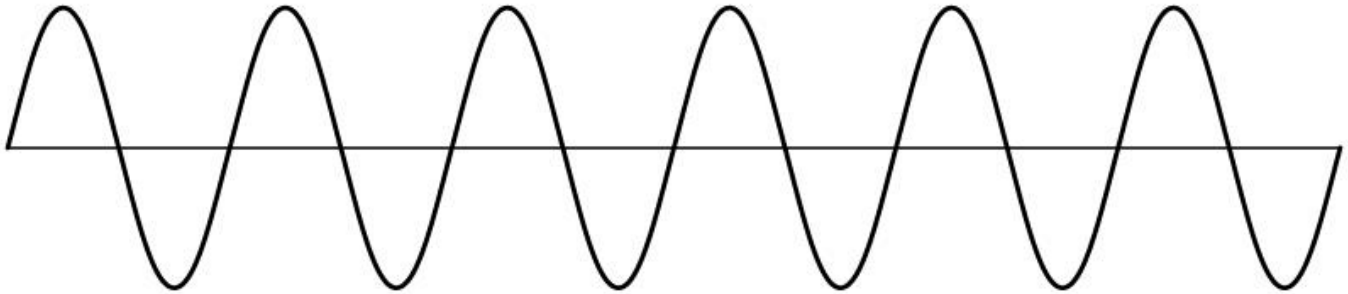
1/4 (2x subsample)

1/8 (4x subsample)

Steve Seitz

Sampling

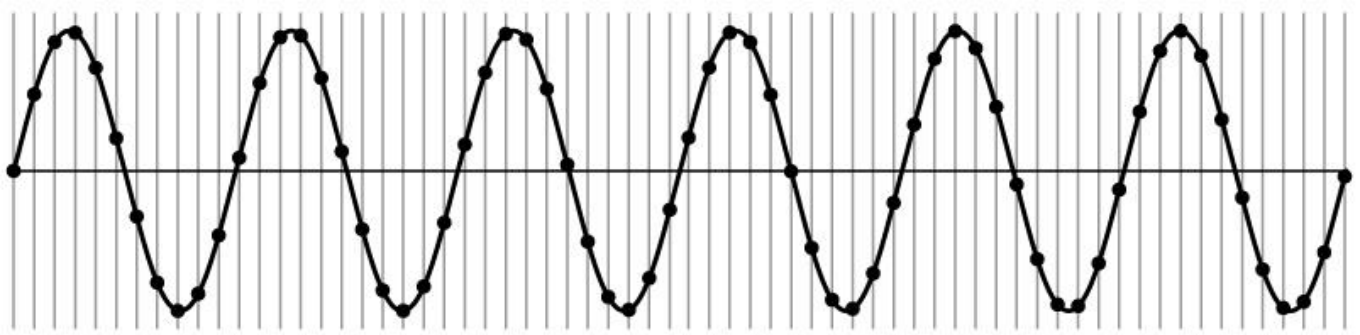
Very simple example: a sine wave



How would you discretize this signal?

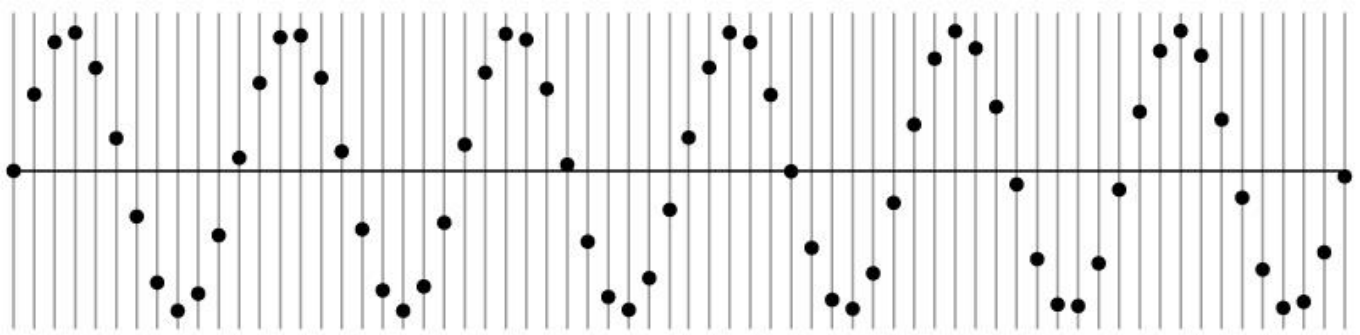
Sampling

Very simple example: a sine wave



Sampling

Very simple example: a sine wave

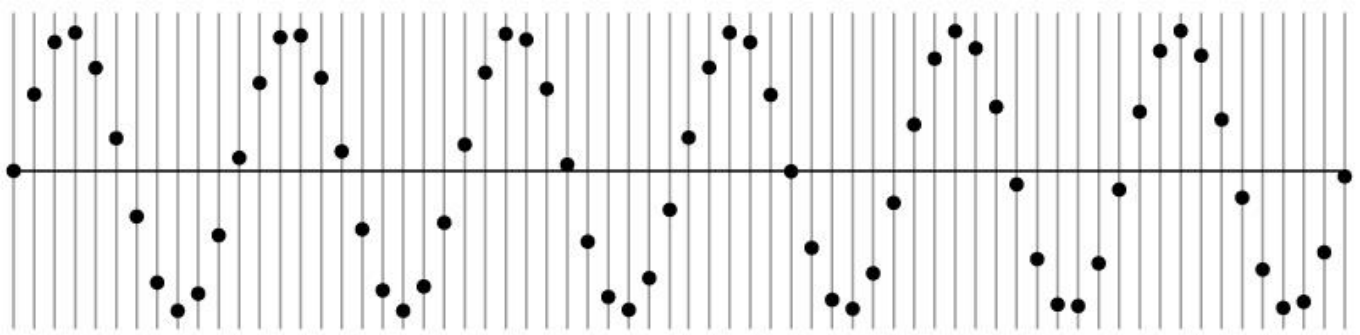


How many samples should I take?

Can I take as *many* samples as I want?

Sampling

Very simple example: a sine wave

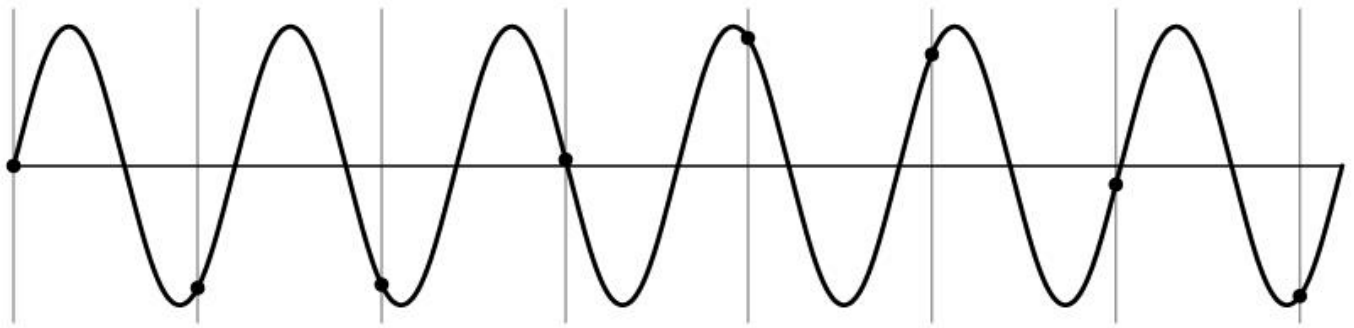


How many samples should I take?

Can I take as *few* samples as I want?

Undersampling

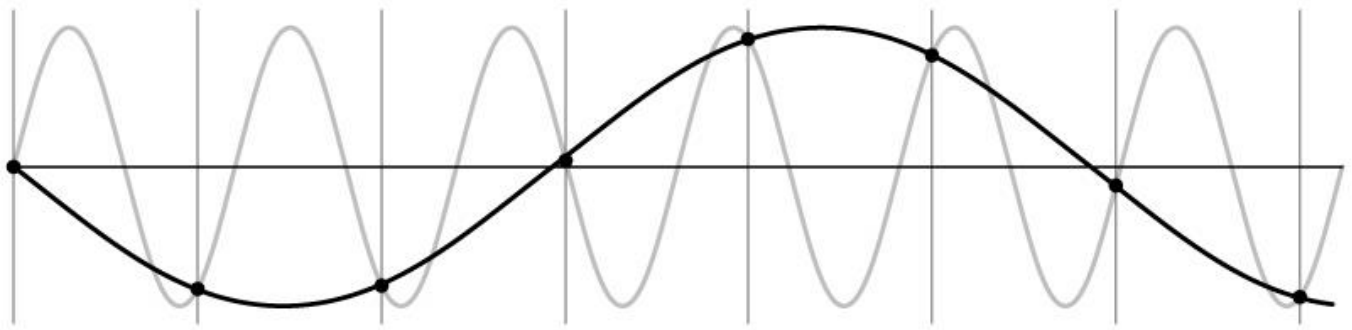
Very simple example: a sine wave



Unsurprising effect: information is lost.

Undersampling

Very simple example: a sine wave

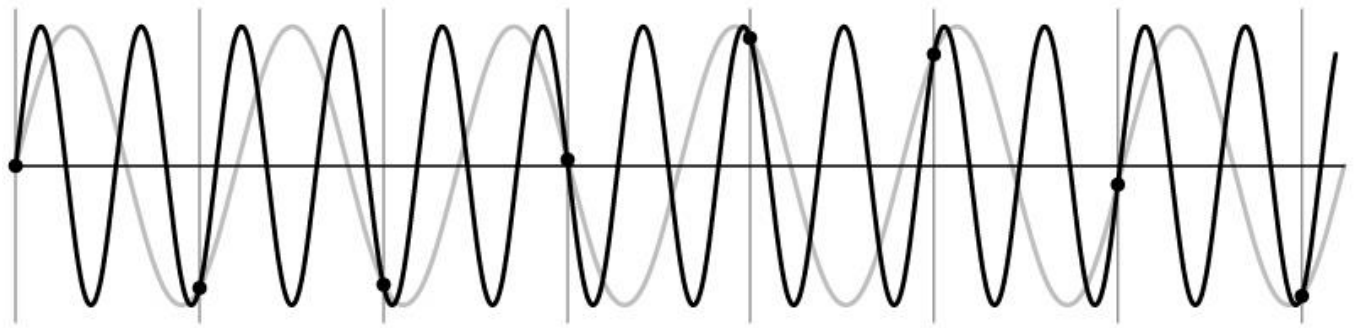


Unsurprising effect: information is lost.

Surprising effect: can confuse the signal with one of *lower* frequency.

Undersampling

Very simple example: a sine wave



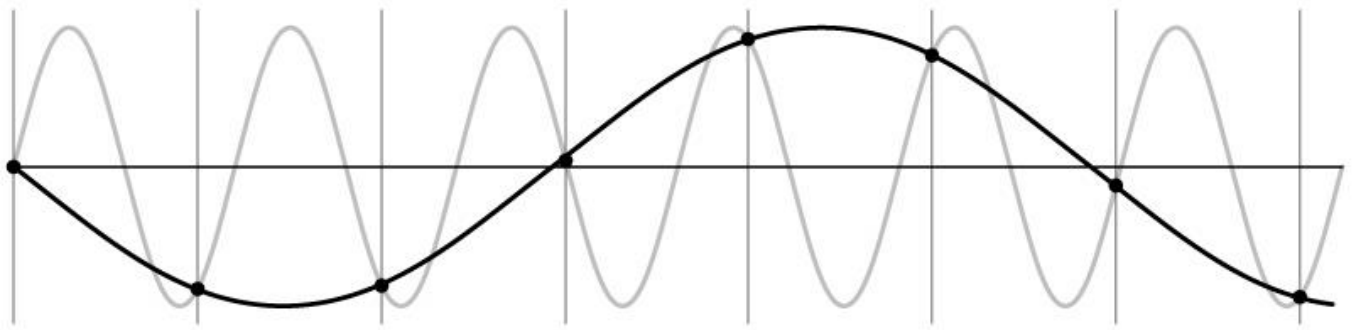
Unsurprising effect: information is lost.

Surprising effect: can confuse the signal with one of *lower* frequency.

Note: we could always confuse the signal with one of *higher* frequency.

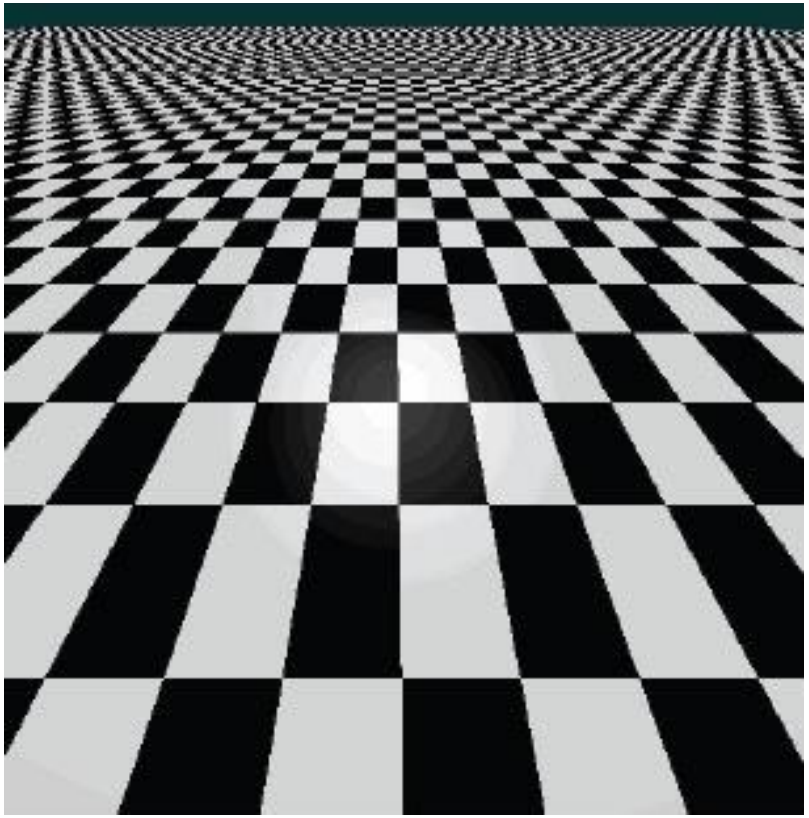
Aliasing

Fancy term for: *Undersampling can disguise a signal as one of a lower frequency*



Unsurprising effect: information is lost.
Surprising effect: can confuse the signal with one of *lower* frequency.
Note: we could always confuse the signal with one of *higher* frequency.

Aliasing in textures



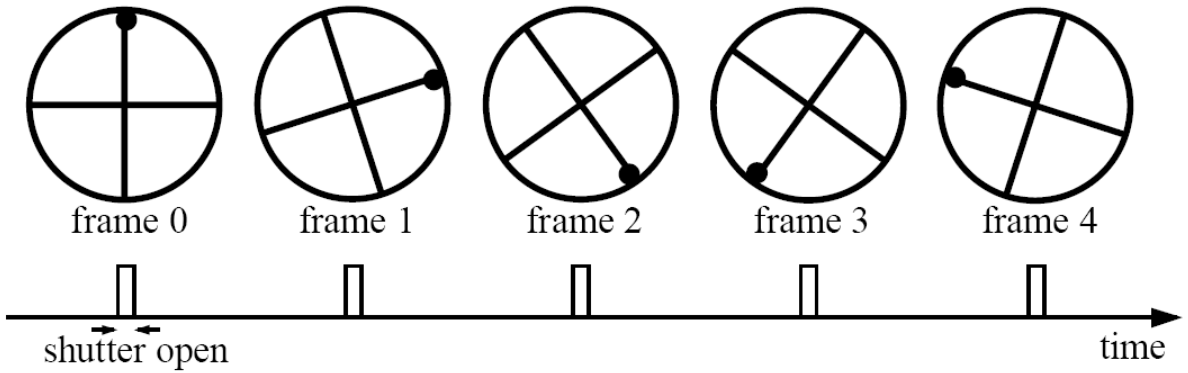
Aliasing in photographs

This is also known as “moire”

Temporal aliasing

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

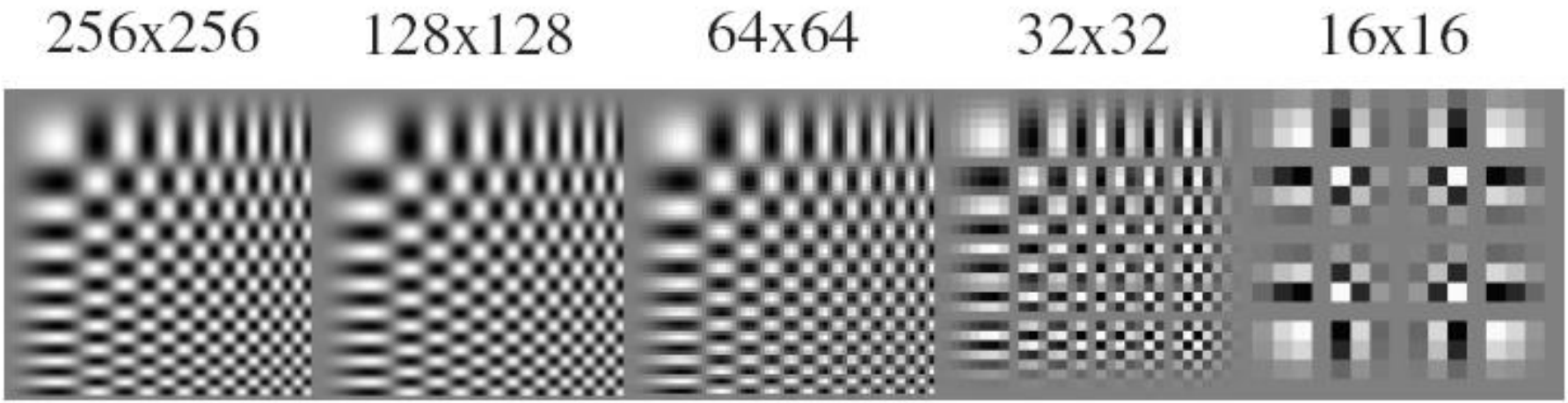
If camera shutter is only open for a fraction of a frame time (frame time = 1/30 sec. for video, 1/24 sec. for film):



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

Wagon wheel effect

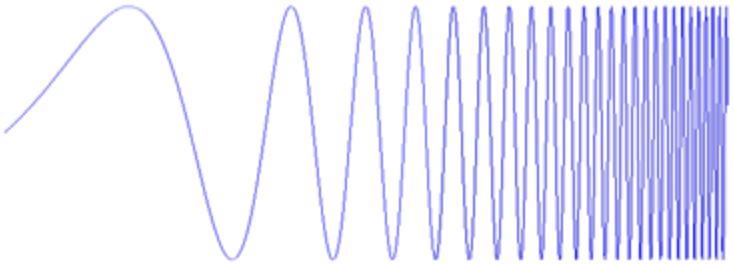
Sampling and aliasing



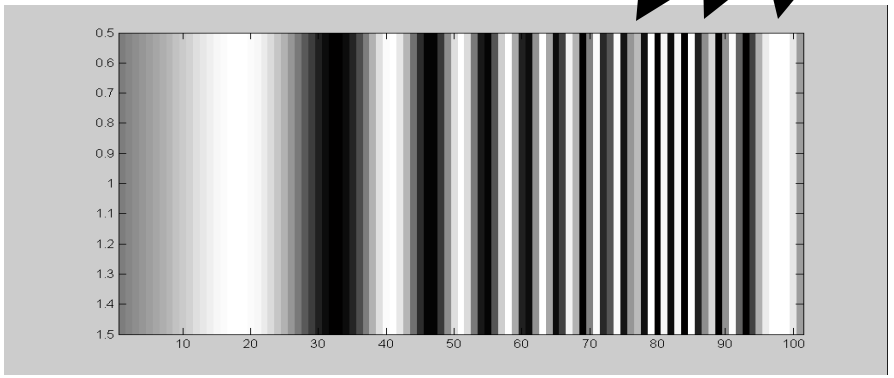
What's happening?

Aliasing! Not enough samples

Input signal:



Plot as image:



x = 0:.05:5; plt.imshow(sin((2.^x).*x))

Aliasing:

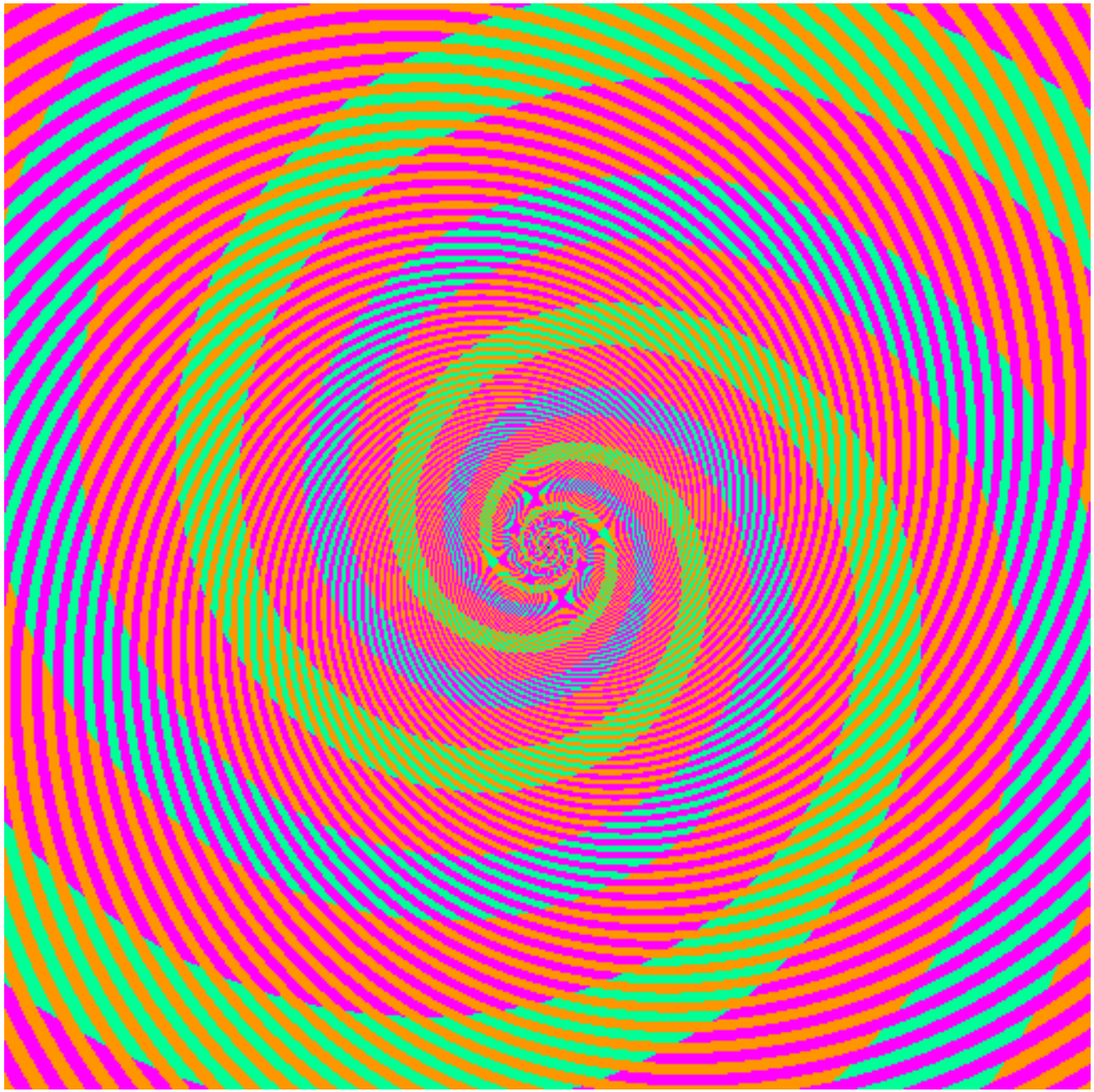
- When two signals become indistinguishable from one another due to sampling.
- They are 'aliases' of one another.

Temporal Aliasing in Videos

[YouTube; JoinBuzzirk; phrancque]

Aliasing and Moiré patterns

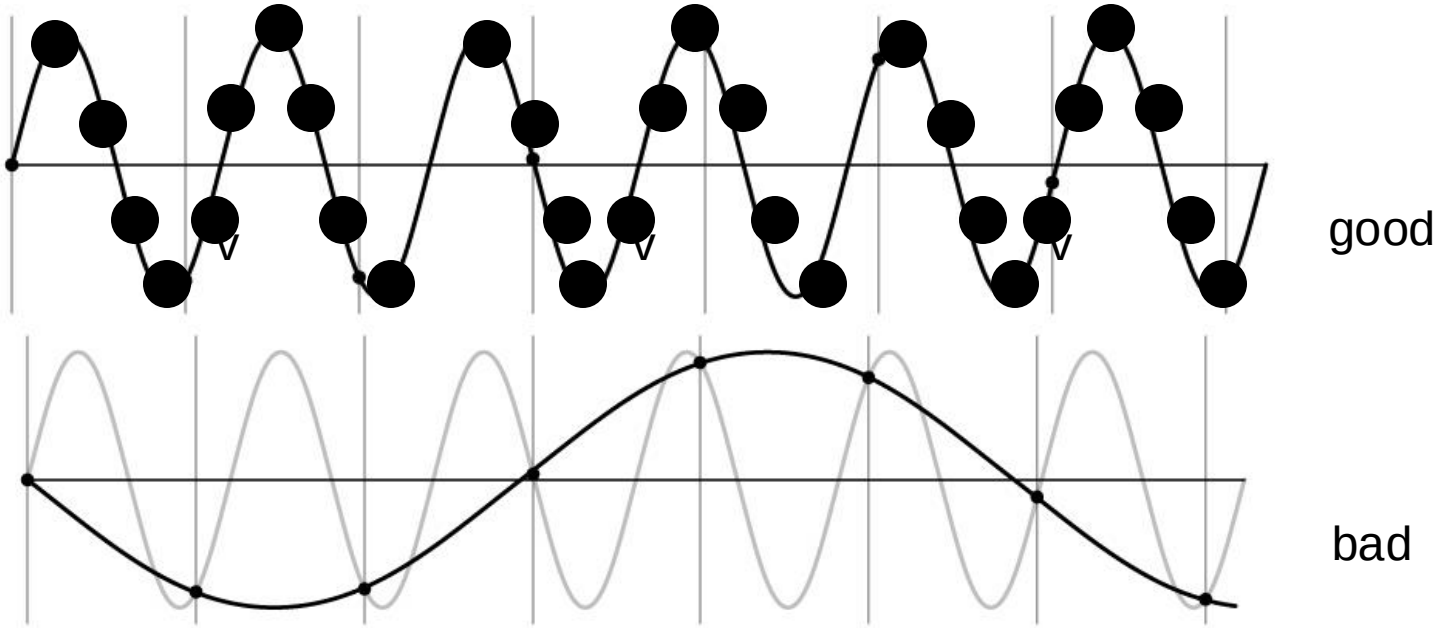
Gong 96, 1932, Claude Tousignant, Musée des Beaux-Arts de Montréal



Severe Moiré pattern

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 allows us to reconstruct the original perfectly from the sampled version



Anti-aliasing

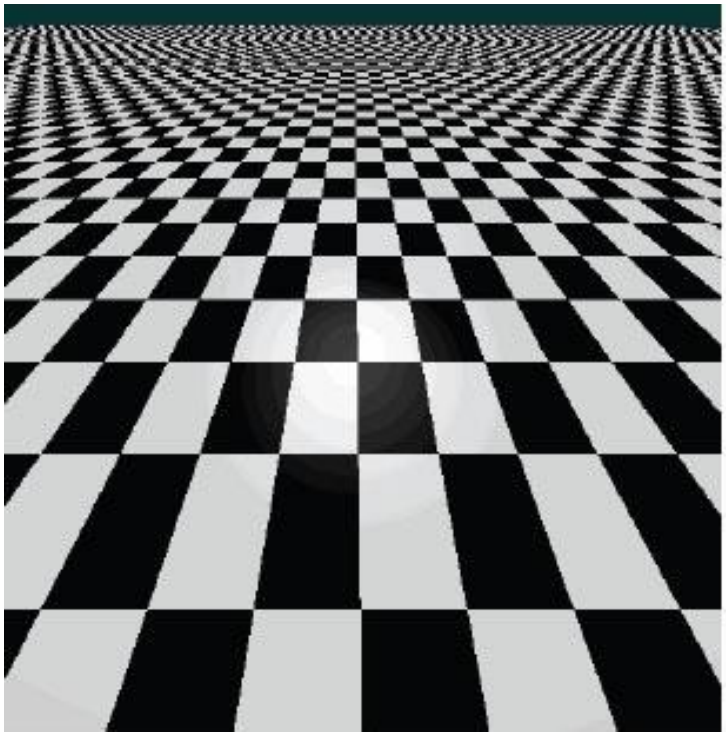
How would you deal with aliasing?

Anti-aliasing

How would you deal with aliasing?

Approach 1: Oversample the signal

Anti-aliasing in textures



aliasing artifacts

anti-aliasing by oversampling

Anti-aliasing

How would you deal with aliasing?

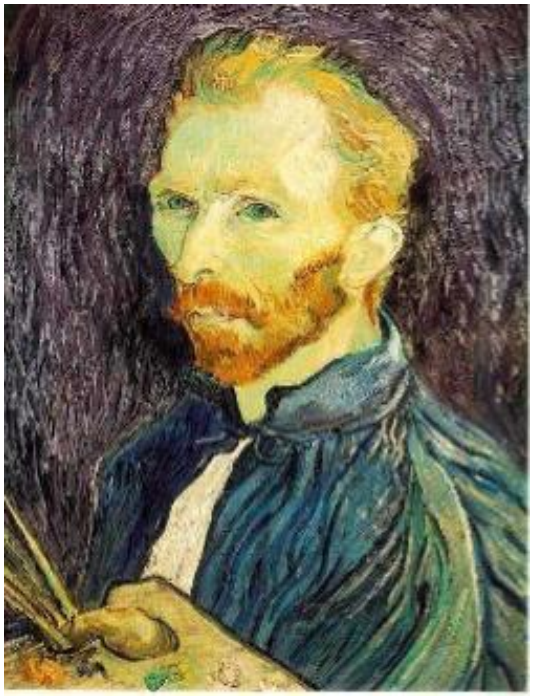
Approach 1: Oversample the signal

Approach 2: Smooth the signal

- Remove some of the detail effects that cause aliasing.
- Lose information, but better than aliasing artifacts.

How would you smooth a signal?

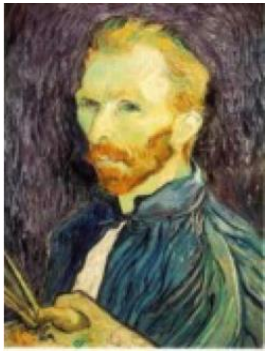
Better image downsampling



1/2

Apply a smoothing filter first, then throw away half the rows and columns

Gaussian filter
delete even rows
delete even columns

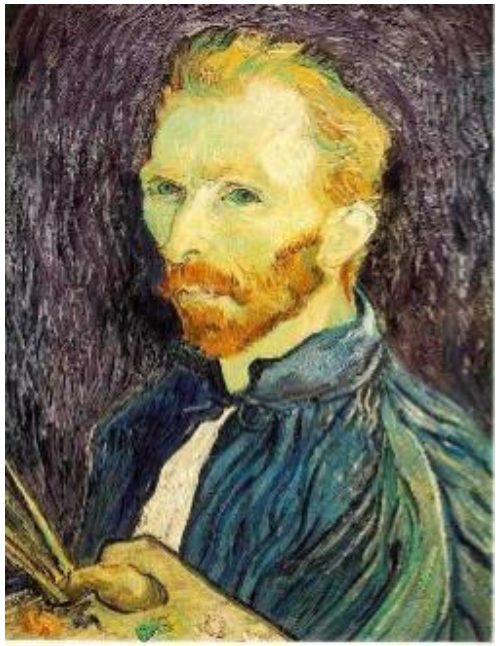


1/4

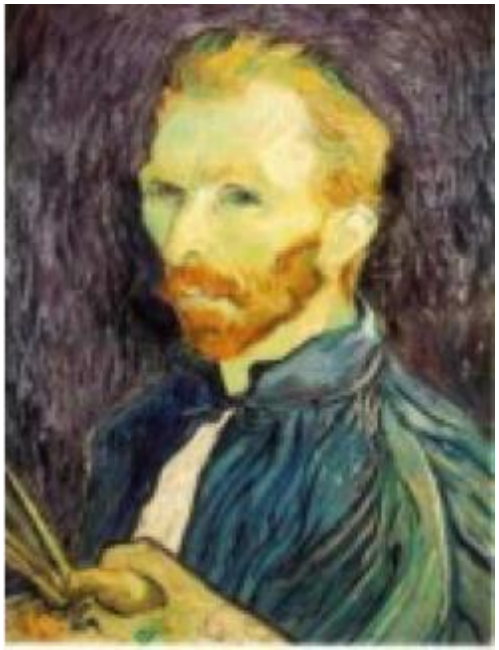
Gaussian filter
delete even rows
delete even columns

1/8

Better image downsampling



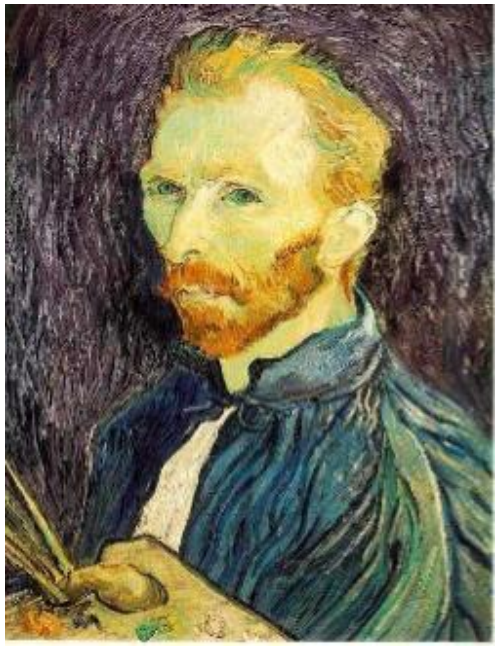
1/2



1/4 (2x zoom)

1/8 (4x zoom)

Naïve image downsampling



1/2

1/4 (2x zoom)

1/8 (4x zoom)

Anti-aliasing

Question 1: How much smoothing do I need to do to avoid aliasing?

Question 2: How many samples do I need to take to avoid aliasing?

Answer to both: Enough to reach the Nyquist limit.

Low-pass and high-pass filtering

Remove high frequencies with a *low pass* filter

- A blur filter!
- *Could also be called a 'high cut' filter (but nobody does)*

Low-pass and high-pass filtering

Remove high frequencies with a *low pass* filter

- A blur filter!
- *Could also be called a 'high cut' filter (but nobody does)*

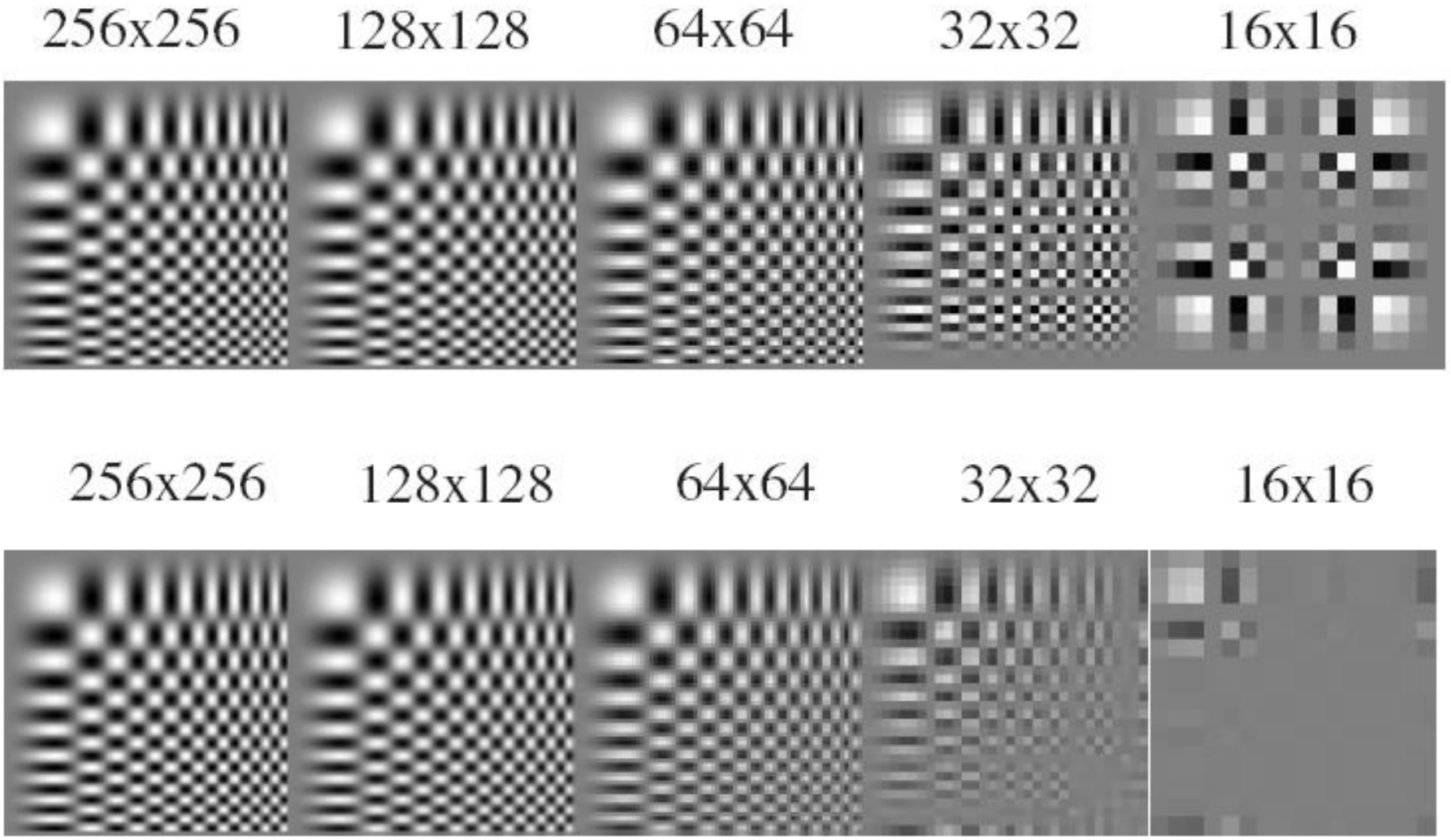
Counterpart: *high pass* filter

- Only keeps the high frequencies
- Edge detection (Sobel) is an example high pass filter

Related: *band pass / band stop* (or *notch)* filter

- Only affect *specific* frequencies
- How could we construct one with linear filters?

Anti-aliasing



Forsyth and Ponce 2002

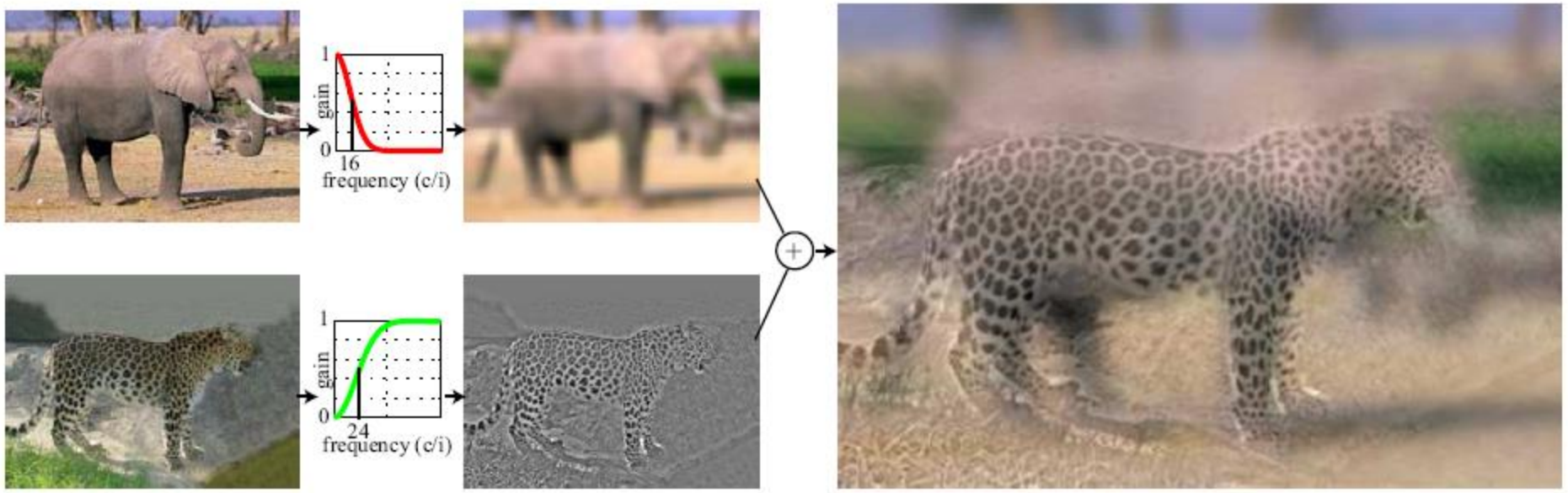
Algorithm for downsampling by factor of 2

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);

Hybrid Images



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

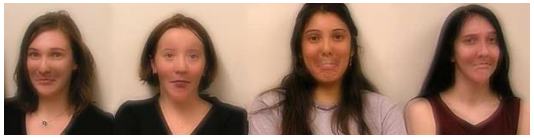
Why do we get different, distance-dependent interpretations of hybrid images?

?

Slide: Hoiem

Application: Hybrid Images

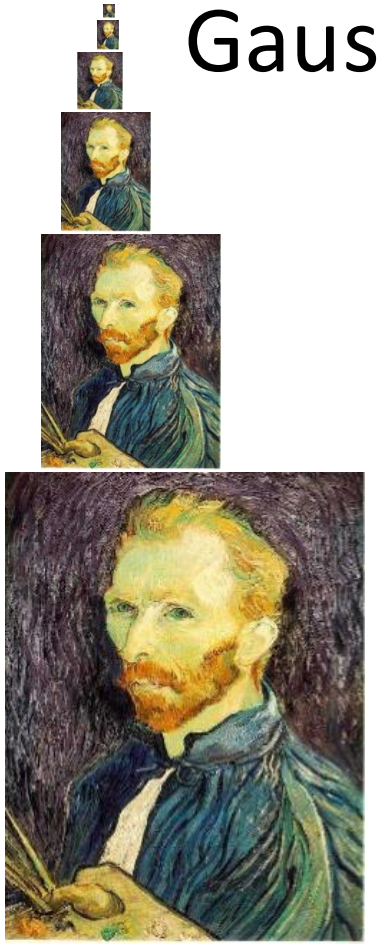
When we see an image from far away, we are effectively subsampling it!



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

Gaussian image pyramid

Gaussian image pyramid



The name of this sequence of subsampled images

Constructing a Gaussian pyramid

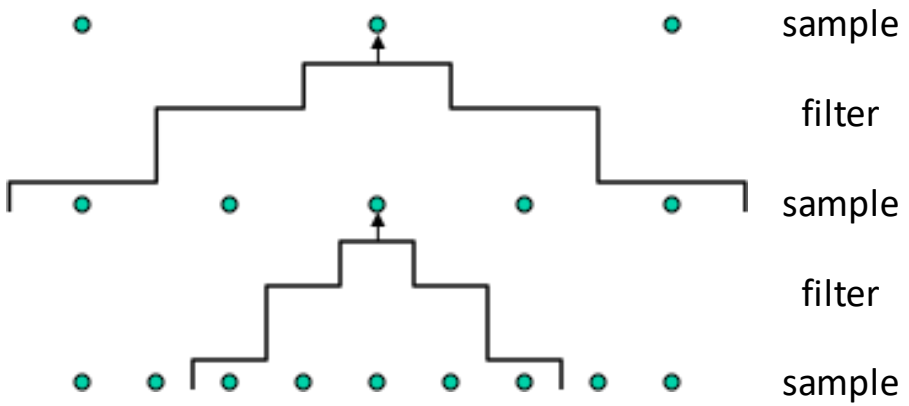
Algorithm

repeat:

filter

subsample

until min resolution reached



Question: How much bigger than the original image is the whole pyramid?

Constructing a Gaussian pyramid

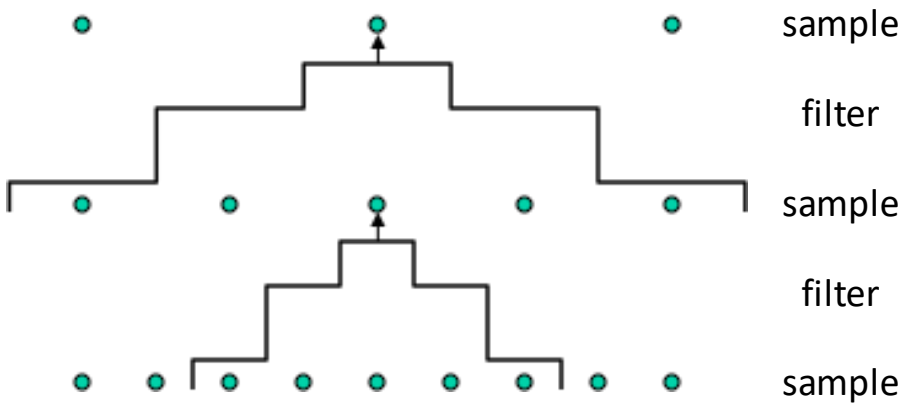
Algorithm

repeat:

filter

subsample

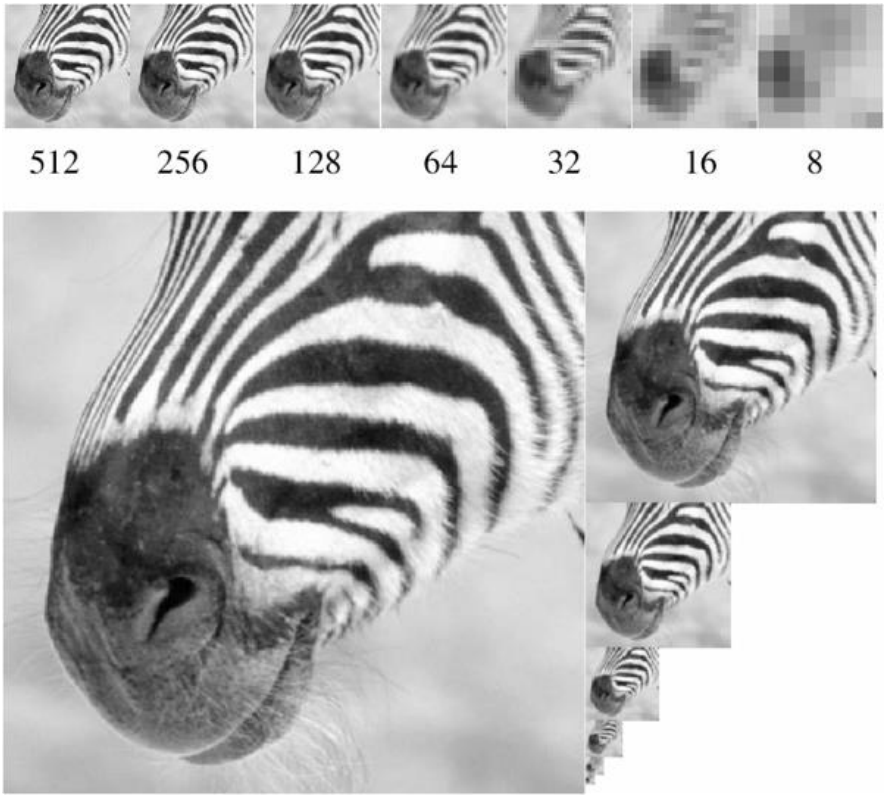
until min resolution reached



Question: How much bigger than the original image is the whole pyramid?

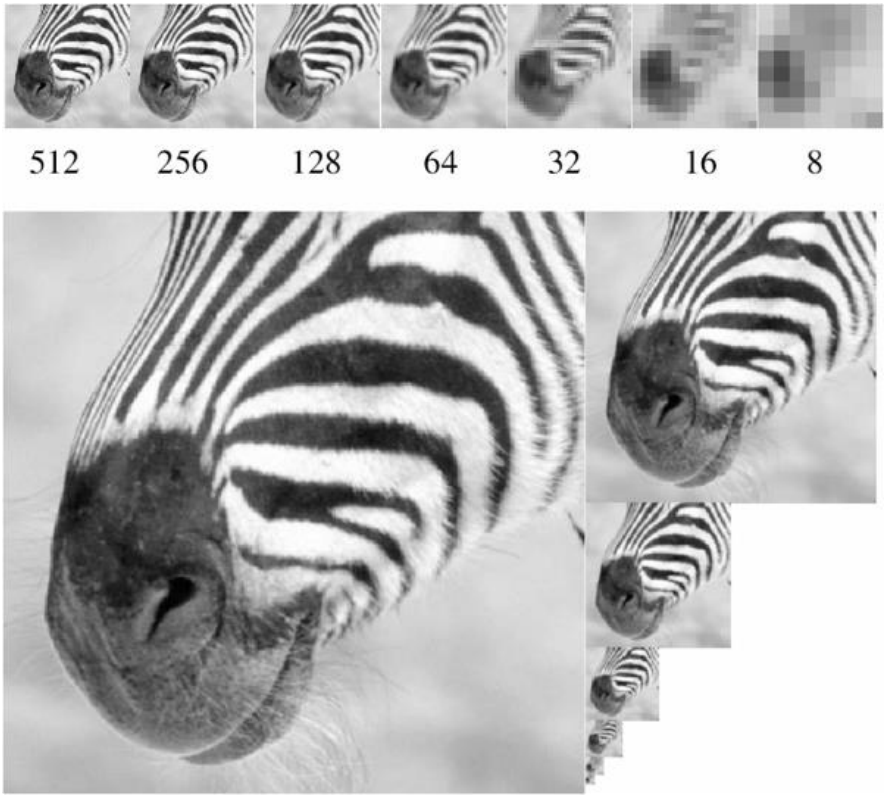
Answer: Just 4/3 times the size of the original image! (How did I come up with this number?)

Some properties of the Gaussian pyramid



What happens to the details of the image?

Some properties of the Gaussian pyramid

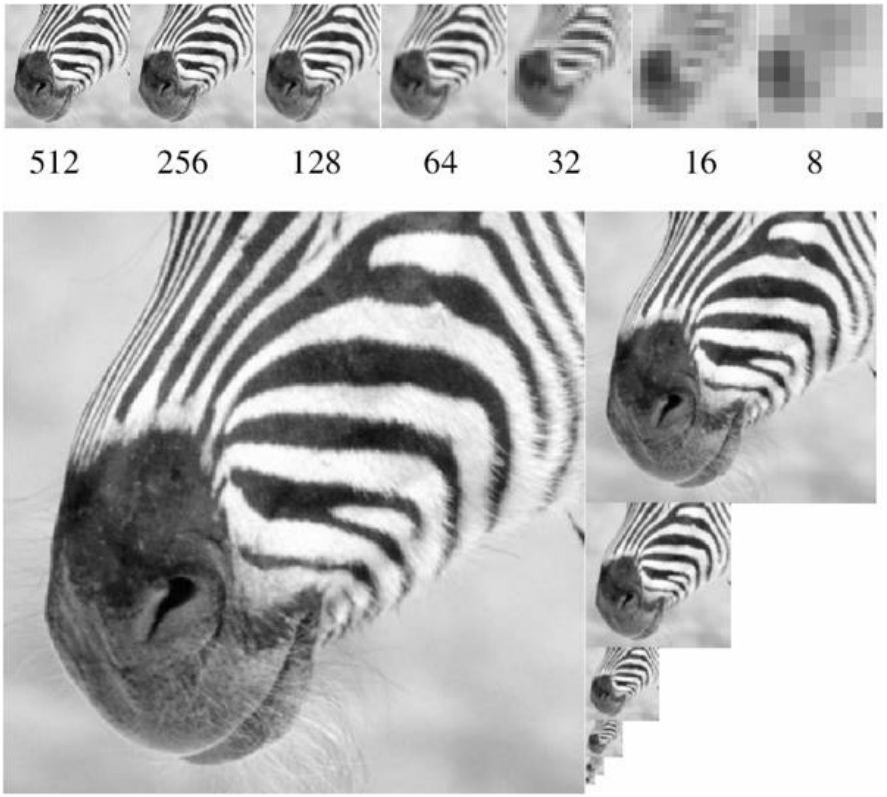


What happens to the details of the image?

- They get smoothed out as we move to higher levels.

What is preserved at the higher levels?

Some properties of the Gaussian pyramid



What happens to the details of the image?

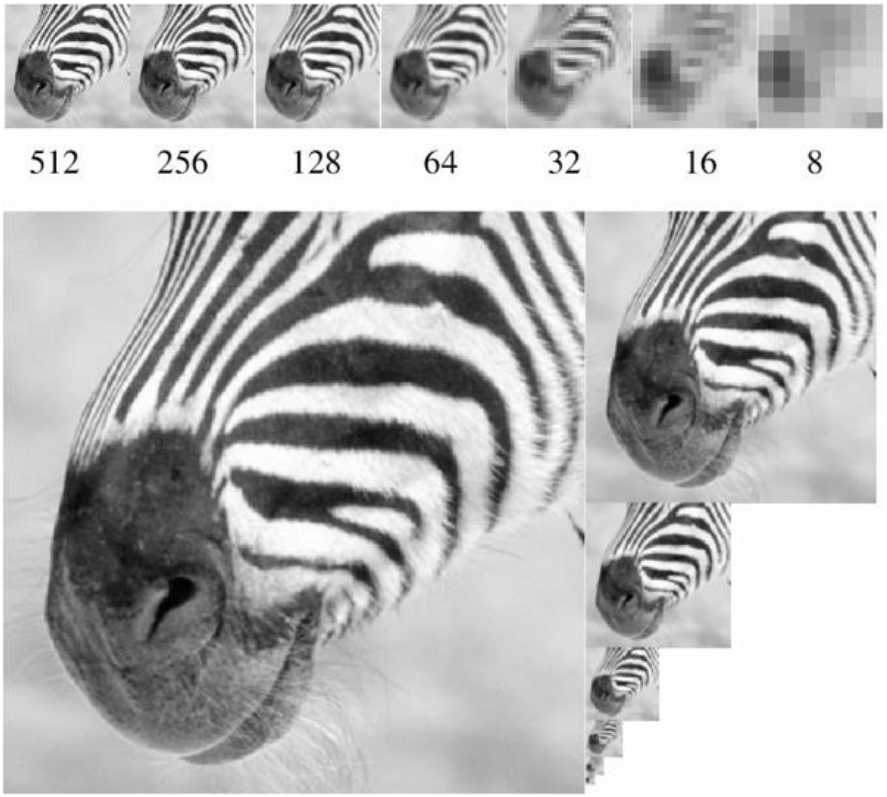
- They get smoothed out as we move to higher levels.

What is preserved at the higher levels?

- Mostly large uniform regions in the original image.

How would you reconstruct the original image from the image at the upper level?

Some properties of the Gaussian pyramid



What happens to the details of the image?

- They get smoothed out as we move to higher levels.

What is preserved at the higher levels?

- Mostly large uniform regions in the original image.

How would you reconstruct the original image from the image at the upper level?

- That's not possible.

Blurring is lossy

level 0

-

level 1 (before downsampling)

=

residual

What does the residual look like?

Blurring is lossy

level 0

-

level 1 (before downsampling)

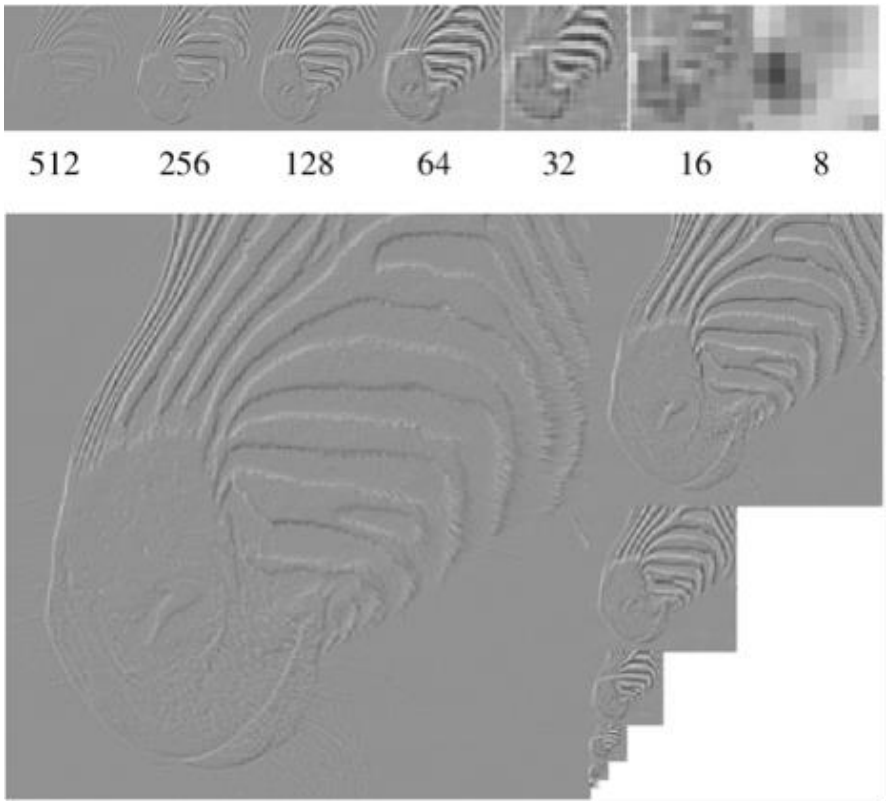
=

residual

Can we make a pyramid that is lossless?

Laplacian image pyramid

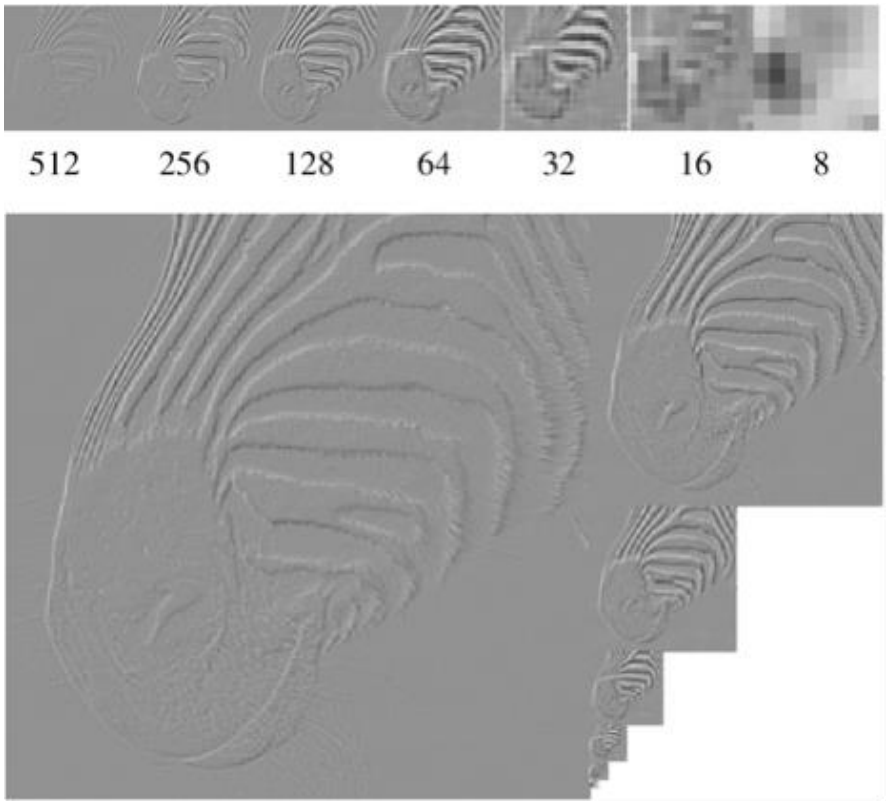
Laplacian image pyramid



At each level, retain the residuals instead of the blurred images themselves.

Can we reconstruct the original image using the pyramid?

Laplacian image pyramid



At each level, retain the residuals instead of the blurred images themselves.

Can we reconstruct the original image using the pyramid?

- Yes we can!

What do we need to store to be able to reconstruct the original image?

Let’s start by looking at just one level

level 0

=

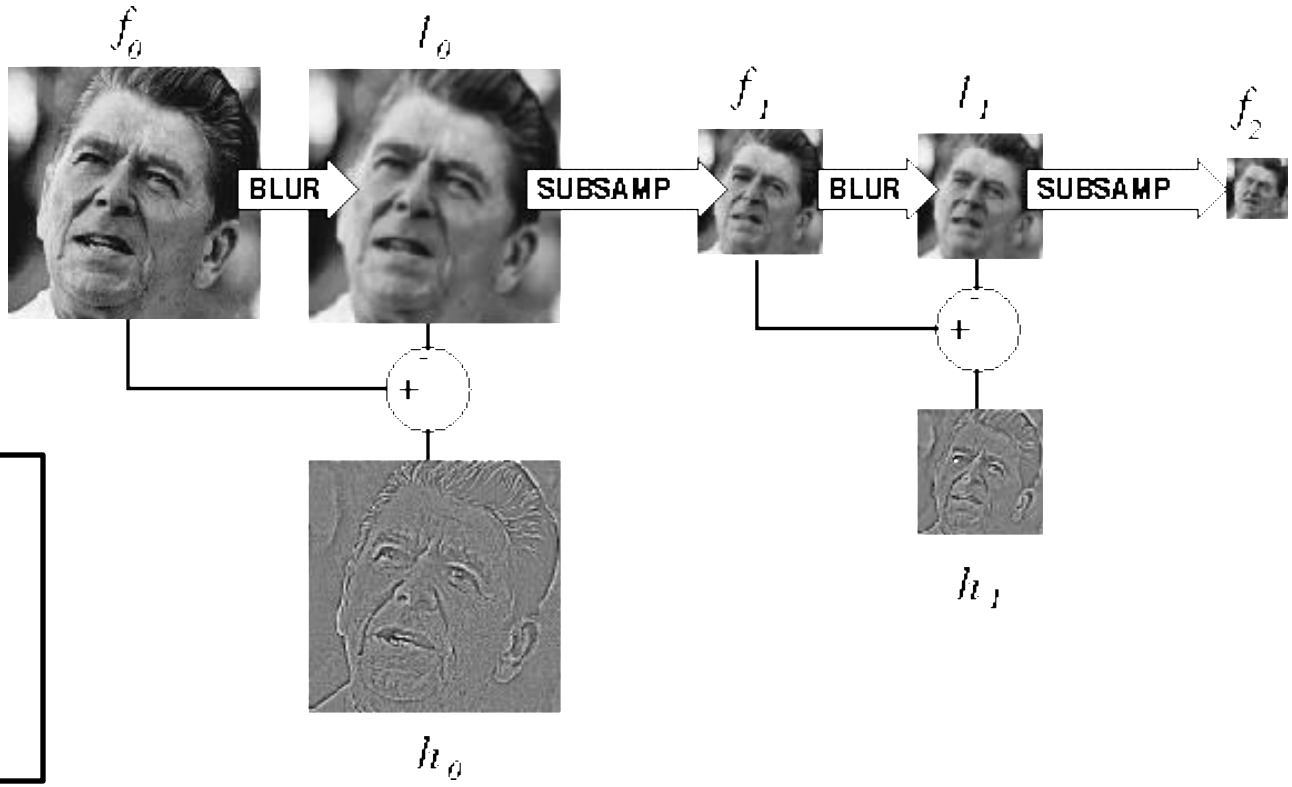
level 1 (upsampled)

+

residual

Does this mean we need to store both residuals and the blurred copies of the original?

Constructing a Laplacian pyramid



Algorithm

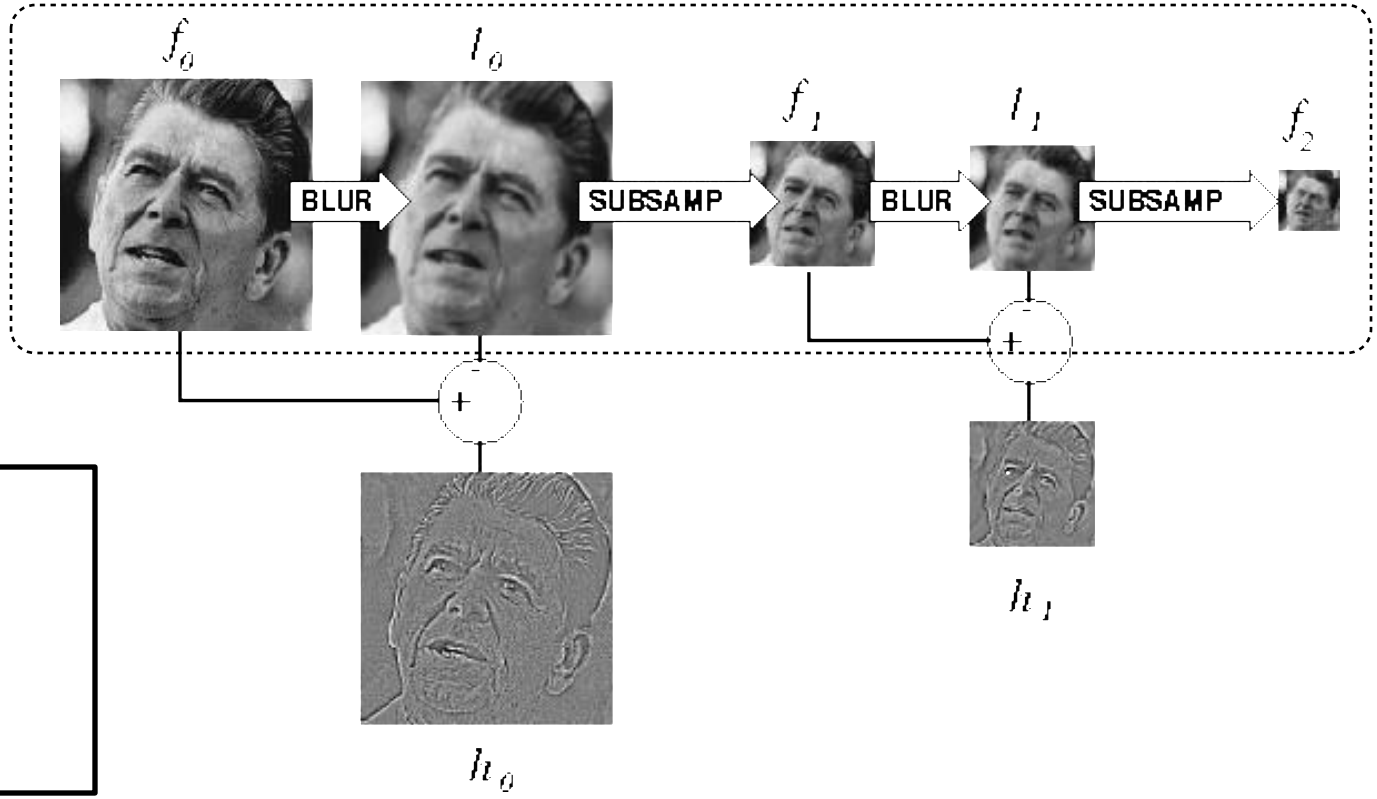
repeat:

- filter
- compute residual
- subsample

until min resolution reached

Constructing a Laplacian pyramid

What is this part?



Algorithm

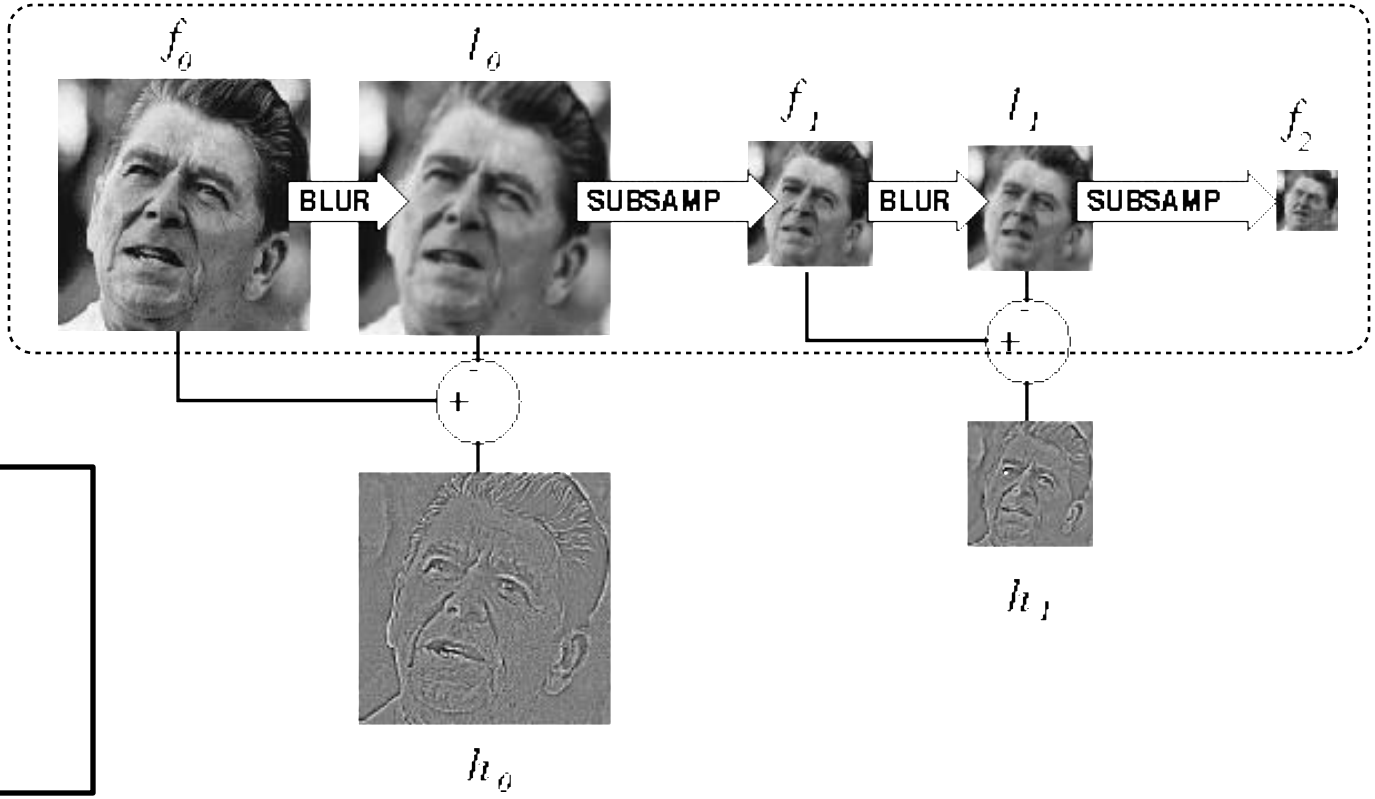
repeat:

- filter
- compute residual
- subsample

until min resolution reached

Constructing a Laplacian pyramid

It's a Gaussian pyramid.



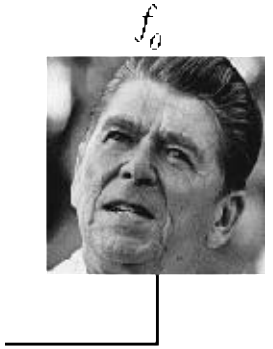
Algorithm

repeat:

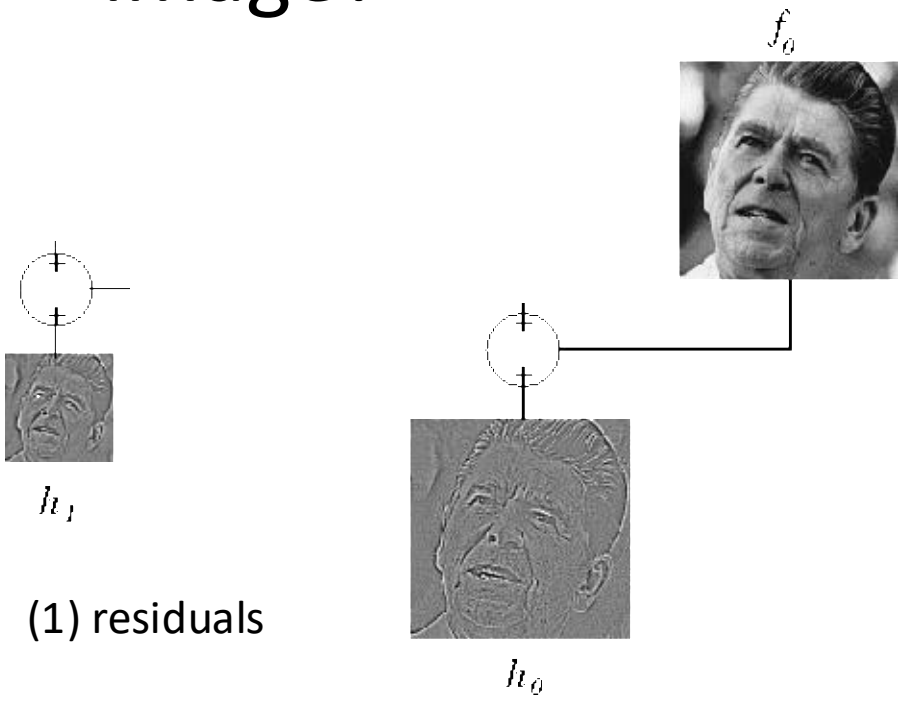
- filter
- compute residual
- subsample

until min resolution reached

What do we need to construct the original image?



What do we need to construct the original image?

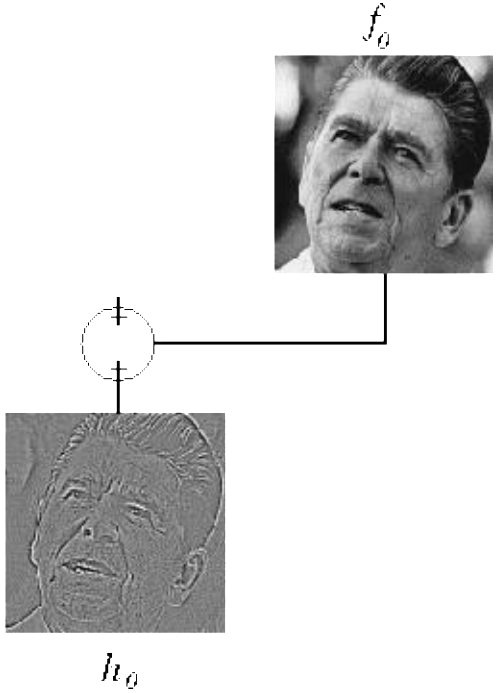


(1) residuals

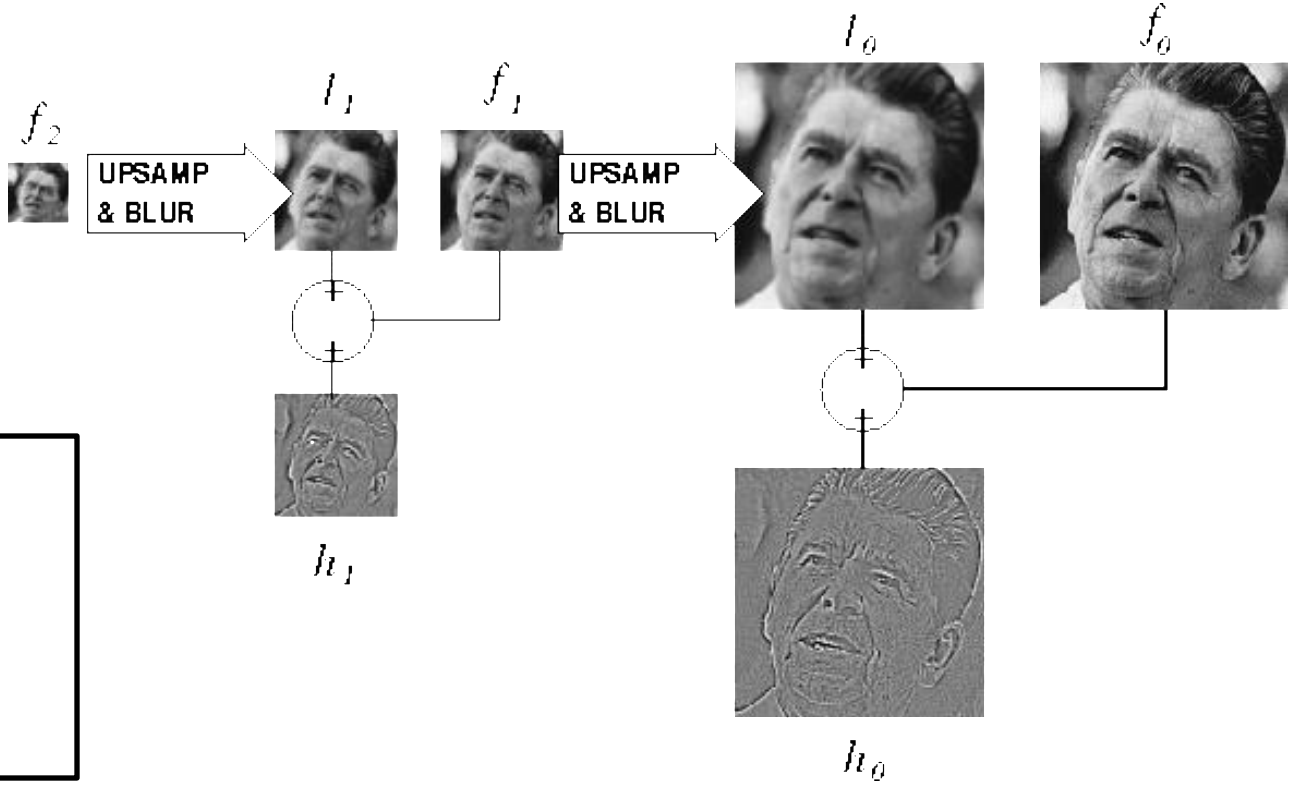
What do we need to construct the original image?

(2) smallest image

(1) residuals



Reconstructing the original image



Algorithm

repeat:

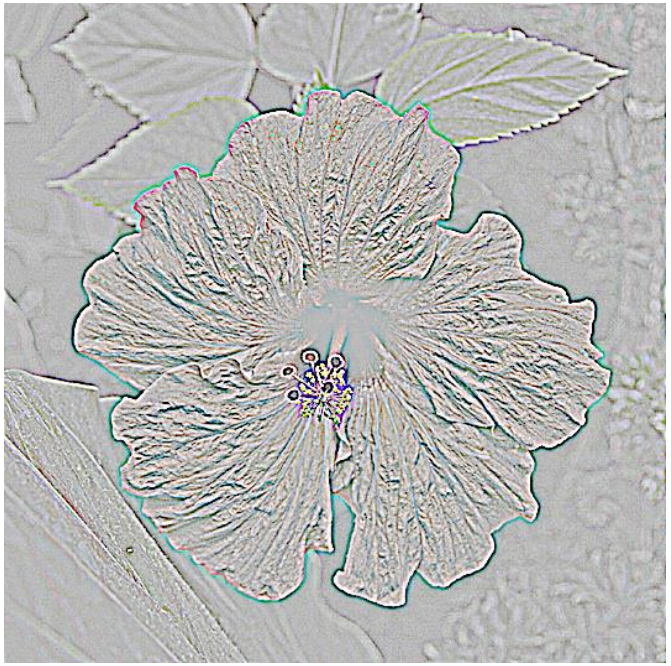
upsample

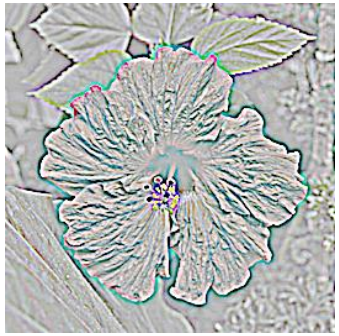
sum with residual

until orig resolution reached

Gaussian vs Laplacian Pyramid

Shown in opposite order for space.





Which one takes more space to store?

Why is it called a Laplacian pyramid?

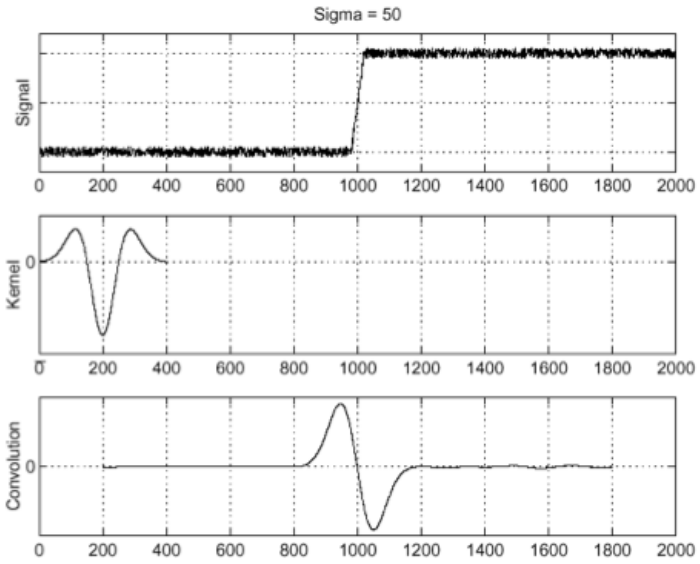
Reminder: Laplacian of Gaussian (LoG) filter

As with derivative, we can combine Laplace filtering with Gaussian filtering

input

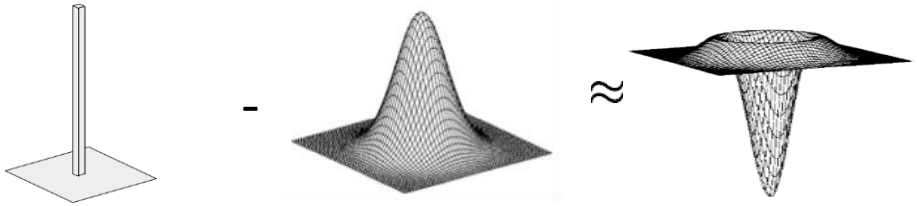
Laplacian of Gaussian

output

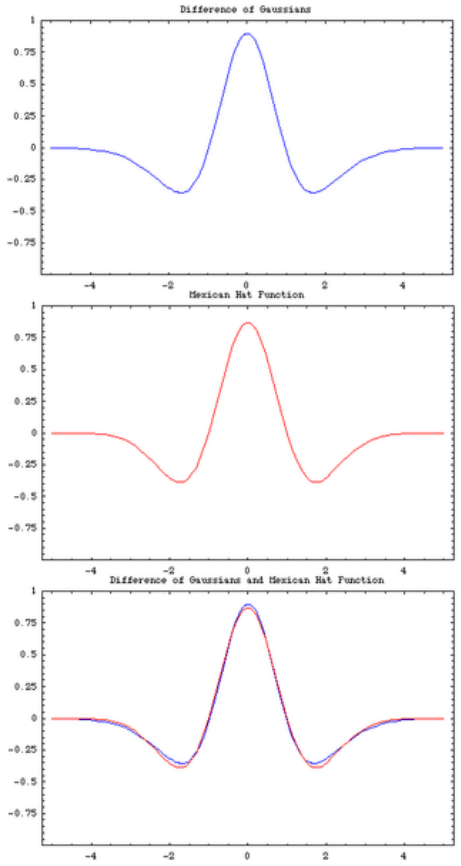


"zero crossings" at edges

Why is it called a Laplacian pyramid?

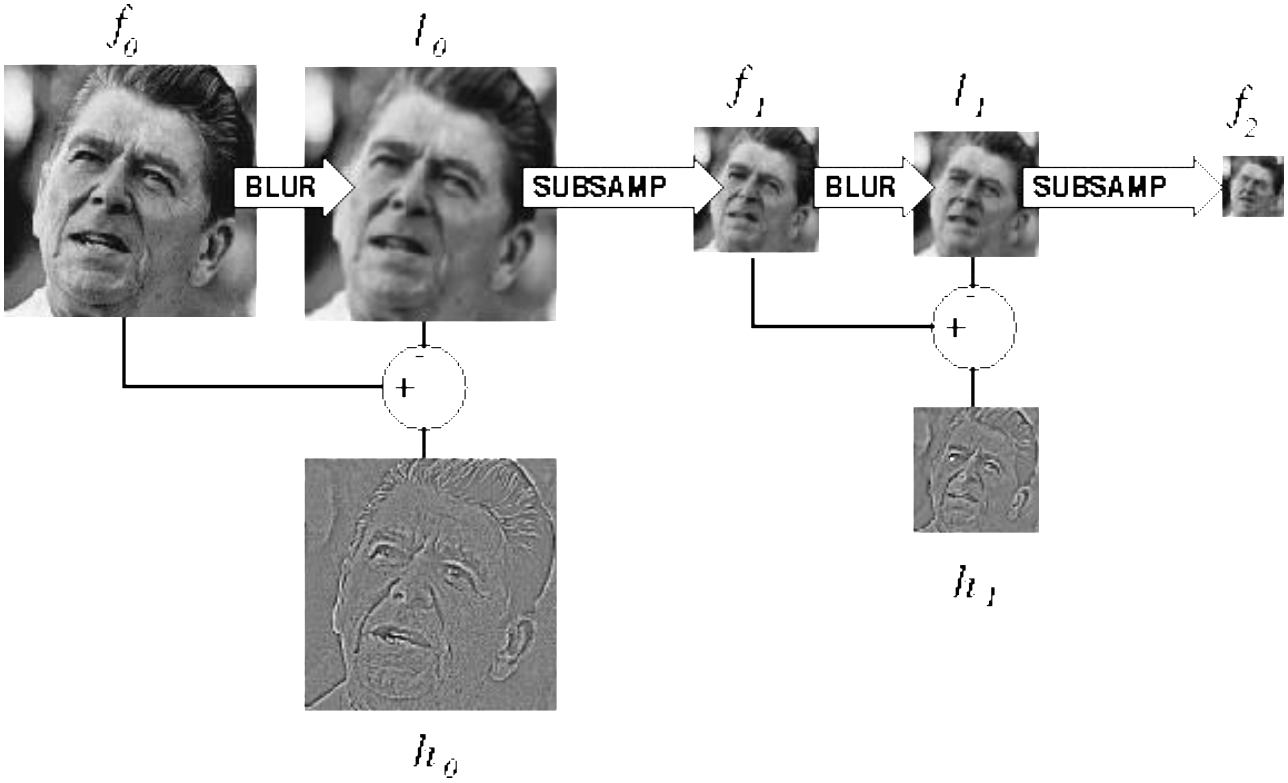


unit Gaussian Laplacian



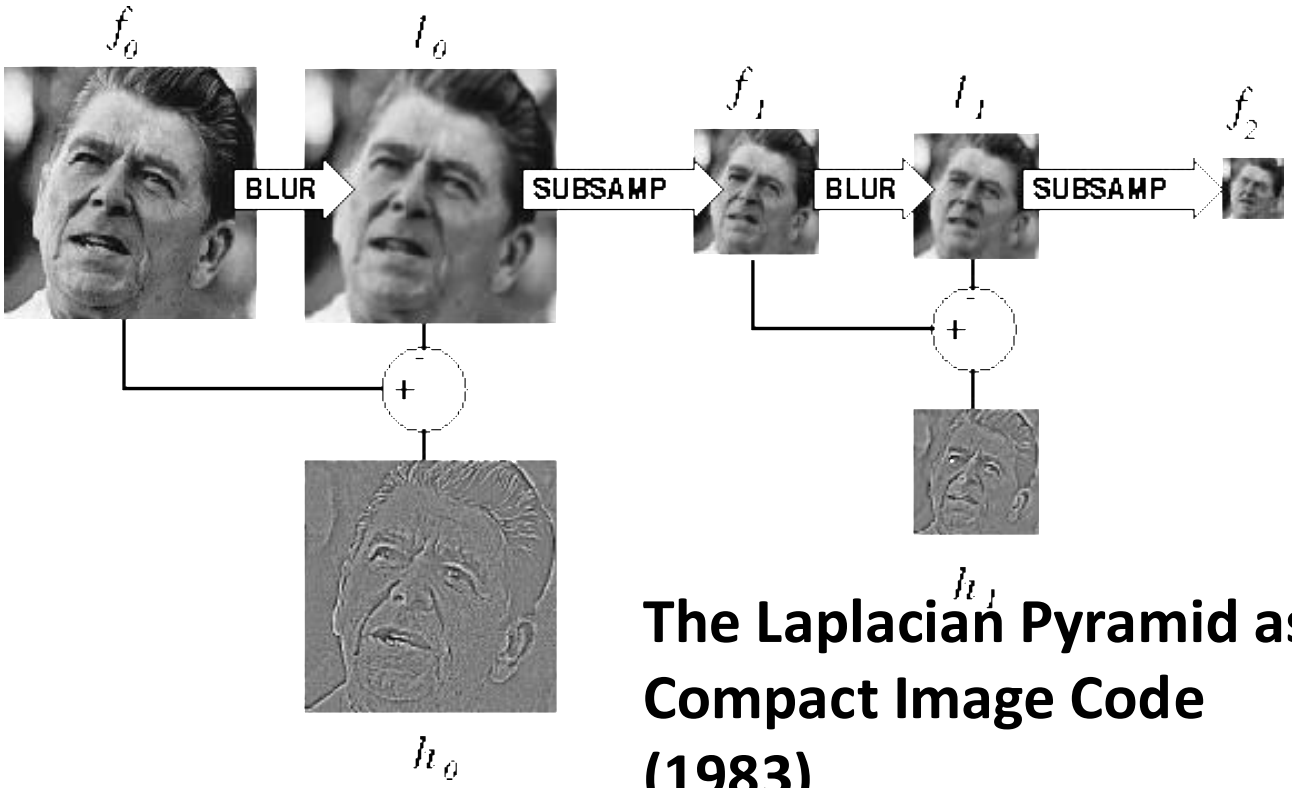
Difference of Gaussians approximates the Laplacian

Why Reagan?



Why Reagan?

Ronald Reagan was President when the Laplacian pyramid was invented



The Laplacian Pyramid as a Compact Image Code (1983)

Peter J. Burt , Edward H. Adelson

Still used extensively

Still used extensively

foreground details enhanced, background details reduced

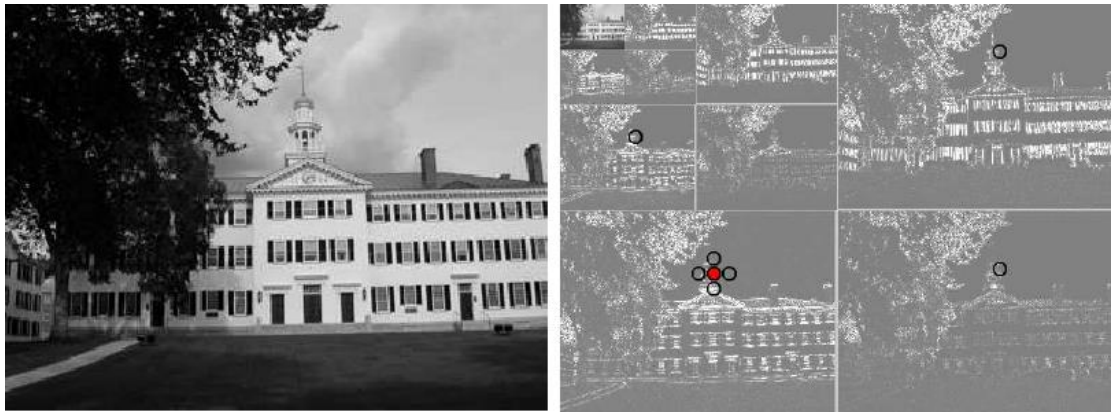
input image

user-provided mask

Other types of pyramids

Steerable pyramid: At each level keep multiple versions, one for each direction.

Wavelets: Huge area in image processing (see 18-793).



What are image pyramids used for?

image compression

multi-scale texture mapping

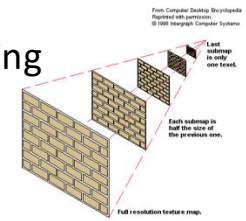
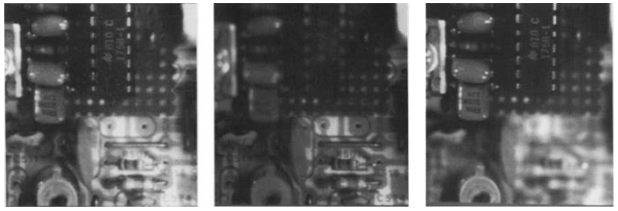
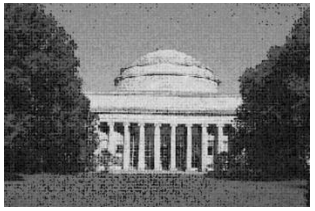


image blending

focal stack compositing



denoising



multi-scale detection

multi-scale registration