Stochastic Sampling and Distributed Ray Tracing, Robert L. Cook

Presented by Marvin Reza

TDT03 - Advanced Topics in Visual Computing
September 17th, 2020
Overview

- Discrete pixel sizes gives an upper limit to the frequencies that can be displayed
  - Restricted by the Nyquist limit
- Displaying higher frequencies can result in artifacts
  - Aliasing, e.g. Moiré patterns
- Problem for ray tracing
  - Regularly spaced sample points
- Can be mitigated with
  - Supersampling
  - Adaptive supersampling
  - Stochastic sampling
The Nyquist Theorem

To reconstruct a signal accurately, the sampling rate must be $\geq 2$ times the highest frequency in a signal.

In other words:

Nyquist limit $= 2 \times \text{max_freq}$
Images as functions

- What does this have to do with graphics?
- An image can be seen as a luminosity function $F(x,y)$ of values defined at the pixel centres.
  - For grayscale image, $F(x,y)$ is the intensity of pixel at $(x,y)$.
  - A row of pixels can be seen as a function of the variable $x$.

Sampling at pixel centers

![Image of a fruit bowl with grid overlay and a sampled signal graph.](image-url)
Sampling theory and graphics

- When the pixel distance is higher than the Nyquist limit of the sampled frequencies one becomes jaggies
- Jaggies are high frequencies appearing as low frequencies, resulting in regular patterns
Anti-aliasing

- Try to avoid the side-effects of aliasing
- Supersampling
  - Raising the Nyquist limit
  - Expensive
- Adaptive supersampling
  - Increase samples only if necessary
    - When is “necessary”?
  - More involved
Stochastic sampling

- A Monte Carlo technique
- Sample at nonuniformly spaced locations
- Aliasing replaced by noise of correct average intensity
  - Aliasing artifacts replaced by noise
  - Our visual systems tolerate noise quite well
- Can be used to evaluate complex integrals
  - Monte Carlo integration
Jittering a regular grid

- Adding noise to the sample locations
- Can result in
  - Attenuation of high frequencies
  - Lost energy appearing as uniform noise.
  - No change in the basic composition of the spectrum

- **Subpixel jittering**
  - Divide pixel into a grid of subpixels
  - Randomly perturb center of each subpixel

- Approximation to a Poisson disk distribution
DISTRIBUTED/PROBABILISTIC RAY TRACING
Estimating integrals

- Use stochastic sampling to evaluate complex integrals:

\[ L_o(x, \vec{\omega}_r) = L_e(x, \vec{\omega}_r) + \int_{\Omega} L_i(x, \vec{\omega}_i)f(x, \vec{\omega}_i, \vec{\omega}_r)(\vec{\omega}_i \cdot \vec{n})d\vec{\omega}_i \]

- Simulate fuzzy fenomenas
- Stochastically distribute the rays in extra dimensions, given by variables of integration
Different ways of distributing rays

- Distributing reflected rays
- Distributing transmitted rays
- Distributing shadow rays through the solid angle of each light source
- Distributing ray origins over camera lens area
- Distributing rays in time
Rough reflections & refractions

Integration of reflected light:
- Distribute rays about *mirror direction*
- Specular reflectance function

Integration of transmitted light:
- Distribute rays about *transmitted light direction*
- Specular transmittance function
- Occurs where a light source is partially obscured
- Distribute shadow rays over light source region
  - Weighted according to e.g. projected area and brightness
- \# rays should be proportional to the amount of the light’s energy if completely unobscured.
- shadow = visible light / total unobscured light
Illustration: soft shadows

All shadow rays hit light source. Fully illuminated
No shadow rays hit light source. Fully shadowed.
Some shadow rays hit light source. Partially shadowed.
Depth of field & Motion Blur

- Motion blur
  - Distribute rays over time to simulate object movement
  - Need to be able to calculate position of object at specific time

- Depth of Field
  - Distribute rays across a discrete camera aperture
Fig. 10. Typical distributed ray path.
Conclusion

- Existing solutions usually try to work around the Nyquist limit
- Aliasing can be minimized by replacing it by noise
  - High frequencies appear as noise instead of aliasing
- Stochastic sampling allows for many fuzzy fenomenas
  - Distributed/probabilistic ray tracing
- Do sampling based on the relevant properties
  - Importance sampling
Questions?