This paper will introduce different implementation in rendering reflection while comparing their quality and complexity.

Introduction：

Rendering technology is developed with game industry for many years. Developers are try their best to provide highly realistic or even surreal virtual environment. But still, there lots of technical challenges in this area, like the simulation of water or smoke, ambient occlusion and high quality reflection. Reflection phenomenon can be seen everywhere in real world but hard for computer simulation in real time. The contradiction of efficiency and accuracy confuses the developer all the time in this area. Screen-space reflection and environment mapping are two kinds of implementation generally used in modern games. Their both simplified the rendering progress by some techniques with the cost of providing a inaccurate result. And an other solution is ray tracing which simulate the refraction and reflection of the ray of light like the real world. It provides high accuracy of reflection image but increase the performance costs of graphic card.

Environment mapping:

Screen-Space reflection:

Ray tracing:

Ray tracing is a technology that calculates the colour of each pixel by tracing the path of their ray of light and simulating the interaction of virtual object and get the final image as output. Because of following the physical rules of light transmission, ray tracing can get more accurate and more realistic image compared with environment mapping and screen-space reflection mentioned above. And it can also simulate almost all the optical phenomenons like refraction, reflection, scattering and dispersion. But it requires massive calculation which hard to be satisfied by personal computer even their performance improved a lot these years. Thus, ray tracing mainly was used in off-line rendering such as 3D animation or special effects in films. But due to requirement of real-time calculation in computer game area, the application of ray tracing is infrequent.

Ray tracing algorithm is highly parallelized. Tracing the ray of light for each pixel in image can execute in parallel because the calculation of each pixel not rely on the result of others. The calculation amount of ray tracing is direct proportional to the quantity of pixels in output image. Thus, the time-consumption can be reduced remarkably if the ray tracing algorithm can run totally in parallel. When apply parallel computing in particular, for example in rendering 3D film, hundreds of computers render the image in same time dividing by block generally. But for personal computer, because the CPU executes the instructions in series, it is hard to apply parallel computing physically. And if solving the problem by adding the cores in CPU, the cooperation between cores will become complex and restrict the software structure.

Differ from CPU, GPU is designed for image-relevant calculation which provides brilliant parallel computing performance. Due to its logical control ability is relatively weak, the main job of GPU was rendering the vertex and fragment for a long time. But the situation is different these years, because of the development of graphic card. With the increasing demand of parallel computing in personal computer, graphic card manufacturer keep upgrading the technology. The concept of rendering streamline and GPGPU(General Purpose Graphic Process Unit) came up providing acceptable solution for apply parallel computing in personal computer. Also some computing language or describe language are provided by manufacturer for graphic engineers to reduce the difficulty of graphic development. All those changes make it possible to apply complex parallel computing, such as ray tracing, in personal computer and give it acceptable performance.

Demand analysis:

Diffuse reflection:

The diffuse reflection happens on object surface when directional light lighting rough surface. The light will scatter off the surface making it possible to be seen in all directions. But the diffuse light not uniformly distributed in all directions. It has some certain rules, like Lambert’s cosine law, which reveal the correlation between brightness and included angle between surface normal and incident direction. Diffuse light is commonly seen in real world which needs appropriate implementation in renderer.

Shadow:

When the light from the light source is blocked by opacity object, dark area will be left as shadow. The performance of the shadow is a important part in graphic rendering, which also is a hard part. The shadow in real world is complex because of the multiple light source and indirect illumination. So, how to provide a realistic and accurate shadow is a focus of graphics. This article will mainly focus on reflection and ray tracing technique itself. So this article only talks about the shadow produced directly block.

Specular reflection:

The specular reflection occurs when the ray of light intersects with smooth surface. Specular reflection follows the Law of Reflection that [wiki] for each incident ray the angle of incidence equals the angle of reflection, and the incident, normal, and reflected directions are [coplanar](https://en.wikipedia.org/wiki/Coplanar" \o "Coplanar).[citation] Thus, the specular light only can be observed in certain direction. The common representation of specular reflection is rendering the combined image of object surface and reflected image based on the smoothness of the surface. Specular reflection is generally used in modern game in which ray tracing algorithm provides more realistic performance than environment mapping and screen-space reflection.

Refraction:

The light will be refracted when it intersects with the interface between two transparent materials with different refraction index. The refraction follow the Snell’s Law which describes the correlation between the included angles that between incident light, refraction light and normal interface normal. Compared with other kinds of renderer, ray tracing can easily implements complex refraction phenomenons like convex lens and concave lens imaging by simulating the propagation of light.

Recursive ray tracing:

As introduced above, when the light hits the surface, it may generates two rays of light based on the refraction and reflection. A ray of shadow may also be generated depends on the transparency of the material it hits. The rays of refraction and reflection light may also hit the surface and generate more rays. Thus, the process of solving the ray tracing should be recursive to solving those rays which provides high degree of realism.

Outline design:

Class design:

The ray tracing renderer is designed as figure 1 based on the features of ray tracing algorithm.

Utility class:

Vector3

Vector3 is a basic data structure in ray tracing renderer. Because this article is going to implement ray tracing a 3D render technique, all calculation of ray tracing is done in 3D space. The position and vector in 3D space are described by x, y, z components. When solving the space geometric problem, normalization, dot product, cross product are generally used. So it is important to implement those method and override the add and minus operator.

Ray

Ray class represent a ray of light which include the origin and its direction normal. Those information are used for ray-object intersection to figure out the intersection point.

Camera

Camera class is used to stored status of the camera, which represent the observer, include its position, pitch and yew which describe the observation angle and projection matrix which giving the information of near and far plane, field of vision and etc. For free observation, the camera class also need implement move and rotate method. When preforming ray tracing, the original ray is build by connecting camera position and pixel in viewport.

Canvas

Canvas class represent the output of the renderer. Color information of pixels may render to frame buffer or screen. Those configuration recorded by canvas, so that when output is changed, only canvas need to be modified.

Scene

Scene class stores the data of the scene to be rendered. Generally, there are two kinds of data stored in scene class: light source and primitive. Scene class provides some interfaces for renderer to access those data. When amount of light source and primitive are massive, it will causing the performance problem. To prevent this situation, scene manager is also needed to sort resources like sort opacity object by depth to make them fail the depth test.

LightSource

LightSource is an abstract class which represents all kinds of light source in scene and provides the pure virtual functions. Different light source inherited from LightSource class just need implement the virtual functions. For ray tracing renderer, the light source should have two member variables, light position for calculating shadow and direction for calculating diffuse and specular light. In this article, to simplify the renderer, only point light and parallel light are implemented.

Material

Material class is used to modify the material of the primitive. Material class stores the important data of the material which can be used by shader. Also, it stores the diffuse reflection coefficient, specular reflection coefficient, refraction coefficient and refractive index. The first three coefficient introduced above describe the energy distribution of diffuse reflection, specular reflection and refraction which add up to one. When recursively tracing the ray of light, the final output will add each light based on this coefficient as weight. And if the specular reflection coefficient or refraction coefficient is zero which means specular reflection or refraction won’t occur on this surface, the renderer won’t generate relevant light to improve the performance.

AABB

AABB(Axis-Aligned Bounding Box) class represent the axis-aligned cube, which completely encircles the primitive. When performing intersection test, the ray of light will run intersection test with AABB first. If the ray not intersect with AABB, the intersection test will stop. Otherwise, the ray will do the test with primitive. Because the AABB is axis-aligned box, it is easy to perform intersection test. By doing this, renderer can greatly reduces the complexity of intersection test and provides a better performance.

Primitive

Primitive class is an abstract class which is the base class of all renderable object. An object must inherit from primitive class and implement its pure virtual class to be rendered. The function in primitive class includes getting normal of a vertex in primitive, getting and setting the material of a primitive, getting the intersection point with given ray. The normal of the vertex is used to define the front and back of the primitive and calculate the reflection and refraction light. The intersection point is one of the most important parameter used by ray tracing renderer. Renderer will choose the closest intersection point and calculate the diffuse light and generate specular reflection and refraction ray of light. The primitive types used by this article are plane, sphere, cube and triangle.