

# Ray Tracer

Help Session

# Outline

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# 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

# 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

# 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](http://www.cs.washington.edu/education/courses/cse457/handouts/triangle_intersection.pdf)

# Requirement: Blinn-Phong Specular-Reflection Model

- Fill in `Material::shade` in `material.cpp`
- Refer to the Ray Tracing lecture
- 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

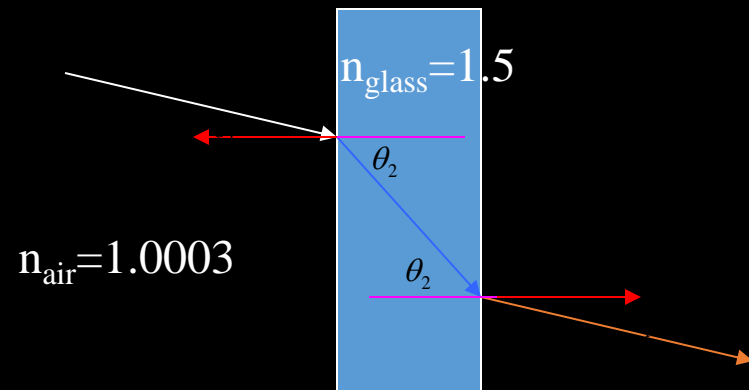
- Fill in `DirectionalLight::shadowAttenuation` and `PointLight::shadowAttenuation` in `light.cpp`
- The ray tracing lecture shows you where to insert this factor into the Blinn-Phong equation (`a_shadow` for each light)
- Rather than simply setting the attenuation to zero if an object blocks the light, 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)
- 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 Shirley, et. al. and lecture slides

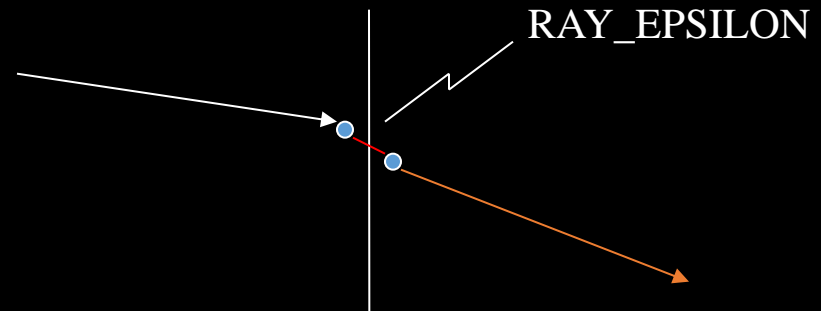
# Requirement: Refraction

- Modify `RayTracer::traceRay` in `RayTracer.cpp` to create refracted rays
- Remember Snell's law, watch out for total internal reflection, 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 reflected ray



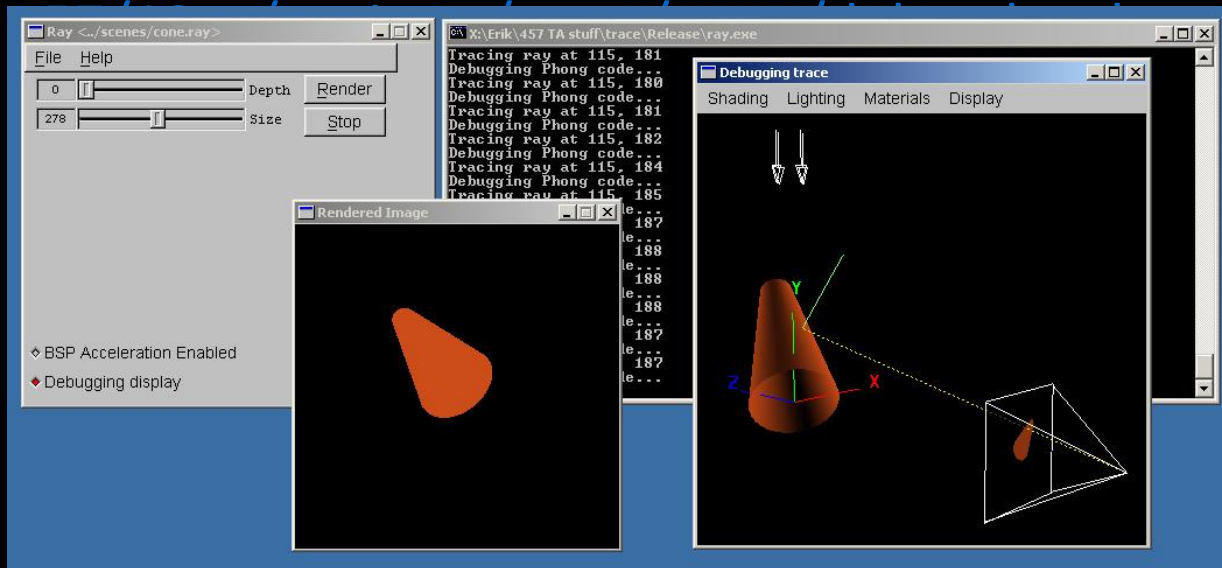
# Tips and Tricks

- 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/cse4>





# 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

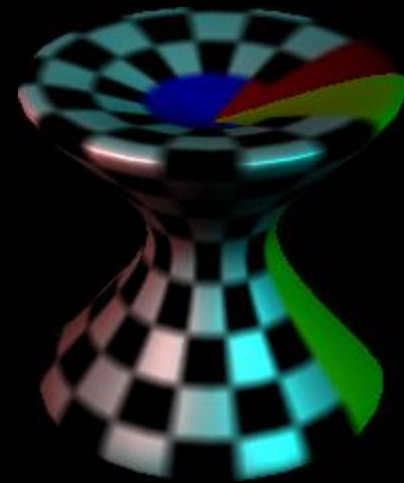
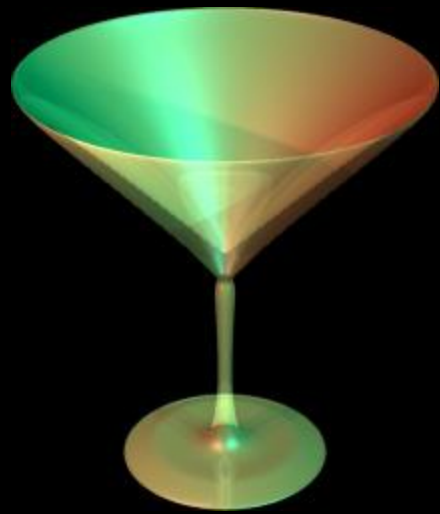
# Artifact Requirement

- 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)

# Ray Tracing Surface of Revolution

- Use this code snippet to write triangle mesh into a file:
  - [http://www.cs.washington.edu/education/courses/cse457/13sp/projects/trace/code/write\\_revolution\\_rayfile.c](http://www.cs.washington.edu/education/courses/cse457/13sp/projects/trace/code/write_revolution_rayfile.c)
- Use this .ray file as a template
  - <http://www.cs.washington.edu/education/courses/cse457/13sp/projects/trace/code/revolution.ray>
  - It contains default lighting of modeler
  - Replace polymesh{} part with your own surface of revolution
- Render your new .ray file in tracer!

# Sample Results



texture mapping

# 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



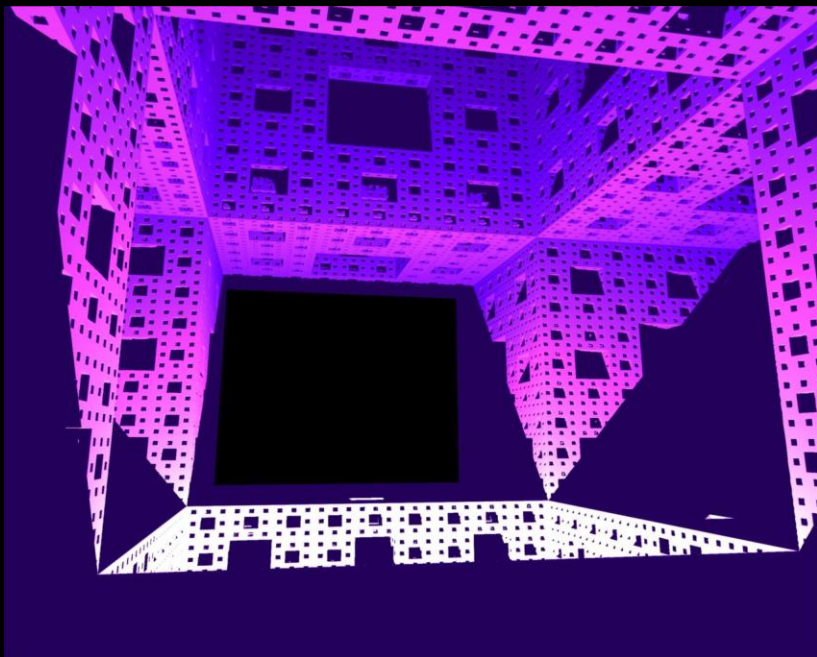
# Comparison Tool

- 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!**
- Anti-aliasing – A must for nice scenes (to render scenes without “jaggies”)
- Interpolate trimesh material properties – will make them look nicer
- 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 extension are easily gradable
  - See sample solution style

# 3D and 4D Fractals





# Constructive Solid Geometry

- Allows for complex objects while still just intersecting simple primitives

