Distributed Ray Tracing

Anti-Aliasing

- Graphics as signal processing
  - Scene description: continuous signal
  - Sample
  - digital representation
  - Reconstruction by monitor

Anti-Aliasing

- Represent any function as sum of sinusoidals
- Sampling
  - Spatial: multiply function by comb function
  - Frequency: convolve function by comb function
- Nyquist limit
- Reconstruction
  - Spatial: convolve with filter
  - Frequency: multiply by filter

Typical anti-aliasing

- Increase sampling frequency
  - Doesn’t solve problem
  - Increases frequencies handled (Nyquist limit)
- Average values after sampling
  - Doesn’t address problem
  - Blurs bad results
Ideal sampling and reconstruction

- Sample at greater than Nyquist frequency
- Reconstruct using sinc (box) filter
- Given sampling frequency, remove all frequencies higher than Nyquist limit
- Filter first, then sample
  - or do both at the same time

Illumination is Integration

Outgoing intensity of reflected light at a point on a surface in a certain direction is
- The point’s emission,
- An integral over the hemisphere above the surface of an illumination function L and a bidirectional reflectance function (BDRF).

\[ I_e(x, w, \lambda, \omega) = E(x, \omega, \lambda, 0) \times \int_{\Omega} f(x, w', \omega, \lambda, 0) \times L(x, w', \lambda, \omega') \, d\omega' \]

Usually referred to as “Kaji’a’s Rendering Equation”

The shading function may be too complex to compute analytically

Distributed Ray Tracing

Sampling to approximate integral
- Anti-Aliasing
- Gloss
- Translucency
- Soft Shadows (Penumbra)
- Motion Blur
- Depth of field

Importance Sampling

- Sample uniformly and average samples according to distribution function
- OR
- Sample according to distribution function and average samples uniformly
Monte Carlo Integration

- Determine area under the curve
- Non-analytic function so can't integrate
- Can tell if point is above or below curve
- Generate random samples
- Count fraction below curve
- Accurate in the limit

Supersampling

- Multiple samples per pixel
- Average together using uniform weights (box filter)
- Average together using a pyramid filter or a truncated Gaussian filter

Adaptive Supersampling

- Trace rays at corner of pixels: initial area
- Trace ray (sample) at center of area
- If center is 'different' from corners:
  - Subdivide area into 4 sub-areas
  - Recurse on sub-areas

Poison Distribution

- Similar to distribution of vision receptors
- Random with minimum distance between samples
Spectrum analysis of regular sampling

- Low frequency signal
- High frequency signal

Original signal
Sampling filter
Sampled signal
Ideal reconstruction filter
Reconstructed signal

Jittered Sampling

Frequencies above Nyquist limit are converted to noise instead of incorrect patterns
Gloss

- Mirror reflections calculated by tracing rays in the direction of reflection
- Gloss is calculated by distributing these rays about the mirror direction
  - The distribution is weighted according to the same distribution function that determines highlights.

Translucency

- Analogous to the problem of gloss
- Distribute the secondary rays about the main direction of the transmitted rays
  - The distribution of transmitted rays is defined by a specular transmittance function
• Consider the light source to be an area, not a point
• Trace rays to random areas on the surface of the light source
• Distribute rays according to areas of varying intensity of light source (if any)
• Use the fraction of the light intensity equal to the fraction of rays which indicate an unobscured light source
Motion Blur

Post-process blurring can get some effects, but consider:
- Two objects moving so that one always obscures the other
  - Can’t render and blur objects separately
- A spinning top with texture blurred but highlights sharp
  - Can’t post-process blur a rendered object
- The blades of a fan creating a blurred shadow
  - Must consider the movement of other objects

Temporal Jittered Sampling

Temporal Jittered Sampling

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Pinhole Camera

Image plane

Perfect focus - low light

Use of lens - more light

\[ a = \frac{F}{n} \]

\[ n = f\text{-stop} \]

Image plane Focal plane

\( s \quad d \)

Use of lens - more light

Image plane Focal plane

\( s \quad d \)

Circle of Confusion

\[ c = \text{circle of confusion} \approx 0.33\text{mm} \]
Depth of Field

1. Construct ray from pixel through lens center to point on focal plane.
2. Randomly generate point on 2D lens.
3. Trace ray from point through point on focal plane.

Summary

- Random on refraction direction
- Random on area light source
- Space-time jitter subsample
- Random on lens