Photonix

Realistic Images Using Photon Mapping

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Photonix is a Real-time 3D CAD Modeler that support most of special effects and accurate light model using photon mapping with best performance

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Preface

Computer graphics represent a technology that is rooted in many disciplines: Virtual reality, Particle Real life Simulation (fog, fire, smoke ...etc), Character modeling and animation, Entertainment, movies, Games, Physics laser lighting applications, Computer aided design (CAD), computer aided manufacturing (CAM) and Advertising.

As the computer Hard Ware technology is increasingly updating computer graphics also follow the same steps of developing.

The final **goal** of computer graphics is to generate realistic images as same as it was taken by human eye, and to simulate realistic images as much as possible.

So our project is a **large step** to this goal which get a realistic images as the same as it was taken by a photographic camera using a new technique for rendering which appeared for the first time in new **millennium** accurately in the year 2002.

This new technique for rendering is called **photon mapping** which uses traditional ray tracing techniques and indirect light illumination technique - as the same as it happen real life - to render 3D objects.

In the following pages of documentation we introduce a summary of hard work in our graduation project.
The documentation is organized as fellow:

1. ***Introductory material***, chapter 1 describes largely in quantities term the problem definition, why this new technique –photon mapping- appears and the old techniques limitations then we describe our objective from the project and its features and outline the project phases.
2. ***Project details***, in chapter 2 which include a description of the traditional ray tracing technique and then we describe the photon mapping technique in details and provide a pseudo code of algorithm of photon mapping, and then we describe the raw basis of the project the 3D rendering engine we describe its features and implementation.
3. ***Applications of the project***, the photon mapping reach a reality of images which will be useful in many applications outlined in the third chapter.
4. ***Source code***, in chapter 4 we provide a source code of the project so that it may be useful for next years students who want to build their work based on our project.

Abstract

Rendering is the process in which a two-dimensional image is created by a computer from a description of a three-dimensional world.

Our Objective is to combine both Hardware and software capabilities and get highest realism in the generated image using most powerful global illumination algorithm, Photon Mapping.

Global illumination is based on light transport mechanism in real world. The light transport mechanism can be expressed in terms of Bidirectional Reflectance Distribution Function (**BRDF**) of each element, and the most common and practical way is dividing the BRDF into specular and diffuse component.
Mathematically Global illumination is a problem of solving numerical equations concerning with the convergence, converging speed and if it converges to right answer.

The initial value is the given light sources and their characteristics. The energy of the light source is propagated into the geometrical space. The **Radiosity and Ray-tracing** methods are used to calculate the energy propagation in each iteration step. The BRDF of geometrical element is important to the efficiency of each method. If the BRDF is ideal diffuse, Radiosity method will converge and converge to right answer. However, Ray tracing algorithm works more efficiently in calculating specular reflection, refraction and caustic surfaces, Those Radiosity and Ray-tracing algorithms can be measured in two aspects, the accuracy and efficiency in BRDF simulation and the rendering speed.

The **photon mapping** is a new method is used extensively in global illumination to render photorealistic pictures.

The **photon mapping** combines the advantages of both radiosity and ray tracing and better than them in terms of the accuracy and efficiency in BRDF simulation and the rendering speed

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1. Introduction

The use of computer graphics is today growing faster than ever. Especially in the entertainment industry, but also in the product developing industry in general, where it is an invaluable tool for construction, design and visualization. Much work has been done to make the computer-generated images as realistic as possible. The goal is to produce images that cannot be distinguished from real life.

I. Problem Definition

The project tries to find answers to the following questions

1- Can the computer generate images realistic as real life images?

2- To what extent is the generated image is close to real life images?

By answering these questions we could find that Lighting is the most important factor in providing live to images that can produce effects like (direct, indirect illumination, shadows).

II. Existing Algorithms Limitations

There are many available tools like 3d Studio Max, Maya and SoftImage and modeling Software development kits (SDK) such as Opengl and Directx provides different solutions for producing computer images.

But these images are not very like to real life because the following problems in existing Algorithms:

In **Software development kits**:

1-It does not support real lighting effects based on **Ray Tracing** such as reflections, refraction and absorption

2- It don't care about scene geometrical description

In **Existing Modeling Tools**

1-It does not support real lighting models because it doesn't use **photon** mapping and global illumination found in real life.

2- It doesn't support object Media and interior such as (glass, crystal and fluids)

III. Objective

Our project target is to develop a modeling tool that can produce high realistic images using Different Global illumination algorithms like (photon mapping, Radiosity)

IV. Project Feature

The Main Features of our project can be summarized in the following points

Rendering Package

- Fully Feature **Ray Tracing Package**
- Supporting Most Realistic Images using **Photon mapping**
- Supporting bump Mapping ,Reflection,Alpha Blending
- High Quality Object Models using **Subdivision** and **Mathematical Representation**
- **Soft Shadow** Objects
- Supporting Corect Light Model using **Radiosity**
- Simulating **Real life particles** (fog) and providing correct Light transport through physical medias
- **Focal blur** by simulating the human eye
- **Sky and Rainbow Simulation System**
- Object Texturing and different Pattern filling (wood ,bozo,cracle)

3D Editor and Modeler

- Easy User interface like most famous CAD Application (3D Max,MAYA)
- Real time Preview
- Object Management (Selection , Manipulation and Deletion)
- 3D File Import (3ds ,IFS)
- Ramaining Time Rendering Support

Project Development

- The project is released as **open source** development at http://photonix.sourceforge.net
- Weekly Updated

V. Previous work

Computer graphics has been an increasingly growing field of computer science.

In 1968, when much of computer graphics was simple raster calculations, Arthur Apple thought of a new way to render objects. His idea was to trace rays from the viewer's eye, through an image plane, and into a scene to discover where objects were located in a three dimensional world. However, it wasn't until Turner Whitted extended this idea into *ray tracing* in 1980 that the technique became noticed. The inclusion of both specular reflection and transmission made the algorithm both versatile and visually appealing. Unfortunately, ray tracing could not handle diffuse reflections, which is where much of real light comes from.

In 1984 the Radiosity algorithm was created by researchers at Japan's Fukuyama and Hiroshima Universities and the United States' Cornell University. This algorithm, borrowed from the field of radiative heat transfer, proposed to give everything ray tracing couldn't to the graphics field. Mainly, this meant that Radiosity could calculate diffuse reflection.

In 1986, Kajiya introduced path tracing, an extension to the ray-tracing algorithm that allowed it to stochastically sample for diffuse reflections. The algorithm worked well, but noise in the image was a major problem. Also, in 1986 Immel, Cohen, and Greenberg developed a specular Radiosity program that could simulate specular reflections. Unfortunately, the excessive time it took to render even a small number of specular surfaces was discouraging.

In 1987, AT&T introduced a MIMD parallel machine that could render simple scenes using ray tracing in real time. Since 1988 there has been an explosion in the number of methods trying to improve either Radiosity or ray tracing, including many attempts at combining the two. Many attempts have been made at creating real time ray tracing and radiosity that used parallel machines.

However, in 1996, Henrik Wann Jensen published the first papers on *photon mapping*. Photon mapping is a technique that allows the inclusion of both diffuse and specular reflections without the speed issues or noise issues that arise from radiosity and ray tracing. Photon mapping uses techniques and ideas from both ray tracing and radiosity.

We can classify the major solutions into a table illustrating the capability of each method dealing with BRDF and its complexity.

Category	BRDF and its complexity	Solutions

Radiosity	Diffuse only	Hemi-cube Radiosity Progressive Radiosity Analytical form-factor method
Radiosity and ray tracing	Diffuse and specular (planar surface only) and single pass	Two-pass method
	Diffuse and specular (nonplanar surface) multi pass	General Two-pass method
Ray tracing (for solving the diffuse component, various techniques are suggested)	Forward statistic ray tracing enables caustic	Kajia's Path tracing
	Diffuse and specular (nonplanar surface) deterministic forward ray tracing	Radiance method
	Forward and backward combination	Bi-directional path tracing
	Path mutation in ray tracing	Metropolis light transfer method
	Bi-directional Photon tracing	Photon map method

However, these solutions have common interest in some points. One major thing is important sampling. To solve a problem using iteration or numerical integration, the variables with large value should be considered first. It is a kind of importance sampling. The other thing is error level adjustment. For the radiosity method, it presented as hierarchical or meshing techniques. In ray tracing, it is represented as ray path level and ray sampling rates.

VI. Project Phases

The project intended to be a modeling tool that helps 3D designers to develop large scenes and render it with high quality using the new **global illumination** Algorithms specified next:

1- **Ray tracing** : is one of the most popular methods used in 3D computer graphics to render an image. It works by tracing the path taken by a ray of light through the scene, and calculating reflection, refraction, or absorption of the ray whenever it intersects an object in the world

2- **Object Models** : providing different object model for testing purposes (sphere ,box ,Constructive solid geometry ,Mesh ,Patches ,…)

3- **photon mapping** is a ray tracing technique by which the transport of light from a light-source through a physical medium such as a glass or a window can be simulated to produce effects similar to those in real life.

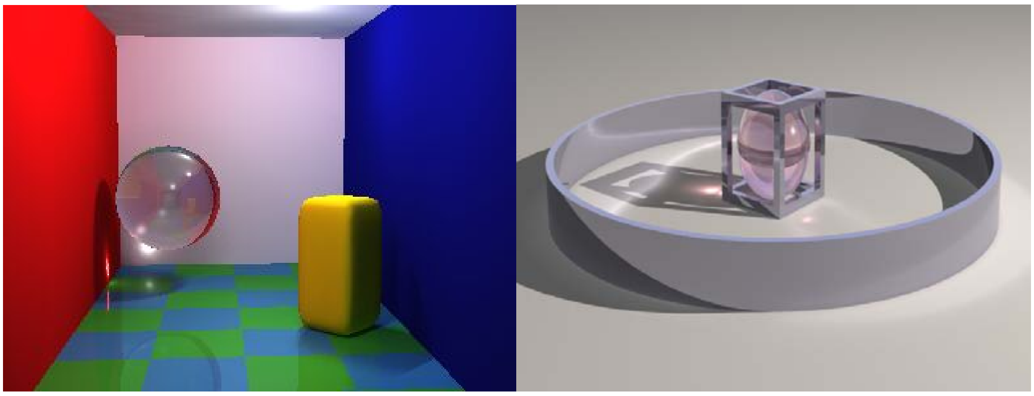


Figure 1.1 Output of photon mapping algorithm

4- **Radiosity:** The idea was to simulate energy (light) transference from diffuse surfaces. Diffuse surfaces are surfaces that reflect light equally in all directions – the opposite of a shiny surface.
Radiosity is quite similar to photon-map based techniques. However, instead of using ray tracing for final gather, the photons in the photon map are used as light sources and fast and hardware supported visibility and shadow algorithms are applied.

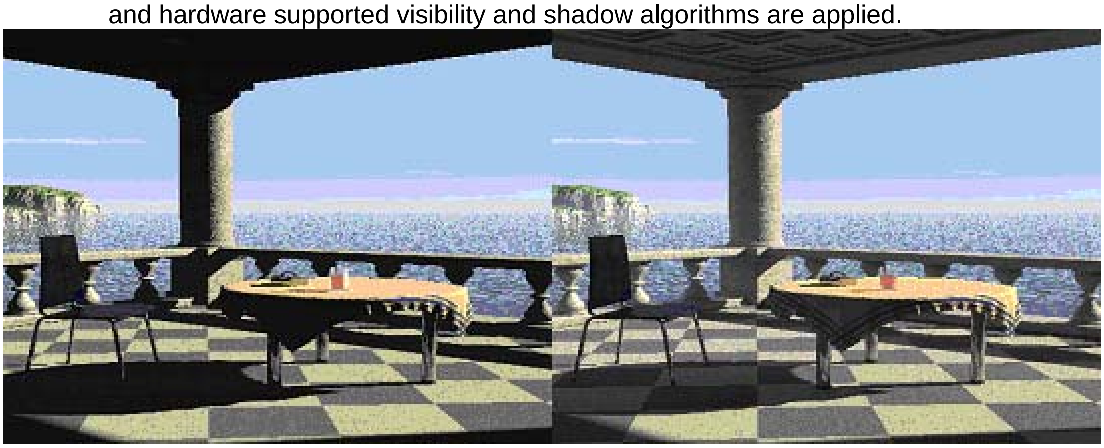


Figure 1.2 Difference between Direct and Indirect illumination

5- **Soft shadows**: provides an elegant way to simulate florescent and laser light by not providing a single sharp shadow maps by with providing shadows in realistic way.

Figure 1.3 Soft Shadow Effect

6- **Focal blur**: simulate the human eye by limiting eye near and far distance planes and providing a focal point where picture is distorted outside this range.

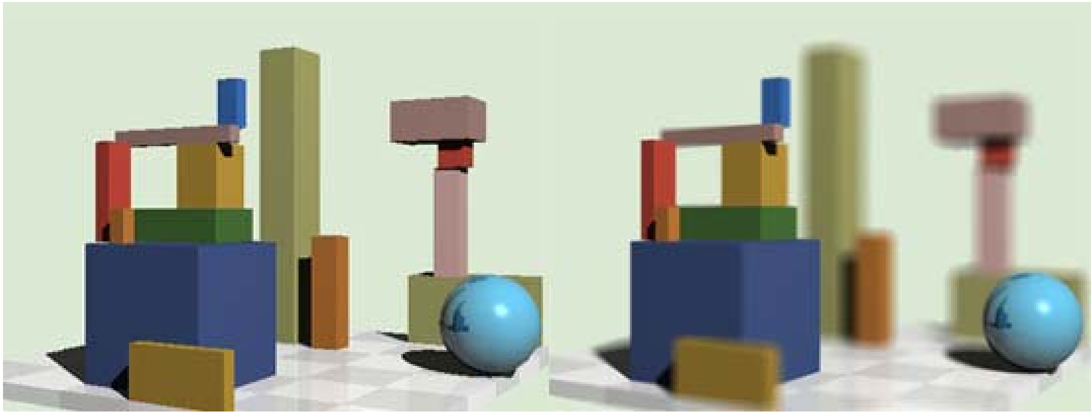


Figure 1.4 output images without and with Focal Blur Effect

7- **Participating Media and Particle systems**: by providing correct Light transport through physical medias .In the same way we interact with space as media helps simulate light scattering in Natural phenomena (smoke, fire, rain and fluids)

Figure 1.5 Output of Participating media and particle system

2. Project Details

I. Ray Tracing

Ray tracing is one of the most popular methods used in 3D computer graphics to render an image. It works by tracing the path taken by a ray of light through the scene, and calculating reflection, refraction, or absorption of the ray whenever it intersects an object in the world - hence the name.

For example, starting at a light source, we may trace a ray of light to a surface, which is transparent but refracts the light beam in a different direction while absorbing some of the spectrum (and altering the color). From here, the beam may strike another surface, which is not transparent and so the light undergoes both absorption (further changing the color) and reflection (changing the direction). Finally, from this second surface it may be reflected directly into the virtual camera, where its color contributes to the final rendered image.

Ray tracing's popularity stems from its realism over other rendering methods (such as scanline algorithms); effects such as reflections and shadows, which are difficult to simulate in other algorithms, follow naturally from the ray tracing algorithm. The main drawback of ray tracing is that it can be an extremely slow process, due mainly to the large numbers of light rays which need to be traced, and the larger number of potentially complicated intersection calculations between light rays and geometry (the result of which may lead to the creation of new rays). Since very few of the potential rays of light emitted from light sources might end up reaching the camera, a common optimization is to trace hypothetical rays of light in the opposite direction. That is, a ray of light is traced starting from the camera into the scene, and back through interactions with geometry, to see if it ends up back at a light source. This is usually referred to as backwards ray tracing.

Nonetheless, since its first use as a graphics technique by Turner Whitted in 1980, much research has been done on acceleration schemes for ray tracing; many of these focus on speeding up the determination of whether a light ray has intersected an arbitrary piece of geometry in the scene, often by storing the geometric database in a spatially organised data structure. Ray tracing has also shown itself to be very versatile, and in the last decade ray tracing has been extended to global illumination rendering methods such as photon mapping and Metropolis light transport.

Ray tracing in computer graphics derives its name and principles from a much older technique used for lens design since the 1900s. Geometric ray tracing is used to describe the propagation of light rays through a lens system or optical instrument, allowing the properties of the system to be modelled. This is used to optimise the design of the instrument (e.g. to minimise effects such as chromatic aberration) before it is built.

The principles of ray tracing for computer graphics and optical design are similar, but the technique in optical design usually uses much more rigorous and physically correct models of how light behaves. In particular, optical effects such as dispersion, diffraction and the behaviour of optical coatings are important in lens design, but are less so in computer graphics.

Before the advent of the computer, ray tracing calculations were performed by hand, but now they are common features of optical design software such as Zemax. A simple version of ray tracing known as ray transfer matrix analysis is often used in the design of optical resonators used in lasers.

II. Photon Mapping Algorithm

A) General

Photon Mapping is a method to achieve global illumination effects, such as color bleeding and caustics. The method was originally developed by Jensen [JEN96]. The method is based on the idea of emitting photons from the light sources and letting them bounce around in the scene until absorption. This emission takes place before any actual rendering is done. Photons hitting scene geometry are stored to be used later during rendering. Many photons are needed to get good image quality, typically 100.000 – 1.000.000 photons depending on the specific scene. The collections of photons are called a photon map. Normal ray tracing methods are combined with the photon map during rendering. The density of photons in the neighborhood of a specific query point is used to get an irradiance estimate during rendering, and this value is used as an approximation instead of performing a costly Monte Carlo integration.

Photon Mapping can be divided into three consecutive steps, each of which is described in the subsequent subsections.

- Photon Tracing
- Photon Map Sorting
- Rendering

B) Photon Tracing

Each light source emits photons which are traced through the scene. A photon hitting a surface can be reflected, transmitted or absorbed. Russian roulette is used to determine which of these three events should occur, with probabilities based on the material properties. A photon path is terminated when it is absorbed. Photons hitting diffuse surfaces are stored for later use, each photon emitted from a light source can therefore be stored many times during its path through the scene (hitting several diffuse surfaces). The collection of stored photons is the *global photon map*.

An additional *caustics photon map* may also be created. This photon map only stores photons hitting diffuse surfaces if they have been reflected or transmitted from a specular surface.

The following information is stored for each photon.

- Photon position
- Photon flux
- Incident direction

C) Photon Map Sorting

All photons created during photon tracing are in this step sorted to allow fast lookups during the rendering step. Jensen [JEN96] uses a balanced kd-tree since it is a compact representation which allows a non-uniform distribution of photons in the scene. The global photons and the caustics photons are stored into separate photon maps.

D) Rendering

Four terms are evaluated and added together to get the color of each pixel in the image.

- Direct light

- Specular light
- Indirect light
- Caustics

Figure A1.a illustrates how the direct light term is calculated. The red arrow represents a primary ray sent from the camera. The black arrows represent shadow rays sent from the intersection point towards all light sources.

Figure A1.b illustrates how specular reflection and transmission are calculated. The blue object is both diffuse and specular. Reflected rays are sent to collect illumination in the specular direction.

Figure A1.c illustrates how indirect light from other surfaces is calculated with a Monte Carlo integration over the hemisphere. Often, hundreds or thousands of gathering rays are needed to get an acceptable integration estimate with low variance. This large number of rays can be reduced with importance sampling methods. It is also possible to reduce the number of Monte Carlo integrations using Ward's interpolation scheme [WAR88][WAR92].

The Monte Carlo gathering rays hitting geometry would normally generate secondary gathering rays, which in turn would generate third generation rays, etc. We can get an irradiance value from the global photon map instead of generating secondary gathering rays. The position and incident direction where a gathering ray hits geometry is used to query the photon map for an irradiance value. The result we get from such a query contains both direct and indirect light as well as caustics effects.

Figure A1.d illustrates how caustics are added to the solution by querying the caustics photon map at the intersection point.

A 'photon density' calculation is used to estimate an irradiance value for both the global photon map and the caustics photon map. This density calculation can be imagined as expanding a sphere around the query point until enough photons have been collected or until a maximum radius is reached. Typically, 50-500 photons are used. The density is then calculated as total photon power divided by the squared radius. The volume is not used since the photons found are most likely located on a surface, i.e. the expanding sphereforms a circle on the surface.

Figure A2 shows a rendering of the Cornell box where each of the four light contributions is rendered as a separate image. Figure A3 shows the four terms added together forming the final image.

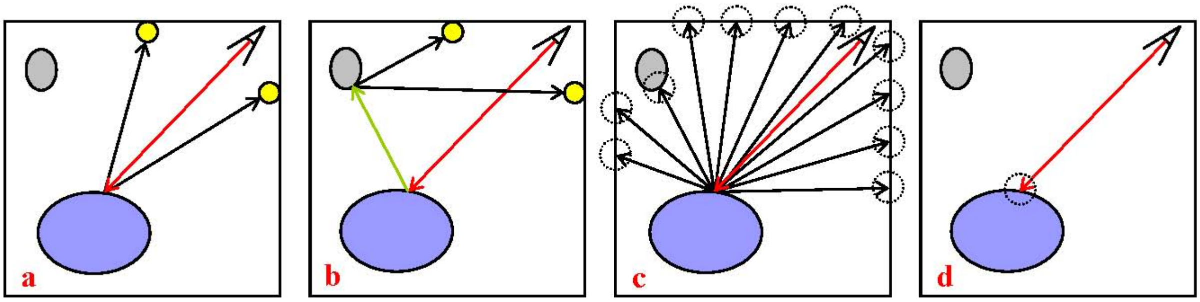


Figure 2.1 – Illustration of the four terms evaluated for each pixel. From left to right, direct light, specular light, indirect light and caustics. The red arrow represents a primary ray sent from the camera. The two ellipses are objects in the scene. The blue object is both diffuse and specular. The yellow circles represent two light sources.

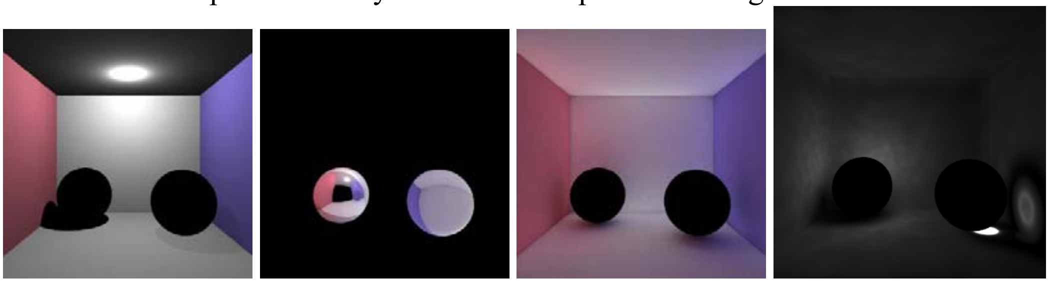


Figure 2.2 – Visualization of the four terms evaluated for each pixel. From left to right, direct light, specular light, indirect light and caustics.

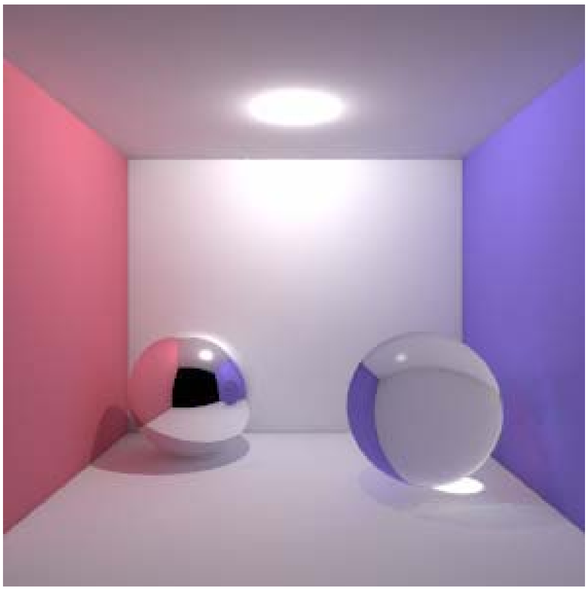


Figure 2.3 – The four terms added together forming the final image.

E) Mathematical Basis

Bi-directional path tracing connects a single gathering walk to a single shooting walk. However, if the effects of a shooting walk, for instance, could be stored, then when a new gathering walk is computed, it could be connected to all of them simultaneously. This is exactly what Jensen [19, 18, and 20] proposed, also giving the definition of a data structure, called the *photon-map* which can efficiently store the effects of many shooting walks.

A photon map is a collection of photon hits generated in the shooting phase of the algorithm. The photon-map is organized in a *kd-tree* to support efficient retrieval. A photon hit is stored with the power of the photon on different wavelengths, position, and direction of arrival and with the surface normal.

The gathering phase is based on the following approximation of the transport operator:

$$L(\vec{x},\omega') = \int_{\Omega} L(h(\vec{x},-\omega'),\omega')\cdot f_r(\omega',\vec{x},\omega)\cdot\cos\theta'\, d\omega' =$$

$$\int_{\Omega} \frac{d\Phi(\omega')}{dA\cos\theta' d\omega'}\cdot f_r(\omega',\vec{x},\omega)\cdot\cos\theta'\, d\omega' \approx$$

$$\sum_{i=1}^{n} \frac{\Delta\Phi(\omega_i')}{\Delta A}\cdot f_r(\omega_i',\vec{x},\omega),$$

Where $\Delta\Phi_i(\mathbf{x},\omega_i)$ is the power of a photon landing at the surface ΔA from direction ω_i' .The $\Delta\Phi$ and ΔA quantities are approximated from the photons in the neighborhood of $\vec{\mathbf{x}}$ in the following way. A sphere centered around $\vec{\mathbf{x}}$ is extended until it contains n photons. If at this point the radius of the sphere is r , then the intersected surface area is $\Delta A = \pi r^2$

- **Photon Shooting**

```
struct photon
{
float x, y, z; // where this photon was stored
char power; char φ , θ ; // its power, and where
it came from
short cd; // the cutting dimension (kd tree)
}
diffuse pointShoot()
n_p = 0; p = lightSource();
while (not enough photons)
{
    d = randomDirection();
    shoot photon in direction d to get pos
    n_p += 1;
}
```

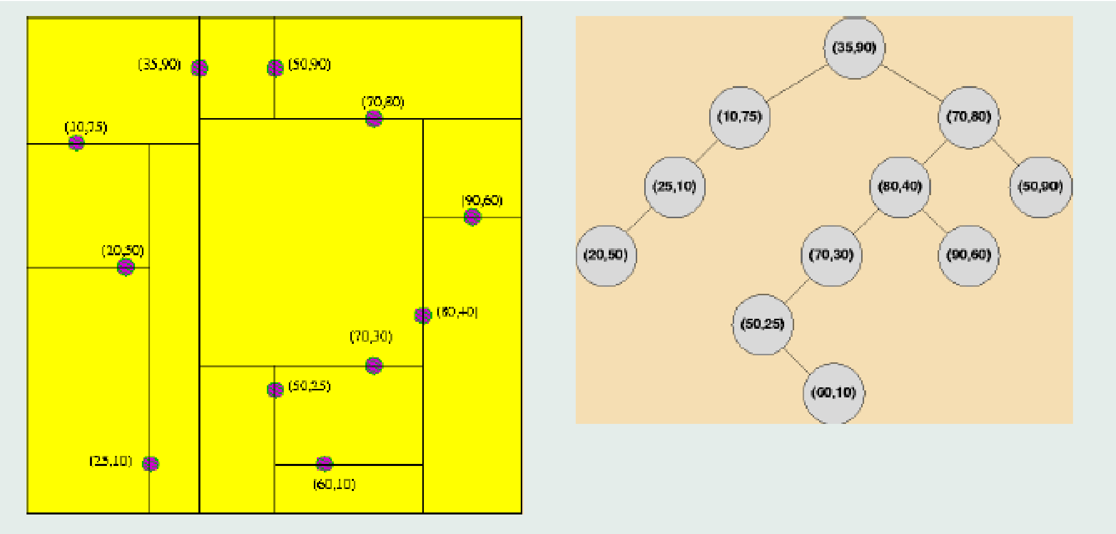
Scale power by $\frac{1}{n_p}$
store photon at pos with power and direction

- **Computing Reflected Radiance**
  We want to the reflected radiance at *x* in the outgoing direction w
  - In the photon map, we find a photon *p* close to *x* and we know it came from

  the direction and it has some differential flux.
  We know the BRDF *fr* at point *x*.

  The reflected radiance
  $$L_r(x,\omega) = \int_{\Omega_x} f_r(x,\omega',\omega)\frac{d^2\phi(x,\omega')}{dA_i}$$
  is approximated as
  $$L_r(x,\omega) \approx \sum_{p=1}^{n} f_r(x,\omega',\omega)\frac{\Delta\phi_p(x,\omega')}{\pi r^2}$$
  where *r* is the distance to the farthest photon *p*.

- kd-trees
  Dimension of data is k (but common to say k-d tree of dimension 3 instead of 3d-tree).
  Kd-trees are binary trees
  Designed to handle spatial data in a simple way
  For n points, O (n) space, O (log n) height (if balanced), supports range and nearest- neighbor queries.
  Node consists of
  - Two child pointers,
  - Satellite information (such as name).
  - A key: Either a single float representing a coordinate value, or a pair of floats (representing a dimension of a rectangle)



- **Basic Idea Behind kd-trees**
  Construct a binary tree
  At each step, choose one of the coordinate as a basis of dividing the rest of the points
  For example, at the root, choose x as the basis
  - Like binary search trees, all items to the left of root will have the x-coordinate less than that of the root
  - All items to the right of the root will have the x-coordinate greater than (or equal to) that of the root

  Choose y as the basis for discrimination for the root's children
  And choose x again for the root's grandchildren
  Note: Equality (corresponding to right child) is signicant

Assume points are sorted on both x and y in a composite array S,S[x] corresponds to a list of points sorted by x.The Algorithm of building the tree is as follows

```
KDNode buildTree(SortedArray S , int cd )
{
        if (S.empty()) return null;
        else if S.singleton() return new KDNode(S[x][0],cd);
        else
        {
                m = median ( S , cd ) // median ( cut t ing dimens ion )
                        left = leftPoints (S , cd ) ; right = S-left;
                t = new KDNode(m);
                t.left= buildTree (left , cd+1);
                t.right= buildTree( right, cd+1);
                return t
        }
}
```

- T(n) = kn + 2T(n=2), so the algorithm takes O(n log n) time.

III. Soft Shadows

Area light sources occupy a finite, one- or two-dimensional area of space. They can cast soft shadows because an object can partially block their light. Point sources are either totally blocked or not blocked. It is approximated as an array of point light sources spread out over the area occupied by the light. The array-effect applies to shadows only. The object's illumination is still that of a point source. The intensity of each individual point light in the array is dimmed so that the total amount of light emitted by the light is equal to the light color specified in the declaration.

The area light command defines the location, the size and orientation of the area light as well as the number of lights in the light source array. The location vector is the centre of a rectangle defined by the two vectors <*Axis_1*> and <*Axis_2*>. These specify the lengths and directions of the edges of the light.

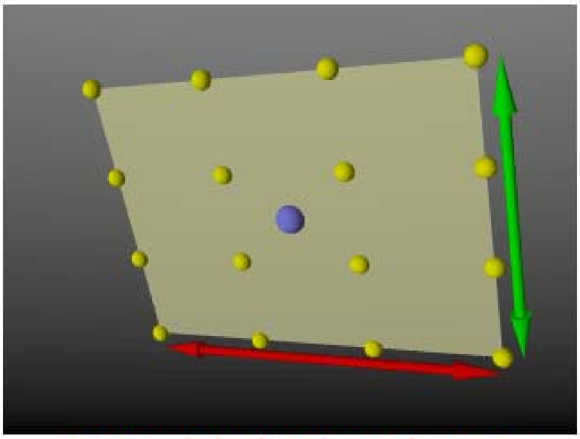


Figure 2.4

4x4 Area light, location and vectors

Since the area lights are rectangular in shape these vectors should be perpendicular to each other. The larger the size of the light the thicker the soft part of shadows will be. The integers Size_1 and Size_2 specify the number of rows and columns of point sources of the. The more lights you use the smoother your shadows will be but the longer they will take to render.

An interesting effect can be created using a linear light source. Rather than having a rectangular shape, a linear light stretches along a line sort of like a thin fluorescent tube. To create a linear light just create an area light with one of the array dimensions set to 1.

The jitter command is optional. When used it causes the positions of the point lights in the array to be randomly jittered to eliminate any shadow banding that may occur. The jittering is completely random from render to render and should not be used when generating animations.

The adaptive command is used to enable adaptive sampling of the light source. By default the algorithm calculates the amount of light that reaches a surface from an area light by shooting a test ray at every point light within the array. As you can imagine this is very slow. Adaptive sampling on the other hand attempts to approximate the same

calculation by using a minimum number of test rays. The number specified after the keyword controls how much adaptive sampling is used. The higher the number the more accurate your shadows will be but the longer they will take to render.
When performing adaptive sampling it starts by shooting a test ray at each of the four corners of the area light. If the amount of light received from all four corners is approximately the same then the area light is assumed to be either fully in view or fully blocked. The light intensity is then calculated as the average intensity of the light received from the four corners. However, if the light intensity from the four corners differs significantly then the area light is partially blocked. The area light is split into four quarters and each section is sampled as described above. This allows to rapidly approximating how much of the area light is in view without having to shoot a test ray at every light in the array. Visually the sampling goes like shown below.

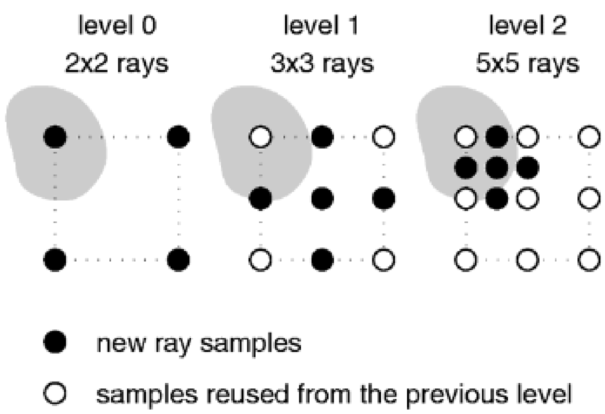


Figure 2.5

Area light adaptive samples

While the adaptive sampling method is fast (relatively speaking) it can sometimes produce inaccurate shadows. The solution is to reduce the amount of adaptive sampling without completely turning it off. The number after the adaptive keyword adjusts the number of times that the area light will be split before the adaptive phase begins. For example if you use adaptive 0 a minimum of 4 rays will be shot at the light. If you use adaptive 1 a minimum of 9 rays will be shot (adaptive 2 gives 25 rays, adaptive 3 gives 81 rays, etc). Obviously the more shadow rays you shoot the slower the rendering will be so you should use the lowest value that gives acceptable results.
The number of rays never exceeds the values you specify for rows and columns of points. For example area light x, y, 4, 4 specifies a 4 by 4 array of lights. If you specify adaptive 3 it would mean that you should start with a 9 by 9 array. In this case no adaptive sampling is done. The 4 by 4 array is used.
The circular command has been added to area lights in order to better create circular soft shadows. With ordinary area lights the pseudo-lights are arranged in a rectangular grid and thus project partly rectangular shadows around all objects, including circular objects. By including the circular tag in an area light, the light is stretched and squashed so that it looks like a circle: this way, circular or spherical light sources are better simulated.
A few things more:

- Circular area lights can be ellipses: the AXIS_1_VECTOR and AXIS_2_VECTOR define the shape and orientation of the circle; if the vectors are not equal, the light source is elliptical in shape.
- Rectangular artifacts may still show up with very large area grids.
- The area of a circular light is roughly 78.5 per cent of a similar size rectangular area light. Increase your axis vectors accordingly if you wish to keep the light source area constant.

- 3D Editor and Modeler Engine

The 3D Editor phase is the most important phase in the project because it helps the users to interact with the application and produce output generated using the global illumination algorithms specified above

The 3D Engine we made to build our 3d modeler above it mainly consists of

1. **Renderables**

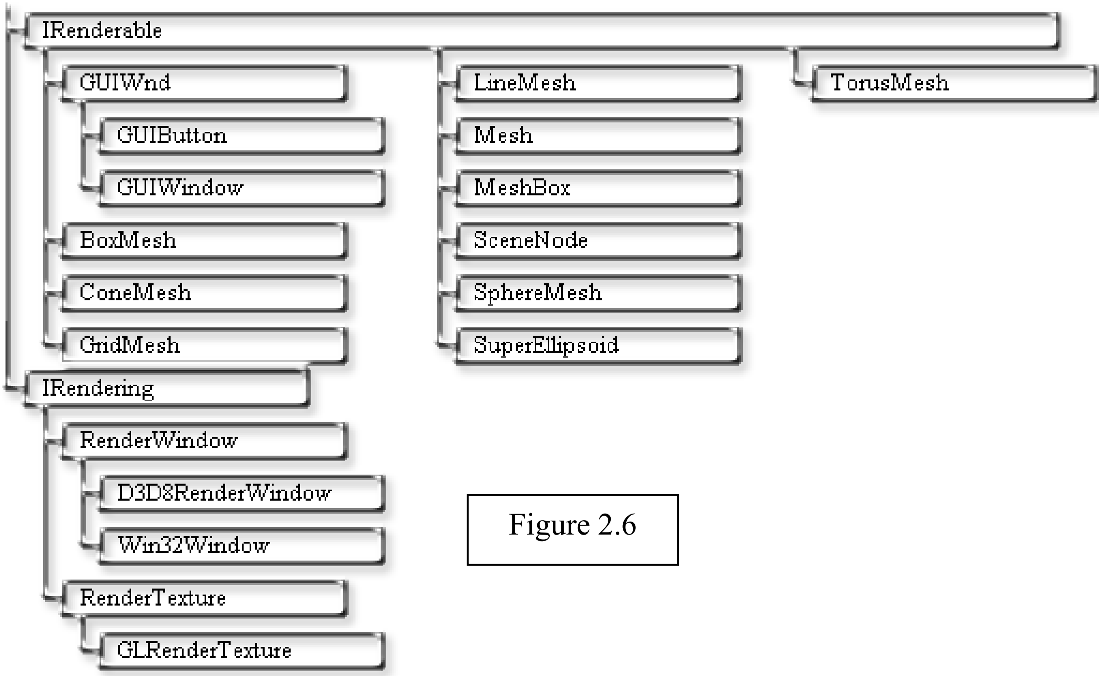


Figure 2.6

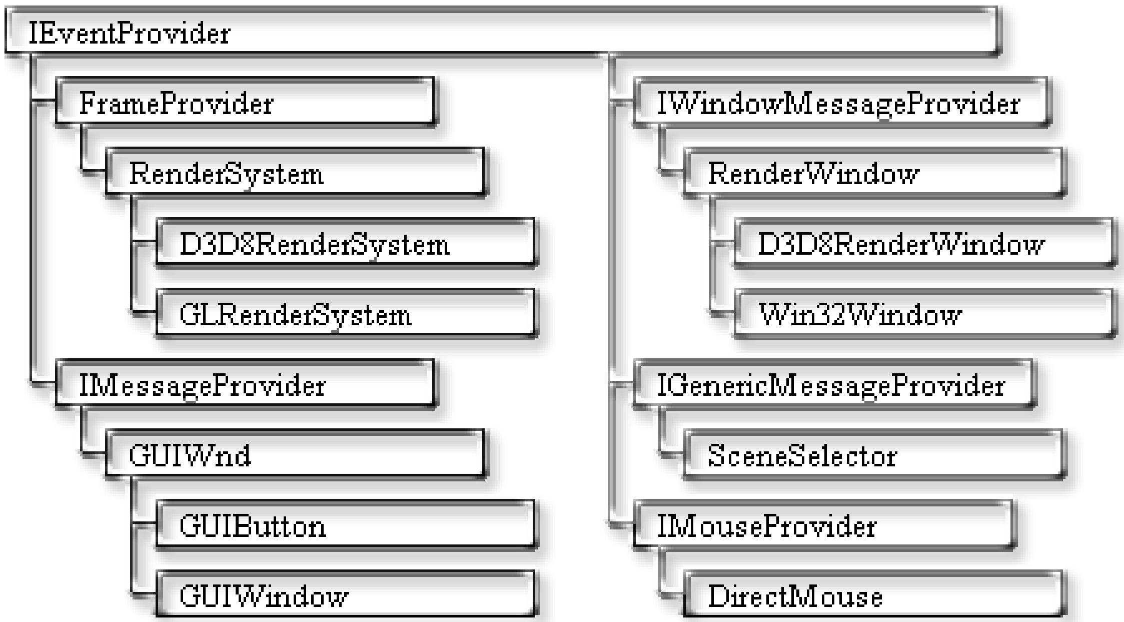
Which they are the set of classes that can be rendered on the screen using different Graphics platforms Like (Opengl & DirectX)
The figure shown is the hierarchy chart of base class and inheritance
And here are some of the classes and its description:

Class Name	**Description**
IRenderable	Base Interface For renderable objects
GUIWnd	Base Interface For regular window
GUIButton	Representation of a reular button
GUIWindow	Representation of a regular window
BoxMesh	Representation of bounding box
ConeMesh	Representation of cone object

GridMesh	Representation of grid object
IRendering	Base Interface For buffer objects
RenderWindow	Base Interface For window buffer objects
D3D8RenderWindow	DirectX Specific implementation
Win32Window	OpenGL Specific implementation
RenderTexture	a texture that can be rendered to it
GLRenderTexture	Specific implementation of render texture
LineMesh	Representation of line object
Mesh	Representation of mesh object
MeshBox	Representation of box object
SceneNode	Base node in the hierarchy tree
SphereMesh	Representation of sphere object
TorusMesh	Representation of torus object
SuperEllipsoid	Representation of SuperEllipsoid object

2. Event Providers

Figure 2.7



This is the part where the events of the operating system are handled and processed by the engine classes like keyboard and mouse input
The design is based on the idea of client server activity where some of the classes described above work as provider of the service and others work as Receiver of the service or event.
The figure shown is the hierarchy chart of base class and inheritance
And here are some of the classes and its description:

Class Name	Description
IEventProvider	Base interface for event providing
FrameProvider	Base interface for frame providing
IMessageProvider	Base interface for message passing

IWindowMessageProvider	Base interface for window message passing
IGenericMessageProvider	Base interface for generic message passing
IMouseProvider	Base interface for mouse events providing

3. Utilities

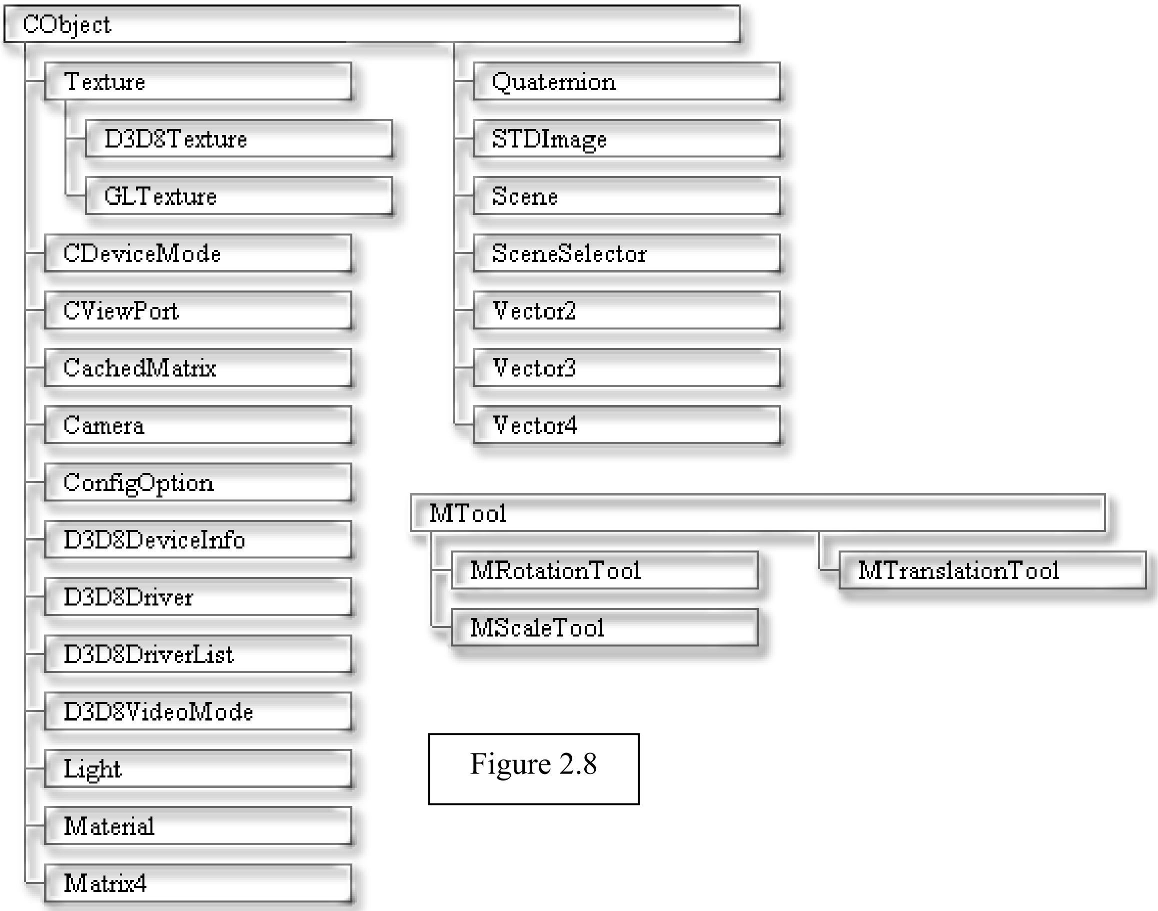


Figure 2.8

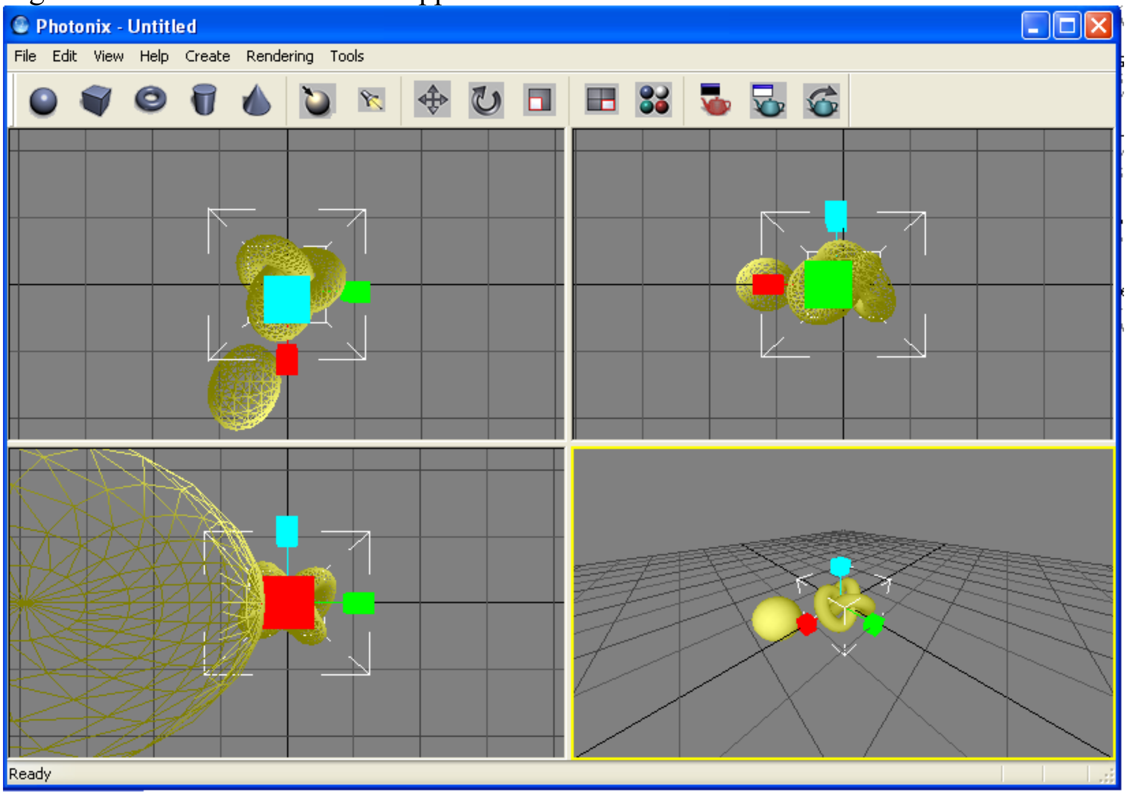
These are some utility classes that have a great help in mathematical calculations and object texturing support, view port, camera …
The figure shown is the hierarchy chart of base class and inheritance
And here are some of the classes and its description:

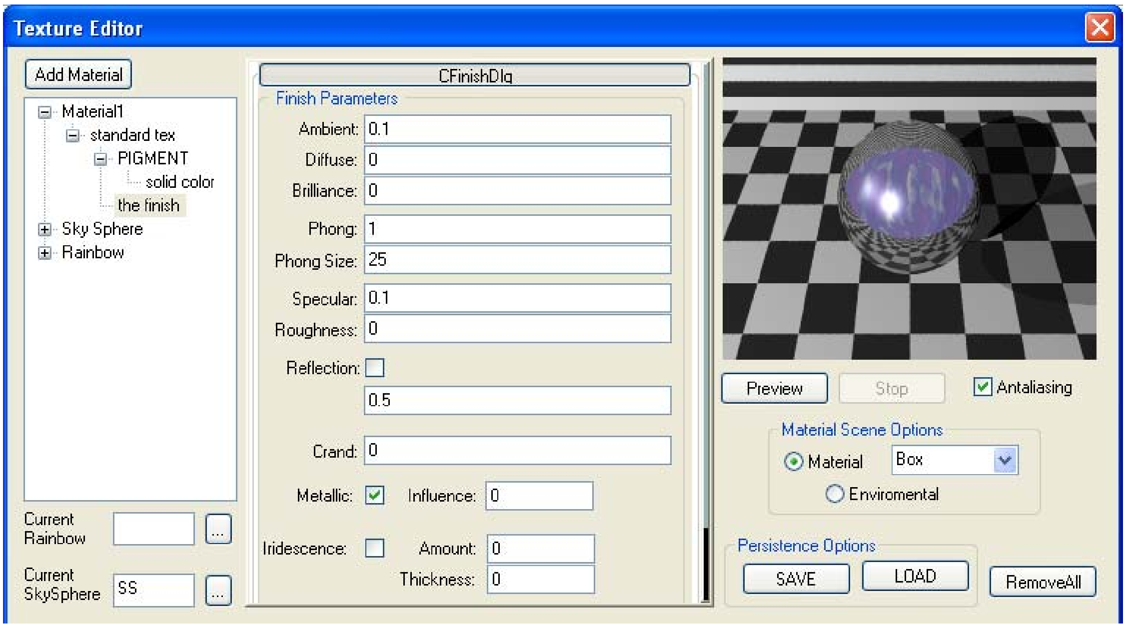
Class Name	Description
Texture	Base implementation for texture
D3D8Texture	DirectX Specific Implementation for Texture object
GLTexture	OpenGL Specific Implementation for Texture object
CViewPort	View Port Manager
CachedMatrix	Caching of the original 4x4 Matrix
Camera	Virtual Camera Manager
D3D8Driver	DirectX Driver Enumerator
Light	Virtual Light Manager
Material	Virtual Material Manager

Matrix4	4x4 Matrix Calculator
Quaternion	Quaternion Implementation
STDImage	Base Image Implementation
Scene	Core of the rendering
SceneSelector	Mouse interactor with scene to support selection
Vector2	2d vector helper function
Vector3	3d vector helper function
Vector4	4d vector helper function
MTool	Base class for selection tools
MTranslationTool	Tool that can do interactive translation
MRotationTool	Tool that can do interactive rotation
MScaleTool	Tool that can do interactive scale

- **Screen Shots**

Figure 2.9: Screen Shots of the Application





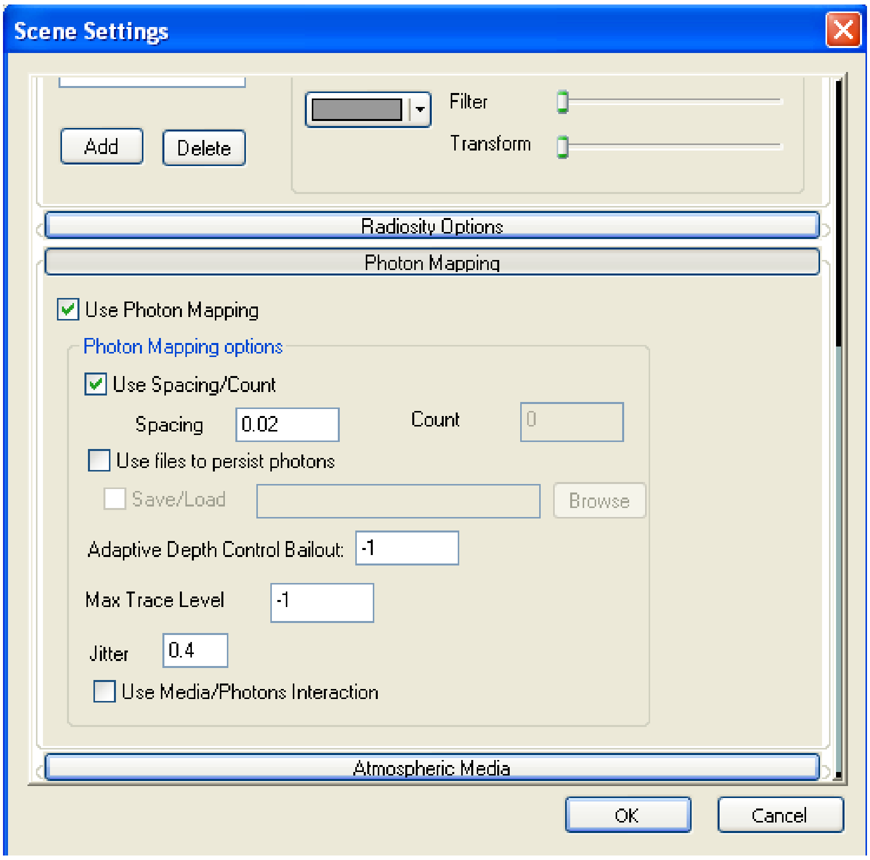
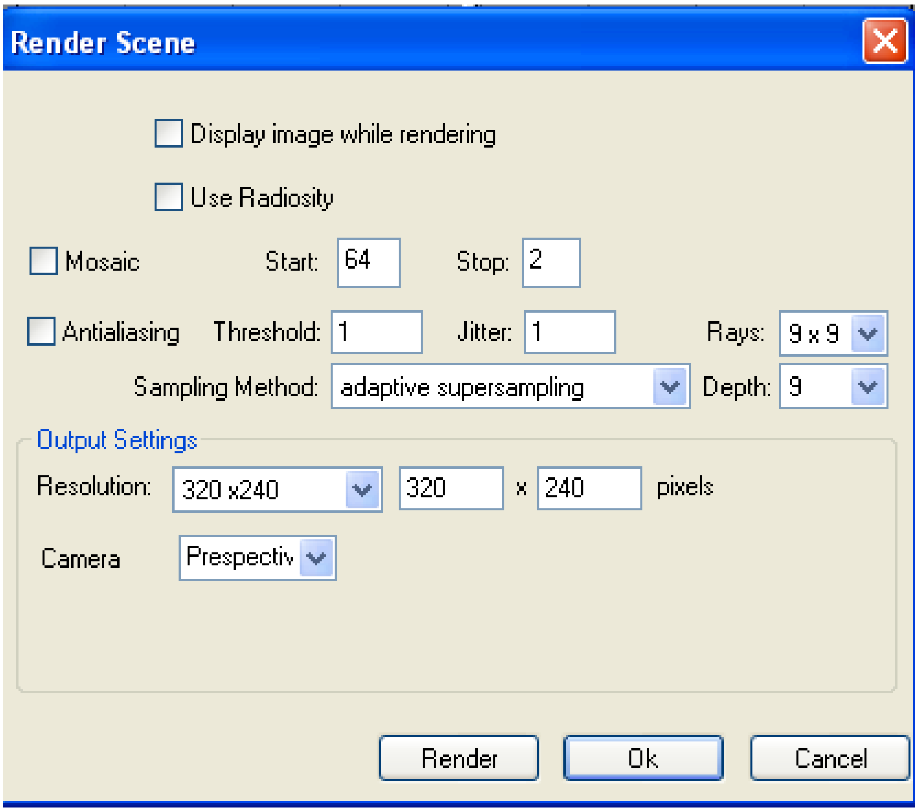


Figure 2.10, 2.11
Screen Shot of the application



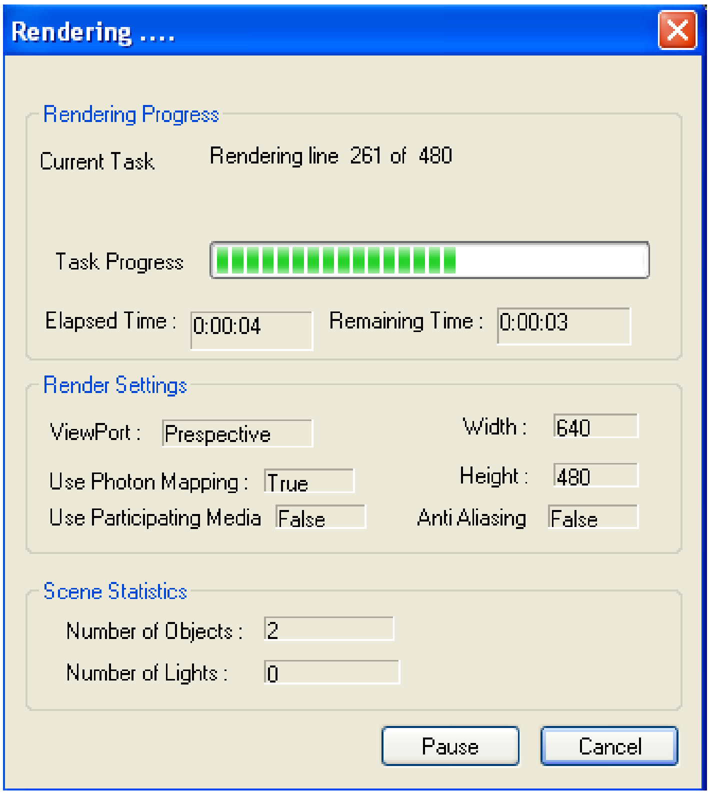
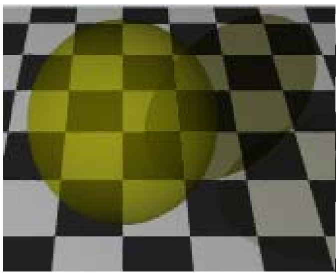
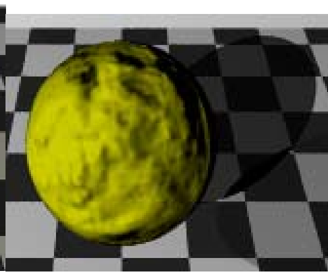
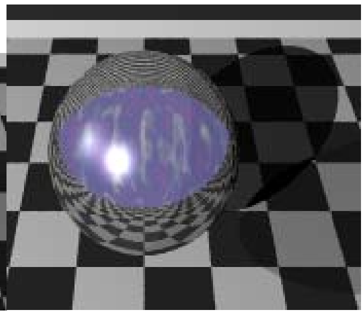


Figure 2.12 ,2.13
Screen Shot of the application

Screen Shots of the OutPut

Pigment Normals Reflection

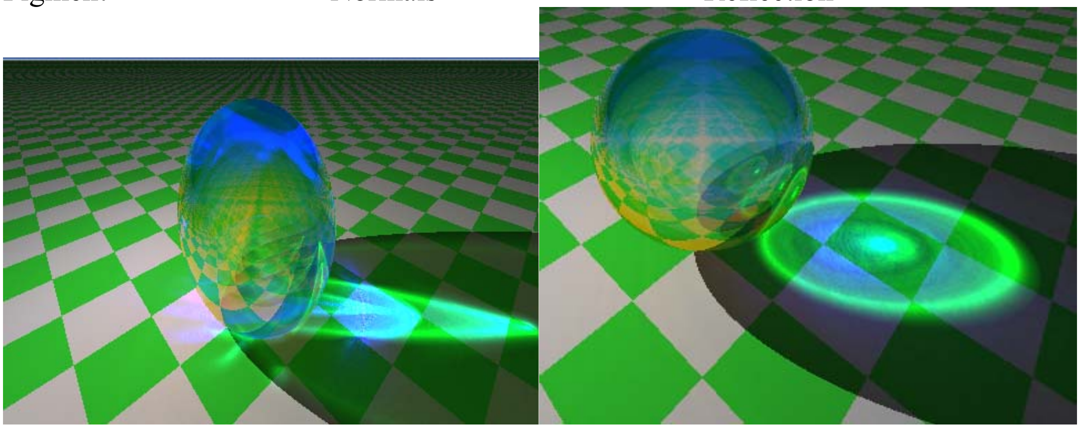


Figure 2.13 : Photon Mapping Output

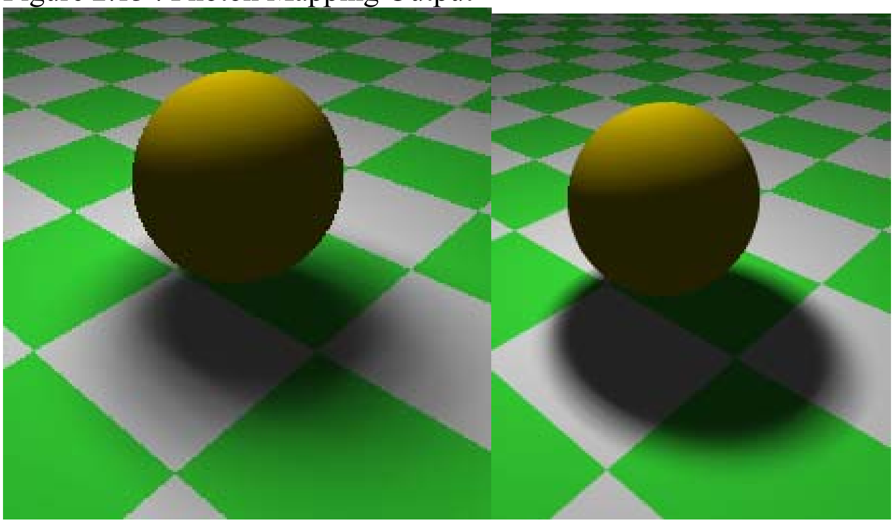


Figure 2.14 : Soft Shadows

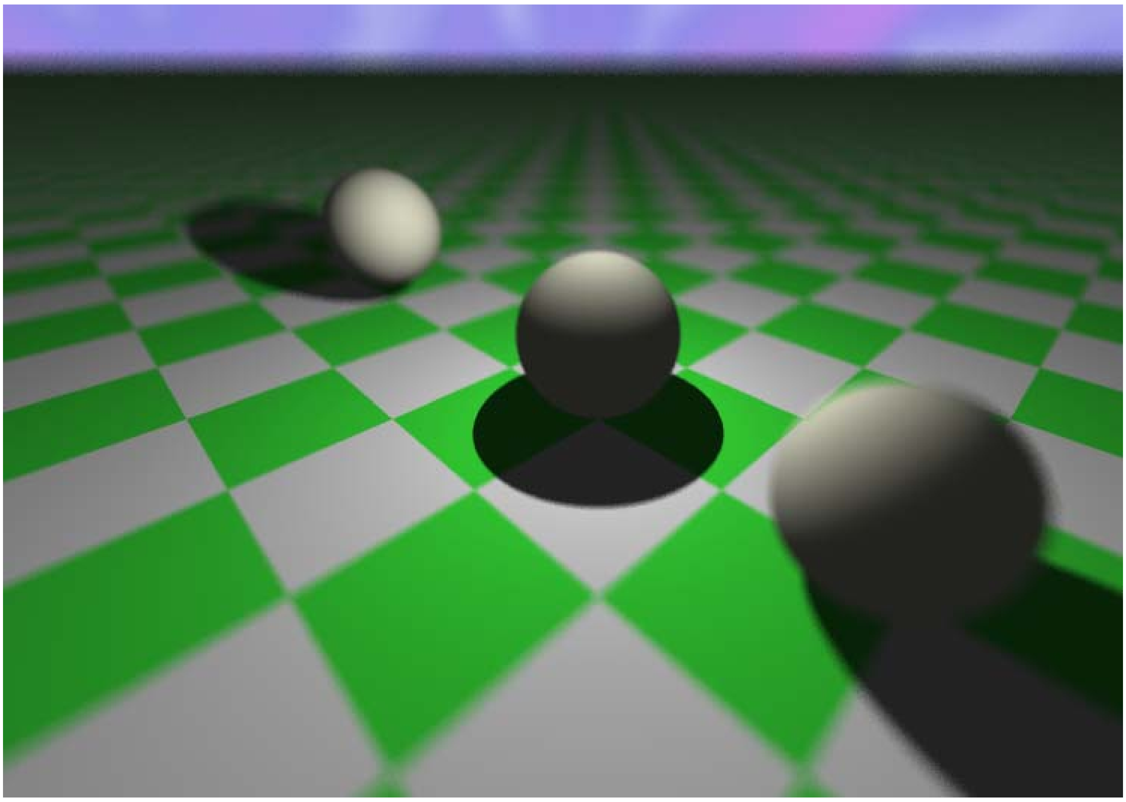


Figure 2.15: Focal Blur

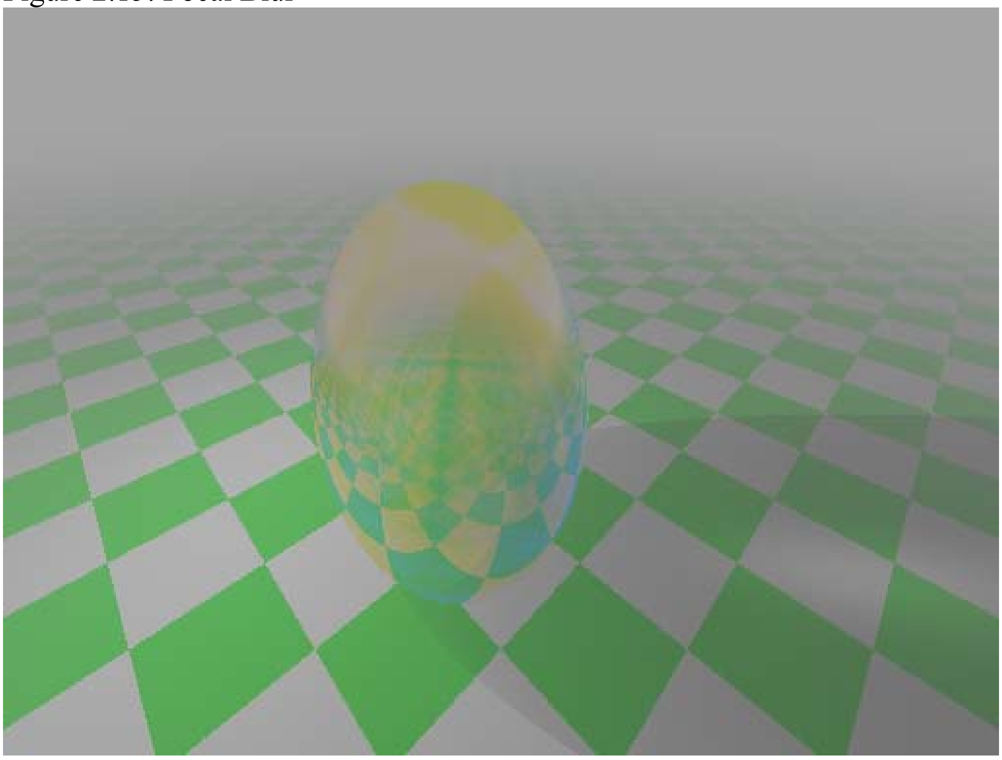



Figure 2.16: Atmospheric Media (Fog)

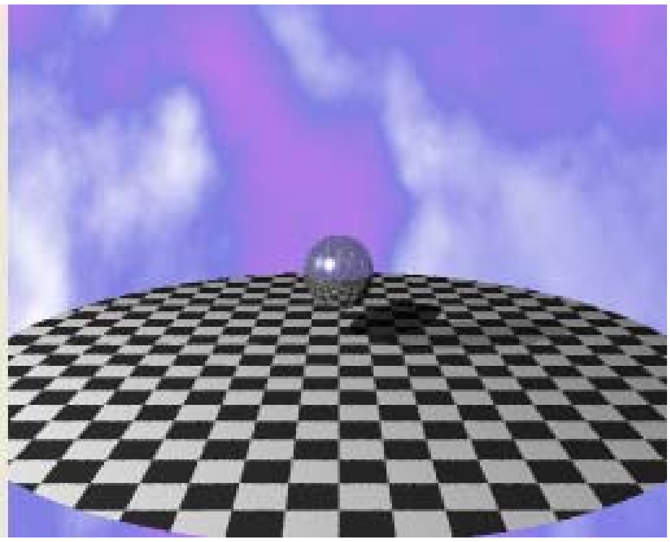


Figure 2.17 Sky Sphere Systems

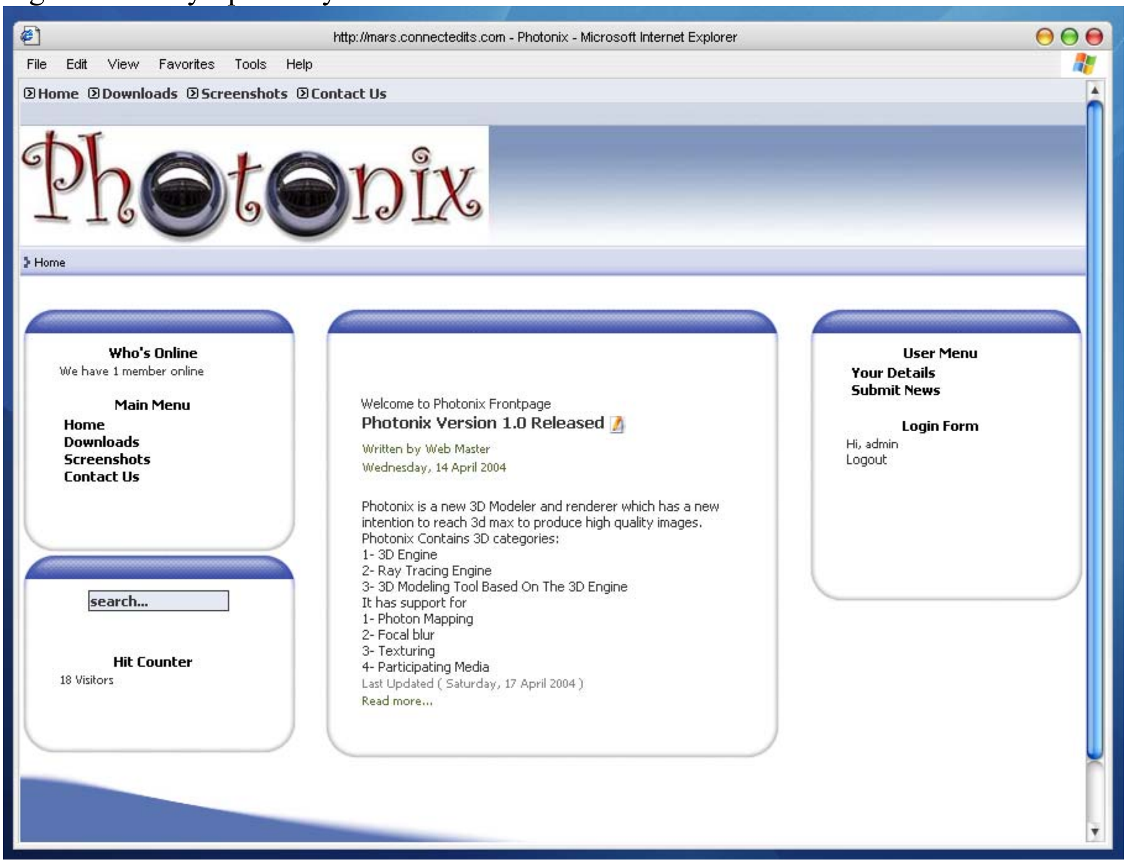


Figure 2.18 :Project Web Site

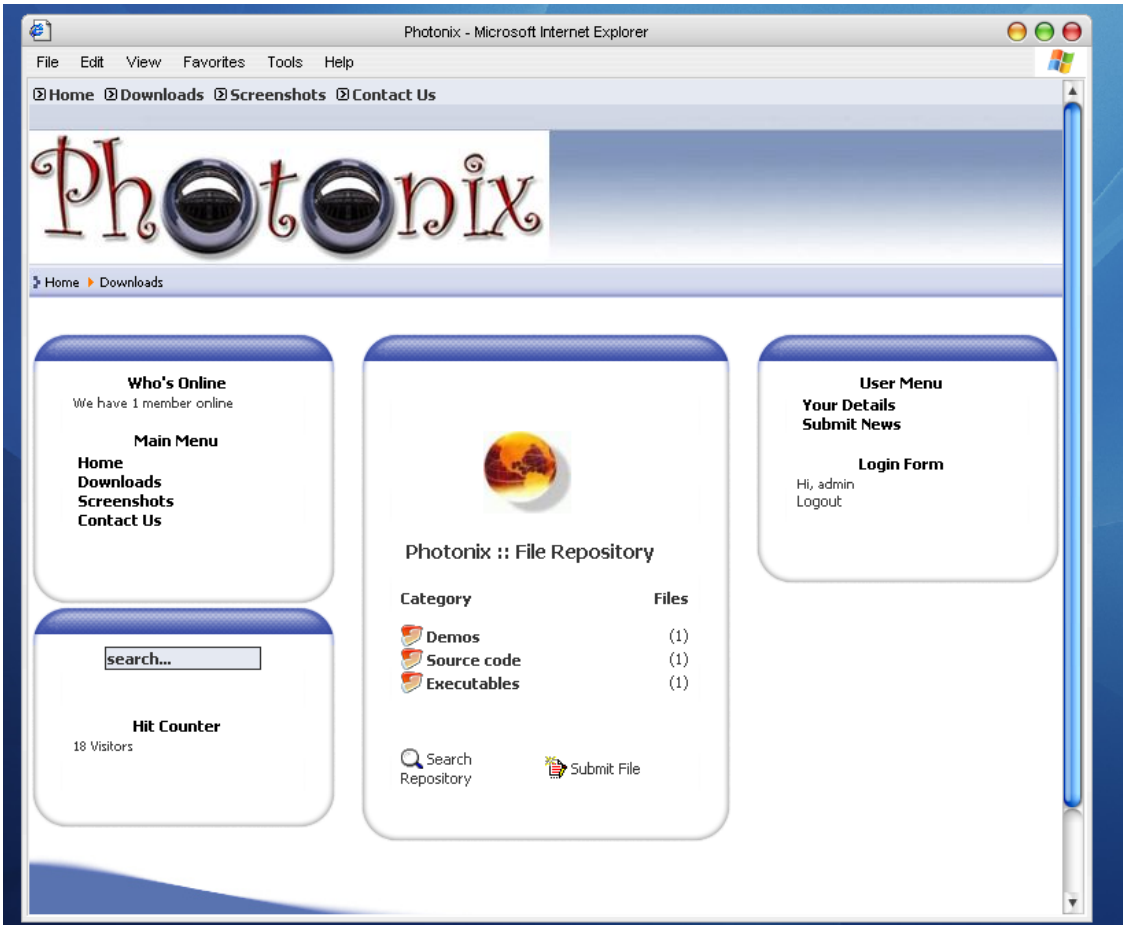


Figure2.19 Download Page

Applications

- Virtual reality
- Particle Real life Simulation(fog , fire,smoke ..etc)
- Character modeling and animation
- Entertainment movies
- Games
- Physics laser lighting applications
- CAD/CAM designing
- Advertising

- **Virtual reality**

  As the photon mapping algorithm reach the computer graphics to high degree of reality so we can use computers to simulate real environments and real scenes.

- **Particle Real life Simulation(fog , fire,smoke ..etc)**

  This on of the main applications of the photon mapping technique since smoke and fires are the hardest particle system simulations and photon mapping ease the modeling of these systems.

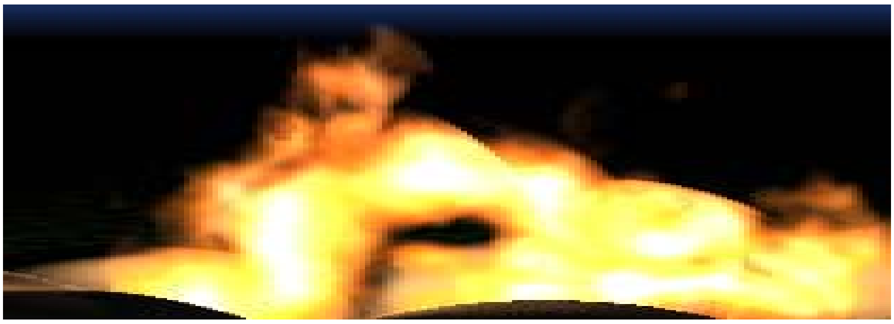


Figure 3.1 Real Life Particle Simulations

- **Character modeling and animation**

  Photon mapping reach a reality in images of human skin using a technique called **Digital Face Cloning** invented by Henrik Wann Jensen and next figure indicate the rendering of human face by photon mapping techniques

Figure 3.2
Character
Modeling

- **Entertainment movies**

The will no need for directors to make a lot of tricks because computers will generate a lot of real scenes.

- **Games**

The animated characters in the current games will be soon as real as the people see them in real world, computer will generate the parson from his model as real as he appear.

Figure 3.3 Facial Animation and games

- **Physics laser lighting applications**

The photon mapping technique can easily simulate the laser lighting effect as shown in the picture bellow.

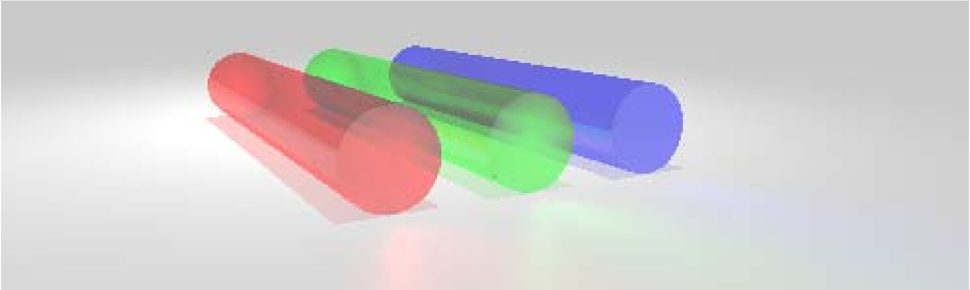


Figure 3.4 Laser Lighting Applications

- **CAD/CAM designing**

The photon mapping can be used to model architectures and building. The new technique of photon mapping can be used in famous applications like 3dmax and AutoCAD

- **Advertising**

The photon mapping technique will give the advertising techniques alt of variations for announcing prducts.

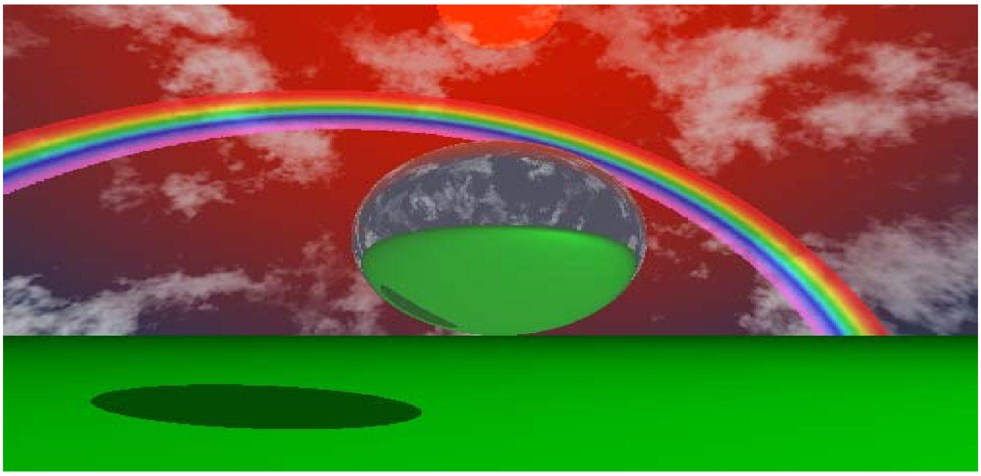


Figure 3.5 Advertising Application

3-Tools

- Microsoft Visual Studio
- nVidia Cg SDK (6.0)
- DirectX SDK (9.0)

4-Sample Source Code From The Project

1-Render Operation

```
#ifndef _RenderOperation_H__
#define _RenderOperation_H__

#include "ColourValue.h"
#include "Material.h"
//#include "isaveload.h"

    class RenderOperation {
    public:
        enum OpType {
            OT_POINT_LIST,
            OT_LINE_LIST,
            OT_LINE_STRIP,
            OT_TRIANGLE_LIST,
            OT_TRIANGLE_STRIP,
            OT_TRIANGLE_FAN
        };
        /** Vertex options - which elements to include.
            @remarks
                Vertices must include their elements in the following
order:
                position, normal, texture co-ords (1-3 dimensions, 1-4
sets),
                diffuse colour, specular colour. Only position is
mandatory,
                although at least ONE OF the following should be
specified,
                even if ambient light on flat coloured objects only is
being used.
         */
        enum VertexOptions {
            /// vertex normals included (for lighting)
            VO_NORMALS = 1,
            /// at least one set of texture coords (exact number
specified in class)
            VO_TEXTURE_COORDS = 2,
            /// Vertex colours - diffuse
            VO_DIFFUSE_COLOURS = 4,
            /// Vertex colours - specular
            VO_SPECULAR_COLOURS = 8,
        };

        /** Vertex blend info */
        struct VertexBlendData
        {
            unsigned short matrixIndex;
            Real blendWeight;
        };

        // true to use pIndexes to reference individual lines/triangles
rather than embed. Allows vertex reuse.
        bool useIndexes;
```

```
        /// Number of vertices (applies to all components)
        unsigned int numVertices;


        // No memory allocation here,
        // assumed that all pointers are pointing
        // elsewhere e.g. model class data

        /** Pointer to list of vertices (float {x, y z} * numVertices).
            @remarks
                If useIndexes is false each group of 3 vertices
describes a face (anticlockwise winding) in
                trianglelist mode.
        */
        Real* pVertices;

        /// The 'Stride' between sets of vertex data. 0 indicates data
is packed with no gaps.
        unsigned short vertexStride;

        /// Optional vertex normals for vertices (float {x, y, z} *
numVertices).
        Real* pNormals;

        /// The 'Stride' between sets of normal data. 0 indicates data
is packed with no gaps.
        unsigned short normalStride;

        /** Optional texture coordinates for vertices (float {u, [v],
[w]} * numVertices).
            @remarks
                There can be up to 8 sets of texture coordinates, and
the number of components per
                vertex depends on the number of texture dimensions (2
is most common).
        */
        Real* pTexCoords[MAX_TEXTURE_COORD_SETS];

        /// The 'Stride' between each set of texture data. 0 indicates
data is packed with no gaps.
        unsigned short texCoordStride[MAX_TEXTURE_COORD_SETS];

        /// Number of groups of u,[v],[w].
        int numTextureCoordSets;

        /** Number of dimensions in each corresponding texture
coordinate set.
            @note
                There should be 1-4 dimensions on each set.
        */
        int numTextureDimensions[MAX_TEXTURE_COORD_SETS];

        /// Optional pointer to a list of diffuse vertex colours (32-
bit RGBA * numVertices).
        RGBA* pDiffuseColour;
```

```
        /// The 'Stride' between sets of diffuse colour data. 0
indicates data is packed with no gaps.
        unsigned short diffuseStride;

        /// Optional pointer to a list of specular vertex colours (32-
bit RGBA * numVertices)
        RGBA* pSpecularColour;

        /// The 'Stride' between sets of specular colour data. 0
indicates data is packed with no gaps.
        unsigned short specularStride;


        /** Pointer to a list of vertex indexes describing faces (only
used if useIndexes is true).
            @note
                Each group of 3 describes a face (anticlockwise winding
order).
        */
        unsigned short* pIndexes;

        /// The number of vertex indexes (must be a multiple of 3).
        unsigned int numIndexes;

        /// Flags indicating vertex types
        int vertexOptions;
        /// The type of rendering operation.
        OpType operationType;

            Material * mMaterial;
int References;
        RenderOperation();
            void AddRef();
            void Free();
            //void DoSerialize(ISaveLoad * archive);
    };

    /* Example usage (camera at (0,0,0) pointing down -Z (lookAt(0,0,-
300))

        RenderOperation ro;
        float vertexData[9] = {100,   0, -300,
                                 0, 200, -300,
                              -100,   0, -300 };
        float normalData[9] = { 0, 0, 1,
                                0, 0, 1,
                                0, 0, 1};
        ro.operationType = RenderOperation::OT_TRIANGLE_LIST;
        ro.numVertices = 3;
        ro.useIndexes = false;
        ro.vertexOptions = RenderOperation::VO_NORMAL;
        ro.pVertices = vertexData;
        ro.pNormals = normalData;
        mDestRenderSystem->_render(ro);
    */
#endif
```

2- Render System

```
// RenderSystem.h: interface for the RenderSystem class.
//
//////////////////////////////////////////////////////////////////////

#ifndef __RENDERSYSTEM_H
#define __RENDERSYSTEM_H

#include "rendertexture.h"
#include "Material.h"
#include "GSMIncludes.h"
#include "RenderOperation.h"

/// Enum describing the ways to generate texture coordinates
enum TexCoordCalcMethod
{
    /// No calculated texture coordinates
    TEXCALC_NONE,
    /// Environment map based on vertex normals
    TEXCALC_ENVIRONMENT_MAP,
    /// Environment map based on vertex positions
    TEXCALC_ENVIRONMENT_MAP_PLANAR,
    TEXCALC_ENVIRONMENT_MAP_REFLECTION,
    TEXCALC_ENVIRONMENT_MAP_NORMAL
};

enum StencilOperation
{
SOP_KEEP,
SOP_ZERO,
SOP_REPLACE,
SOP_INCREMENT,
SOP_DECREMENT,
SOP_INVERT
};
#include "supportedinterfaces.h"

//class CViewPort;
class RenderSystem  :public FrameProvider
{


public:
      RenderSystem();
      virtual ~RenderSystem();

      /** Returns the name of the rendering system.
      */
      virtual const CString& getName(void) const = 0;
      /** Returns the details of this API's configuration options
        @remarks
            Each render system must be able to inform the world
            of what options must/can be specified for it's
            operation.
        @par
            These are passed as strings for portability, but
```

```
            grouped into a structure (_ConfigOption) which includes
            both options and current value.
        @par
            Note that the settings returned from this call are
            affected by the options that have been set so far,
            since some options are interdependent.
        @par
            This routine is called automatically by the default
            configuration dialogue produced by Root::showConfigDialog
            or may be used by the caller for custom settings dialogs
        @returns
            A 'map' of options, i.e. a list of options which is also
            indexed by option name.
     */
     virtual CMapStringToOb& getConfigOptions(void) = 0;

               /** Sets an option for this API
            @remarks
                Used to confirm the settings (normally chosen by the
user) in
                order to make the renderer able to initialise with the
settings as required.
                This may be video mode, D3D driver, full screen /
windowed etc.
                Called automatically by the default configuration
                dialog, and by the restoration of saved settings.
                These settings are stored and only activated when
                RenderSystem::initialise or RenderSystem::reinitialise
                are called.
            @par
                If using a custom configuration dialog, it is advised
that the
                caller calls RenderSystem::getConfigOptions
                again, since some options can alter resulting from a
selection.
            @param
                name The name of the option to alter.
            @param
                value The value to set the option to.
         */
     virtual void setConfigOption(const CString &name, const CString
&value) = 0;

        /** Validates the options set for the rendering system,
returning a message if there are problems.
            @note
                If the returned string is empty, there are no problems.
        */
     virtual CString validateConfigOptions(void) = 0;

               /** Start up the renderer using the settings selected
(Or the defaults if none have been selected).
            @remarks
                Called by Root::setRenderSystem. Shouldn't really be
called
                directly, although  this can be done if the app wants
to.
```

```
            @param
                autoCreateWindow If true, creates a render window
                automatically, based on settings chosen so far. This
saves
                an extra call to RenderSystem::createRenderWindow
                for the main render window.
            @par
                If an application has more specific window
requirements,
                however (e.g. a level design app), it should specify
false
                for this parameter and do it manually.
            @returns
                A pointer to the automatically created window, if
requested, otherwise null.
        */
       virtual RenderWindow* initialise(bool autoCreateWindow);

       /** Restart the renderer (normally following a change in
settings).
      */
      virtual void reinitialise(void) = 0;

      /** Shutdown the renderer and cleanup resources.
      */
      virtual void shutdown(void){};

      /** Registers a FrameListener which will be called back every
frame.
            @remarks
                A FrameListener is a class which implements methods
which
                will be called during me's automatic rendering loop
(started
                with RenderSystem::startRendering).
            @par
                See the FrameListener class for more details on the
specifics.
                It is imperitive that the instance passed to this
method is
                not destroyed before iether the rendering loop ends, or
the
                class is removed from the listening list using
removeFrameListener.
            @see
                FrameListener
        */
//^        virtual void addFrameListener(FrameListener* newListener);

        /** Removes a FrameListener from the list of listening classes.
        */
//^        virtual void removeFrameListener(FrameListener*
oldListener);

        /** Starts / restarts the automatic rendering cycle.
            @remarks
```

```
                This method begins the automatic rendering of the
scene.
                This method will NOT RETURN until the rendering
                cycle is halted.
            @par
                During rendering, any FrameListener classes registered
using
                addFrameListener will be called back for each frame
that is to be rendered,
                These classes can tell GSM to halt the rendering if
required,
                which will cause this method to return.
            @par
                Note - users of the GSM library do not have to use this
                automatic rendering loop. It is there as a convenience
and is most
                useful for high frame rate applications e.g. games. For
applications that
                don't need to constantly refresh the rendering targets
(e.g. an editor
                utility), it is better to manually refresh each render
target only when
                required by calling RenderTarget::update.
            @par
                This frees up the CPU to do other things in between
refreshes, since in
                this case frame rate is less important.
         */
        virtual void startRendering(void);

        /** Sets the colour & strength of the ambient (global
directionless) light in the world.
        */
        virtual void setAmbientLight(float r, float g, float b) = 0;

        /** Sets the type of light shading required (default =
Gouraud).
        */
        virtual void setShadingType(ShadeOptions so) = 0;

        /** Sets the type of texture filtering used when rendering
            @remarks
                This method sets the kind of texture filtering applied
when rendering textures onto
                primitives. Filtering covers how the effects of
minification and magnification are
                disguised by resampling.
            @param
                fo The type of filtering to apply. The options are
described in
                TextureFilterOptions
         */
        virtual void setTextureFiltering(TextureFilterOptions fo) = 0;

        /** Sets whether or not dynamic lighting is enabled.
            @param
```

```
                enabled If true, dynamic lighting is performed on
geometry with normals supplied, geometry without
                normals will not be displayed. If false, no lighting is
applied and all geometry will be full brightness.
        */
        virtual void setLightingEnabled(bool enabled) = 0;
        /** Creates a new rendering window.
            @remarks
                This method creates a new rendering window as specified
                by the paramteters. The rendering system could be
                responible for only a single window (e.g. in the case
                of a game), or could be in charge of multiple ones (in
the
                case of a level editor). The option to create the
window
                as a child of another is therefore given.
                This method will create an appropriate subclass of
                RenderWindow depending on the API and platform
implementation.
            @par
                After creation, this window can be retrieved using
getRenderTarget().
            @param
                name The name of the window. Used in other methods
                later like setRenderTarget and getRenderWindow.
            @param
                width The width of the new window.
            @param
                height The height of the new window.
            @param
                colourDepth The colour depth in bits per pixel.
                Only applicable if fullScreen = true
            @param
                fullScreen Specify true to make the window full screen
                without borders, title bar or menu bar.
            @param
                left The x position of the new window. Only applicable
                if fullScreen is false. Units are relative to the
parent window
                if applicable, otherwise they are in screen
coordinates.
            @param
                top The y position of the new window.
            @param
                depthBuffer If true, a depth buffer will be assigned to
this window.
            @param
                parentWindowHandle Should be null if this window is to
be
                stand-alone. Otherwise, specify a pointer to a
RenderWindow
                which represents the parent window.
        */
        virtual RenderWindow* createRenderWindow(const CString &name,
int width, int height, int colourDepth,
            bool fullScreen, int left = 0, int top = 0, bool
depthBuffer = true,
```

```
            HWND parentWindowHandle = 0) = 0;

            /** Creates and registers a render texture object.
                  @param name
                        The name for the new render texture. Note that
names must be unique.
                  @param width
                        The requested width for the render texture. See
Remarks for more info.
                  @param height
                        The requested width for the render texture. See
Remarks for more info.
                  @returns
                        On succes, a pointer to a new platform-
dependernt, RenderTexture-derived
                        class is returned. On failiure, NULL is
returned.
                  @remarks
                        Because a render texture is basically a wrapper
around a texture object,
                        the width and height parameters of this method
just hint the preferred
                        size for the texture. Depending on the hardware
driver or the underlying
                        API, these values might change when the texture
is created.
            */
//&         virtual RenderTexture * createRenderTexture( const String &
name, int width, int height ) = 0;

        /** Attaches the passed render target to the render system.
        */
//^         virtual void attachRenderTarget( RenderTarget &target );
        /** Returns a pointer to the render target with the passed
name, or NULL if that
            render target cannot be found.
        */
//^         virtual RenderTarget * getRenderTarget( const String &name
);
        /** Detaches the render target with the passed name from the
render system and
            returns a pointer to it.
            @note
                If the render target cannot be found, NULL is returned.
        */
//^         virtual RenderTarget * detachRenderTarget( const String
&name );

        /** Returns a description of an error code.
        */
        virtual CString getErrorDescription(long errorNumber) = 0;

        /** Defines whether or now fullscreen render windows wait for
the vertical blank before flipping buffers.
            @remarks
                By default, all rendering windows wait for a vertical
blank (when the CRT beam turns off briefly to move
```

```
                from the bottom right of the screen back to the top
left) before flipping the screen buffers. This ensures
                that the image you see on the screen is steady. However
it restricts the frame rate to the refresh rate of
                the monitor, and can slow the frame rate down. You can
speed this up by not waiting for the blank, but
                this has the downside of introducing 'tearing'
artefacts where part of the previous frame is still displayed
                as the buffers are switched. Speed vs quality, you
choose.
            @note
                Has NO effect on windowed mode render targets. Only
affects fullscreen mode.
            @param
                enabled If true, the system waits for vertical blanks -
quality over speed. If false it doesn't - speed over quality.
        */
        void setWaitForVerticalBlank(bool enabled);

        /** Returns true if the system is synchronising frames with the
monitor vertical blank.
        */
        bool getWaitForVerticalBlank(void);

        // ------------------------------------------------------------
------------
        //                      Internal Rendering Access
        // All methods below here are normally only called by other GSM
classes
        // They can be called by library user if required
        // ------------------------------------------------------------
------------


        /**
          Adds a light to the renderers list of active lights

          This method should not be called directly by user
          processes - this is adding a light at the rendering
          level. User processes should add lights using the
          SceneNode attachLight method
         */
        virtual void _addLight(Light *lt) = 0;
        /**
          Removes a light from the renderers list.

          As with RenderSystem::_addLight
          this method is for use internally, not by user processes.
          See SceneNode for user-level light maintenance.
         */
        virtual void _removeLight(Light *lt) = 0;
        /** Modifies a light in the renderer.
            Modifies a light which has already been added using
_addLight.
        */
        virtual void _modifyLight(Light* lt) = 0;
        /**
```

```
          Clears all the lights from the renderer

          As with RenderSystem::_addLight
          this method is for use internally, not by user processes.
          See SceneManager for user-level light maintenance.
         */
        virtual void _removeAllLights(void) = 0;

        /**
          Saves the current rendering state

          Stores the current rendering state on the
          render state stack. The state may then be altered
          and restored back to it's previous state using
          RenderSystem::_popRenderState. Used internally by me
          to manage changes like model/view matrices, active
          materials/textures without having to repecify them
          every time.
         */
        virtual void _pushRenderState(void) = 0;
        /** Restores the render state to a previous state. */
        virtual void _popRenderState(void) = 0;
        /** Sets the world transform matrix. */
        virtual void _setWorldMatrix(const Matrix4 &m) = 0;
        /** Sets multiple world matrices (vertex blending). */
        virtual void _setWorldMatrices(const Matrix4* m, unsigned short
count);
        /** Sets the view transform matrix */
        virtual void _setViewMatrix(const Matrix4 &m) = 0;
        /** Sets the projection transform matrix */
        virtual void _setProjectionMatrix(const Matrix4 &m) = 0;
        /** Utility function for setting all the properties of a
texture unit at once.
            This method is also worth using over the individual texture
unit settings because it
            only sets those settings which are different from the
current settings for this
            unit, thus minimising render state changes.
        */
        virtual void _setTextureUnitSettings(int texUnit,
Material::TextureLayer& tl);
        /** Turns off a texture unit. */
        virtual void _disableTextureUnit(int texUnit);
        /** Sets the surface properties to be used for future
rendering.

            This method sets the the properties of the surfaces of
objects
            to be rendered after it. In this context these surface
properties
            are the amount of each type of light the object reflects
(determining
            it's colour under different types of light), whether it
emits light
            itself, and how shiny it is. Textures are not dealt with
here,
            see the _setTetxure method for details.
```

```
            This method is used by _setMaterial so does not need to be
called
            direct if that method is being used.

            @param ambient The amount of ambient (sourceless and
directionless)
            light an object reflects. Affected by the colour/amount of
ambient light in the scene.
            @param diffuse The amount of light from directed sources
that is
            reflected (affected by colour/amount of point, directed and
spot light sources)
            @param specular The amount of specular light reflected.
This is also
            affected by directed light sources but represents the
colour at the
            highlights of the object.
            @param emissive The colour of light emitted from the
object. Note that
            this will make an object seem brighter and not dependent on
lights in
            the scene, but it will not act as a light, so will not
illuminate other
            objects. Use a light attached to the same SceneNode as the
object for this purpose.
            @param shininess A value which only has an effect on
specular highlights (so
            specular must be non-black). The higher this value, the
smaller and crisper the
            specular highlights will be, imitating a more highly
polished surface.
            This value is not constrained to 0.0-1.0, in fact it is
likely to
            be more (10.0 gives a modest sheen to an object).

        */
        virtual void _setSurfaceParams(const ColourValue &ambient,
            const ColourValue &diffuse, const ColourValue &specular,
            const ColourValue &emissive, Real shininess) = 0;
        /**
          Sets the status of a single texture stage.

          Sets the details of a texture stage, to be used for all
primitives
          rendered afterwards. User processes would
          not normally call this direct unless rendering
          primitives themselves - the SubEntity class
          is designed to manage materials for objects.
          Note that this method is called by _setMaterial.

          @param unit The index of the texture unit to modify.
Multitexturing hardware
          can support multiple units (see _getNumTextureUnits)
          @param enabled Boolean to turn the unit on/off
          @param texname The name of the texture to use - this should
have
              already been loaded with TextureManager::load.
```

```
         */
        virtual void _setTexture(int unit, bool enabled, const CString
&texname) = 0;
        /** Returns the number of texture units the current output
hardware supports.

            For use in rendering, this determines how many texture
units the
            are available for multitexturing (i.e. rendering multiple
textures
            in a single pass). Where a Material has multiple texture
layers,
            it will try to use multitexturing where available, and
where
            it is not available, will perform multipass rendering to
            achieve the same effect.
        */
        virtual int _getNumTextureUnits(void) = 0;

        /**
          Sets the texture coordinate set to use for a texture unit.

          Meant for use internally - not generally used directly by
apps - the Material and TextureLayer
          classes let you manage textures far more easily.

          @param unit Texture unit as above
          @param index The index of the texture coordinate set to use.
         */
        virtual void _setTextureCoordSet(int unit, int index) = 0;

        /**
          Sets a method for automatically calculating texture
coordinates for a stage.
          Should not be used by apps - for use by me only.
          @param unit Texture unit as above
          @param m Calculation method to use
         */
        virtual void _setTextureCoordCalculation(int unit,
TexCoordCalcMethod m) = 0;

        /** Sets the texture blend modes from a TextureLayer record.
            Meant for use internally only - apps should use the
Material
            and TextureLayer classes.
            @param unit Texture unit as above
            @param bm Details of the blending mode
        */
        virtual void _setTextureBlendMode(int unit, const
LayerBlendModeEx& bm) = 0;

            /** Sets the texture filtering type for a texture unit.*/
            virtual void _setTextureLayerFiltering(int unit, const
TextureFilterOptions texLayerFilterOps) = 0;

            /** Sets the maximal anisotropy for the specified texture
unit.*/
```

```
            virtual void _setTextureLayerAnisotropy(int unit, int
maxAnisotropy) = 0;

            /** Sets the maximal anisotropy.*/
            virtual void _setAnisotropy(int maxAnisotropy) = 0;

            /** Sets the texture addressing mode for a texture unit.*/
        virtual void _setTextureAddressingMode(int unit,
TextureAddressingMode tam) = 0;

        /** Sets the texture coordinate transformation matrix for a
texture unit.
            @param unit Texture unit to affect
            @param xform The 4x4 matrix
        */
        virtual void _setTextureMatrix(int unit, const Matrix4& xform)
= 0;

        /** Sets the global blending factors for combining subsequent
renders with the existing frame contents.
            The result of the blending operation is:</p>
            <p align="center">final = (texture * sourceFactor) + (pixel
* destFactor)</p>
            Each of the factors is specified as one of a number of
options, as specified in the SceneBlendFactor
            enumerated type.
            @param sourceFactor The source factor in the above
calculation, i.e. multiplied by the texture colour components.
            @param destFactor The destination factor in the above
calculation, i.e. multiplied by the pixel colour components.
        */
        virtual void _setSceneBlending(SceneBlendFactor sourceFactor,
SceneBlendFactor destFactor) = 0;

        /** Sets the global alpha rejection approach for future
renders.
            By default images are rendered regardless of texture alpha.
This method lets you change that.
            @param func The comparison function which must pass for a
pixel to be written.
            @param val The value to compare each pixels alpha value to
(recommended 0 or 128 for compatibility)
        */
        virtual void _setAlphaRejectSettings(CompareFunction func,
unsigned char value) = 0;
        /**
         * Signifies the beginning of a frame, ie the start of
rendering on a single viewport. Will occur
         * several times per complete frame if multiple viewports
exist.
         */
        virtual void _beginFrame(void) = 0;

        /**
          Render something to the active viewport.

          Low-level rendering interface to perform rendering
```

```
          operations. Unlikely to be used directly by client
          applications, since the SceneManager and various support
          classes will be responsible for calling this method.
          Can only be called between _beginScene and _endScene

          @param op A rendering operation instance, which contains
            details of the operation to be performed.
         */
        virtual void _render(RenderOperation* op);


        /**
         * Ends rendering of a frame to the current viewport.
         */
        virtual void _endFrame(void) = 0;
        /**
          Sets the provided viewport as the active one for future
          rendering operations. This viewport is aware of it's own
          camera and render target. Must be implemented by subclass.

          @param target Pointer to the appropriate viewport.
         */
//&        virtual void _setViewport(Viewport *vp) ;
        /** Get the current active viewport for rendering. */
//&        virtual Viewport* _getViewport(void);

        /** Sets the culling mode for the render system based on the
'vertex winding'.
            A typical way for the rendering engine to cull triangles is
based on the
            'vertex winding' of triangles. Vertex winding refers to the
direction in
            which the vertices are passed or indexed to in the
rendering operation as viewed
            from the camera, and will wither be clockwise or
anticlockwise (that's 'counterclockwise' for
            you Americans out there ;) The default is CULL_CLOCKWISE
i.e. that only triangles whose vertices
            are passed/indexed in anticlockwise order are rendered -
this is a common approach and is used in 3D studio models
            for example. You can alter this culling mode if you wish
but it is not advised unless you know what you are doing.
            You may wish to use the CULL_NONE option for mesh data that
you cull yourself where the vertex
            winding is uncertain.
        */
        virtual void _setCullingMode(CullingMode mode)      = 0;

        virtual CullingMode _getCullingMode(void);

        /** Sets the mode of operation for depth buffer tests from this
point onwards.
            Sometimes you may wish to alter the behaviour of the depth
buffer to achieve
            special effects. Because it's unlikely that you'll set
these options for an entire frame,
```

```
            but rather use them to tweak settings between rendering
objects, this is an internal
            method (indicated by the '_' prefix) which will be used by
a SceneManager implementation
            rather than directly from the client application.
            If this method is never called the settings are
automatically the same as the default parameters.
            @param depthTest If true, the depth buffer is tested for
each pixel and the frame buffer is only updated
                if the depth function test succeeds. If false, no test
is performed and pixels are always written.
            @param depthWrite If true, the depth buffer is updated with
the depth of the new pixel if the depth test succeeds.
                If false, the depth buffer is left unchanged even if a
new pixel is written.
            @param depthFunction Sets the function required for the
depth test.
        */
        virtual void _setDepthBufferParams(bool depthTest = true, bool
depthWrite = true, CompareFunction depthFunction = CMPF_LESS_EQUAL) =0;

        /** Sets whether or not the depth buffer check is performed
before a pixel write.
            @param enabled If true, the depth buffer is tested for each
pixel and the frame buffer is only updated
                if the depth function test succeeds. If false, no test
is performed and pixels are always written.
        */
        virtual void _setDepthBufferCheckEnabled(bool enabled = true)
=0;
        /** Sets whether or not the depth buffer is updated after a
pixel write.
            @param enabled If true, the depth buffer is updated with
the depth of the new pixel if the depth test succeeds.
                If false, the depth buffer is left unchanged even if a
new pixel is written.
        */
        virtual void _setDepthBufferWriteEnabled(bool enabled = true)
=0;
        /** Sets the comparison function for the depth buffer check.
            Advanced use only - allows you to choose the function
applied to compare the depth values of
            new and existing pixels in the depth buffer. Only an issue
if the deoth buffer check is enabled
            (see _setDepthBufferCheckEnabled)
            @param  func The comparison between the new depth and the
existing depth which must return true
             for the new pixel to be written.
        */
        virtual void _setDepthBufferFunction(CompareFunction func =
CMPF_LESS_EQUAL) =0;
        /** Sets the depth bias, NB you should use the Material version
of this.
        @remarks
            When polygons are coplanar, you can get problems with
'depth fighting' where
```

```
            the pixels from the two polys compete for the same screen
pixel. This is particularly
            a problem for decals (polys attached to another surface to
represent details such as
            bulletholes etc.).
        @par
            A way to combat this problem is to use a depth bias to
adjust the depth buffer value
            used for the decal such that it is slightly higher than the
true value, ensuring that
            the decal appears on top.
        @param bias The bias value, should be between 0 and 16.
        */
        virtual void _setDepthBias(ushort bias) =0;
        /** Sets the fogging mode for future geometry.
            @param mode Set up the mode of fog as described in the
FogMode enum, or set to FOG_NONE to turn off.
            @param colour The colour of the fog. Either set this to the
same as your viewport background colour,
                or to blend in with a skydome or skybox.
            @param expDensity The density of the fog in FOG_EXP or
FOG_EXP2 mode, as a value between 0 and 1. The default is 1. i.e.
completely opaque, lower values can mean
                that fog never completely obscures the scene.
            @param linearStart Distance at which linear fog starts to
encroach. The distance must be passed
                as a parametric value between 0 and 1, with 0 being the
near clipping plane, and 1 being the far clipping plane. Only
applicable if mode is FOG_LINEAR.
            @param linearEnd Distance at which linear fog becomes
completely opaque.The distance must be passed
                as a parametric value between 0 and 1, with 0 being the
near clipping plane, and 1 being the far clipping plane. Only
applicable if mode is FOG_LINEAR.
        */
        virtual void _setFog(FogMode mode = FOG_NONE, ColourValue
colour = ColourValue::White, Real expDensity = 1.0, Real linearStart =
0.0, Real linearEnd = 1.0) = 0;


        /** The RenderSystem will keep a count of tris rendered, this
resets the count. */
        virtual void _beginGeometryCount(void);
        /** Reports the number of tris rendered since the last
_beginGeometryCount call. */
        virtual unsigned int _getFaceCount(void);
        /** Reports the number of vertices passed to the renderer since
the last _beginGeometryCount call. */
        virtual unsigned int _getVertexCount(void);

        /** Generates a packed data version of the passed in
ColourValue suitable for
            use as with this RenderSystem.
        @remarks
            Since different render systems have different colour data
formats (eg
```

```
            RGBA for GL, ARGB for D3D) this method allows you to use 1
method for all.
        @param colour The colour to convert
        @param pDest Pointer to location to put the result.
       */
        virtual void convertColourValue(const ColourValue& colour,
unsigned long* pDest) =0;

        /** Returns whether or not this RenderSystem supports hardware
vertex blending, ie multiple
            world matrices per vertex with blending weights.
        */
        virtual bool _isVertexBlendSupported(void);

        /** Returns the number of matrices available to hardware vertex
blending for this rendering system. */
        virtual unsigned short _getNumVertexBlendMatrices(void);

        /** Builds a perspective projection matrix suitable for this
render system.
        @remarks
            Because different APIs have different requirements (some
incompatible) for the
            projection matrix, this method allows each to implement
their own correctly and pass
            back a generic matrix for storage in the engine.
        */
        virtual void _makeProjectionMatrix(Real fovy, Real aspect, Real
nearPlane, Real farPlane, Matrix4& dest) =0;

        /** Sets how to rasterise triangles, as points, wireframe or
solid polys. */
        virtual void _setRasterisationMode(SceneDetailLevel level) =0;

        /** Turns stencil buffer checking on or off.
        @remarks
            Stencilling (masking off areas of the rendering target
based on the stencil
            buffer) canbe turned on or off using this method. By
default, stencilling is
            disabled.
        */
        virtual void setStencilCheckEnabled(bool enabled) =0;
        /** Determines if this system supports hardware accelerated
stencil buffer.
        @remarks
            Note that the lack of this function doesn't mean you can't
do stencilling, but
            the stencilling operations will be provided in software,
which will NOT be
            fast.
        @par
            Generally hardware stencils are only supported in 32-bit
colour modes, because
            the stencil buffer shares the memory of the z-buffer, and
in most cards the
```

```
            z-buffer has to be the same depth as the colour buffer.
This means that in 32-bit
            mode, 24 bits of the z-buffer are depth and 8 bits are
stencil. In 16-bit mode there
            is no room for a stencil (although some cards support a
15:1 depth:stencil option,
            this isn't useful for very much) so 8 bits of stencil are
provided in software.
            This can mean that if you use stencilling, your
applications may be faster in
            32-but colour than in 16-bit, which may seem odd to some
people.
        */
        virtual bool hasHardwareStencil(void) = 0;

        /** Determines the bit depth of the hardware accelerated
stencil buffer, if supported.
        @remarks
            If hardware stencilling is not supported, the software will
provide an 8-bit
            software stencil.
        */
        virtual ushort getStencilBufferBitDepth(void) = 0;

        /** This method allows you to set all the stencil buffer
parameters in one call.
        @remarks
            The stencil buffer is used to mask out pixels in the render
target, allowing
            you to do effects like mirrors, cut-outs, stencil shadows
and more. Each of
            your batches of rendering is likely to ignore the stencil
buffer,
            update it with new values, or apply it to mask the output
of the render.
            The stencil test is:<PRE>
            (Reference Value & Mask) CompareFunction (Stencil Buffer
Value & Mask)</PRE>
            The result of this will cause one of 3 actions depending on
whether the test fails,
            succeeds but with the depth buffer check still failing, or
succeeds with the
            depth buffer check passing too.
        @par
            Unlike other render states, stencilling is left for the
application to turn
            on and off when it requires. This is because you are likely
to want to change
            parameters between batches of arbitrary objects and control
the ordering yourself.
            In order to batch things this way, you'll want to use GSM's
separate render queue
            groups (see RenderQueue) and register a RenderQueueListener
to get notifications
            between batches.
        @par
```

```
            There are individual state change methods for each of the
parameters set using
            this method.
            Note that the default values in this method represent the
defaults at system
            start up too.
        @param func The comparison function applied.
        @param refValue The reference value used in the comparison
        @param mask The bitmask applied to both the stencil value and
the reference value
            before comparison
        @param stencilFailOp The action to perform when the stencil
check fails
        @param depthFailOp The action to perform when the stencil check
passes, but the
            depth buffer check still fails
        @param passOp The action to take when both the stencil and
depth check pass.
        */
        virtual void setStencilBufferParams(CompareFunction func =
CMPF_ALWAYS_PASS,
            ulong refValue = 0, ulong mask = 0xFFFFFFFF,
            StencilOperation stencilFailOp = SOP_KEEP,
            StencilOperation depthFailOp = SOP_KEEP,
            StencilOperation passOp = SOP_KEEP);

        /** Sets the stencil test function.
        @remarks
            The stencil test is:<PRE>
            (Reference Value & Mask) CompareFunction (Stencil Buffer
Value & Mask)</PRE>
        */
        virtual void setStencilBufferFunction(CompareFunction func) =0;
        /** Sets the stencil buffer reference value.
        @remarks
            This value is used in the stencil test:<PRE>
            (Reference Value & Mask) CompareFunction (Stencil Buffer
Value & Mask)</PRE>
            It can also be used as the destination value for the
stencil buffer if the
            operation which is performed is SOP_REPLACE.
        */
        virtual void setStencilBufferReferenceValue(ulong refValue) =
0;
        /** Sets the stencil buffer mask value.
        @remarks
            This is applied thus:<PRE>
            (Reference Value & Mask) CompareFunction (Stencil Buffer
Value & Mask)</PRE>
        */
        virtual void setStencilBufferMask(ulong mask) = 0;
        /** Sets the action to perform if the stencil test fails. */
        virtual void setStencilBufferFailOperation(StencilOperation op)
= 0;
        /** Sets the action to perform if the stencil test passes, but
the depth
            buffer test fails. */
```

```
        virtual void
setStencilBufferDepthFailOperation(StencilOperation op) = 0;
        /** Sets the action to perform if both the stencil test and the
depth buffer
            test passes. */
        virtual void setStencilBufferPassOperation(StencilOperation op)
= 0;

        /** Performs a software vertex blend on the passed in
operation.
        @remarks
            This function is supplied to calculate a vertex blend when
no hardware
            support is available, or when the results are required by
another
            software component. The vertices contained in the passed in
operation
            will be modified by the matrices supplied according to the
blending weights
            also in the operation. To avoid accidentally modifying core
vertex data, a
            temporary vertex buffer is used for the result, which is
then used in the
            RenderOperation instead of the original passed in vertex
data.
        */
     //   void softwareVertexBlend(RenderOperation& op, Matrix4*
pMatrices);

        /** Indicates the type of event to be considered by
calculateEventTime(). */
        enum FrameEventTimeType {
            FETT_ANY, FETT_STARTED, FETT_ENDE
      };


        /** Internal method for calculating the average time between
recently fired events.
        @param now The current time in ms.
        @param type The type of event to be considered.
        */
//^        Real calculateEventTime(unsigned long now,
FrameEventTimeType type);

        /** The render targets. */
//^        RenderTargetMap mRenderTargets;
            /** The render targets, ordered by priority. */
//^         RenderTargetPriorityMap mPrioritisedRenderTargets;
            /** The Active render target. */
      //    IRendering * mActiveRenderin;

        // Texture manager
        // A concrete class of this will be created and
        // made available under the TextureManager singleton,
        // managed by the RenderSystem
//^        TextureManager* mTextureManager;
```

```
        CullingMode mCullingMode;

        bool mVSync;

        // Store record of texture unit settings for efficient
alterations
        Material::TextureLayer mTextureUnits[MAX_TEXTURE_LAYERS];
bool mTextureBlank[MAX_TEXTURE_LAYERS];
        unsigned int mFaceCount;
        unsigned int mVertexCount;

        /// Saved set of world matrices
        Matrix4 mWorldMatrices[256];

          bool m_CapMultitexture;
            bool m_CapSpecularAfterTexture;
            bool m_CapPlanarReflection;
            bool m_CapPlanarShadow;
            bool m_CapTextureClampToBorder;
            bool m_CapTextureApplyAdd;
            bool m_CapTextureApplyCombine;
            bool m_CapTextureApplyCombineDot3;
            bool m_CapDot3BumpMapping;

virtual void SetViewport(CViewPort *vp) = 0;
  // Active viewport (dest for future rendering operations)
        CViewPort* mActiveViewport;
virtual void SetCamera(Camera* cam)=0;
      //    RenderWindow *mWindow;
CObArray mRenderIn;

            virtual void DrawGrid(void) = 0;
            virtual Texture* CreateTexture(void)=0;
            virtual RenderTexture * CreateRenderTexture(CString  Name,
uint Width, uint Height, TextureType TexType = TEX_TYPE_2D )=0;
            virtual RenderWindow* createRenderWindow(HWND
ExternalWnd,int colourDepth){return 0;};
// Rendering loop control
        bool mStopRendering;
            //rendered with the default material
            virtual void Polygon(Vector3 Vertex1,Vector3
Vertex2,Vector3 Vertex3)=0;
            virtual void Polygon(Real* Vertices,int
NumVertices,RenderOperation::OpType
OpType=RenderOperation::OpType::OT_TRIANGLE_STRIP ,DWORD rgba = 0)=0;
            virtual void Polygon(Real* Vertices,Real* Indices,int
NumIndices,RenderOperation::OpType
OpType=RenderOperation::OpType::OT_TRIANGLE_STRIP,DWORD rgba = 0)=0;
            virtual void Line(Vector3* Vertex1,Vector3
*Vertex2,ColourValue &color=ColourValue(0,0,0))=0;
//intending to put funcs for strides
//          void Polygon(Vector3 Vertex,Vector2 TexCoord1,Vector2
TexCoord2,Vector2 TexCoord2);
//          void Polygon(Real* Vertices,int
NumVertices,RenderOperation::OpType OpType);
```

```
//          void Polygon(Real* Vertices,Real* 
Indices,RenderOperation::OpType OpType,int NumVertices,int NumIndices);

            virtual void PushMatrix(void);
            virtual void PopMatrix(void);
            virtual void SetViewport(int x,int y,int h,int w)=0;

};

#endif
```

3-OpenGL Render System Implementation

```
#ifndef __GLRenderSystem_H__
#define __GLRenderSystem_H__

#include "GLPrerequisites.h"
#include "GSMIncludes.h"
#include "stdimage.h"
#include "GLSupport.h"
//#include "GSMIncludes.h"
//#include "RenderSystem.h"

    /**
      Implementation of SDL as a rendering system.
     */
    class GLRenderSystem : public RenderSystem
    {
    public:


            static GLenum m_ImageComponents[STDImage::IT_QUANTITY];
            static GLenum m_ImageFormats[STDImage::IT_QUANTITY];


            // maps from Magic enums to OpenGL enums


            static GLenum 
m_TextureCorrection[Material::TextureLayer::CM_QUANTITY];
            static GLenum 
m_TextureApply[Material::TextureLayer::AM_QUANTITY];
            static GLenum 
m_TextureFilter[Material::TextureLayer::FM_QUANTITY];
            static GLenum 
m_TextureCombineFunc[Material::TextureLayer::ACF_QUANTITY];
            static GLenum 
m_TextureCombineSrc[Material::TextureLayer::ACS_QUANTITY];
            static GLenum 
m_TextureCombineOperand[Material::TextureLayer::ACO_QUANTITY];
            static GLfloat 
m_TextureCombineScale[Material::TextureLayer::ACSC_QUANTITY];
            static GLenum 
m_TextureMipmap[Material::TextureLayer::MM_QUANTITY];
```

```
        // Array of up to 8 lights, indexed as per API
        // Note that a null value indicates a free slot
        #define MAX_LIGHTS 8
        Light* mLights[MAX_LIGHTS];

        // view matrix to set world against
        Matrix4 mViewMatrix;
        Matrix4 mWorldMatrix;
        Matrix4 mTextureMatrix;

        // XXX 8 max texture units?
        int mTextureCoordIndex[MAX_TEXTURE_COORD_SETS];

        void initConfigOptions(void);
        void initInputDevices(void);
        void processInputDevices(void);

        void setGLLight(int index, Light* lt);
        void makeGLMatrix(GLfloat gl_matrix[16],const Matrix4& m,int
rowByRow=0);

        GLint getBlendMode(SceneBlendFactor Blendtype);

        void setLights();

        // Store last depth write state
        bool mDepthWrite;

        GLint convertCompareFunction(CompareFunction func);
        GLint convertStencilOp(StencilOperation op);

        // Save stencil settings since GL insists on having them in
groups
        // Means we have to call functions more than once, but what the
hey
        GLint mStencilFunc, mStencilRef;
        GLuint mStencilMask;
        GLint mStencilFail, mStencilZFail, mStencilPass;

            // internal method for anisotrophy validation
            GLfloat _getCurrentAnisotropy();

        /// GL support class, used for creating windows etc
        GLSupport* mGLSupport;

        /// Internal method to set pos / direction of a light
        void setGLLightPositionDirection(Light* lt, int lightindex);

    public:
          //virtual void SetMaterial(Material *mat);
        // Default constructor / destructor
        GLRenderSystem();
        ~GLRenderSystem();

        // ----------------------------------
        // Overridden RenderSystem functions
```

```
        // ----------------------------------
        /** See
          RenderSystem
         */
        const CString& getName(void) const;
        /** See
          RenderSystem
         */
        CMapStringToOb& getConfigOptions(void);
        /** See
          RenderSystem
         */
        void setConfigOption(const CString &name, const CString
&value);
        /** See
          RenderSystem
         */
        CString validateConfigOptions(void);
        /** See
          RenderSystem
         */
        RenderWindow* initialise(bool autoCreateWindow);
        /** See
          RenderSystem
         */
        void reinitialise(void); // Used if settings changed mid-
rendering
        /** See
          RenderSystem
         */
        void shutdown(void);

        /** See
          RenderSystem
         */
        void startRendering(void);
        /** See
          RenderSystem
         */
        void setAmbientLight(float r, float g, float b);
        /** See
          RenderSystem
         */
        void setShadingType(ShadeOptions so);
        /** See
          RenderSystem
         */
        void setTextureFiltering(TextureFilterOptions fo);
        /** See
          RenderSystem
         */
        void setLightingEnabled(bool enabled);
        /** See
          RenderSystem
         */
        RenderWindow* createRenderWindow(const CString &name, int
width, int height, int colourDepth,
```

```
            bool fullScreen, int left = 0, int top = 0, bool
depthBuffer = true,
            HWND parentWindowHandle = 0);

//        RenderTexture * createRenderTexture( const CString & name,
int width, int height );

        /** See
          RenderSystem
         */
     //   void destroyRenderWindow(RenderWindow* pWin);
        /** See
          RenderSystem
         */
        CString getErrorDescription(long errorNumber);

        /** See
          RenderSystem
         */
        void convertColourValue(const ColourValue& colour, unsigned
long* pDest);

        // -----------------------------
        // Low-level overridden members
        // -----------------------------
        /** See
          RenderSystem
         */
        void _addLight(Light *lt);
        /** See
          RenderSystem
         */
        void _removeLight(Light *lt);
        /** See
          RenderSystem
         */
        void _modifyLight(Light* lt);
        /** See
          RenderSystem
         */
        void _removeAllLights(void);
        /** See
          RenderSystem
         */
        void _pushRenderState(void);
        /** See
          RenderSystem
         */
        void _popRenderState(void);
        /** See
          RenderSystem
         */
        void _setWorldMatrix(const Matrix4 &m);
        /** See
          RenderSystem
         */
        void _setViewMatrix(const Matrix4 &m);
```

```
        /** See
          RenderSystem
         */
        void _setProjectionMatrix(const Matrix4 &m);
        /** See
          RenderSystem
         */
        void _setSurfaceParams(const ColourValue &ambient,
            const ColourValue &diffuse, const ColourValue &specular,
            const ColourValue &emissive, Real shininess);
        /** See
          RenderSystem
         */
        int _getNumTextureUnits(void);
        /** See
          RenderSystem
         */
        void _setTexture(int unit, bool enabled, const CString
&texname);
        /** See
          RenderSystem
         */
        void _setTextureCoordSet(int stage, int index);
        /** See
          RenderSystem
         */
        void _setTextureCoordCalculation(int stage, TexCoordCalcMethod
m);
        /** See
          RenderSystem
         */
        void _setTextureBlendMode(int stage, const LayerBlendModeEx&
bm);
        /** See
          RenderSystem
         */
        void _setTextureAddressingMode(int stage, TextureAddressingMode
tam);
        /** See
          RenderSystem
         */
        void _setTextureMatrix(int stage, const Matrix4& xform);
        /** See
          RenderSystem
         */
        void _setSceneBlending(SceneBlendFactor sourceFactor,
SceneBlendFactor destFactor);
        /** See
          RenderSystem
         */
        void _setAlphaRejectSettings(CompareFunction func, unsigned
char value);
        /** See
          RenderSystem
         */
        void SetViewport(CViewPort *vp);
        /** See
```

```
          RenderSystem
         */
        void _beginFrame(void);
        /** See
          RenderSystem
         */
        void _render(RenderOperation* op);
        /** See
          RenderSystem
         */
        void _endFrame(void);
        /** See
          RenderSystem
         */
        void _setCullingMode(CullingMode mode);
        /** See
          RenderSystem
         */
        void _setDepthBufferParams(bool depthTest = true, bool
depthWrite = true, CompareFunction depthFunction = CMPF_LESS_EQUAL);
        /** See
          RenderSystem
         */
        void _setDepthBufferCheckEnabled(bool enabled = true);
        /** See
          RenderSystem
         */
        void _setDepthBufferWriteEnabled(bool enabled = true);
        /** See
          RenderSystem
         */
        void _setDepthBufferFunction(CompareFunction func =
CMPF_LESS_EQUAL);
        /** See
          RenderSystem
         */
        void _setDepthBias(ushort bias);
        /** See
          RenderSystem
         */
        void _setFog(FogMode mode, ColourValue colour, Real density,
Real start, Real end);
        /** See
          RenderSystem
         */
        void _makeProjectionMatrix(Real fovy, Real aspect, Real
nearPlane, Real farPlane, Matrix4& dest);
        /** See
          RenderSystem
         */
        void _setRasterisationMode(SceneDetailLevel level);
        /** See
          RenderSystem
         */
        void setStencilCheckEnabled(bool enabled);
        /** See
          RenderSystem
```

```
          */
        bool hasHardwareStencil(void);
        /** See
          RenderSystem
         */
        ushort getStencilBufferBitDepth(void);
        /** See
          RenderSystem
         */
        void setStencilBufferFunction(CompareFunction func);
        /** See
          RenderSystem
         */
        void setStencilBufferReferenceValue(ulong refValue);
        /** See
          RenderSystem
         */
        void setStencilBufferMask(ulong mask);
        /** See
          RenderSystem
         */
        void setStencilBufferFailOperation(StencilOperation op);
        /** See
          RenderSystem
         */
        void setStencilBufferDepthFailOperation(StencilOperation op);
        /** See
          RenderSystem
         */
        void setStencilBufferPassOperation(StencilOperation op);
        /** See RenderSystem.
        @remarks
            This is overridden because GL likes to set stencil options
together, so we can
            provide a better custom implementation of this than using
the superclass.
         */
        void setStencilBufferParams(CompareFunction func =
CMPF_ALWAYS_PASS,
            ulong refValue = 0, ulong mask = 0xFFFFFFFF,
            StencilOperation stencilFailOp = SOP_KEEP,
            StencilOperation depthFailOp = SOP_KEEP,
            StencilOperation passOp = SOP_KEEP);
        /** See
          RenderSystem
         */
            void _setTextureLayerFiltering(int unit, const
TextureFilterOptions texLayerFilterOps);
        /** See
          RenderSystem
         */
            void _setAnisotropy(int maxAnisotropy);
        /** See
          RenderSystem
         */
            void _setTextureLayerAnisotropy(int unit, int
maxAnisotropy);
```

```
            virtual void SetCamera(Camera* cam);


            // ----------------------------------
        // End Overridden members
        // ----------------------------------

            virtual void DrawGrid(void);
            Texture* CreateTexture(void);
            RenderTexture * CreateRenderTexture(CString  Name, uint
Width, uint Height, TextureType TexType = TEX_TYPE_2D);
            bool SuppportMultiTex;
            virtual RenderWindow* createRenderWindow(HWND
ExternalWnd,int colourDepth);

            virtual void Polygon(Vector3 Vertex1,Vector3
Vertex2,Vector3 Vertex3);
            virtual void Polygon(Real* Vertices,int
NumVertices,RenderOperation::OpType
OpType=RenderOperation::OpType::OT_TRIANGLE_STRIP ,DWORD rgba = 0);
            virtual void Polygon(Real* Vertices,Real* Indices,int
NumIndices,RenderOperation::OpType
OpType=RenderOperation::OpType::OT_TRIANGLE_STRIP,DWORD rgba = 0);
            virtual void Line(Vector3 *Vertex1,Vector3
*Vertex2,ColourValue &color);

            virtual void PushMatrix(void);
            virtual void PopMatrix(void);
            virtual void SetViewport(int x,int y,int h,int w);
};
#endif
```

GLOSSARY

BRDF	Bidirectional Reflectance Distribution Function. A function that defines the reflectance properties of an object. It describes how light is scattered at the surfaces and determines the appearance of the object.
Flux	The radiometry term for power.
Irradiance	Incident flux per unit area.
Lambertian	Material that is perfectly diffuse. Light is reflected equally in all directions.
Monte Carlo integration	In this context integration of indirect light by sampling a hemisphere above a point in the scene. The hemisphere is sampled by shooting many rays in random directions and computing the radiance at the intersection points.
Participating media	Media that scatters light as it passes through. Examples are smoke, fog and dust.
Projection map	A spherical projection of the scene geometry as seen from a light source. Used to optimize photon emission from the light source.
Radiance	Flux per unit projected area and per solid angle. What we use for the color of a pixel.
Recursive grid	A spatial data structure used to speedup intersection testing. The scene is divided into grid voxels were each voxel in turn can be further divided.
Russian roulette	Making decisions based on a random variable.
Solid angle	The projection of an area onto a unit sphere. Measured in steradians. A sphere subtends 4πsteradians.
Voxel	An element in a spatial data structure. In this context one of the cells in a three dimensional grid.

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