Subsampling and image pyramids

15-463, 15-663, 15-862
Computational Photography
Fall 2017, Lecture 5

http://graphics.cs.cmu.edu/courses/15-463

Course announcements

Respond to Doodle about rescheduling the September 27th lecture!

- Link available on Piazza.
- Currently 11 responses. Only one more since Monday :-(.

Course announcements

- Homework 1 is due tomorrow.
  - Any remaining questions?
  - How was it?

- Homework 2 will be posted tonight and will be due two weeks from now.
  - Much larger than homework 1.
  - Start early! Experiments take a long time to run.

Overview of today's lecture

- Finish non-linear filtering: non-local means.
- Image downsampling.
- Aliasing.
- Gaussian image pyramid.
- Laplacian image pyramid.

Slide credits

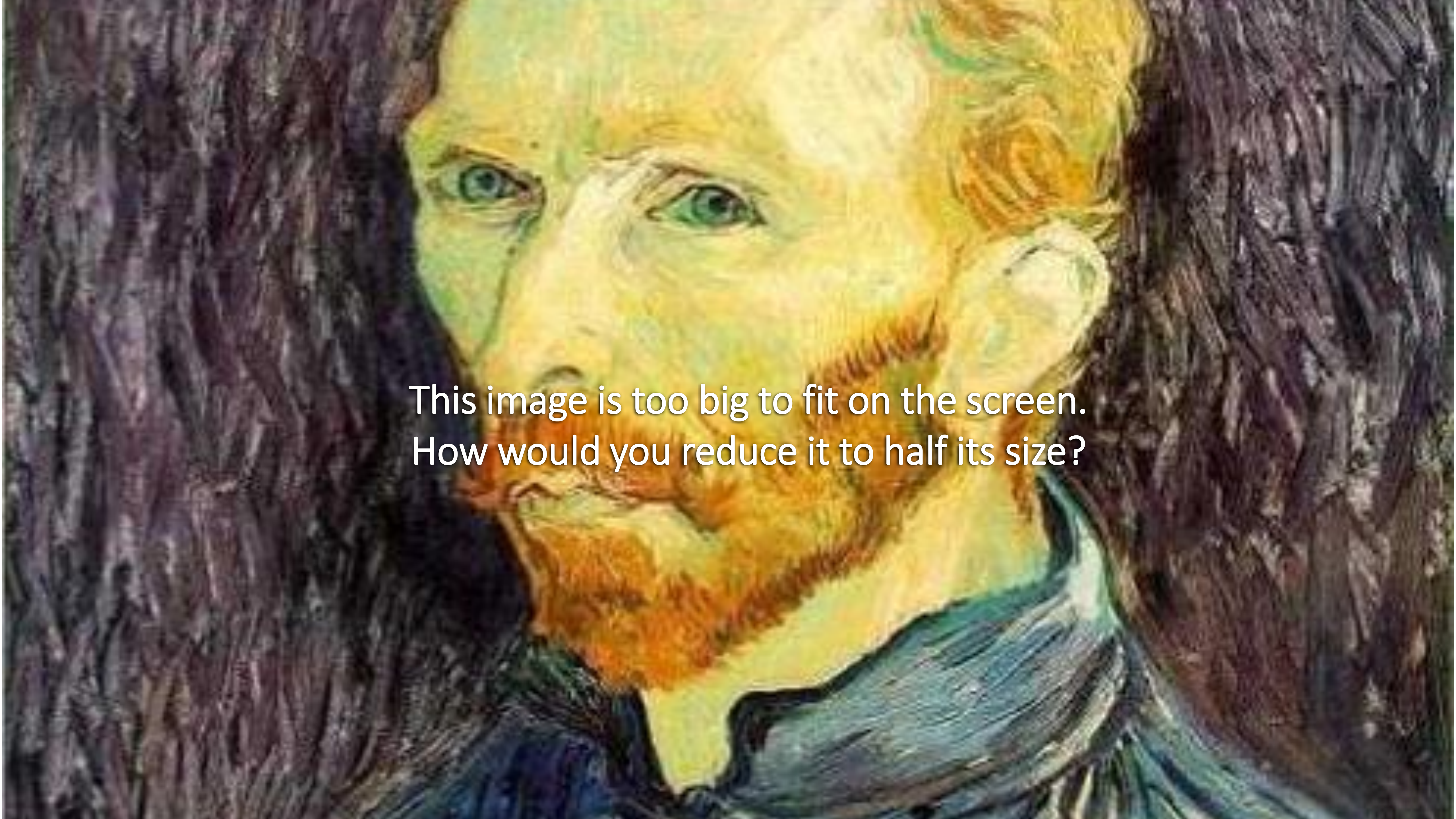
Most of these slides were adapted directly from:

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

Some slides were inspired or taken from:

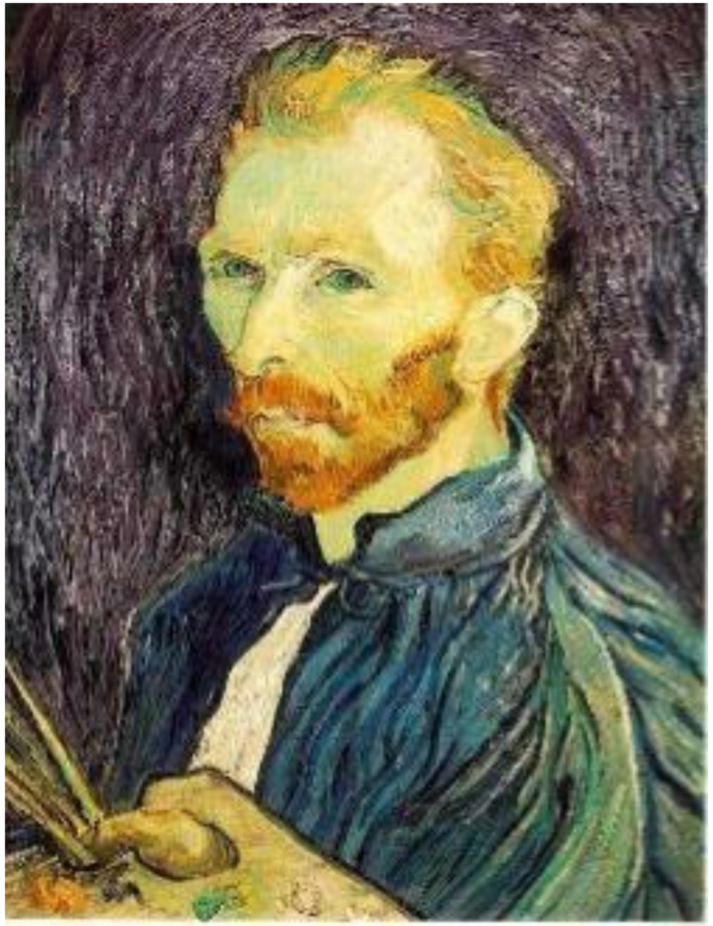
- Bernd Girod (Stanford University).
- Steve Marschner (Cornell University).
- Steve Seitz (University of Washington).

Image downsampling


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

Naïve image downsampling

Throw away half the rows and columns



1/2

delete even rows
delete even columns

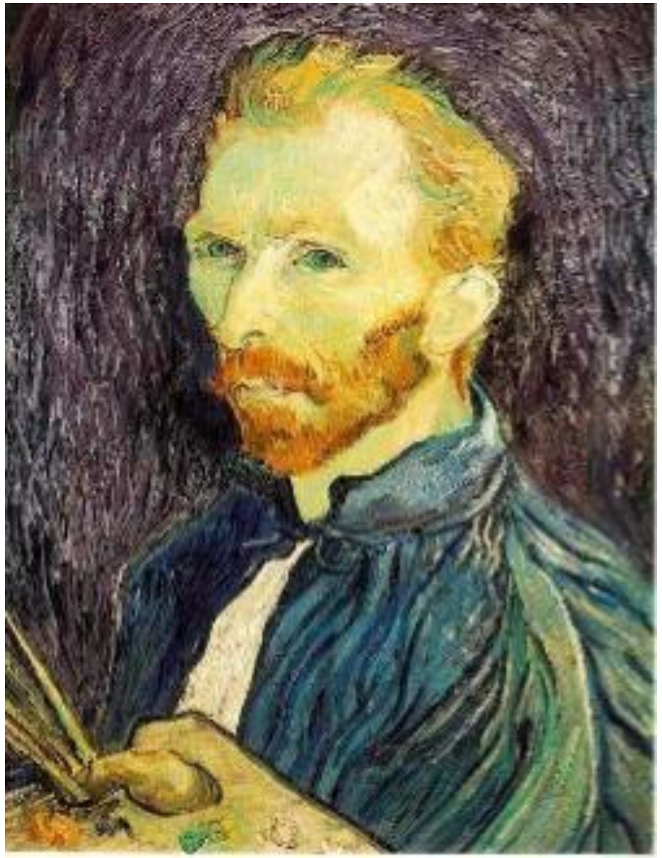
1/4

delete even rows
delete even columns

1/8

What is the problem with this approach?

Naïve image downsampling



1/2

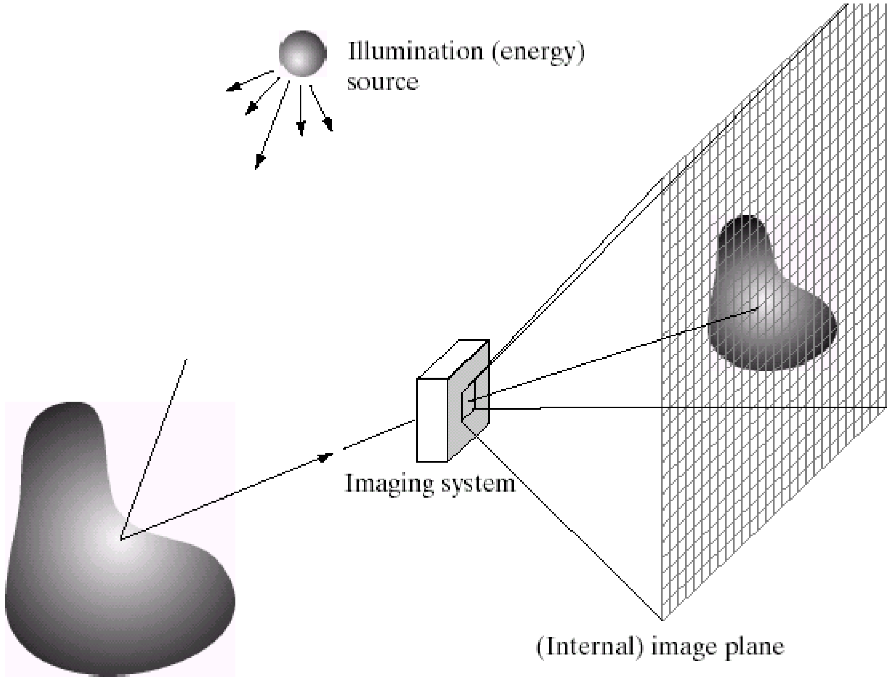
1/4 (2x zoom)

1/8 (4x zoom)

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

Aliasing

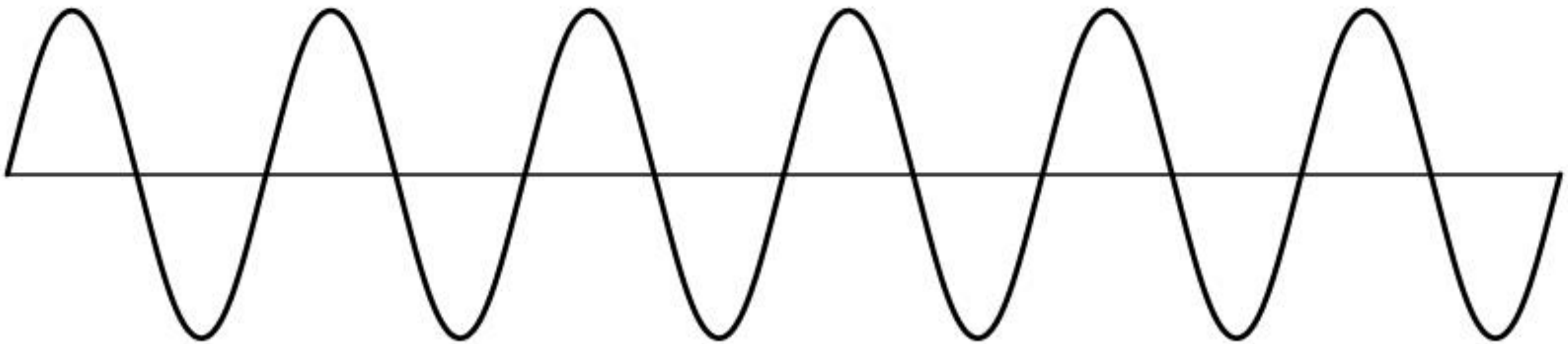
Reminder



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

Sampling

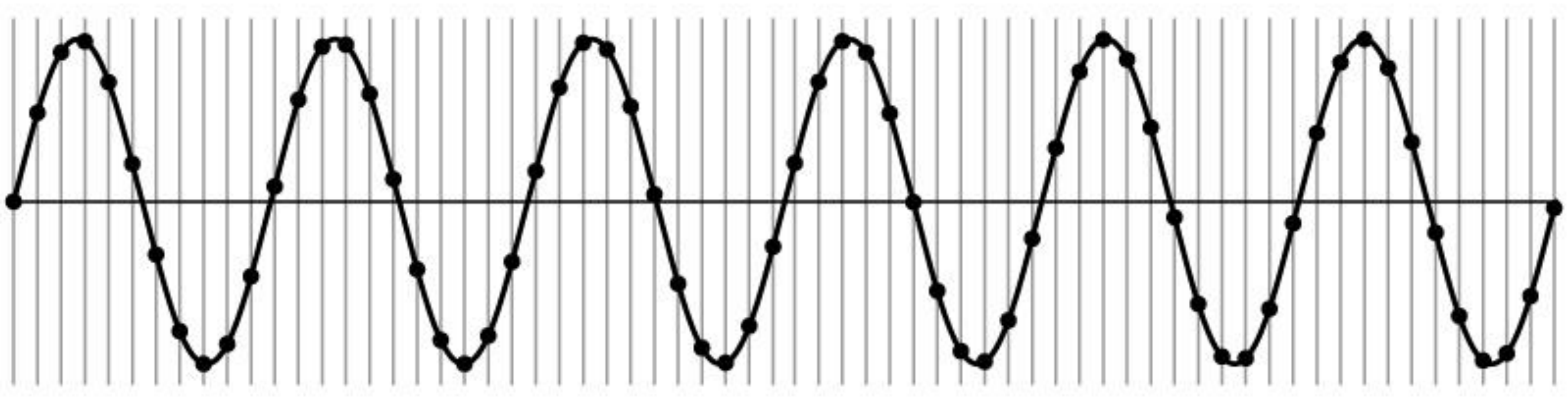
Very simple example: a sine wave



How would you discretize this signal?

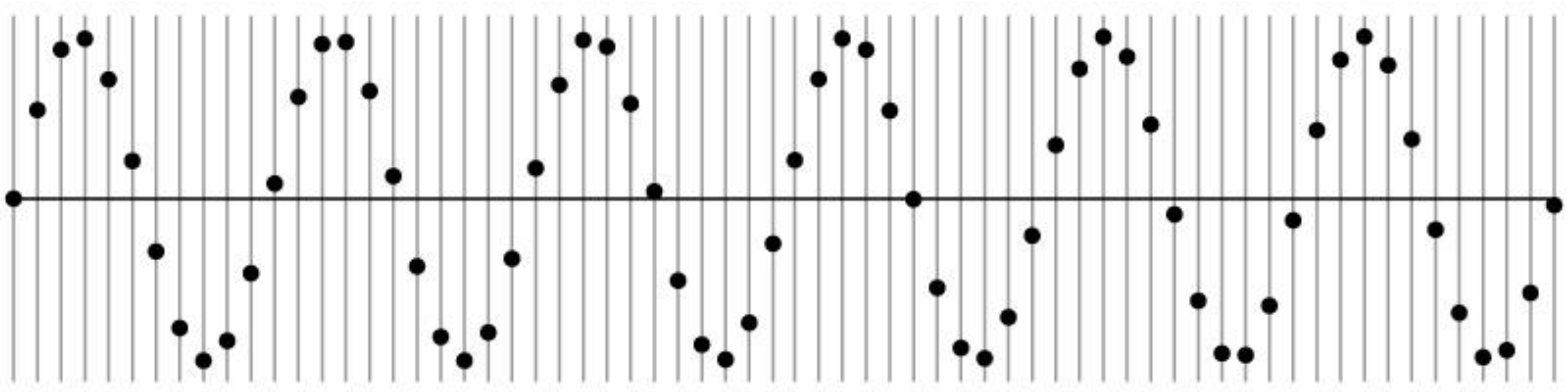
Sampling

Very simple example: a sine wave



Sampling

Very simple example: a sine wave

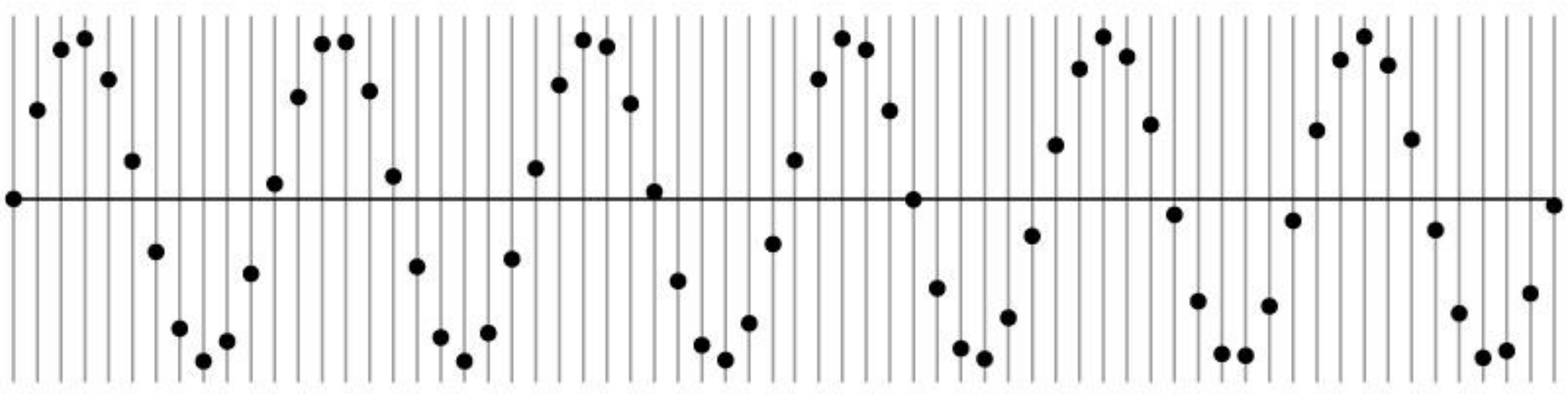


How many samples should I take?

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

Sampling

Very simple example: a sine wave

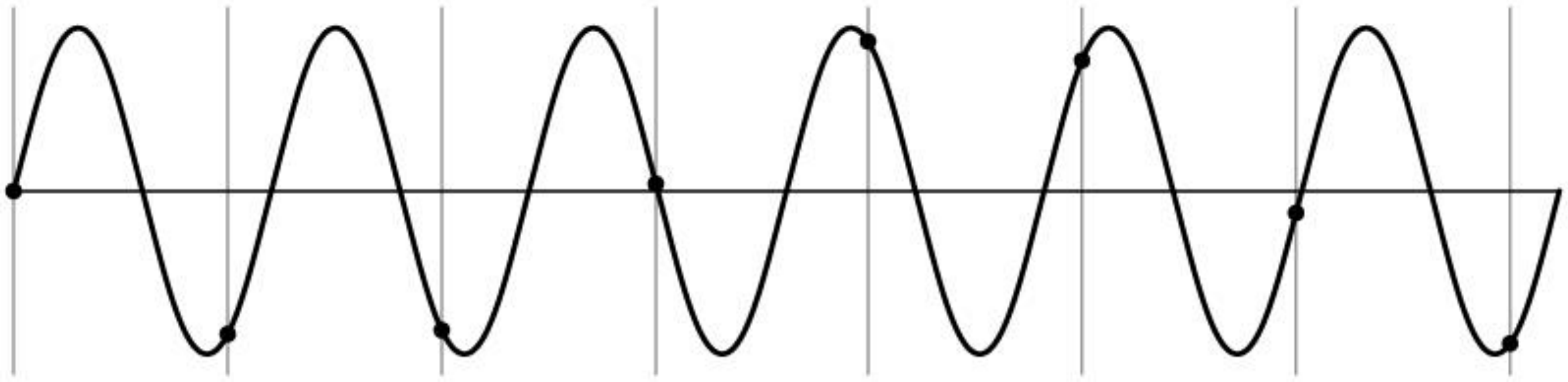


How many samples should I take?

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

Undersampling

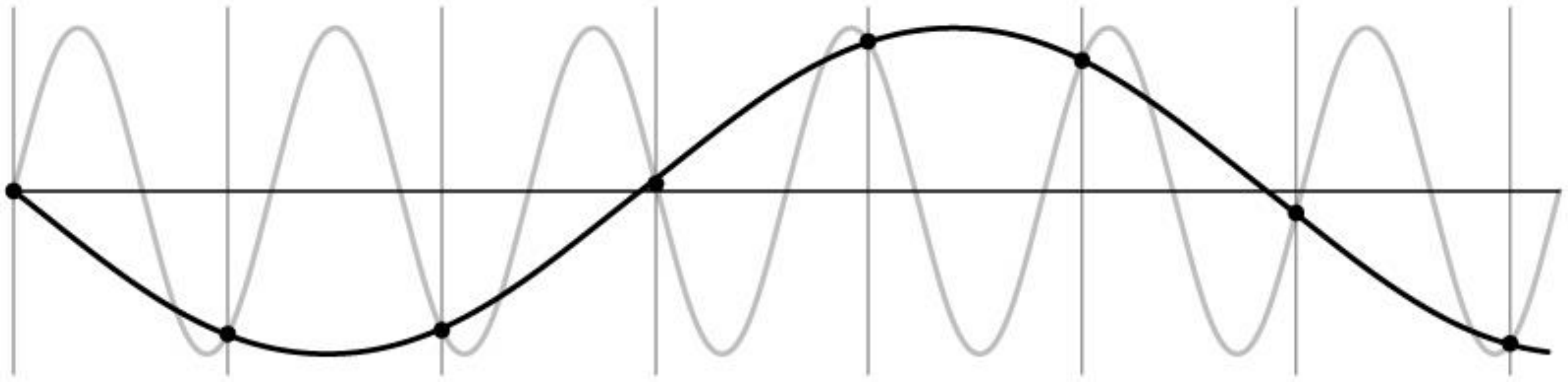
Very simple example: a sine wave



Unsurprising effect: information is lost.

Undersampling

Very simple example: a sine wave

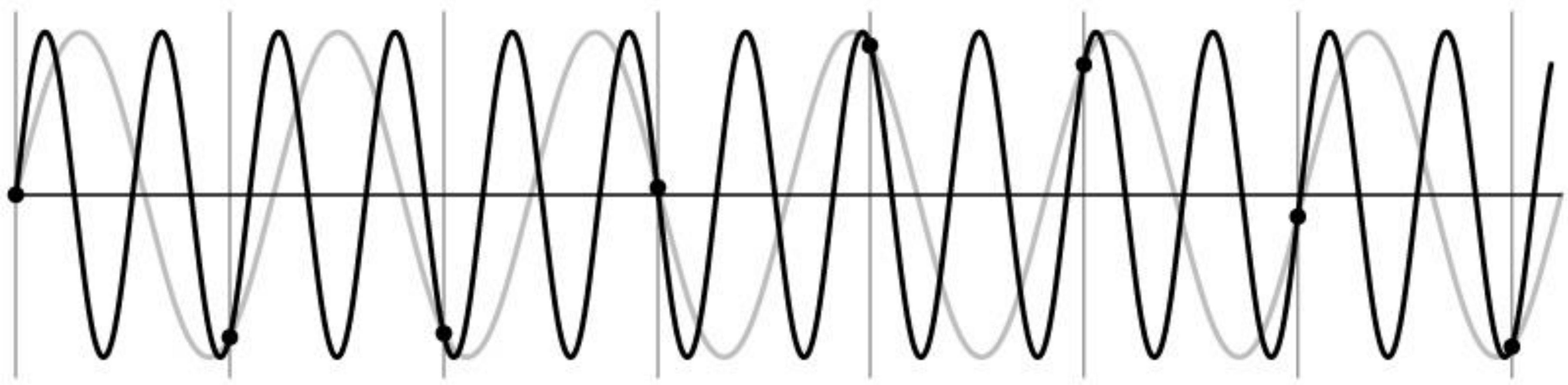


Unsurprising effect: information is lost.

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

Undersampling

Very simple example: a sine wave



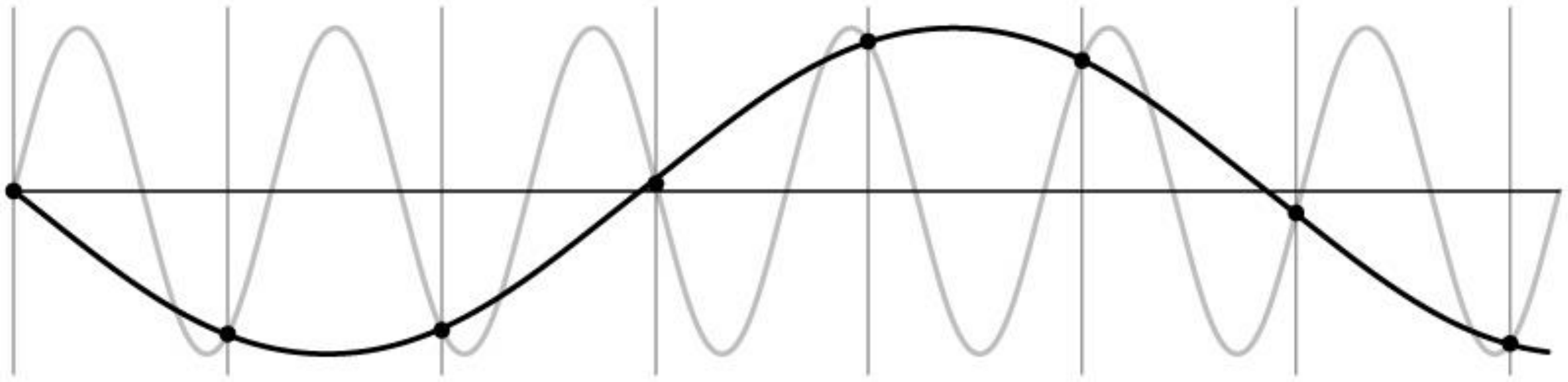
Unsurprising effect: information is lost.

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*

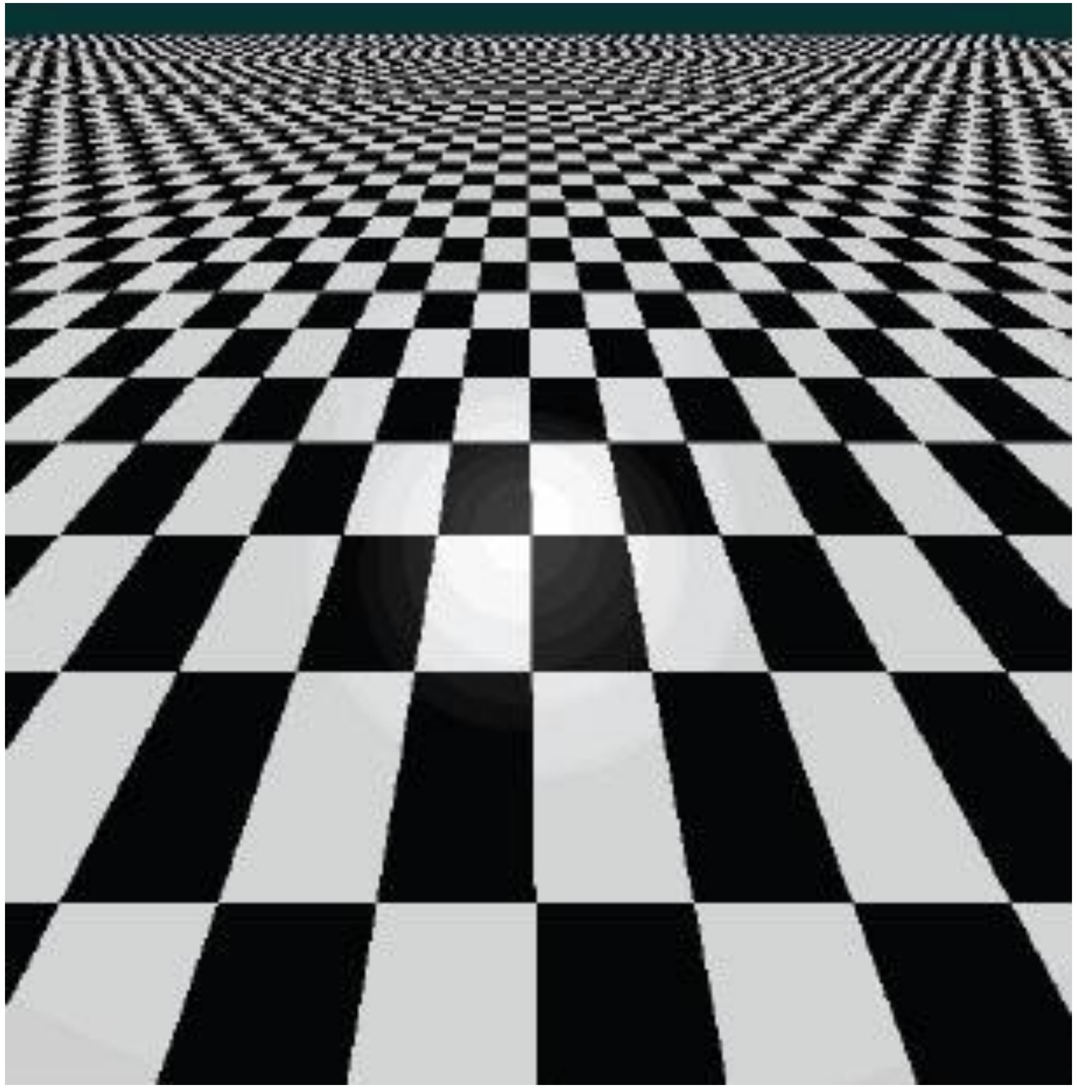


Unsurprising effect: information is lost.

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



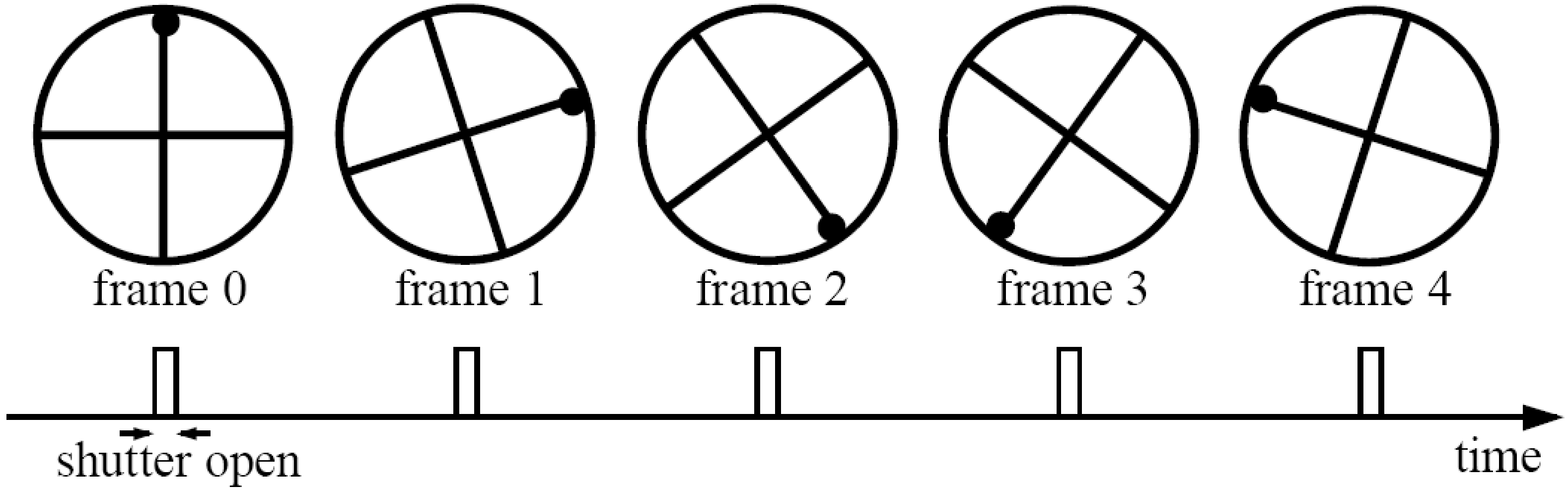
Aliasing in photographs

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

Anti-aliasing

How would you deal with aliasing?

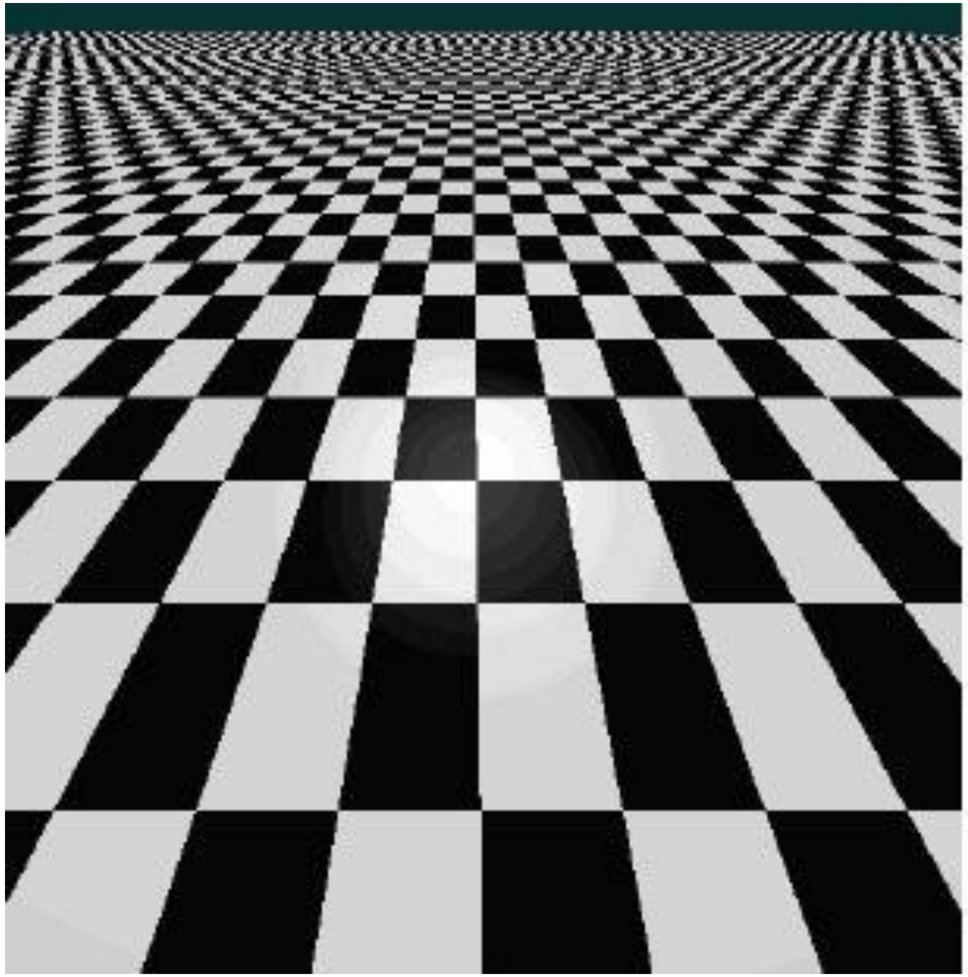
Anti-aliasing

How would you deal with aliasing?

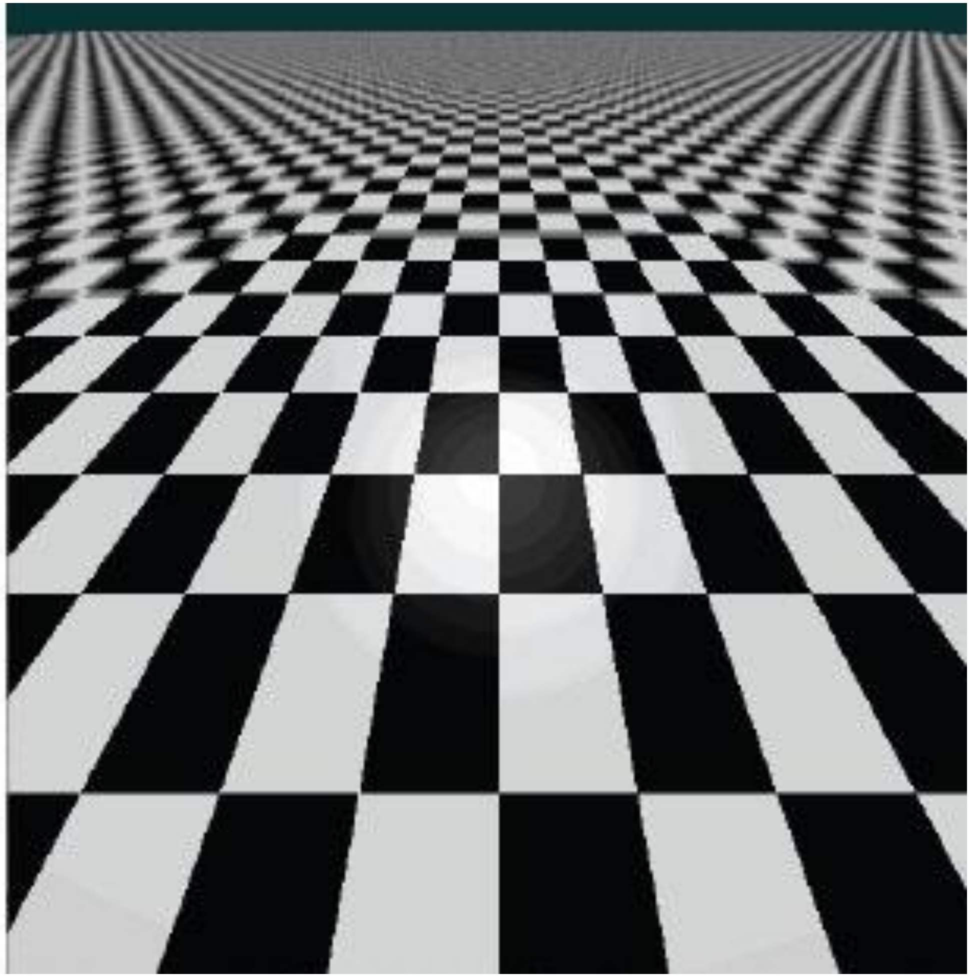
Approach 1: Oversample the signal

- This is how camera manufacturers started focusing so heavily on number of megapixels.

Anti-aliasing in textures



aliasing artifacts



anti-aliasing by oversampling

Anti-aliasing

How would you deal with aliasing?

Approach 1: Oversample the signal

- This is how camera manufacturers started focusing so heavily on number of megapixels.

Approach 2: Smooth the signal

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

How would you smooth a signal?

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.

We'll see what this means in the next lecture.

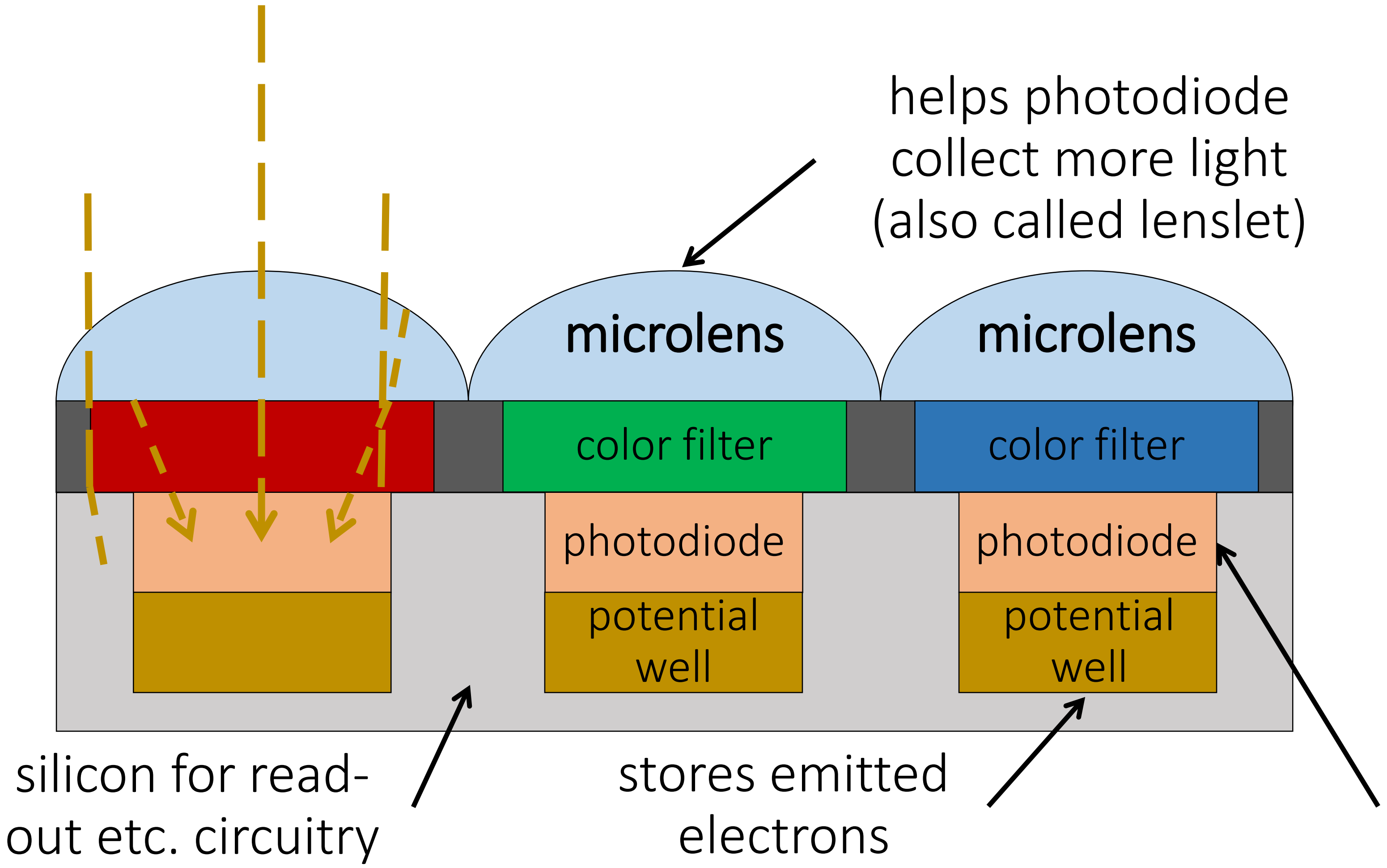
Quick aside: optical anti-aliasing

Lenses act as (optical) smoothing filters.

Quick aside: optical anti-aliasing

Lenses act as (optical) smoothing filters.

Slide from lecture 2: Basic imaging sensor design



- **Lenslets also filter the image to avoid resolution artifacts.**
- Lenslets are problematic when working with coherent light.
- Many modern cameras do not have lenslet arrays.

We will discuss these issues in more detail at a later lecture.

Quick aside: optical anti-aliasing

Lenses act as (optical) smoothing filters.

- Sensors often have a lenslet array in front of them as an anti-aliasing (AA) filter.
- However, the AA filter means you also lose resolution.
- Nowadays, due the large number of sensor pixels, AA filters are becoming unnecessary.

Photographers often hack their cameras to remove the AA filter, in order to avoid the loss of resolution.

a.k.a. “hot rodding”

Quick aside: optical anti-aliasing

Example where AA filter is needed

without AA filter

with AA filter

Quick aside: optical anti-aliasing

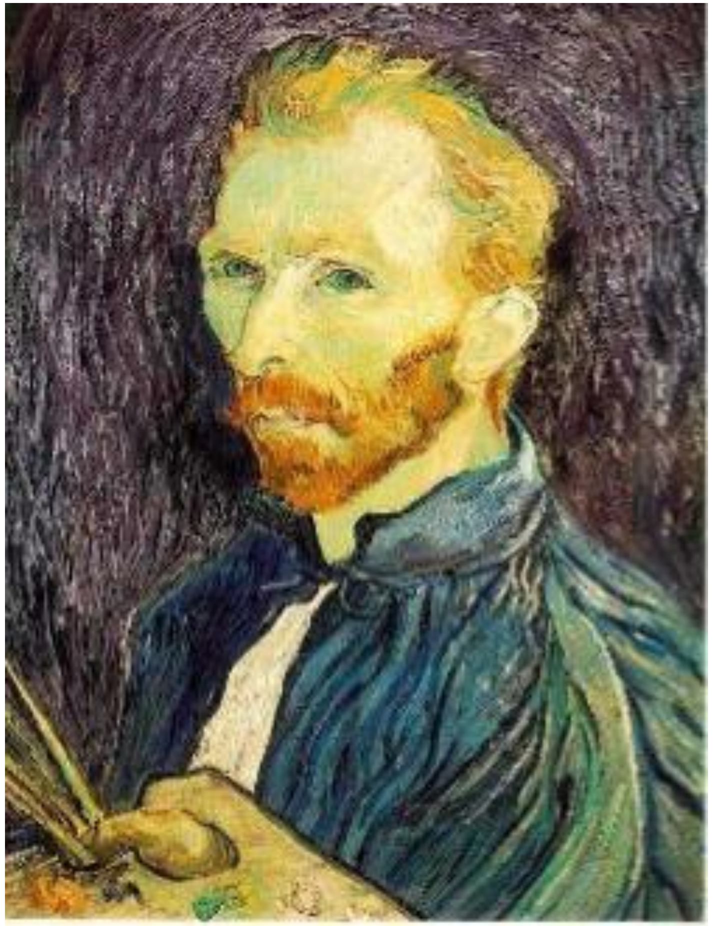
Example where AA filter is unnecessary

without AA filter

with AA filter

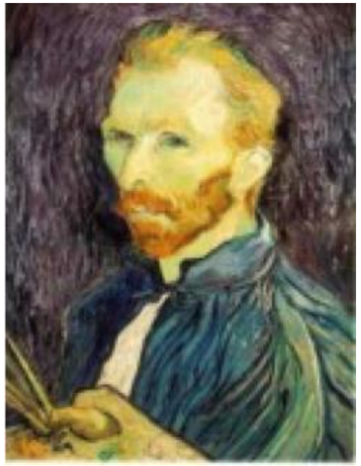
Better image downsampling

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



1/2

Gaussian filter
delete even rows
delete even columns

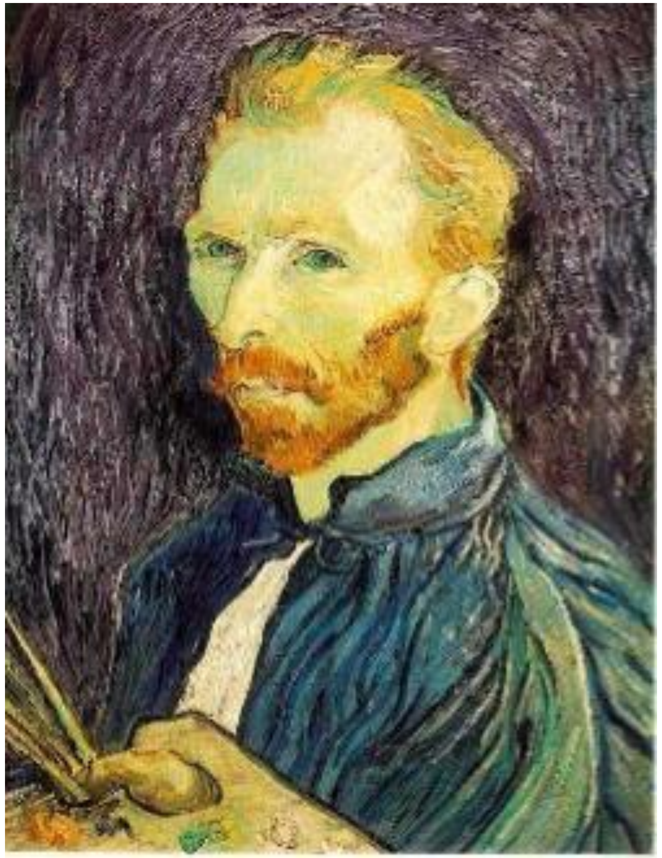


1/4

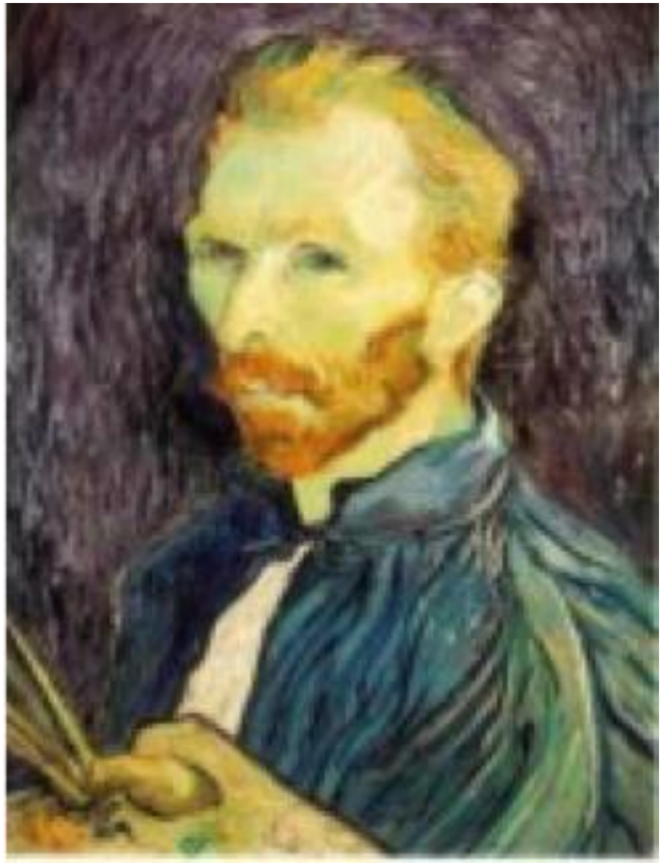
Gaussian filter
delete even rows
delete even columns

1/8

Better image downsampling



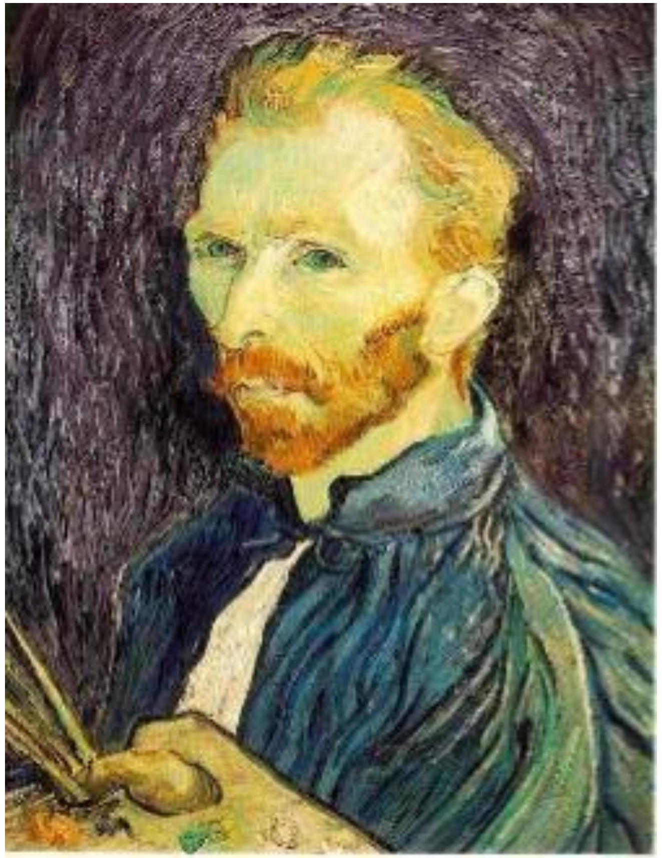
1/2



1/4 (2x zoom)

1/8 (4x zoom)

Naïve image downsampling



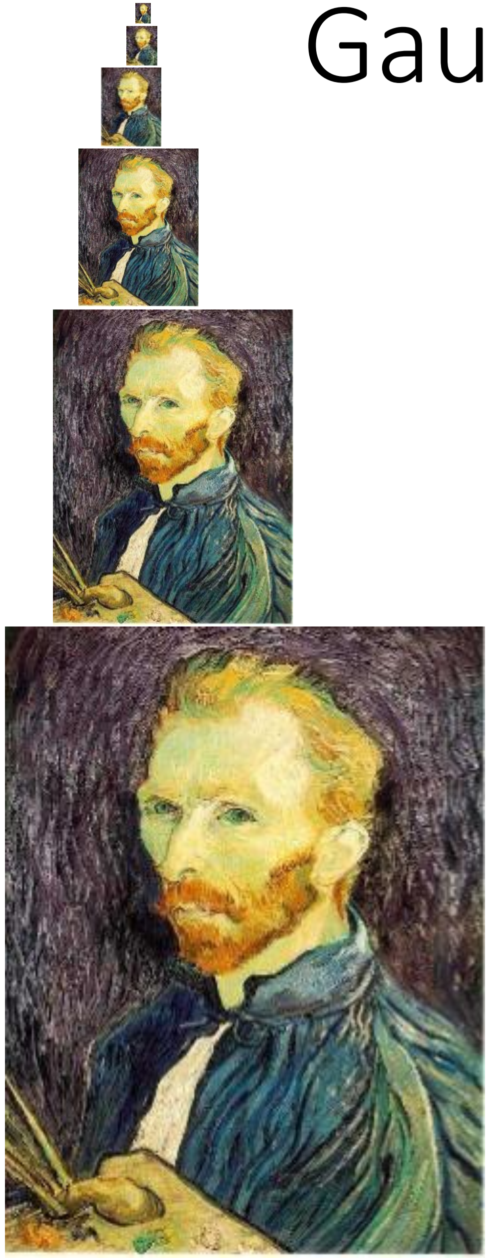
1/2

1/4 (2x zoom)

1/8 (4x zoom)

Gaussian image pyramid

Gaussian image pyramid



The name of this sequence of subsampled images

Constructing a Gaussian pyramid

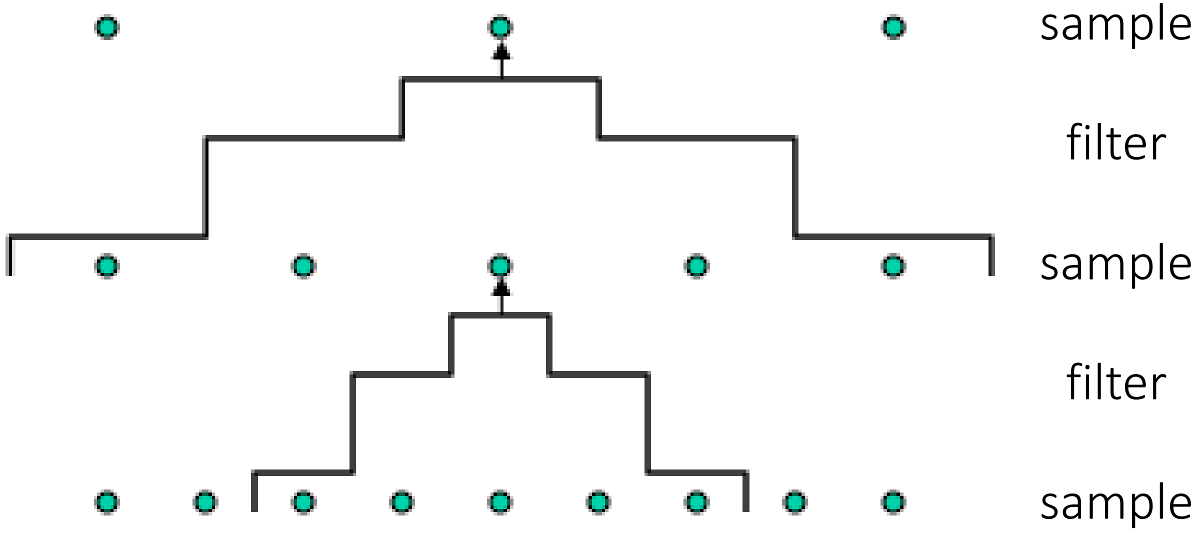
Algorithm

repeat:

filter

subsample

until min resolution reached



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

Constructing a Gaussian pyramid

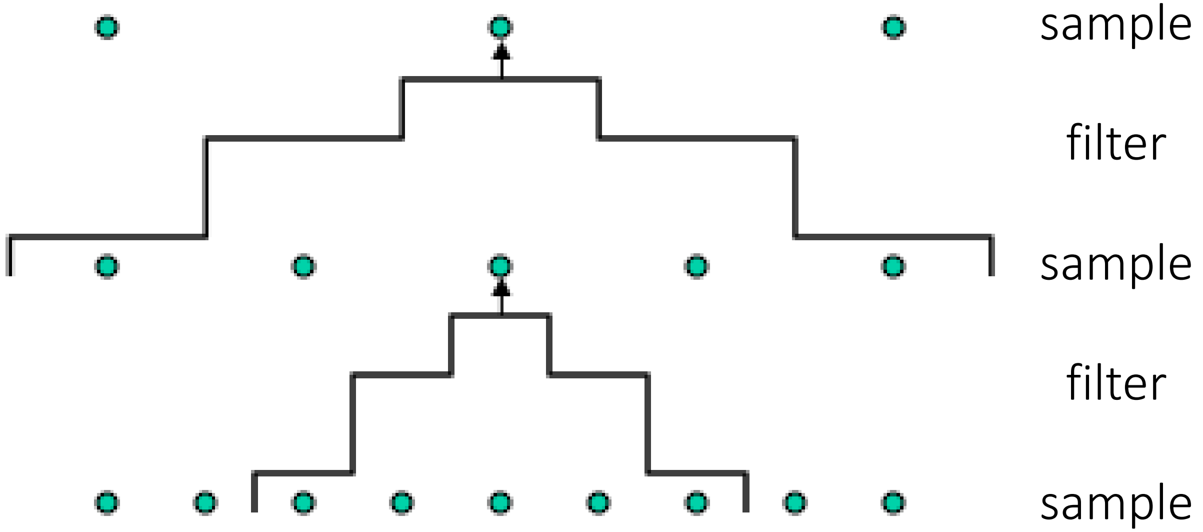
Algorithm

repeat:

filter

subsample

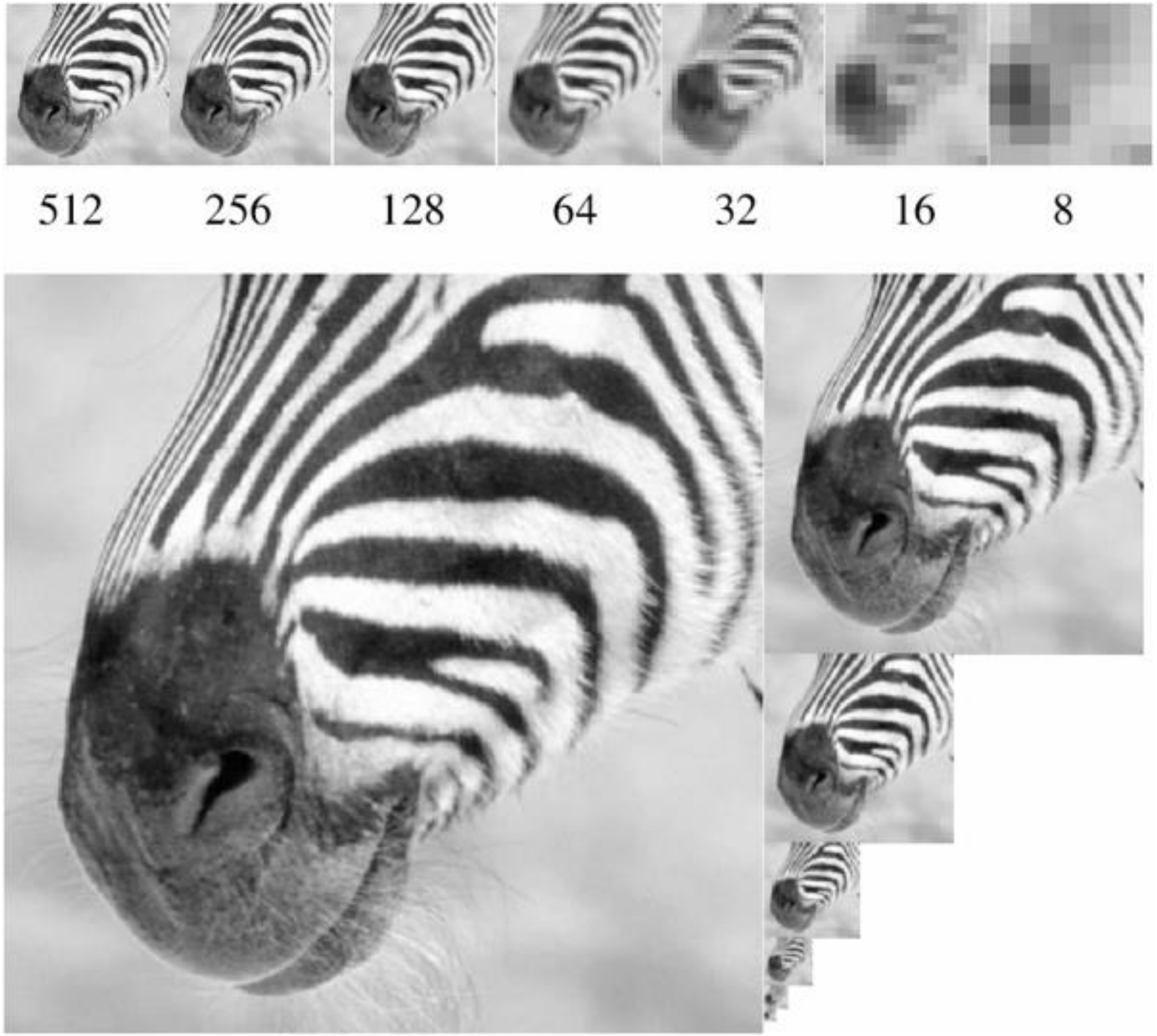
until min resolution reached



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

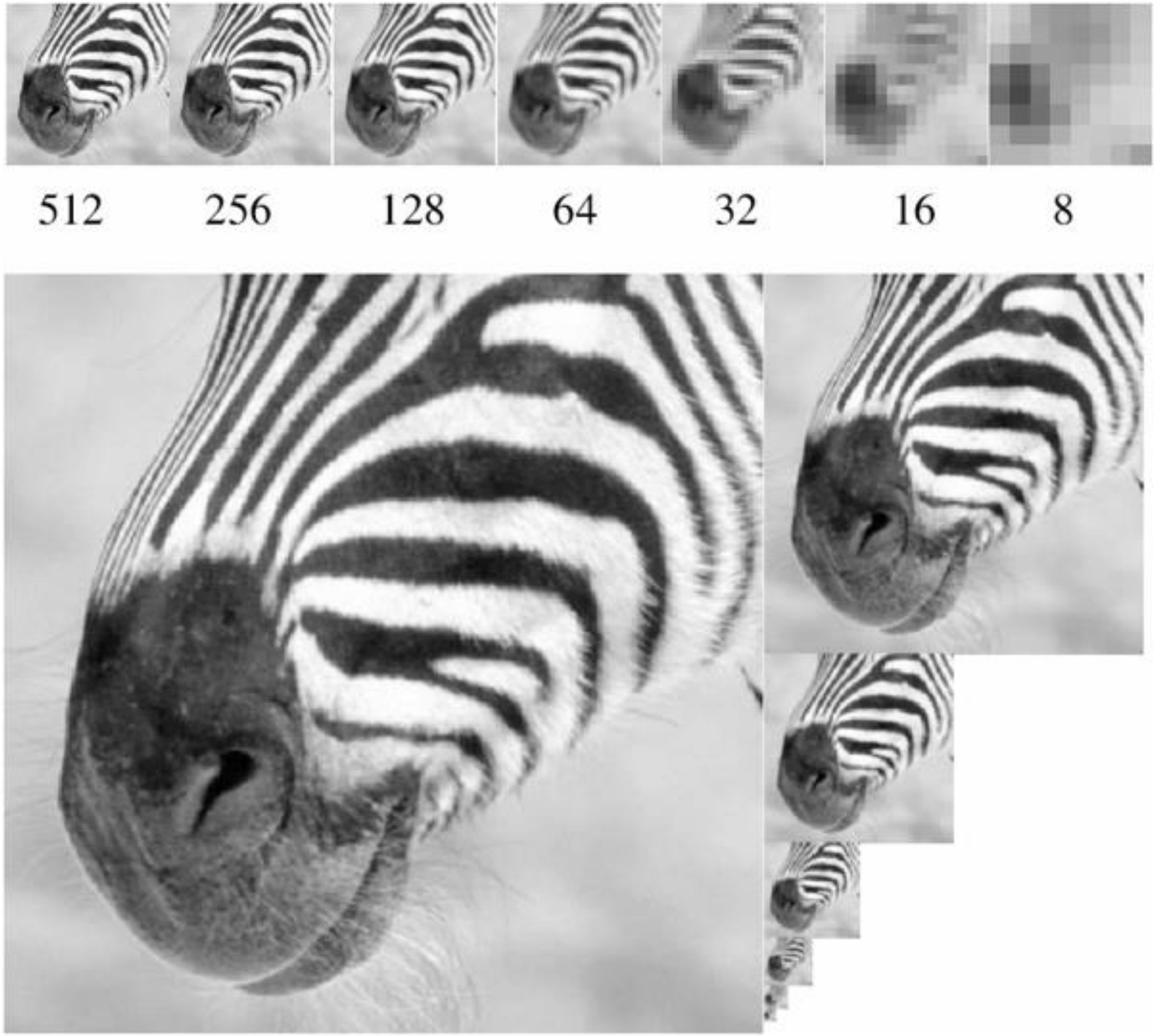
Answer: Just 4/3 times the size of the original image! (How did I come up with this number?)

Some properties of the Gaussian pyramid



What happens to the details of the image?

Some properties of the Gaussian pyramid

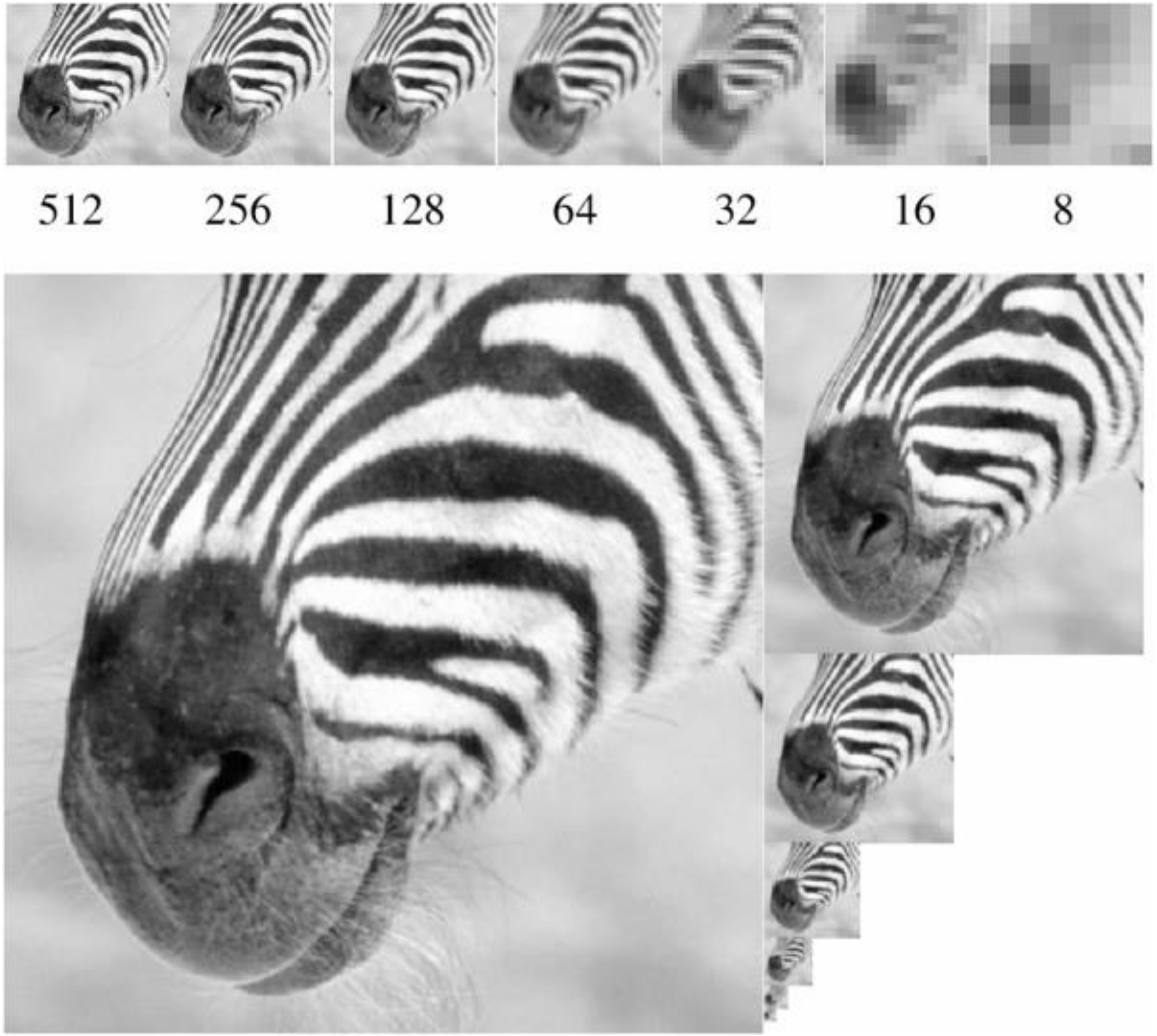


What happens to the details of the image?

- 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?

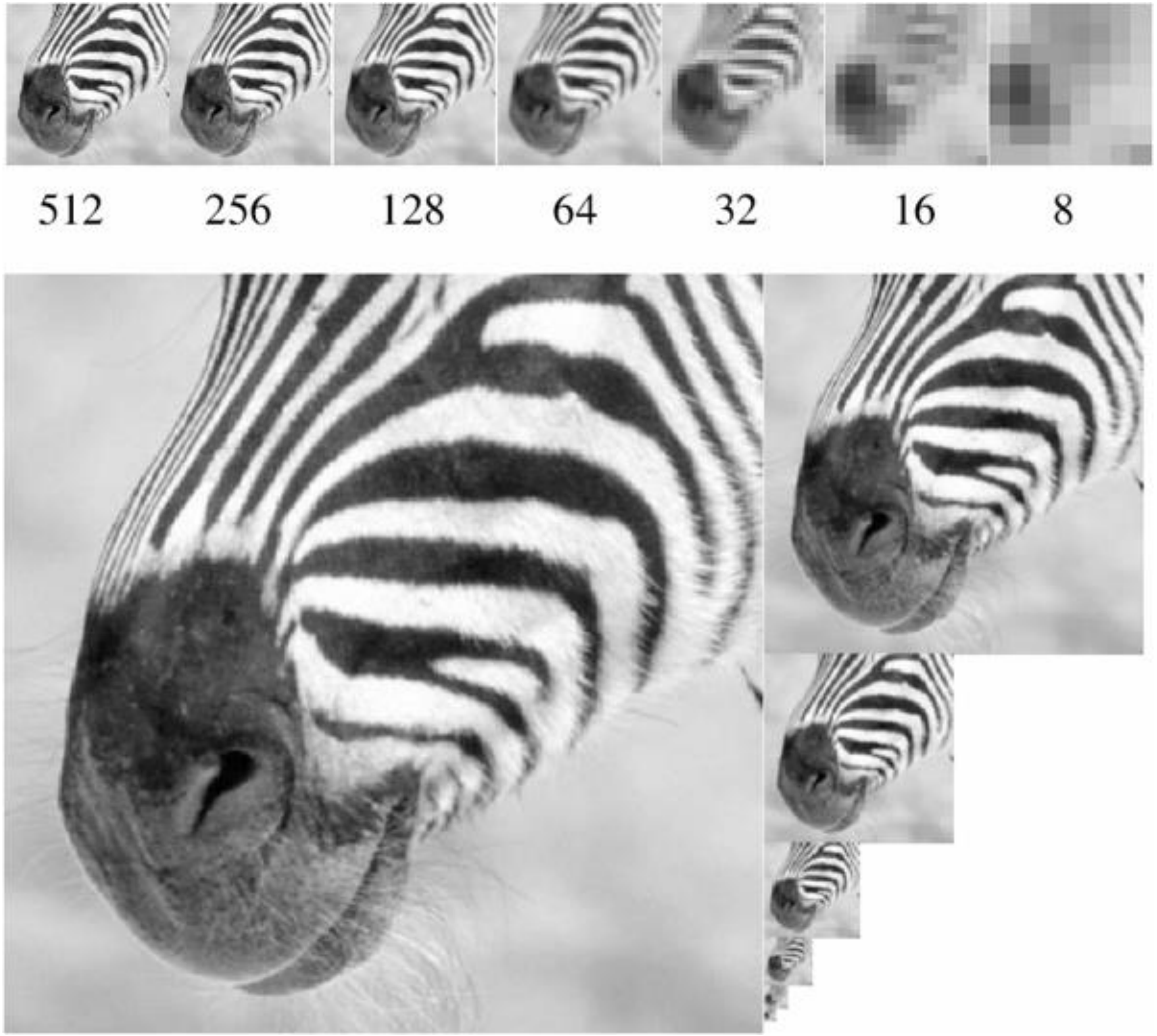
- They get smoothed out as we move to higher levels.

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

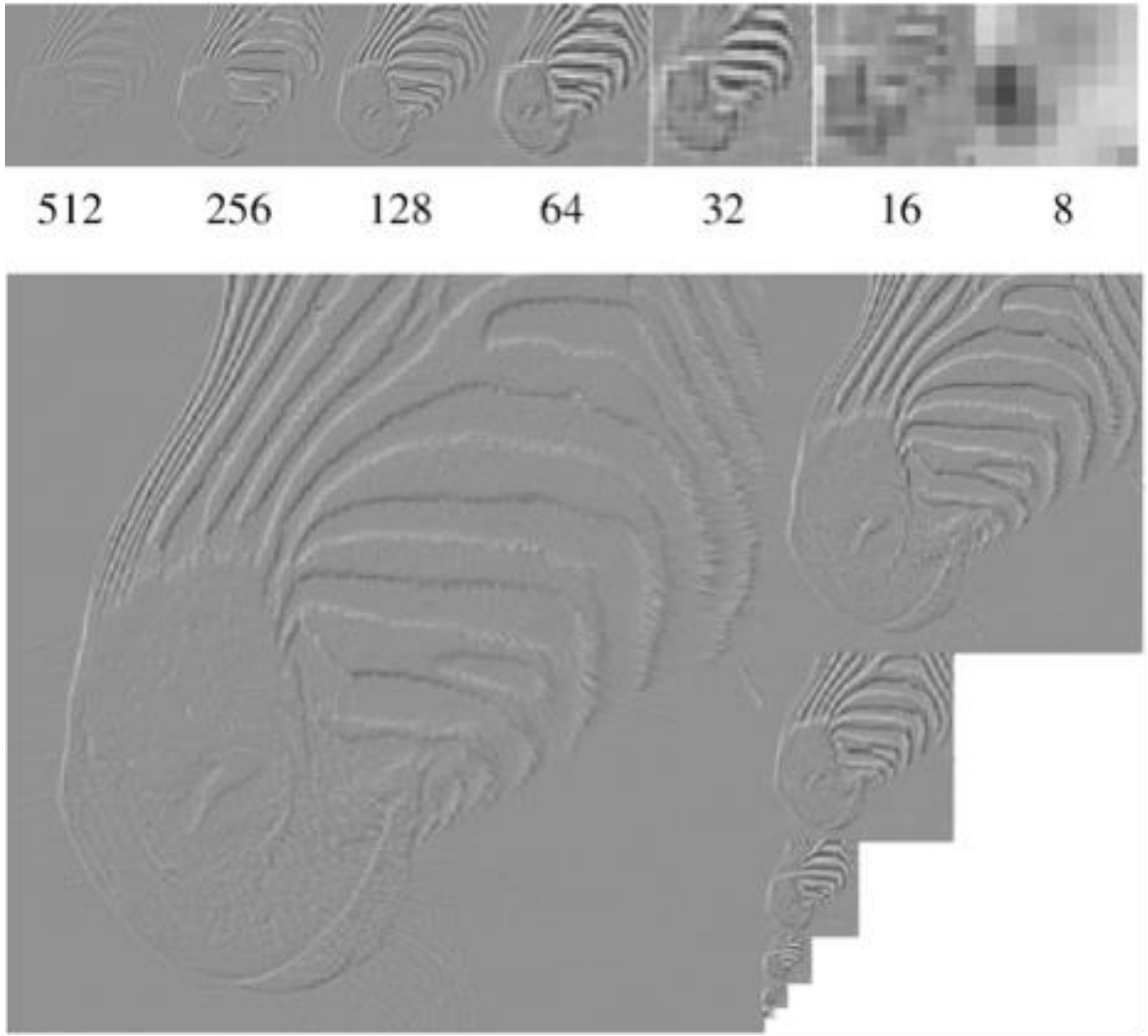
level 1 (before downsampling)

residual

Can we make a pyramid that is lossless?

Laplacian image pyramid

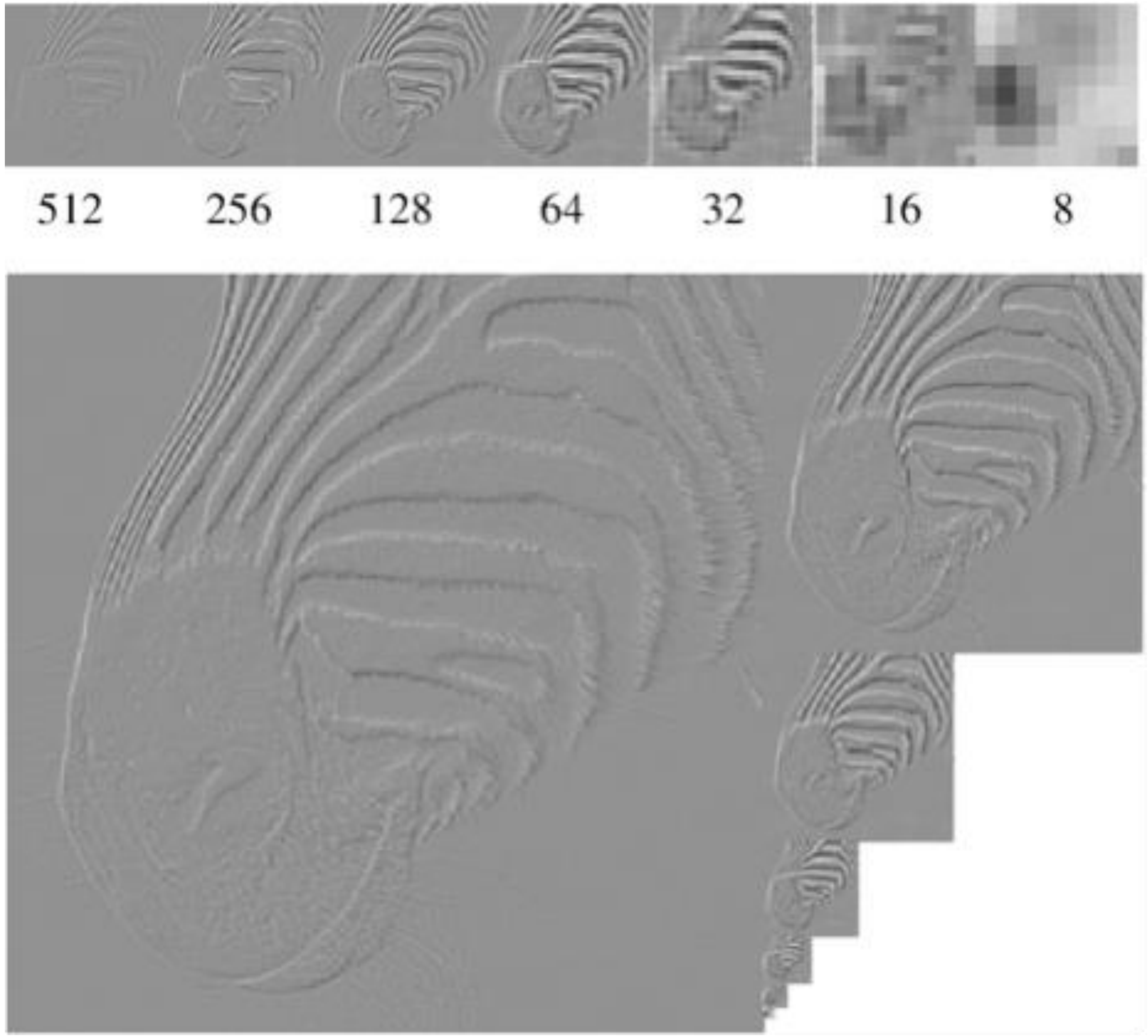
Laplacian image pyramid



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

=

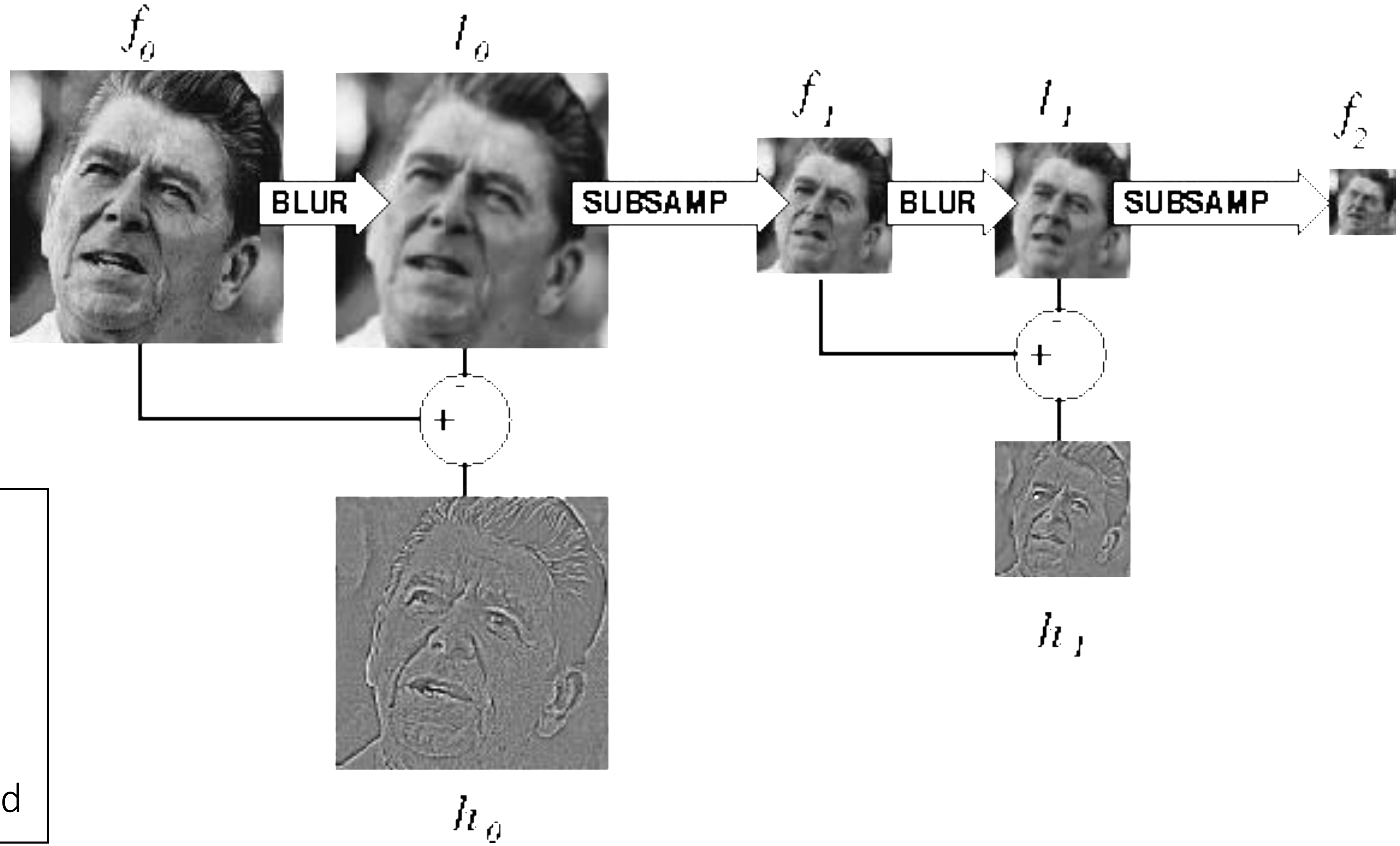
level 1 (upsampled)

+

residual

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

Constructing a Laplacian pyramid



Algorithm

repeat:

filter

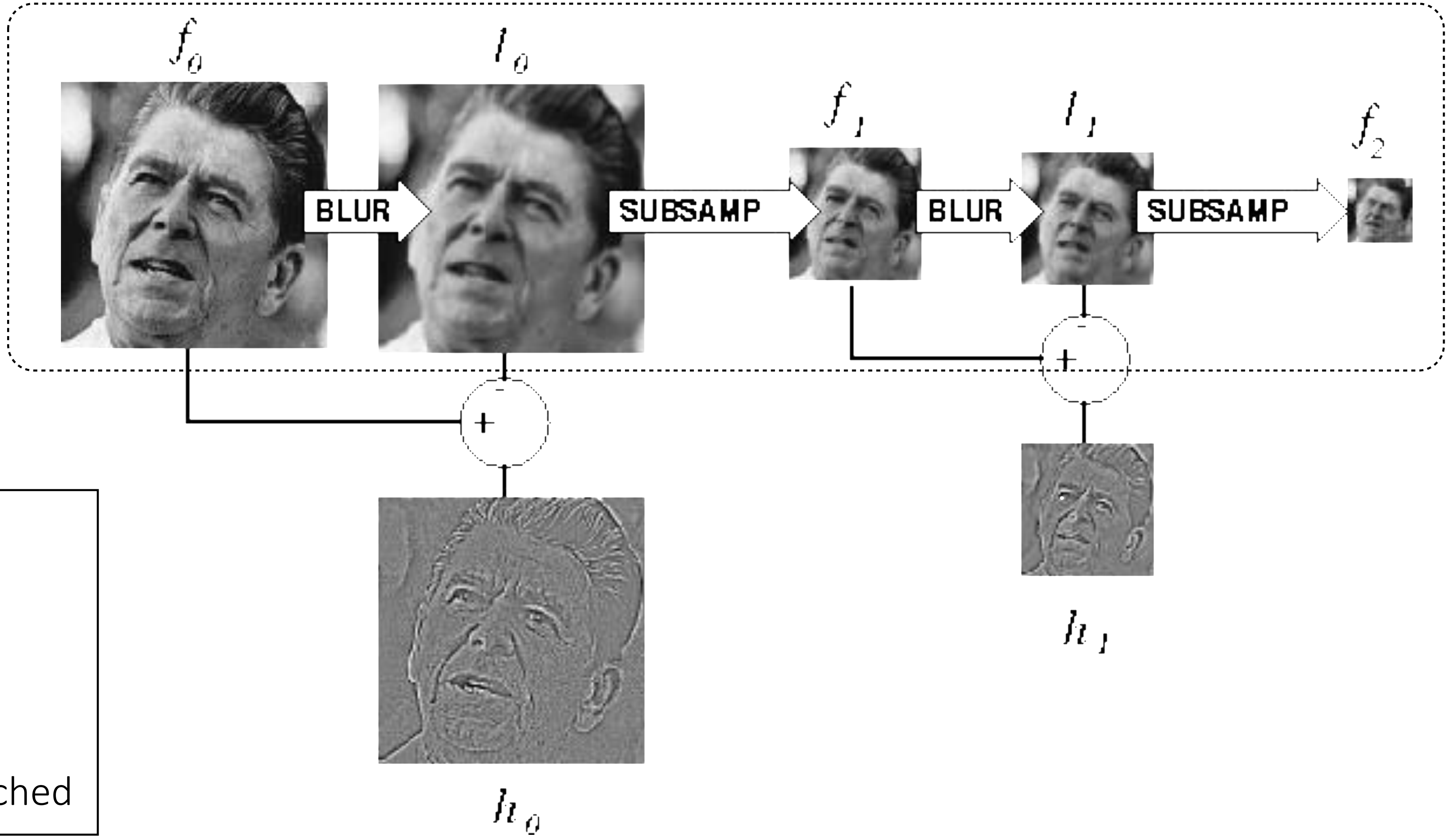
compute residual

subsample

until min resolution reached

Constructing a Laplacian pyramid

What is this part?



Algorithm

repeat:

filter

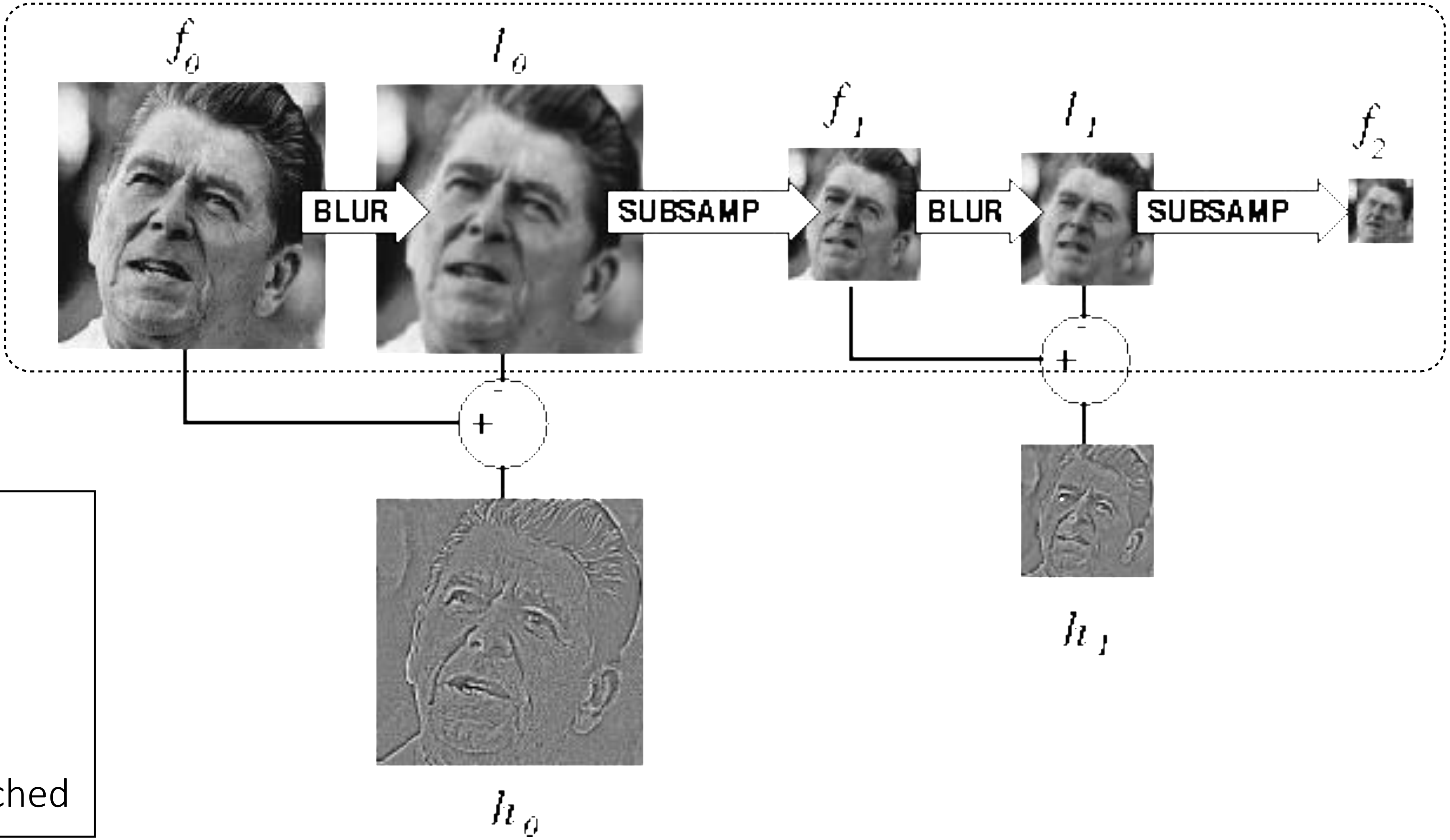
compute residual

subsample

until min resolution reached

Constructing a Laplacian pyramid

What is this part?



Algorithm

repeat:

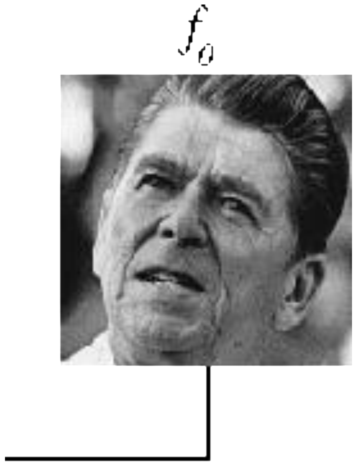
filter

compute residual

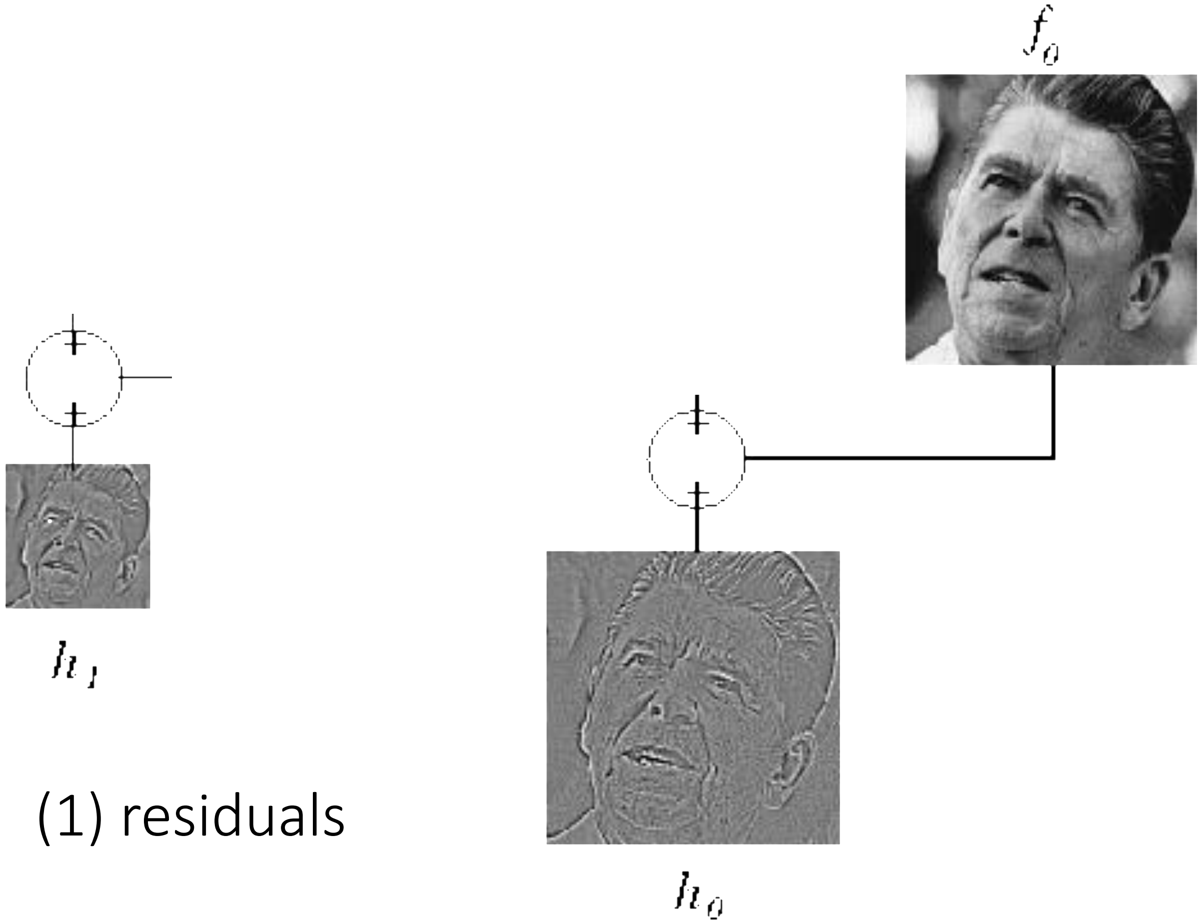
subsample

until min resolution reached

What do we need to construct the original image?



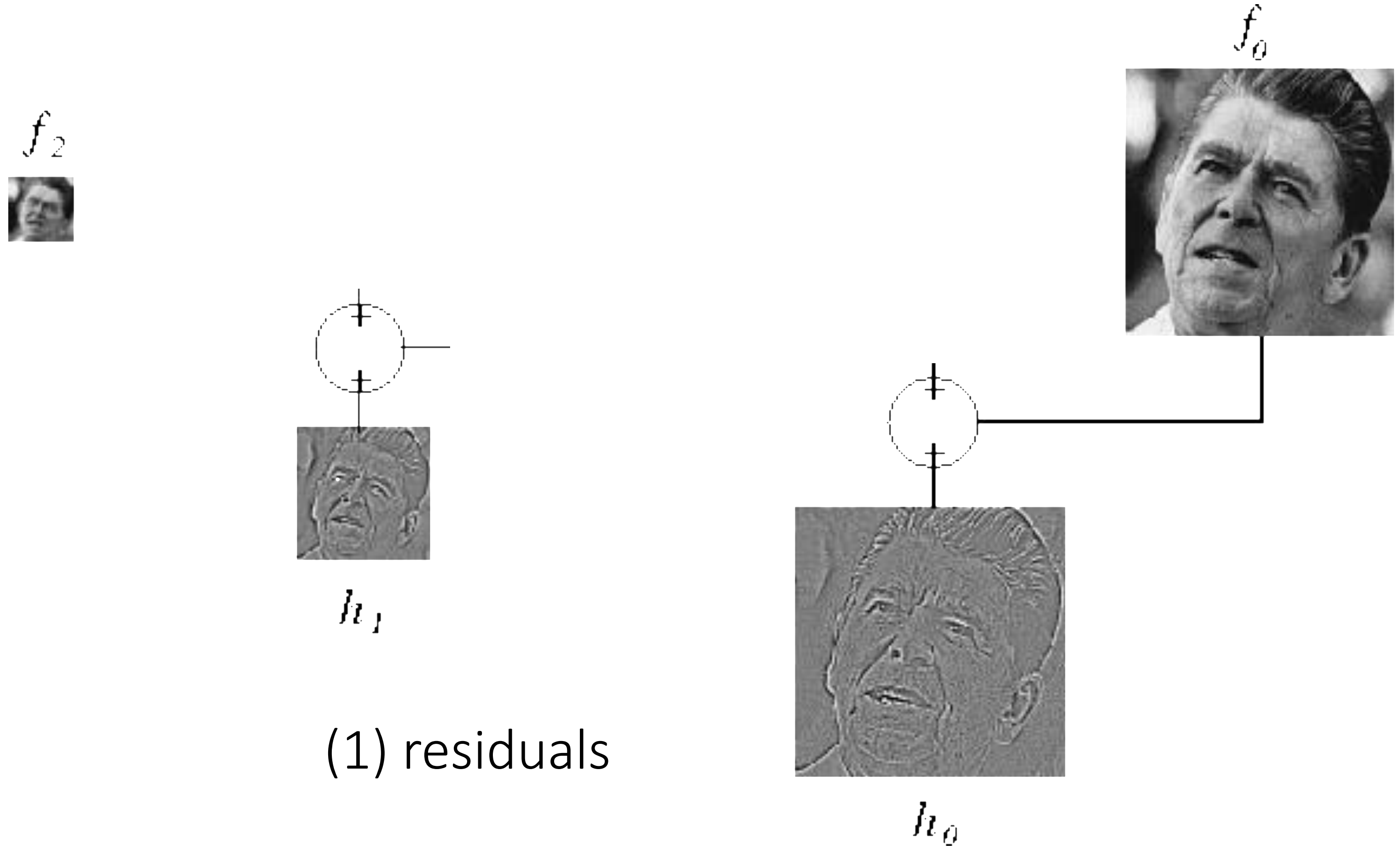
What do we need to construct the original image?



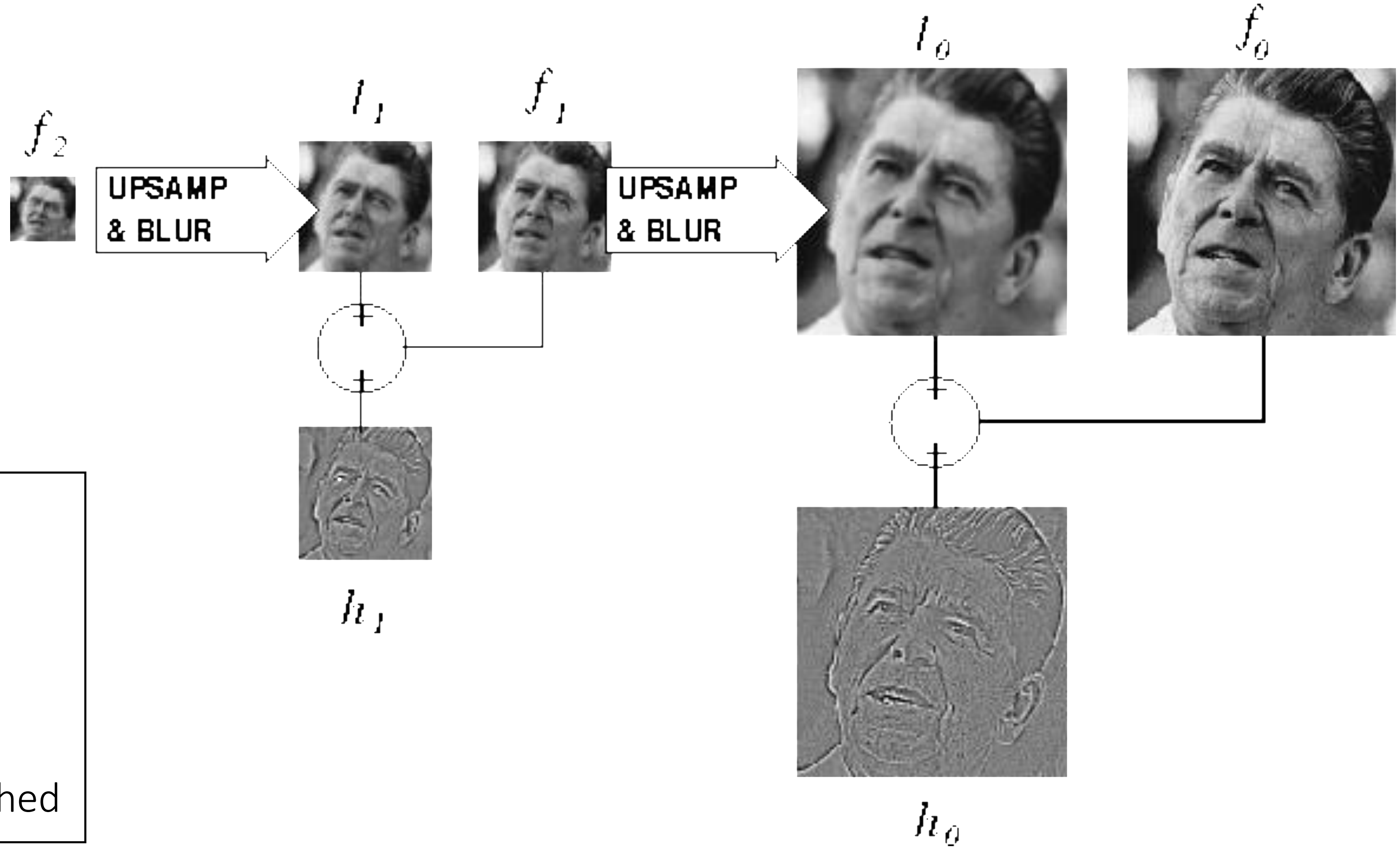
(1) residuals

What do we need to construct the original image?

(2) smallest image



Reconstructing the original image



Algorithm

repeat:

upsample

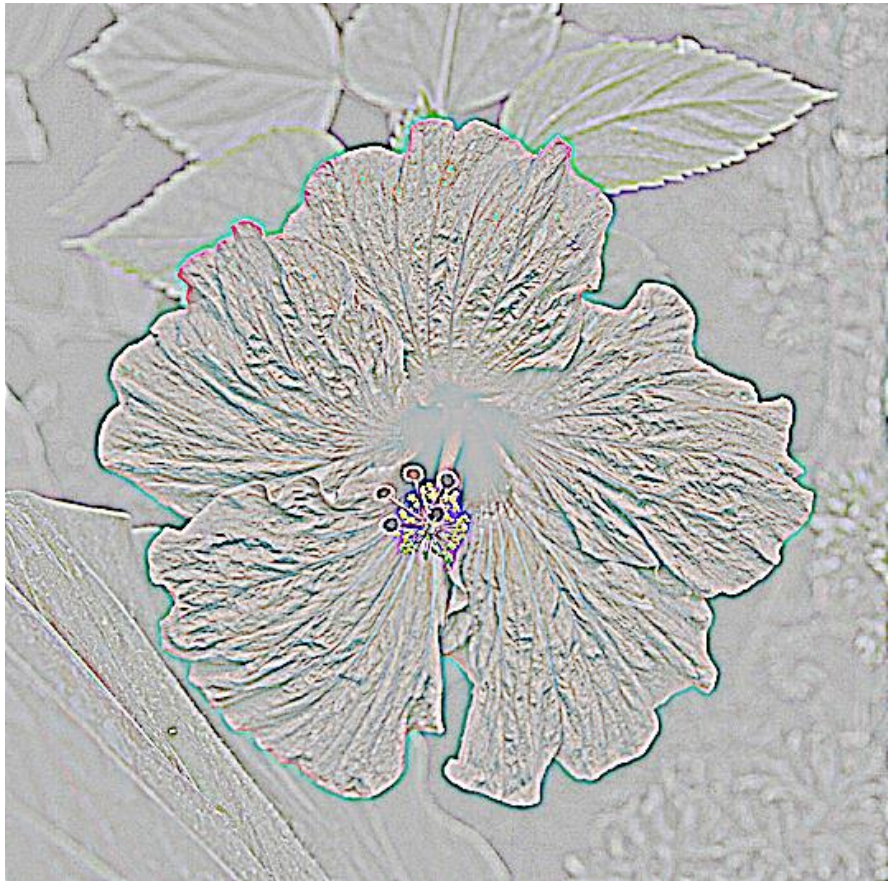
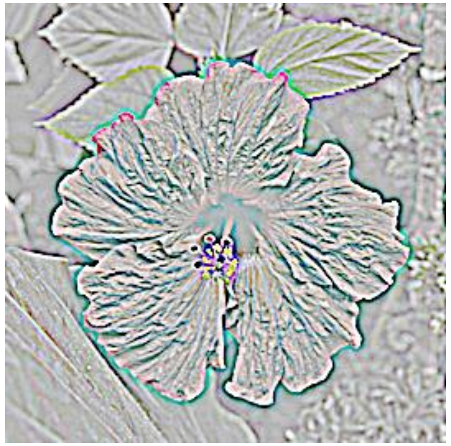
sum with residual

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?

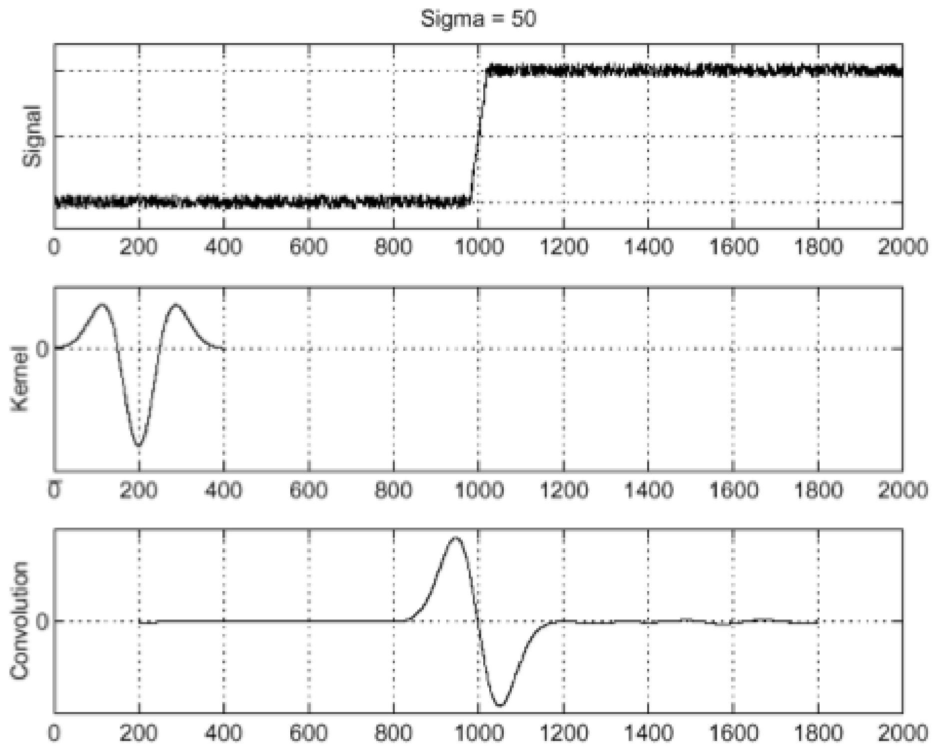
Reminder: Laplacian of Gaussian (LoG) filter

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

input

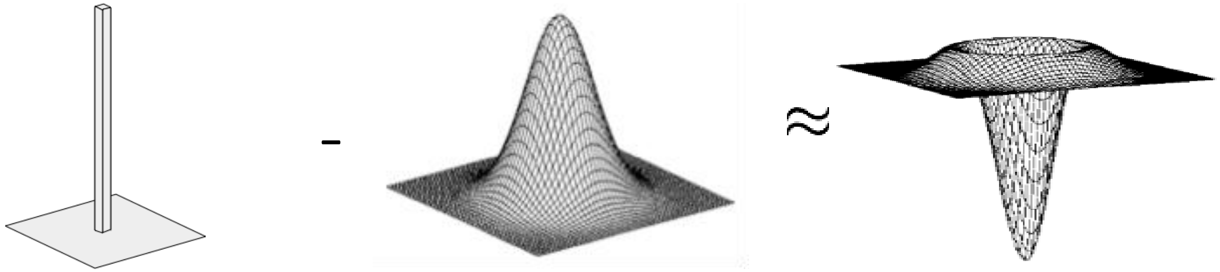
Laplacian of Gaussian

output

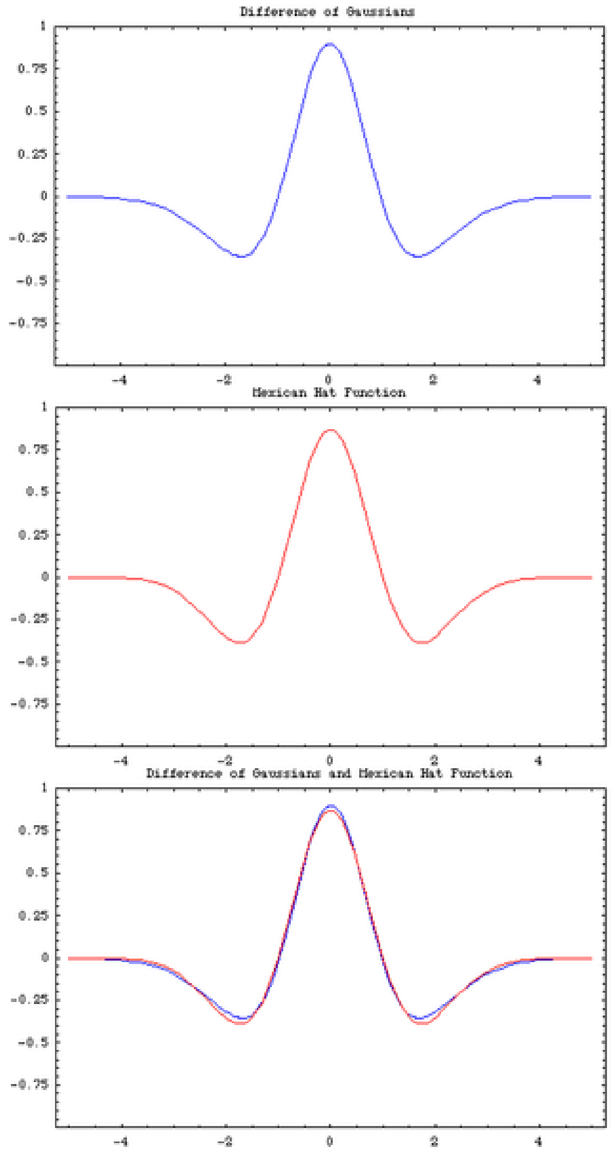


“zero crossings” at edges

Why is it called a Laplacian pyramid?

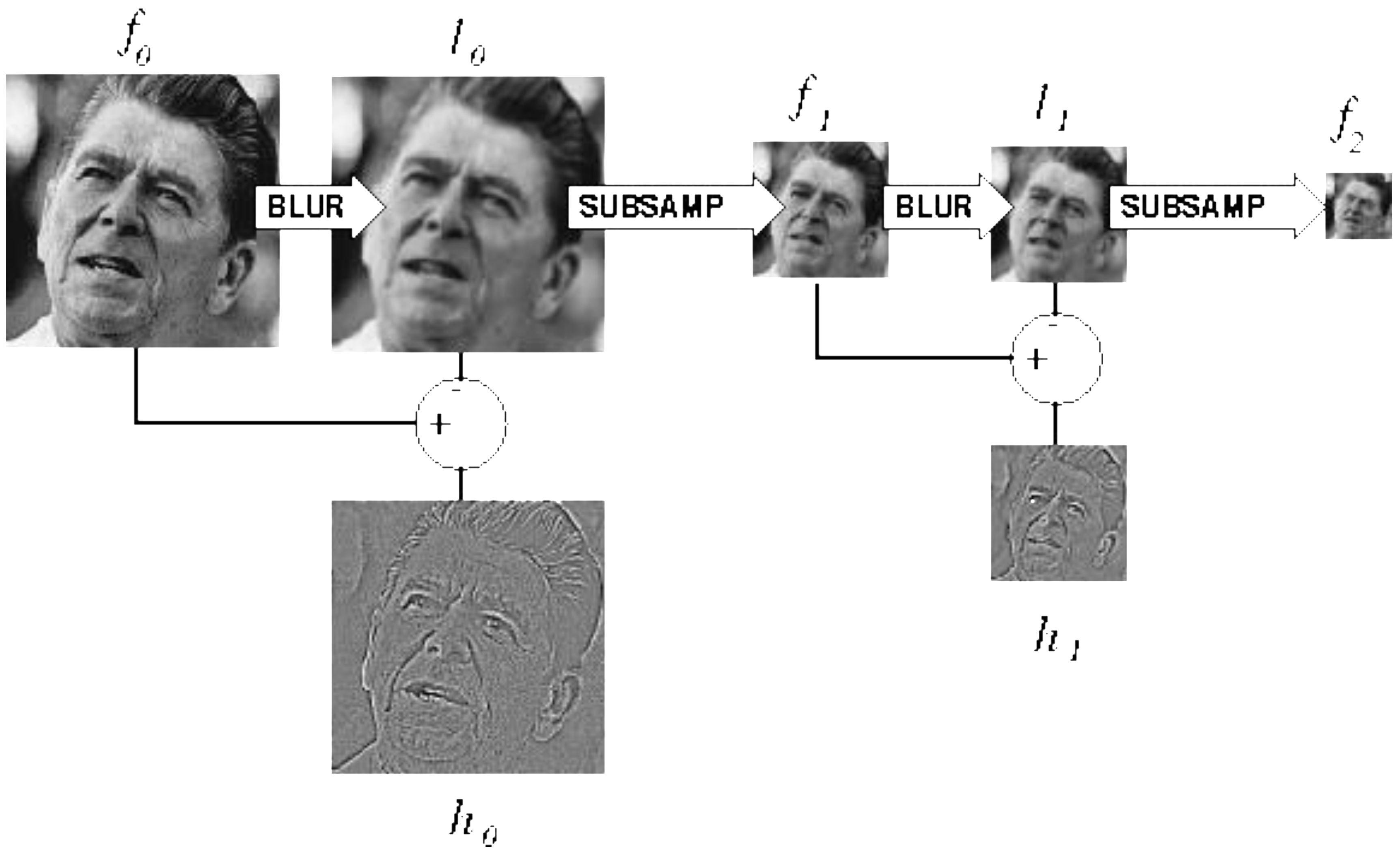


unit Gaussian Laplacian



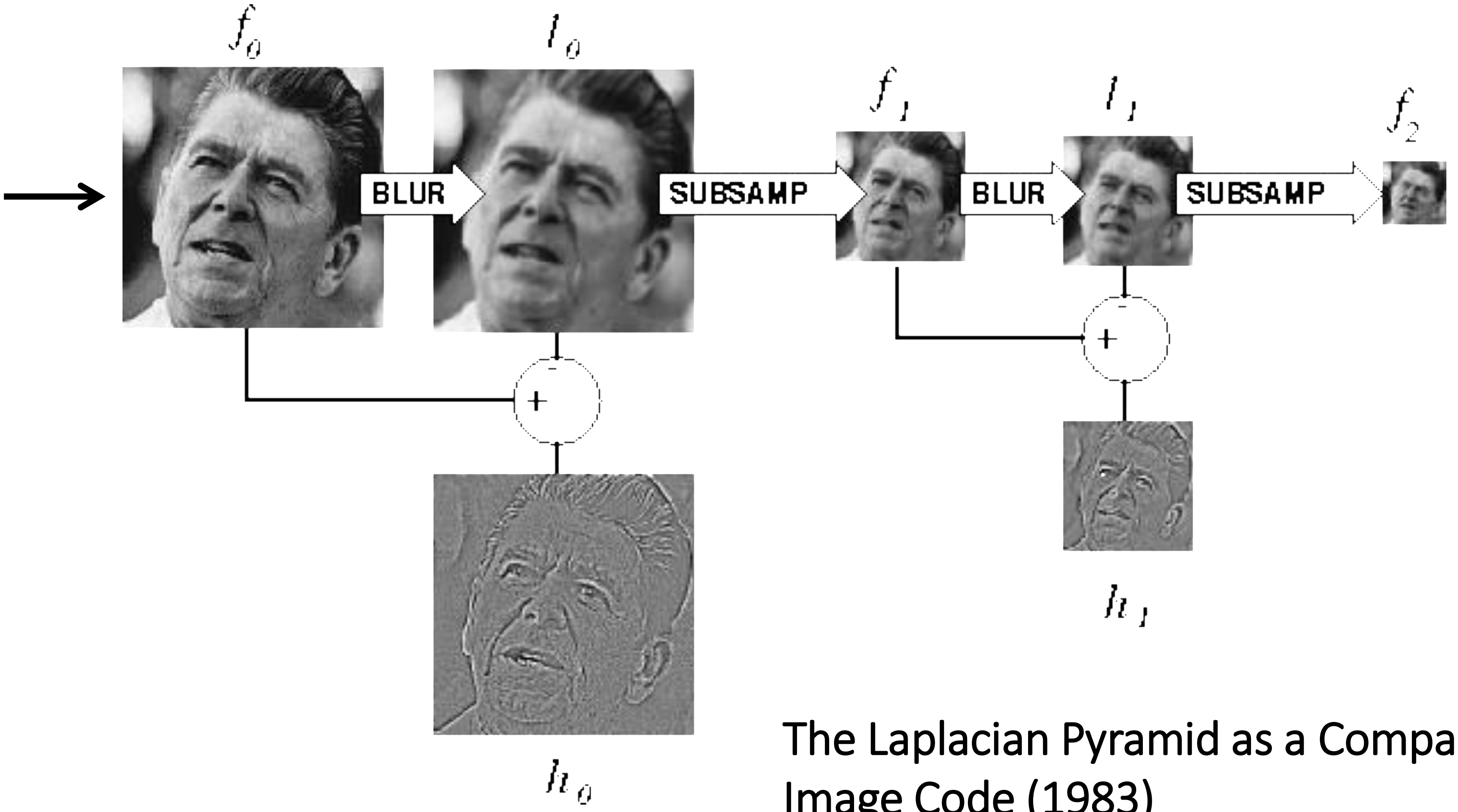
Difference of Gaussians approximates the Laplacian

Why Reagan?



Why Reagan?

Donald 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

Still used extensively

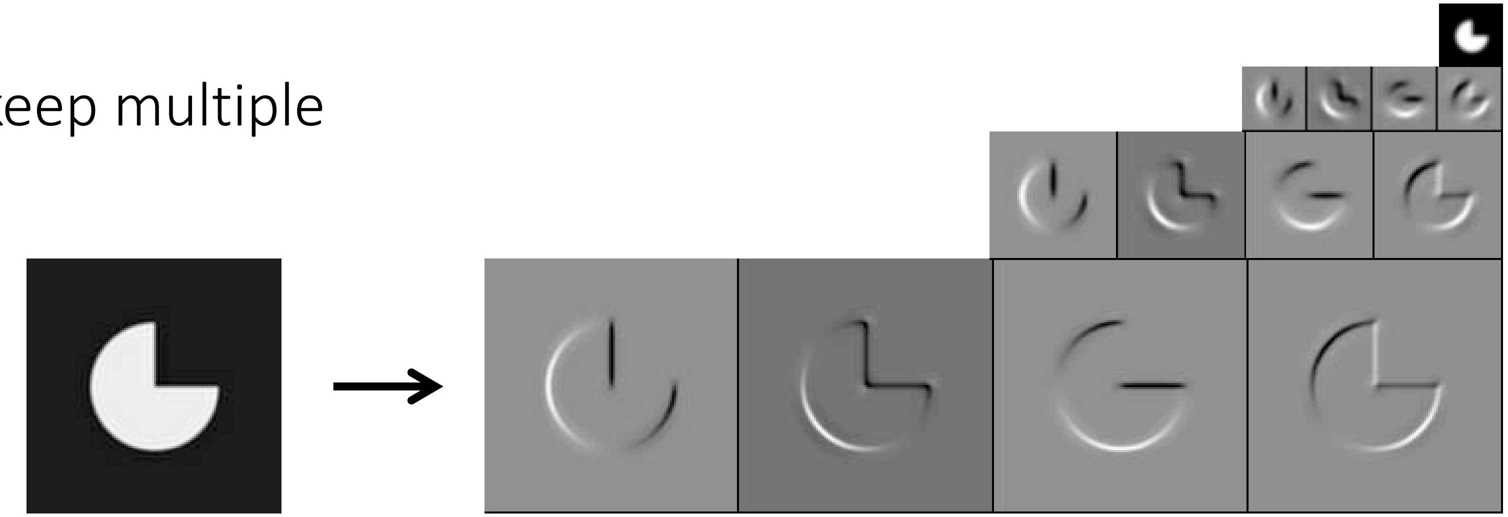
Result from:

Paris et al., “Local Laplacian Filters: Edge-aware Image Processing with a Laplacian Pyramid,” SIGGRAPH 2011 and CACM 2015

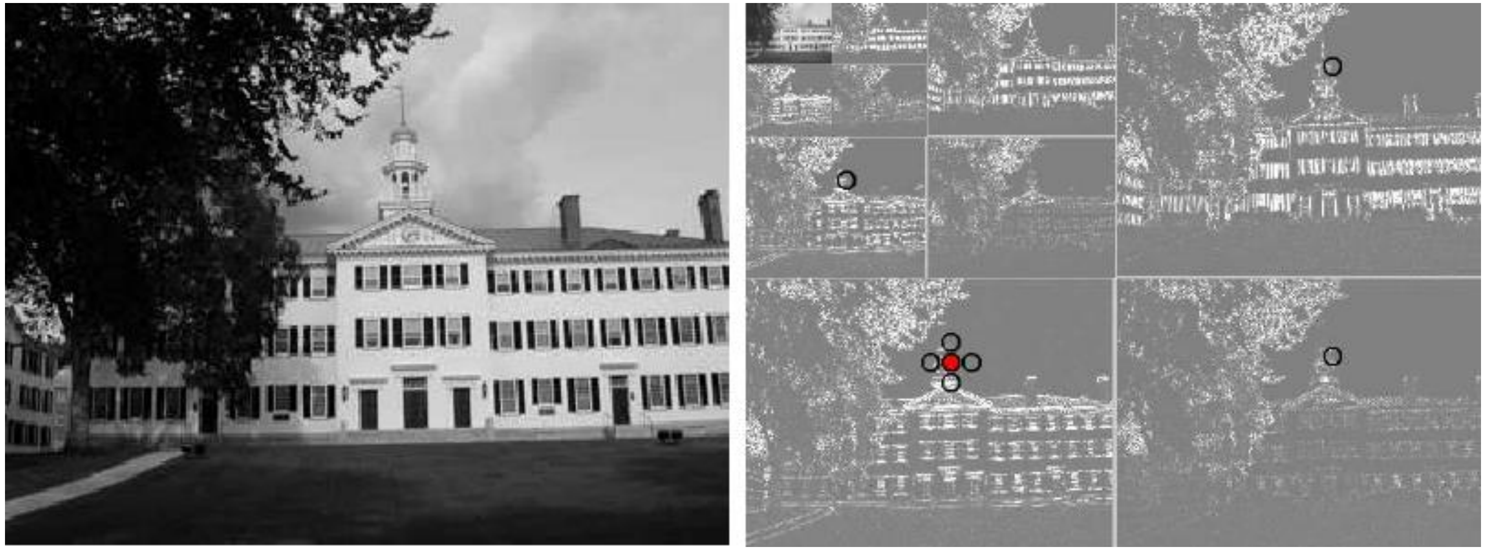
Why “local”?

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

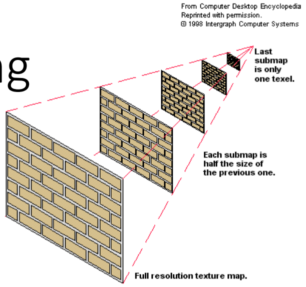
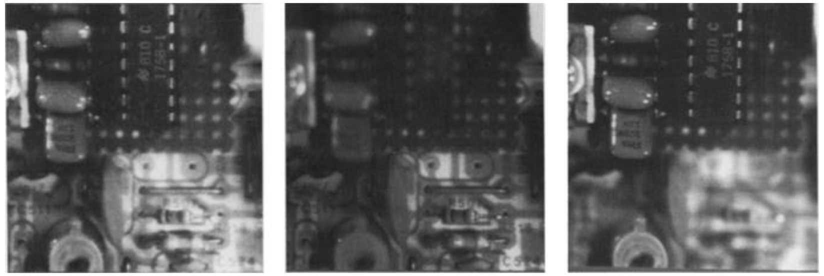
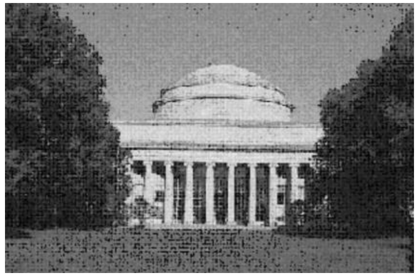


image blending

focal stack compositing



denoising

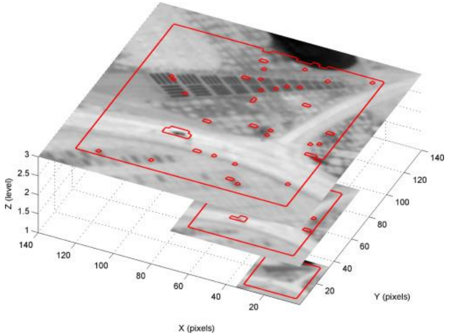


motion magnification

your homework 2

multi-scale detection

multi-scale registration



References

Basic reading:

- Szeliski textbook, Sections 3.5

Additional reading:

- Burt and Adelson, “The Laplacian Pyramid as a Compact Image Code,” IEEE ToC 1983.

  the original Laplacian pyramid paper
- Paris et al., “Local Laplacian Filters: Edge-aware Image Processing with a Laplacian Pyramid,” SIGGRAPH 2011 and CACM 2015,

  great paper on modern uses of the Laplacian pyramid, see also the project website
  https://people.csail.mit.edu/sparis/publi/2011/siggraph/