Lecture 14:
Ray Tracing 2
(Acceleration & Radiometry)

Announcements

• Grading of resubmissions — we’re working on that

• GTC news: DLSS 2.0
  - https://zhuanlan.zhihu.com/p/116211994

• GTC news: RTXGI

• Personal feeling
  - Offline rendering techniques will soon become real-time
  - Current real-time rendering techniques will still be useful

• Next lectures won’t be easy
Last Lecture

• Why ray tracing?

• Whitted-style ray tracing

• Ray-object intersections
  - Implicit surfaces
  - Triangles

• Axis-Aligned Bounding Boxes (AABBs)
  - Understanding — pairs of slabs
  - Ray-AABB intersection
Today

• Using AABBSs to accelerate ray tracing
  - Uniform grids
  - Spatial partitions

• Basic radiometry (辐射度量学)
Uniform Spatial Partitions (Grids)
Preprocess – Build Acceleration Grid

1. Find bounding box
Preprocess – Build Acceleration Grid

1. Find bounding box
2. Create grid
Preprocess – Build Acceleration Grid

1. Find bounding box
2. Create grid
3. Store each object in overlapping cells
Ray-Scene Intersection

Step through grid in ray traversal order

For each grid cell
Test intersection with all objects stored at that cell
Grid Resolution?

One cell
• No speedup
Grid Resolution?

Too many cells
- Inefficiency due to extraneous grid traversal
Grid Resolution?

Heuristic:

- \( \#\text{cells} = C \times \#\text{objs} \)
- \( C \approx 27 \) in 3D
Uniform Grids – When They Work Well

Grids work well on large collections of objects that are distributed evenly in size and space.
Uniform Grids – When They Fail

“Teapot in a stadium” problem
Spatial Partitions
Spatial Partitioning Examples

Oct-Tree  KD-Tree  BSP-Tree

Note: you could have these in both 2D and 3D. In lecture we will illustrate principles in 2D.
KD-Tree Pre-Processing
KD-Tree Pre-Processing
KD-Tree Pre-Processing

Note: also subdivide nodes 1 and 2, etc.
Data Structure for KD-Trees

Internal nodes store

• split axis: x-, y-, or z-axis
• split position: coordinate of split plane along axis
• children: pointers to child nodes
• **No objects are stored in internal nodes**

Leaf nodes store

• list of objects
Traversing a KD-Tree

A

D

C

B

1

B

C

D

3

4

5

A
Traversing a KD-Tree

Internal node: split

$\text{Internal node: split}$
Traversing a KD-Tree

Assume it’s leaf node: intersect all objects
Traversing a KD-Tree

Internal node: split

$t_{\text{min}}$ $t_{\text{max}}$
Traversing a KD-Tree

Leaf node: intersect all objects

A

B

C

D

1

2

3

4

5
Traversing a KD-Tree

Internal node: split

$\min_t$

$\max_t$
Traversing a KD-Tree

Leaf node: intersect all objects

A

B

C

D

1

2

3

4

5

$\mathbf{t_{min}}$

$\mathbf{t_{max}}$
Traversing a KD-Tree

Intersection found
Object Partitions &
Bounding Volume Hierarchy (BVH)
Bounding Volume Hierarchy (BVH)
Bounding Volume Hierarchy (BVH)
Bounding Volume Hierarchy (BVH)
Bounding Volume Hierarchy (BVH)
Summary: Building BVHs

- Find bounding box
- Recursively split set of objects in two subsets
- **Recompute** the bounding box of the subsets
- Stop when necessary
- Store objects in each leaf node
Building BVHs

How to subdivide a node?

• Choose a dimension to split
• Heuristic #1: Always choose the longest axis in node
• Heuristic #2: Split node at location of median object

Termination criteria?

• Heuristic: stop when node contains few elements (e.g. 5)
Data Structure for BVHs

Internal nodes store
  • Bounding box
  • Children: pointers to child nodes

Leaf nodes store
  • Bounding box
  • List of objects

Nodes represent subset of primitives in scene
  • All objects in subtree
BVH Traversal

`Intersect(Ray ray, BVH node) {`

if (ray misses node.bbox) return;

if (node is a leaf node)
    test intersection with all objs;
return closest intersection;

hit1 = `Intersect(ray, node.child1);`
hit2 = `Intersect(ray, node.child2);`

return the closer of hit1, hit2;
}`
Spatial vs Object Partitions

Spatial partition (e.g. KD-tree)
- Partition space into non-overlapping regions
- An object can be contained in multiple regions

Object partition (e.g. BVH)
- Partition set of objects into disjoint subsets
- Bounding boxes for each set may overlap in space
Today

• Using AABBs to accelerate ray tracing
  - Uniform grids
  - Spatial partitions

• Basic radiometry (辐射度量学)
  - Advertisement: new topics from now on, scarcely covered in other graphics courses
Radiometry — Motivation

Observation

- In assignment 3, we implement the Blinn-Phong model
- Light intensity $I$ is 10, for example
- But 10 what?

Do you think Whitted style ray tracing gives you CORRECT results?

All the answers can be found in radiometry

- Also the basics of “Path Tracing”
Radiometry

Measurement system and units for illumination

Accurately measure the spatial properties of light
- New terms: Radiant flux, intensity, irradiance, radiance

Perform lighting calculations in a physically correct manner

My personal way of learning things:
- WHY, WHAT, then HOW
Radiant Energy and Flux (Power)
Radiant Energy and Flux (Power)

Definition: Radiant energy is the energy of electromagnetic radiation. It is measured in units of joules, and denoted by the symbol:

\[ Q \ [J = \text{Joule}] \]

Definition: Radiant flux (power) is the energy emitted, reflected, transmitted or received, per unit time.

\[ \Phi \equiv \frac{dQ}{dt} \ [W = \text{Watt}] \ [\text{lm} = \text{lumen}]^{*} \]
Flux – #photons flowing through a sensor in unit time

From London and Upton
Important Light Measurements of Interest

Light Emitted From A Source

"Radiant Intensity"

Light Falling On A Surface

"Irradiance"

Light Traveling Along A Ray

"Radiance"
Radiant Intensity
Radiant Intensity

Definition: The radiant (luminous) intensity is the power per unit solid angle (立体角) emitted by a point light source.

\[
I(\omega) \equiv \frac{d\Phi}{d\omega}
\]

\[
\begin{bmatrix}
\frac{W}{\text{sr}} \\
\frac{\text{lm}}{\text{sr}}
\end{bmatrix}
= \text{cd} = \text{candela}
\]

The candela is one of the seven SI base units.
Angles and Solid Angles

Angle: ratio of subtended arc length on circle to radius

- $\theta = \frac{l}{r}$
- Circle has $2\pi$ radians

Solid angle: ratio of subtended area on sphere to radius squared

- $\Omega = \frac{A}{r^2}$
- Sphere has $4\pi$ steradians
Differential Solid Angles

\[ dA = (r \, d\theta)(r \sin \theta \, d\phi) \]
\[ = r^2 \sin \theta \, d\theta \, d\phi \]

\[ d\omega = \frac{dA}{r^2} = \sin \theta \, d\theta \, d\phi \]
Differential Solid Angles

Sphere: $S^2$

$$\Omega = \int_{S^2} d\omega$$

$$= \int_0^{2\pi} \int_0^\pi \sin \theta \, d\theta \, d\phi$$

$$= 4\pi$$
$\omega$ as a direction vector

Will use $\omega$ to denote a direction vector (unit length)
Isotropic Point Source

\[ \Phi = \int_{S^2} I \, d\omega \]

\[ = 4\pi I \]

\[ I = \frac{\Phi}{4\pi} \]
Modern LED Light

Output: 815 lumens

(11W LED replacement for 60W incandescent)

Radiant intensity?

Assume isotropic:
Intensity = \( \frac{815 \text{ lumens}}{4\pi \text{ sr}} \)
= 65 candelas
Thank you!

(And thank Prof. Ravi Ramamoorthi and Prof. Ren Ng for many of the slides!)