

Antialiasing

CS4620 Lecture 23

Pixel coverage

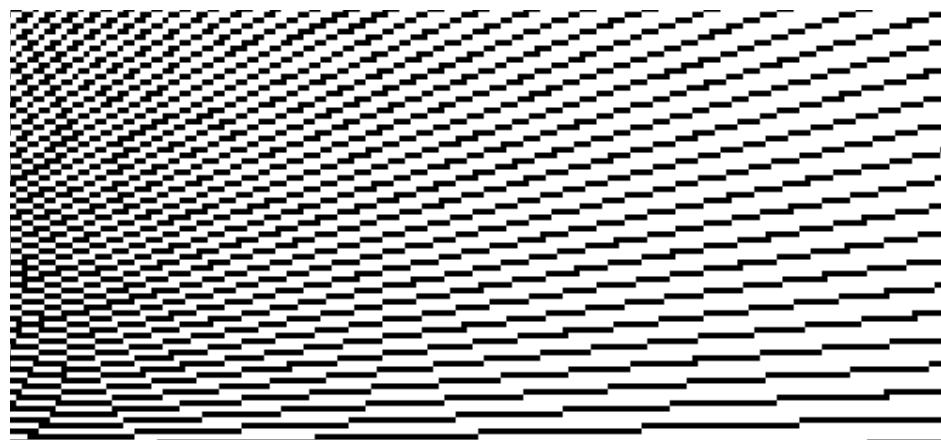
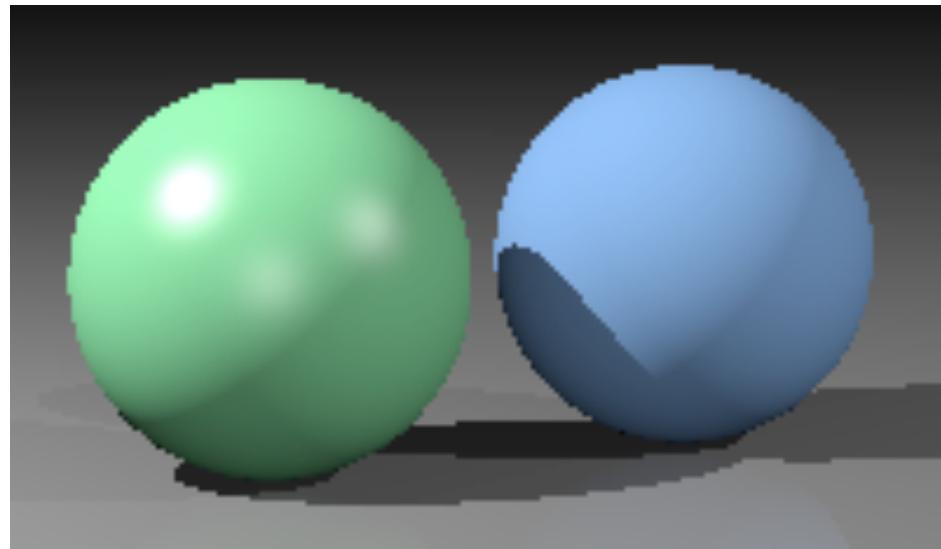
- Antialiasing and compositing both deal with questions of pixels that contain unresolved detail
- Antialiasing: how to carefully throw away the detail
- Compositing: how to account for the detail when combining images

Aliasing

point sampling a
continuous image:

continuous image defined
by ray tracing procedure

continuous image defined
by a bunch of black rectangles

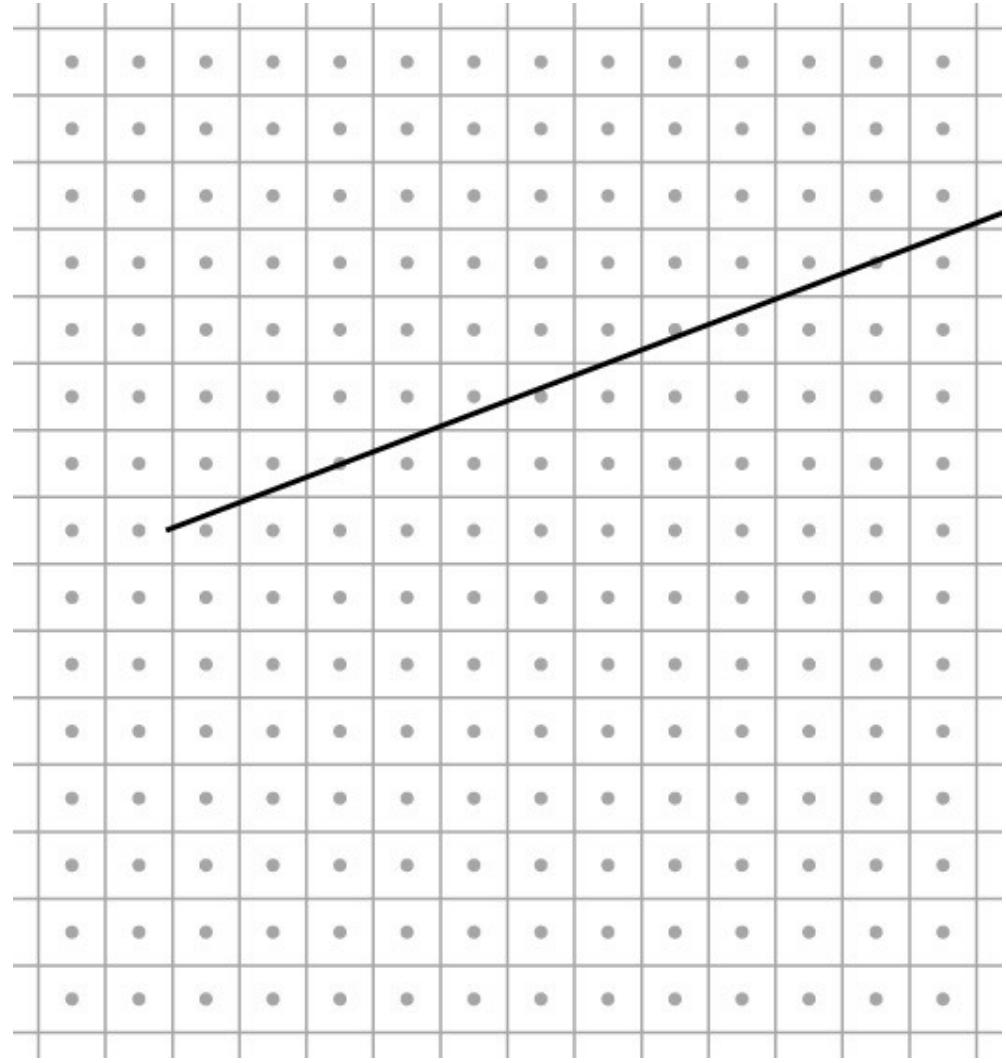


Antialiasing

- A name for techniques to prevent aliasing
- In image generation, we need to *filter*
 - Boils down to averaging the image over an area
 - Weight by a filter
- Methods depend on source of image
 - Rasterization (lines and polygons)
 - Point sampling (e.g. raytracing)
 - Texture mapping

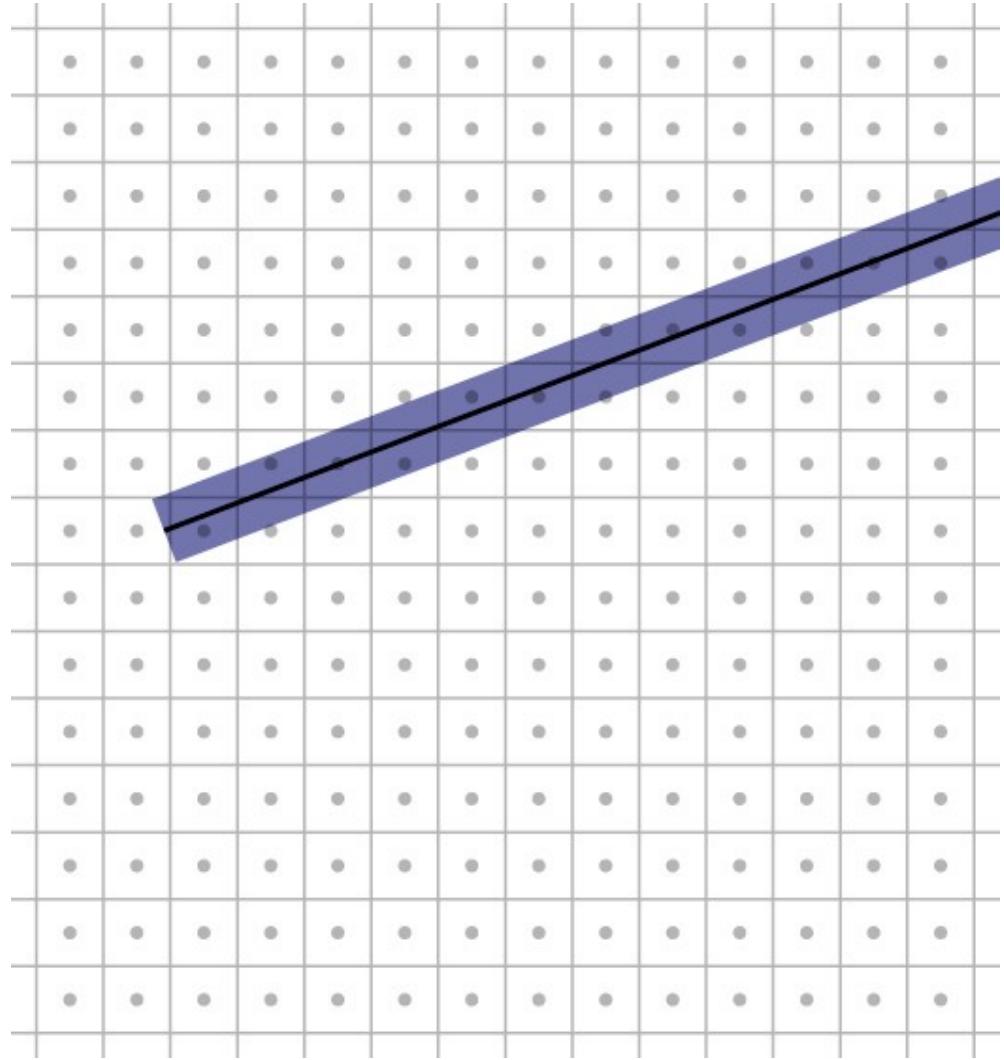
Rasterizing lines

- Define line as a rectangle
- Specify by two endpoints
- Ideal image: black inside, white outside



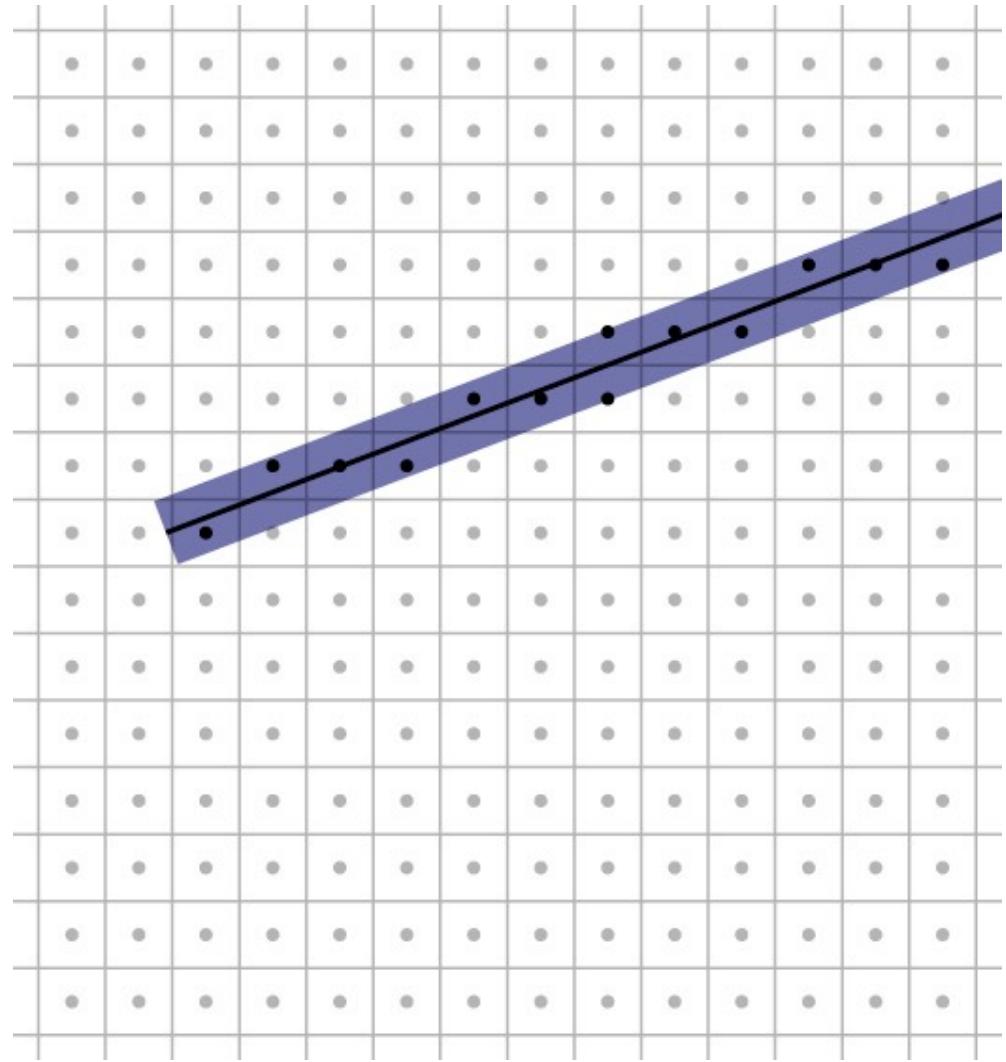
Rasterizing lines

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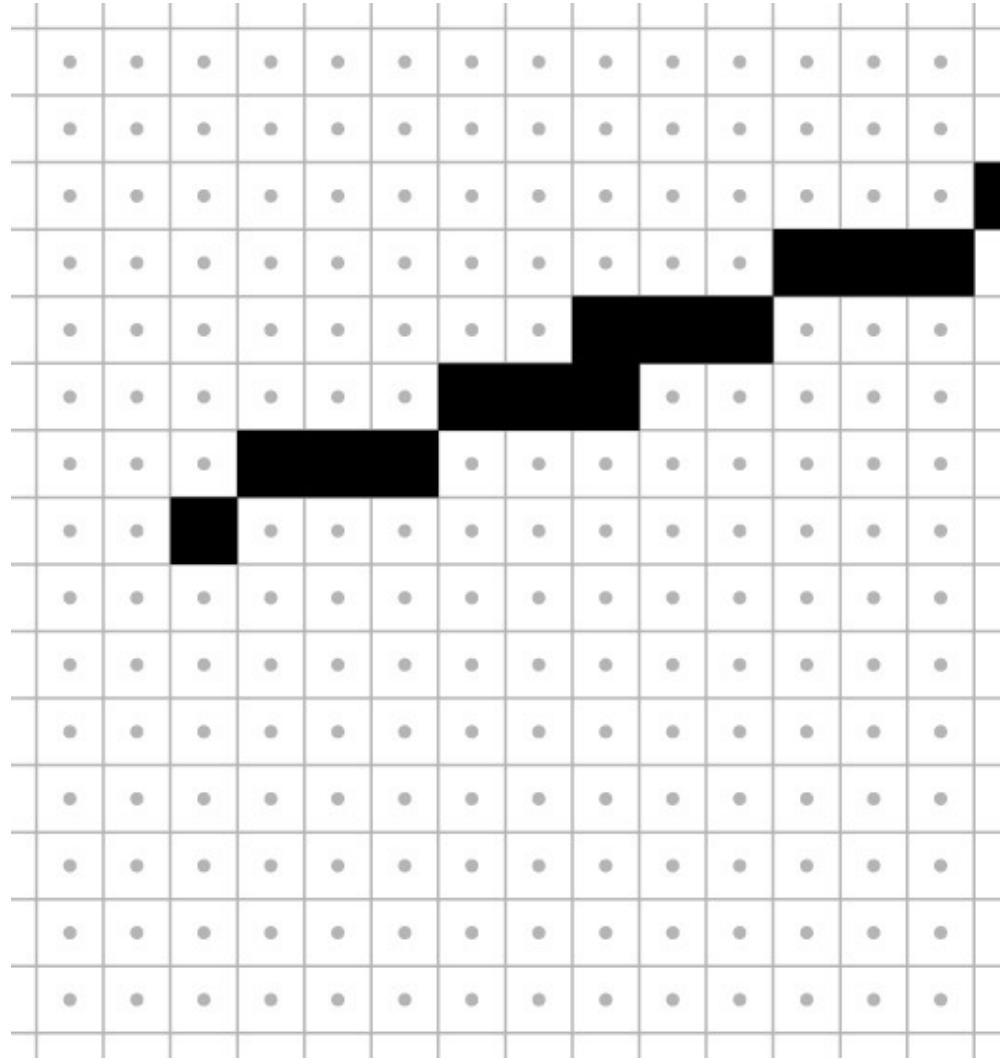
Point sampling

- Approximate rectangle by drawing all pixels whose centers fall within the line
- Problem: all-or-nothing leads to jaggies
 - this is sampling with no filter (aka. point sampling)

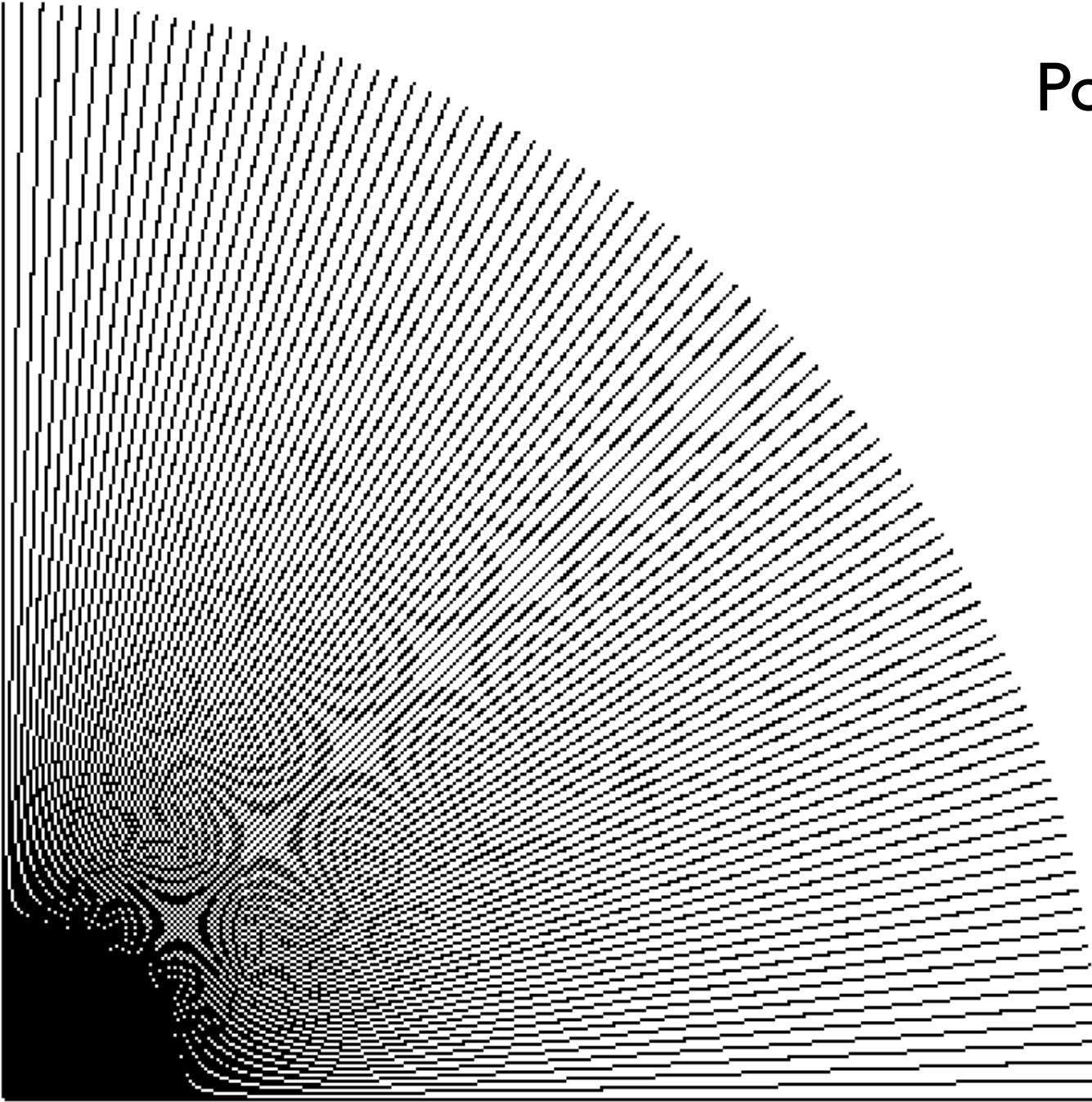


Point sampling

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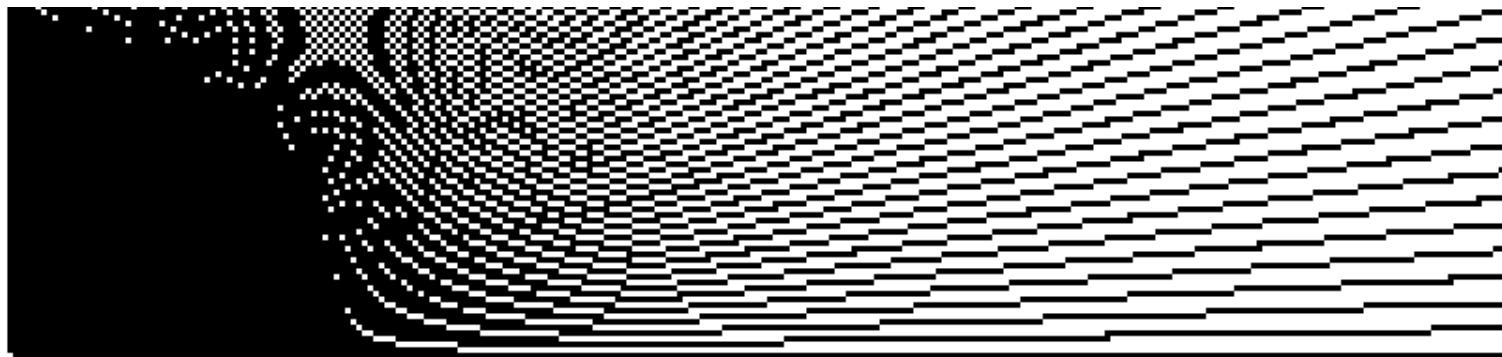


Point sampling in action



Aliasing

- Point sampling is fast and simple
- But the lines have stair steps and variations in width
- This is an aliasing phenomenon
 - Sharp edges of line contain high frequencies
- Introduces features to image that are not supposed to be there!

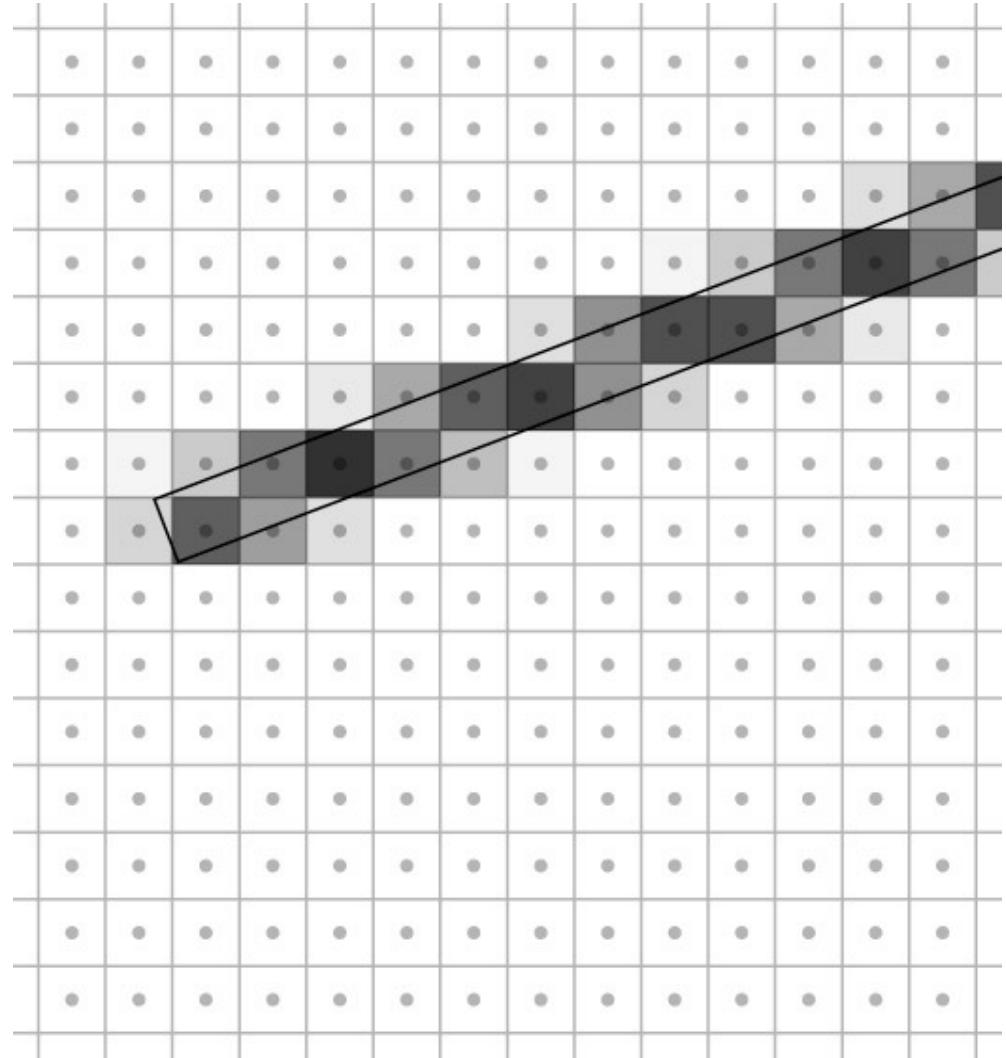


Antialiasing

- Point sampling makes an all-or-nothing choice in each pixel
 - therefore steps are inevitable when the choice changes
 - yet another example where discontinuities are bad
- On bitmap devices this is necessary
 - hence high resolutions required
 - 600+ dpi in laser printers to make aliasing invisible
- On continuous-tone devices we can do better

Antialiasing

- Basic idea: replace “is the image black at the pixel center?” with “how much is pixel covered by black?”
- Replace yes/no question with quantitative question.

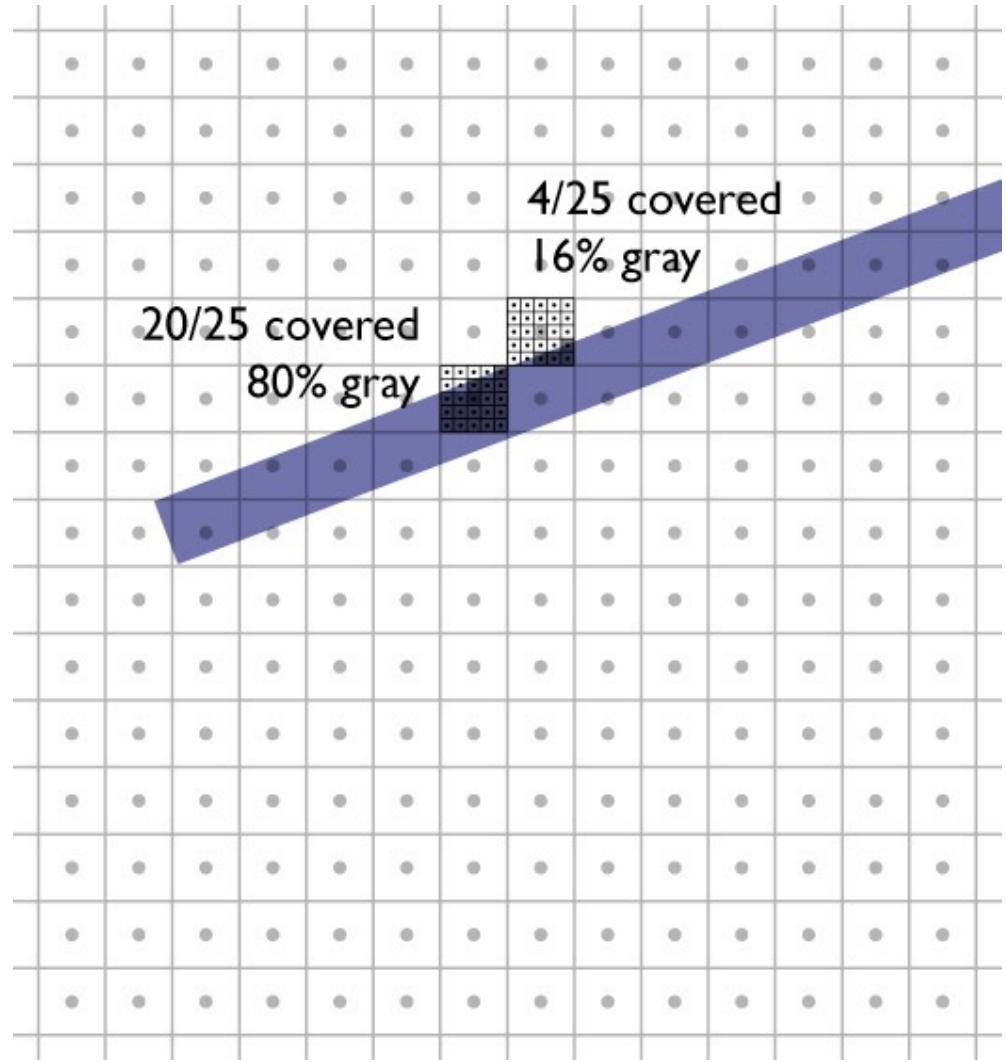


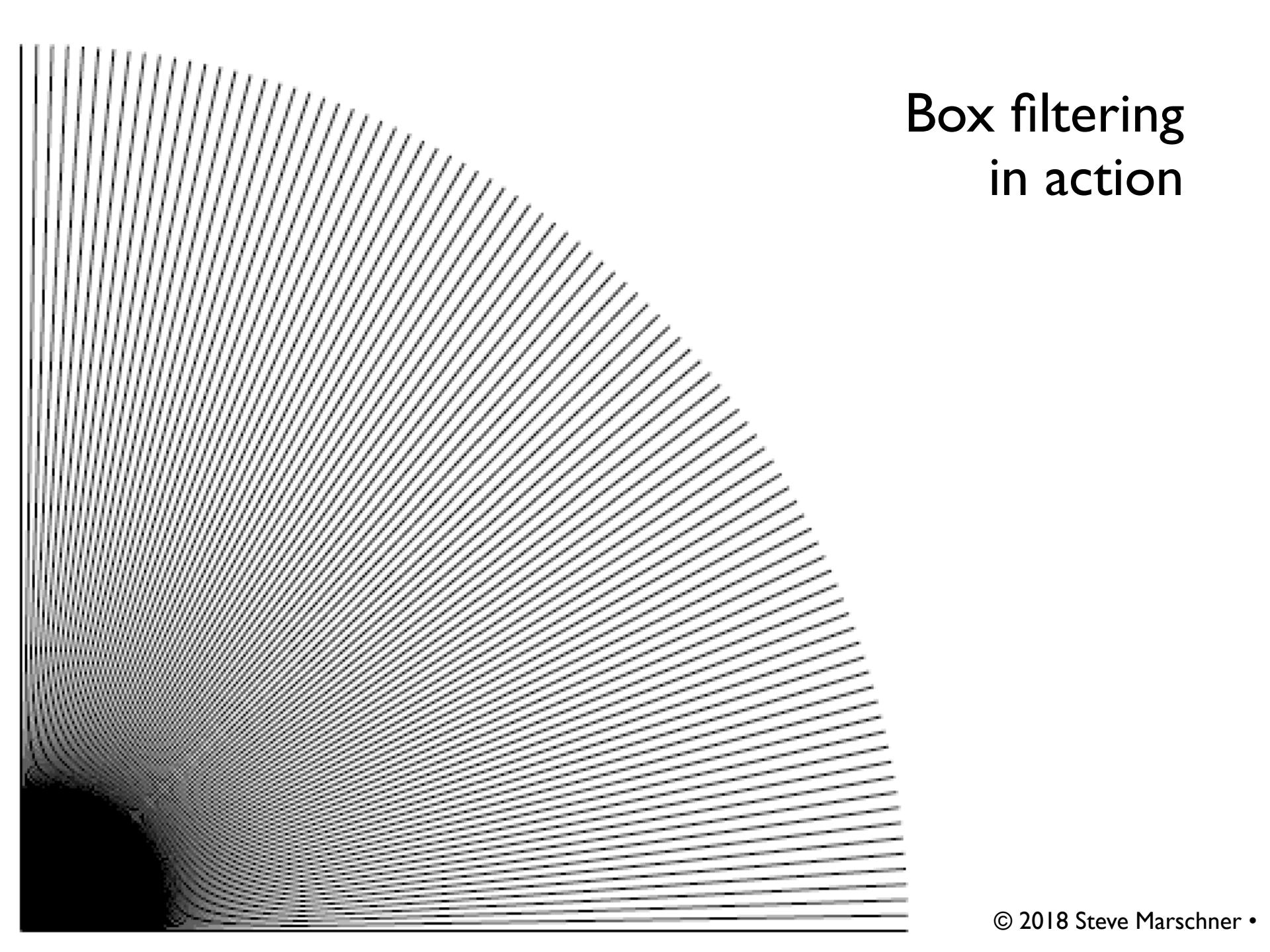
Box filtering

- Pixel intensity is proportional to area of overlap with square pixel area
- Also called “unweighted area averaging”

Box filtering by supersampling

- Compute coverage fraction by counting subpixels
- Simple, accurate
- But slow





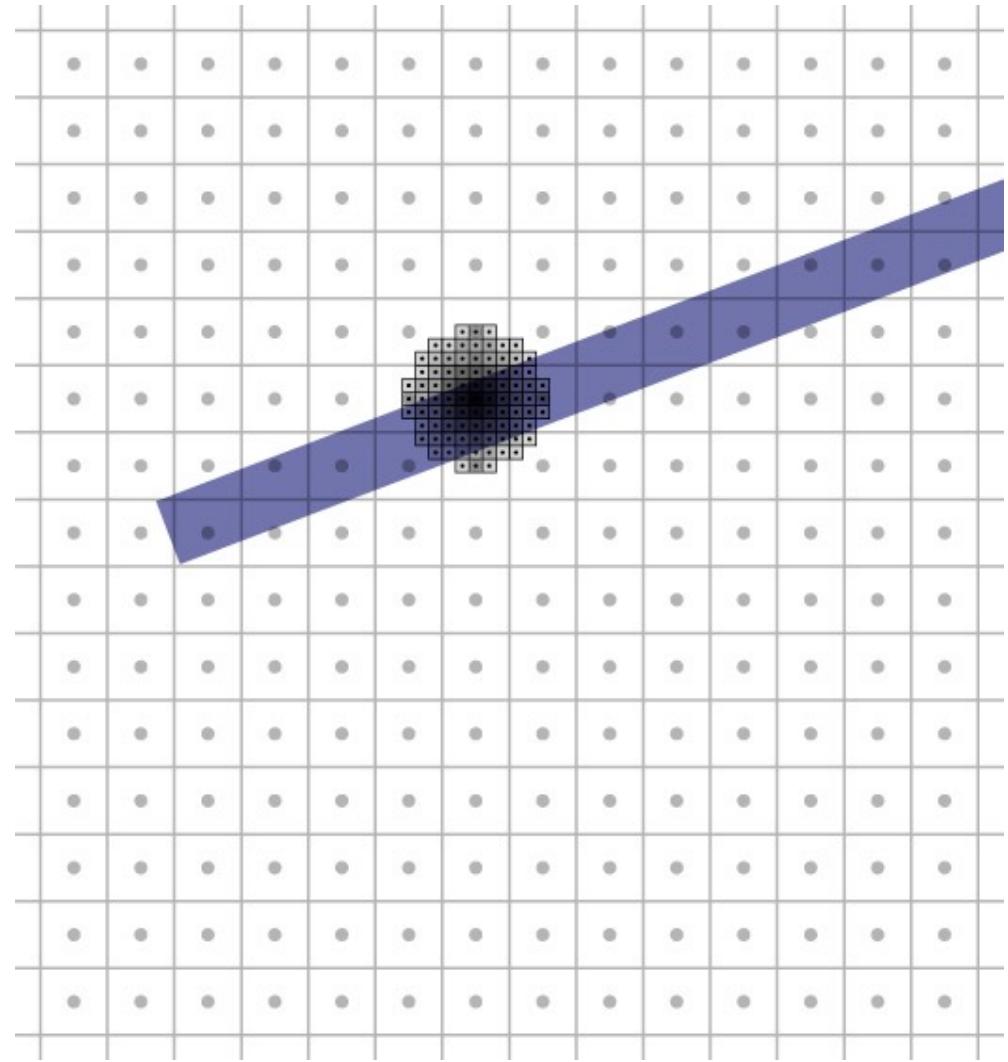
Box filtering in action

Weighted filtering

- Box filtering problem: treats area near edge same as area near center
 - results in pixel turning on “too abruptly”
- Alternative: weight area by a smooth function
 - unweighted averaging corresponds to using a box function
 - a gaussian is a popular choice of smooth filter
 - important property: normalization (unit integral)

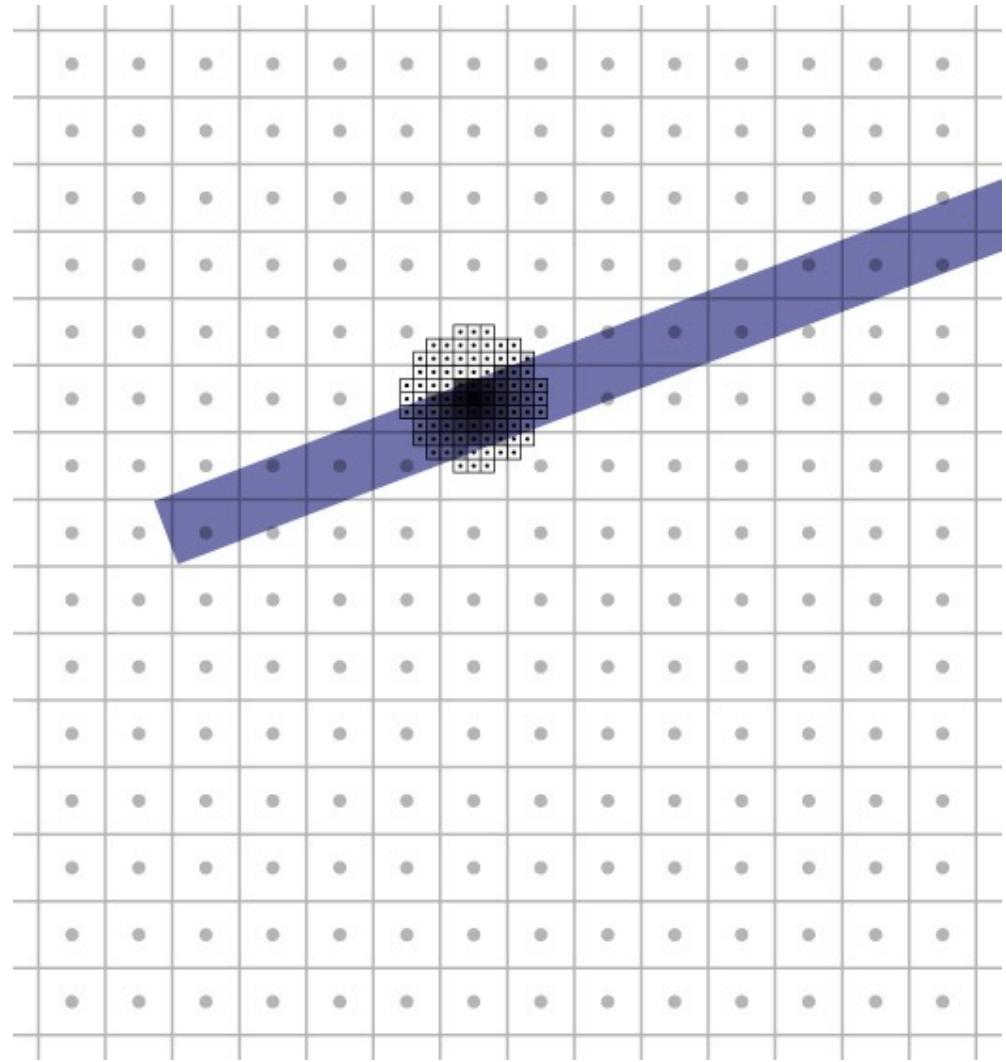
Weighted filtering by supersampling

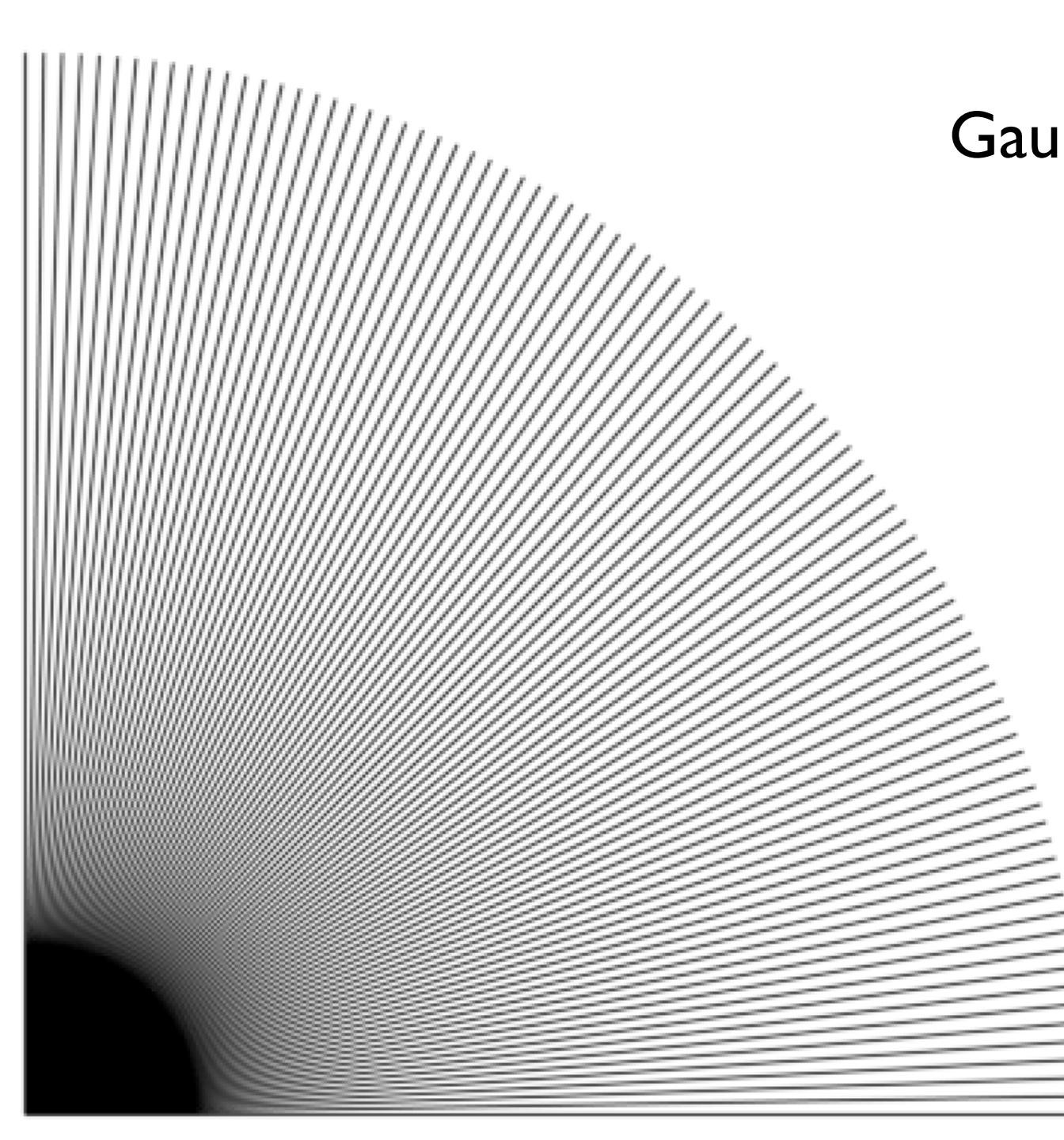
- Compute filtering integral by summing filter values for covered subpixels
- Simple, accurate
- But really slow



Weighted filtering by supersampling

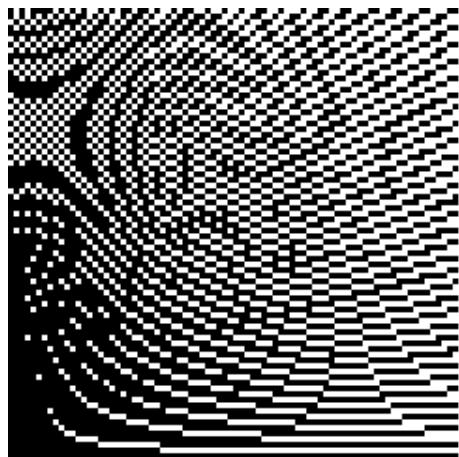
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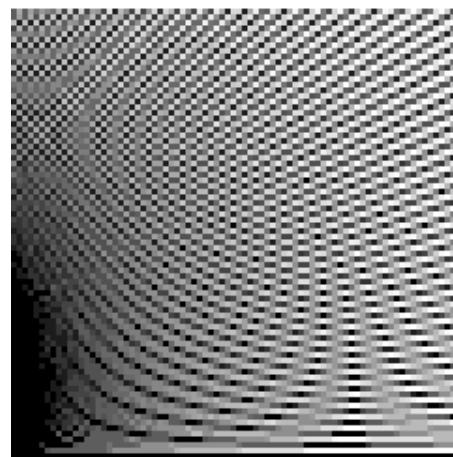


Gaussian filtering in action

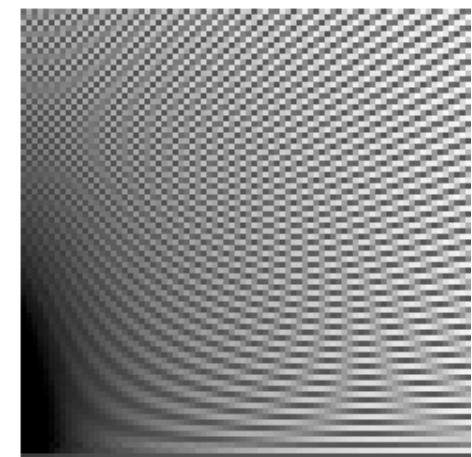
Filter comparison



Point sampling

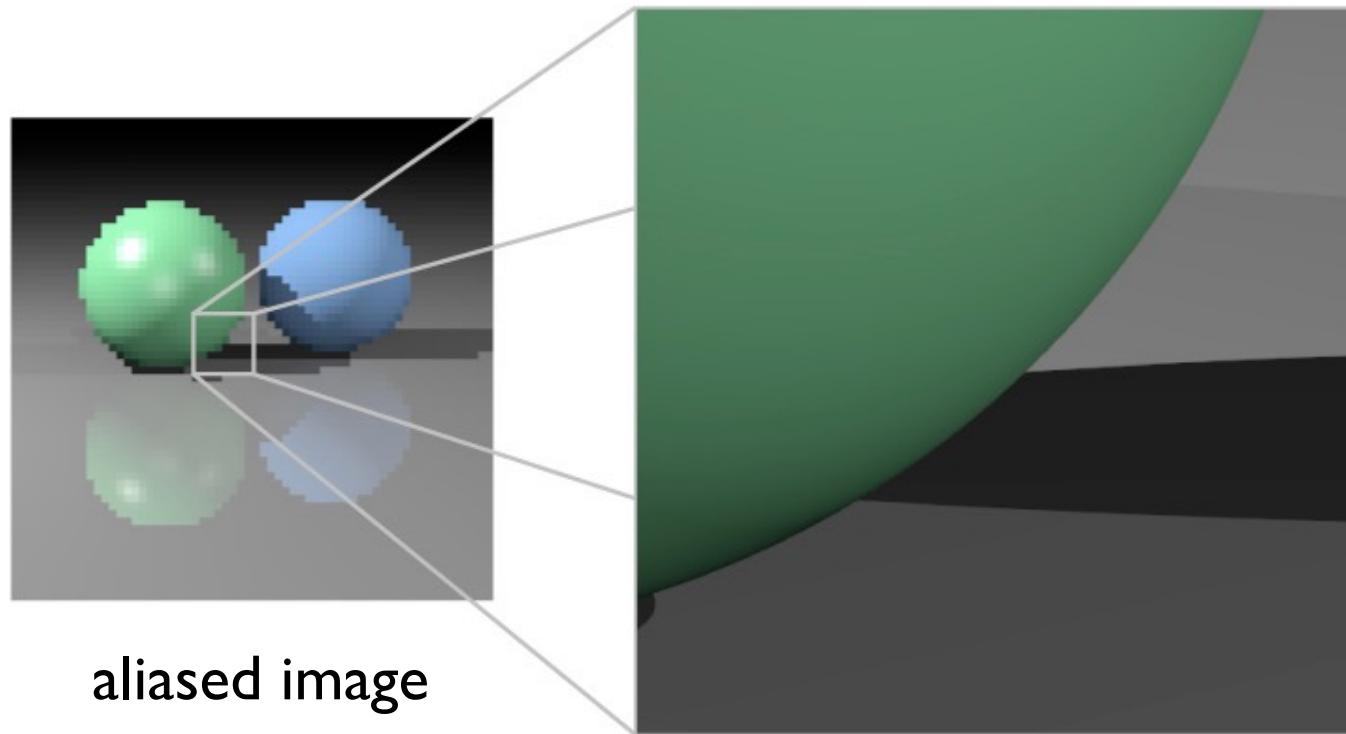


Box filtering

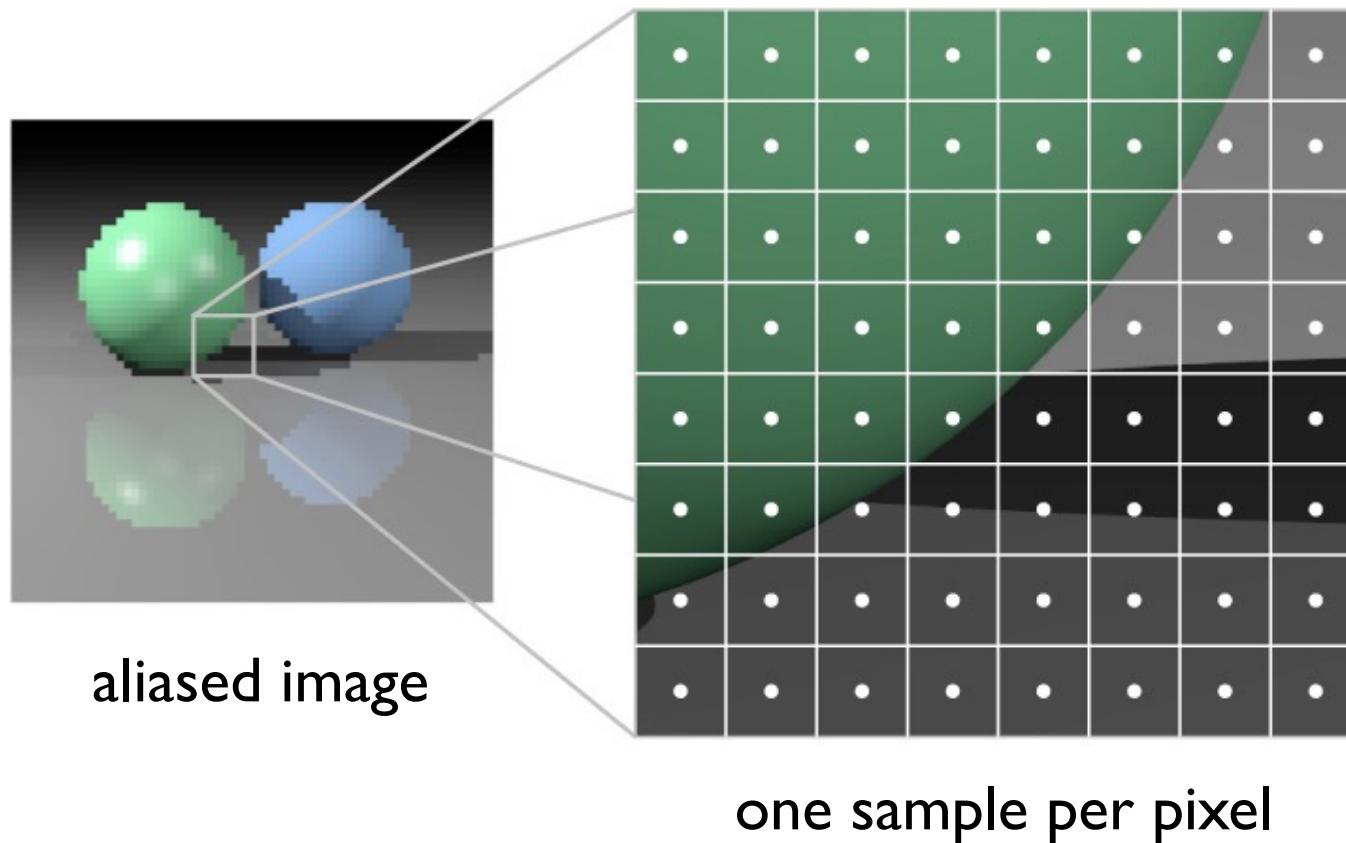


Gaussian filtering

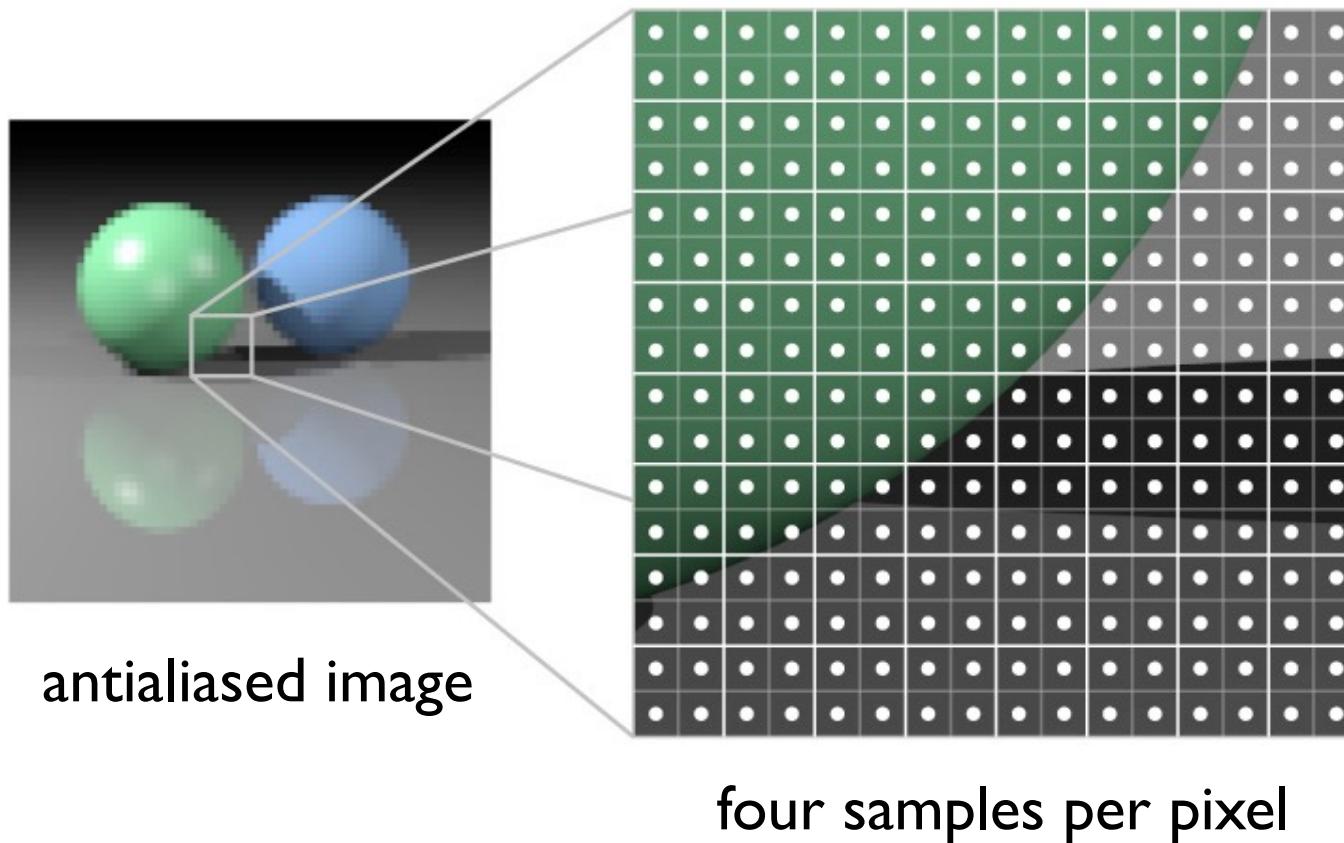
Antialiasing in ray tracing



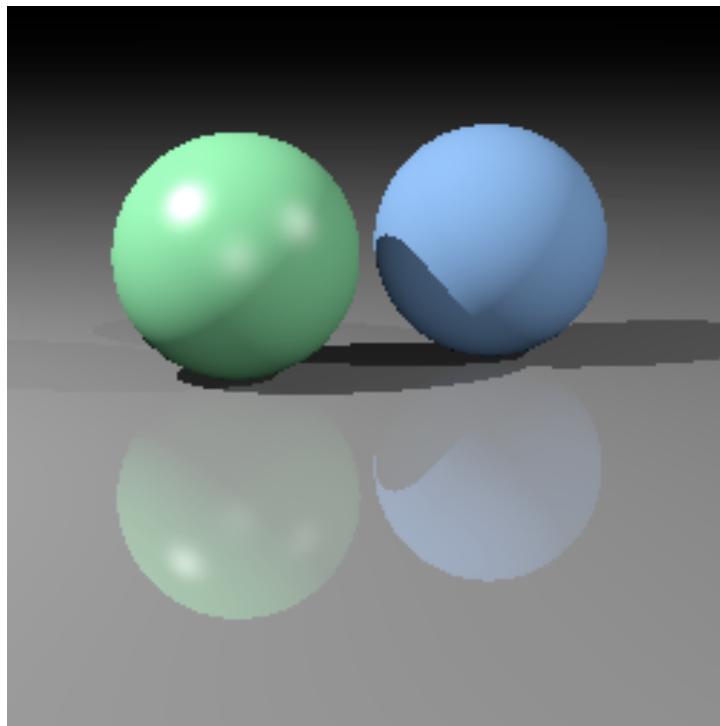
Antialiasing in ray tracing



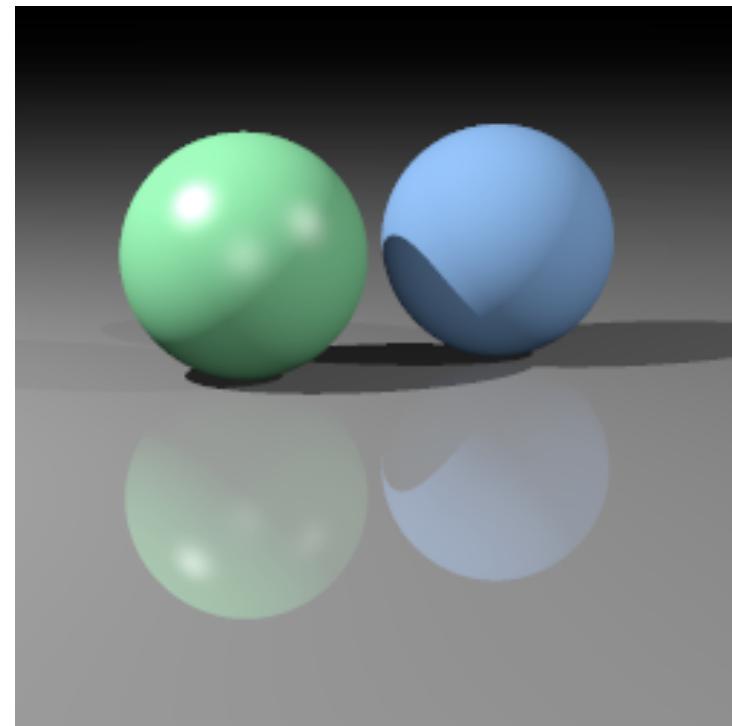
Antialiasing in ray tracing



Antialiasing in ray tracing



one sample/pixel

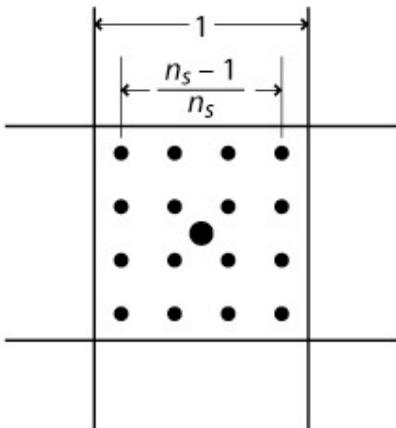


9 samples/pixel

Details of supersampling

- For image coordinates with integer pixel centers:

```
// one sample per pixel
for iy = 0 to (ny-1) by 1
  for ix = 0 to (nx-1) by 1 {
    ray = camera.getRay(ix, iy);
    image.set(ix, iy, trace(ray));
  }
```



```
// ns^2 samples per pixel
for iy = 0 to (ny-1) by 1
  for ix = 0 to (nx-1) by 1 {
    Color sum = 0;
    for dx = -(ns-1)/2 to (ns-1)/2 by 1
      for dy = -(ns-1)/2 to (ns-1)/2 by 1 {
        x = ix + dx / ns;
        y = iy + dy / ns;
        ray = camera.getRay(x, y);
        sum += trace(ray);
      }
    image.set(ix, iy, sum / (ns*ns));
  }
```

Details of supersampling

- For image coordinates in unit square

```
// one sample per pixel
for iy = 0 to (ny-1) by 1
    for ix = 0 to (nx-1) by 1 {
        double x = (ix + 0.5) / nx;
        double y = (iy + 0.5) / ny;
        ray = camera.getRay(x, y);
        image.set(ix, iy, trace(ray));
    }
```

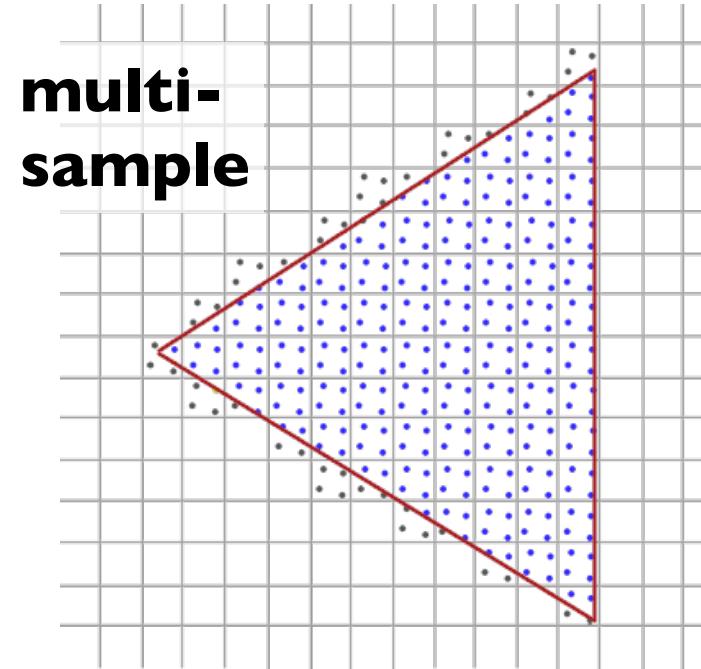
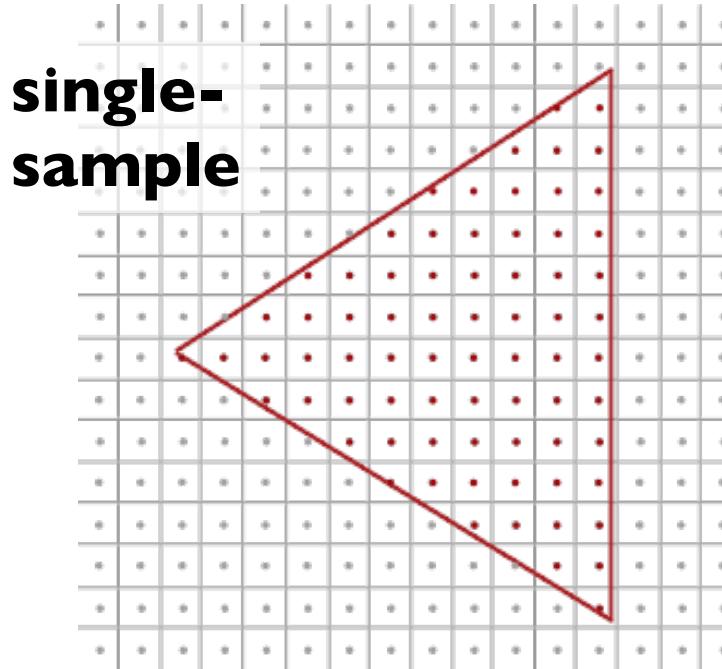
```
// ns^2 samples per pixel
for iy = 0 to (ny-1) by 1
    for ix = 0 to (nx-1) by 1 {
        Color sum = 0;
        for dx = 0 to (ns-1) by 1
            for dy = 0 to (ns-1) by 1 {
                x = (ix + (dx + 0.5) / ns) / nx;
                y = (iy + (dy + 0.5) / ns) / ny;
                ray = camera.getRay(x, y);
                sum += trace(ray);
            }
        image.set(ix, iy, sum / (ns*ns));
    }
```

Supersampling vs. multisampling

- Supersampling is terribly expensive
- GPUs use an approximation called *multisampling*
 - Compute one shading value per pixel
 - Store it at many subpixel samples, each with its own depth

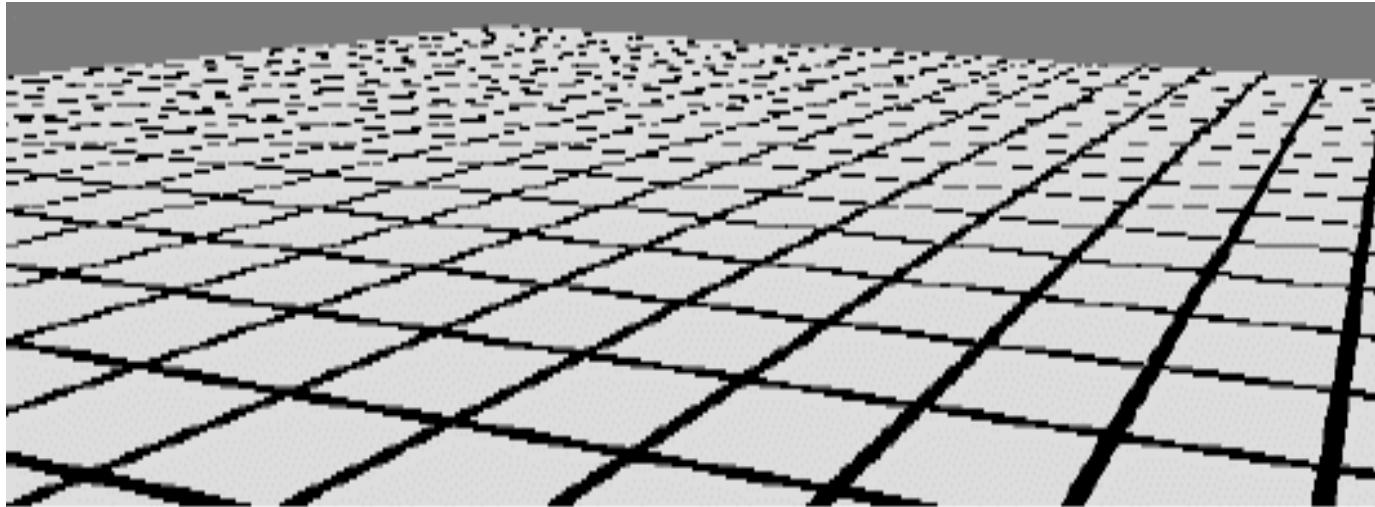
Multisample rasterization

- Each fragment carries several (color,depth) samples
 - shading is computed per-fragment
 - depth test is resolved per-sample
 - final color is average of sample colors



Antialiasing in textures

- Even with multisampling, we still only evaluate textures once per fragment
- Need to filter the texture somehow!
 - perspective produces very fine subpixel detail



[Akenine-Möller & Haines 2002]

Texture mapping from 0 to infinity

- When you go close...

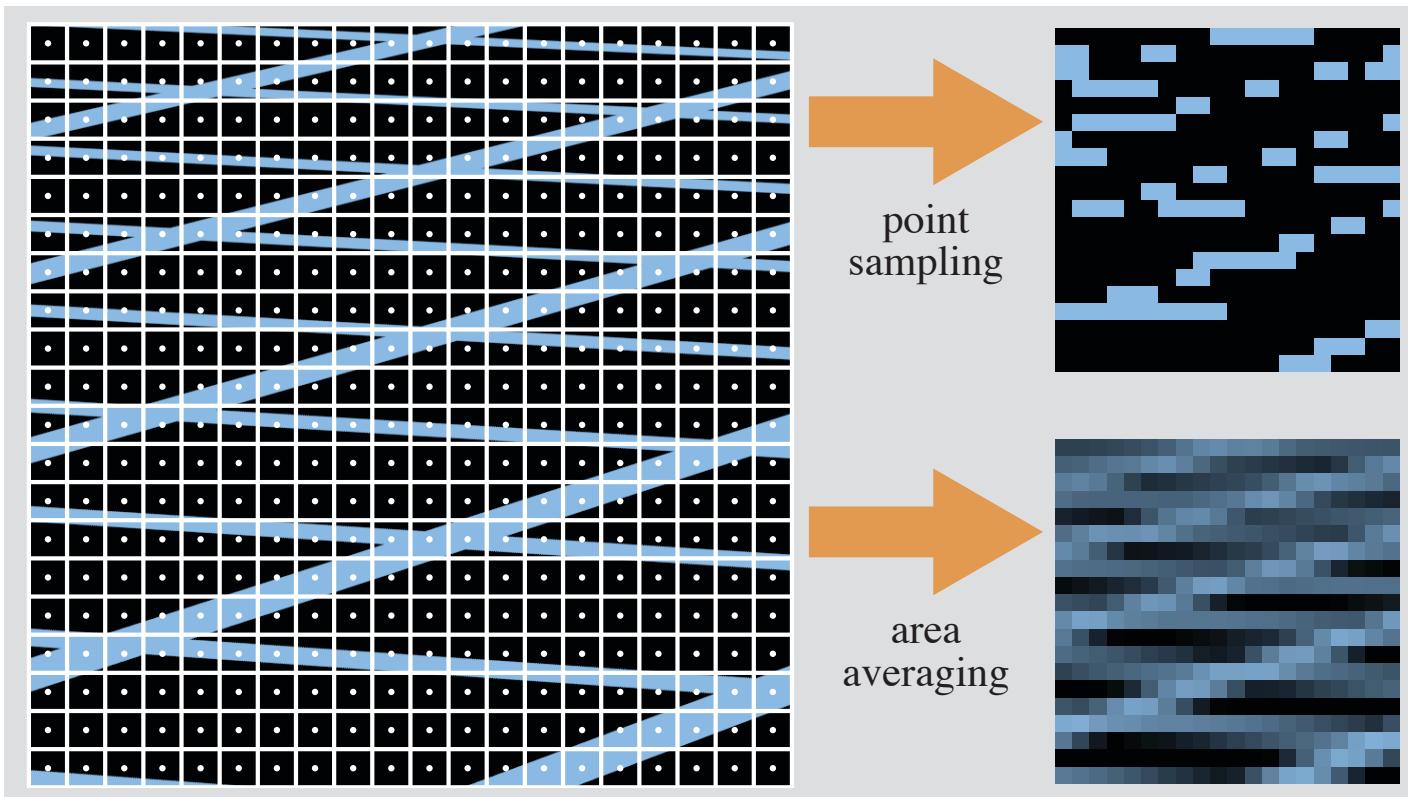


Texture mapping from 0 to infinity

- When you go far...



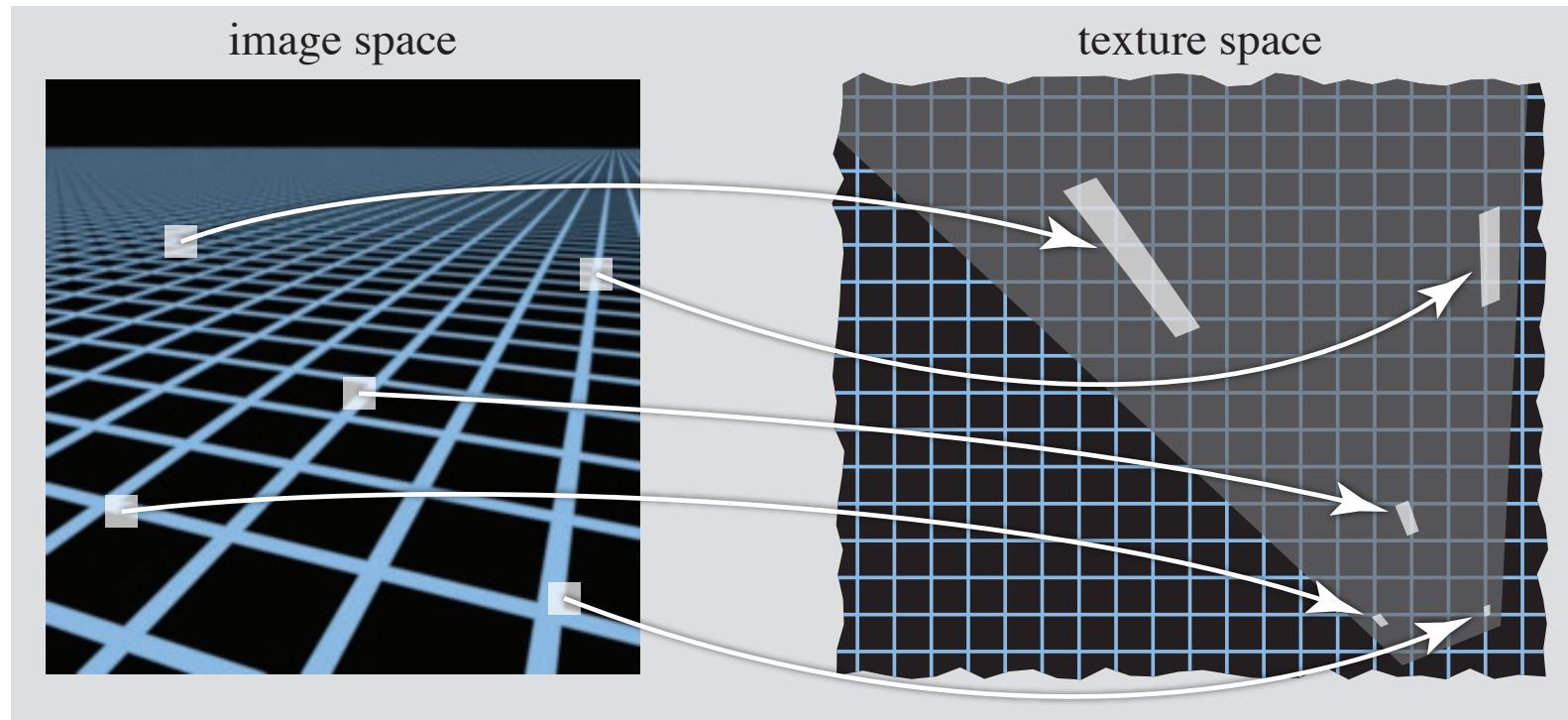
Solution: pixel filtering



Pixel filtering in texture space

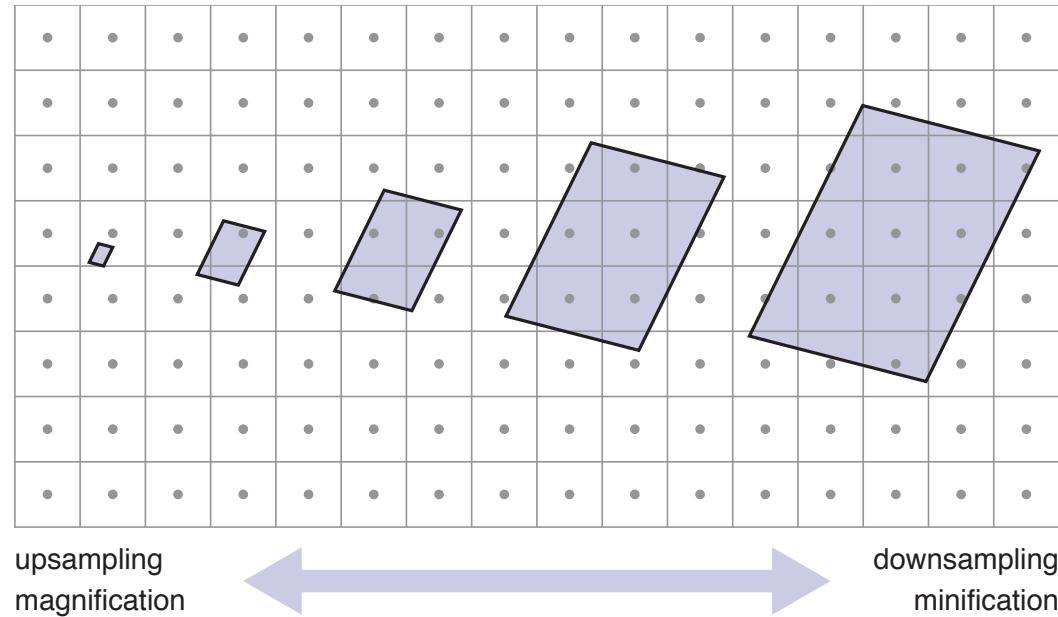
- Sampling is happening in image space
 - sample is a weighted average over a pixel-sized area
 - uniform, predictable, friendly problem!
- Signal is defined in texture space
 - mapping between image and texture is nonuniform
 - each sample is a weighted average over a different sized and shaped area
 - irregular, unpredictable, unfriendly!
- This is a change of variable
 - integrate over texture coordinates rather than image coordinates

Pixel footprints

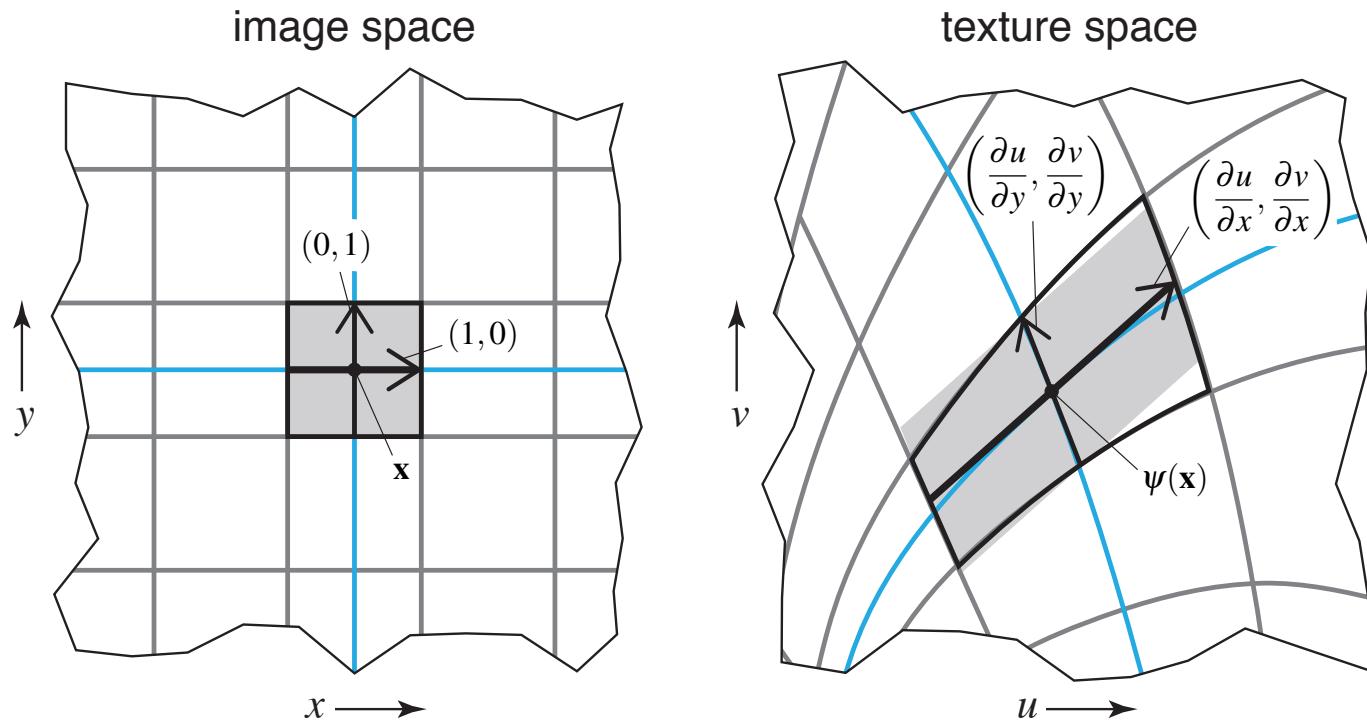


How does area map over distance?

- At optimal viewing distance:
 - One-to-one mapping between pixel area and texel area
- When closer
 - Each pixel is a small part of the texel
 - magnification
- When farther
 - Each pixel could include many texels
 - “minification”

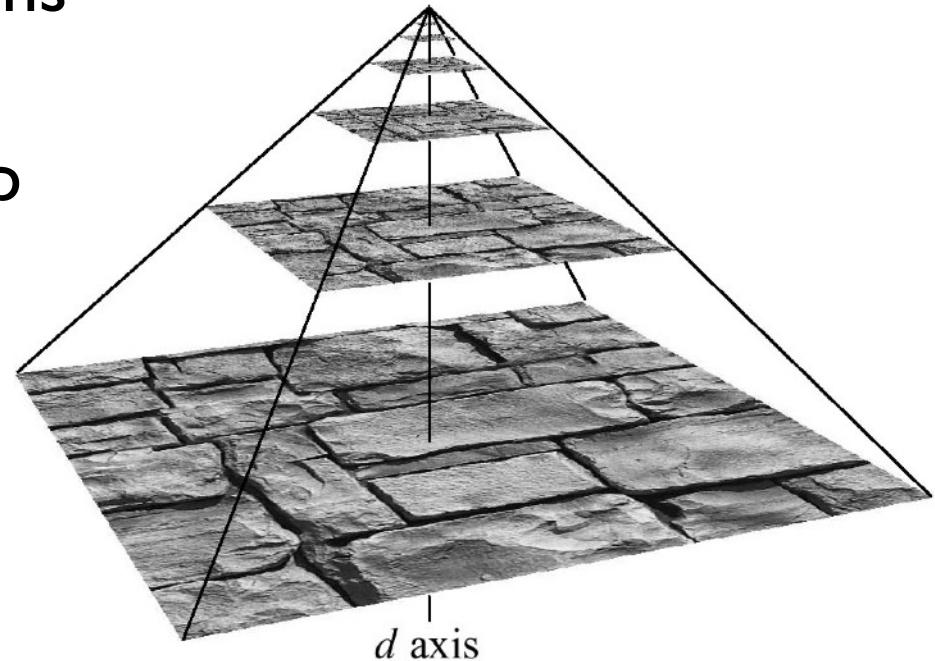


Sizing up the situation with the Jacobian



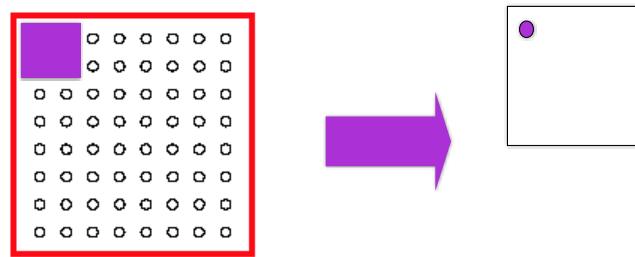
Mipmap image pyramid

- MIP Maps
 - Multum in Parvo: Much in little, many in small places
 - Proposed by Lance Williams
- Stores pre-filtered versions of texture
- Supports very fast lookup
 - but only of circular filters at certain scales



[Akenine-Möller & Haines 2002]

Filtering by Averaging



- Each pixel in a level corresponds to 4 pixels in lower level
 - Average
 - Gaussian filtering

Using the MIP Map

- Find the MIP Map level where the pixel has a 1-to-1 mapping
- How?
 - Find largest side of pixel footprint in texture space
 - Pick level where that side corresponds to a texel
 - Compute derivatives to find pixel footprint

- x derivative:

$$\frac{\partial u}{\partial x} \quad \frac{\partial v}{\partial x}$$

- y derivative:

$$\frac{\partial u}{\partial y} \quad \frac{\partial v}{\partial y}$$

Given derivatives: what is level?

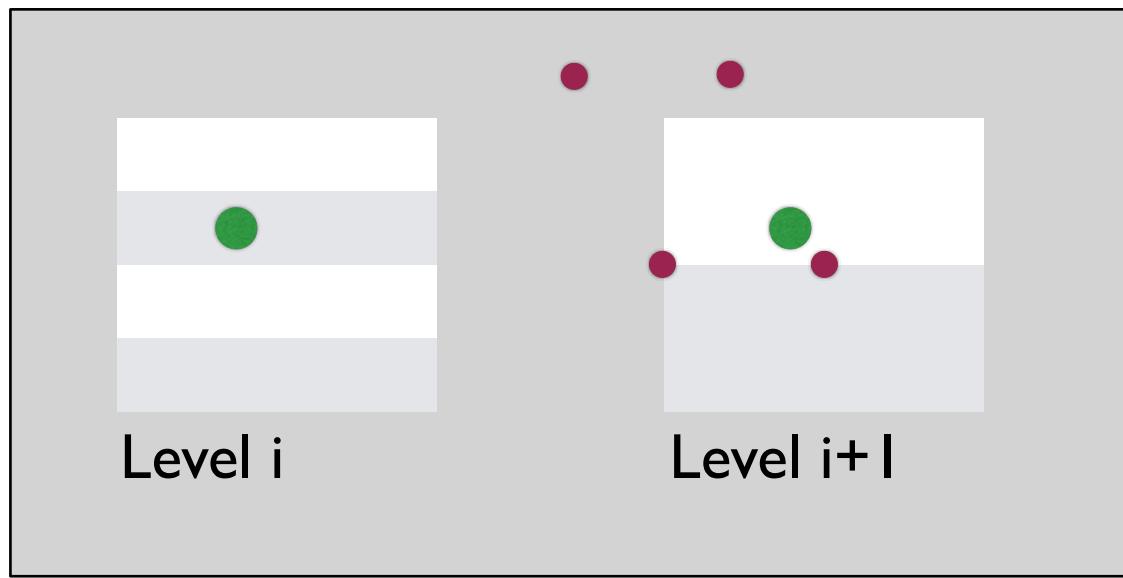
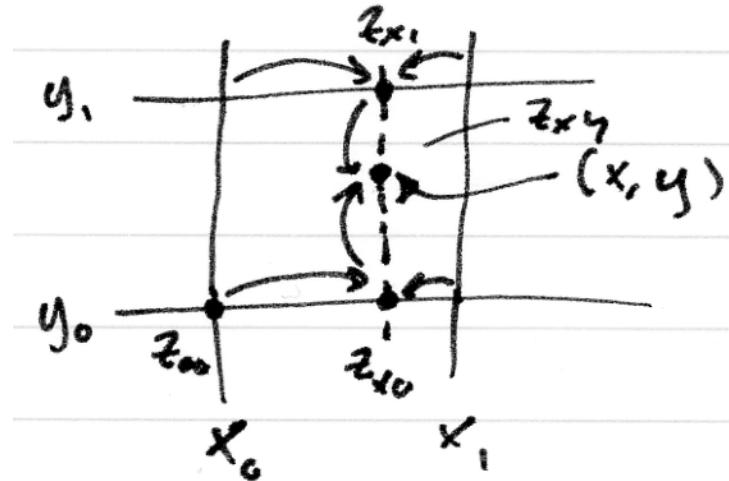
- Derivatives
 - Available in pixel shader (except where there is dynamic branching)

$$level = \log[\max\left(\frac{du}{dx}, \frac{dv}{dx}, \frac{du}{dy}, \frac{dv}{dy}\right)]$$

$$level = \log \sqrt{\left(\frac{du}{dx}\right)^2 + \left(\frac{dv}{dx}\right)^2 + \left(\frac{du}{dy}\right)^2 + \left(\frac{dv}{dy}\right)^2}$$

Using the MIP Map

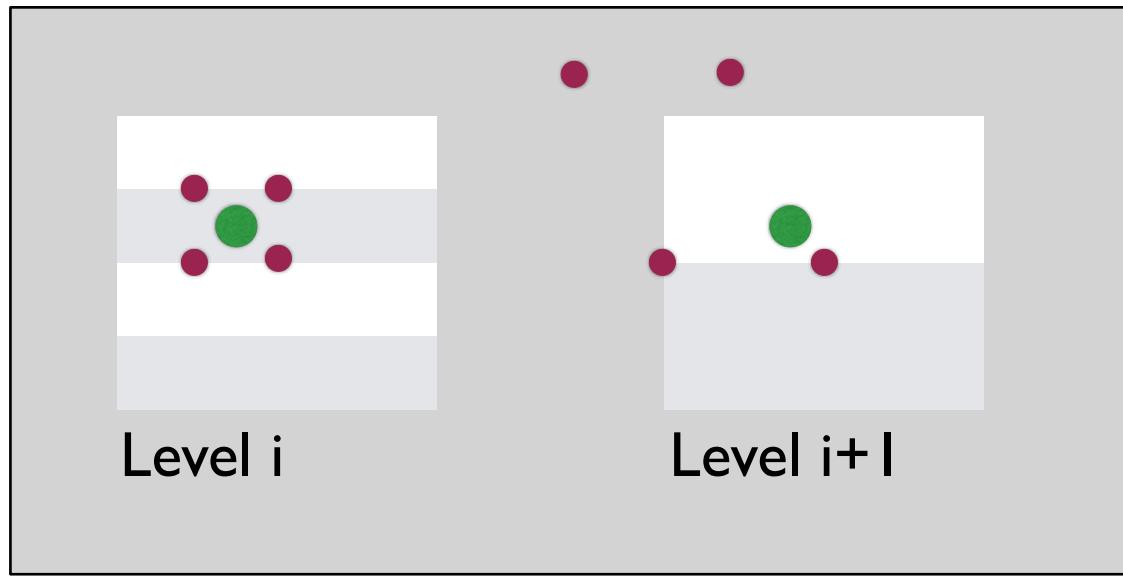
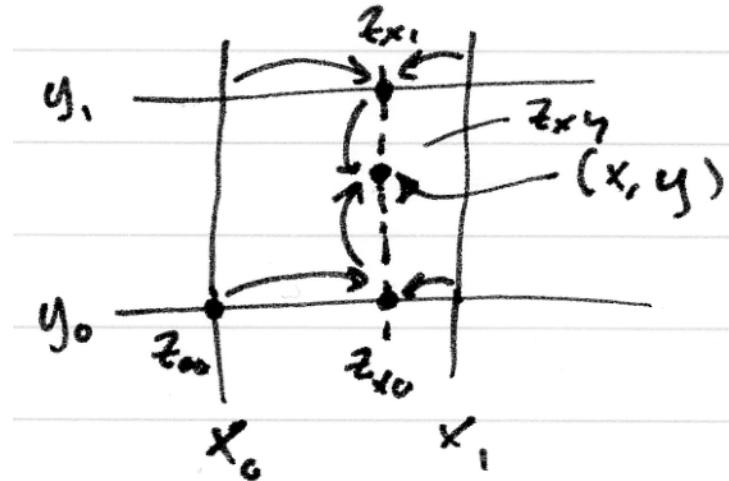
- In level, find texel and
 - Return the texture value:
point sampling (but still better)!
 - Bilinear interpolation
 - Trilinear interpolation



[Kavita Bala]

Using the MIP Map

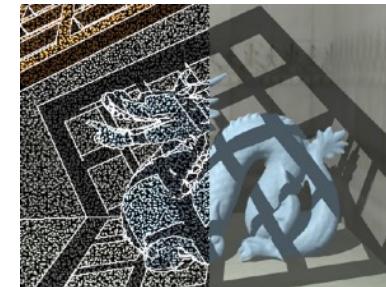
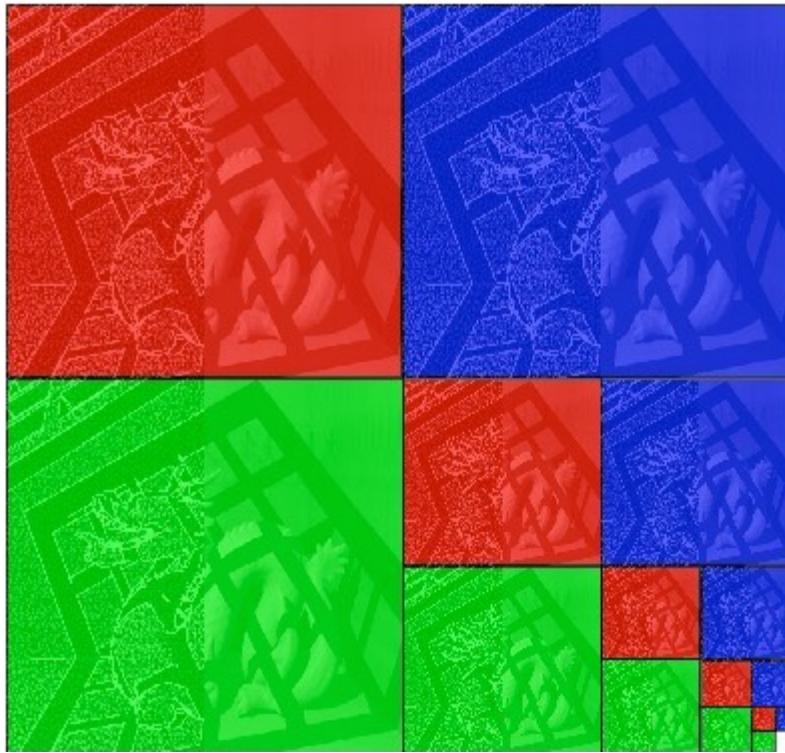
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[Kavita Bala]

Memory Usage

- What happens to size of texture?

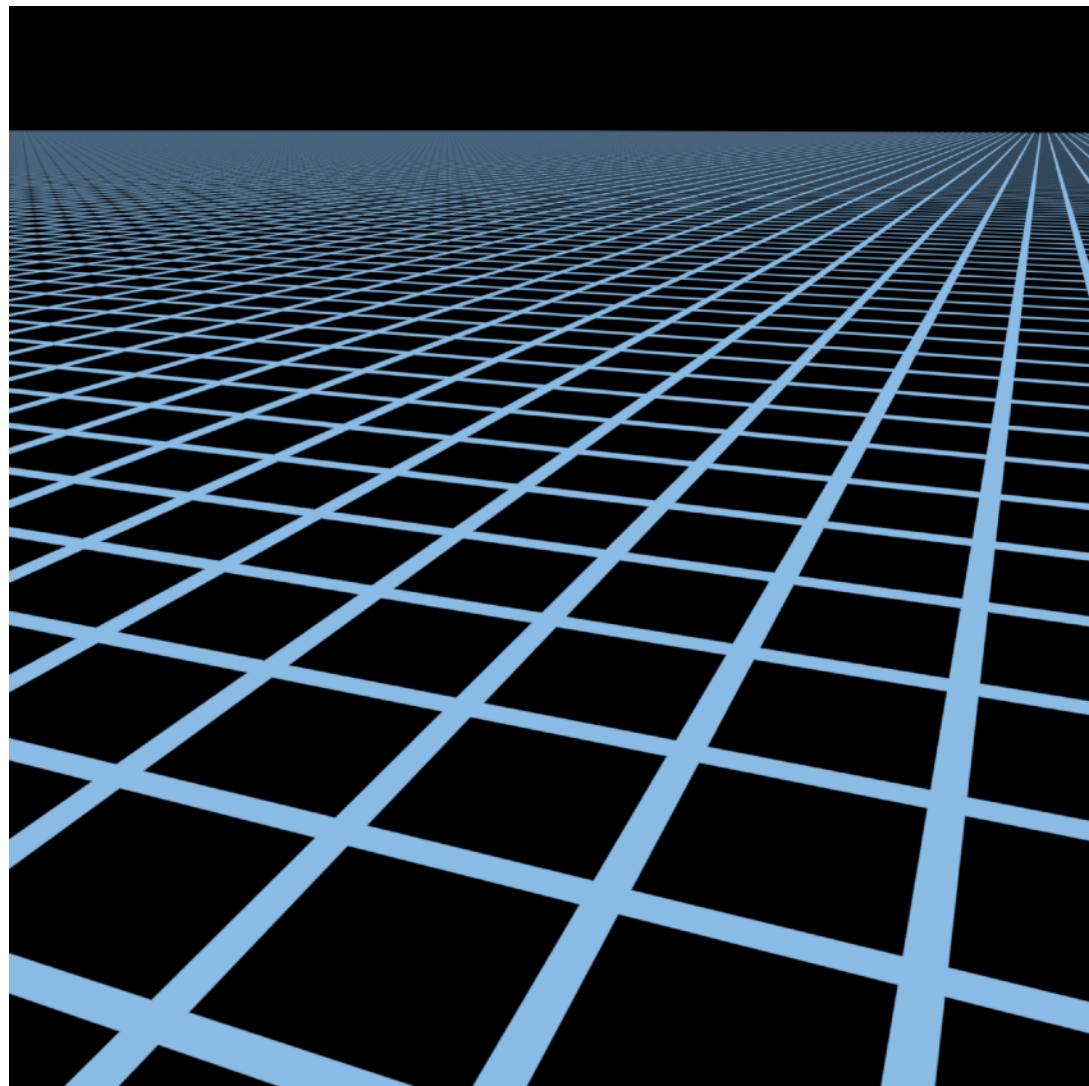


[Kavita Bala]

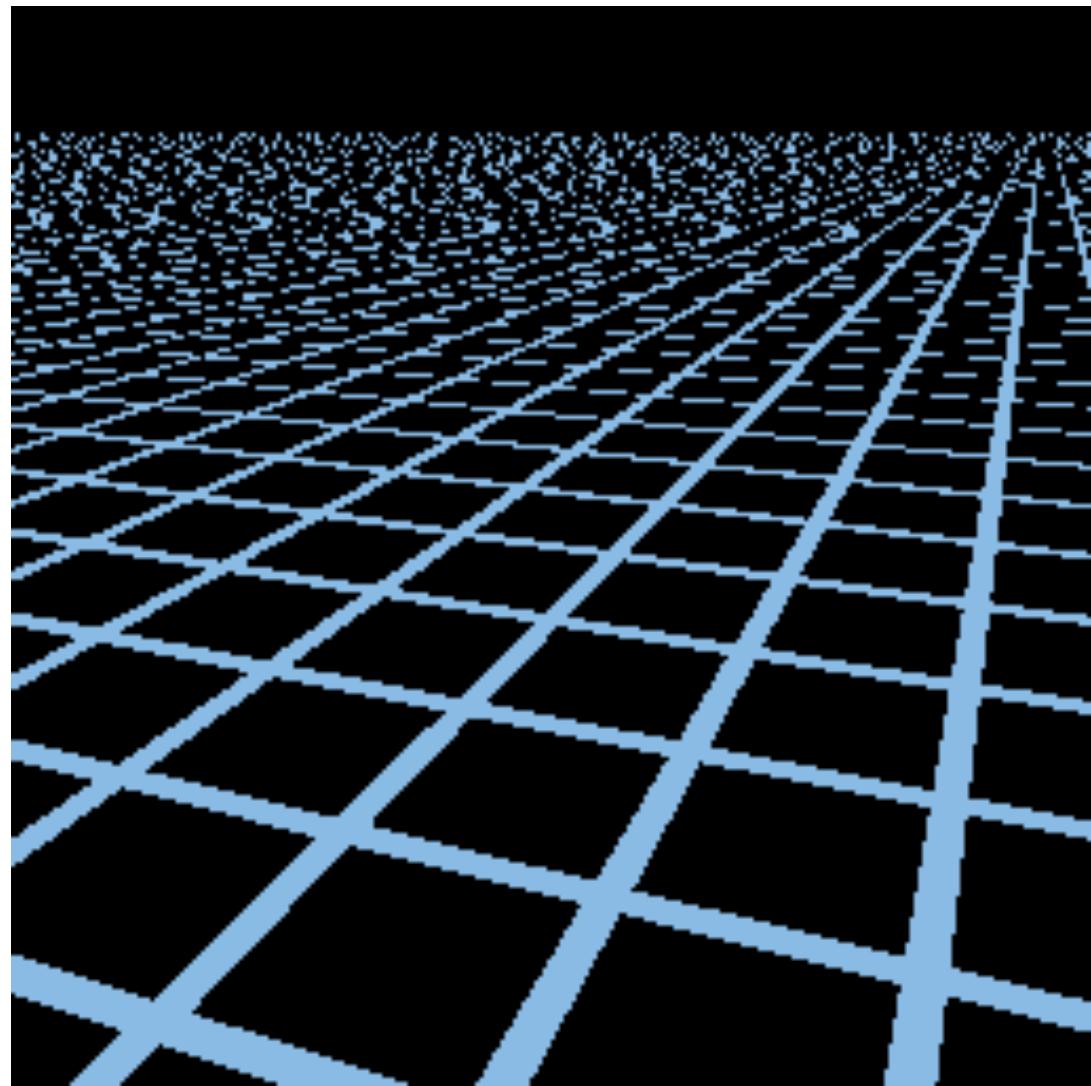
MIPMAP

- Multi-resolution image pyramid
 - Pre-sampled computation of MIPMAP
 - 1/3 more memory
- Bilinear or Trilinear interpolation

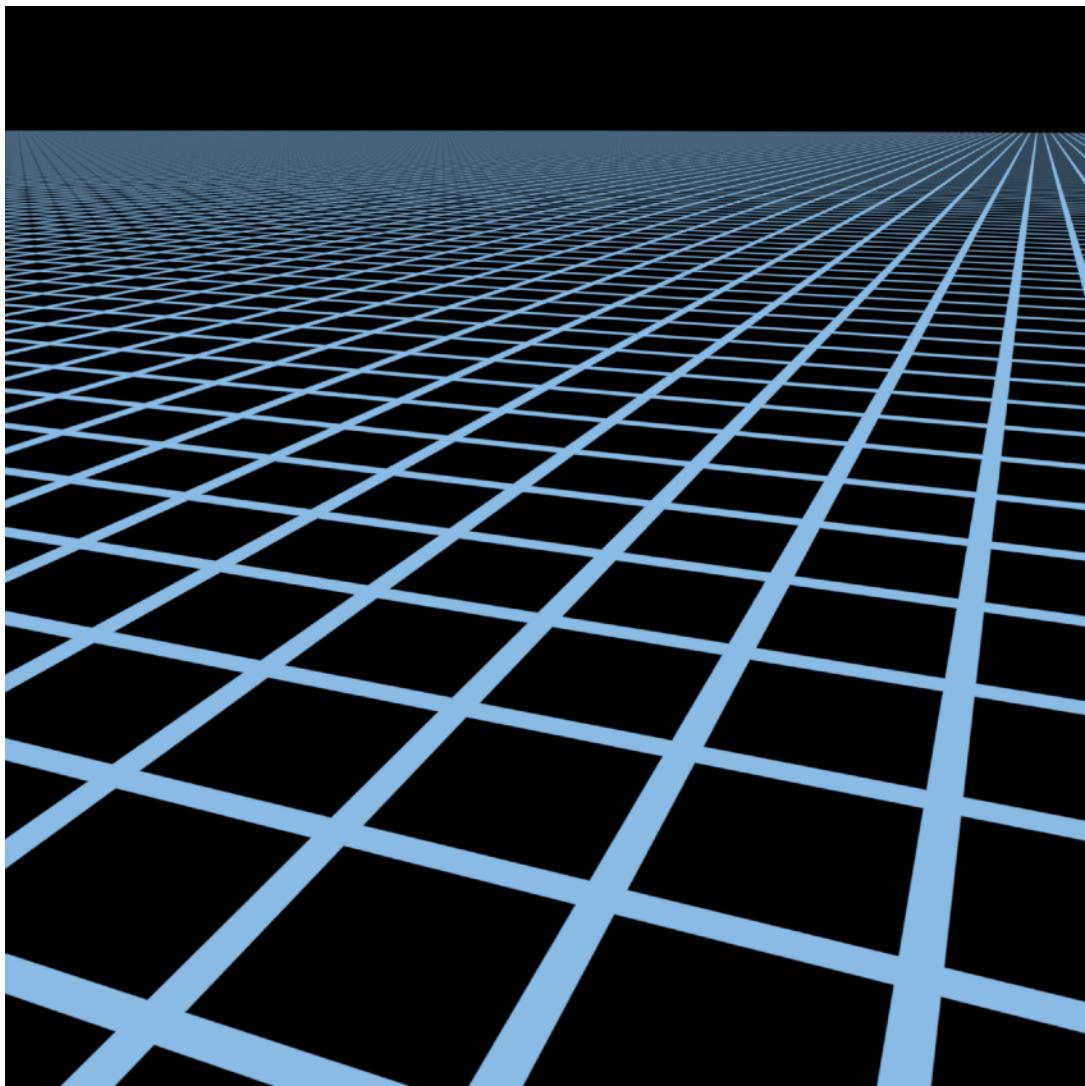
Point sampling



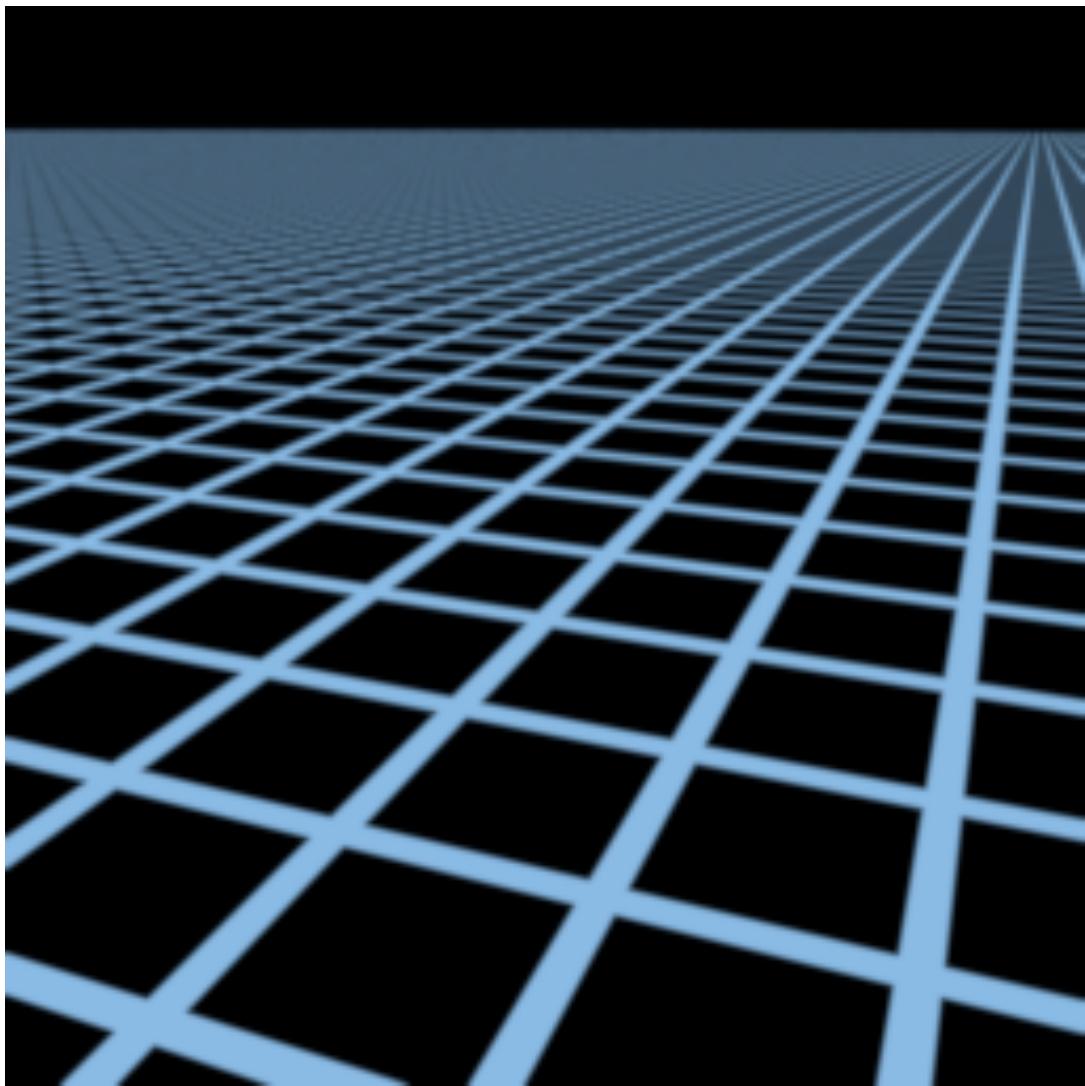
Point sampling



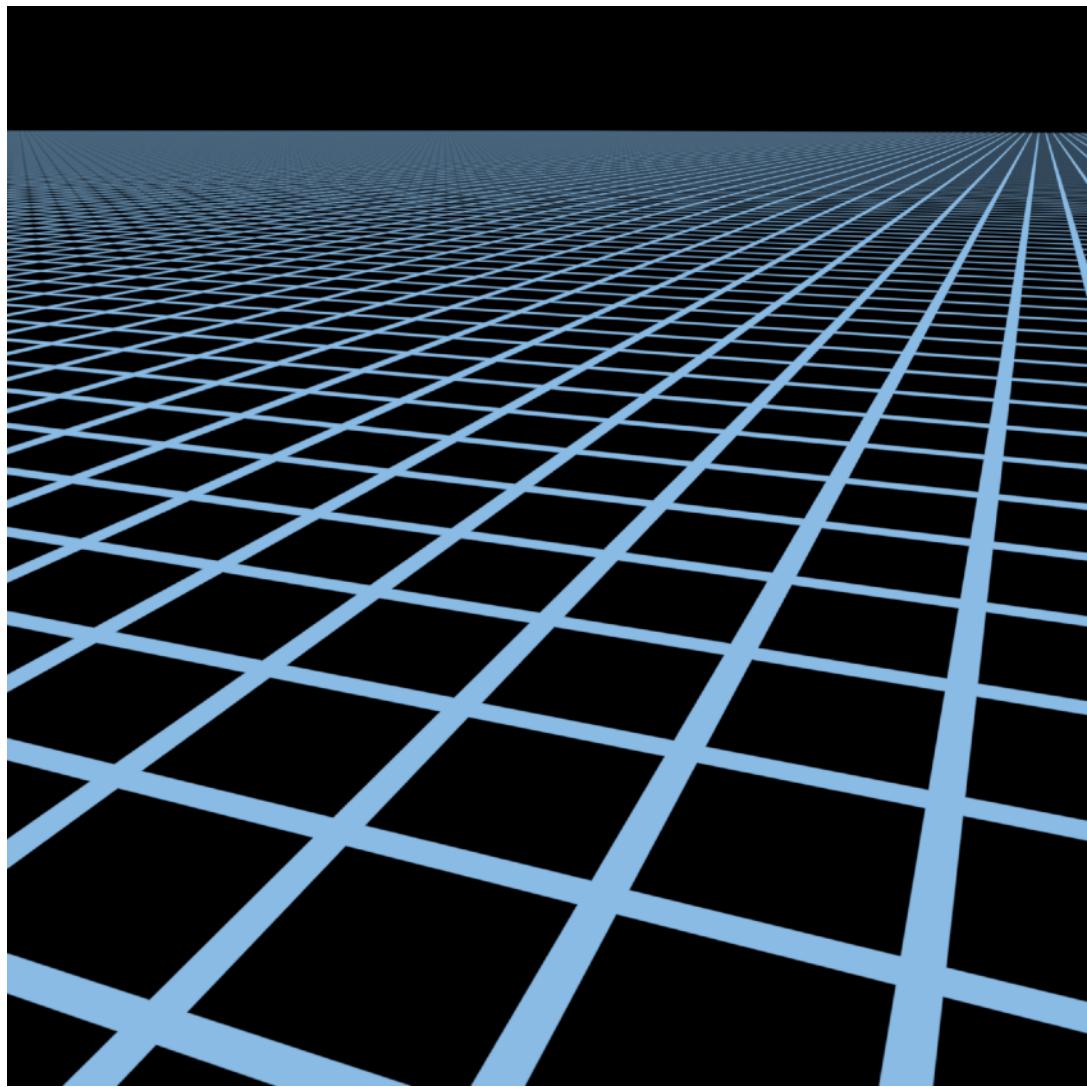
Reference: gaussian sampling by 512x supersampling



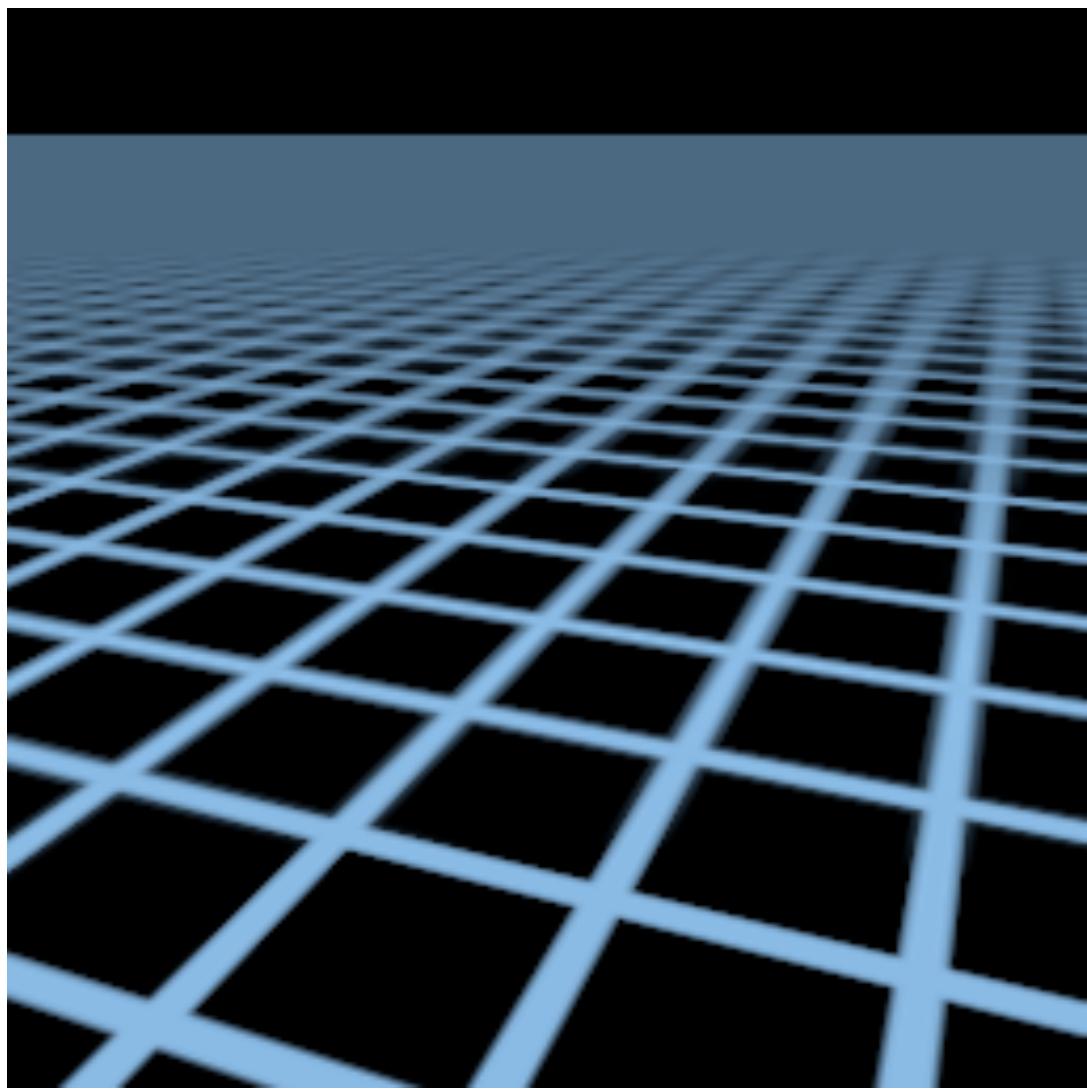
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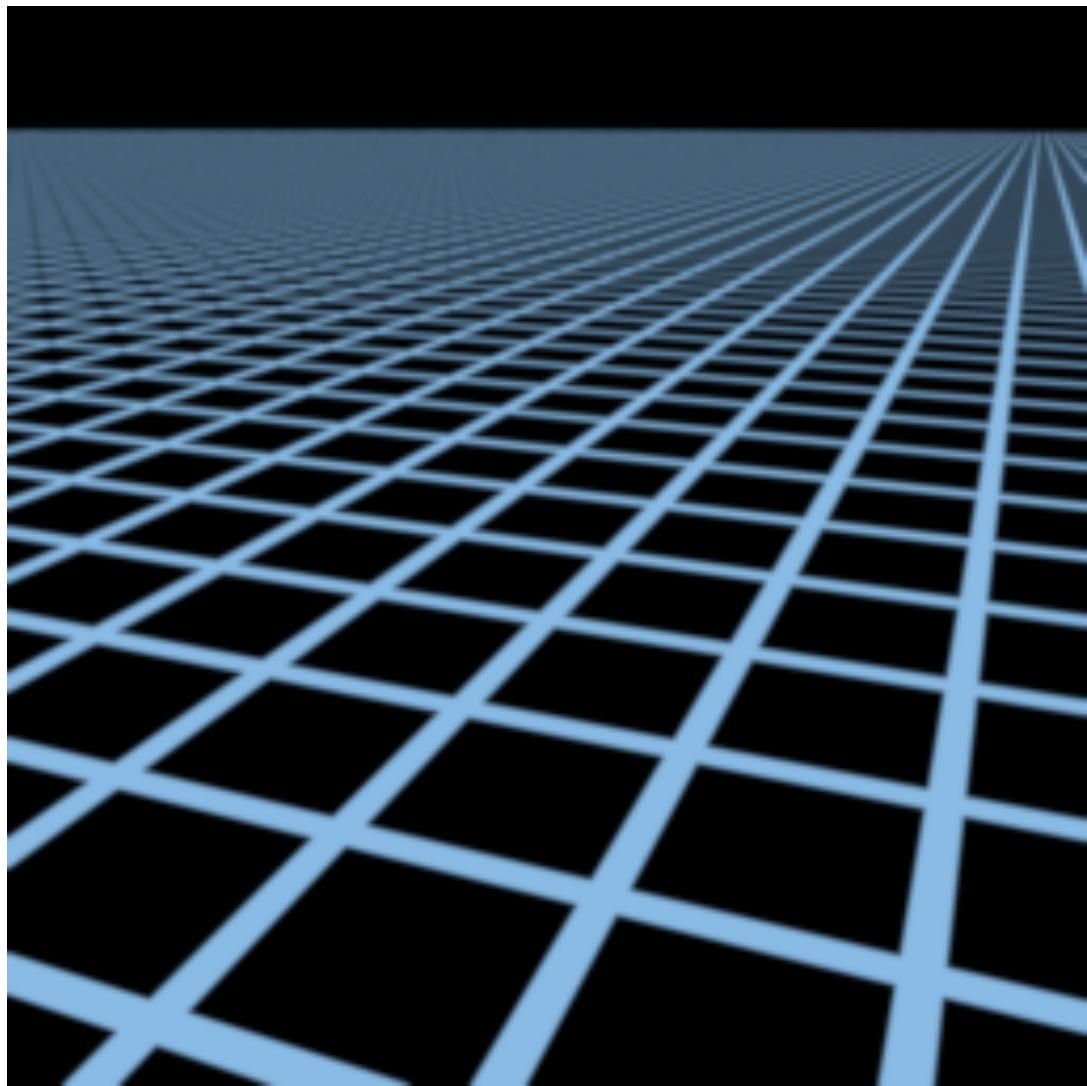
Texture minification with a mipmap



Texture minification with a mipmap



Texture minification: supersampling vs. mipmap



Texture minification: supersampling vs. mipmap

