Antialiasing

CS4620 Lecture 23

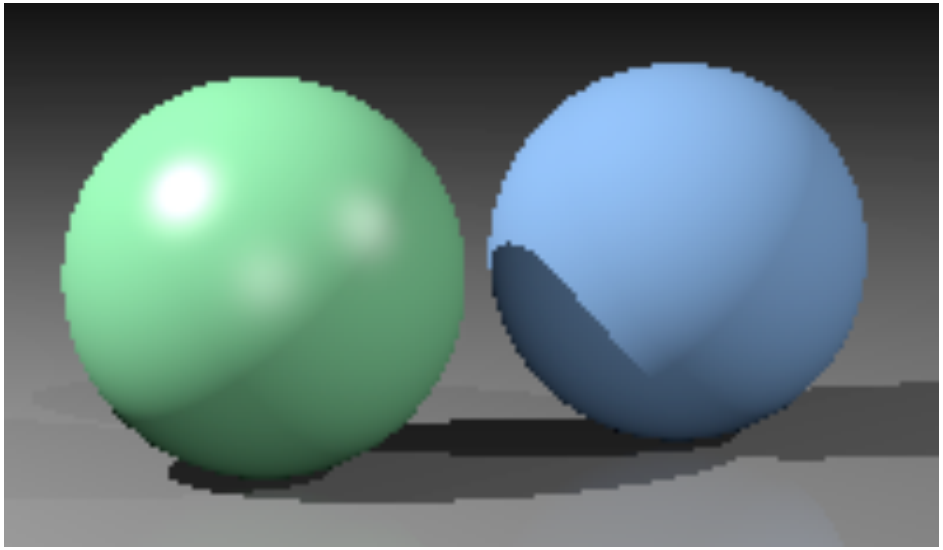
(with previous instructors James/Bala, and some slides courtesy Leonard McMillan)

Pixel coverage

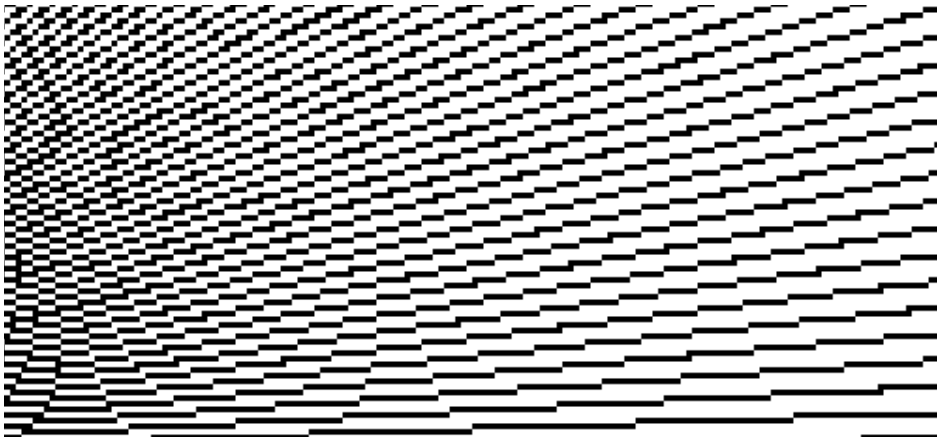
- Antialiasing and compositing both deal with questions of pixels that contain unresolved detail
- Antialiasing: how to carefully throw away the detail
- Compositing: how to account for the detail when combining images

Aliasing

point sampling a continuous image:



continuous image defined by ray tracing procedure



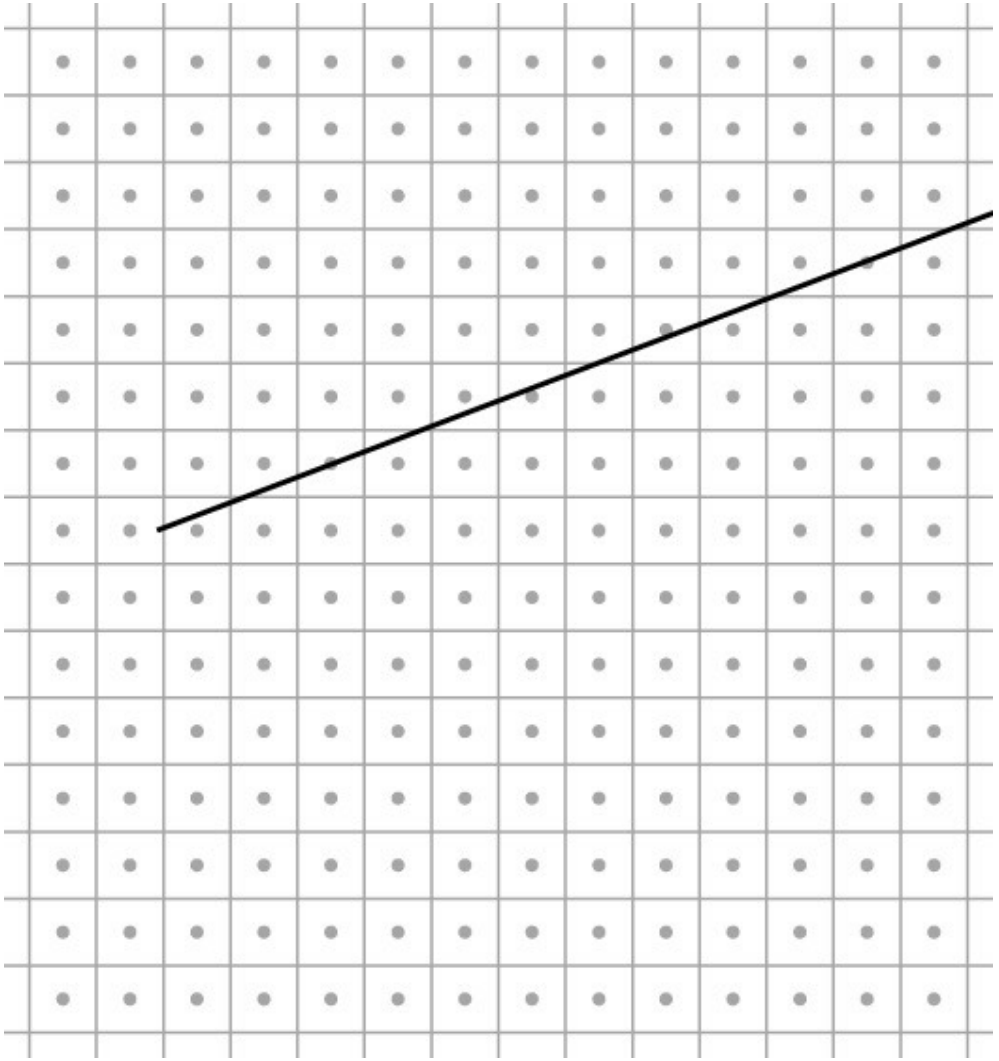
continuous image defined by a bunch of black rectangles

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

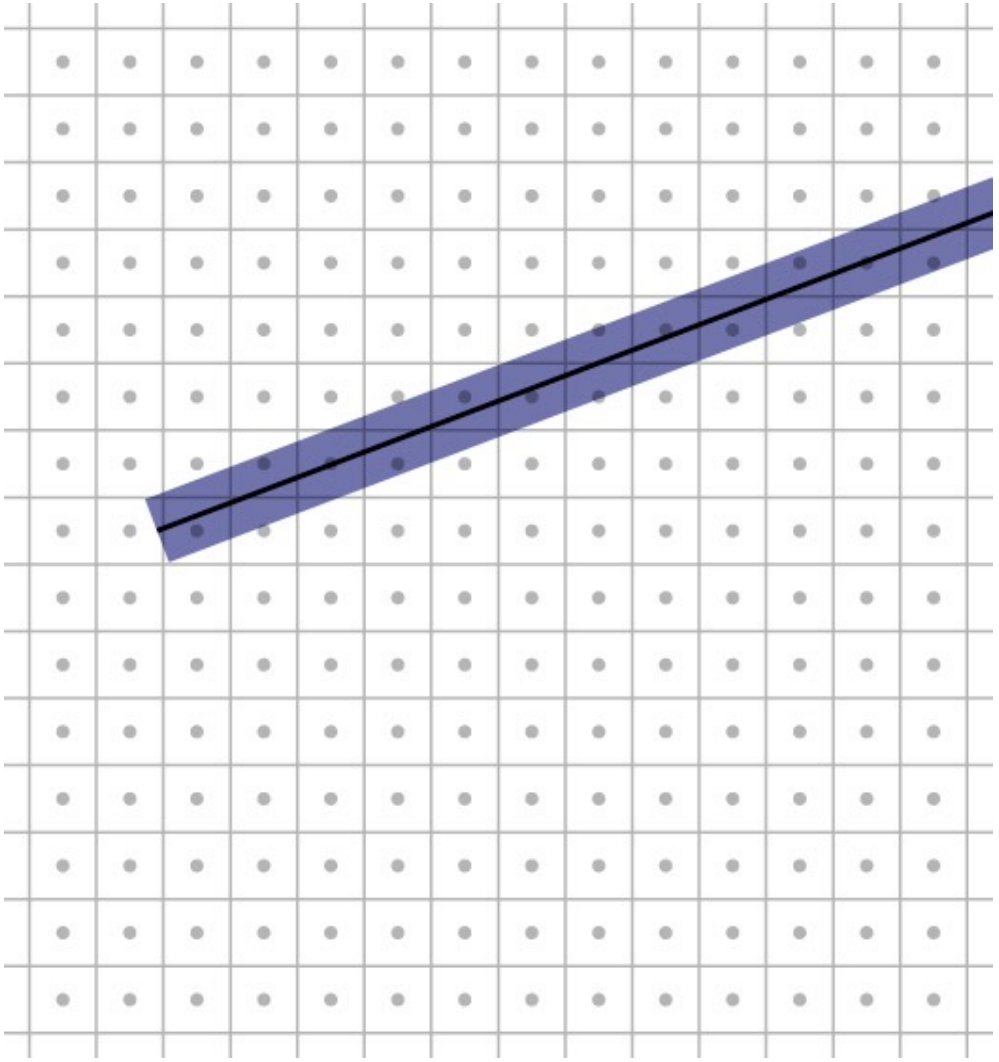
Rasterizing lines

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



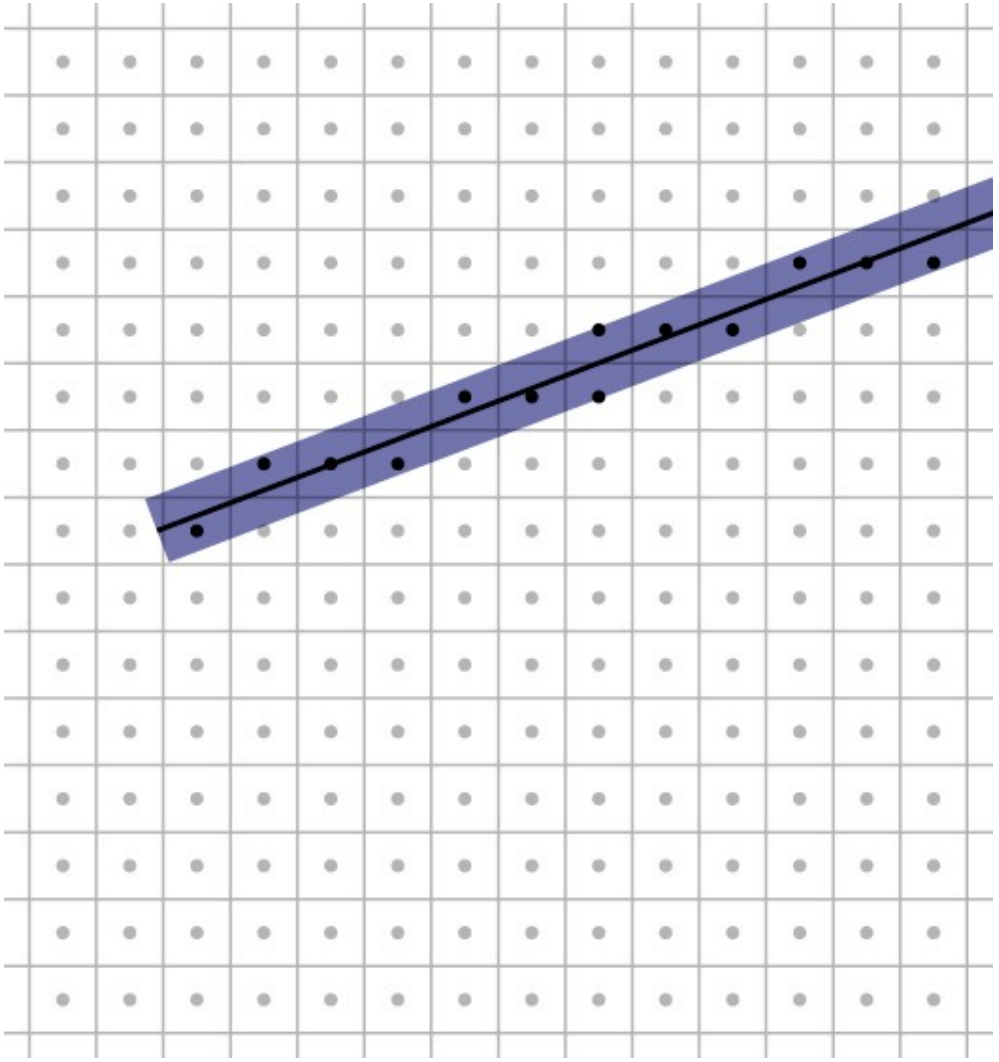
Rasterizing lines

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



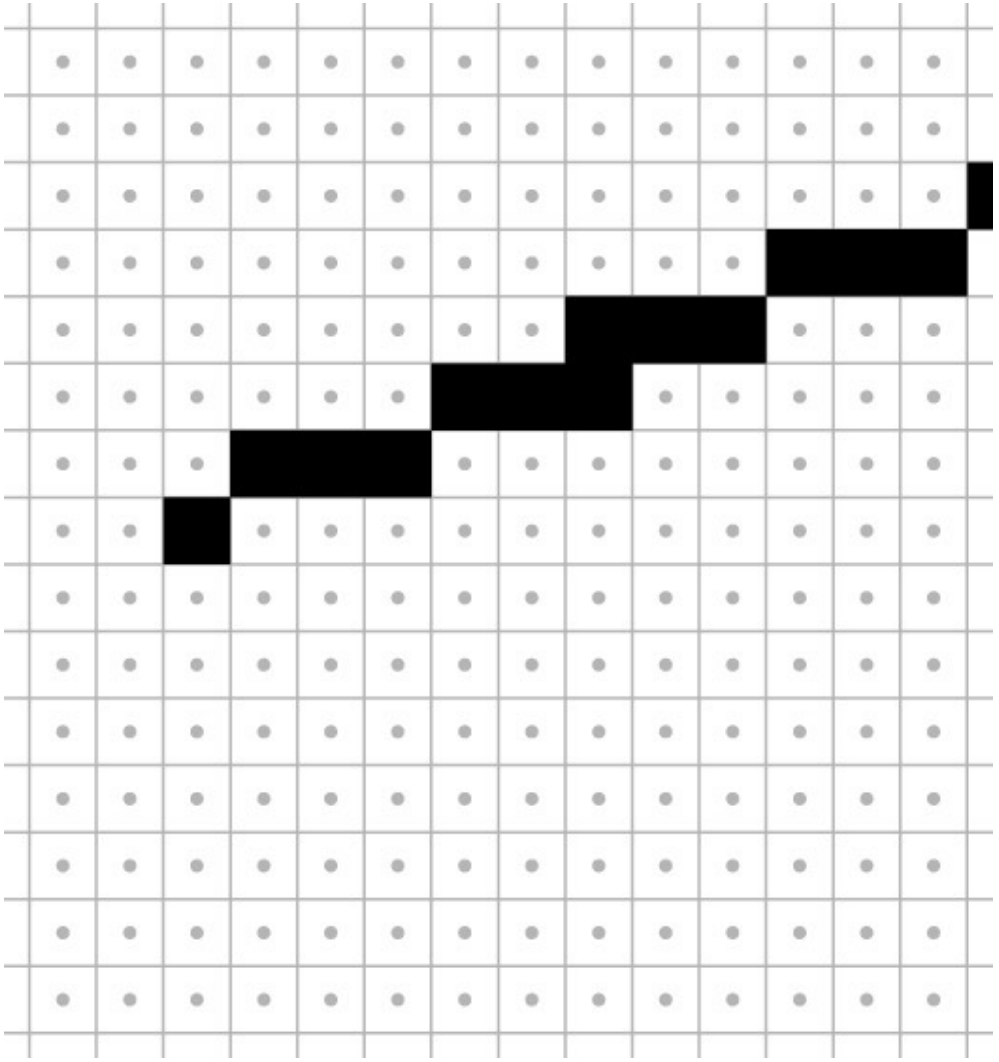
Point sampling

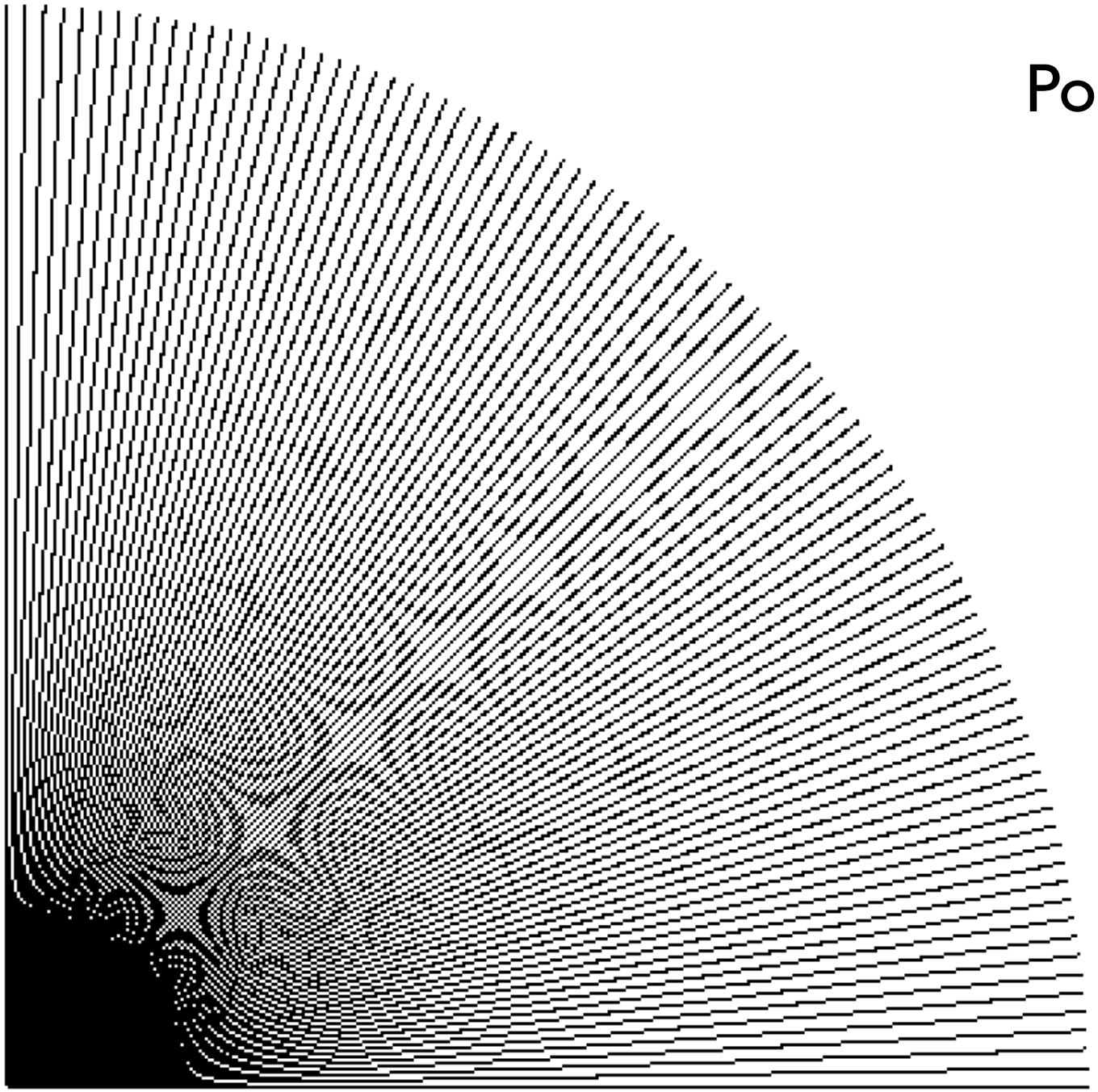
- Approximate rectangle by drawing all pixels whose centers fall within the line
- Problem: all-or-nothing leads to jaggies
  - this is sampling with no filter (aka. point sampling)



Point sampling

- 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)

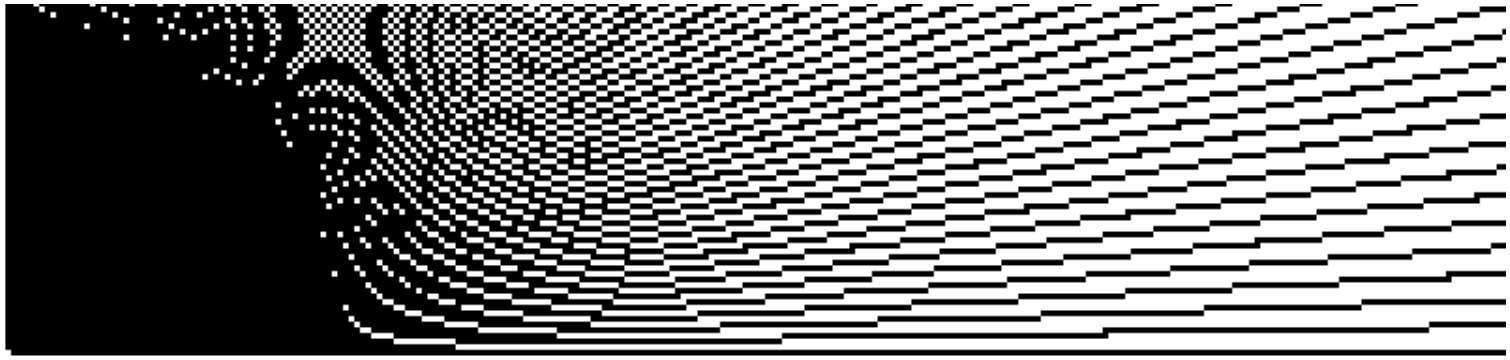




Point sampling in action

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!

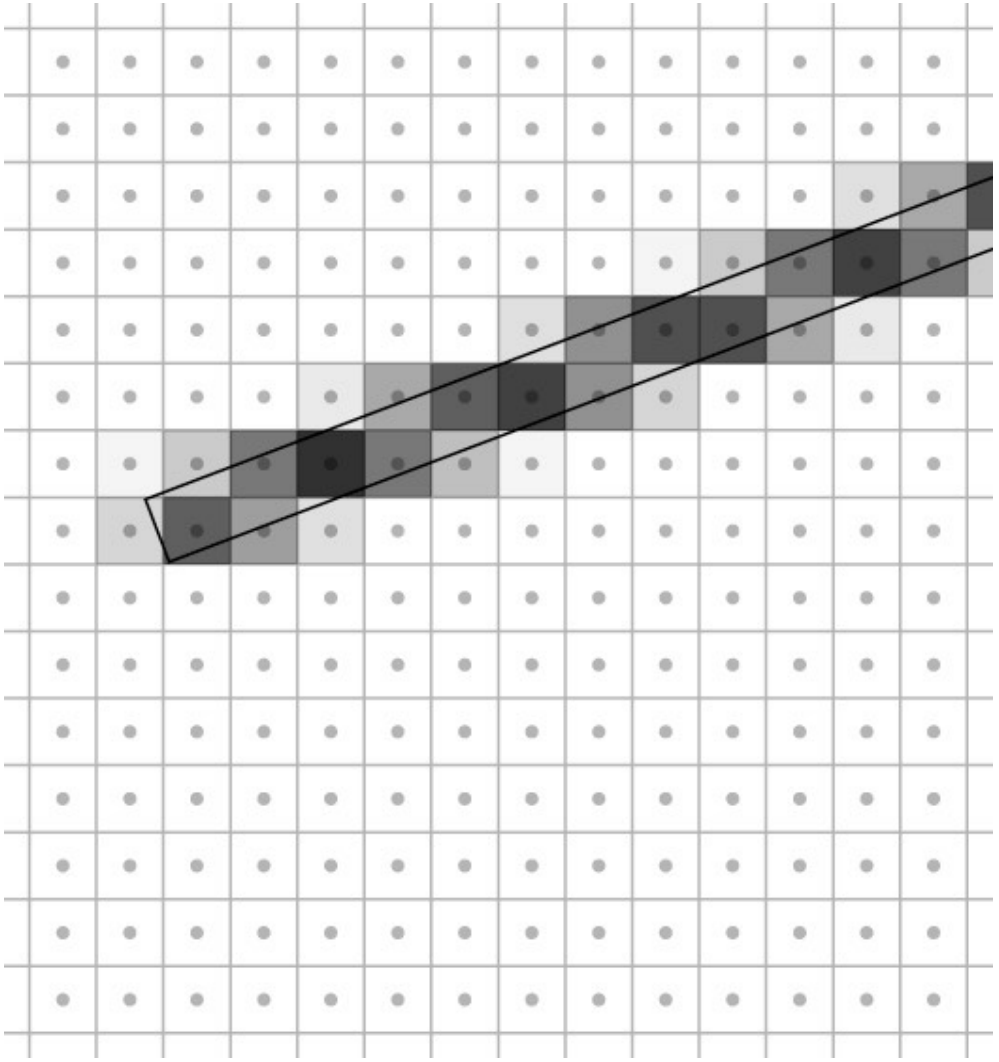


Antialiasing

- 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.

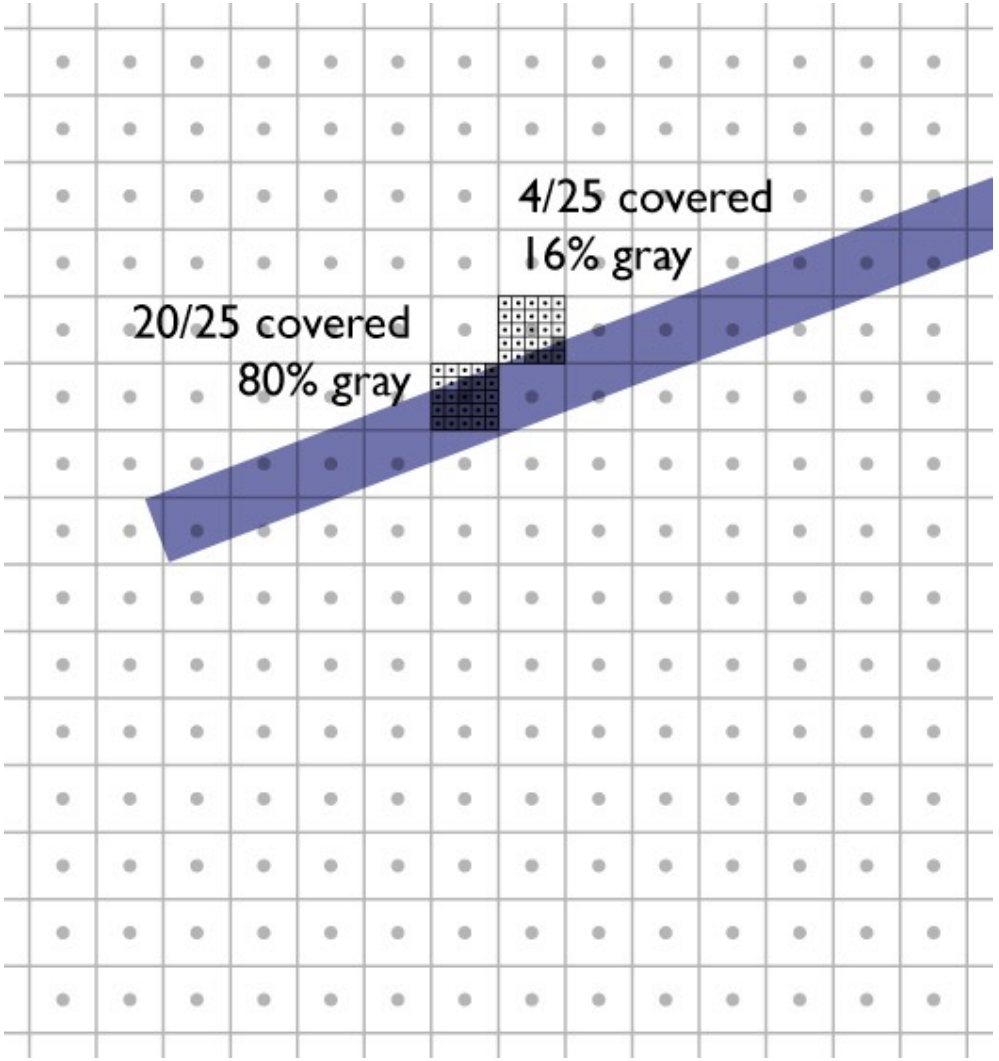


Box filtering

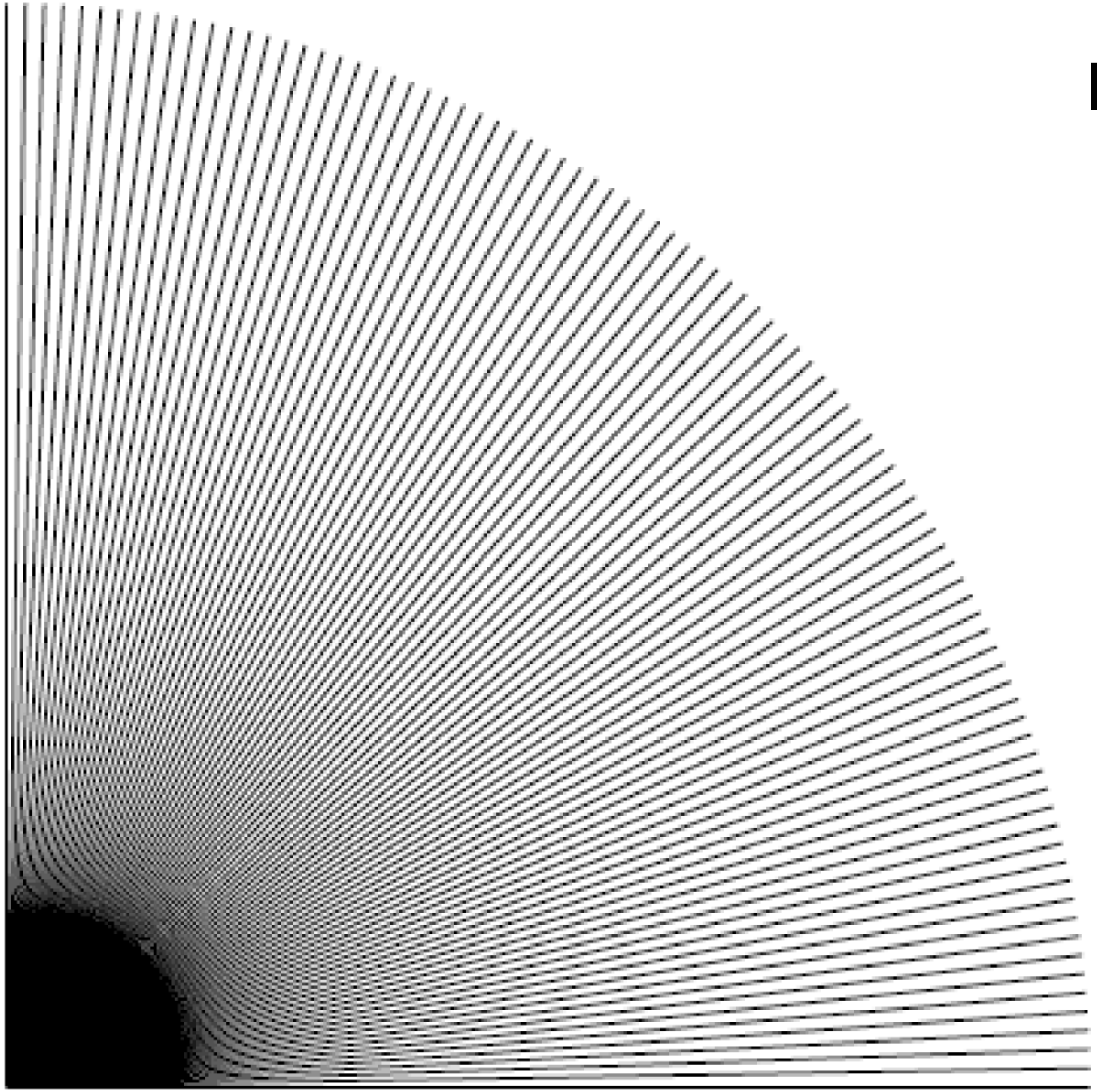
- Pixel intensity is proportional to area of overlap with square pixel area
- Also called "unweighted area averaging"

Box filtering by supersampling

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



Box filtering in action

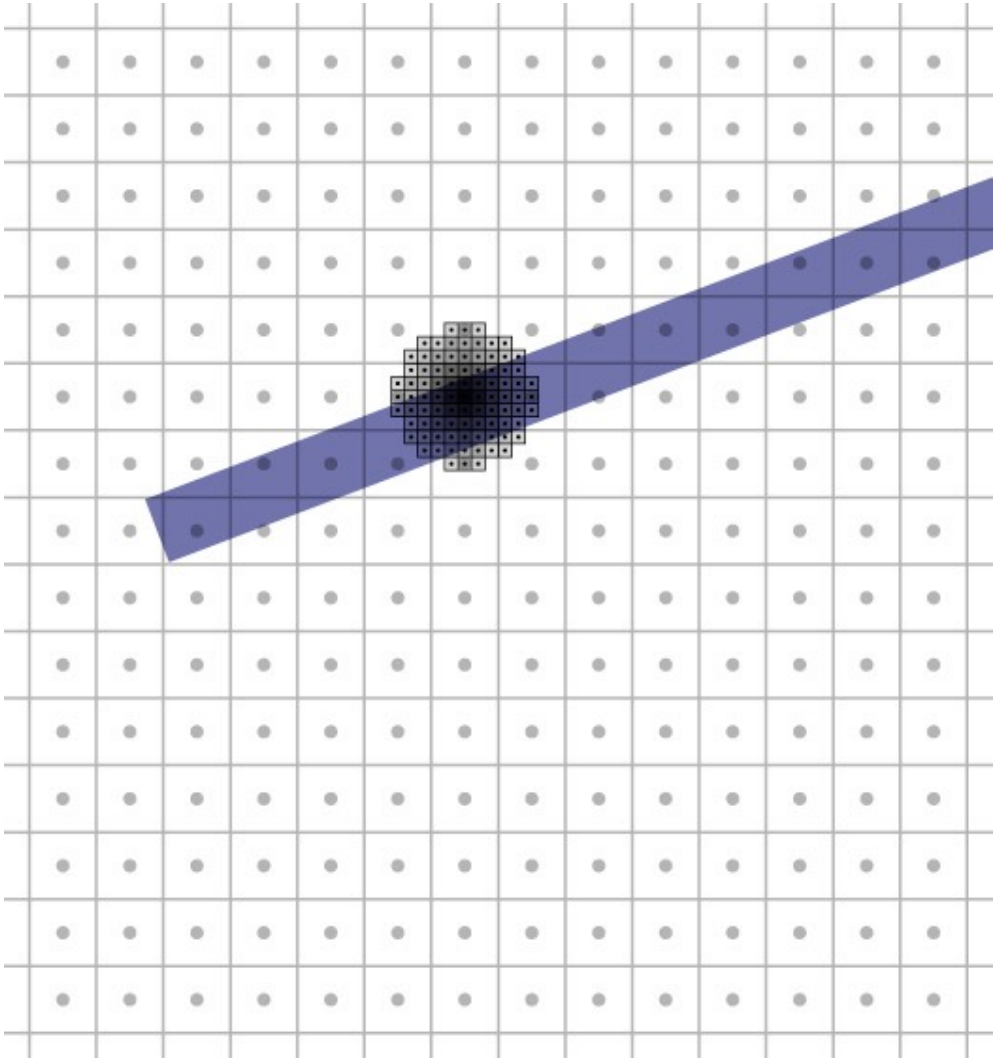


Weighted filtering

- 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)

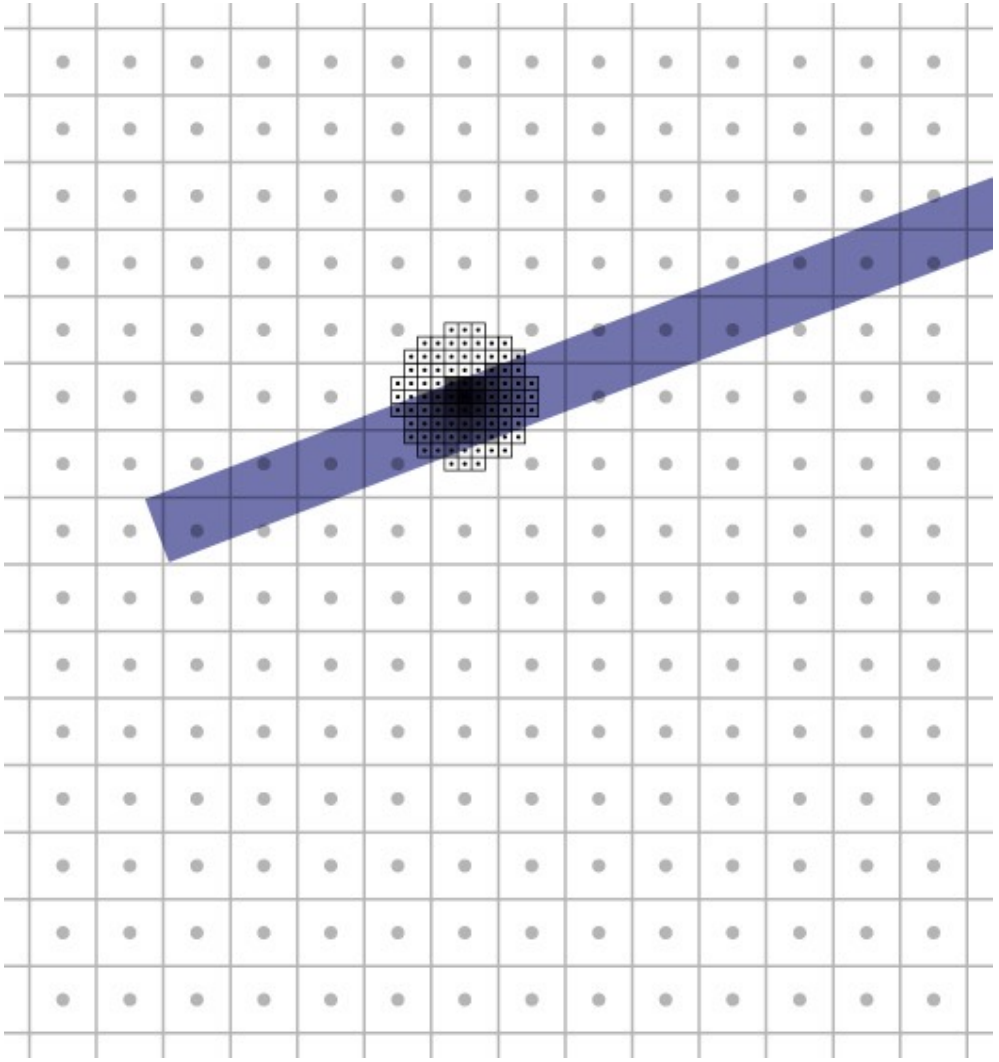
Weighted filtering by supersampling

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



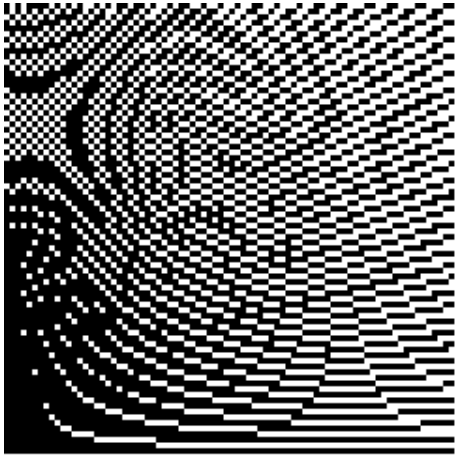
Weighted filtering by supersampling

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

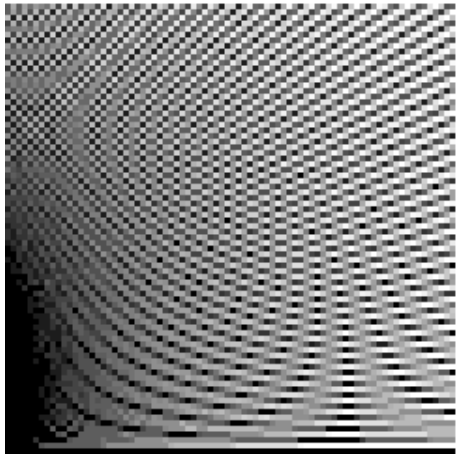


Gaussian filtering in action

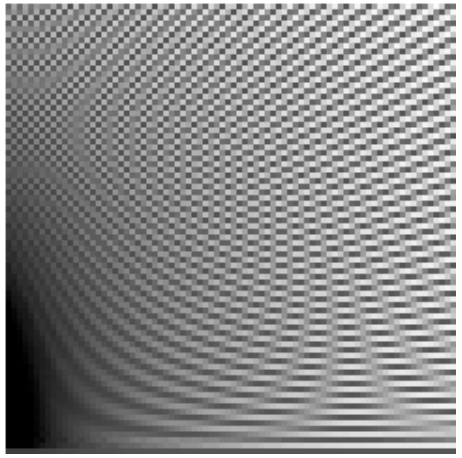
Filter comparison



Point sampling

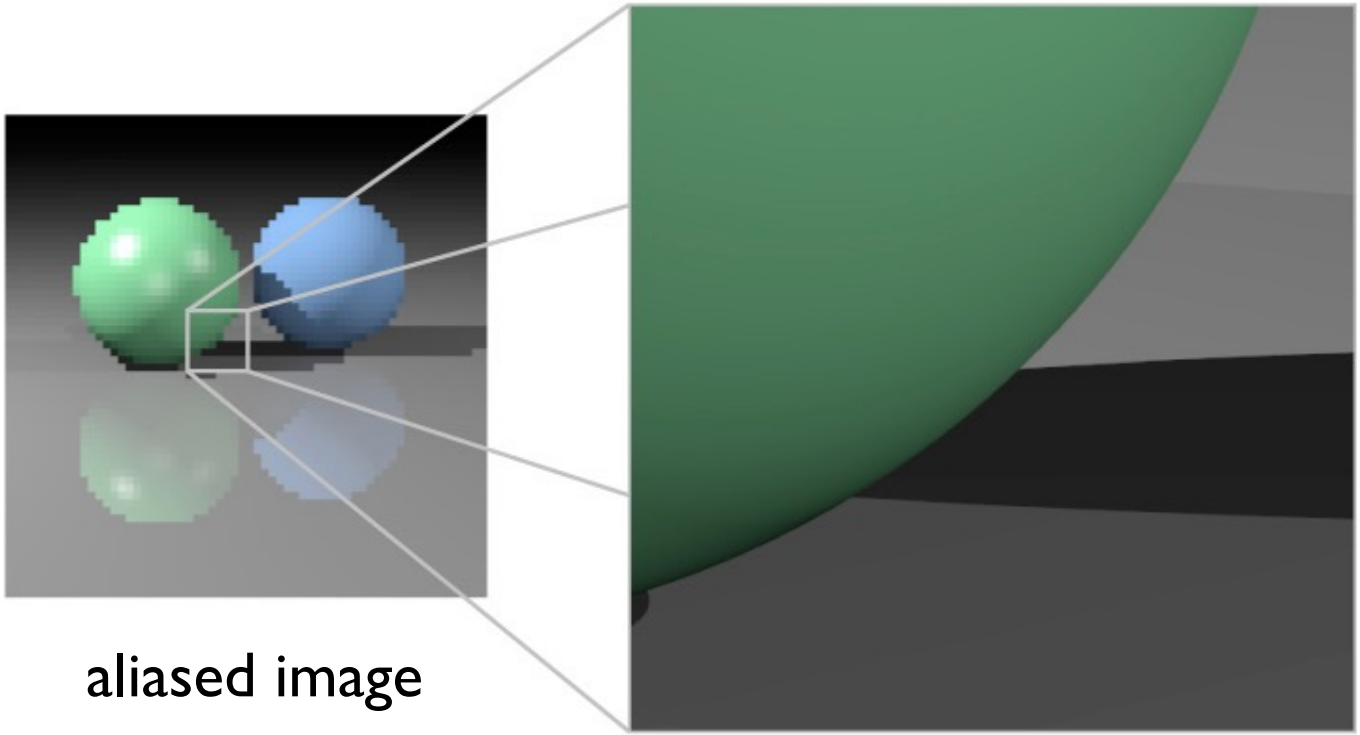


Box filtering



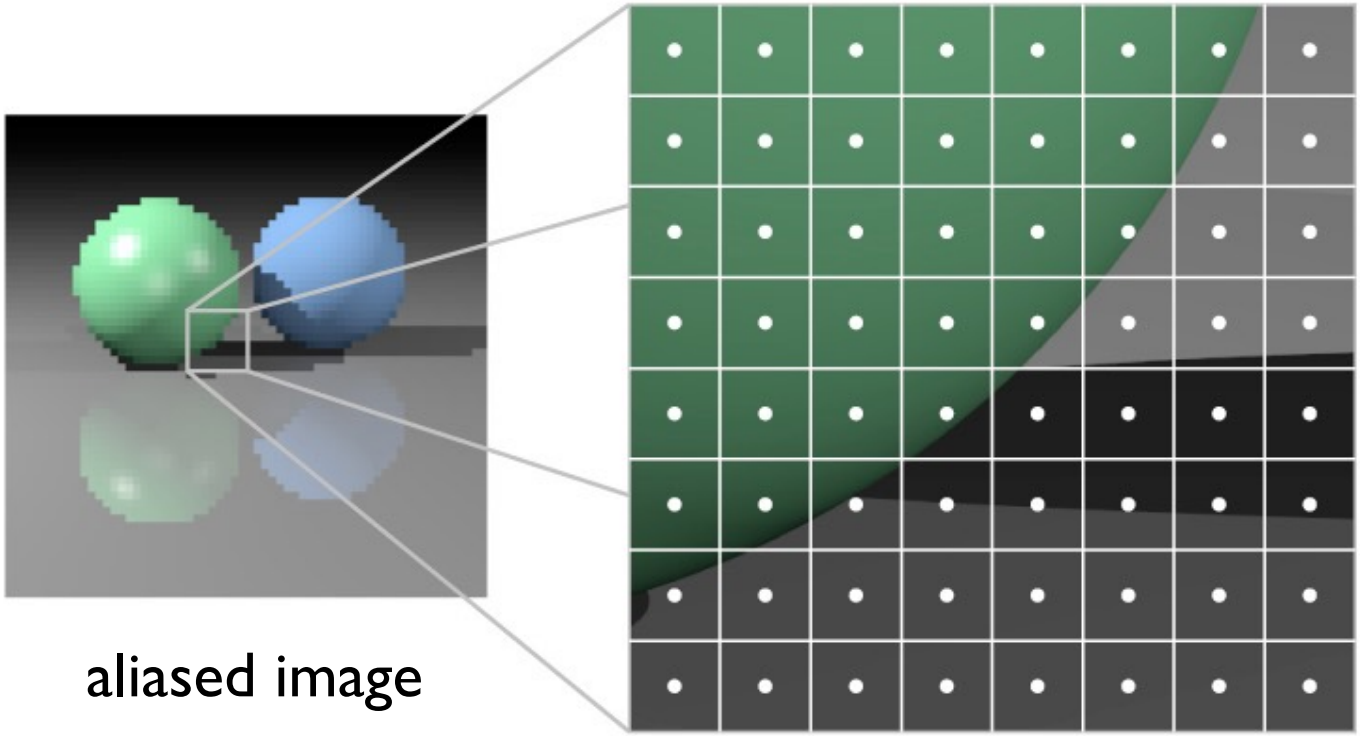
Gaussian filtering

Antialiasing in ray tracing



aliased image

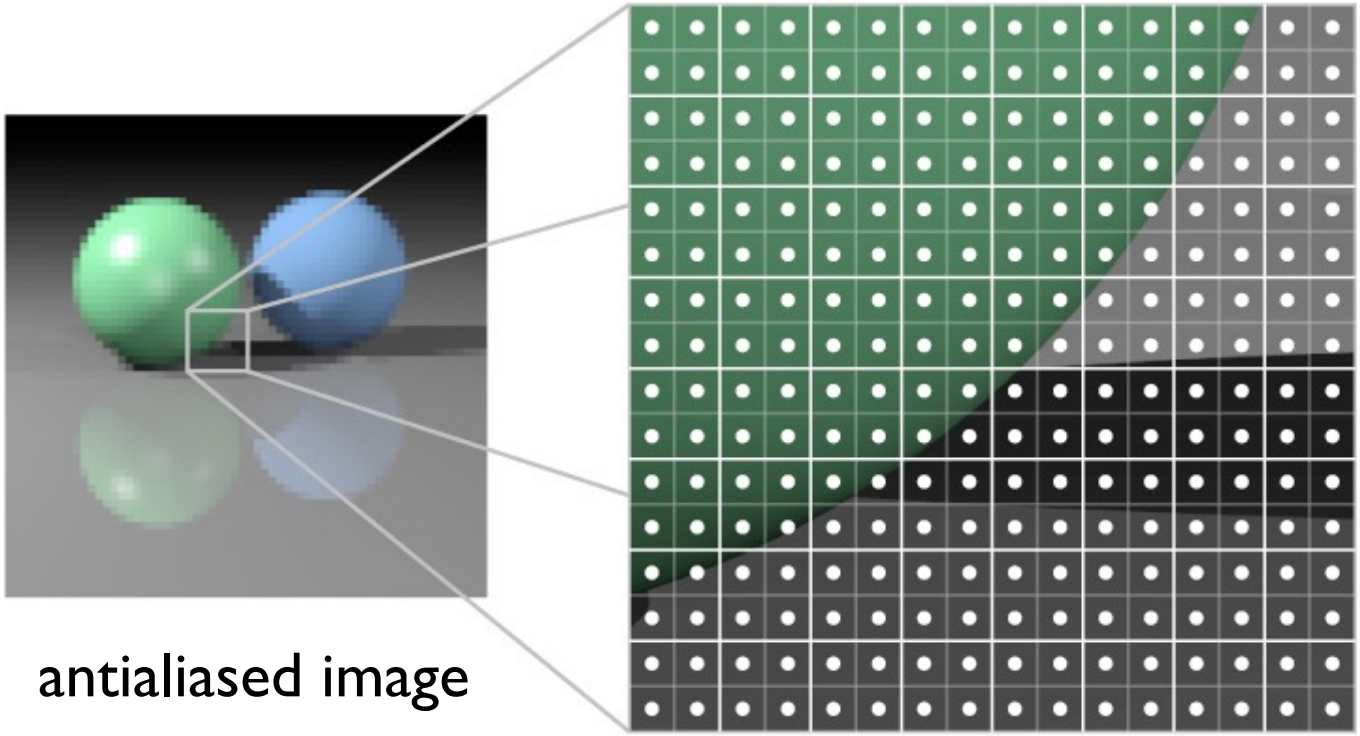
Antialiasing in ray tracing



aliased image

one sample per pixel

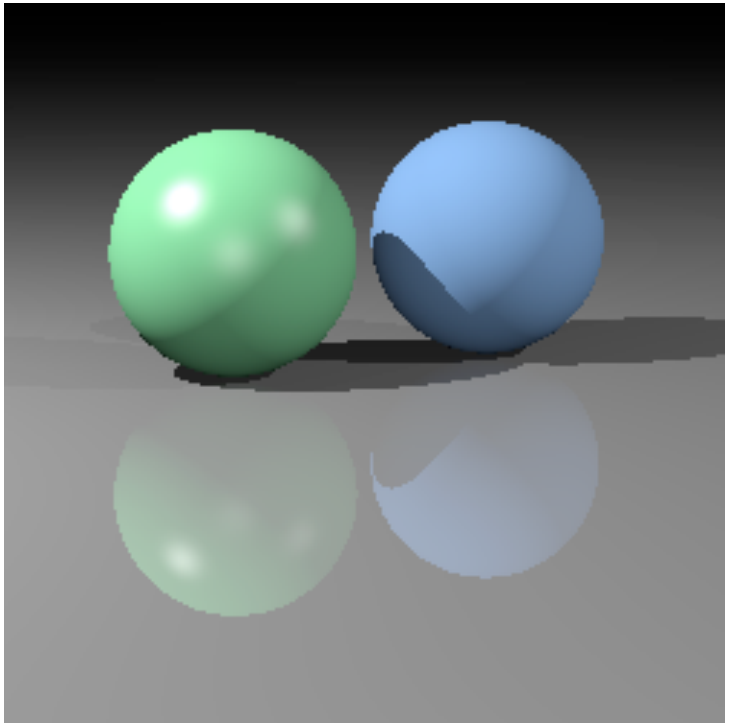
Antialiasing in ray tracing



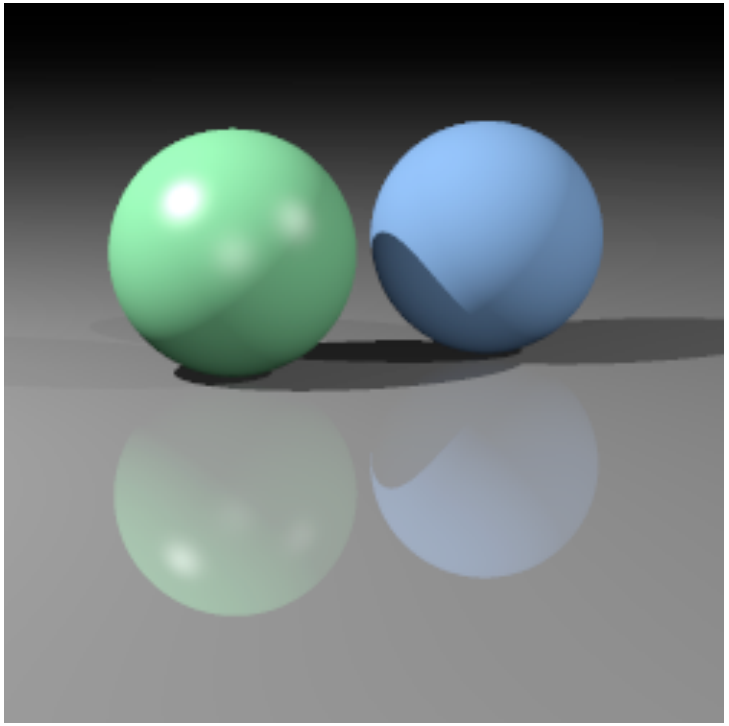
antialiased image

four samples per pixel

Antialiasing in ray tracing



one sample/pixel

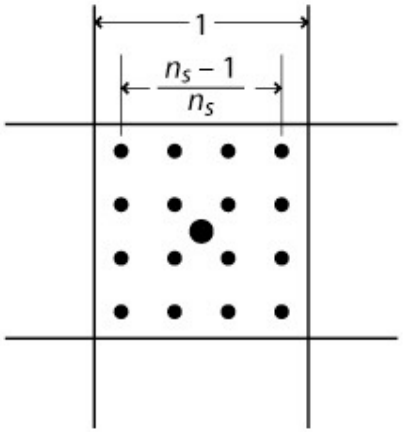


9 samples/pixel

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));
   }
```

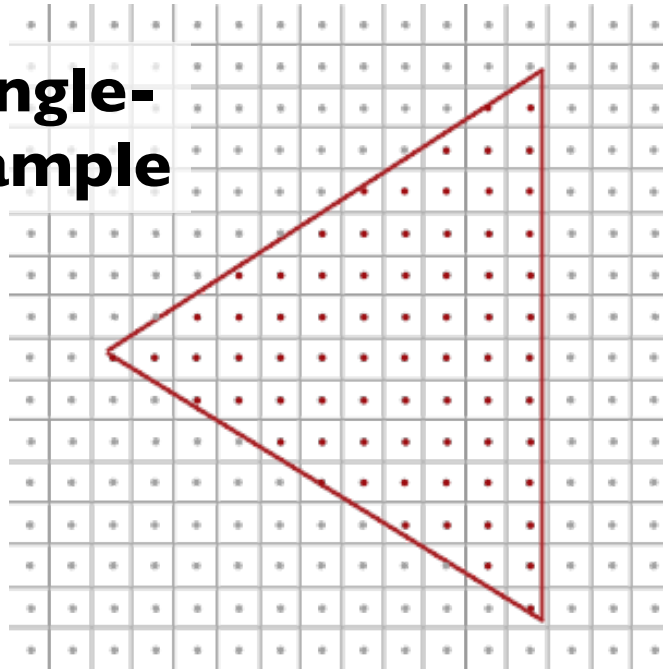
Supersampling vs. multisampling

- 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

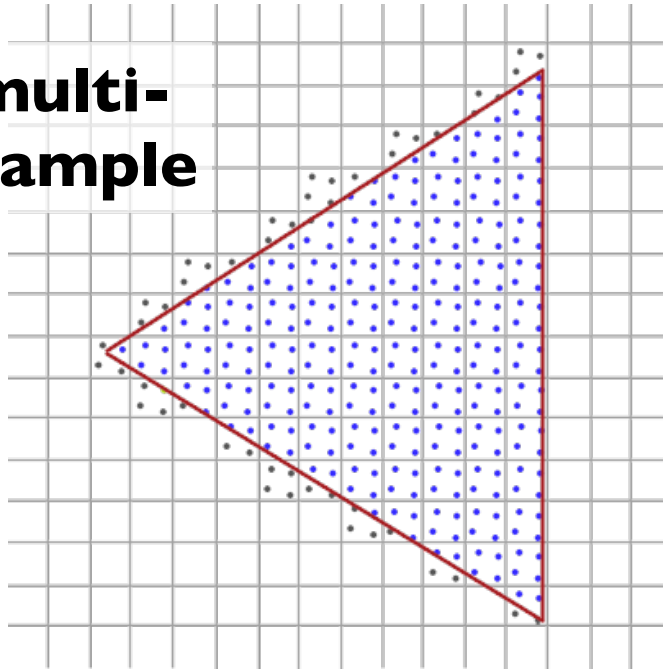
Multisample rasterization

- 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

single-sample



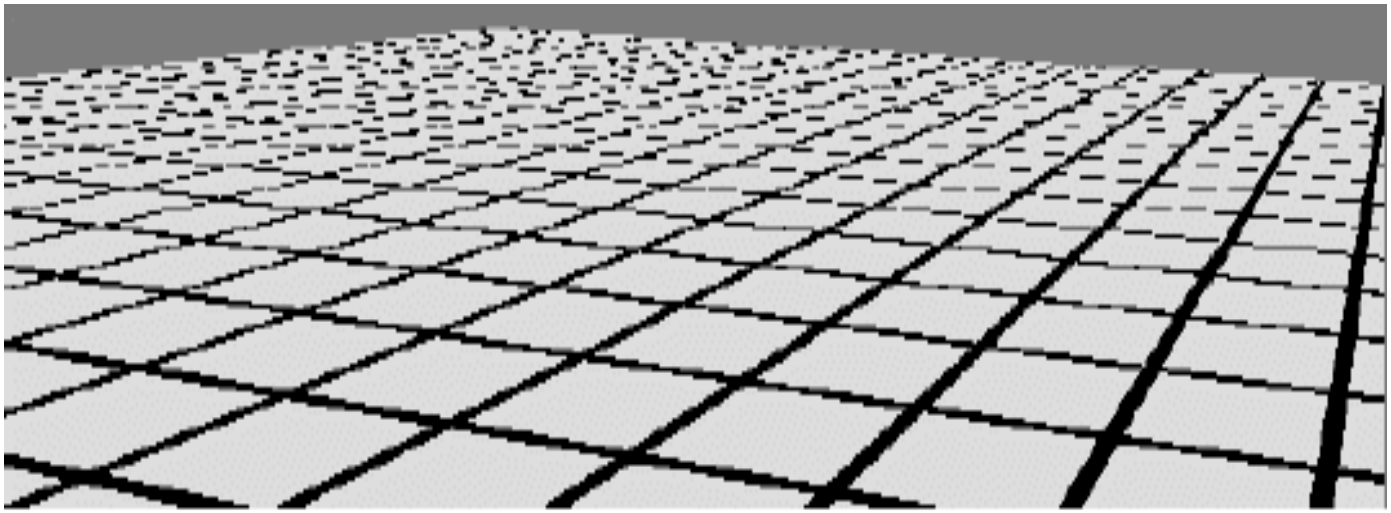
multi-sample



[http://www.learnopengl.com]

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]

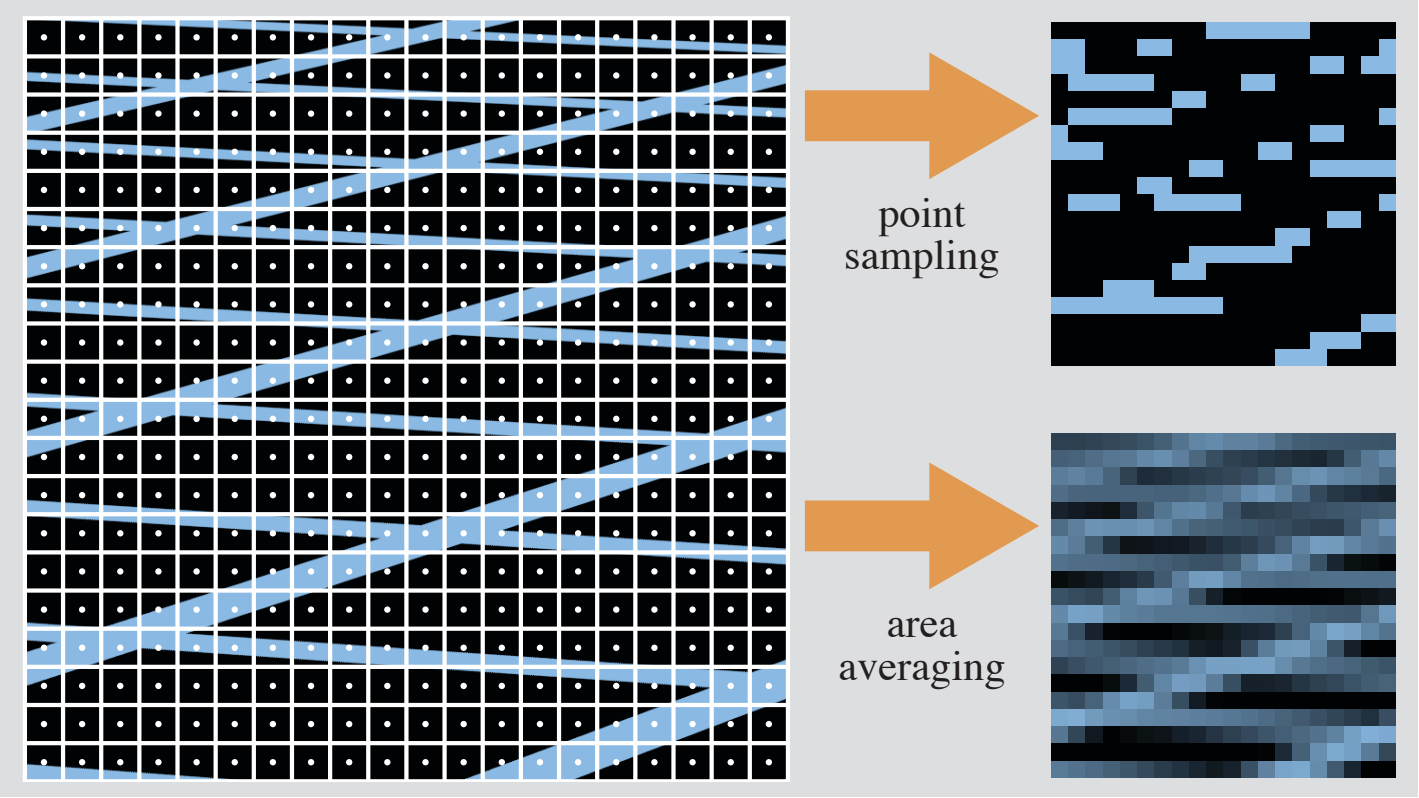
Texture mapping from 0 to infinity

- When you go close…

Texture mapping from 0 to infinity

- When you go far…

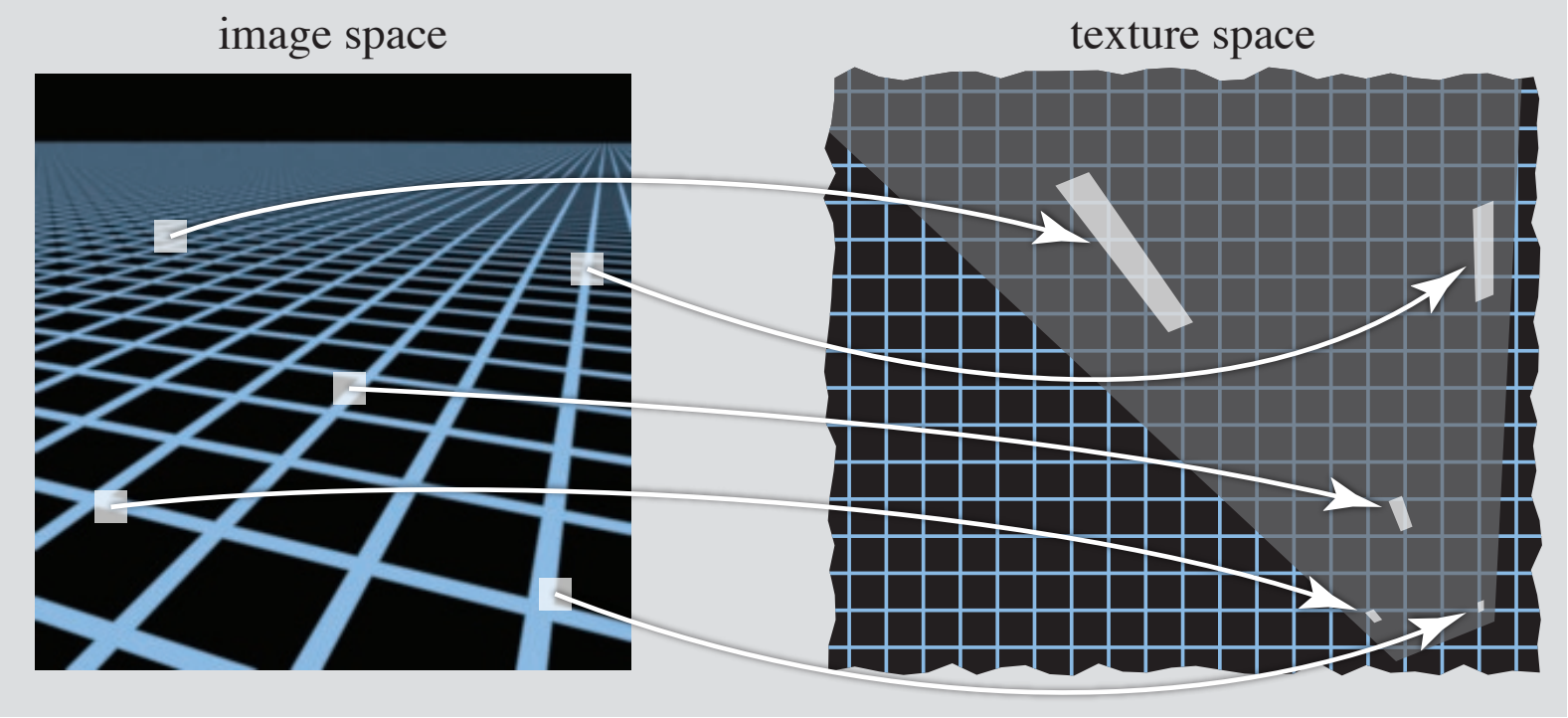
Solution: pixel filtering



Pixel filtering in texture space

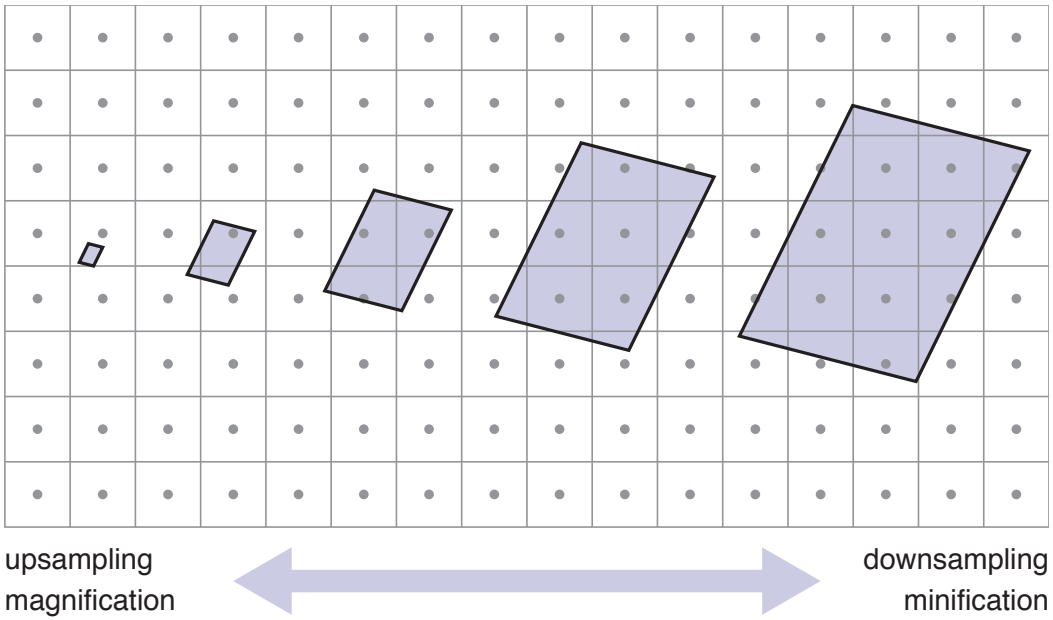
- Sampling is happening in image space
  - sample is a weighted average over a pixel-sized area
  - uniform, predictable, friendly problem!
- Signal is defined in texture space
  - mapping between image and texture is nonuniform
  - each sample is a weighted average over a different sized and shaped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

Pixel footprints

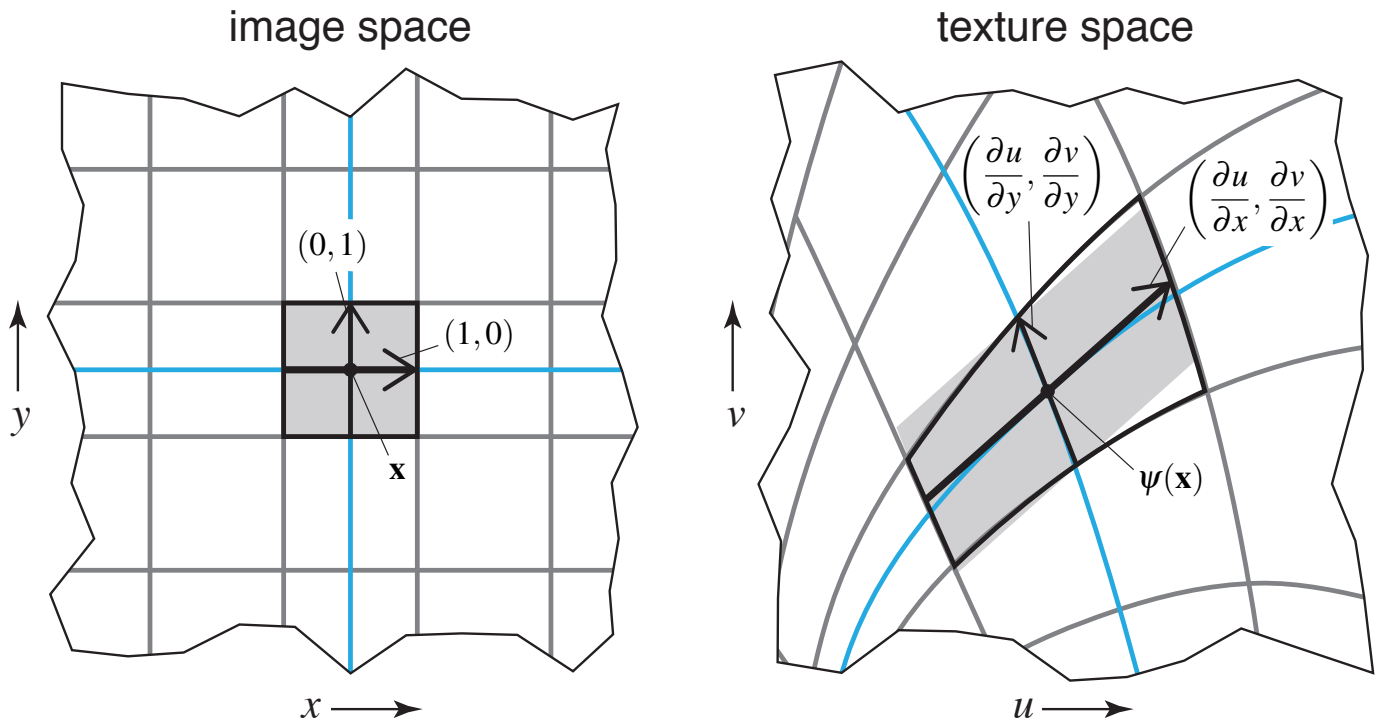


How does area map over distance?

- 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”

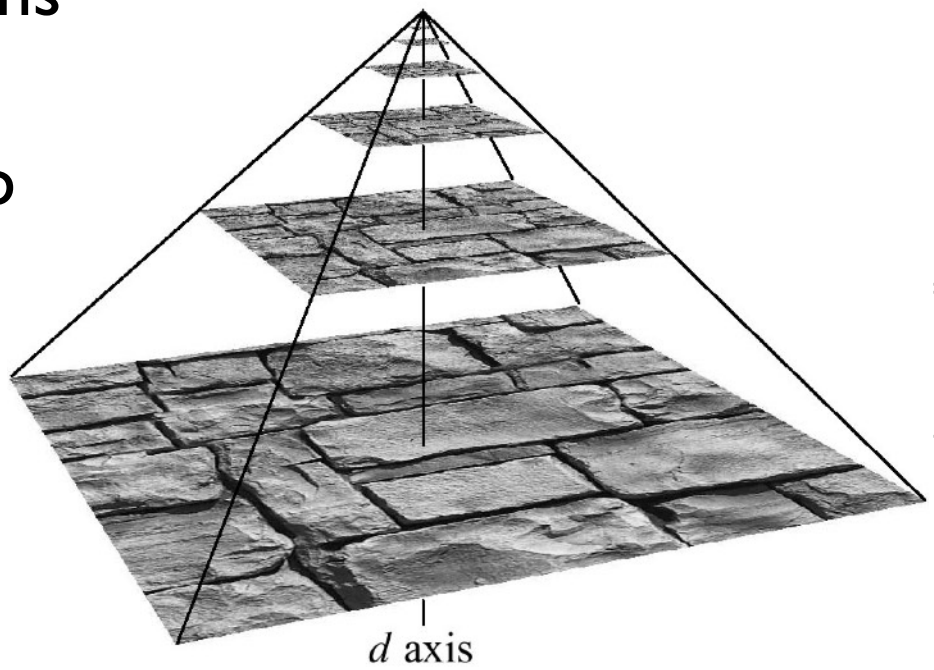


Sizing up the situation with the Jacobian



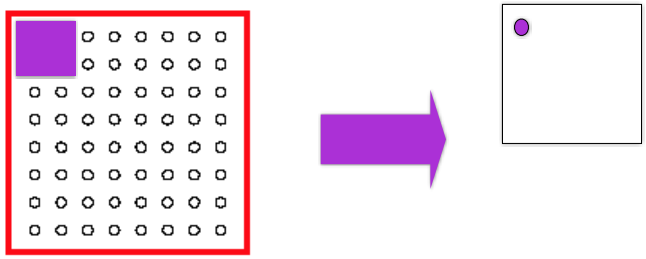
Mipmap image pyramid

- 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: $\frac{\partial u}{\partial x}$ $\frac{\partial v}{\partial x}$
    - y derivative: $\frac{\partial u}{\partial y}$ $\frac{\partial v}{\partial y}$

Given derivatives: what is level?

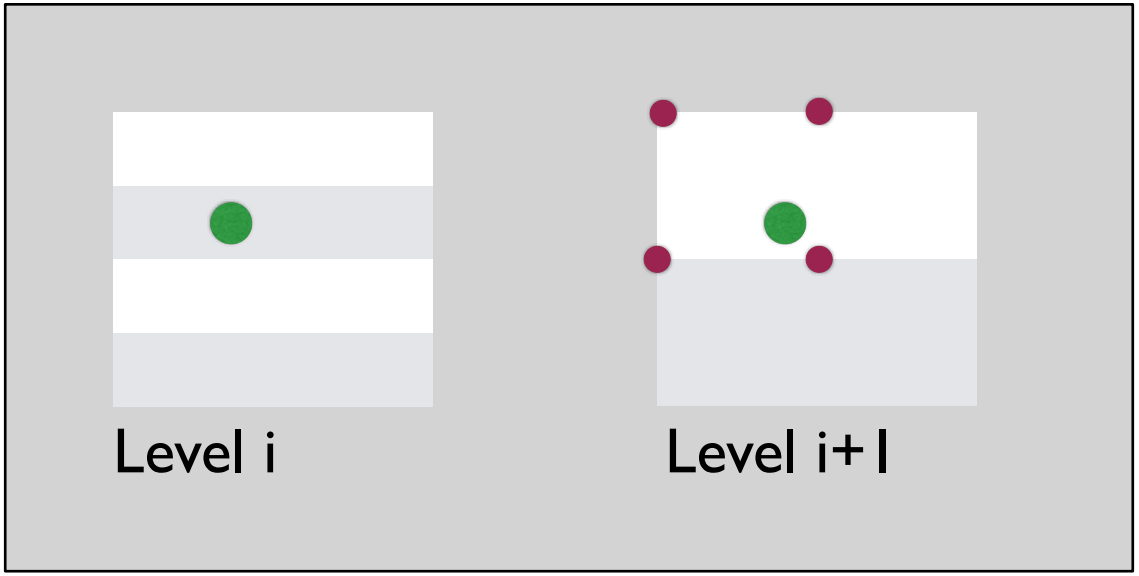
- Derivatives
  - Available in pixel shader (except where there is dynamic branching)

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

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

Using the MIP Map

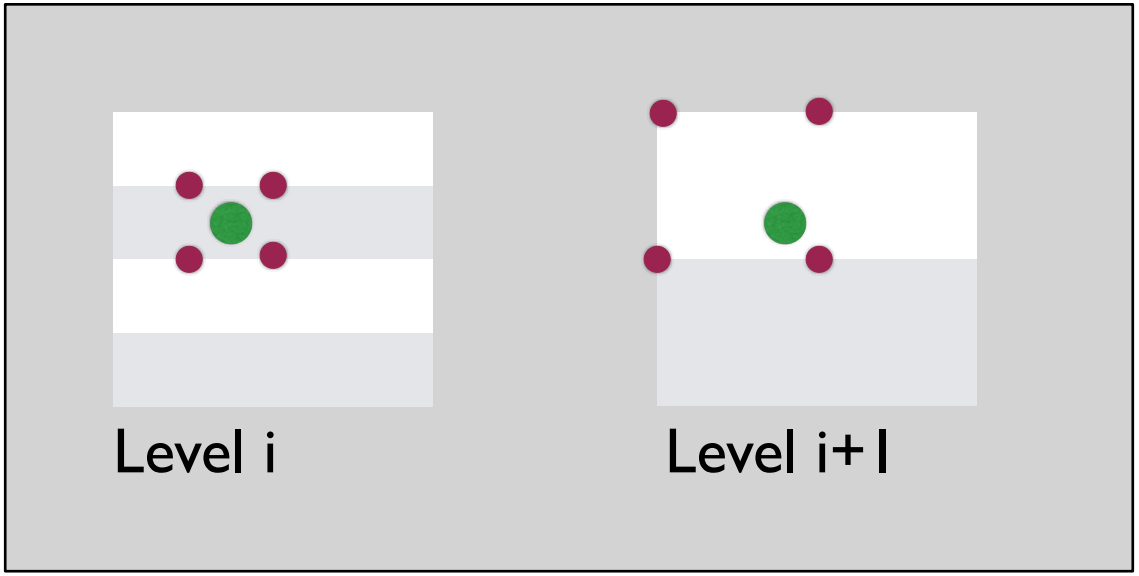
- In level, find texel and
  - Return the texture value: point sampling (but still better)!
  - Bilinear interpolation
  - Trilinear interpolation



[Kavita Bala]

Using the MIP Map

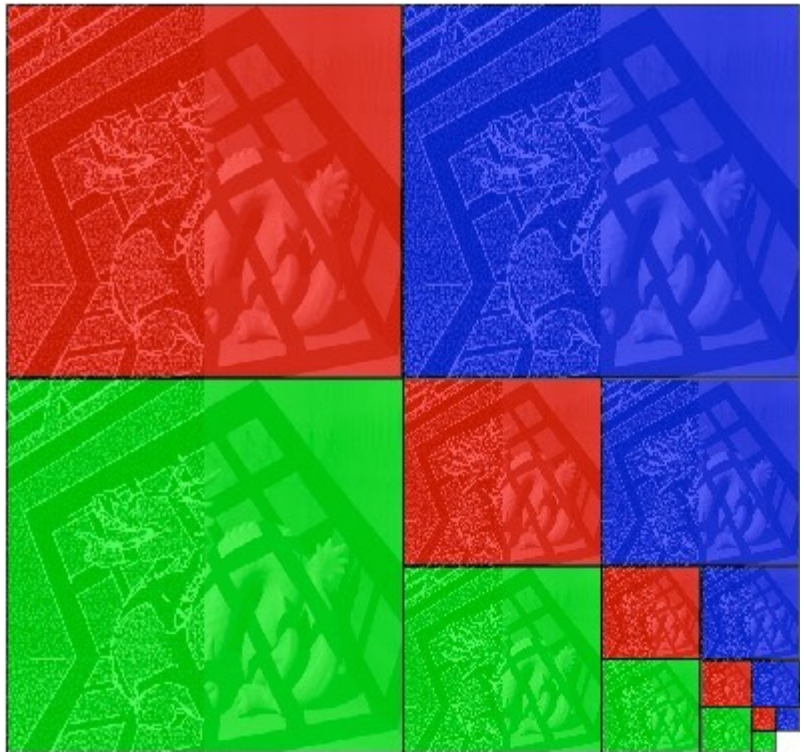
- In level, find texel and
  - Return the texture value: point sampling (but still better)!
  - Bilinear interpolation
  - Trilinear interpolation

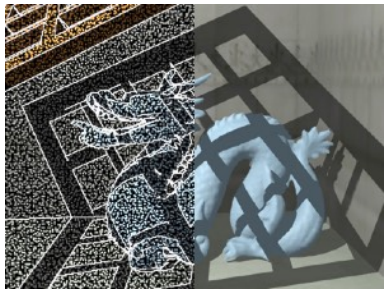


[Kavita Bala]

Memory Usage

- What happens to size of texture?





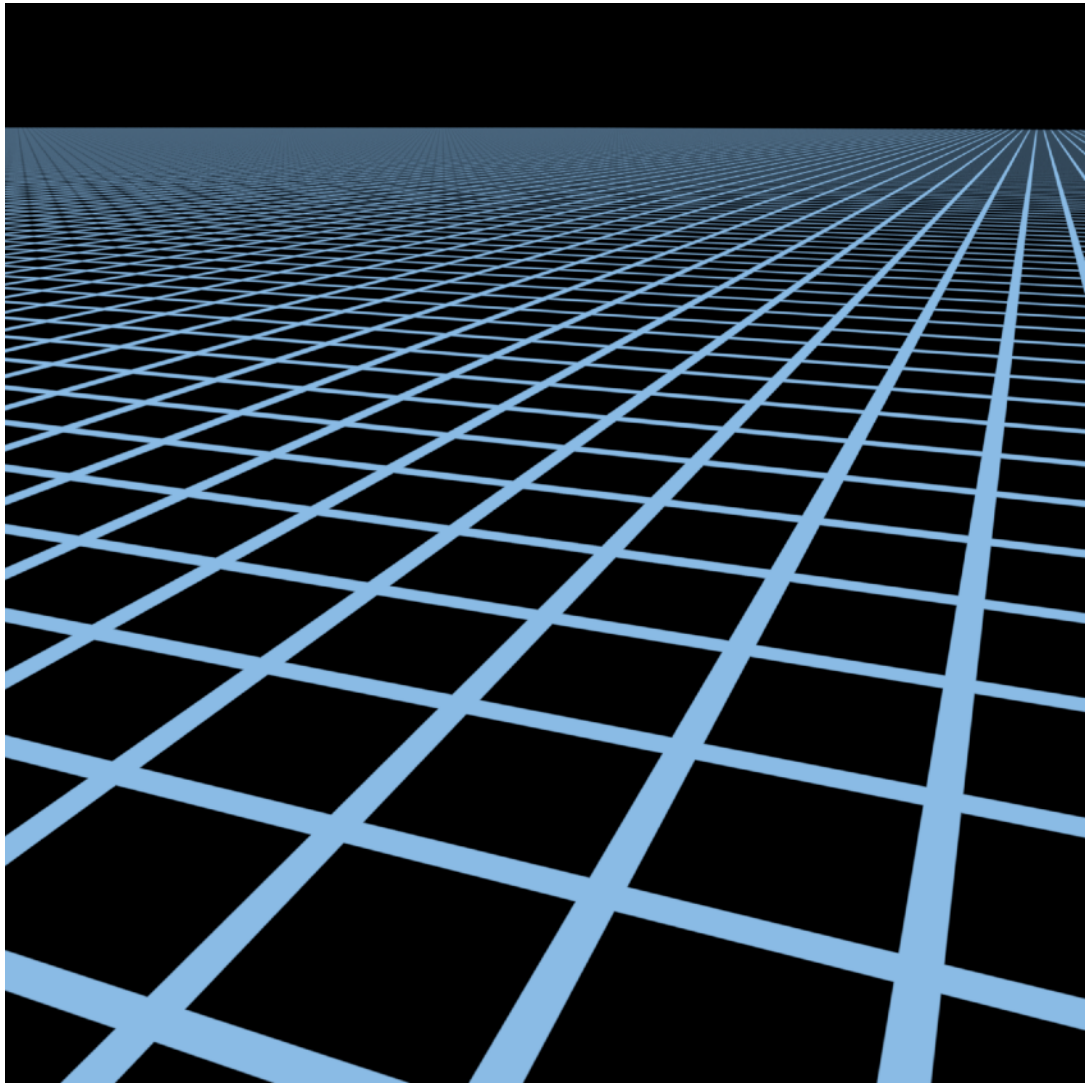
[Kavita Bala]

MIPMAP

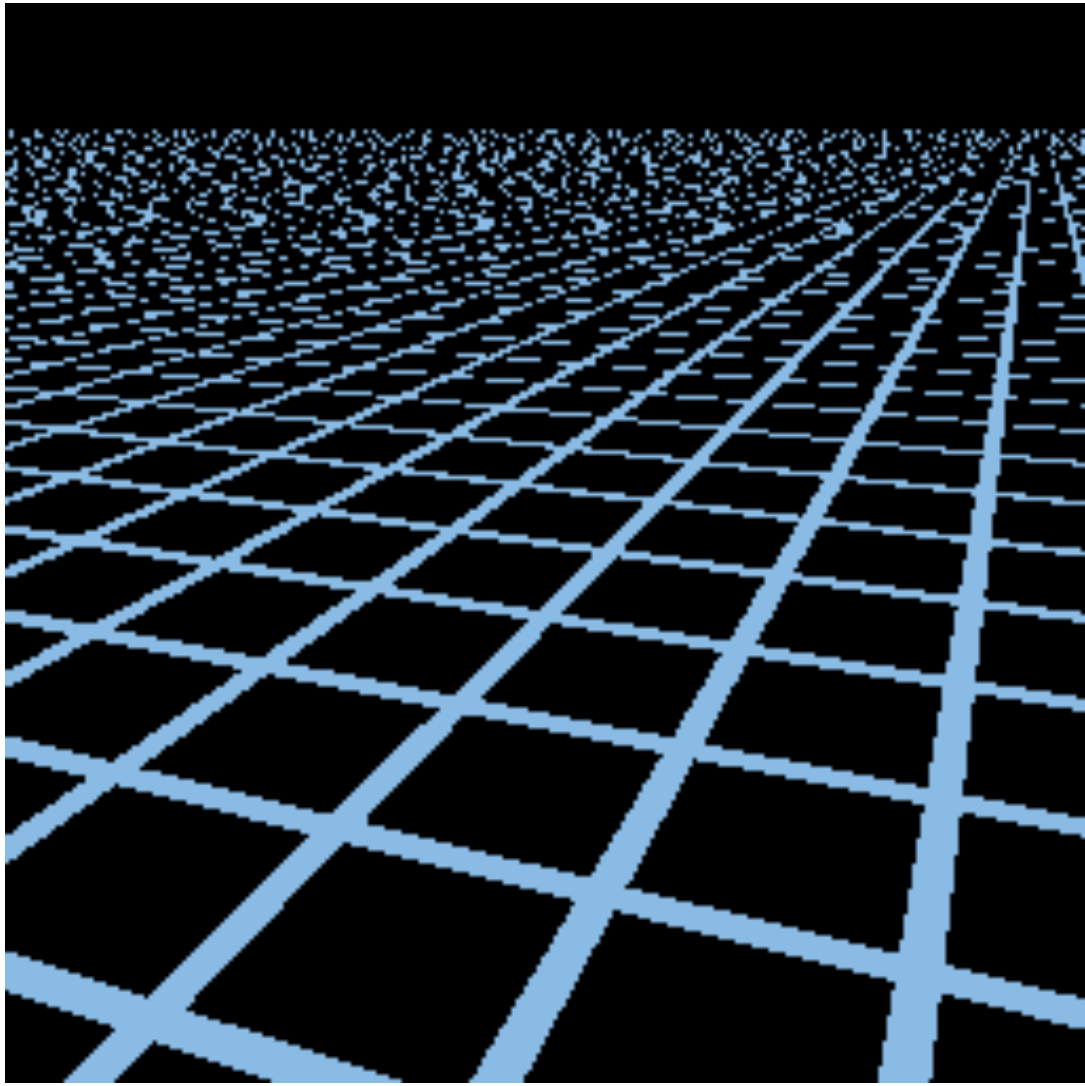
- Multi-resolution image pyramid
  - Pre-sampled computation of MIPMAP
  - 1/3 more memory

- Bilinear or Trilinear interpolation

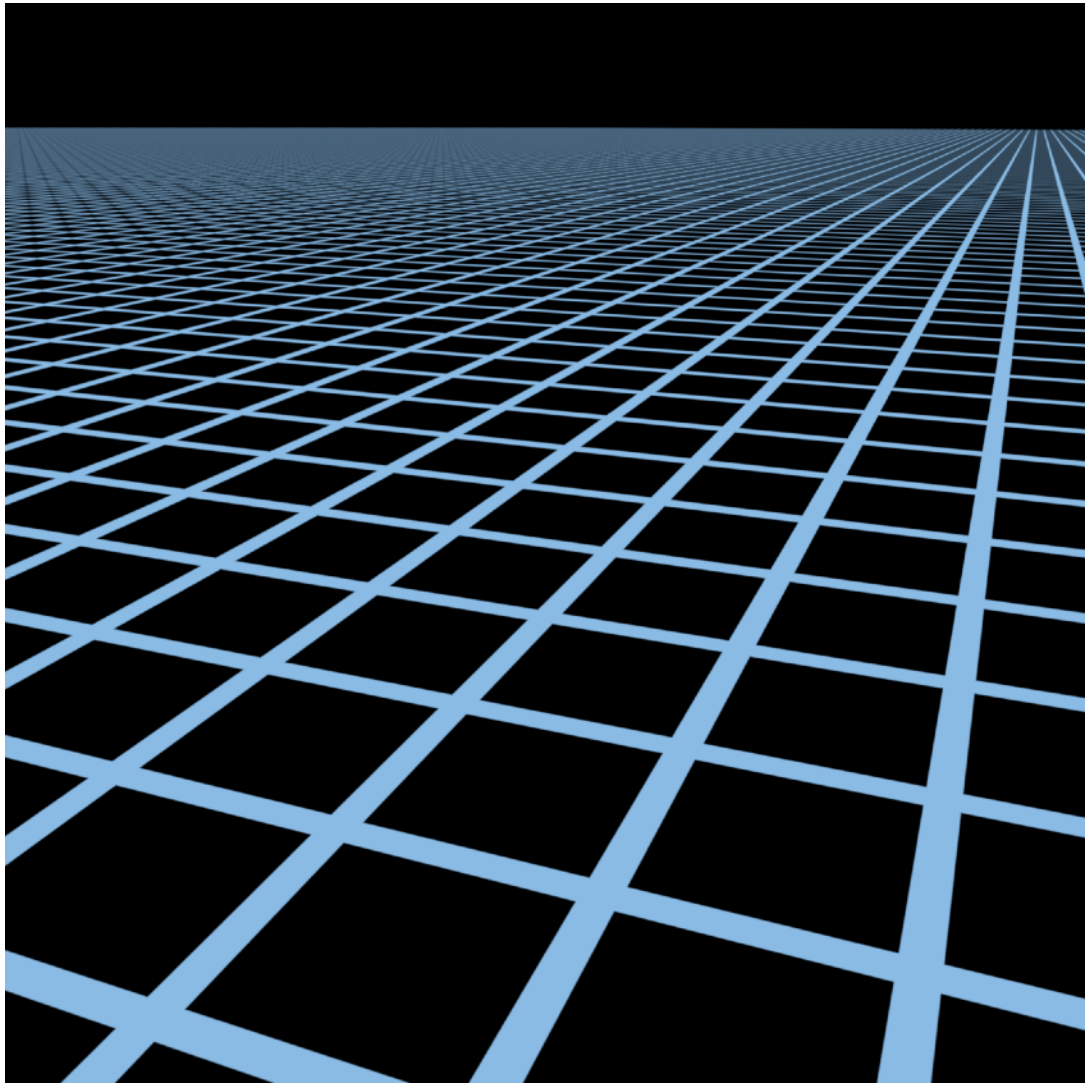
Point sampling



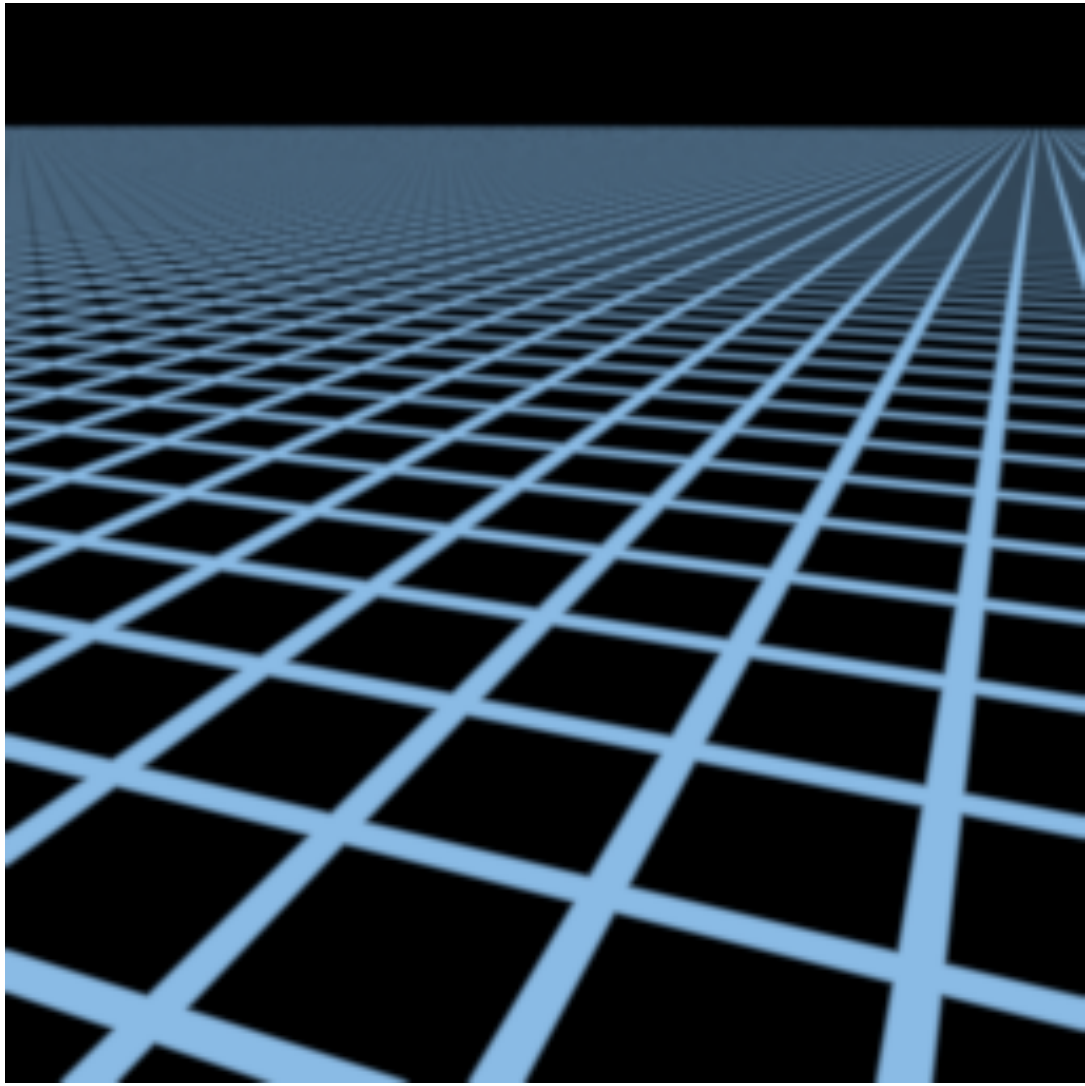
Point sampling



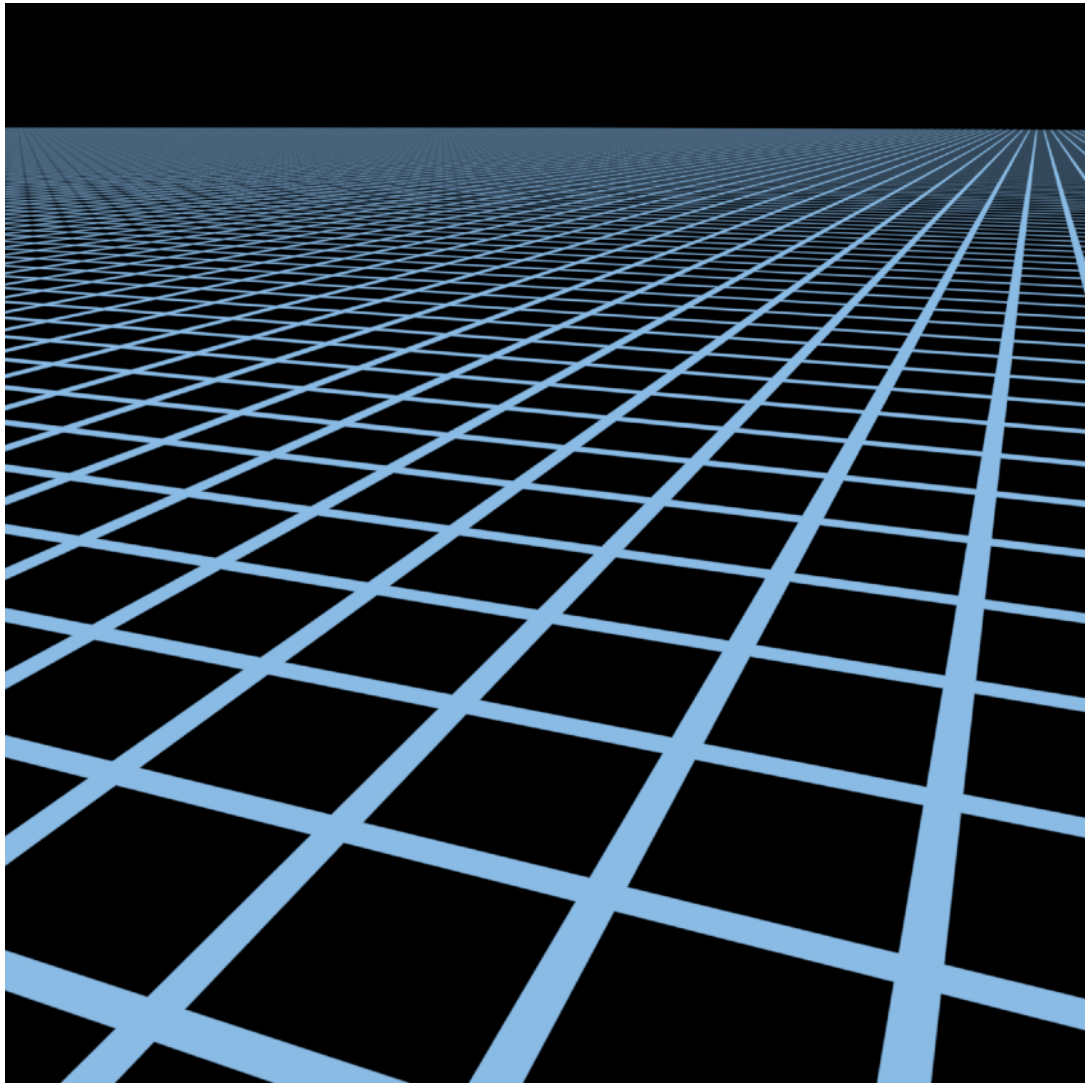
Reference: gaussian sampling by



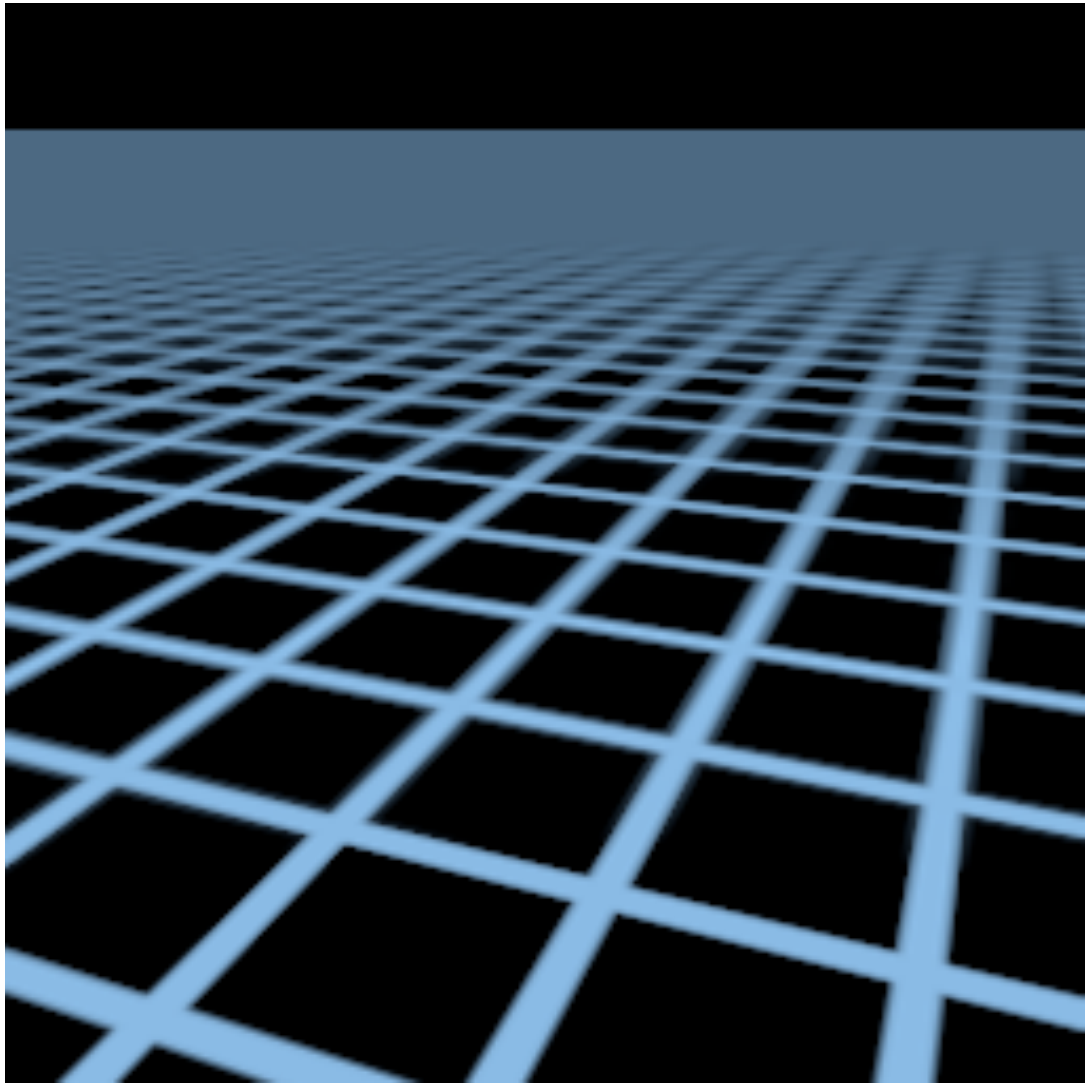
Reference: gaussian sampling by



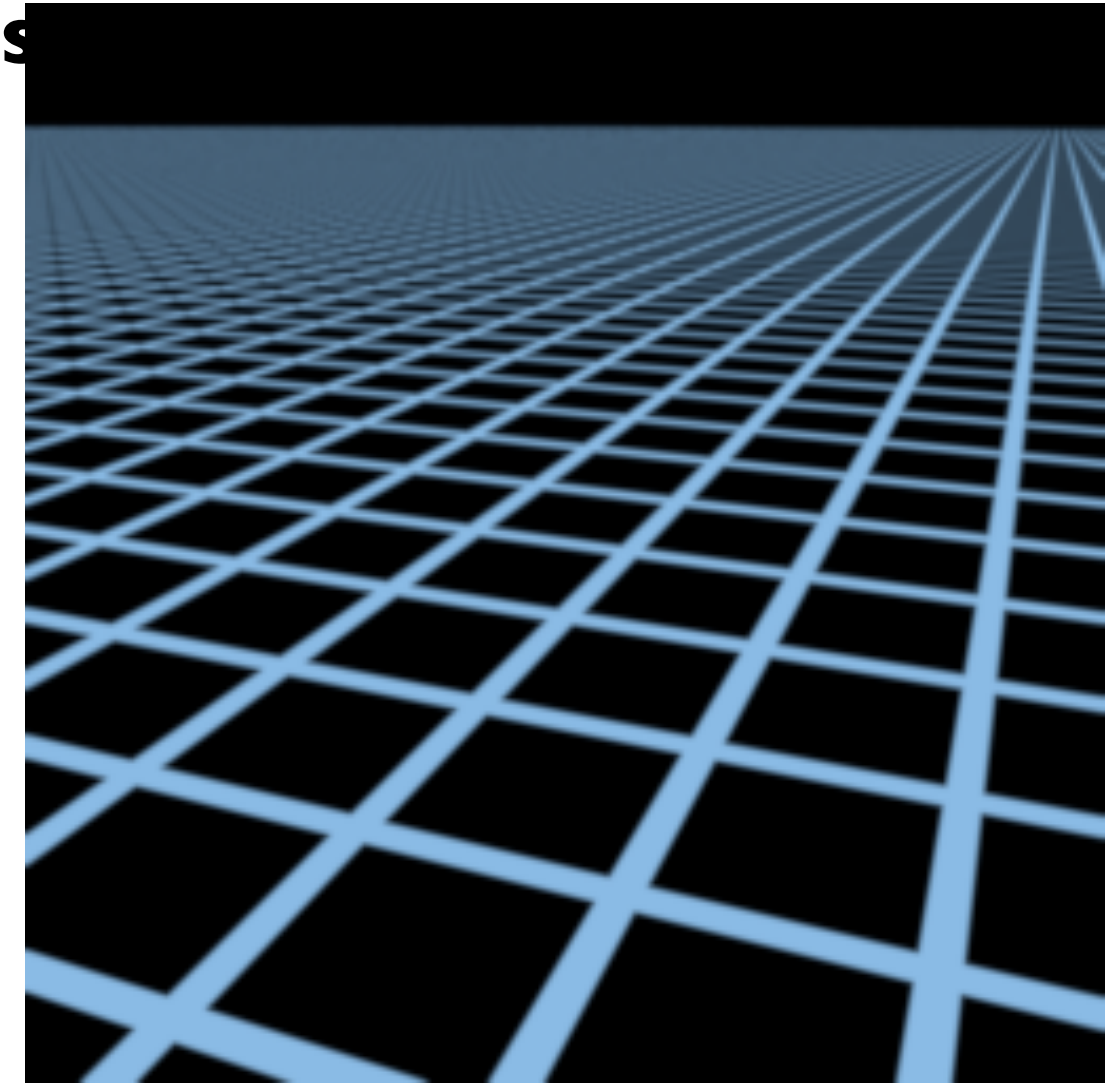
Texture minification with a mipmap



Texture minification with a mipmap



Texture minification: supersampling vs



Texture minification: supersampling vs