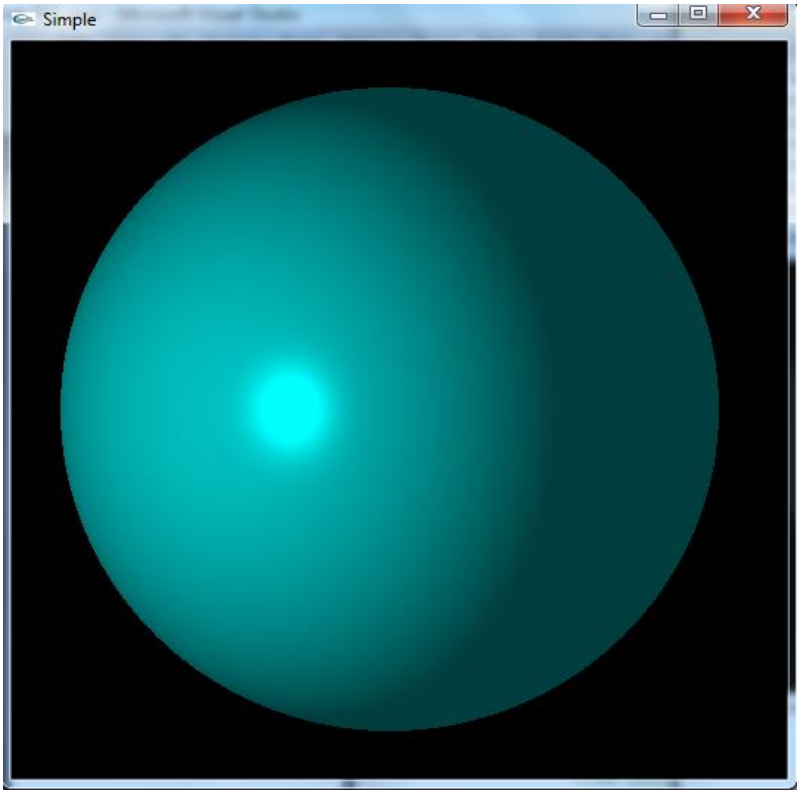
Assignment 1 – Ray Tracing



Overview

The concept of ray tracing: a technique for generating an image by tracing the path of light through pixels in an image plane and simulating the effects of its encounters with virtual objects. The technique is capable of producing a very high degree of visual realism, usually higher than that of typical scan line rendering methods, but at a greater computational cost.

The objective of this exercise is to implement a ray casting/tracing engine. A ray tracer shoots rays from the observer's eye through a screen and into a scene of objects. It calculates the ray's intersection with objects, finds the nearest intersection and calculates the color of the surface according to its material and lighting conditions. **(This is the way you should think about it – this will help your implementation).**

Requirements

Read this entire explanation before starting. Understand the slides taught in class especially.

The feature set you are required to implement in your ray tracer is as follows:

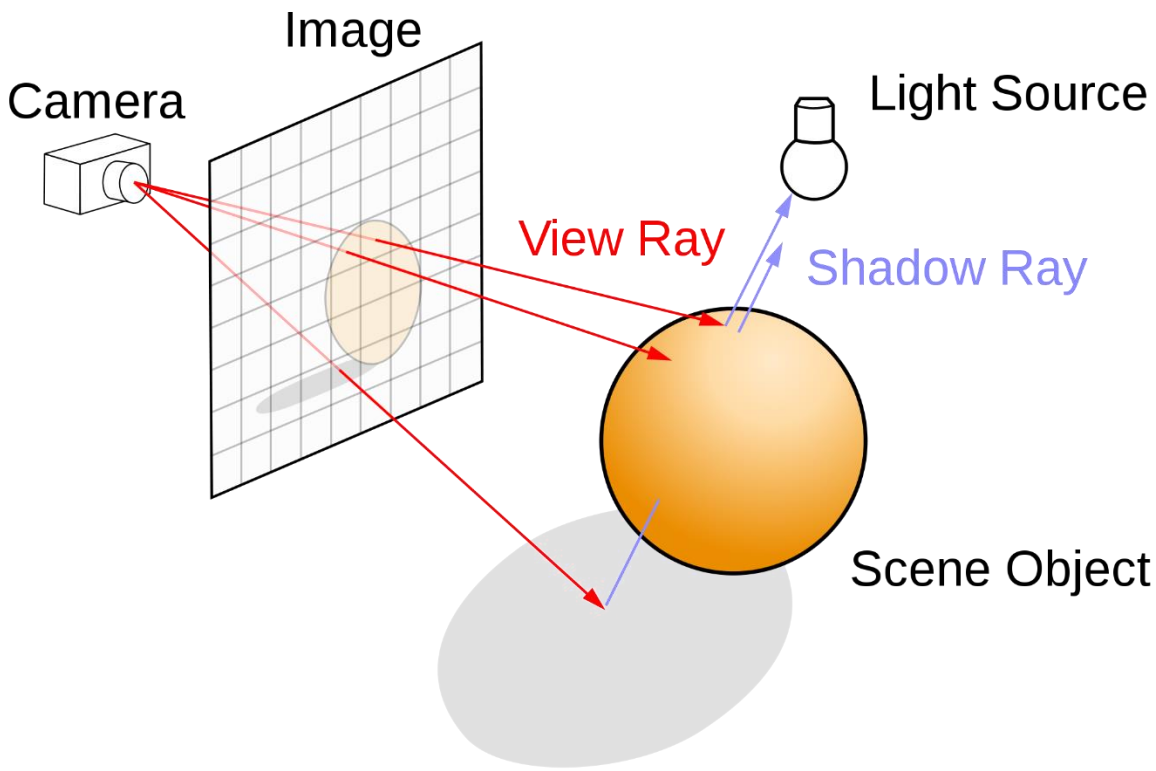
- Background
  - Plain color background
- Display geometric primitives in space:
  - Spheres
  - Planes
- Basic lighting
  - Directional lights
  - Spot lights
  - Ambient light
  - Simple materials (ambient, diffuse, specular...)
- Basic hard shadows
- One Reflection (10 Points bonus)

Scene Definition

The 3D scene your ray tracer which will be rendering will be defined in a scene definition text file. The scene definition contains all of the parameters required to render the scene and the objects in it. The specific language used in the definition file is defined later.

Screen

The screen is located on z=0 plane. The right up corner of the screen is located at (1,1,0) and the left bottom corner of the screen is located at (-1,-1,0). All in the scene coordinates.



Geometry

Geometric primitives

Sphere

A sphere is defined by a center point and scalar radius. The normal of each point on the sphere's surface is easily computed as the normalized subtraction of the point and the center.

Plane

A plane is defined by a normal to the plane and a negative scalar which represents the "d" in the plane equation ($ax + by + cz + d = 0$). Every plane is an infinite plane and will be divided to squares in checkers board pattern. In the dark square the diffuse component of Phong model has 0.5 coefficient.

Hint:

```
(mod(int(1.5*p.x),2) == mod(int(1.5*p.y),2))
```

Spheres and plane may intersect each other.

Background

The background of the rendered scene is a flat color.

Camera

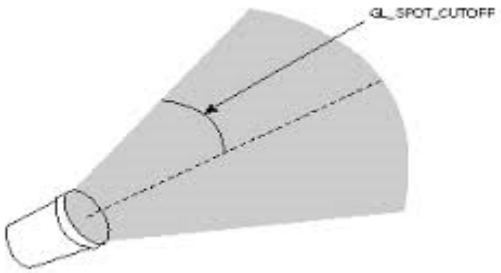
The camera is a simple pinhole camera as described in the lecture slides and will be located at eye coordinates (you will get as input) and looks towards the center of the screen.

Lighting

Basic lights and shadows

For basic lighting you need to implement:

1. Ambient lighting – a color that reflects from all surfaces with equal intensity.
2. Directional – A light source like the sun, which lies at infinity and has just a direction.
3. Spot light – A point light source that illuminates in a direction given by a vector D. This light source has a cutoff angle as describe in the following image.



Every light source has its own intensity (color) and there can be multiple light sources in a scene. Shadows appear where objects obscure a light source. In the equation they are expressed in the S_i term. To know if a point p in space (usually on a surface) lies in a shadow of a light source, you need to shoot a ray from p in the direction of the light and check if it hits something. If it does, make sure that it really hits it before reaching the light source and that the object hit is not actually a close intersection with the object the ray emanated from.

Materials

You need to implement the lighting formula (Phong) from the lecture slides. The material of a surface should be flat with ambient, diffuse, specular reflections, and a shininess parameter (the power of $V \cdot R \; when \; V \; and \; R \; are \; unit \; vectors$).

Shadow

You can choose to add shadow effect to your scene using S_i parameter in Phong model (see lecture slides). Shadow appears when some object located between the light source and another object which can be observed by the viewer. In that case you should ignore the covered light source part in Phong model. Some common mistakes may cause spurious shadows to appear. Make sure you understand the vector math involved and all the edge-cases.

Reflection (10 points bonus)

You can choose the first plane which is defined in the objects file to be a mirror. Each ray hit a mirror plane breaks symmetrically to the normal. The color of the pixel in a mirror plane is calculating according to the breaking ray. Don't forget to consider the light sources rays which break by the mirror plane. If you choose to implement this task ignore mirror objects material parameters: ambient, diffuse, specular.

Transparent spheres (10 points bonus)

Use Snell's law with refractive indices of 1 and 1.5 to determine the direction of the light rays intersect with the sphere.

Input

You will get one text file named scene.txt (see example).

- The first line in the file will start with the letter "e" flowing by camera (eye) coordinates. The fourth coordinate can use to transfer additional data (if you choose to implement a bonus you can use it as bonus mode flag).
- Second line starts with "a" followed by (R,G,B,A) coordinate represents the ambient light.

From the third row we will describe the object and lights in scene:

- Light direction will describe by "d" letter followed by light direction (x, y, z, w). 'w' value will be 0.0 for directional light and 1.0 for spotlight.
- For spotlights the position will appease afterwards after the letter "p" (x,y,z,w).
- Light intensity will describe by "i" followed by light intensity (R, G, B, A).
- Spheres and planes will description will appear after "o". For spheres (x,y,z,r) when (x,y,z) is the center position and r is the radius (always positive, greater than zero). For planes (a,b,c,d) which represents the coefficients of the plane equation when 'd' gets is a non-positive value.
- The color of an object will appears after "c" and will represents the ambient and diffuse values (R,G,B,A). 'A' represents the shininess parameter value.
- **The specular value of an object is always (0.7,0.7,0.7,1.0).**

Input example

e 0.0 0.0 4.0 1.0

a 0.1 0.2 0.3 1.0

o 0.0 -0.5 -1.0 -3.5

o -0.7 -0.7 -2.0 0.5

o 0.6 -0.5 -1.0 0.5

c 0.0 1.0 1.0 10.0

c 1.0 0.0 0.0 10.0

c 0.6 0.0 0.8 10.0

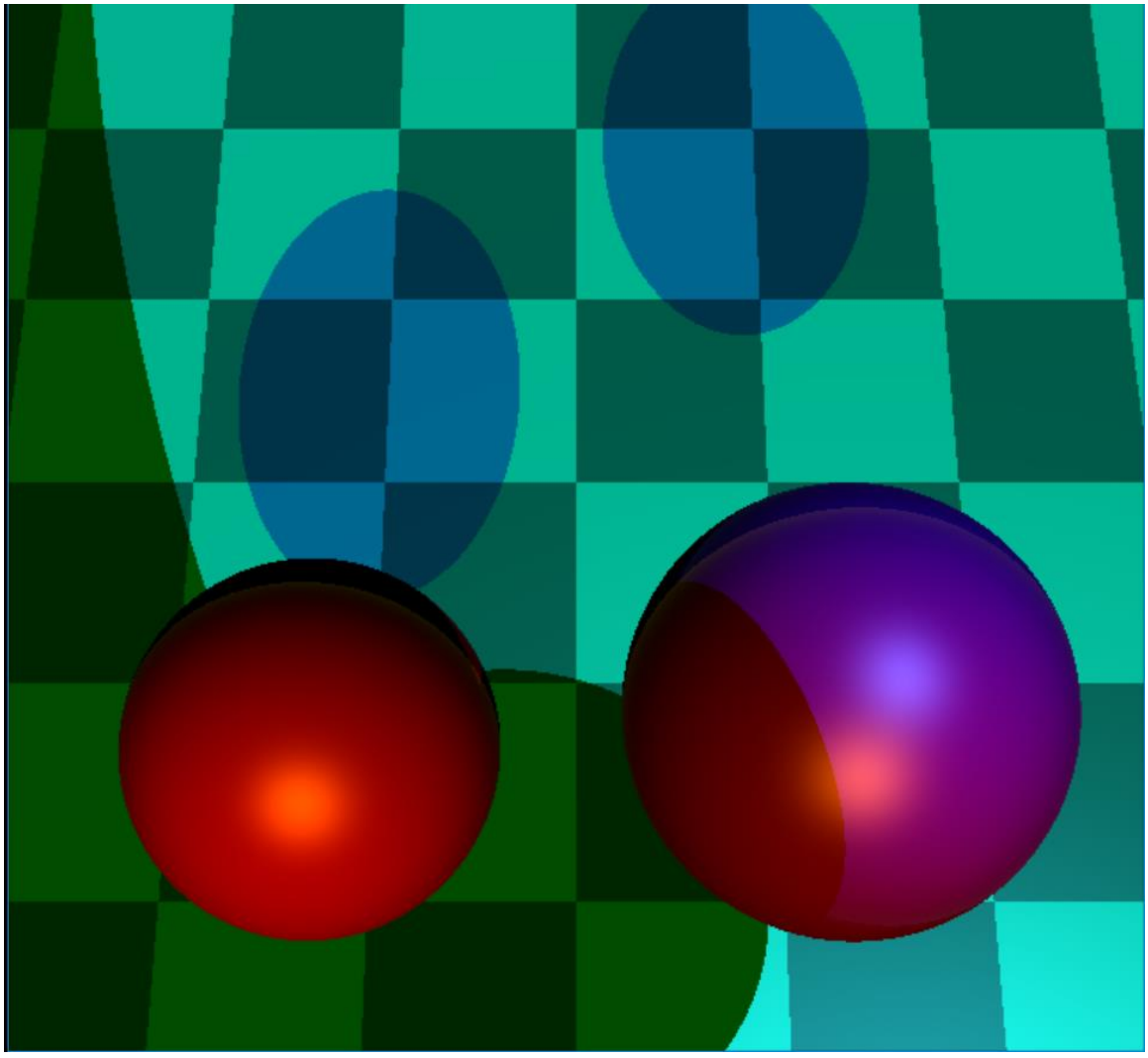
d 0.5 0.0 -1.0 1.0

d 0.0 0.5 -1.0 0.0

p 2.0 1.0 3.0 0.6

i 0.2 0.5 0.7 1.0

i 0.7 0.5 0.0 1.0



Notes

Recommended Milestones

Design Before you start coding! You should think carefully about the structure and design of your Shader. Start from a small scene with one or two objects.

Validation

We will provide you with sample scenes for validation and the way they are supposed to render in your ray tracer. Your implementation may vary from the supplied image in little details but in general the scene should look the same.

Some general hints:

- Before plotting a pixel, make sure that its color does not exceed the range of 0-1 for every color channel.
- Right vector of the screen will be orthogonal to up vector and toward vector (see slide 42 of PS 3.
- Use file parser we supply you to parse the scene file
- You can debug shaders by coloring pixels differently or you can implement problematic parts in c++ and than copy the implementation to the fragment shader.

Submission:

Submission is in pairs.

Everything should be submitted inside a single zip file named
<ID1> _<ID2>.zip
The zip file should include one file of raytracer.fs (your fragment shader). We will use the code we provide to check examples.

Appendix A – Step by Step Guidance

Following are some practical suggestions that could make the exercise easier for you. There are many other ways to approach it as well, and you don't necessarily have to follow these directions.

1. Go through the RayTracer code and understand what does what. Really, deeply understand. Only when you're done, write your own RayTracer.
2. Make sure you read the scene definition file correctly.
3. Define you C++ object for each light source, sphere and a plane.
4. Try to render small scenes with one light.
5. Add lights and compare your results which friends.
6. Implement the other lighting types.
7. Add support for shadows and reflection by recursively shooting additional rays.
8. Go through the exercise definition and make sure you haven't forgotten anything.

Helpful links:

http://en.wikipedia.org/wiki/Ray_tracing_(graphics)

http://www.cl.cam.ac.uk/teaching/1999/AGraphHCI/SMAG/node2.html

http://www.siggraph.org/education/materials/HyperGraph/raytrace/rtrace0.htm

Good Luck!