Irradiance Caching & Photon Mapping

Last Time?

- Rendering Equation
- Monte-Carlo Integration
- Monte Carlo Rendering
- Forward Ray Tracing
- Stratified Sampling

source

hemisphere

\[ L(x', \omega') = L(x, \omega) + \int \rho(x, \omega, x', \omega') L(x, \omega) G(x, x') V(x, x') \, dA \]

Today

- Monte-Carlo Ray Tracing vs. Path Tracing
- Irradiance Caching
- Photon Mapping
- Acceleration Data Structures
- Ray Grammar

Ray Casting

- Cast a ray from the eye through each pixel

Ray Tracing

- Cast a ray from the eye through each pixel
- Trace secondary rays (light, reflection, refraction)

Monte-Carlo Ray Tracing

- Cast a ray from the eye through each pixel
- Cast random rays to accumulate radiance contribution
  - Recurse to solve the Rendering Equation

Should also systematically sample the primary light
Importance of Sampling the Light

<table>
<thead>
<tr>
<th>Without explicit light sampling</th>
<th>With explicit light sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 path per pixel</td>
<td>4 path per pixel</td>
</tr>
</tbody>
</table>

Monte Carlo Path Tracing

- Trace only one secondary ray per recursion
- But send many primary rays per pixel (performs antialiasing as well)

Ray Tracing vs. Path Tracing

- 2 bounces
- 5 glossy samples
- 5 shadow samples
- How many rays cast per pixel?
  - 1 main ray + 5 shadow rays + 5 glossy rays + 5x5 shadow rays + 5x5 glossy rays + 5x5x5 shadow rays = 186 rays
- How many 3 bounce paths can we trace per pixel for the same cost?
  - 186 rays / 8 ray casts per path = ~23 paths
- Which will probably have less error?

Questions?

- 10 paths/pixel
- 100 paths/pixel

Images from Henrik Wann Jensen

Today

- Monte-Carlo Ray Tracing vs. Path Tracing
- Irradiance Caching
- Photon Mapping
- Acceleration Data Structures
- Ray Grammar

Path Tracing is costly

- Needs tons of rays per pixel
Direct Illumination

Global Illumination

Indirect Illumination: smooth

Irradiance Cache
- The indirect illumination is smooth
- Store the indirect illumination

Irradiance Cache
- Interpolate nearby cached values
- But do full calculation for direct lighting
Questions?

- Why do we need “good” random numbers?
  - With a fixed random sequence, we see the structure in the error

Today

- Monte-Carlo Ray Tracing vs. Path Tracing
- Irradiance Caching
- Photon Mapping
- Acceleration Data Structures
- Ray Grammar

Readings for Today (pick one)


Photon Mapping

- Preprocess: cast rays from light sources
  - independent of viewpoint

Photon Mapping

- Store photons
  - position + light power + incoming direction

Photon Map

- Efficiently store photons for fast access
- Use hierarchical spatial structure (kd-tree)
Rendering with Photon Map

- Cast primary rays
- For secondary rays
  - reconstruct irradiance using k closest photons
- Combine with irradiance caching and other techniques

Photon Map Results

Photon Mapping - Caustics

- Special photon map for specular reflection and refraction

Glass sphere

Comparison

Path Tracing
1000 paths/pixel

Photon mapping

Today

- Monte-Carlo Ray Tracing vs. Path Tracing
- Irradiance Caching
- Photon Mapping
- Acceleration Data Structures
- Ray Grammar

Regular Grid

- Primitives that overlap multiple cells?
- Insert into multiple cells (use pointers)
For Each Cell Along a Ray

- Does the cell contain an intersection?
- Yes: return closest intersection
- No: continue

Regular Grid Discussion

- Advantages?
  - easy to construct
  - easy to traverse

- Disadvantages?
  - may be only sparsely filled
  - geometry may still be clumped

Adaptive Grids

- Subdivide until each cell contains no more than $n$ elements, or maximum depth $d$ is reached

Variations of Adaptive Grids

- When to split? When a cell contains “lots” of geometry, but has not yet reached the max tree depth
- Where to split?
  - Quadtree/Octree: split every dimension in half, always axis aligned
  - kd-tree: choose one dimension (often the largest dimension) and split it axis aligned (but not necessarily at the midpoint)
  - Binary Space Partition (BSP): choose a arbitrary cut plane
- Which one is best? It depends…. Often they are all equally good!

Primitives in an Adaptive Grid

- Can live at intermediate levels, or be pushed to lowest level of grid

Adaptive Grid Discussion

- Advantages?
  - grid complexity matches geometric density
- Disadvantages?
  - more expensive to traverse (binary tree, lots of pointers)
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse

Intersection with BVH

- Check sub-volume with closer intersection first

Where to split objects?

- At midpoint  OR
- Sort, and put half of the objects on each side  OR
- Use modeling hierarchy

Bounding Volume Hierarchy Discussion

- Advantages
  - easy to construct
  - easy to traverse
  - binary

- Disadvantages
  - may be difficult to choose a good split for a node
  - poor split may result in minimal spatial pruning

Today

- Monte-Carlo Ray Tracing vs. Path Tracing
- Irradiance Caching
- Photon Mapping
- Acceleration Data Structures
- Ray Grammar
Ray Grammar

- Classify local interaction:
  - E = eye
  - L = light
  - S = perfect specular reflection or refraction
  - G = glossy scattering
  - D = diffuse scattering

From Dutre et al.’s slides

Classic Ray Casting/Tracing

Ray casting: L D E
Ray tracing: L D S* E

“Adaptive Radiosity Textures for Bi-directional Ray Tracing”
Heckbert SIGGRAPH 1990

Photon Tracing

Radiosity: L D* E
Caustics: L S* D E
(or worse!)

“Adaptive Radiosity Textures for Bi-directional Ray Tracing”
Heckbert SIGGRAPH 1990

Questions?

Reading for Tuesday 3/30:

“Two Methods for the Display of High Contrast Images”,
Tumblin, Hodgins, & Guenter, ACM Trans on Graphics 1999

Truncation  Compression  "Layering"

A  B  C