

Ray Tracer

Spring 2017 Help Session

Outline

- Introduction
- ray
- vec.h and mat.h
- isect
- Requirements
- Tips and Tricks
- Memory Leaks
- Artifact Requirement
- Ray Tracing Surface of Revolution
- Using ply Models
- Bells and Whistles

Ray Tracer

- Given a ray “caster”, you have to implement:
 - Shading (multiple parts)
 - Reflection and Refraction
 - Sphere Intersection
 - Triangle Intersection
 - Complex objects consist of a 3D mesh made up of triangles
 - Anti-Aliasing

ray

- A 3D ray is a fundamental component of a ray tracer.
- ray r(start position, direction, RayType)
 - RayType, an enum, includes:
 - VISIBILITY
 - REFLECTION
 - REFRACTION
 - SHADOW
 - Example:
 - ray r(foo, bar, ray::SHADOW);
- r.at(t) – direction of r * distance t
 - Returns the end position of the ray r after going a distance of t from its start position

vec.h and mat.h

- `vec.h` provides useful tools for 2D, 3D, and 4D vectors
 - Easy Vector Construction – `Vec3d x = Vec3d(0,0,0);`
 - Basic operators are overridden:
 - `+` and `-` arithmetic, `Vec3d v3 = v1 + v2;`
 - `*`, multiply by a constant, `Vec3d v2 = 2*v1;`
 - `*`, dot product, `double dot = v1 * v2;`
 - `^`, cross product, `Vec3d cross = v1 ^ v2;`
 - For other useful functionality, such as `normalize()`, `length()`, and `iszero()`, read `vec.h` for complete details
- `mat.h` is very similar, but for matrix operations not heavily used in this project

isect

- An isect represents the location where a ray intersects an object
- Important member variables:
 - `const SceneObject *obj` – the object that was intersected
 - `double t` – the distance along the ray where it occurred
 - `Vec3d N` – the normal to the surface where it occurred
 - `Vec2d uvCoordinates` – texture coordinates on the surface [1.0, 1.0]
 - `Material *material` – non-NULL if exists a unique material for this intersect
 - `const Material &getMaterial() const` – return the material to use

Requirements

- The following requirements need to be implemented:
 - Sphere intersection
 - Triangle intersection
 - Blinn-Phong Specular-Reflection Model
 - Multiple light sources
 - Shadow attenuation
 - Reflection
 - Refraction
 - Texture Mapping
 - Anti-Aliasing

Requirement: Sphere Intersection

- Fill in `Sphere::intersectLocal` in `SceneObjects\Sphere.cpp`
- Return *true* if ray *r* intersects the canonical sphere (sphere centered at the origin with radius 1.0) in positive time
- Set the values of `isect i`:
 - `i.obj = this`
 - `i.setT` (time of intersection)
 - `i.setN` (normal at intersection)

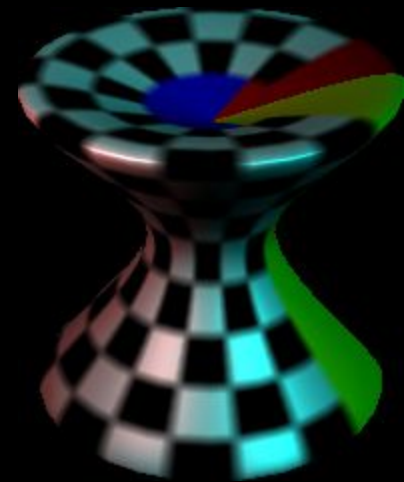
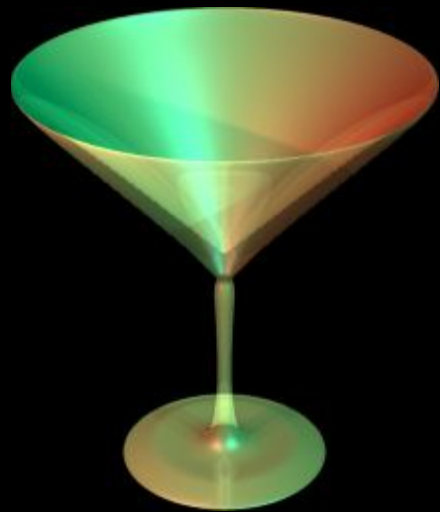
Requirement: Triangle Intersection

- Fill in `TrimeshFace::intersectLocal` in `SceneObjects\trimesh.cpp`
- Intersect `r` with the triangle `abc`:
 - `Vec3D &a = parent->vertices[ids [0]];`
 - `Vec3D &b = parent->vertices[ids [1]];`
 - `Vec3D &c = parent->vertices[ids [2]];`
- Return *true* if ray `r` intersects the triangle
- Need more help? See triangle intersection handout linked to on project website:
 - http://www.cs.washington.edu/education/courses/cse457/handouts/triangle_intersection.pdf

Trimesh Interpolation

- Interpolate trimesh material properties – will make them look nicer
- Interpolate texture coordinates (if they are supplied) and map the correct texture value when shading.

Sample Results



texture mapping

Requirement: Blinn-Phong Specular-Reflection Model

- Fill in `Material::shade` in `material.cpp`
- Refer to the Ray Tracing lecture:
 - <http://www.cs.washington.edu/education/courses/cse457/13sp/lectures/markup/ray-tracing-markup-1pp.pdf>
- To sum over the light sources, use an iterator as described in the comments of the code
- CAUTION: If you are on the inside of an object, the object's normal will point outside. For this case, you will need to flip the normal for any shading, reflection, or refraction.

Requirement: Multiple Light Sources

- Fill in `PointLight::distanceAttenuation` in `light.cpp` (distance attenuation for directional light is done for you)
- Use the alternative described in the ray tracing lecture where:
 - a – constant term
 - b – linear term
 - c – quadratic term
- These terms are defined in `light.h`

Requirement: Shadow Attenuation

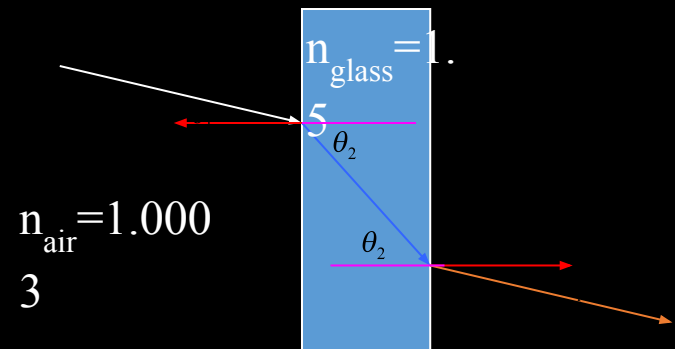
- Fill in `DirectionalLight::shadowAttenuation` and `PointLight::shadowAttenuation` in `light.cpp`
- The ray tracing lecture shows you where to insert this factor into the Blinn-Phong equation (`a_shadow` for each light)
- Rather than simply setting the attenuation to zero if an object blocks the light, accumulate the product of k_t 's for objects which block the light (use the `prod` function from `vec.h`)
- Count each intersection with an object by the shadow ray (includes entering and exiting)
- See Marschner and Shirley 4.7
- Extra Credit: Better shadow handling (caustics, global illumination, etc.)

Requirement: Reflection

- Modify `RayTracer::traceRay` in `RayTracer.cpp` to implement recursive ray tracing, which takes into account reflected rays
- See Marschner and Shirley 4.8 and lecture slides

Requirement: Refraction

- Modify `RayTracer::traceRay` in `RayTracer.cpp` to create refracted rays
- Remember Snell's law, watch out for total internal refraction, and consider the case when the ray is exiting a material into air (think about the direction of the normal)
- You can test refraction with `simple/cube_transparent.ray`
- Unlike reflection, this routine has several cases to consider:
 - An incoming ray
 - An outgoing ray
 - Totally internally refracted ray
- Marschner and Shirley 13.1

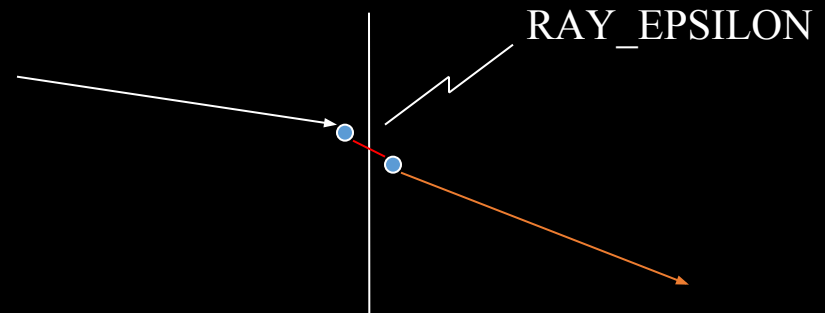


Anti-Aliasing

- Gets rid of jaggies.
- Implement using oversampling.
- See “Distribution Ray Tracing” (sect 13.1) in the Marschner and Shirley handout.
 - Extra credit available for implementing the “jittering” technique described at the end of that section.

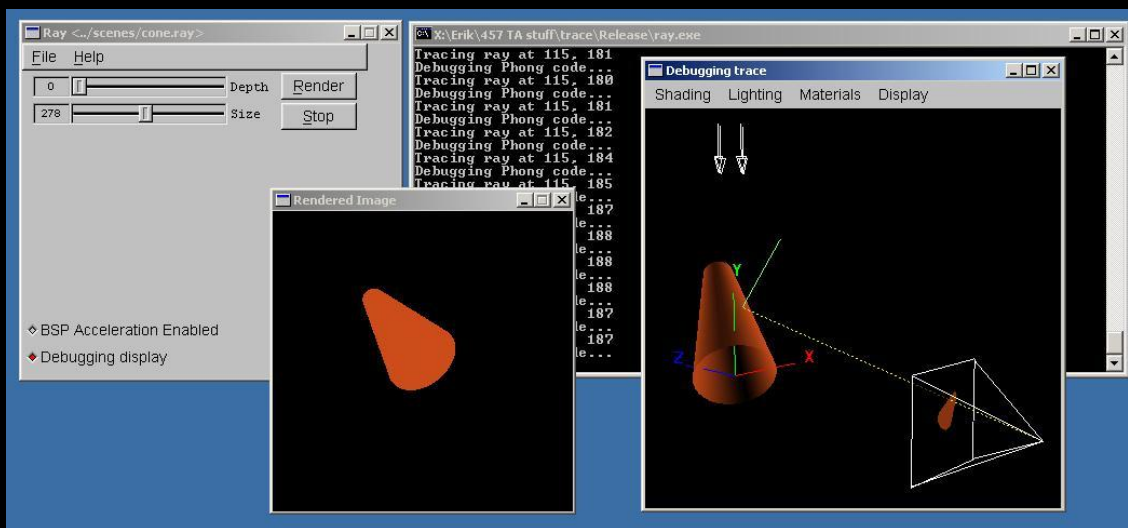
Tips and Tricks

- Use the sign of the dot product `r.getDirection()` with `i.N` to determine whether you are entering or exiting an object
- Don't write too much code without testing!
 - Lots of dependencies, you need to know what works to proceed
- Use `RAY_EPSILON` (which is defined as `0.00001`) to account for computer precision error when checking for intersections



The Debugger Tool

- USE THIS, IT WILL SAVE YOUR LIFE!
- Shipped with skeleton code
- Find out how to use it here:
 - <http://www.cs.washington.edu/education/courses/cse457/14wi/projects/trace/extra/debug.html>



Memory Leaks

- A memory leak can (and probably will) ruin your night hours before your artifact is due
- To test, try to ray trace a complex model (the dragon) with depth 10, anti-aliasing, HUGE Image
- Cause: not calling free after allocating memory
 - Object constructors, vector (array) creation
- Solution: free stuff!
 - Call the “delete [object]” on ANYTHING you create that is temporary
 - i.e. 3 byte temporary vectors in the rayTrace function
- It is **HIGHLY RECOMMENDED** you have no memory leaks

Artifact Requirement

- Draw a pretty picture!
- One JPEG/PNG image traced with your Ray Tracer submitted for voting
- Has to be a (somewhat) original scene
- For each image submitted for voting, a short .txt description of the scene or special features
- Examples of each bell/whistle implemented with an accompanying readme.txt specifying which image demonstrates which feature (and where/how)

Making Scenes

- Coming Soon: An export button for Modeler!
- Convert from another program: ply2ray.

Using ply Models

- ply is one of the standard formats for 3D models:
 - [http://en.wikipedia.org/wiki/PLY_\(file_format\)](http://en.wikipedia.org/wiki/PLY_(file_format))
- There are a plethora of ply models available online
- We provide a simple tool (ply2ray) that converts ply models into .ray files
 - It is in your source folder, so check it out!
- You still need to add lightning and material property



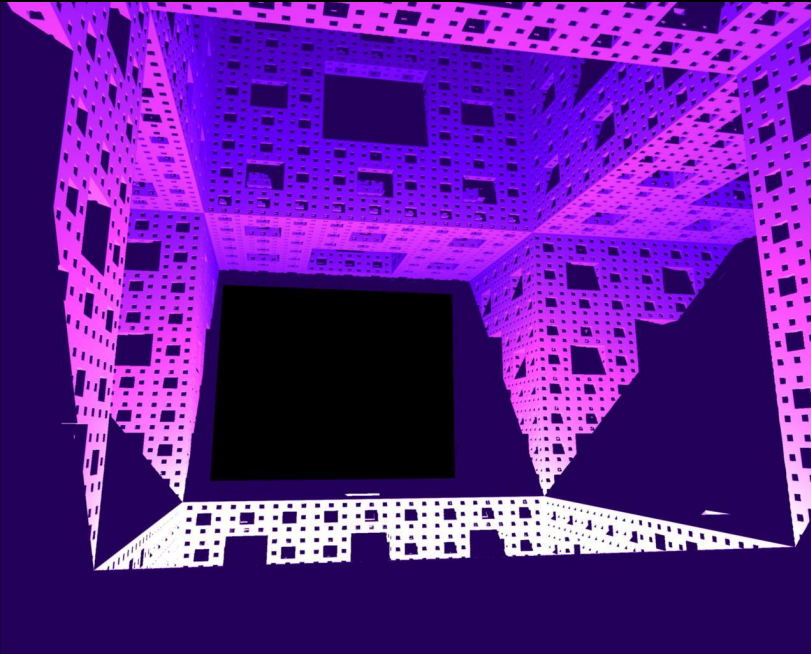
Comparison Tool

- We will be using this tool (link on the course webpage) to evaluate your solution versus the sample. So you should check too !!
- Demo of comparison tool

Bells and Whistles

- TONS of awesome extra credit!
- Environment/Texture/Bump Mapping – Relatively easy ways to create complex and compelling scenes
- Single Image Random Dot Stereograms
- Depth of field, soft shadows, motion blur, glossy reflection – most images we're used to seeing have at least one of these effects
- **NOTE:** Please add control boxes for substantial ray tracing modifications so that required extensions are easily gradable
 - See sample solution style

3D and 4D Fractals



Constructive Solid Geometry

- Allows for complex objects while still just intersecting simple primitives

