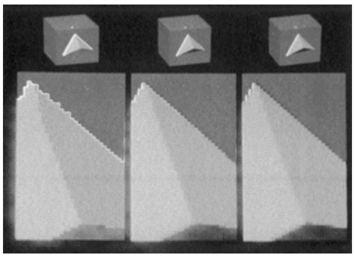
Anti-Aliasing Techniques



How do we remove aliasing ?

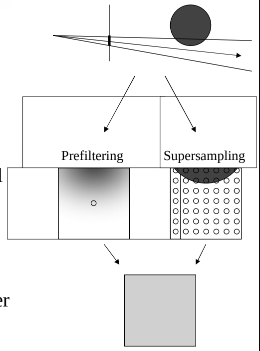
- Cheaper solution : take multiple samples for each pixel and average them together → supersampling.
- Can weight them towards the centre → weighted average sampling
- Stochastic sampling

Removing aliasing is called *antialiasing*

Antialiasing Strategies

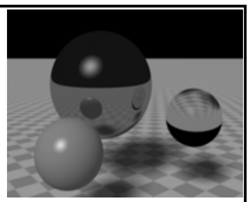
Pixel needs to represent average color over its entire area

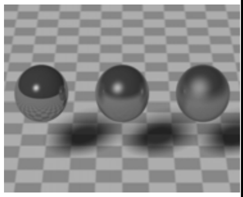
1. Prefiltering
   - averages the image function so a single sample represents the average color
   - Limits bandwidth of image signal to avoid overlap
2. Supersampling
   - Supersampling averages together many samples over pixel area
   - Moves the spectral replicas farther apart in frequency domain to avoid overlap



Cone Tracing

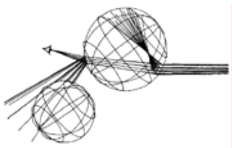
- Amanatides SIGGRAPH 84
- Replace rays with cones
- Cone samples pixel area
- Intersect cone with objects
  - Analytic solution of cone-object intersection similar to ray-object intersection
  - Expensive





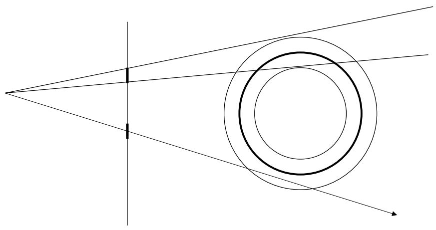
Images courtesy John Amanatides

Beam Tracing

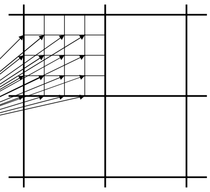


- Heckbert & Hanrahan SIGGRAPH 84
- Replace rays with generalized pyramids
- Intersection with polygonal scenes
  - Plane-plane intersections easy, fast
  - Existing scan conversion antialiasing
- Can perform some recursive beam tracing
  - Scene transformed to new viewpoint
  - Result clipped to reflective polygon

Covers

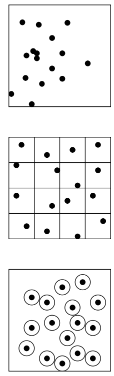


Supersampling



- Trace at higher resolution, average results
- Adaptive supersampling
  - trace at higher resolution only where necessary
- Problems
  - Does not eliminate aliases (e.g. moire patterns)
  - Makes aliases higher-frequency
  - Due to uniformity of samples

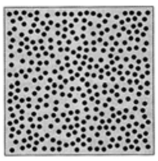
Stochastic Sampling



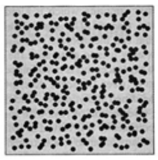
- Eye is extremely sensitive to patterns
- Remove pattern from sampling
- Randomize sampling pattern
- Result: patterns -> noise
- Some noises better than others
- *Jitter*: Pick *n* random points in sample space
  - Easiest, but samples cluster
- *Uniform Jitter*: Subdivide sample space into *n* regions, and randomly sample in each region
  - Easier, but can still cluster
- *Poisson Disk*: Pick *n* random points, but not too close to each other
  - Samples can't cluster, but may run out of room

Stochastic Sampling

Poisson

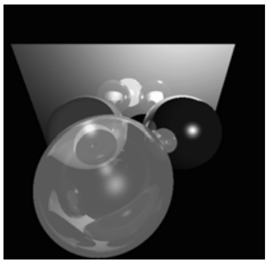


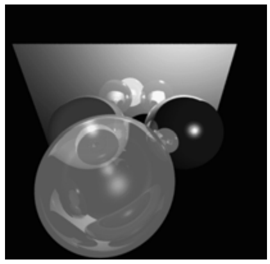
Poisson Disc



Jitter

Stochastic Sampling

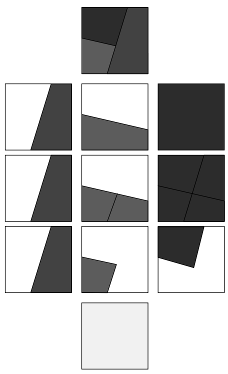




OpenGL Aliases

- Aliasing due to rasterization
- Opposite of ray casting
- New polygons-to-pixels strategies
- Prefiltering
  - Edge aliasing
    - Analytic Area Sampling
    - A-Buffer
  - Texture aliasing
    - MIP Mapping
    - Summed Area Tables
- Postfiltering
  - Accumulation Buffer

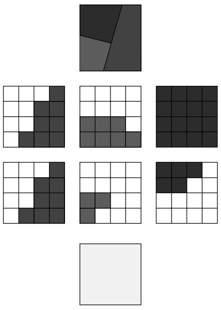
Analytic Area Sampling



- Ed Catmull, 1978
- Eliminates edge aliases
- Clip polygon to pixel boundary
- Sort fragments by depth
- Clip fragments against each other
- Scale color by visible area
- Sum scaled colors

A-Buffer

- Loren Carpenter, 1984
- Subdivides pixel into 4x4 bitmasks
- Clipping = logical operations on bitmasks
- Bitmasks used as index to lookup table



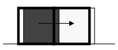
Texture Aliasing

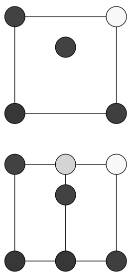
- Image mapped onto polygon
- Occur when screen resolution differs from texture resolution
- Magnification aliasing
  - Screen resolution finer than texture resolution
  - Multiple pixels per texel
- Minification aliasing
  - Screen resolution coarser than texture resolution
  - Multiple texels per pixel

Magnification Filtering

- Nearest neighbor
  - Equivalent to spike filter

- Linear interpolation
  - Equivalent to box filter



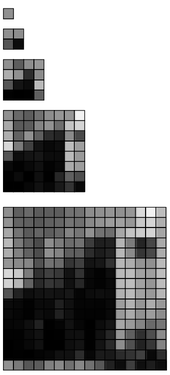


Minification Filtering

- Multiple texels per pixel
- Potential for aliasing since texture signal bandwidth greater than framebuffer
- Box filtering requires averaging of texels
- Precomputation
  - MIP Mapping
  - Summed Area Tables

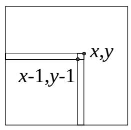
MIP Mapping

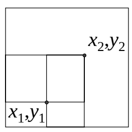
- Lance Williams, 1983
- Create a resolution pyramid of textures
  - Repeatedly subsample texture at half resolution
  - Until single pixel
  - Need extra storage space
- Accessing
  - Use texture resolution closest to screen resolution
  - Or interpolate between two closest resolutions



Summed Area Table

- Frank Crow, 1984
- Replaces texture map with summed-area texture map
  - $S(x,y)$ = sum of texels <= x,y
  - Need double range (e.g. 16 bit)
- Creation
  - Incremental sweep using previous computations
  - $S(x,y) = T(x,y) + S(x\text{-}1,y) + S(x,y\text{-}1) - S(x\text{-}1,y\text{-}1)$
- Accessing
  - $\Sigma\, T([x_1,x_2],[y_1,y_2]) = S(x_2,y_2) - S(x_1,y_2) - S(x_2,y_1) + S(x_1,y_1)$
  - Ave $T([x_1,x_2],[y_1,y_2])/((x_2 - x_1)(y_2 - y_1))$





Accumulation Buffer

- Increases OpenGL’s resolution
- Render the scene 16 times
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- Samples in different location in pixel
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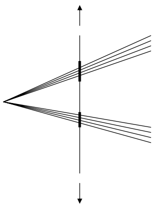
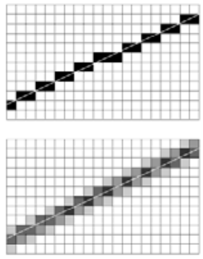
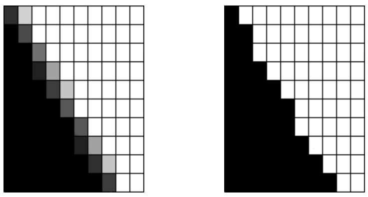


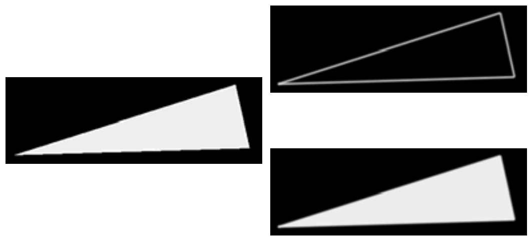
Aliased vs. Antialiased



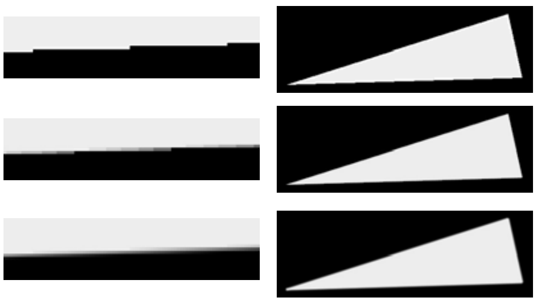
Polygon Edges



Line Antialising

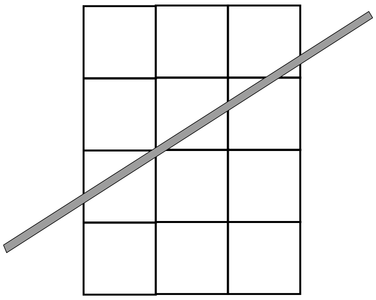


Polygon Antialising



Close-up

Line Anti-aliasing



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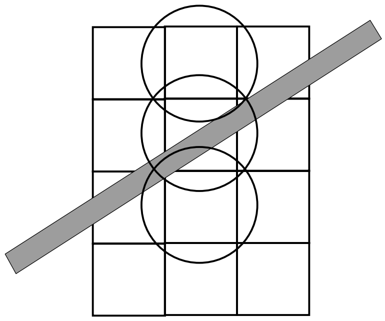
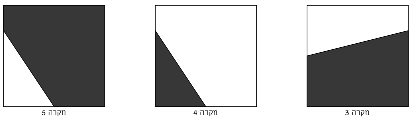


Abram & Westover, 1983



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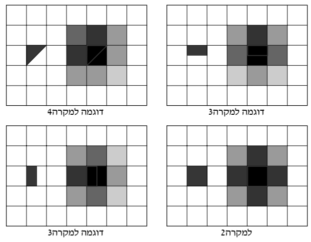

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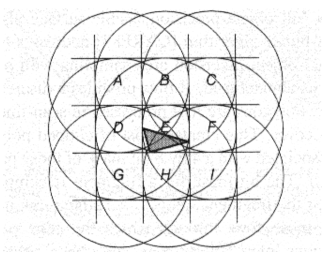
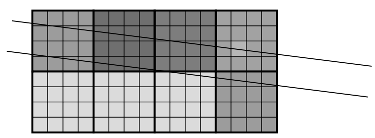
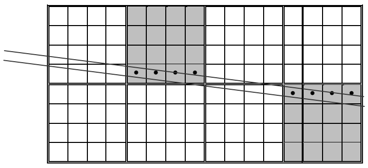


SuperSampling



Sample at 4x4 subpixels and color the pixel according to the portion of the coverage.

Andreas Schilling



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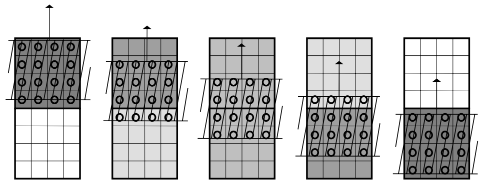

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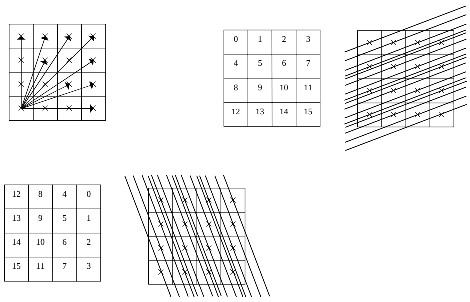
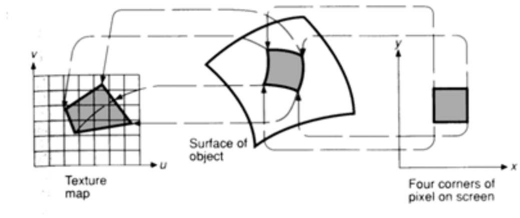
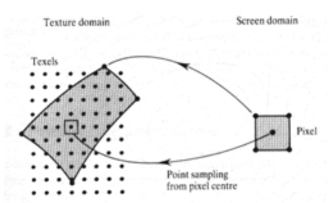


Texture Aliasing

- A single screen space pixel might correspond to many texels (texture elements):



Texture Mapping



Two special cases:

- Magnification: No real need in prefiltering. The main decision is what kind of reconstruction (interpolation) to use.

- Minification: No real need in reconstruction. The main problem is proper prefiltering.

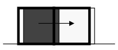
Nearest neighbor sampling

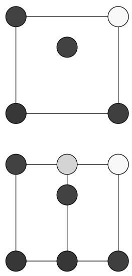
Filtered Texture:

Magnification Filtering

- Nearest neighbor
  - Equivalent to spike filter

- Linear interpolation
  - Equivalent to box filter





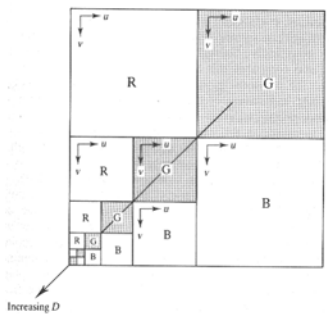
Texture Pre-Filtering

- Problem: filtering the texture during rendering is too slow for interactive performance.
- Solution: pre-filter the texture in advance
  - Summed area tables - gives the average value of each axis-aligned rectangle in texture space
  - Mip-maps (tri-linear interpolation) - supported by most of today's texture mapping hardware

MIP-Maps

- Precompute a set of prefiltered textures (essentially an image pyramid).
- Based on the area of the pre-image of the pixel:
  - Select two "best" resolution levels
  - Use bilinear interpolation inside each level
  - Linearly interpolate the results
- Referred to as trilinear interpolation

MIP Maps



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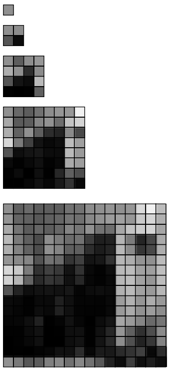

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- Box filtering requires averaging of texels
- Precomputation
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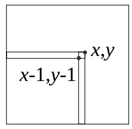
  - Summed Area Tables

Summed Area Table



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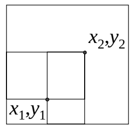
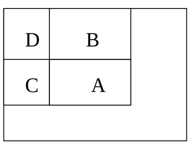


Summed Area Tables

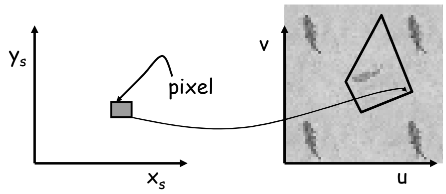
- A 2D table the size of the texture. At each entry (i,j), store the sum of all texels in the rectangle defined by (0,0) and (i,j).
- Given any axis aligned rectangle, the sum of all texels is easily obtained from the summed area table:

$$\text{area} = \mathrm{A} - \mathrm{B} - \mathrm{C} + \mathrm{D}$$



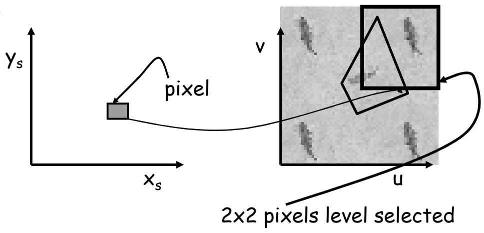
Quality considerations

- Pixel area maps to "weird" (warped) shape in texture space



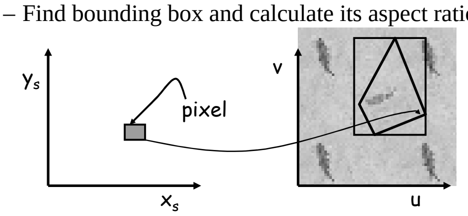
Mip-maps

- Find level of the mip-map where the area of each mip-map pixel is closest to the area of the mapped pixel.



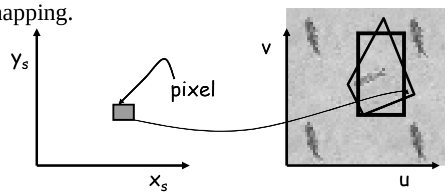
Summed Area Table (SAT)

- Determining the rectangle:
  – Find bounding box and calculate its aspect ratio



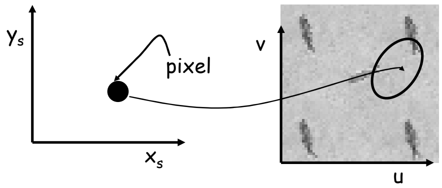
Summed Area Table (SAT)

- Determine the rectangle with the same aspect ratio as the bounding box and the same area as the pixel mapping.

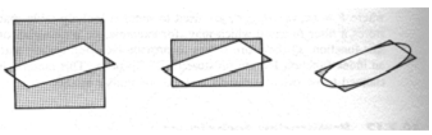


Elliptical Weighted Average (EWA) Filter

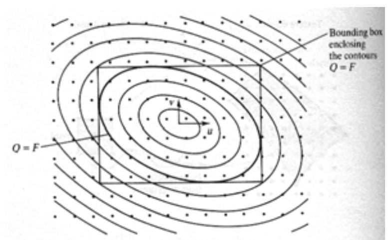
- Treat each pixel as circular, rather than square.
- Mapping of a circle is elliptical in texel space.



Texture Domain



Elliptical Weighted Average



Accumulation Buffer

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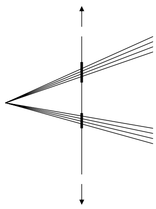
- Render the scene 16 times
- Shear projection matrices
- Samples in different location in pixel
- Average result
- Jittered, but same jitter sampling pattern in each pixel



tests