Johns Hopkins
Engineering for Professionals

605.767 Applied Computer Graphics

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Module 3D
Advanced Techniques

Advanced Ray Tracing Techniques

- Anti-aliasing
- Distributed ray tracing
- Forward ray tracing / Photon Mapping
  - Shadows from semi-transparent objects

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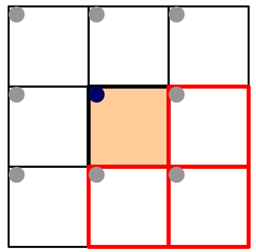
Anti-Aliasing in Ray Tracing: Super-Sampling

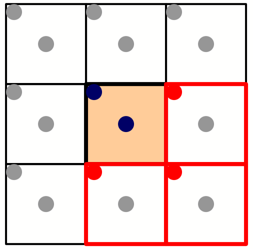
- Supersampling is an anti-aliasing technique that combines several samples within a pixel to determine the final pixel color
  - Rendering the image at a higher resolution
  - Down-sample to the desired size
  - http://en.wikipedia.org/wiki/Supersampling
- Super-sampling in ray-tracing
  - Increasing the number of rays shot through the image plane
- One possibility:
  - Shoot rays through a pixel corner
    - e.g, upper left
  - Image pixel color is the average through the 4 corners
    - Each pixel uses values from its neighbors
      - Below, right, and right-lower
  - Only requires 1 ray per pixel
    - Need an extra row and column of pixels



Average 4 corners

Quincunx Anti-Aliasing

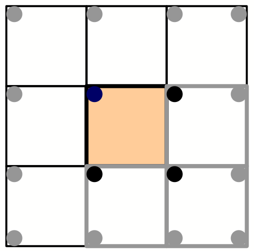
- Quincunx is a common pattern for supersampling
  - Pattern of 5 points arranged like the five-spot on dice
- Quincunx anti-aliasing samples image at the corners and centers of each pixel
  - 5 sample points are combined to produce each displayed pixel.
  - Samples at the corner points are shared with adjacent pixels
  - Number of rays through image plane is twice the number of displayed pixels
- Possible implementation
  - Shoot ray through center and upper left corner
  - Uneven weight distribution
    - Weigh each corner 1/8 of final color
    - Weight center 1/2 of final color



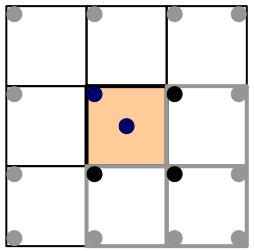
Quincunx Sampling

Adaptive Super Sampling

- Adaptive Supersampling (Whitted)
  - Shoot rays through the four corners
  - Find average
  - Compare average to color at the 4 corners
    - If difference is above a threshold, shoot additional rays in the interior of the pixel
    - Recursively subdivide regions of the pixel until threshold is met



Average 4 corners



Shoot additional ray(s)

Beam Tracing and Cone Tracing

- Beam tracing and cone tracing are variants of ray tracing
  - Use a solid volume rather than an infinitely thin ray
- Heckbert and Hanrahan developed beam tracing
  - Beams are pyramids emanating from the intersect point
- Cone tracing uses cones emanating from the intersect point
- Beam tracing and cone tracing provide solutions to aliasing problems and can create soft shadows and blurred reflections
- Beam and cone tracing have higher computational complexity
  - Much more complex intersection methods
- Distributed ray tracing techniques have become much more popular

Distributed Ray Tracing

- Conventional ray tracing uses single rays
  - Reflection rays, shadow rays
    - Produces hard-edged shadows and sharp reflections
- Distributed ray tracing is an enhancement to ray tracing to allow:
  - Soft shadows, blurred and glossy reflections, blurred refractions, motion blur, depth of field (focusing effects)
    - Adds realism to ray-traced images
- Cook, Porter, and Carpenter introduced this concept in 1984

Image shows depth of field effects using distributed ray tracing

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Distributed Ray Tracing

- Distributed ray tracing averages multiple rays distributed over an interval
  - Anti-aliasing (supersampling) is an integral part of the method
  - Monte-Carlo techniques to stochastically distribute a specific number of rays
    - **Importance sampling** may be used to distribute the samples
- Reflected and refracted rays are distributed over a solid angle about the true reflection or transmission direction
  - Sampling the reflected ray according to a specular distribution function produces gloss (blurred reflection)
  - Sampling the transmitted ray produces translucency (blurred transparency)
- Soft shadows
  - Sampling the solid angle of the light source produces penumbras (soft shadows)
- Sampling the camera lens area produces depth of field (focusing)
- Sampling in time produces motion blur

Forward Ray Tracing

- Forward ray tracing follows rays from the light source instead of following rays from the eye
- Since most rays from the light will never reach the viewer, this can be wasteful, but it can also lead to more realistic images by including diffuse effects

Shadows from Semi-Transparent Objects

- Semi-transparent objects often act as color filters
  - Color of shadow may not just be a diminished color of the shadowed surface
  - Use shadow feelers for each color band (R,G,B) of interest
    - Along with distance attenuation factors
      - Based on distance traveled through transparent material

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Caustics

- **Caustics** are formed by light that is reflected or transmitted by a number of surfaces before interacting with a diffuse surface
  - Example: the light patterns on the bottom of a swimming pool
  - Caustics need to handled by “forward” ray tracing techniques
- **Photon mapping** combines forward and backward ray tracing
  - Simulates all possible light paths

Raytracing (left) is enhanced by the addition of Caustics (right).
http://www.3drender.com/light/caustics.html