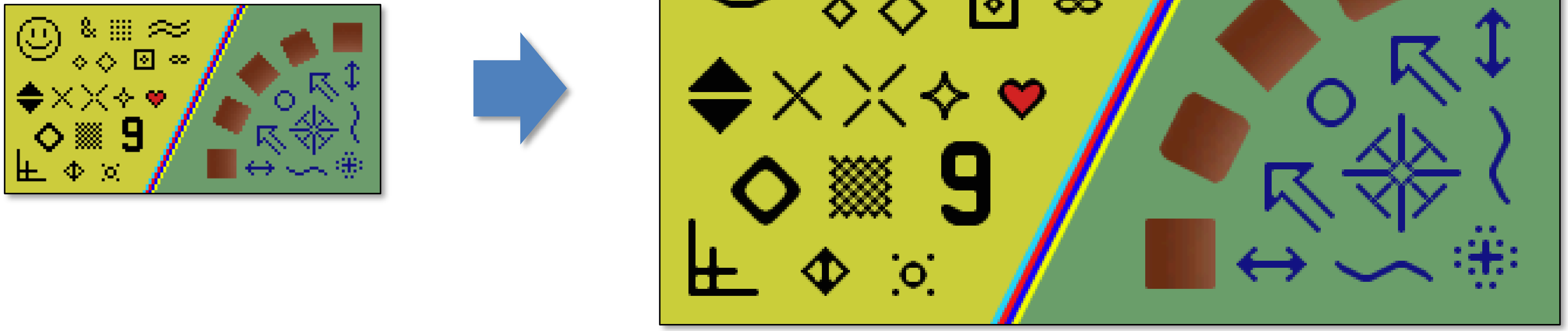
CS5670: Computer Vision

Image Resampling & Interpolation

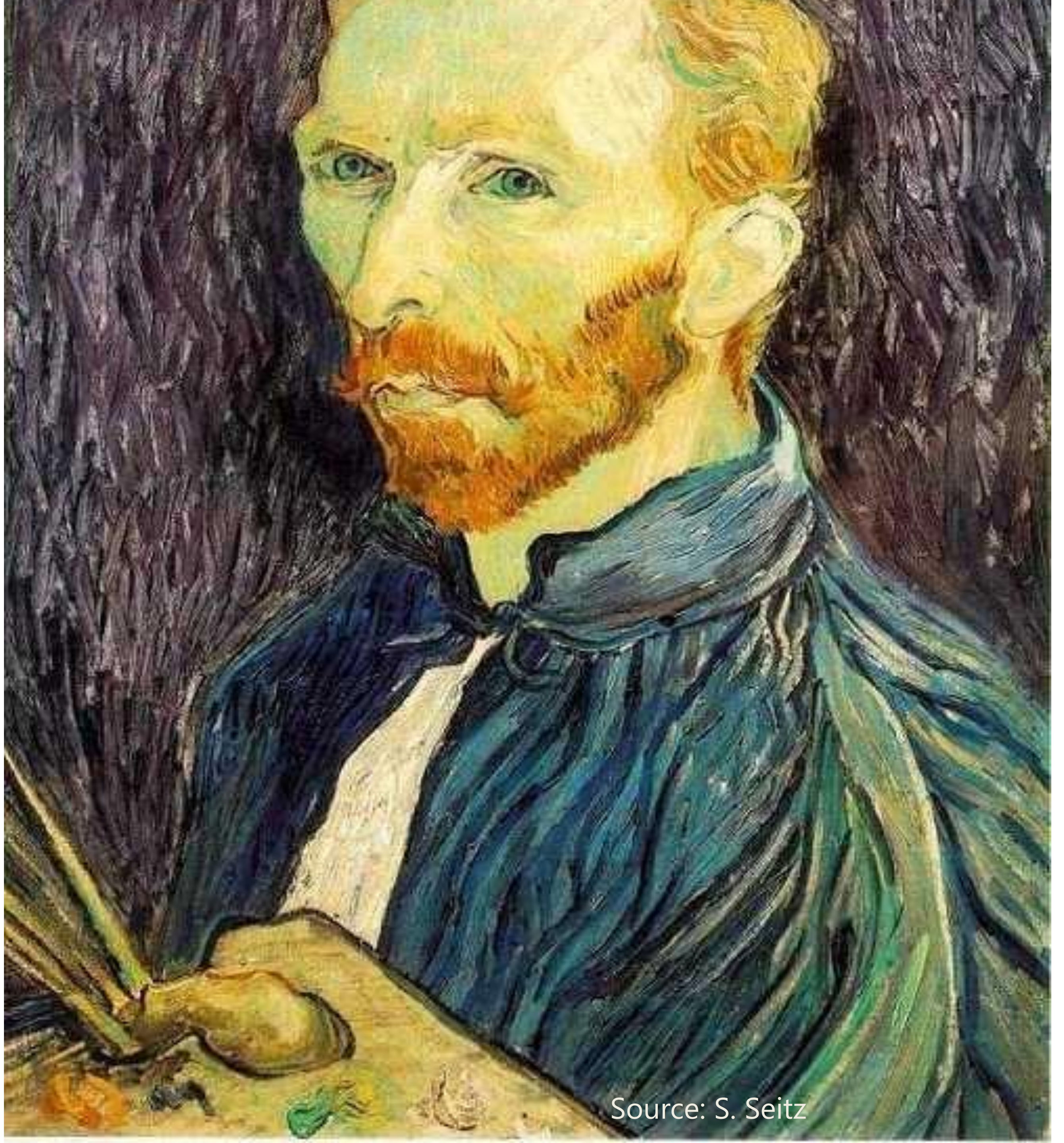


Announcements

- Project 1 released, due Friday, February 11 by 11:59pm on GitHub Classroom
    - Project to be done solo (teams of one)
    - Artifact due Monday, Feb 14 by 11:59pm
- First quiz next week, format TBA

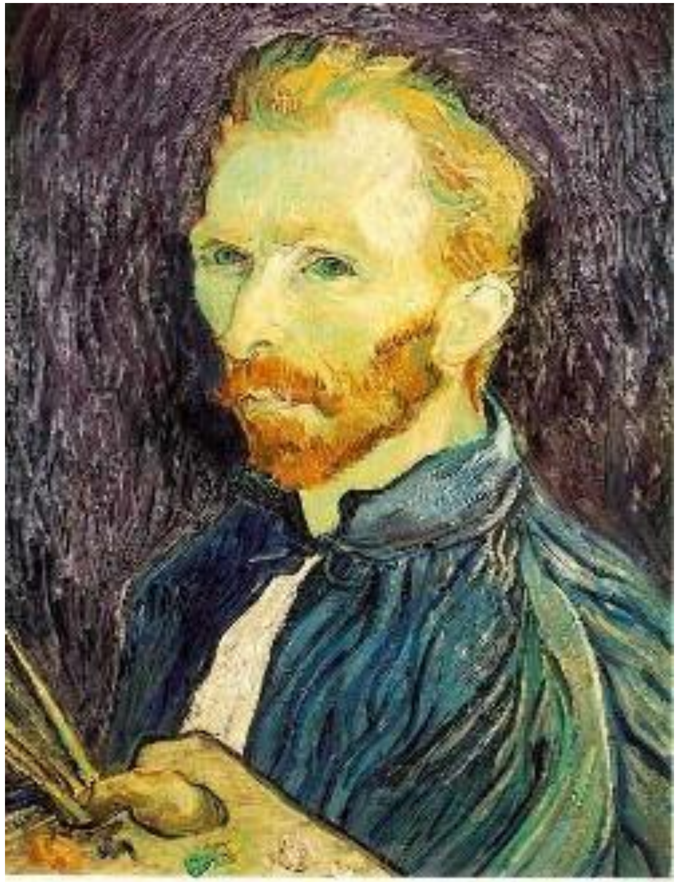
Image scaling

This image is too big to fit on the screen. How can we generate a half-sized version?



Source: S. Seitz

Image sub-sampling



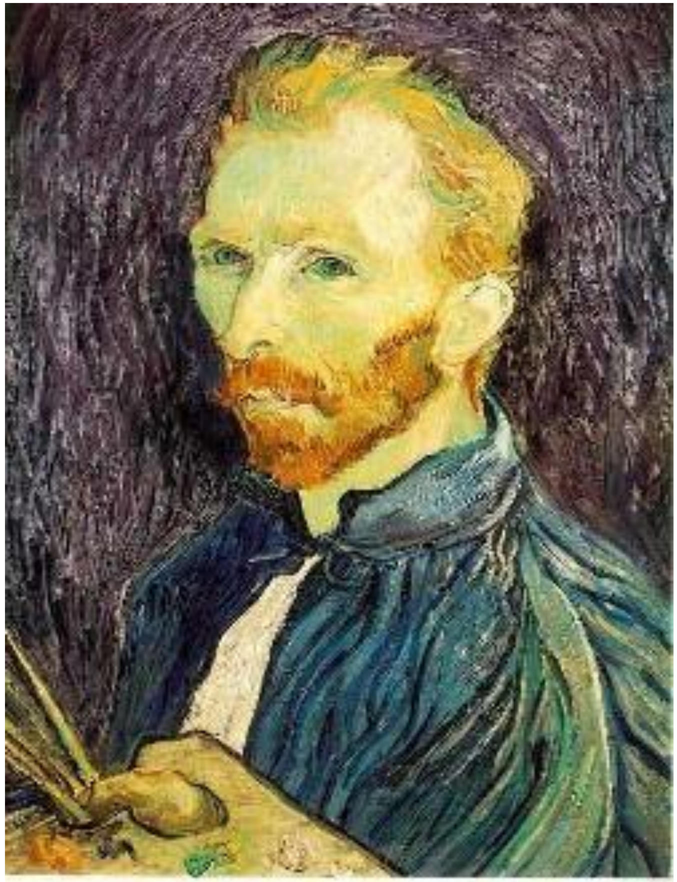
1/4

1/8

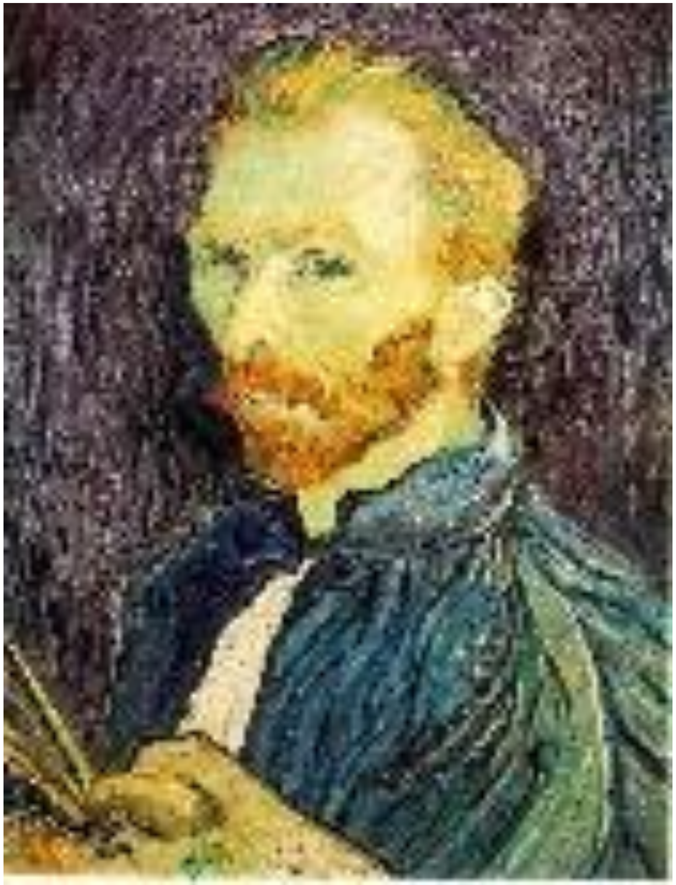
Throw away every other row and column to create a 1/2 size image
- called *image sub-sampling*

Source: S. Seitz

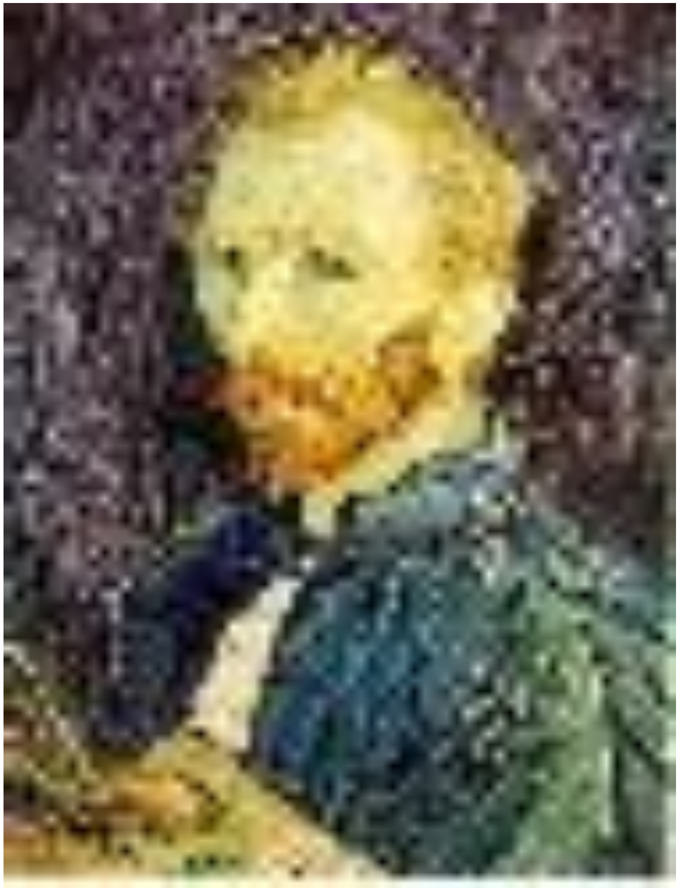
Image sub-sampling



1/2



1/4 (2x zoom)

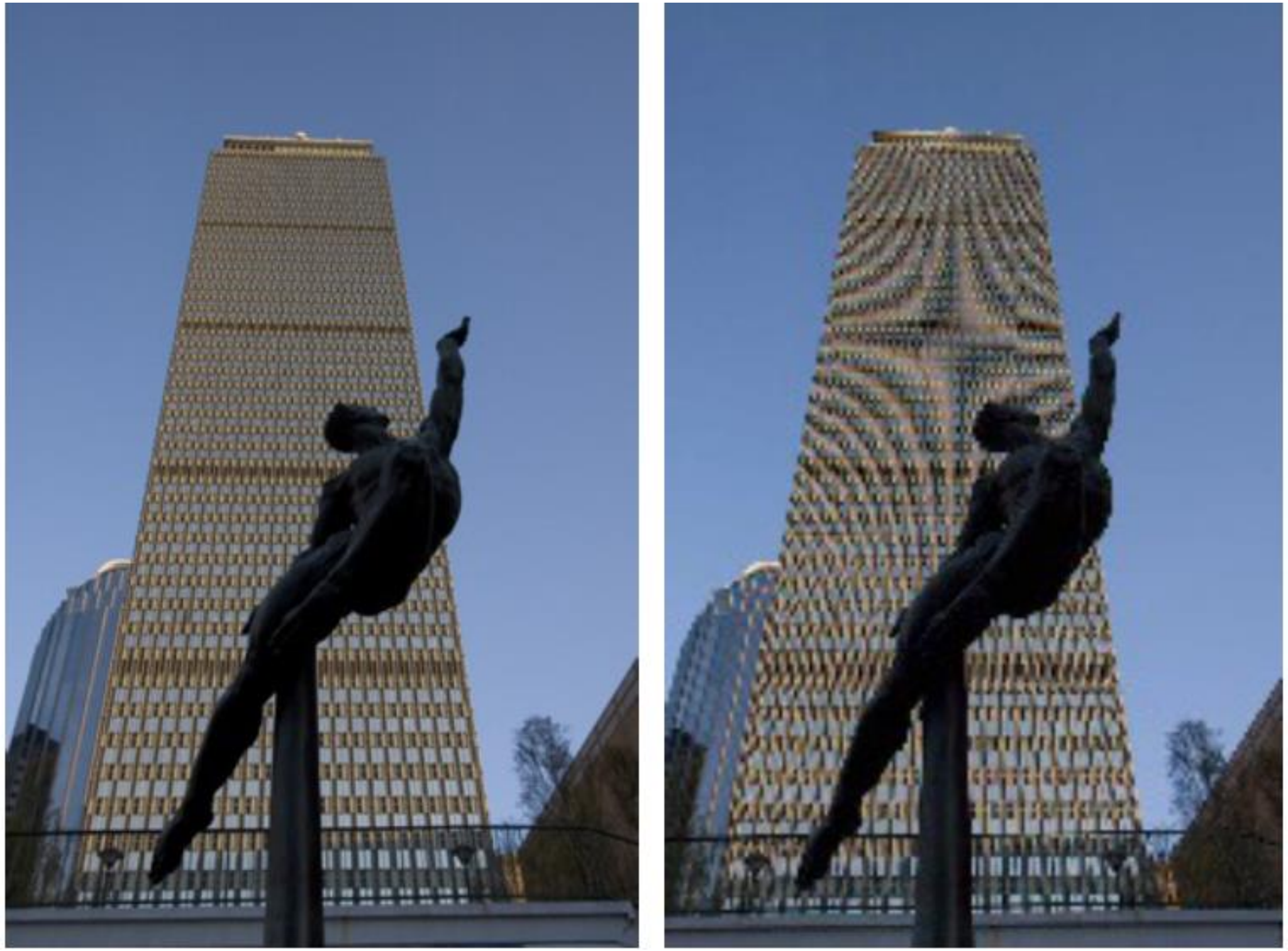


1/8 (4x zoom)

Why does this look so crufty?

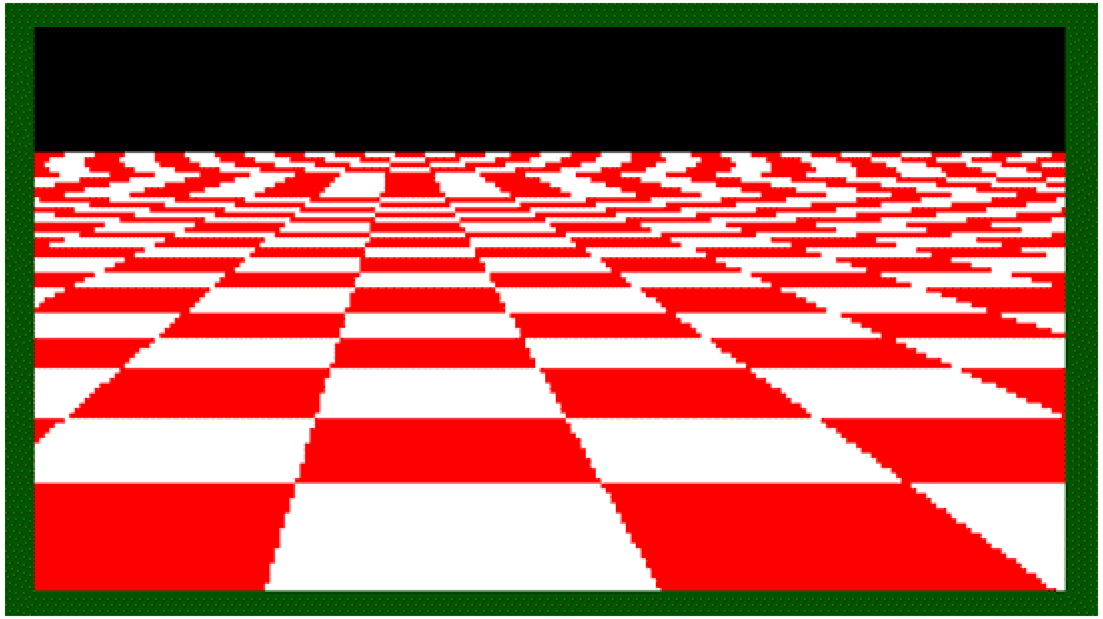
Source: S. Seitz

Image sub-sampling – another example



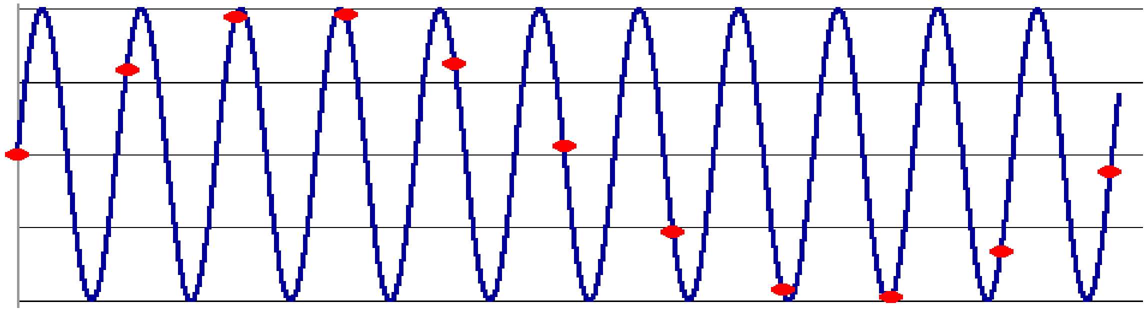
Source: F. Durand

Even worse for synthetic images



Source: L. Zhang

Aliasing



- Occurs when your sampling rate is not high enough to capture the amount of detail in your image
- Can give you the wrong signal/image—an *alias*

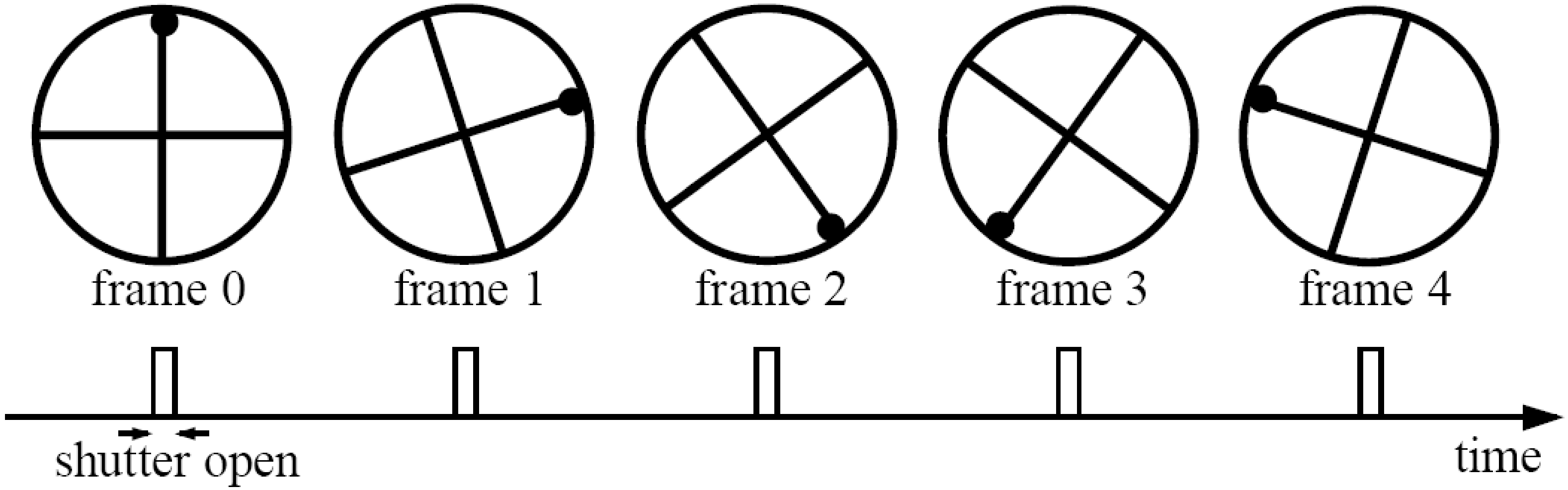
- To do sampling right, need to understand the structure of your signal/image
- Enter Monsieur Fourier…
  - "But what is the Fourier Transform? A visual introduction." https://www.youtube.com/watch?v=spUNpyF58BY
- To avoid aliasing:
  - sampling rate ≥ 2 * max frequency in the image
    - said another way: ≥ two samples per cycle
  - This minimum sampling rate is called the **Nyquist rate**

Source: L. Zhang

Wagon-wheel effect

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)

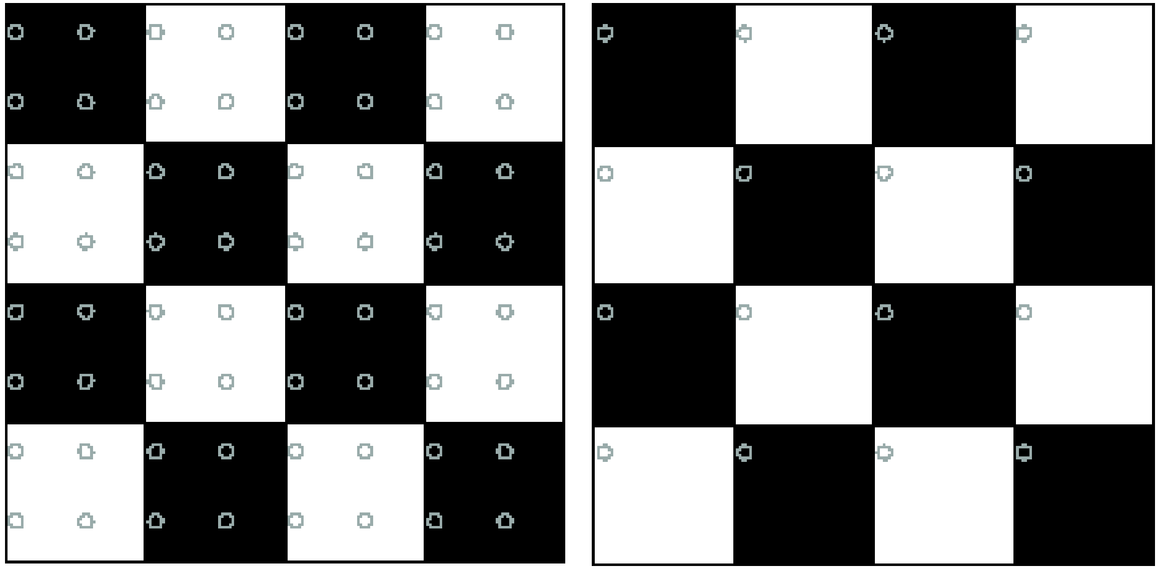
(See http://www.michaelbach.de/ot/mot-wagonWheel/index.html)

Source: L. Zhang

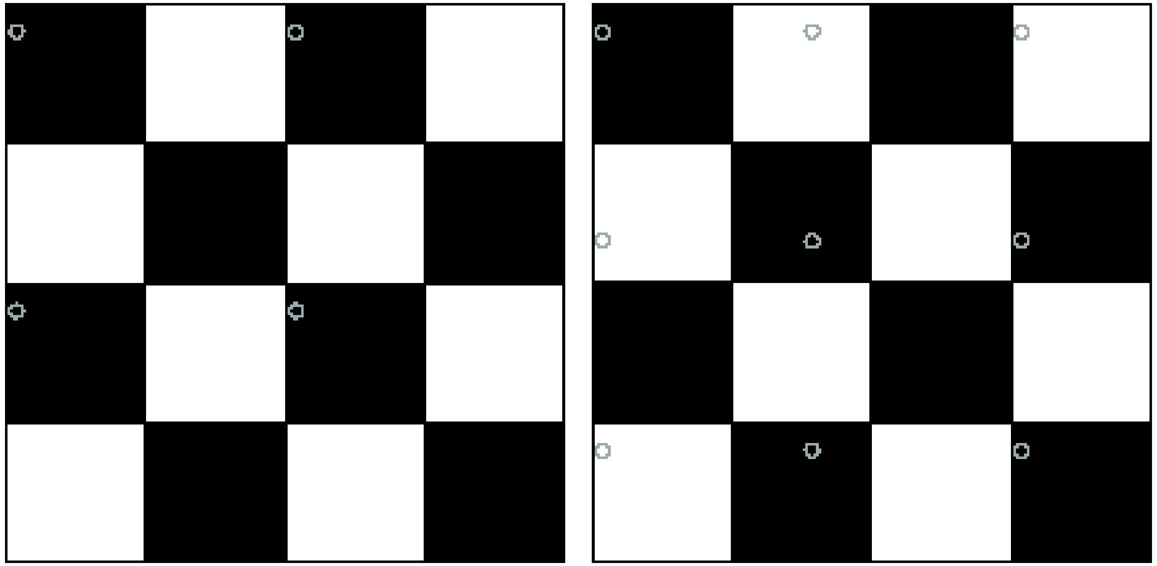
Wagon-wheel effect

https://en.wikipedia.org/wiki/Wagon-wheel_effect

Nyquist limit – 2D example



Good sampling



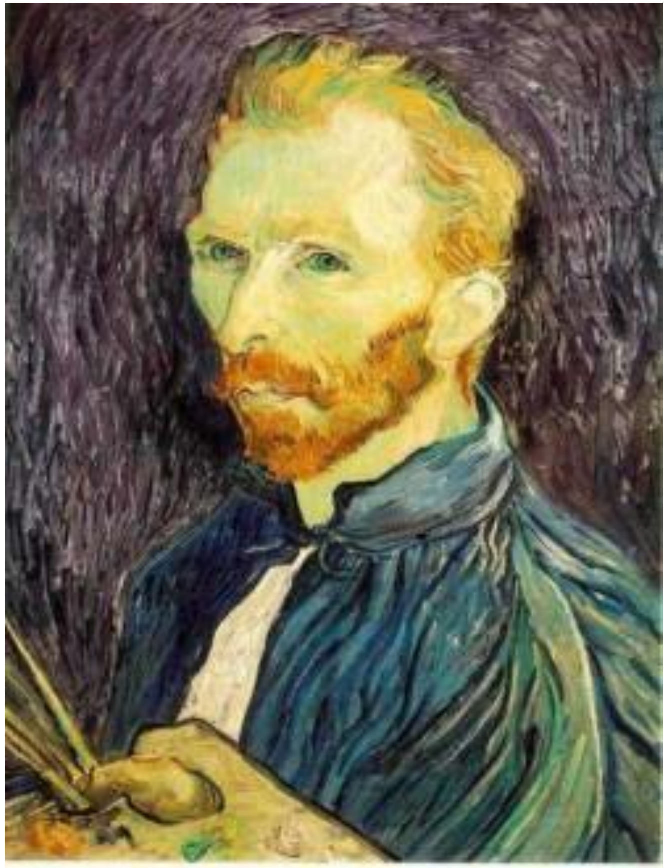
Bad sampling

Aliasing

- When downsampling by a factor of two
  - Original image has frequencies that are too high

- How can we fix this?

Gaussian pre-filtering



Gaussian 1/2

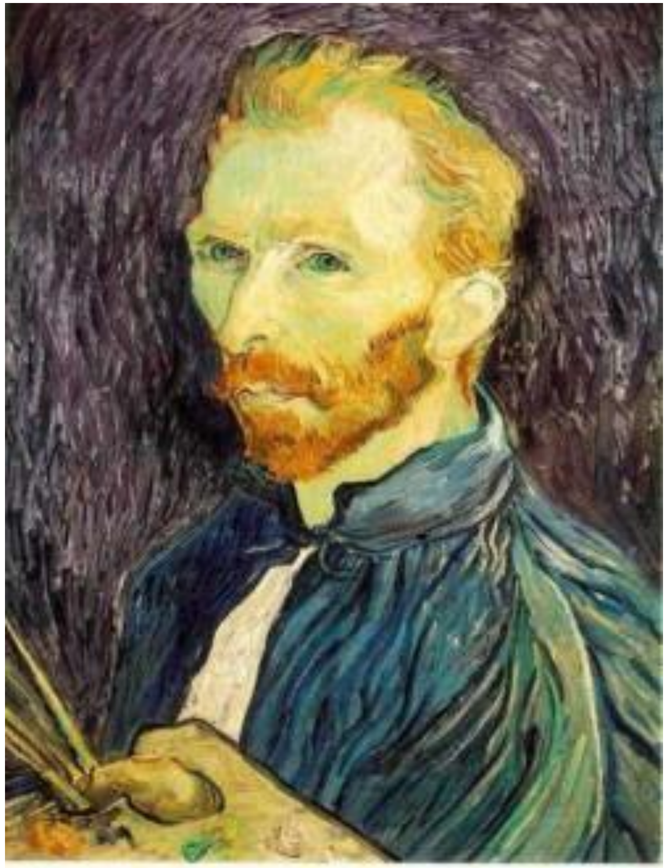
G 1/4

G 1/8

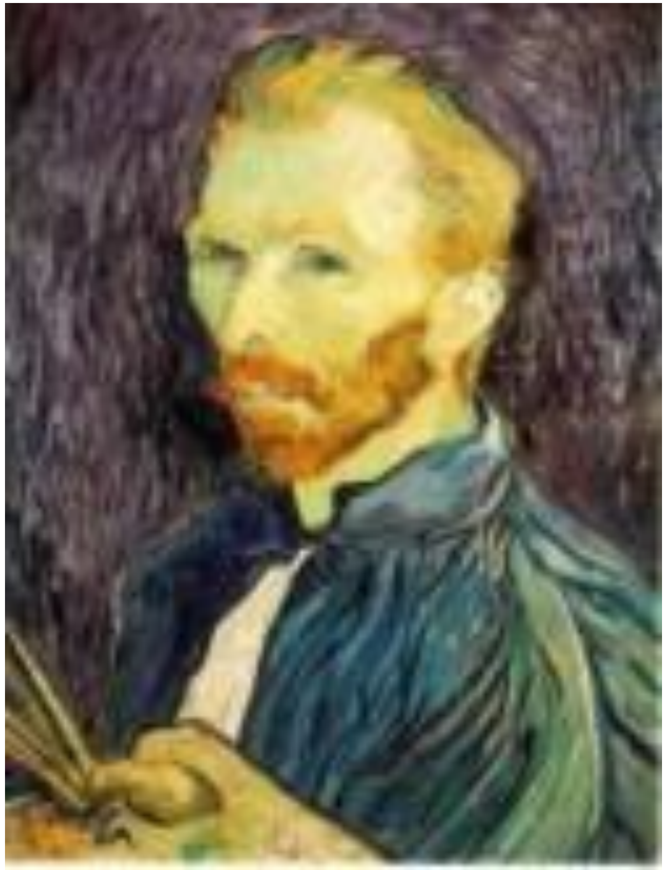
- Solution: filter the image, *then* subsample

Source: S. Seitz

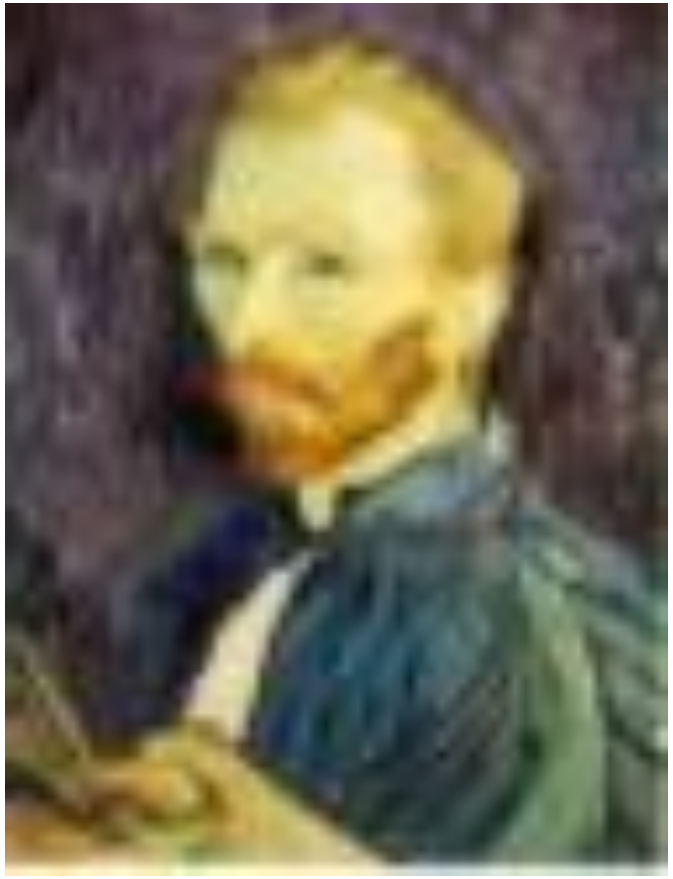
Subsampling with Gaussian pre-filtering



Gaussian 1/2



G 1/4

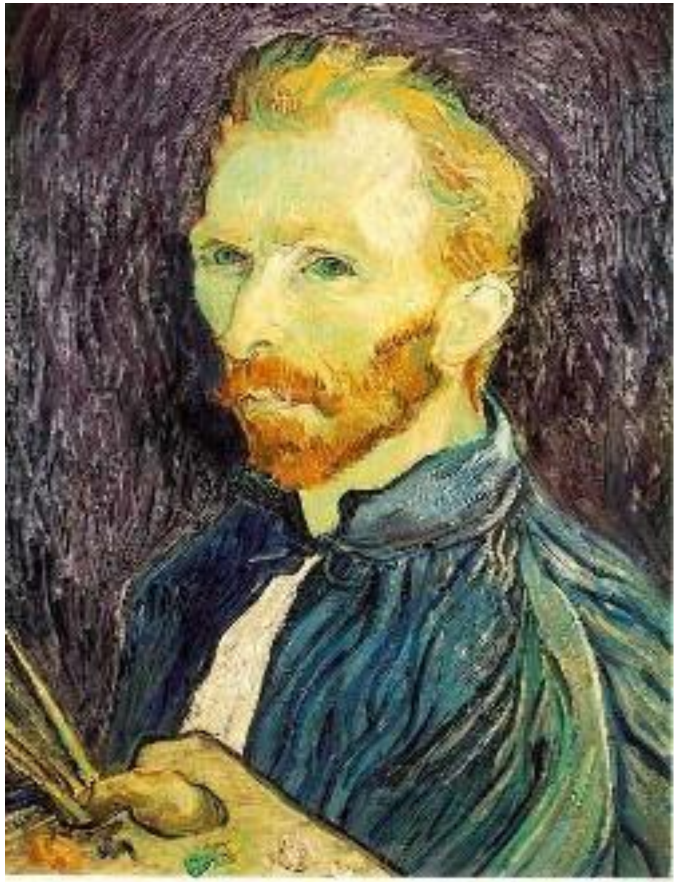


G 1/8

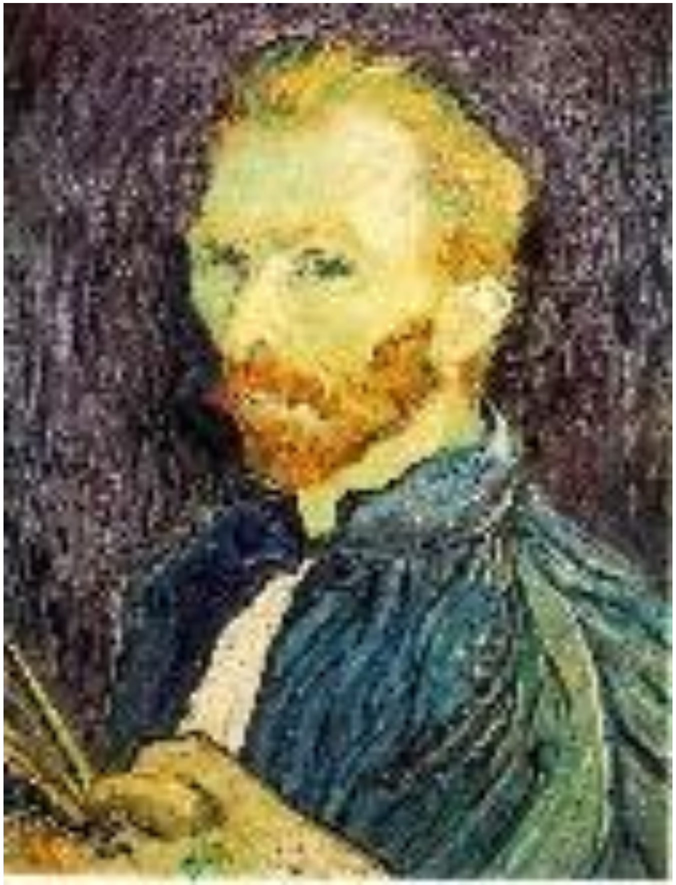
- Solution: filter the image, *then* subsample

Source: S. Seitz

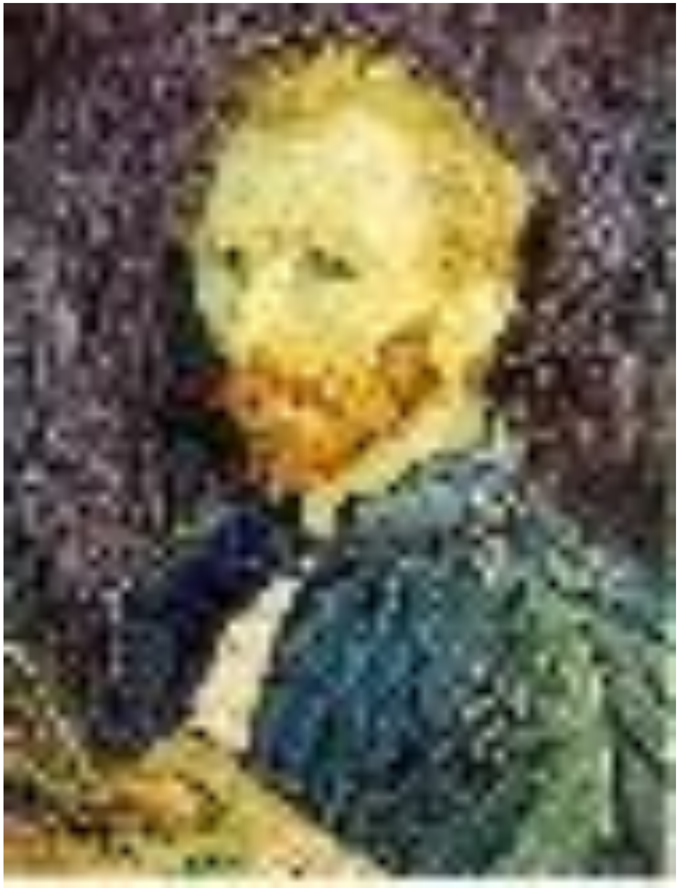
Compare with...



1/2



1/4 (2x zoom)

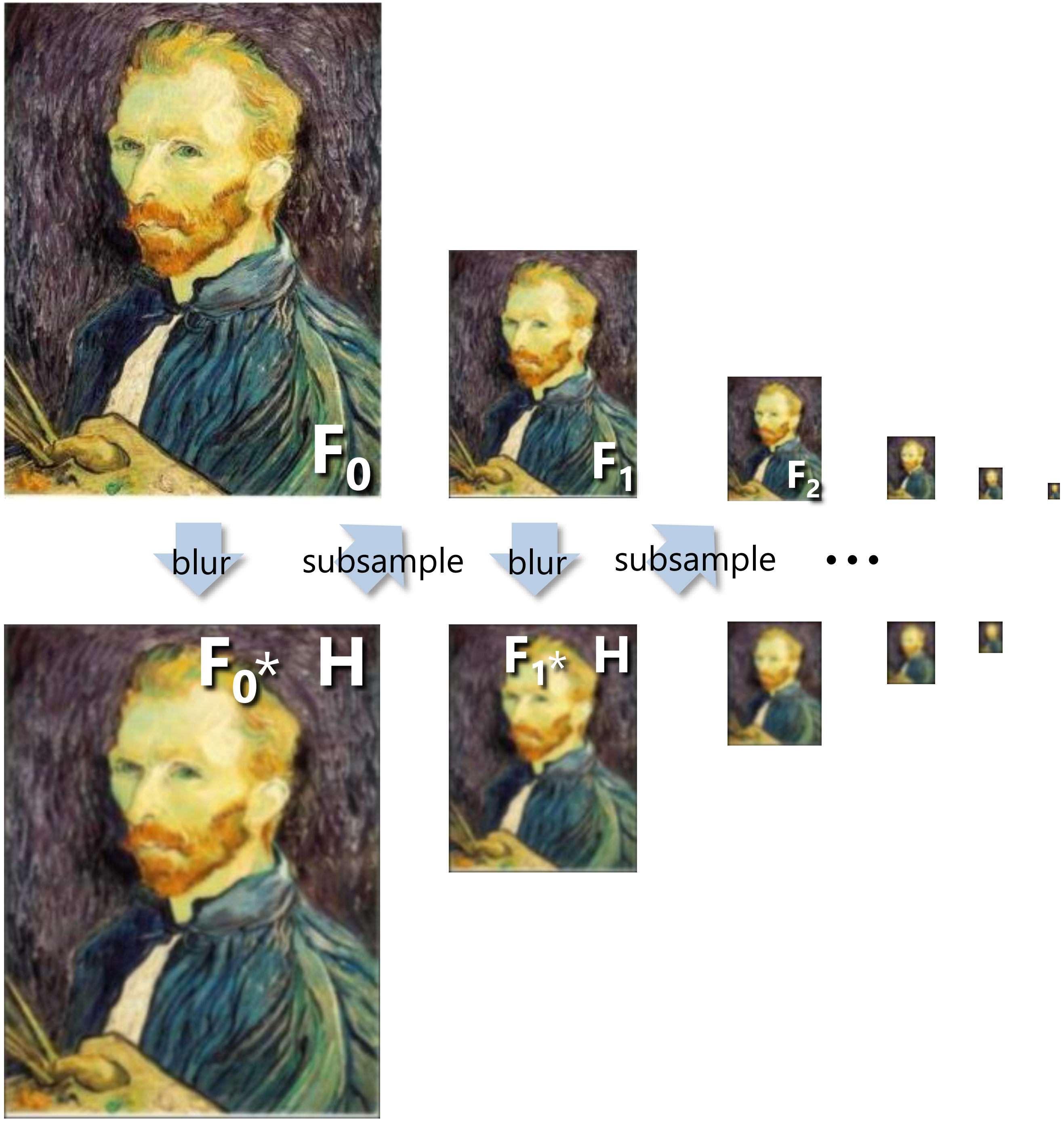


1/8 (4x zoom)

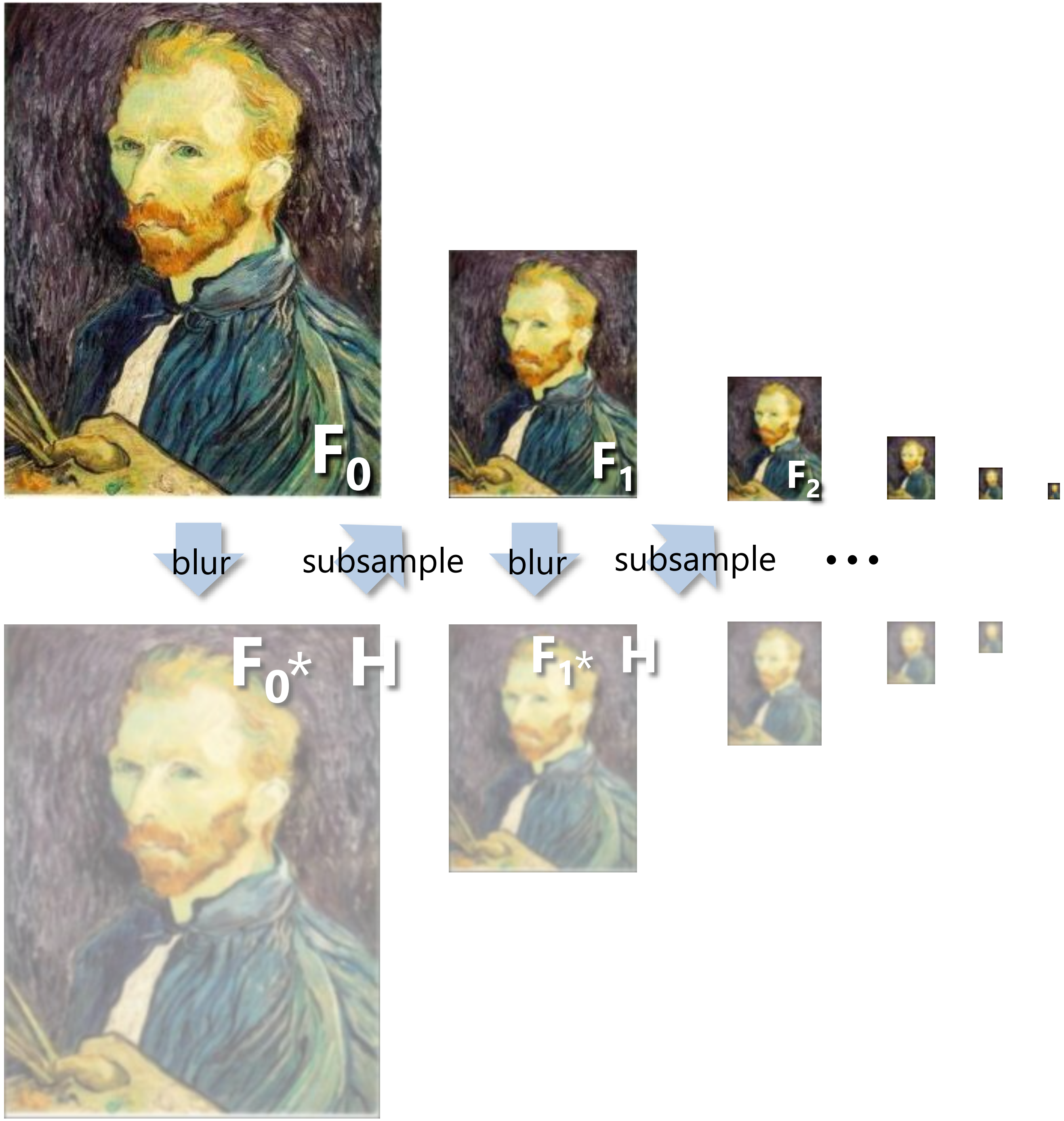
Source: S. Seitz

Gaussian pre-filtering

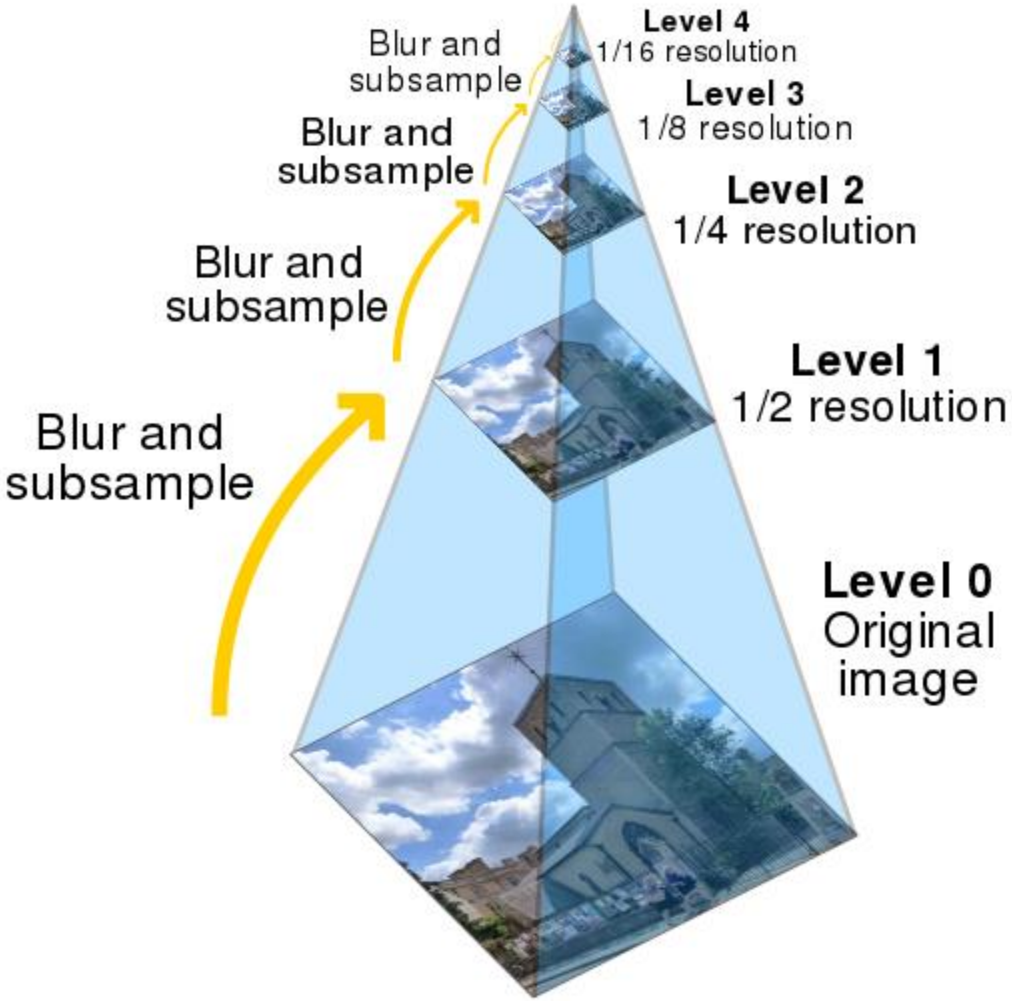
- Solution: filter the image, *then* subsample



Gaussian pyramid



blur subsample blur subsample • • •



Blur and subsample

Level 4
1/16 resolution

Blur and subsample

Level 3
1/8 resolution

Blur and subsample

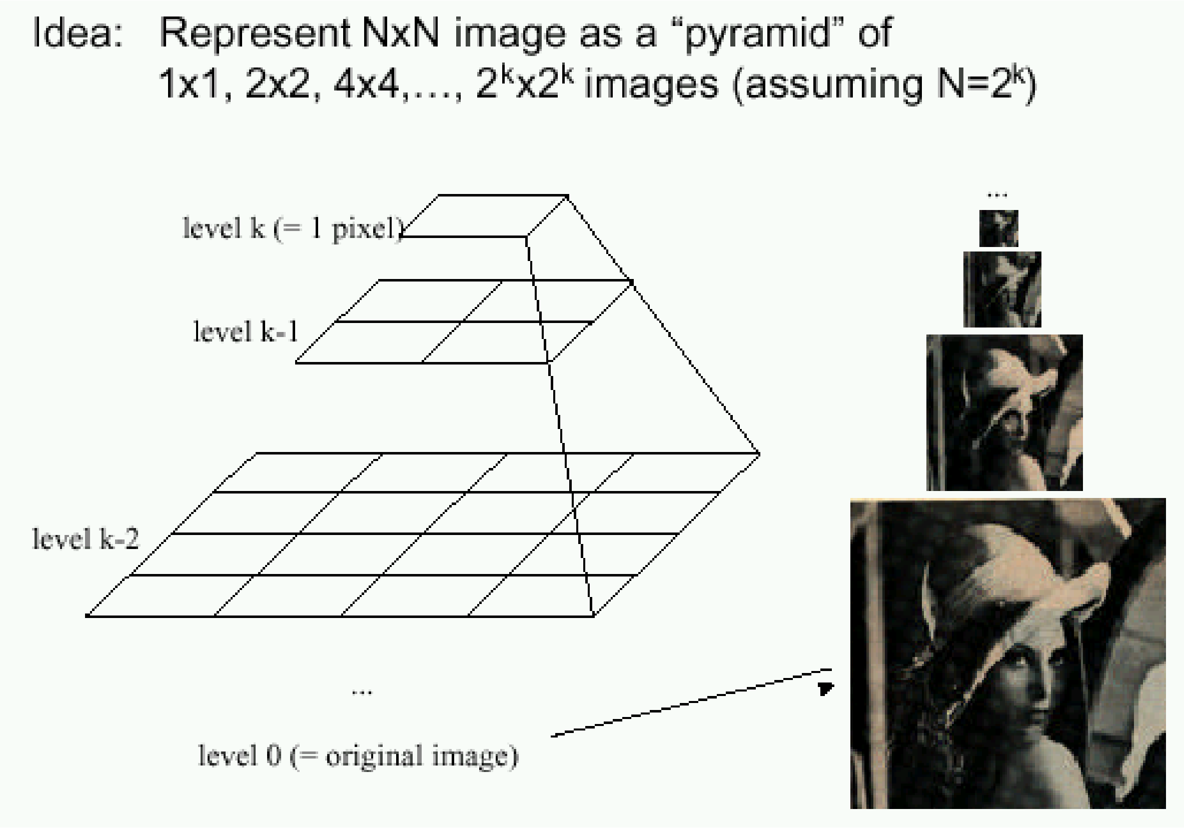
Level 2
1/4 resolution

Blur and subsample

Level 1
1/2 resolution

Level 0
Original image

Gaussian pyramids [Burt and Adelson, 1983]



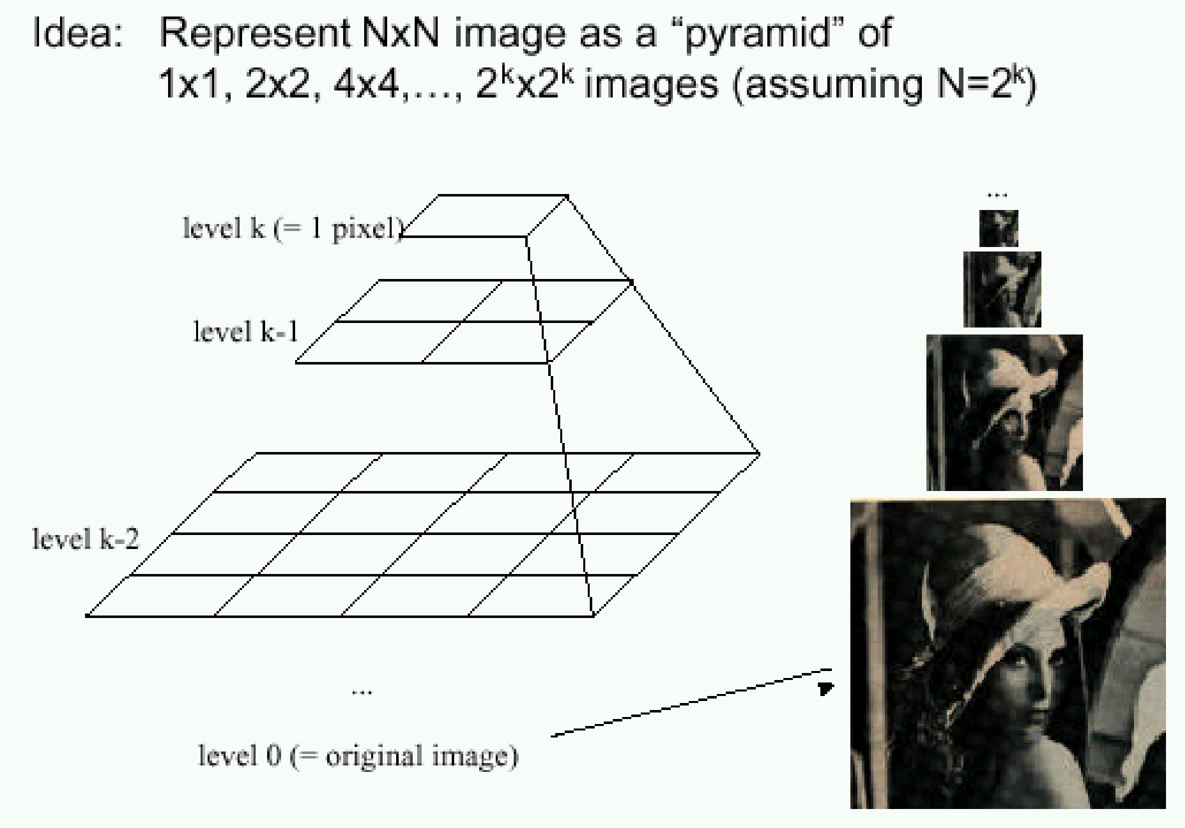
Idea: Represent NxN image as a “pyramid” of 1x1, 2x2, 4x4,…, 2^kx2^k images (assuming N=2^k)

- In computer graphics, a *mip map* [Williams, 1983]
- A precursor to *wavelet transform*

Gaussian Pyramids have all sorts of applications in computer vision

Source: S. Seitz

Gaussian pyramids [Burt and Adelson, 1983]

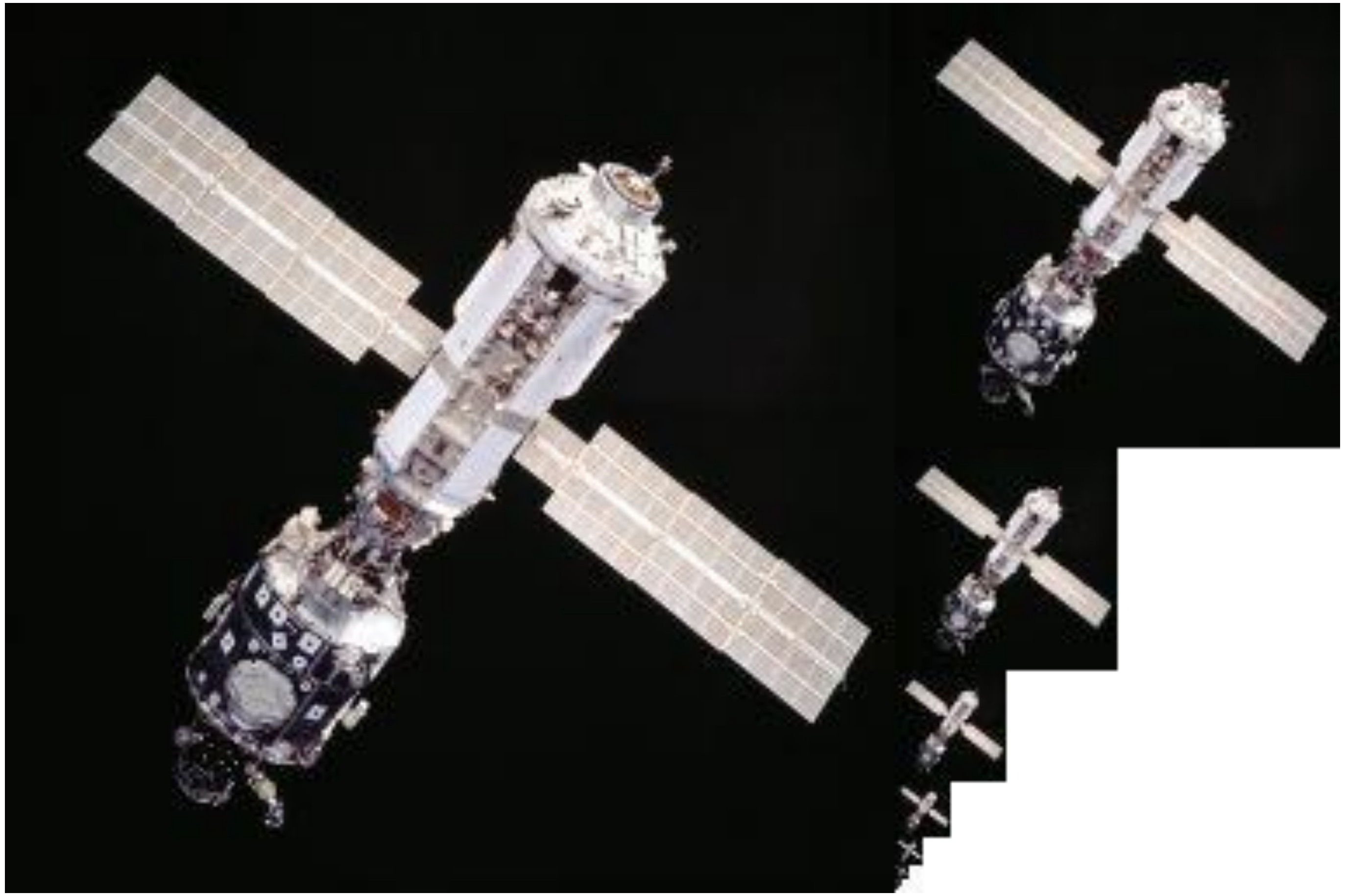


Idea: Represent NxN image as a “pyramid” of 1x1, 2x2, 4x4,…, 2^kx2^k images (assuming N=2^k)

- How much space does a Gaussian pyramid take compared to the original image?

Source: S. Seitz

Gaussian pyramid

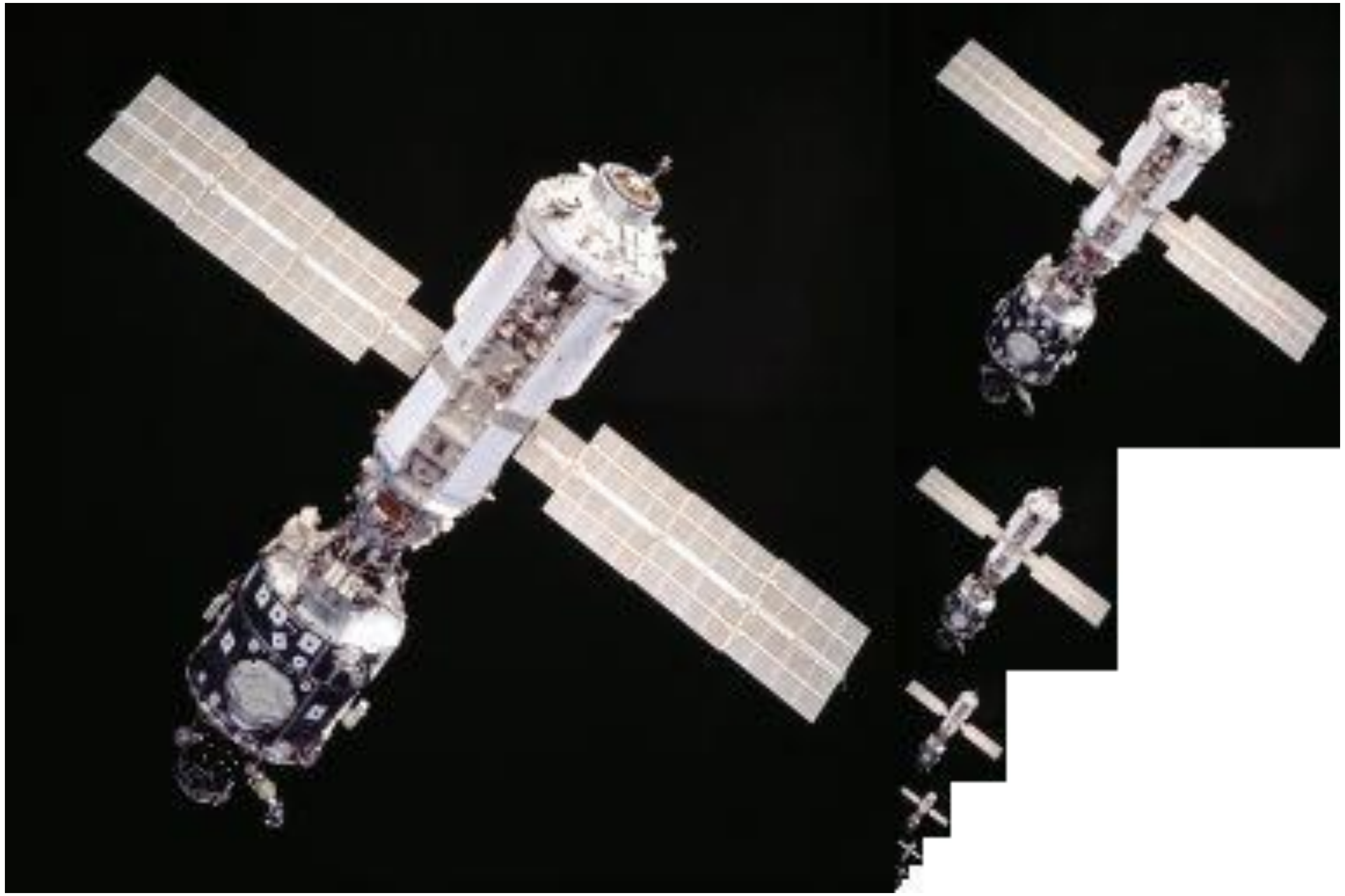


slido

How much space (number of pixels) does a Gaussian pyramid of an image take compared to the original image?

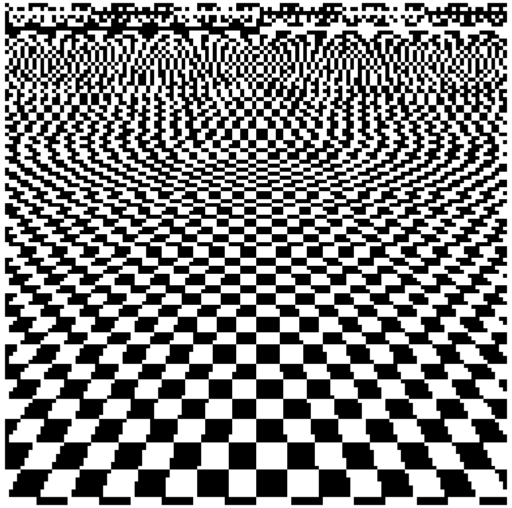
ⓘ Start presenting to display the poll results on this slide.

Gaussian pyramid



Back to the checkerboard

- What should happen when you make the checkerboard smaller and smaller?



Naïve subsampling

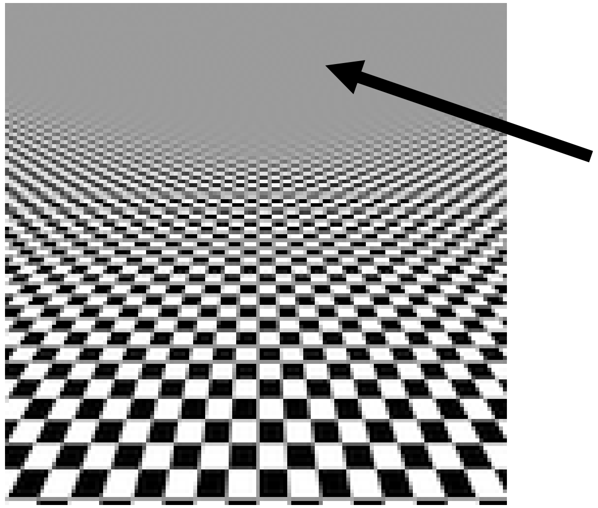


Image turns grey! (Average of black and white squares, because each pixel contains both.)

Proper prefiltering (“antialiasing”)

Questions?

Upsampling

- This image is too small for this screen:
- How can we make it 10 times as big?
- Simplest approach: repeat each row and column 10 times
- (“Nearest neighbor interpolation”)

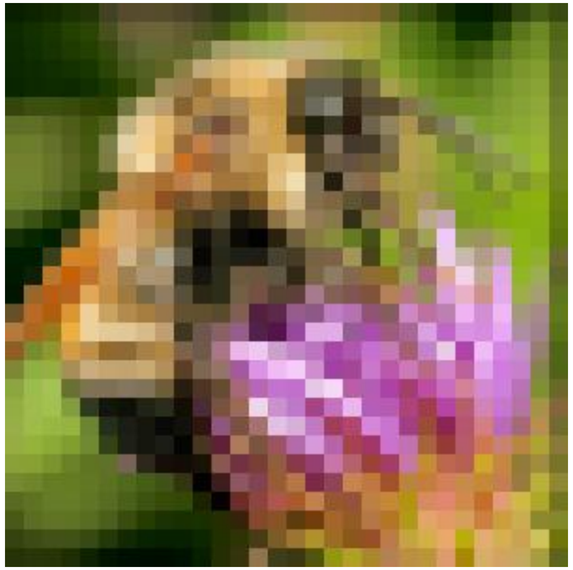
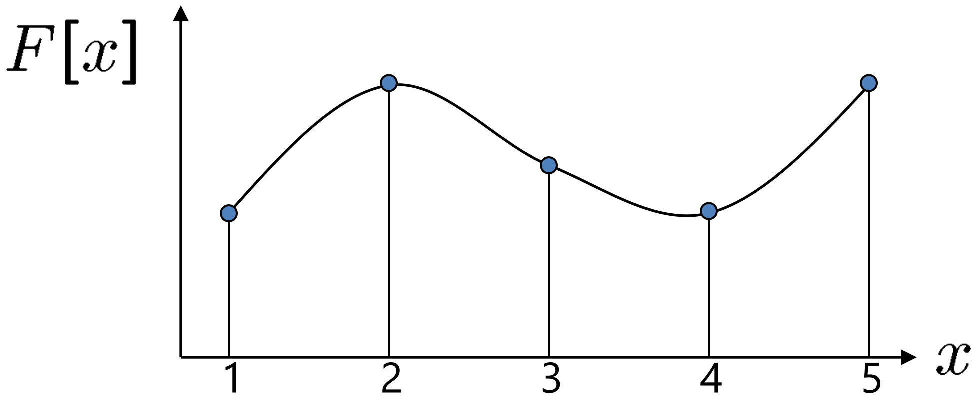


Image interpolation



d = 1 in this example

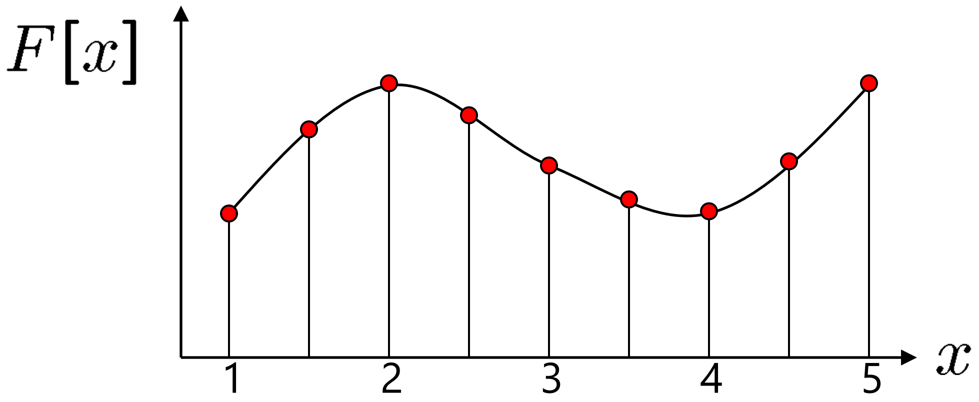
Recall that a digital images is formed as follows:

$$F[x,y] = \text{quantize}\{f(xd, yd)\}$$

- It is a discrete point-sampling of a continuous function
- If we could somehow reconstruct the original function, any new image could be generated, at any resolution and scale

Adapted from: S. Seitz

Image interpolation



d = 1 in this example

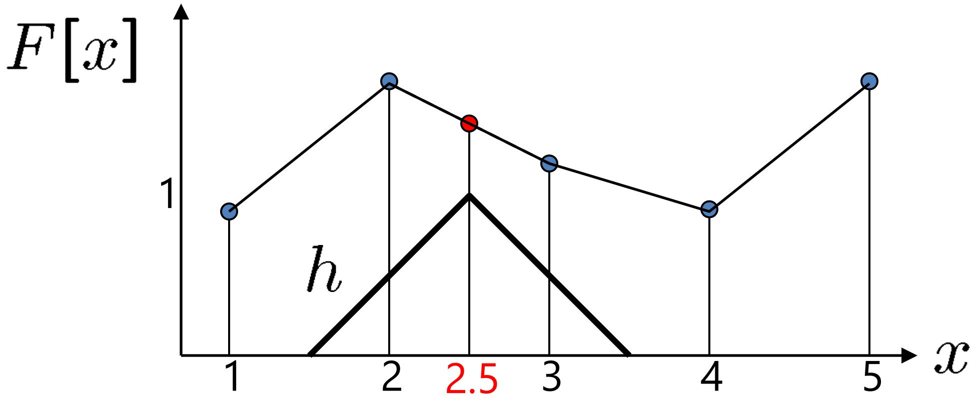
Recall that a digital images is formed as follows:

$$F[x,y] = \text{quantize}\{f(xd, yd)\}$$

- It is a discrete point-sampling of a continuous function
- If we could somehow reconstruct the original function, any new image could be generated, at any resolution and scale

Adapted from: S. Seitz

Image interpolation



d = 1 in this example

- What if we don’t know f ?
  - Guess an approximation: $\tilde{f}$
  - Can be done in a principled way: filtering
  - Convert F to a continuous function:

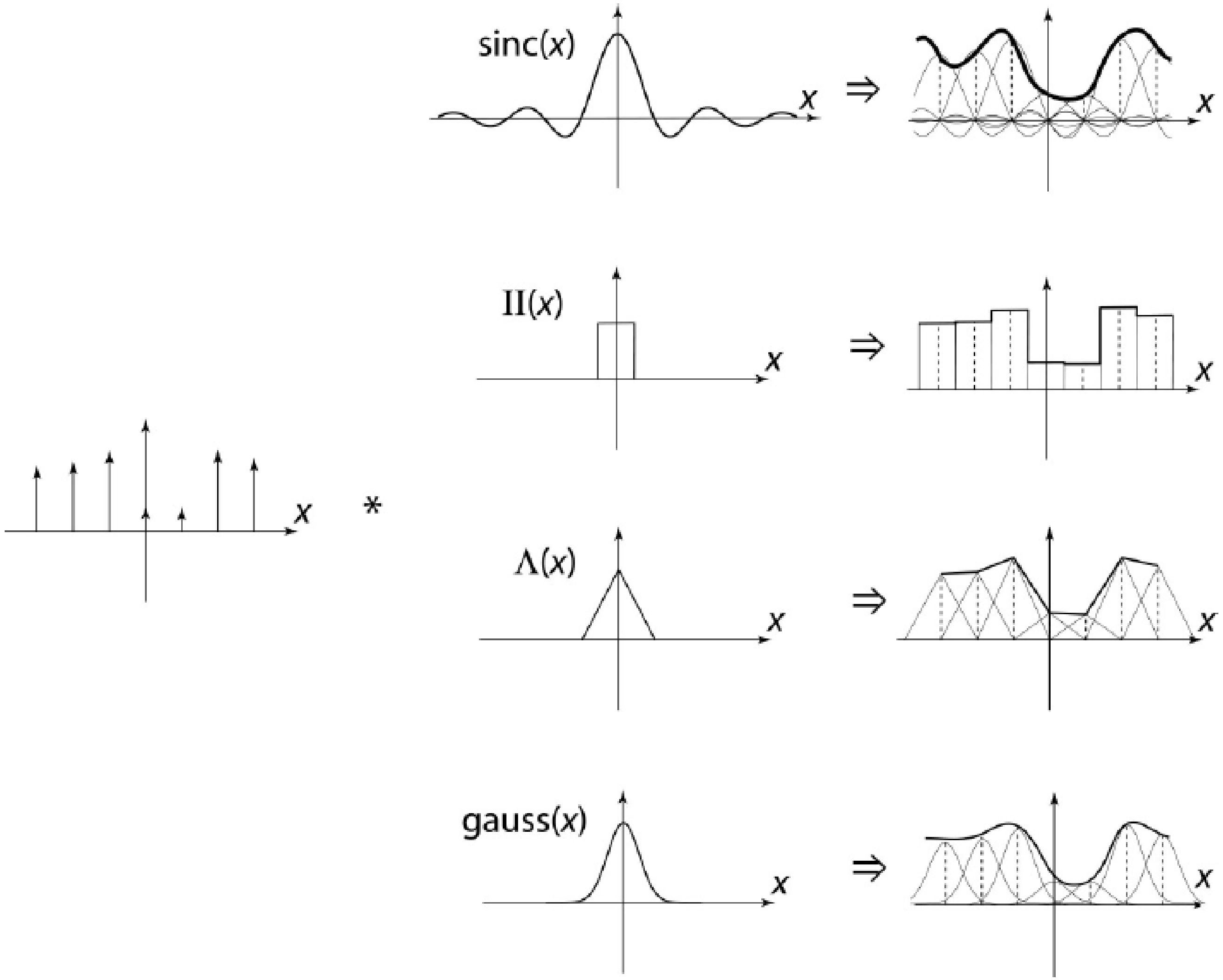
$$f_F(x) = F(\tfrac{x}{d}) \text{ when } \tfrac{x}{d} \text{ is an integer, 0 otherwise}$$

  - Reconstruct by convolution with a *reconstruction filter, h*

$$\tilde{f} = h * f_F$$

Adapted from: S. Seitz

Image interpolation



“Ideal” reconstruction

Nearest-neighbor interpolation

Linear interpolation

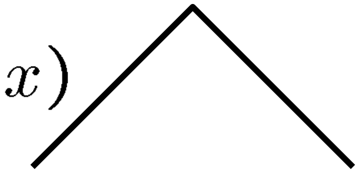
Gaussian reconstruction

Source: B. Curless

Reconstruction filters

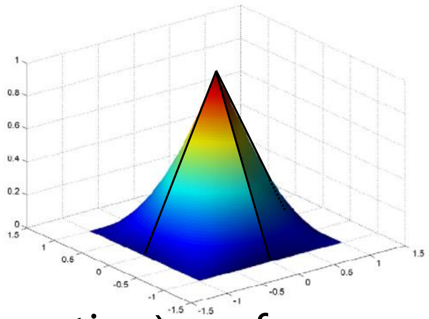
- What does the 2D version of this hat function look like?

$h(x)$



performs
linear interpolation

$h(x, y)$



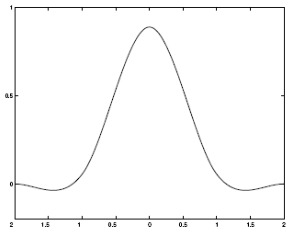
(tent function) performs
bilinear interpolation

Often implemented without cross-correlation

- E.g., http://en.wikipedia.org/wiki/Bilinear_interpolation

Better filters give better resampled images

- **Bicubic** is common choice

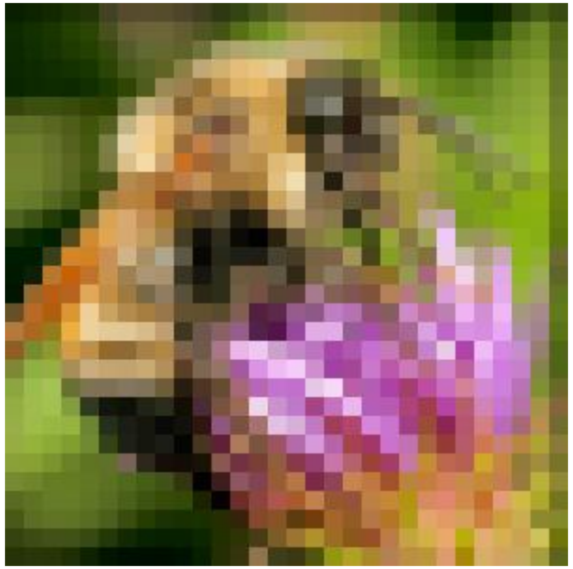


Cubic reconstruction filter

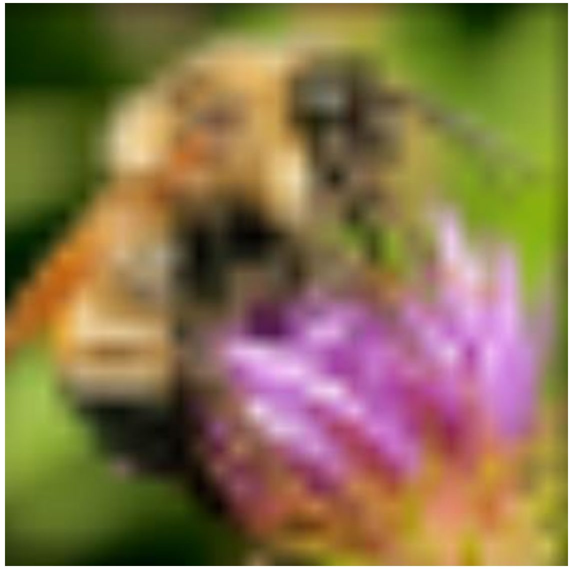
$$r(x)=\frac{1}{6}\begin{cases}(12-9B-6C)|x|^3+(-18+12B+6C)|x|^2+(6-2B) & |x|<1\\((-B-6C)|x|^3+(6B+30C)|x|^2+(-12B-48C)|x|+(8B+24C) & 1\le|x|<2\\0 & \textit{otherwise}\end{cases}$$

Image interpolation

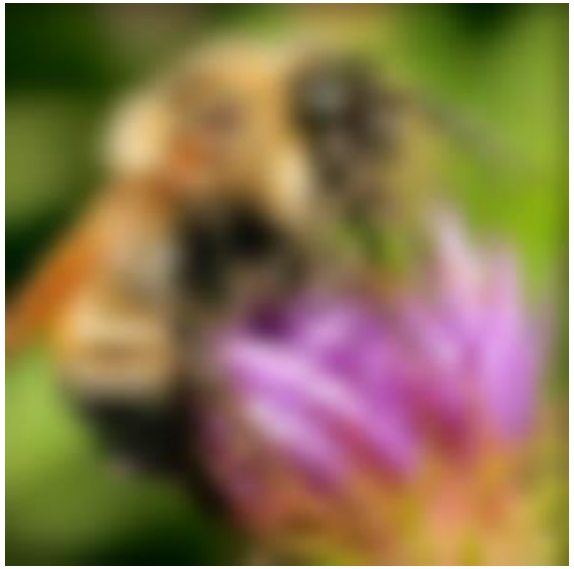
Original image: x 10



Nearest-neighbor interpolation



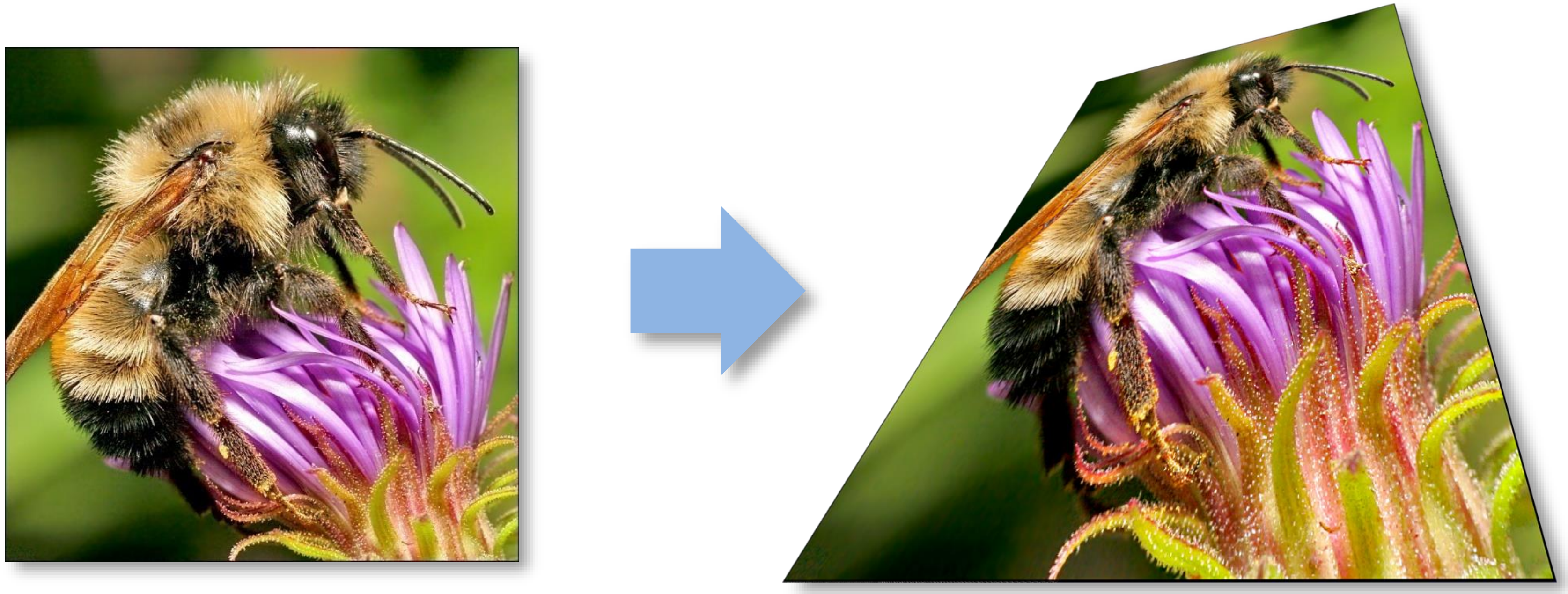
Bilinear interpolation



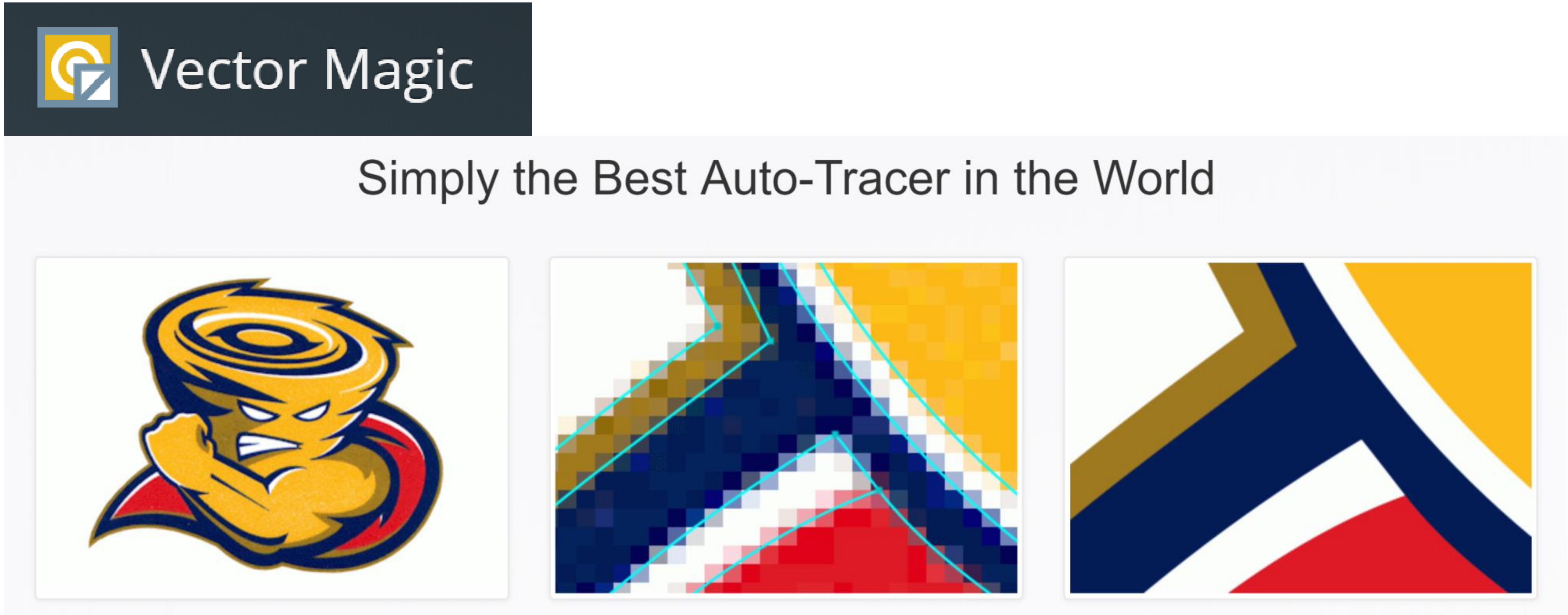
Bicubic interpolation

Image interpolation

Also used for *resampling*



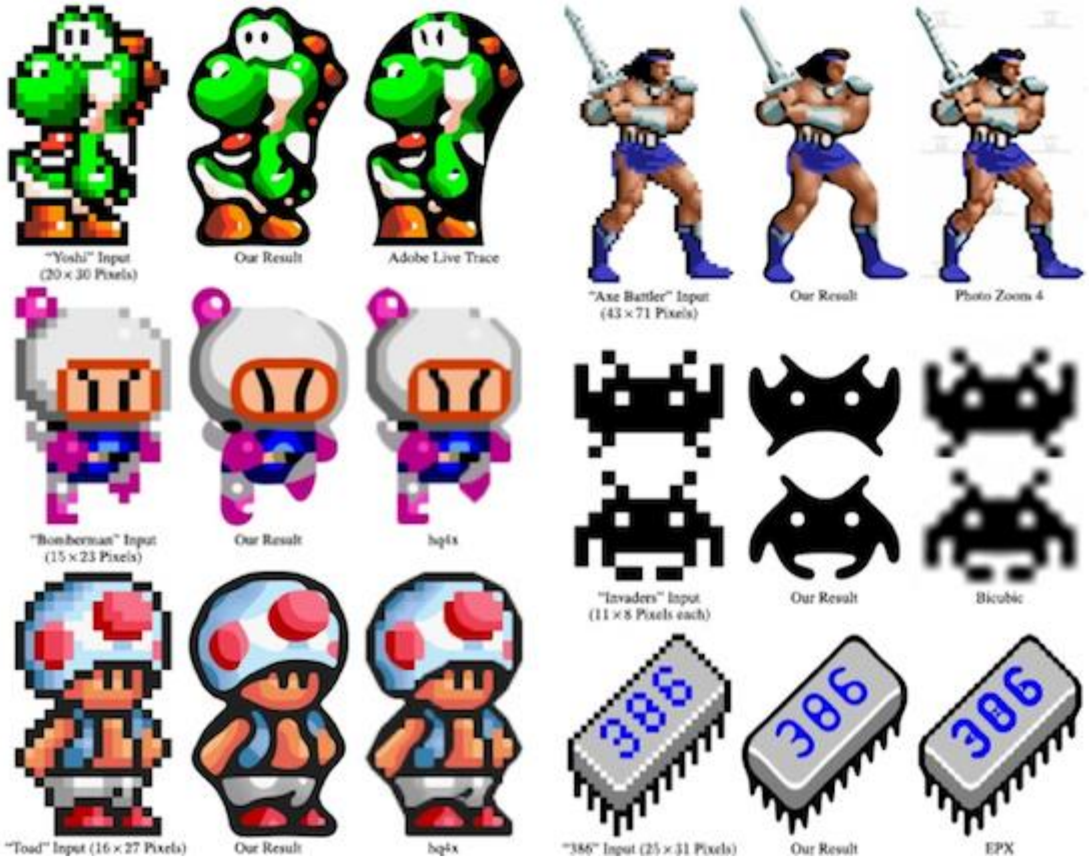
Raster-to-vector graphics



Vector Magic

Simply the Best Auto-Tracer in the World

Depixelating Pixel Art



"Yoshi" Input (20 × 30 Pixels)

Our Result

Adobe Live Trace

"Bomberman" Input (15 × 23 Pixels)

Our Result

hq4x

"Toad" Input (16 × 27 Pixels)

Our Result

hq4x

"Axe Battler" Input (43 × 71 Pixels)

Our Result

Photo Zoom 4

"Invaders" Input (11 × 8 Pixels each)

Our Result

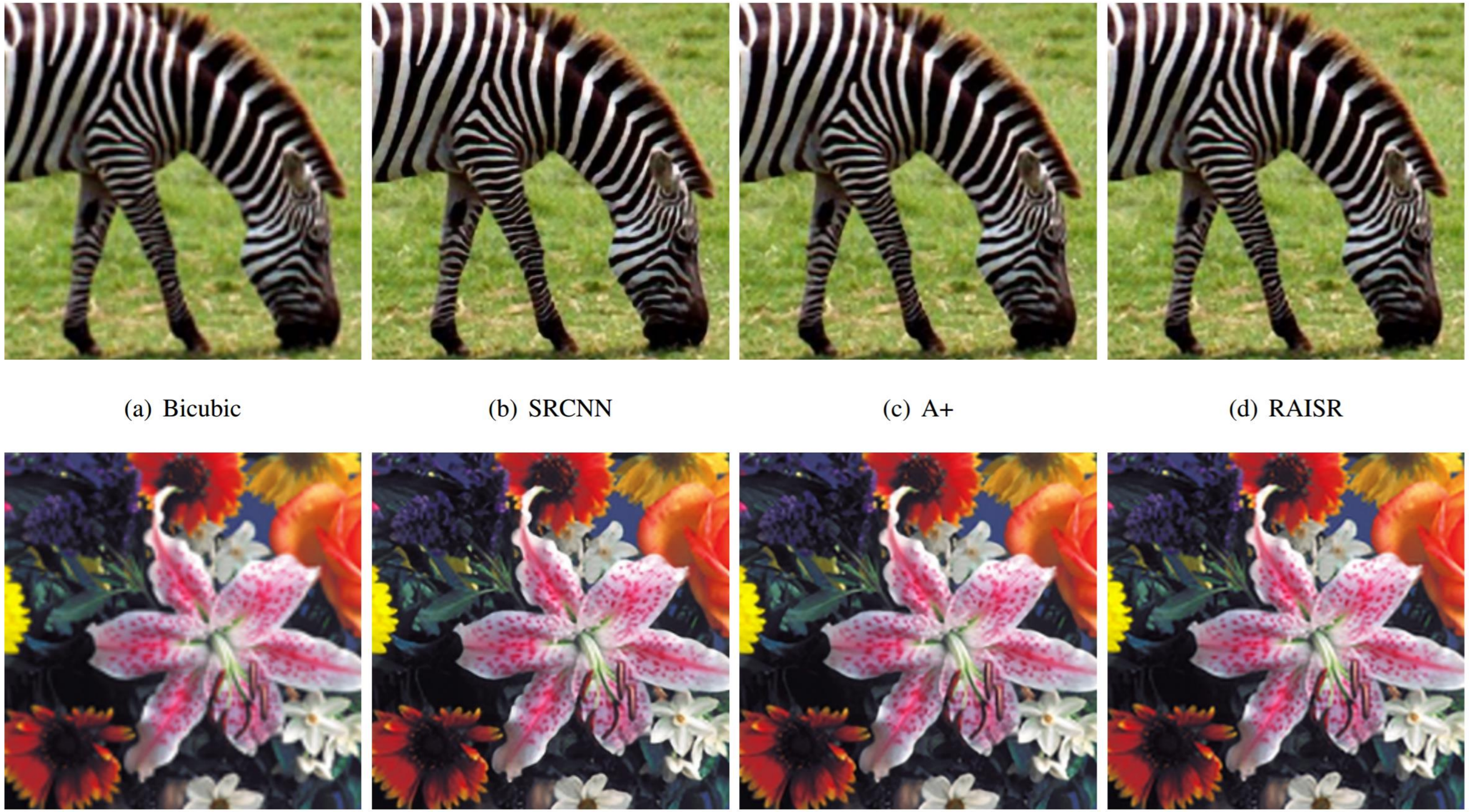
Bicubic

"386" Input (25 × 31 Pixels)

Our Result

EPX

Modern methods



(a) Bicubic (b) SRCNN (c) A+ (d) RAISR

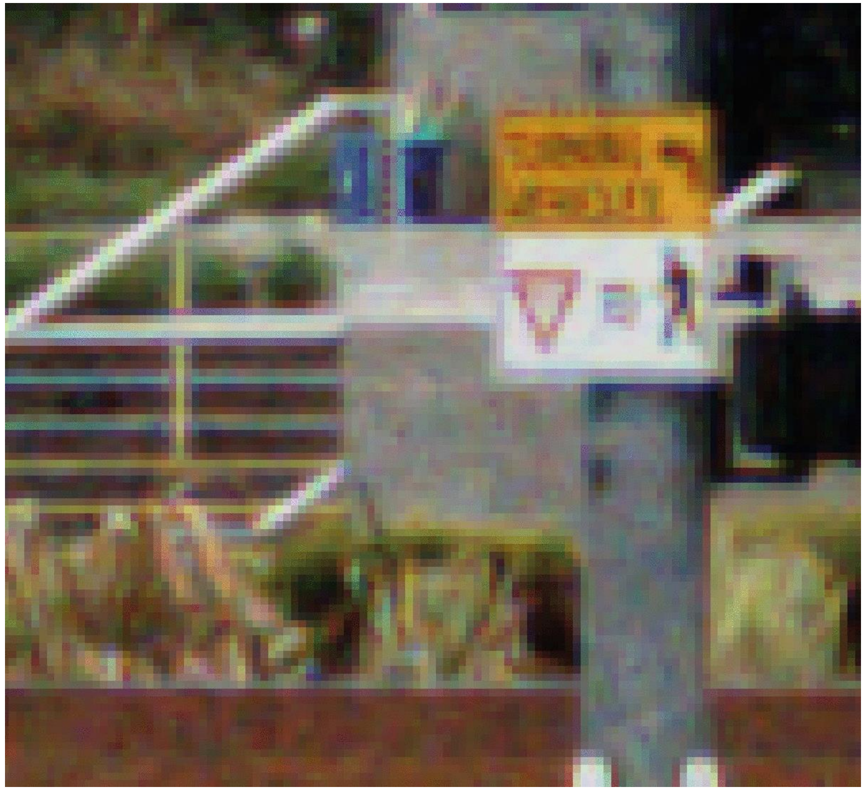
(e) Bicubic (f) SRCNN (g) A+ (h) RAISR

From Romano, et al: RAISR: Rapid and Accurate Image Super Resolution, https://arxiv.org/abs/1606.01299

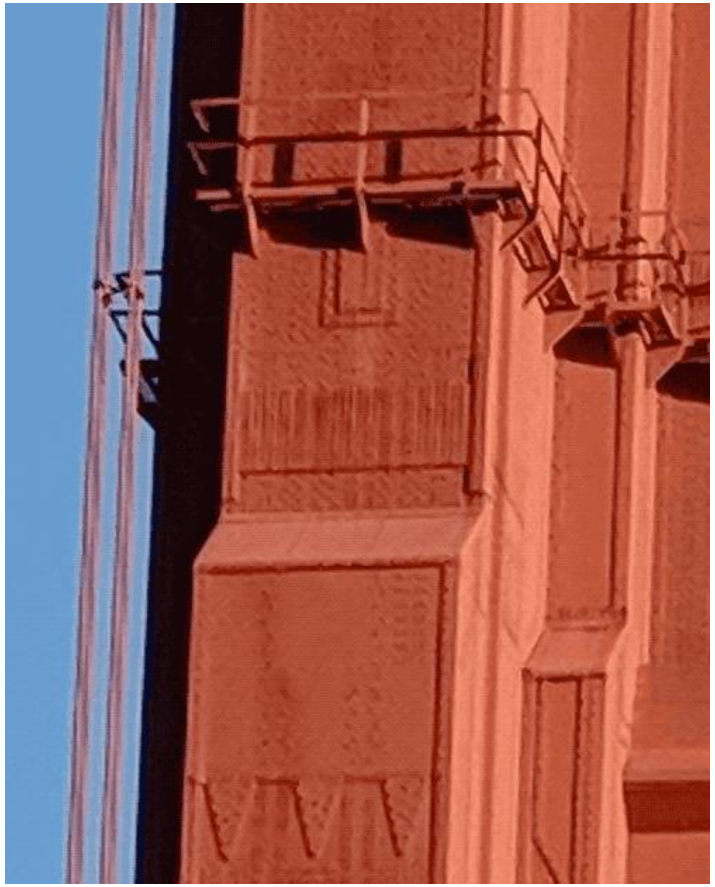
Super-resolution with multiple images

- Can do better upsampling if you have multiple images of the scene taken with small (subpixel) shifts
- Some cellphone cameras (like the Google Pixel line) capture a **burst** of photos
- Can we use that burst for upsampling?

Google Pixel 3 Super Res Zoom



Effect of hand tremor as seen in a cropped burst of photos, after global alignment



Example photo with and without super res zoom (smart burst align and merge)

https://ai.googleblog.com/2018/10/see-better-and-further-with-super-res.html

Questions?