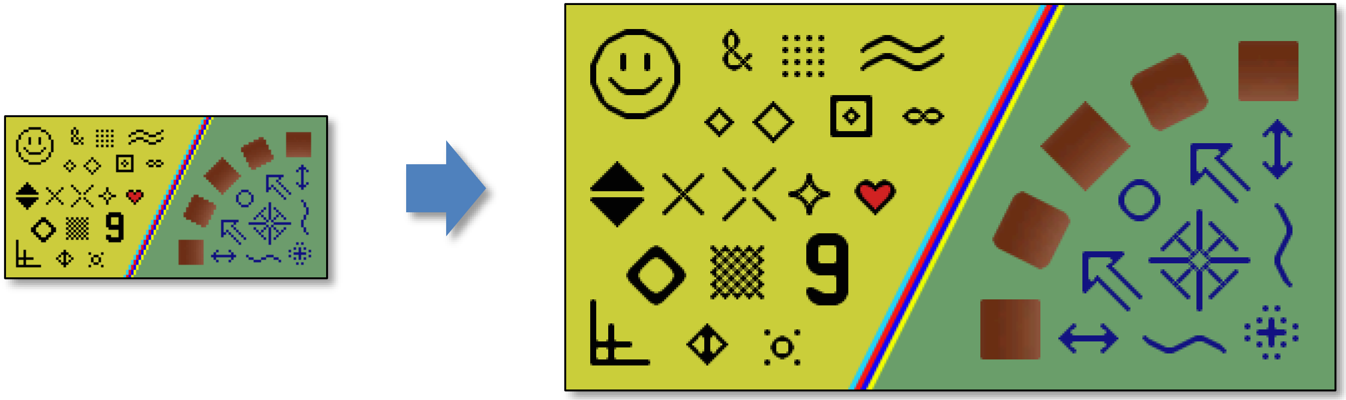
CS4670: Computer Vision

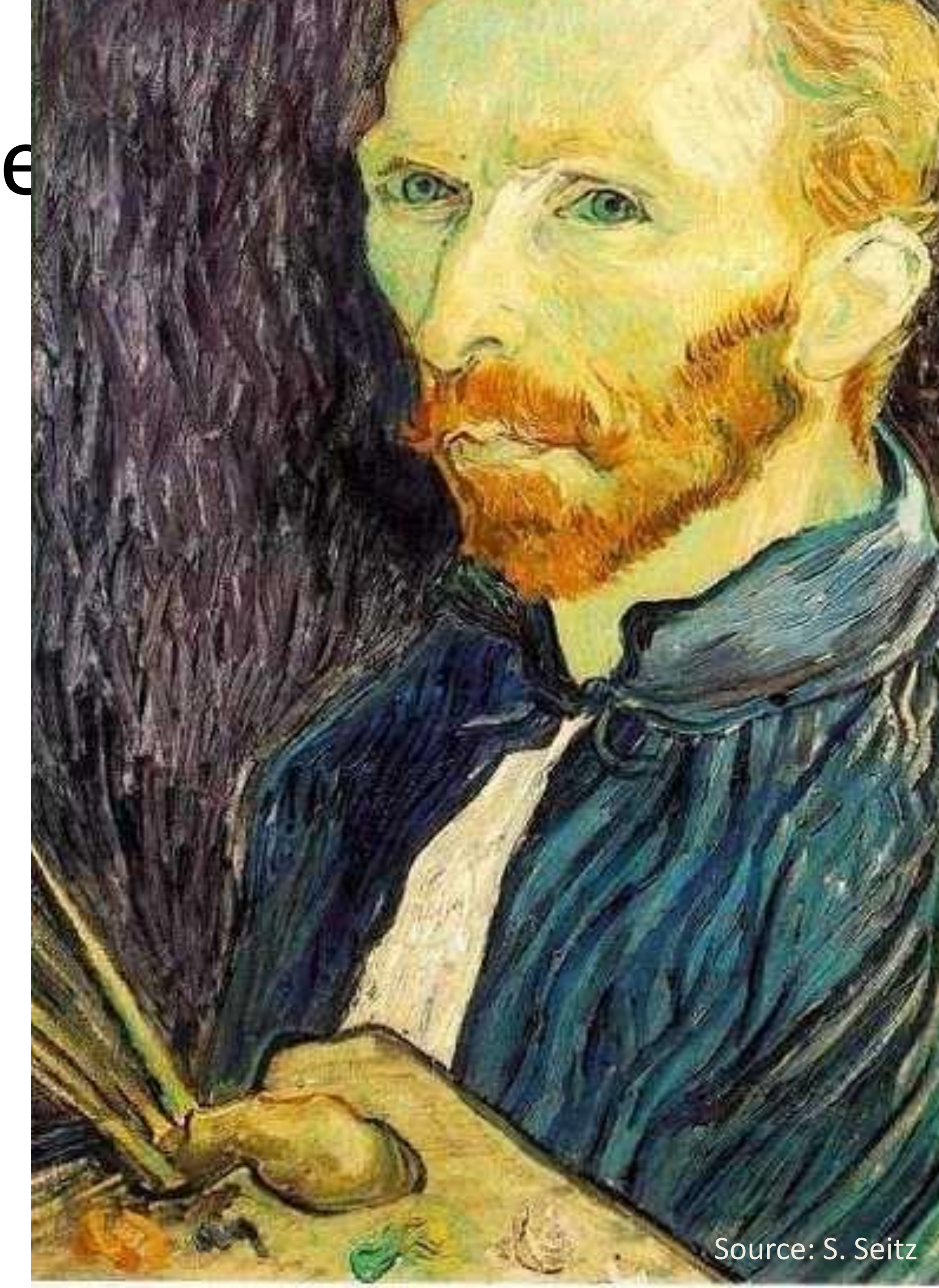
Noah Snavely

Image Resampling



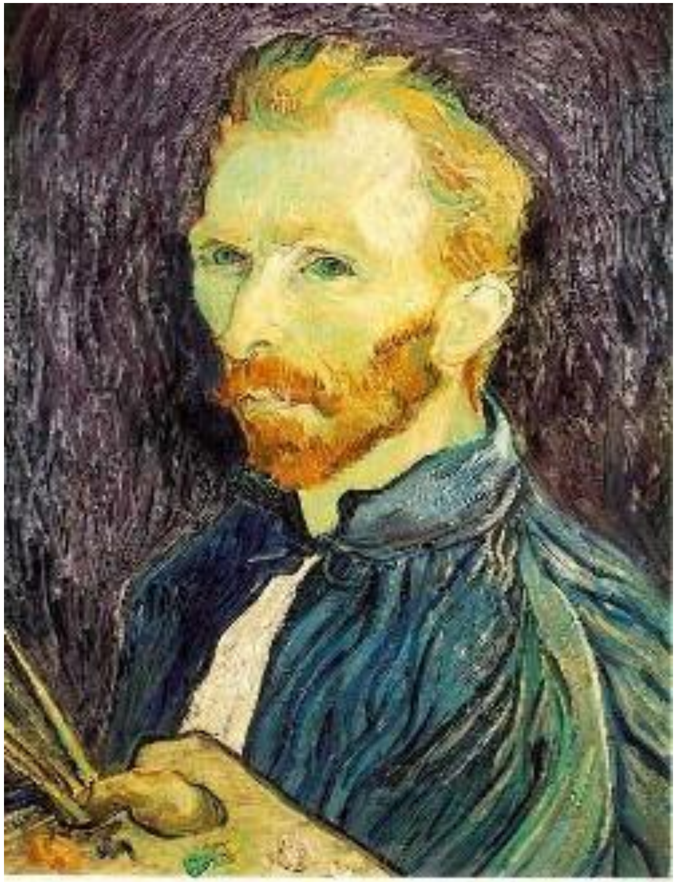
Image

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



Source: S. Seitz

Image sub-sampling



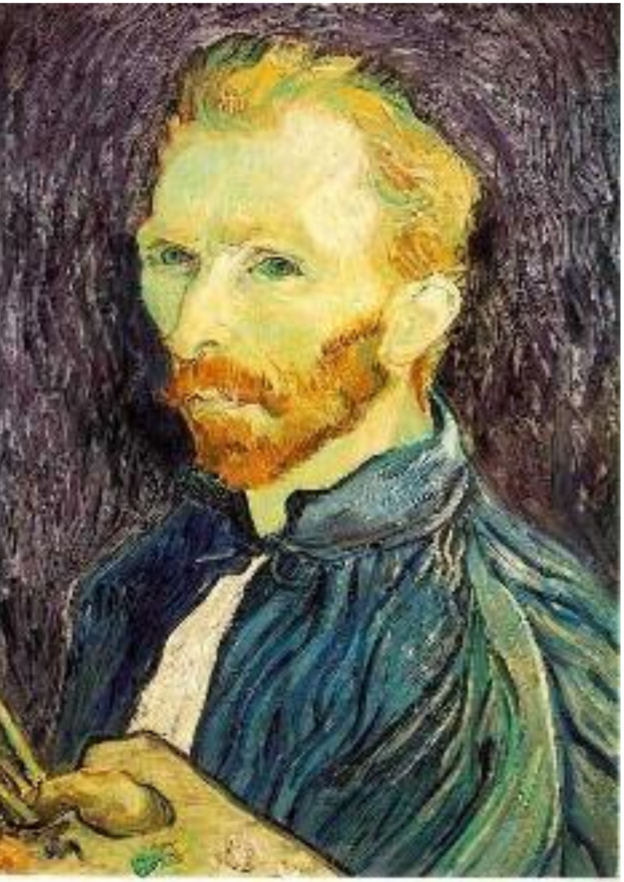
Throw away every other row and column to create a 1/2 size image
- called *image sub-sampling*

1/4

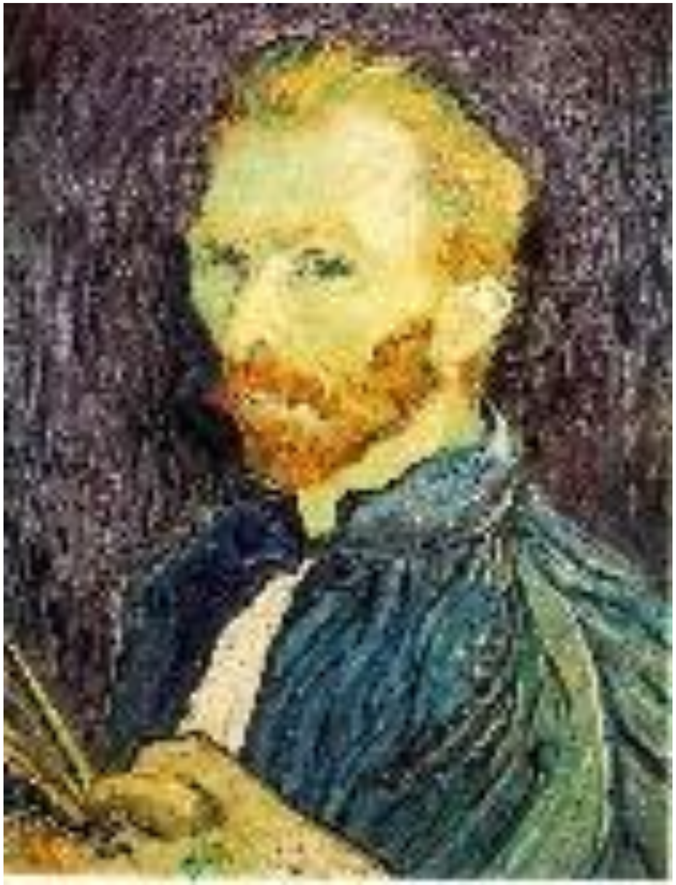
1/8

Source: S. Seitz

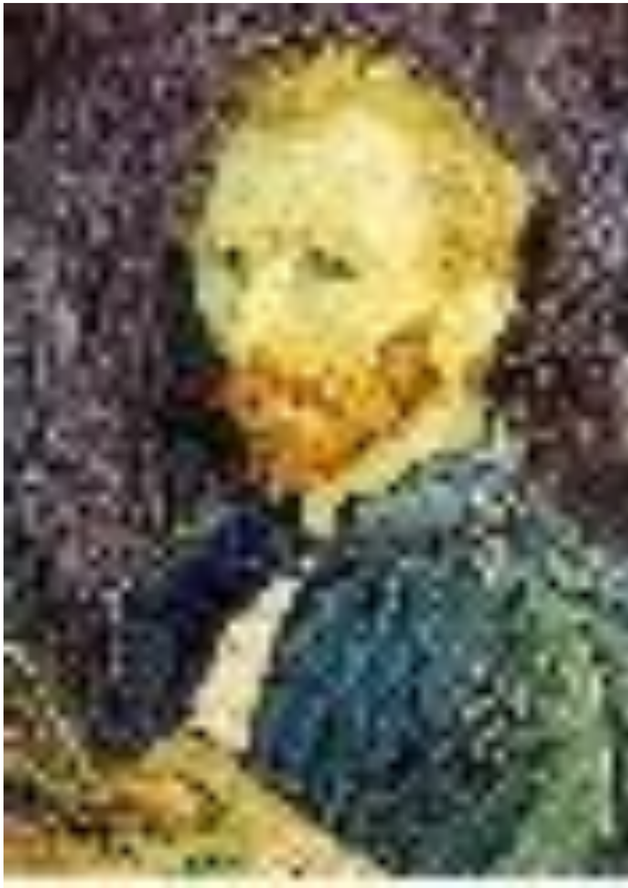
Image sub-sampling



1/2



1/4 (2x zoom)

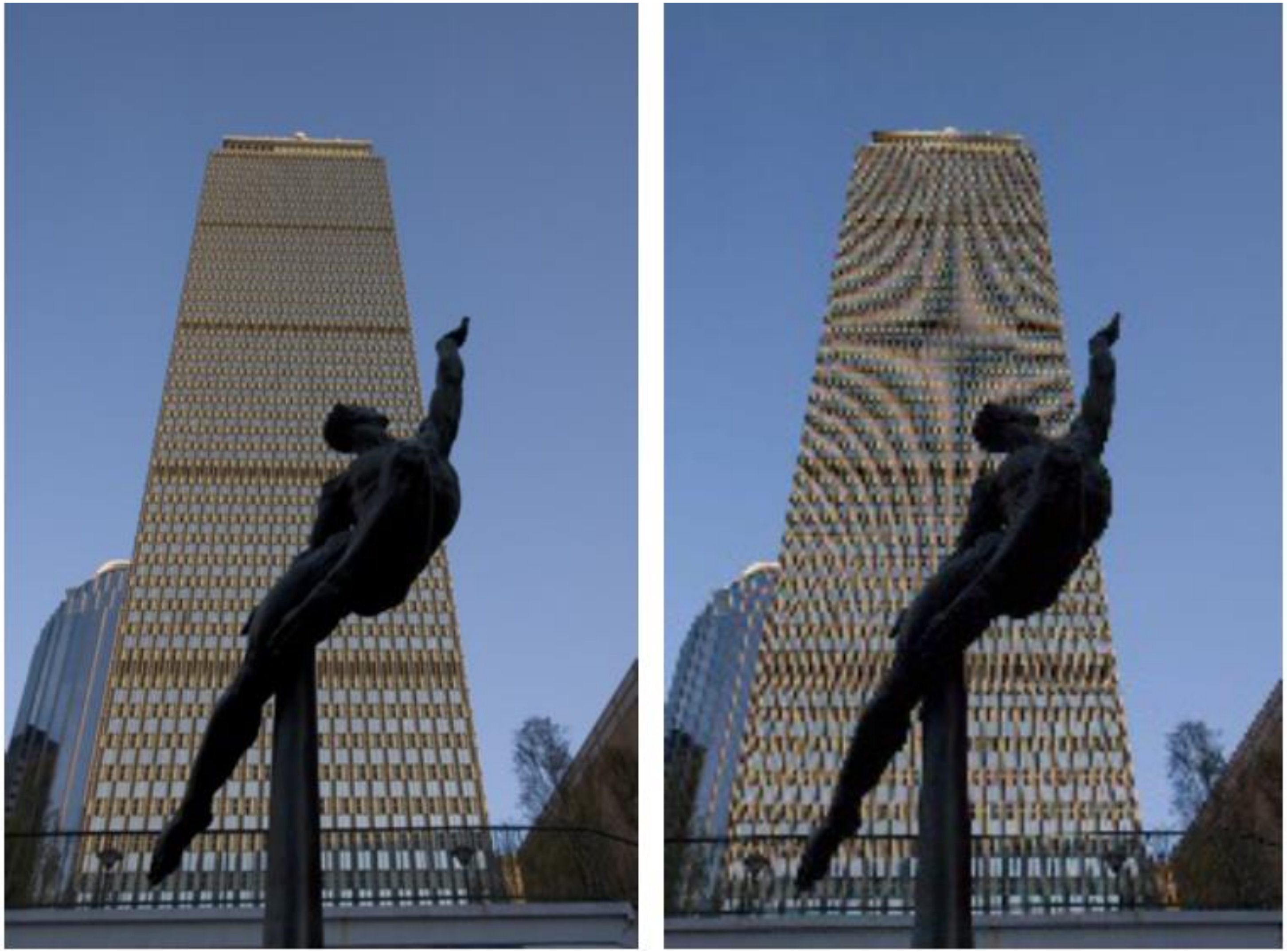


1/8 (4x zoom)

Why does this look so crufty?

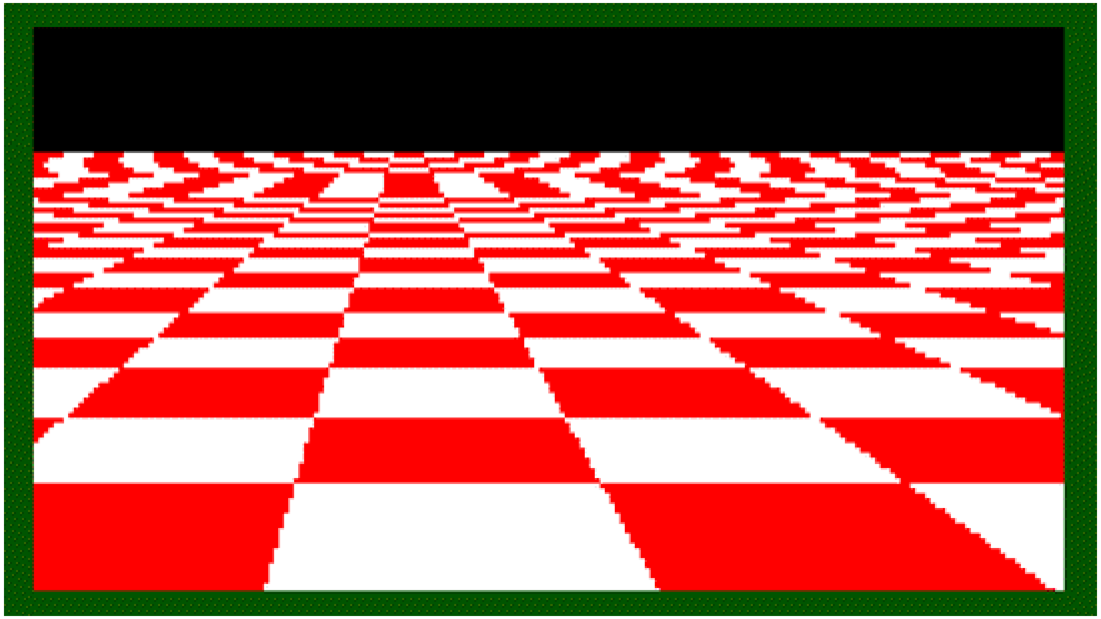
Source: S. Seitz

Image sub-sampling



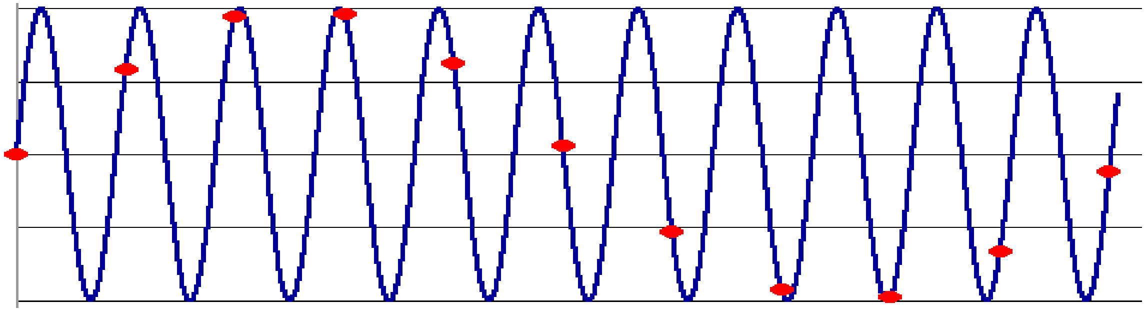
Source: F. Durand

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…

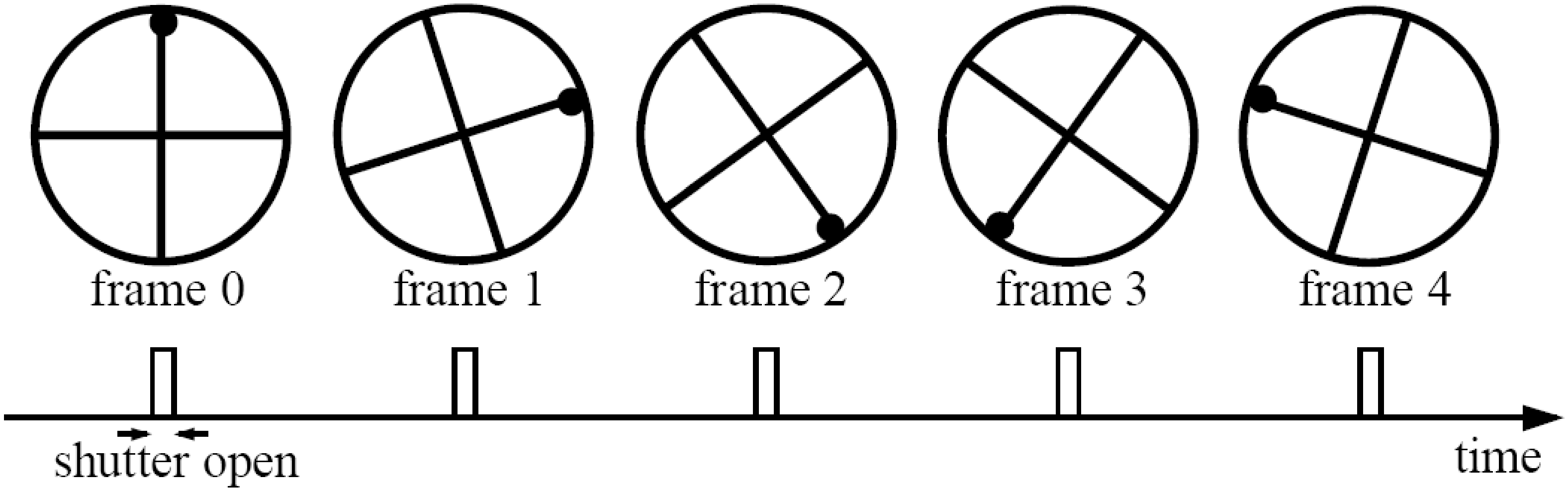
- To avoid aliasing:
  - sampling rate ≥ 2 * max frequency in the image
    - said another way: ≥ two samples per cycle
  - This minimum sampling rate is called the **Nyquist rate**

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):

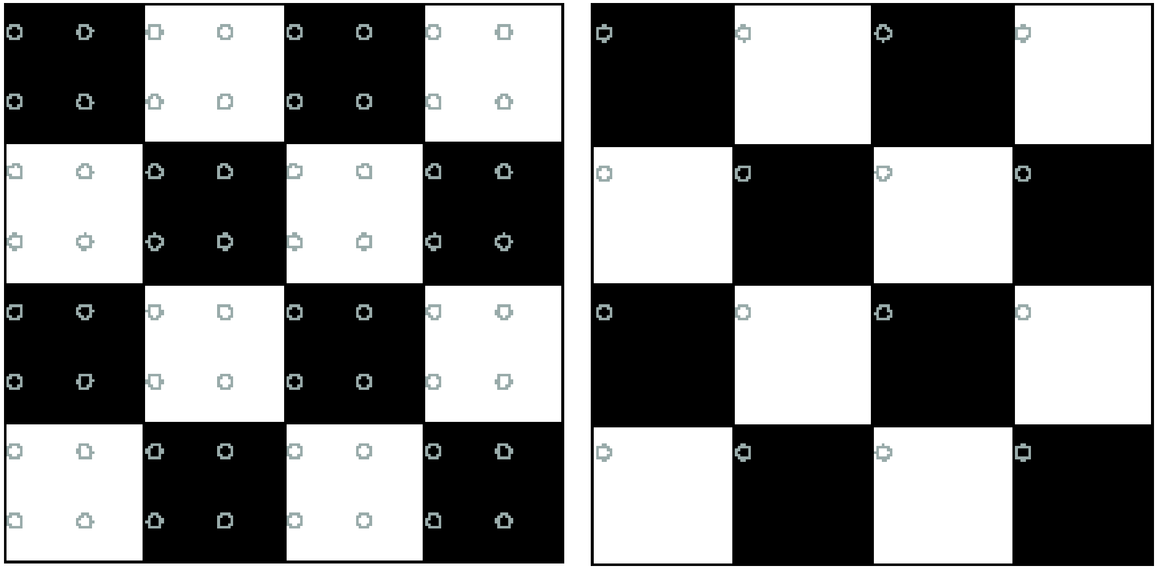


Without dot, wheel appears to be rotating slowly backwards! (counterclockwise)

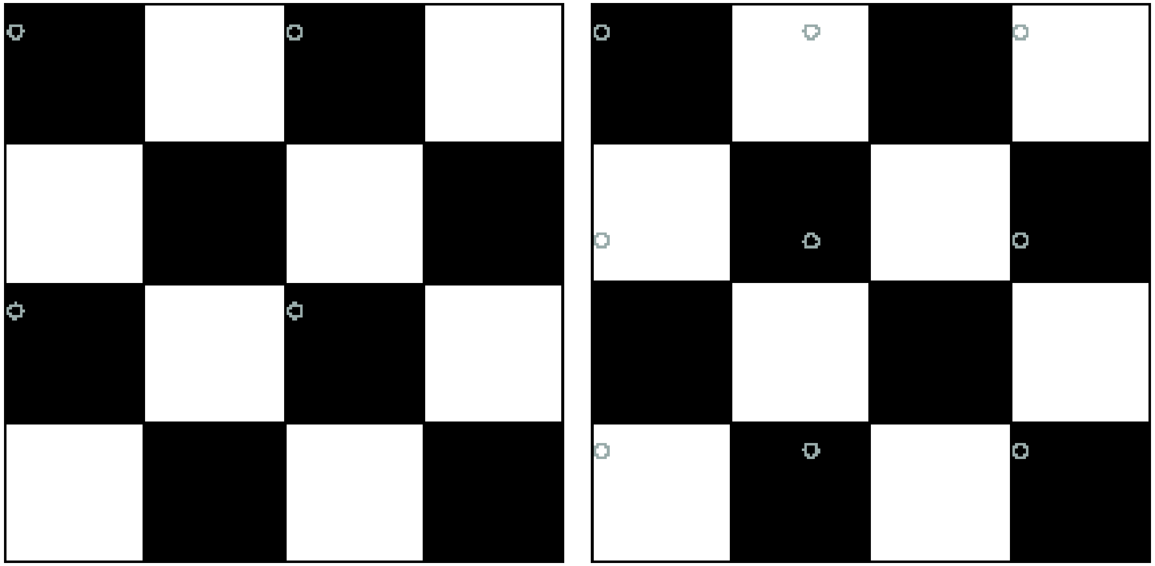
(See http://www.michaelbach.de/ot/mot_wagonWheel/index.html)

Source: L. Zhang

Nyquist limit – 2D example



Good sampling



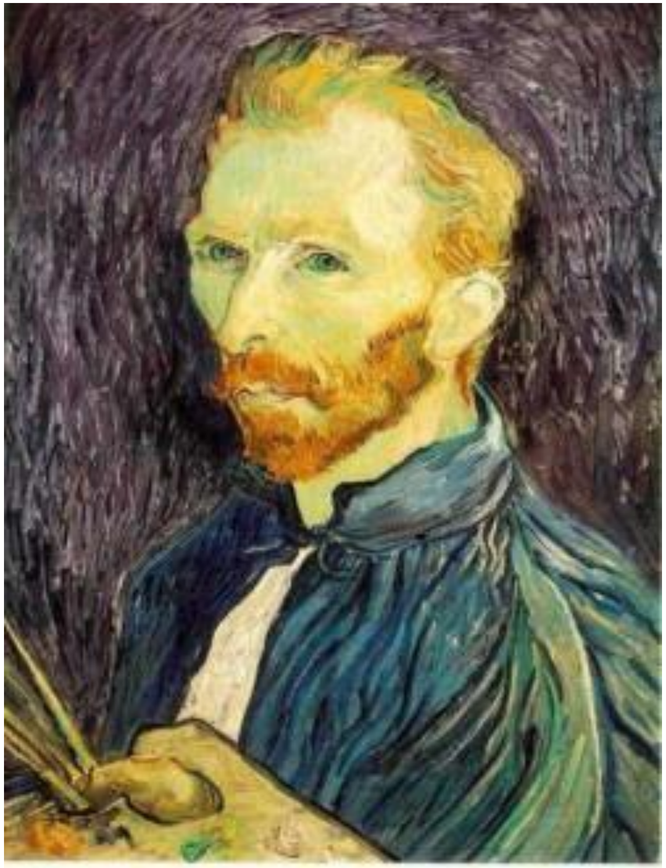
Bad sampling

Aliasing

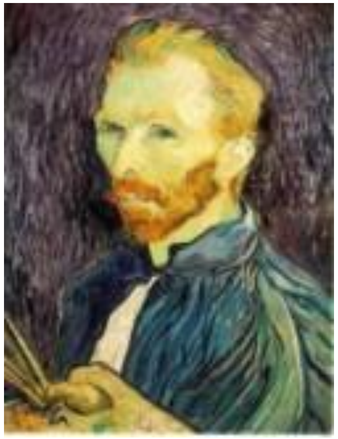
- When downsampling by a factor of two
  - Original image has frequencies that are too high

- How can we fix this?

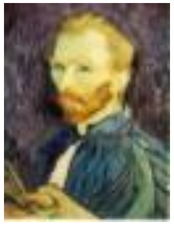
Gaussian pre-filtering



Gaussian 1/2



G 1/4

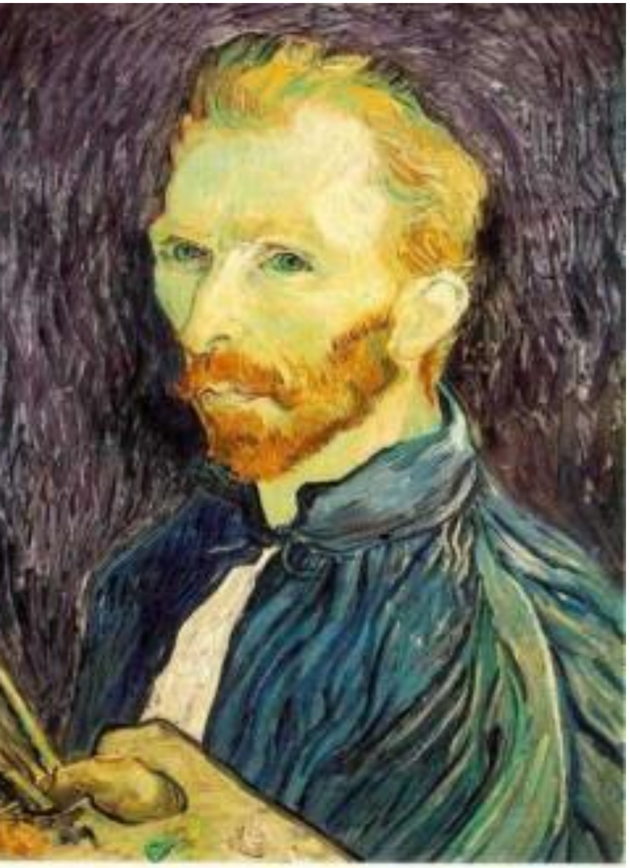


G 1/8

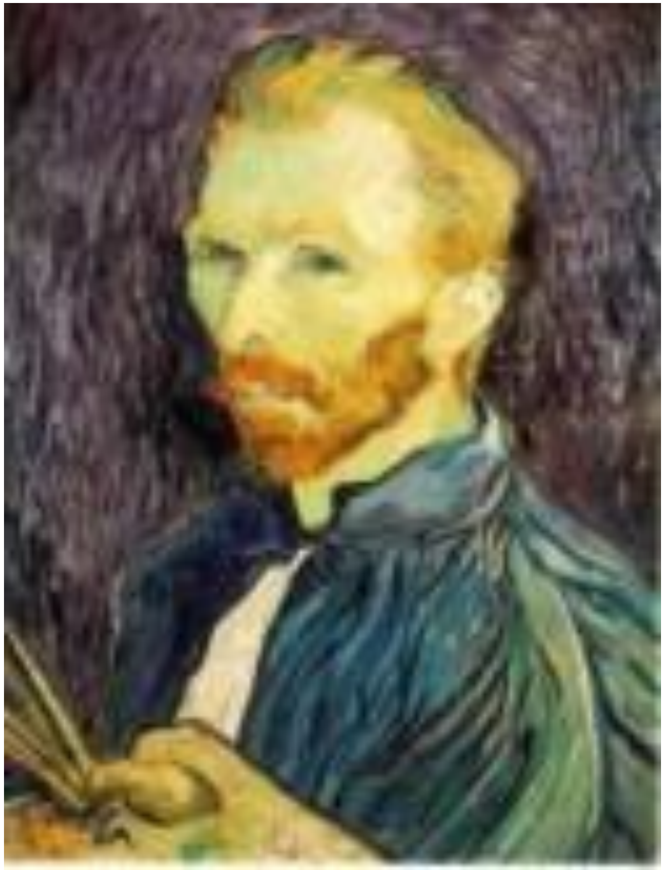
- Solution: filter the image, *then* subsample

Source: S. Seitz

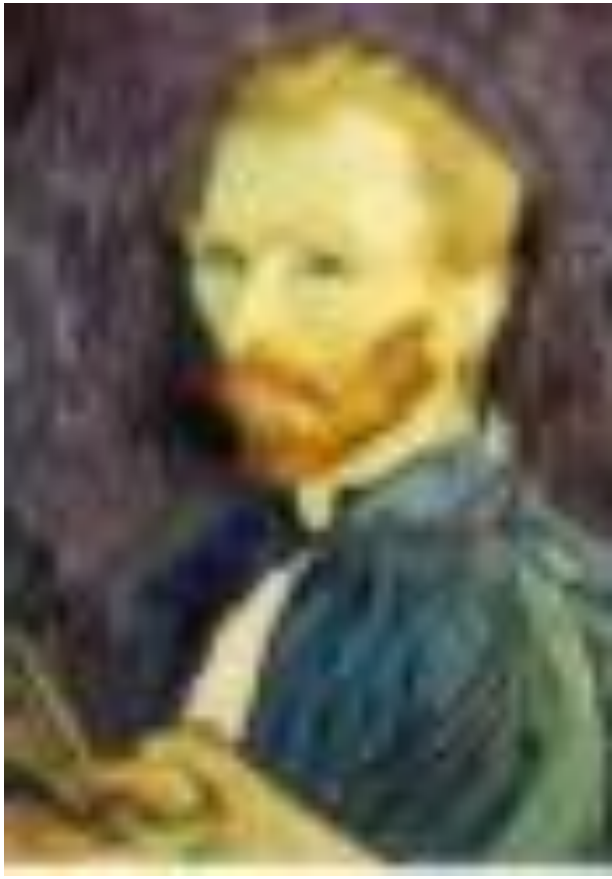
Subsampling with Gaussian pre-filtering



Gaussian 1/2



G 1/4

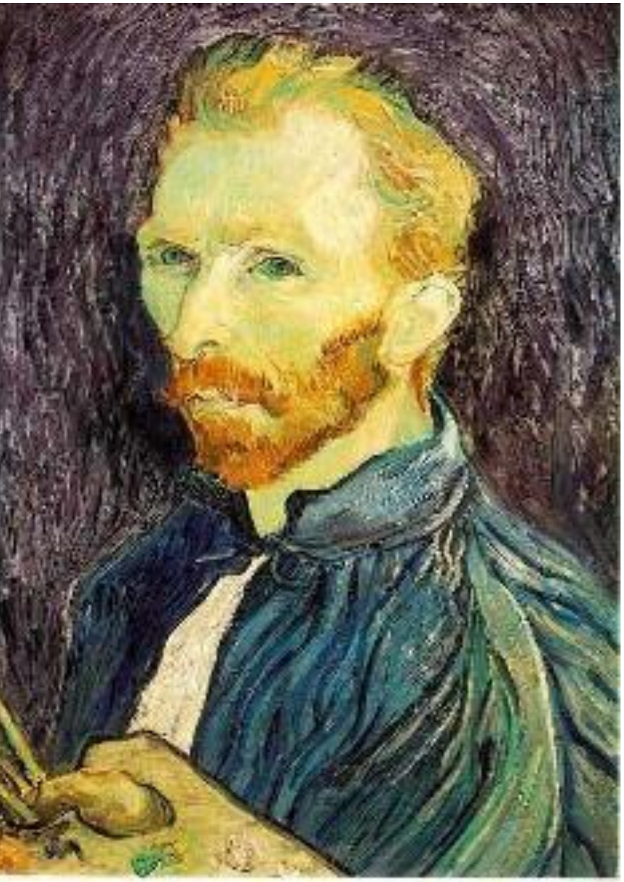


G 1/8

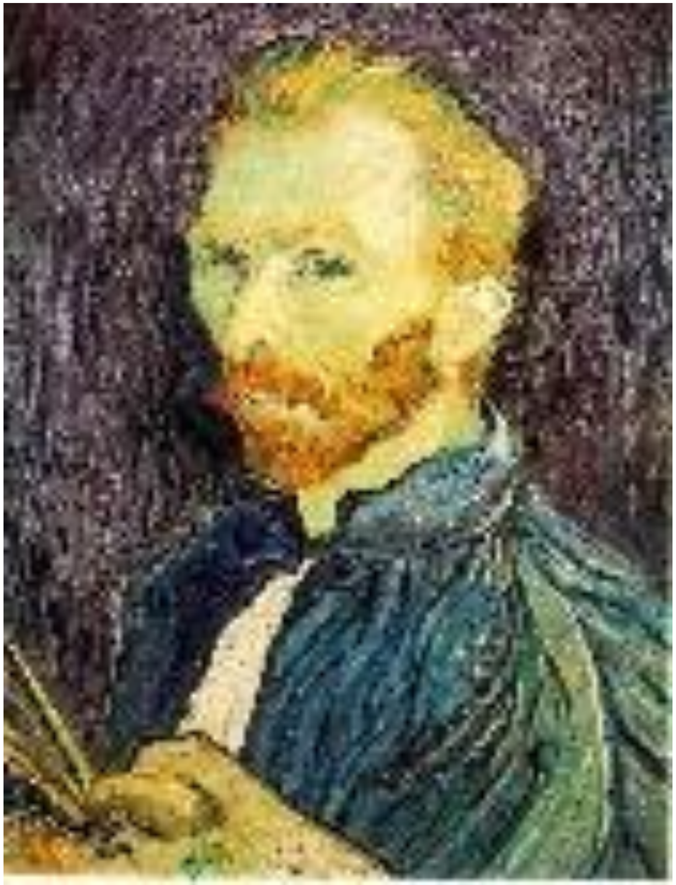
- Solution: filter the image, *then* subsample

Source: S. Seitz

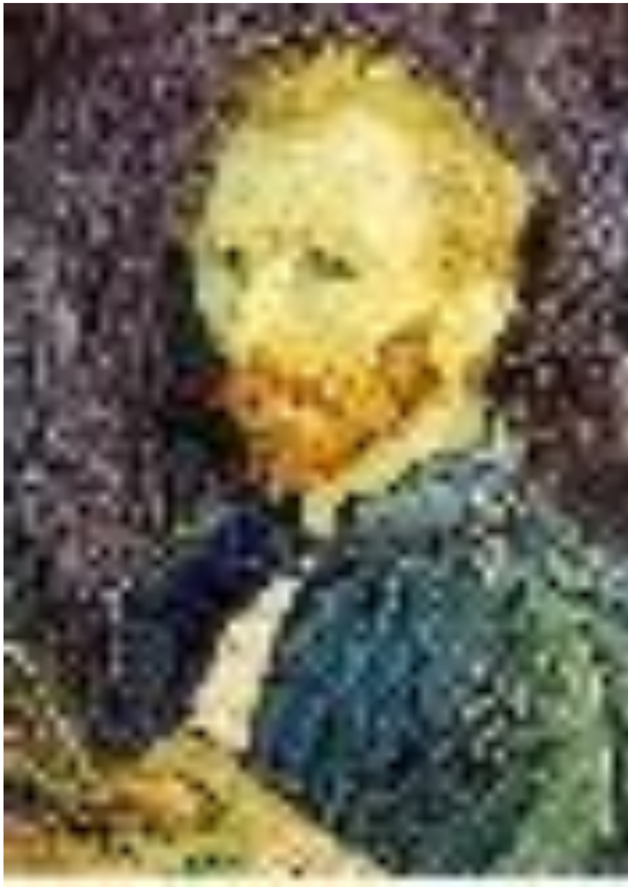
Compare with...



1/2



1/4 (2x zoom)

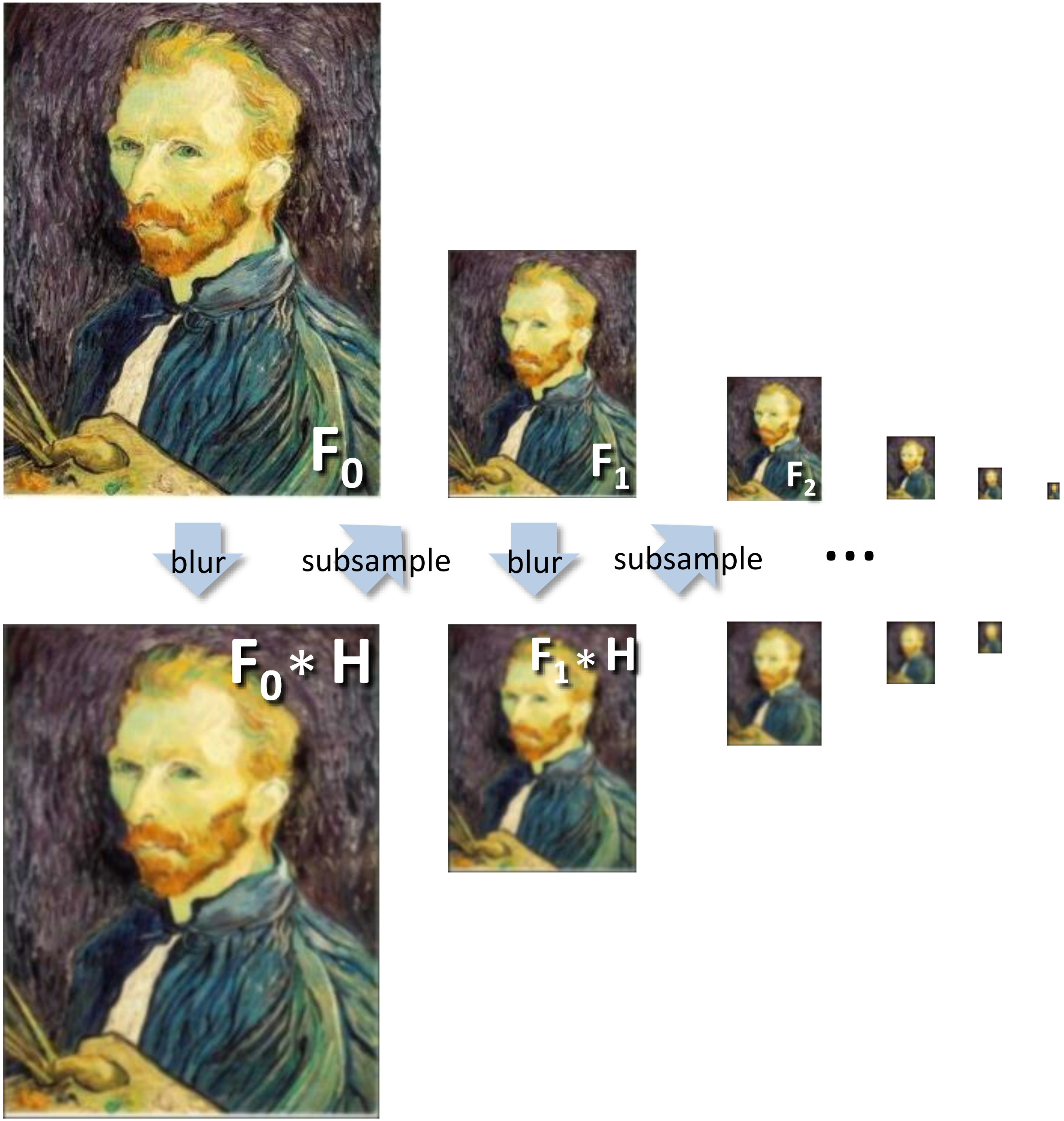


1/8 (4x zoom)

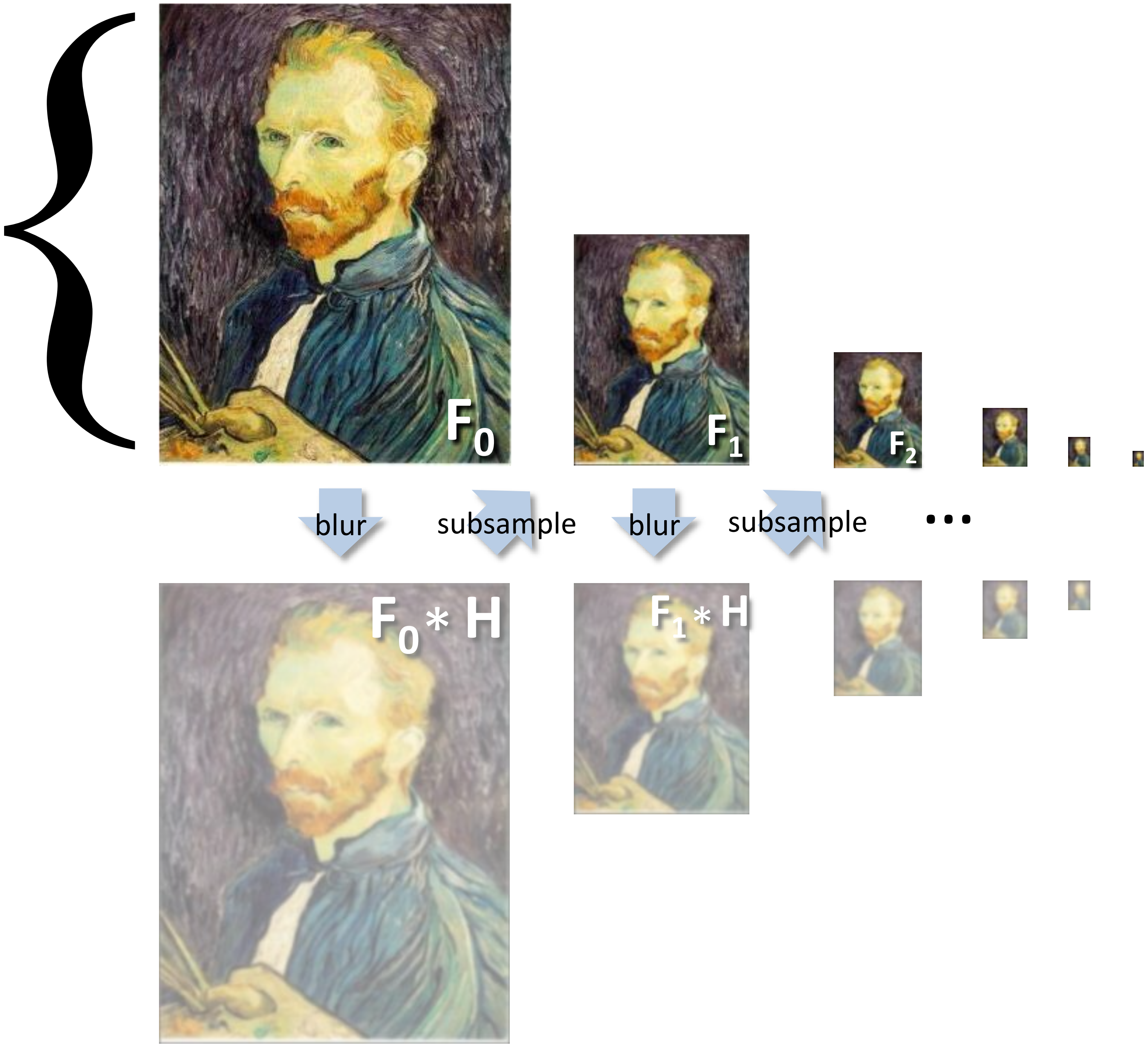
Source: S. Seitz

Gaussian pre-filtering

- Solution: filter the image, *then* subsample



Gaussian pyramid

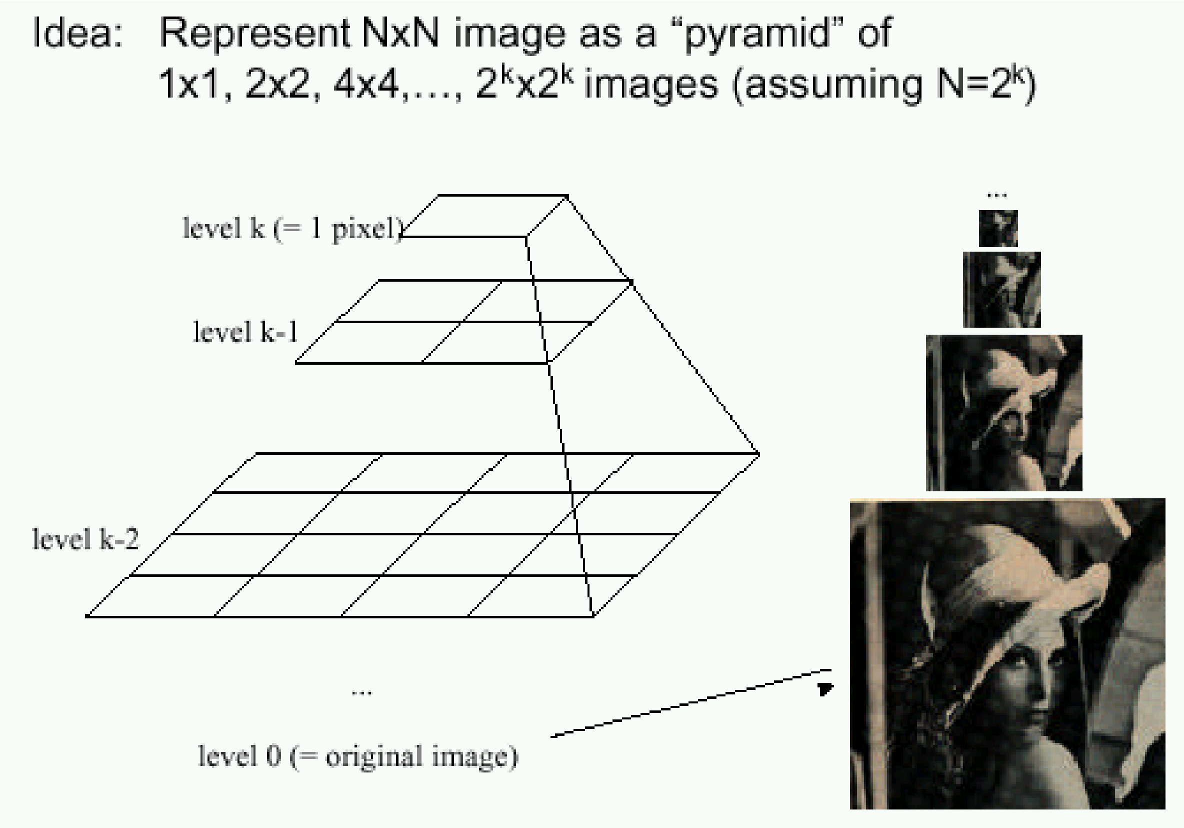


F_0 F_1 F_2

blur subsample blur subsample …

$F_0 * H$ $F_1 * H$

Gaussian pyramids
[Burt and Adelson, 1983]



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

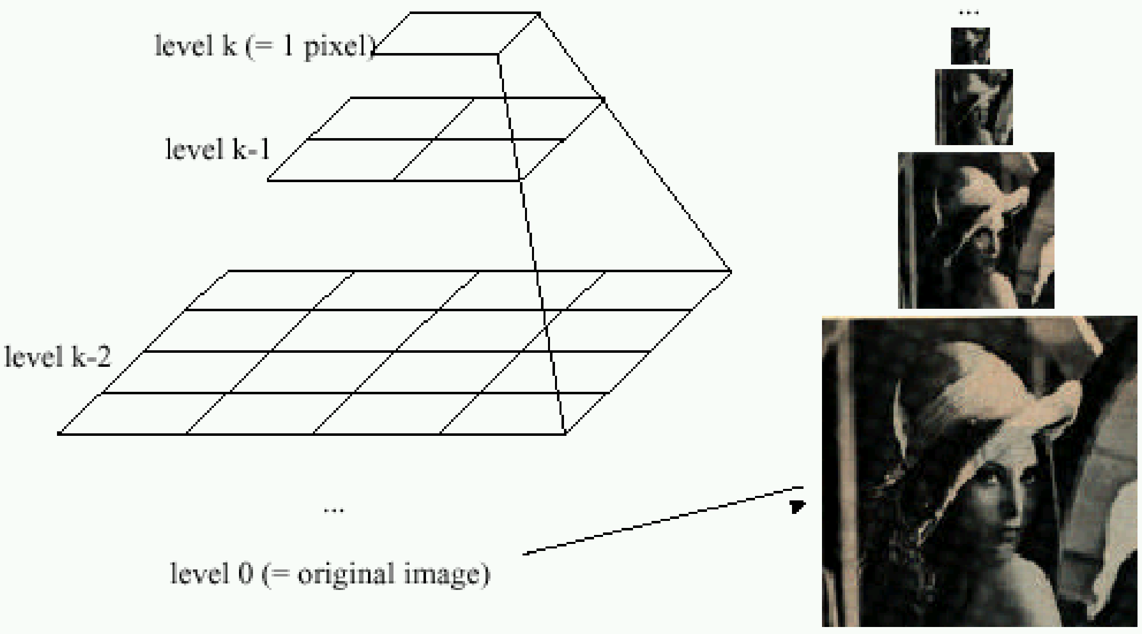
- In computer graphics, a *mip map* [Williams, 1983]
- A precursor to *wavelet transform*

Gaussian Pyramids have all sorts of applications in computer vision

Source: S. Seitz

Gaussian pyramids [Burt and Adelson, 1983]

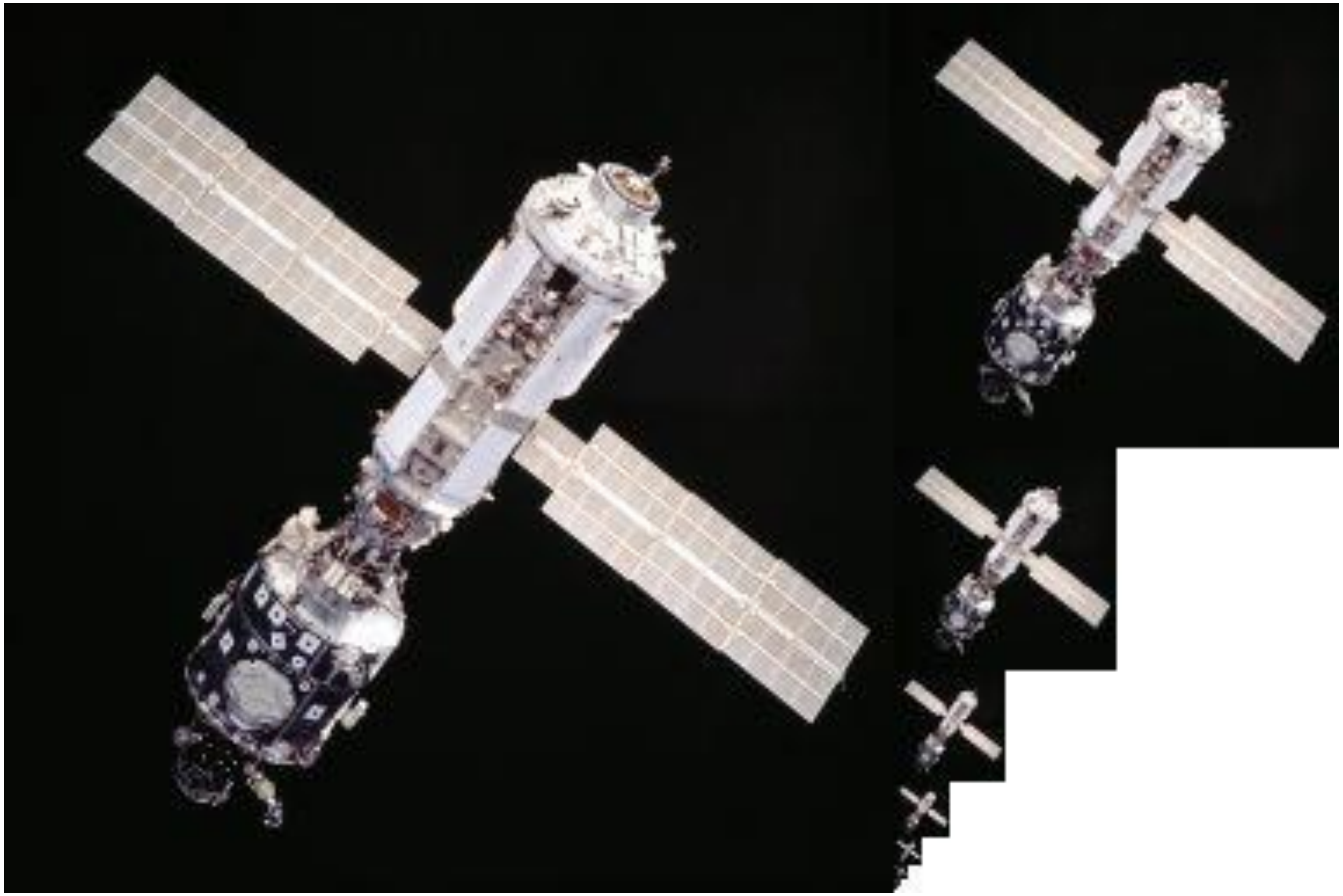
Idea: Represent NxN image as a “pyramid” of 1x1, 2x2, 4x4,…, 2^kx2^k images (assuming N=2^k)



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

Source: S. Seitz

Gaussian Pyramid



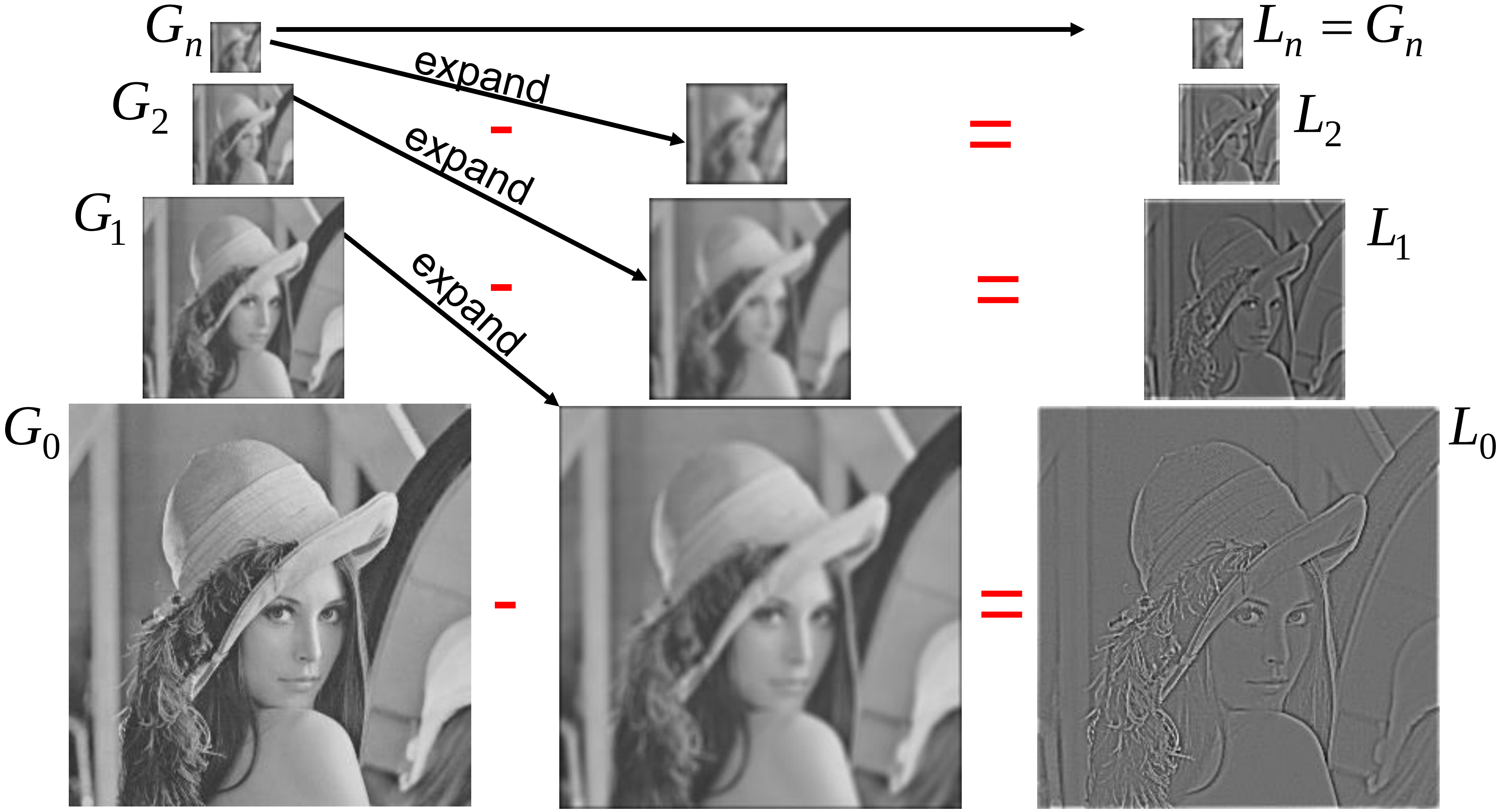
The Laplacian Pyramid

$$L_i = G_i - \mathrm{expand}(G_{i+1})$$

Gaussian Pyramid

$$G_i = L_i + \mathrm{expand}(G_{i+1})$$

Laplacian Pyramid



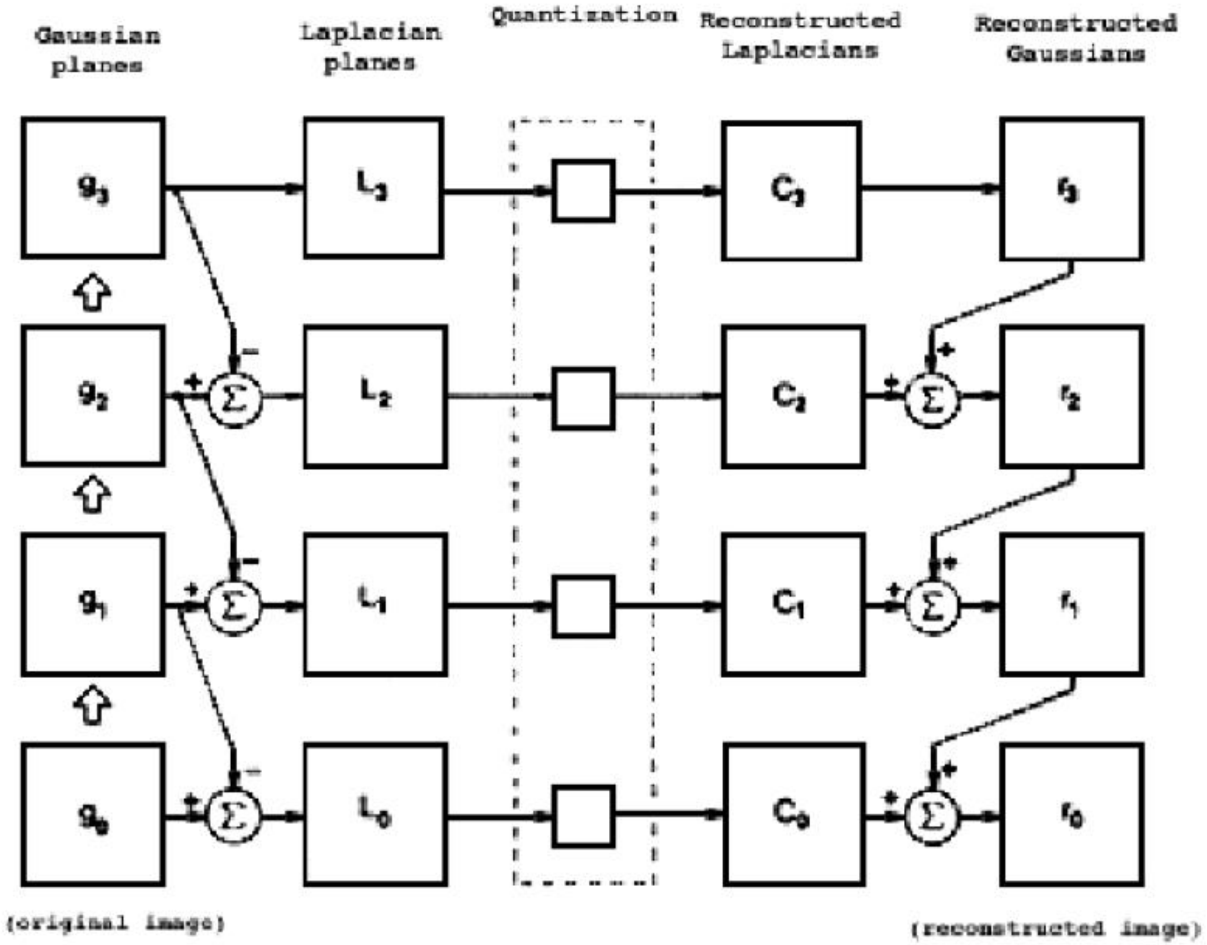


Fig. 10. A summary of the steps in Laplacian pyramid coding and decoding. First, the original image g_0 (lower left) is used to generate Gaussian pyramid levels g_1, g_2, … through repeated local averaging. Levels of the Laplacian pyramid L_0, L_1, … are then computed as the differences between adjacent Gaussian levels. Laplacian pyramid elements are quantized to yield the Laplacian pyramid code C_0, C_1, C_2, …. Finally, a reconstructed image r_0 is generated by summing levels of the code pyramid.

Questions?

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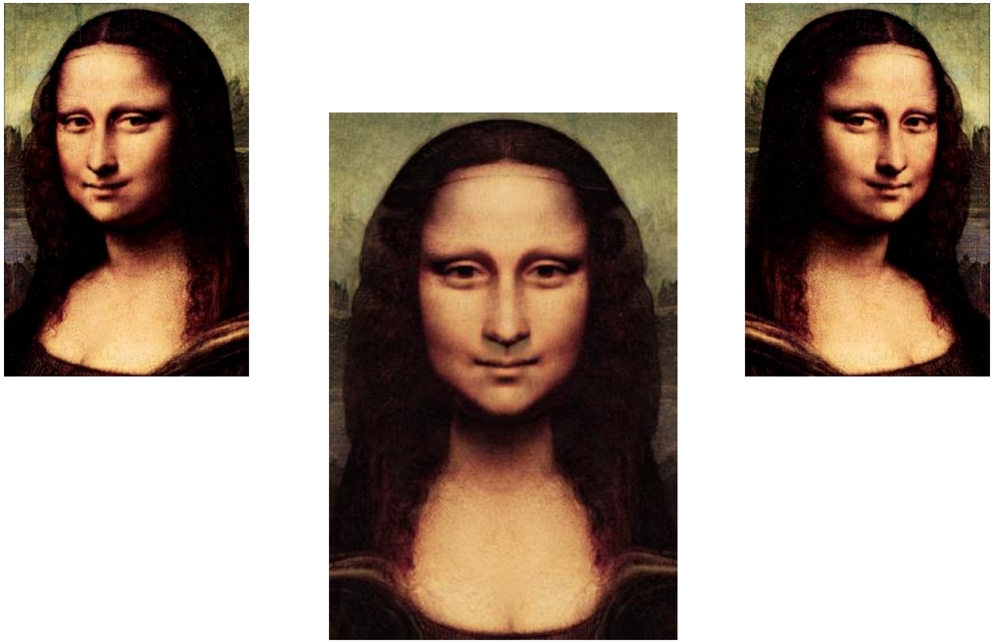
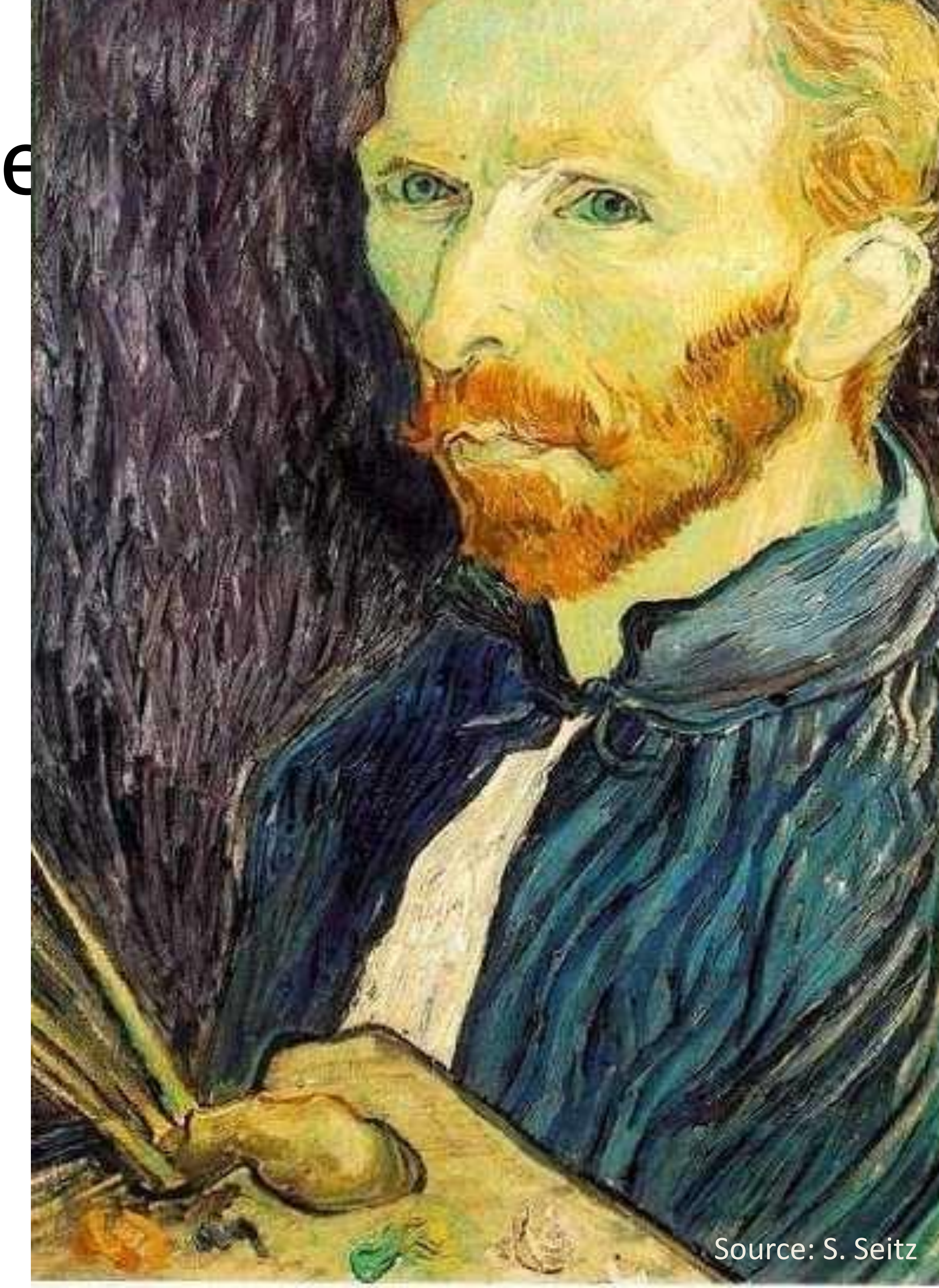
Image Interpolation



Image

Last time:

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



Source: S. Seitz

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”)

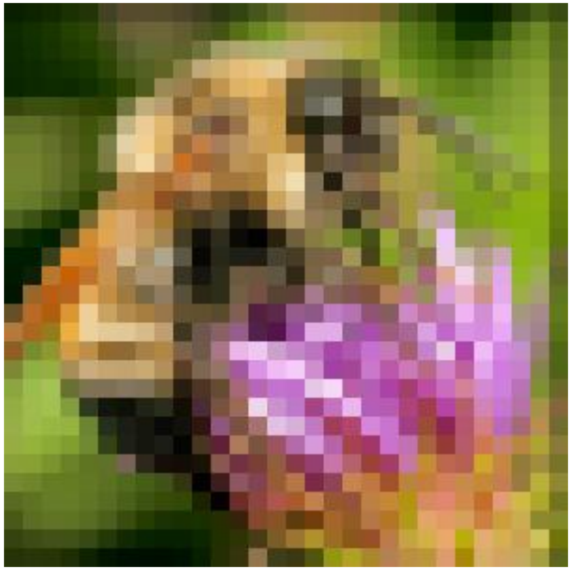
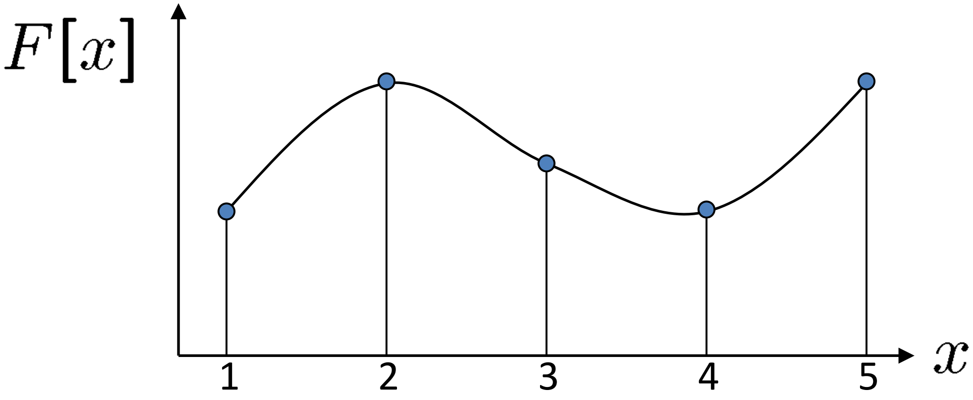


Image interpolation



d = 1 in this example

Recall how a digital image is formed

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

- 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

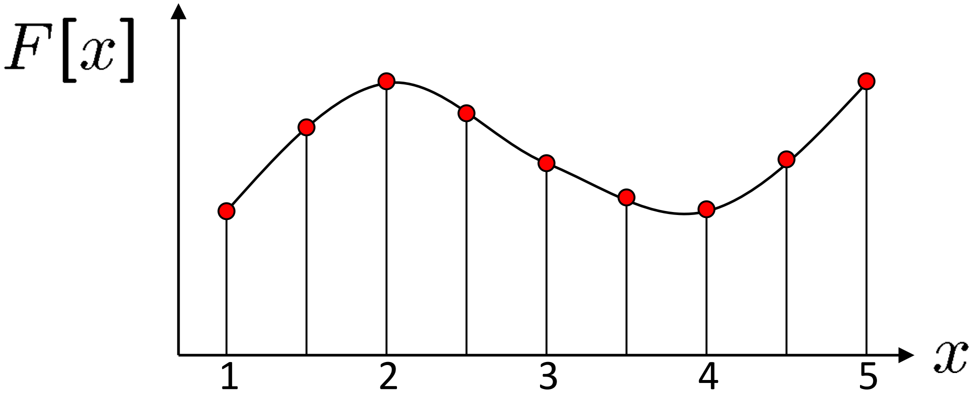


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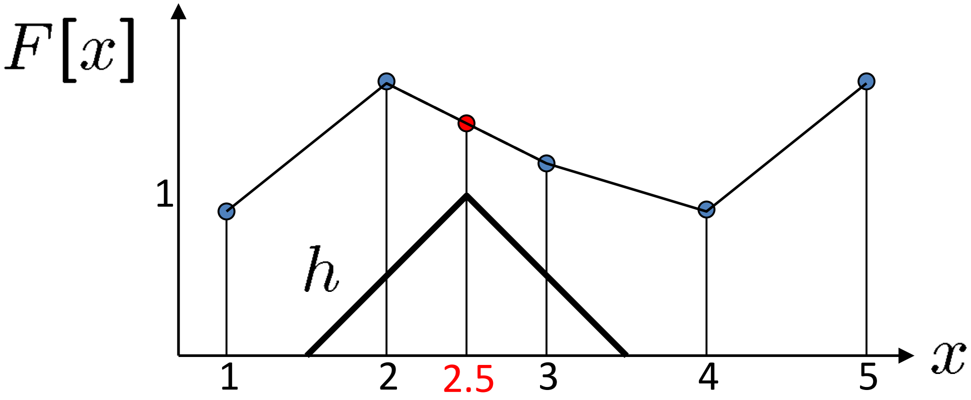
Image interpolation



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:

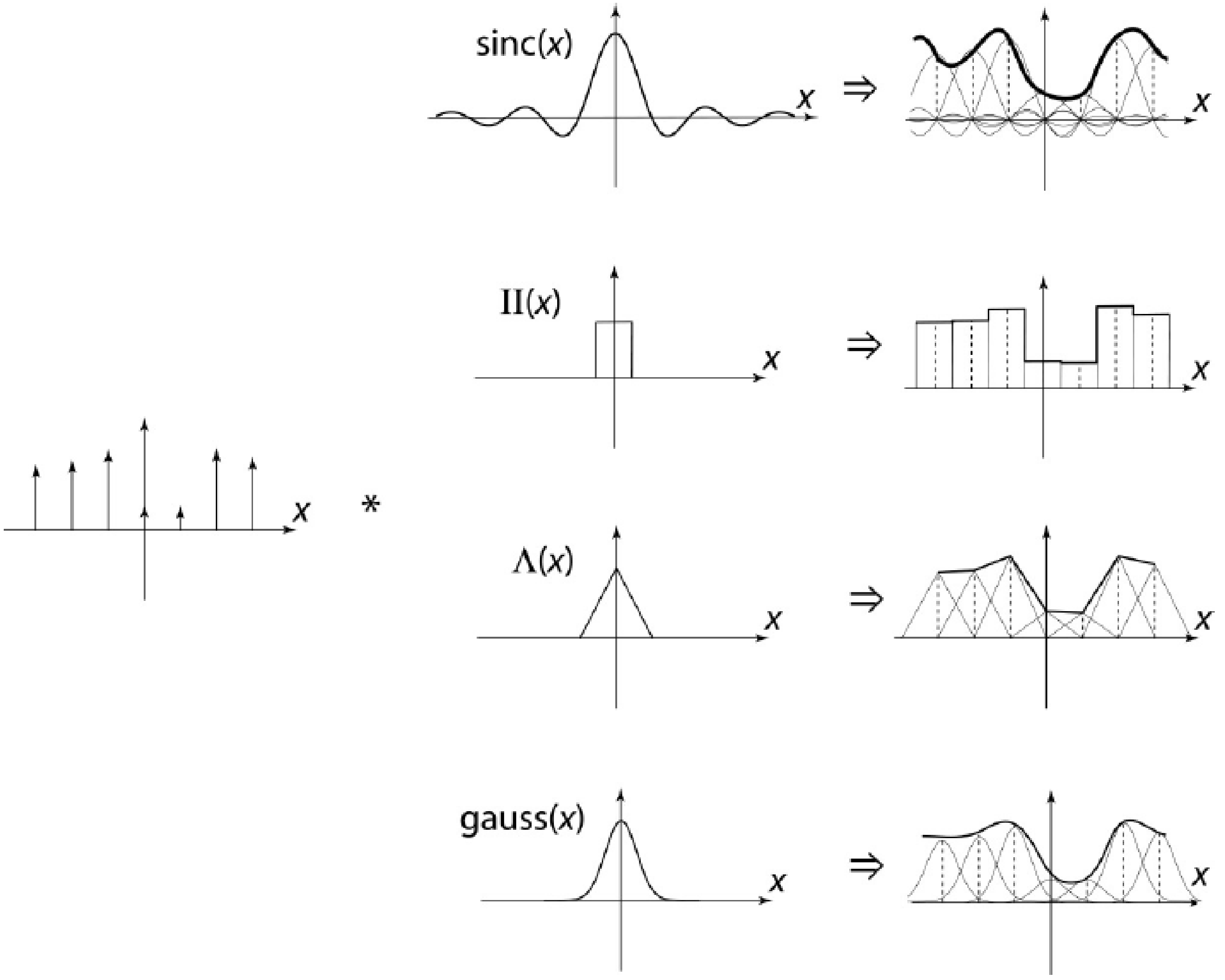
$$f_F(x) = F(\tfrac{x}{d}) \text{ when } \tfrac{x}{d} \text{ is an integer, 0 otherwise}$$

  - 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

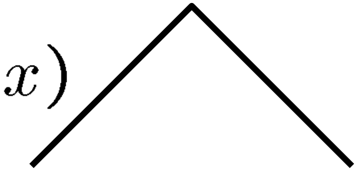
Gaussian reconstruction

Source: B. Curless

Reconstruction filters

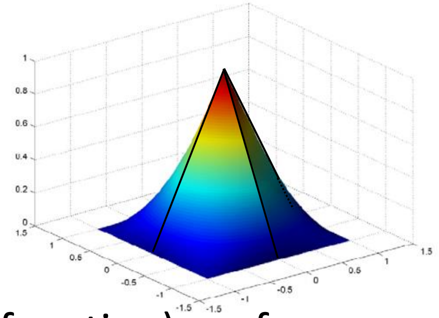
- What does the 2D version of this hat function look like?

$h(x)$



performs
linear interpolation

$h(x, y)$



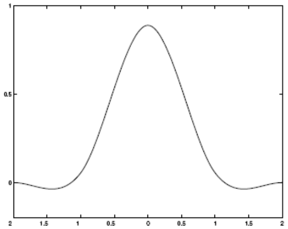
(tent function) performs
bilinear interpolation

Often implemented without cross-correlation

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

Better filters give better resampled images

- **Bicubic** is common choice

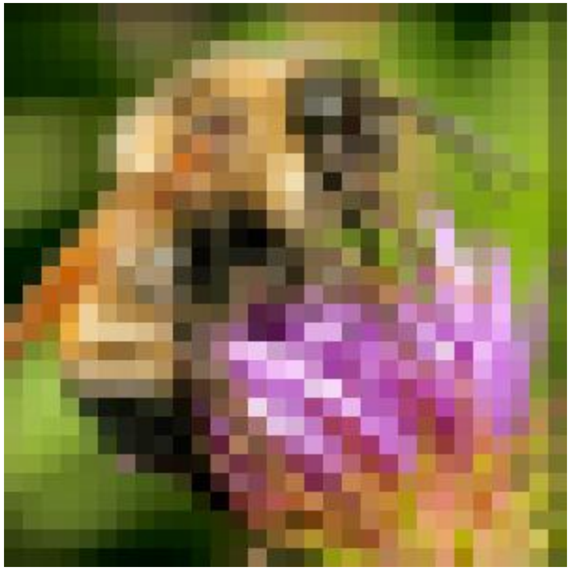


Cubic reconstruction filter

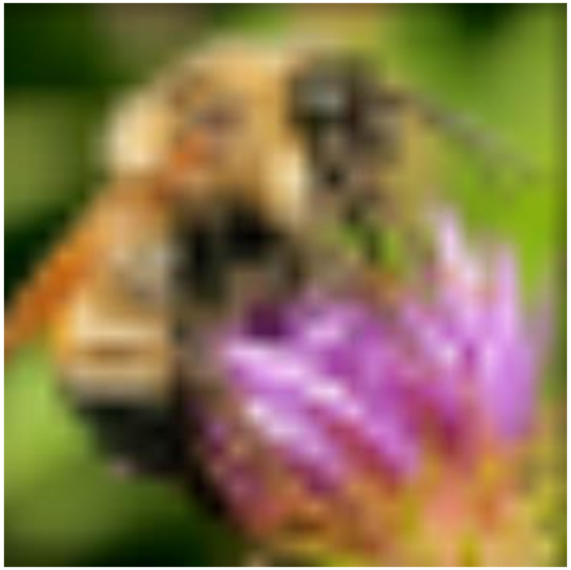
$$r(x) = \frac{1}{6}\begin{cases} (12-9B-6C)|x|^3 + (-18+12B+6C)|x|^2 + (6-2B) & |x| < 1 \\ ((-B-6C)|x|^3 + (6B+30C)|x|^2 + (-12B-48C)|x| + (8B+24C) & 1 \le |x| < 2 \\ 0 & \textit{otherwise} \end{cases}$$

Image interpolation

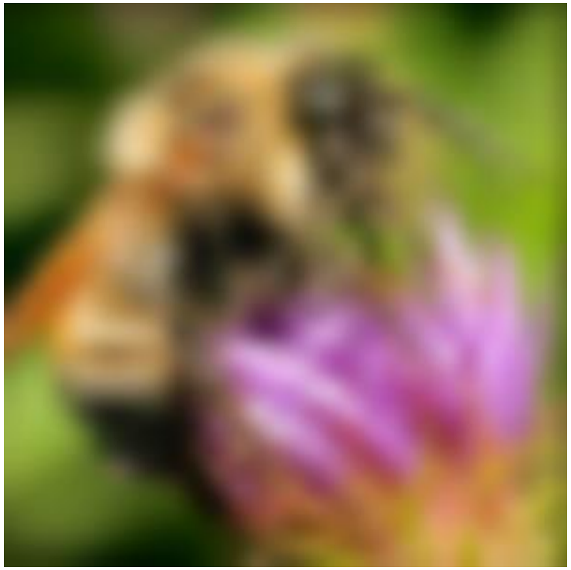
Original image: x 10



Nearest-neighbor interpolation



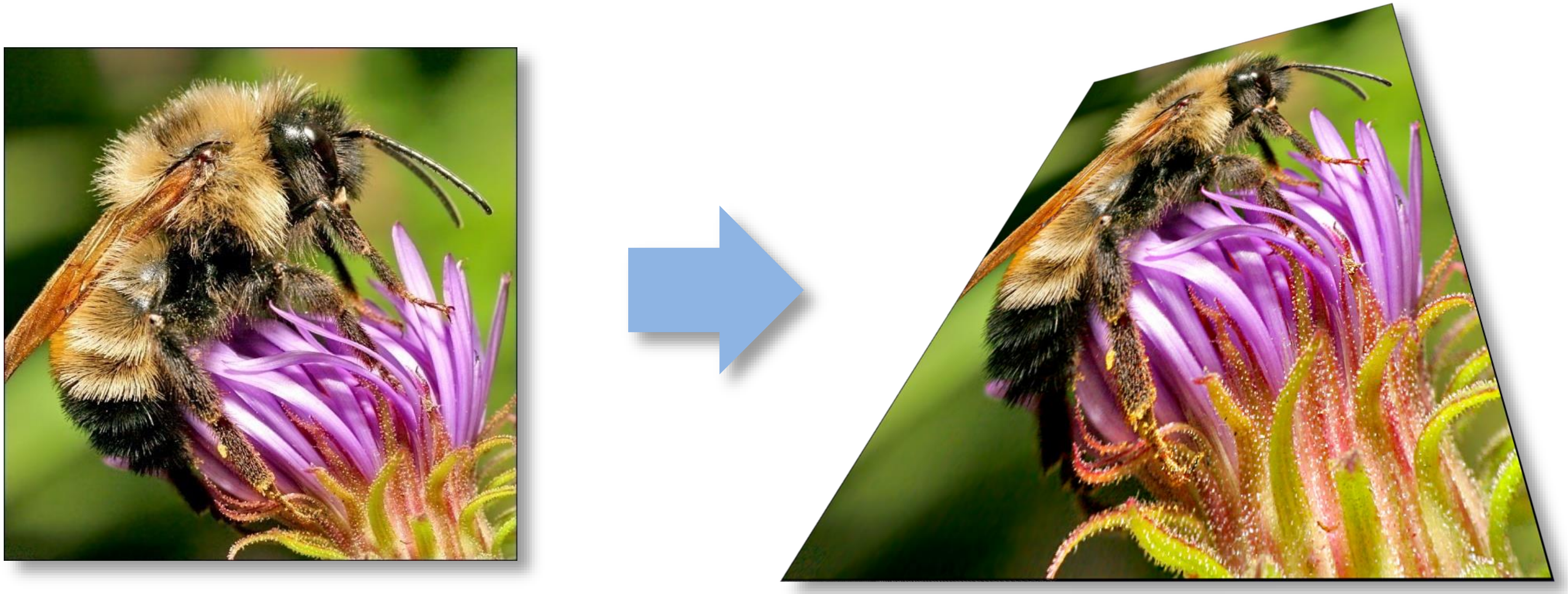
Bilinear interpolation



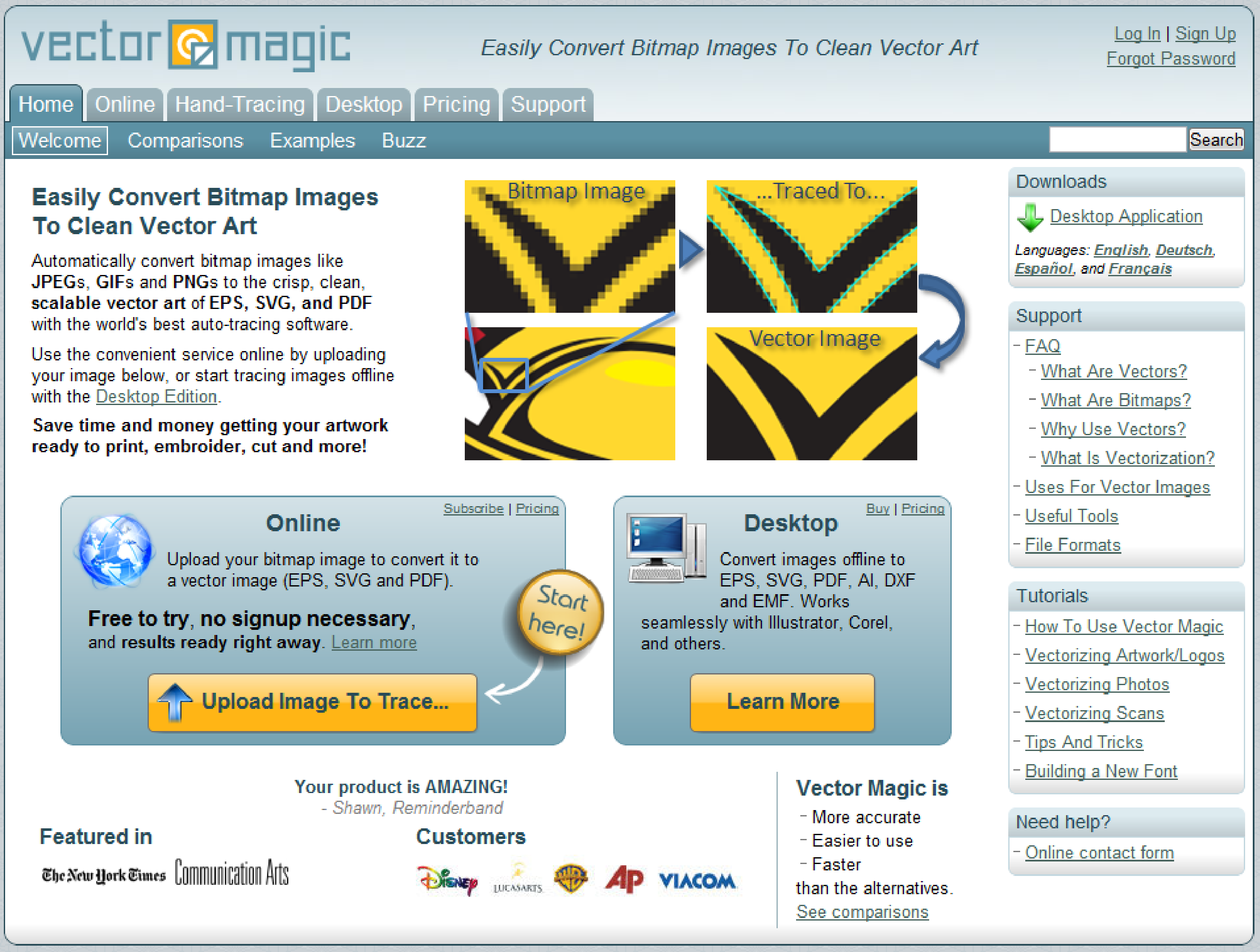
Bicubic interpolation

Image interpolation

Also used for *resampling*



Raster to Vector Graphics



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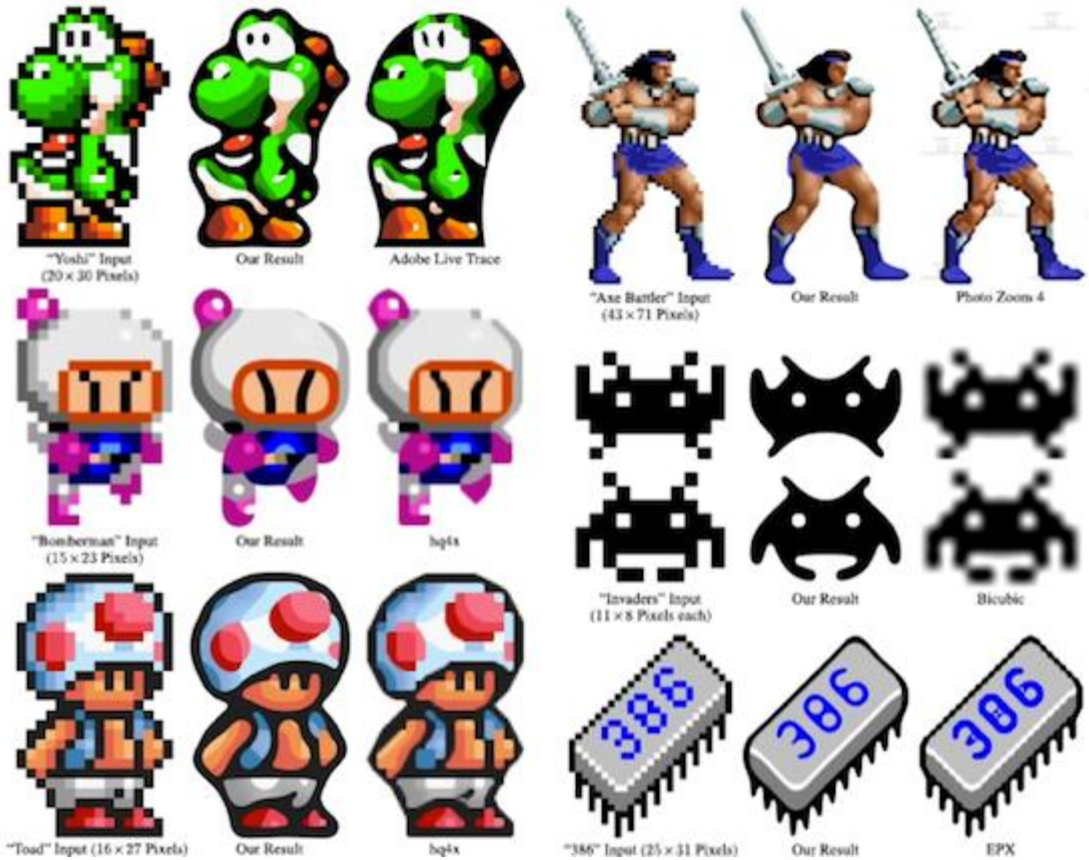
Depixelating Pixel Art



"Yoshi" Input (20 × 30 Pixels)

Our Result

Adobe Live Trace

"Axe Battler" Input (43 × 71 Pixels)

Our Result

Photo Zoom 4

"Bomberman" Input (15 × 23 Pixels)

Our Result

hq4x

"Invaders" Input (11 × 8 Pixels each)

Our Result

Bicubic

"Toad" Input (16 × 27 Pixels)

Our Result

hq4x

"386" Input (25 × 31 Pixels)

Our Result

EPX

Questions?