Today

- Review & Schedule
- Motivation – Distribution Ray Tracing
- Bounding Boxes
- Spatial Acceleration Data Structures
- Flattening the transformation hierarchy

Cool results from Assignment 2

- koi
- seantek

Last Week:

- Ray Tracing
  - Shadows
  - Reflection
  - Refraction
- Local Illumination
  - Bidirectional Reflectance Distribution Function (BRDF)
  - Phong Model

Schedule

- Wednesday October 1st:
  Assignment 3 (Ray Tracing & Phong Materials) due

- Sunday October 5th, 5 PM, Room TBA:
  Review Session for Quiz 1

- Tuesday October 7th:
  Quiz 1: In class

- Wednesday October 15th:
  Assignment 4 (Grid Acceleration) due

Questions?
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Extra rays needed for these effects:

- Distribution Ray Tracing
  - Soft shadows
  - Anti-aliasing (getting rid of jaggies)
  - Glossy reflection
  - Motion blur
  - Depth of field (focus)

Shadows

- one shadow ray per intersection per point light source

Soft Shadows

- multiple shadow rays to sample area light source

Antialiasing – Supersampling

- multiple rays per pixel

Reflection

- one reflection ray per intersection
**Glossy Reflection**
- multiple reflection rays

**Motion Blur**
- Sample objects temporally

**Depth of Field**
- multiple rays per pixel

**Algorithm Analysis**
- Ray casting
- Lots of primitives
- Recursive
- Distributed Ray Tracing Effects
  - Soft shadows
  - Anti-aliasing
  - Glossy reflection
  - Motion blur
  - Depth of field

- \( \text{cost} \leq \text{height} \times \text{width} \times \) \( \text{num primitives} \times \) \( \text{intersection cost} \times \) \( \text{num shadow rays} \times \) \( \text{supersampling} \times \) \( \text{num glossy rays} \times \) \( \text{num temporal samples} \times \) \( \text{max recursion depth} \times \) . . .

- can we reduce this?

**Questions?**

**Today**
- Review & Schedule
- Motivation – Distribution Ray Tracing
- **Bounding Boxes**
  - of each primitive
  - of groups
  - of transformed primitives
- Spatial Acceleration Data Structures
- Flattening the transformation hierarchy
Acceleration of Ray Casting

- Goal: Reduce the number of ray/primitive intersections

Conservative Bounding Region

- First check for an intersection with a conservative bounding region
- Early reject

Conservative Bounding Regions

- tight $\rightarrow$ avoid false positives
- fast to intersect

Intersection with Axis-Aligned Box

From Lecture 3, Ray Casting II

- For all 3 axes, calculate the intersection distances $t_1$ and $t_2$
- $t_{\text{tnear}} = \max (t_{1x}, t_{1y}, t_{1z})$
- $t_{\text{tfar}} = \min (t_{2x}, t_{2y}, t_{2z})$
- If $t_{\text{tfar}} < t_{\text{min}}$, box is behind
- If $t_{\text{tnear}} < t_{\text{min}}$, box is missed
- If box survived tests, report intersection at $t_{\text{tnear}}$

Bounding Box of a Triangle

- $(x_{\text{tnear}}, y_{\text{tnear}}, z_{\text{tnear}}) = (\max(x_0, x_1, x_2), \max(y_0, y_1, y_2), \max(z_0, z_1, z_2))$
- $(x_{\text{tnear}}, y_{\text{tnear}}, z_{\text{tnear}}) = (\min(x_0, x_1, x_2), \min(y_0, y_1, y_2), \min(z_0, z_1, z_2))$

Bounding Box of a Sphere

- $(x_{\text{tnear}}, y_{\text{tnear}}, z_{\text{tnear}}) = (x+r, y+r, z+r)$
- $(x_{\text{tnear}}, y_{\text{tnear}}, z_{\text{tnear}}) = (x-r, y-r, z-r)$
Bounding Box of a Plane

\( (x_{\text{min}}, y_{\text{min}}, z_{\text{min}}) = (-\infty, -\infty, -\infty) ) \)

\( (x_{\text{max}}, y_{\text{max}}, z_{\text{max}}) = (+\infty, +\infty, +\infty) ) \)

* unless \( n \) is exactly perpendicular to an axis

\( n = (a, b, c) \)

\( ax + by + cz = d \)

Bounding Box of a Group

\( (x_{\text{min}}^{a}, y_{\text{min}}^{a}, z_{\text{min}}^{a}) \)

\( (x_{\text{max}}^{a}, y_{\text{max}}^{a}, z_{\text{max}}^{a}) \)

\( (x_{\text{min}}^{b}, y_{\text{min}}^{b}, z_{\text{min}}^{b}) \)

\( (x_{\text{max}}^{b}, y_{\text{max}}^{b}, z_{\text{max}}^{b}) \)

\( = (\min(x_{\text{min}}^{a}, x_{\text{min}}^{b}), \min(y_{\text{min}}^{a}, y_{\text{min}}^{b}), \min(z_{\min}^{a}, z_{\text{min}}^{b})) \)

\( = (\max(x_{\text{max}}^{a}, x_{\text{max}}^{b}), \max(y_{\text{max}}^{a}, y_{\text{max}}^{b}), \max(z_{\text{max}}^{a}, z_{\text{max}}^{b})) \)

Bounding Box of a Transform

\( (x_{\text{min}}', y_{\text{min}}', z_{\text{min}}') \)

\( (x_{\text{max}}', y_{\text{max}}', z_{\text{max}}') \)

\( = (\min(x_{\text{min}}^{a}, x_{\text{min}}^{b}, x_{\text{min}}^{c}, x_{\text{min}}^{d}, x_{\text{min}}^{e}, x_{\text{min}}^{f}, x_{\text{min}}^{g}), \min(y_{\text{min}}^{a}, y_{\text{min}}^{b}, y_{\text{min}}^{c}, y_{\text{min}}^{d}, y_{\text{min}}^{e}, y_{\text{min}}^{f}, y_{\text{min}}^{g}), \min(z_{\text{min}}^{a}, z_{\text{min}}^{b}, z_{\text{min}}^{c}, z_{\text{min}}^{d}, z_{\text{min}}^{e}, z_{\text{min}}^{f}, z_{\text{min}}^{g})) \)

\( = (\max(x_{\text{max}}^{a}, x_{\text{max}}^{b}, x_{\text{max}}^{c}, x_{\text{max}}^{d}, x_{\text{max}}^{e}, x_{\text{max}}^{f}, x_{\text{max}}^{g}), \max(y_{\text{max}}^{a}, y_{\text{max}}^{b}, y_{\text{max}}^{c}, y_{\text{max}}^{d}, y_{\text{max}}^{e}, y_{\text{max}}^{f}, y_{\text{max}}^{g}), \max(z_{\text{max}}^{a}, z_{\text{max}}^{b}, z_{\text{max}}^{c}, z_{\text{max}}^{d}, z_{\text{max}}^{e}, z_{\text{max}}^{f}, z_{\text{max}}^{g})) \)

Special Case: Transformed Triangle

Can we do better?

Special Case: Transformed Triangle

Questions?
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- Bounding Boxes
- Spatial Acceleration Data Structures
  - Regular Grid
  - Adaptive Grids
  - Hierarchical Bounding Volumes
- Flattening the transformation hierarchy

Regular Grid

Create grid

- Find bounding box of scene
- Choose grid spacing
- gridx need not = gridy

Insert primitives into 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

Preventing repeated computation

- Perform the computation once, "mark" the object
- Don't reintersect marked objects
Don't return distant intersections

- If intersection $t$ is not within the cell range, continue (there may be something closer)

Where do we start?

- Intersect ray with scene bounding box
- Ray origin may be inside the scene bounding box

Is there a pattern to cell crossings?

- Yes, the horizontal and vertical crossings have regular spacing

What's the next cell?

- 3DDDA – Three Dimensional Digital Difference Analyzer
- We'll see this again later, for line rasterization

Pseudo-code

create grid
insert primitives into grid
for each ray $r$
    find initial cell $c(i,j)$, $t_{min}$, $t_{next_v}$ & $t_{next_h}$
    compute $dt_v$, $dt_h$, $sign_x$ and $sign_y$
    while $c$ != NULL
        for each primitive $p$ in $c$
            intersect $r$ with $p$
            if intersection in range found
                return
        $c$ = find next cell
Regular Grid Discussion

• Advantages?
  – easy to construct
  – easy to traverse

• Disadvantages?
  – may be only sparsely filled
  – geometry may still be clumped

Questions?

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Adaptive Grids

• Subdivide until each cell contains no more than \( n \) elements, or maximum depth \( d \) is reached

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 (especially octree)
Bounding Volume Hierarchy

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

Where to split objects?

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

• Check subvolume with closer intersection first

Intersection with BVH

• Don't return intersection immediately if the other subvolume may have a closer intersection

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

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Transformation Hierarchy

• Group & Transformation hierarchy may not be a good spatial hierarchy

Questions?
Assignment 4 (due Oct 15th)

- Bounding boxes for primitives
- Regular grid acceleration data structure
- Flatten the transformation hierarchy
- Collect statistics
  - Average # of rays per pixel
  - Average # of ray/primitive intersections per pixel
- Extra Credit: Distribution Ray Tracing
  (and anything else from past weeks)

Next Time:

Curves & Surfaces