<u>MSc Computer Games and Entertainment</u>

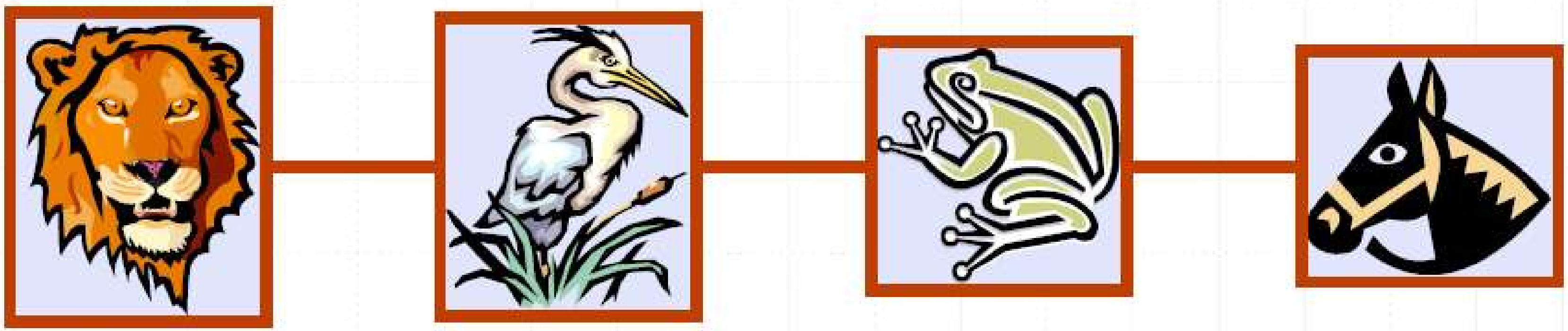
Maths & Graphics Unit 2011/12

Lecturer: Gareth Edwards

Linked Lists

Linked Lists - Materials

- 3 x sets of Lectures notes
- 2 x documents



Advanced Rendering Techniques

Global Illumination Model

- Global illumination is a general name for a group of algorithms used in 3D computer graphics that are meant to add more realistic lighting to 3D scenes.

- Such algorithms take into account not only the light which comes directly from a light source (*direct illumination*), but also subsequent cases in which light rays from the same source are reflected by other surfaces in the scene, whether reflective or not (*indirect illumination*).

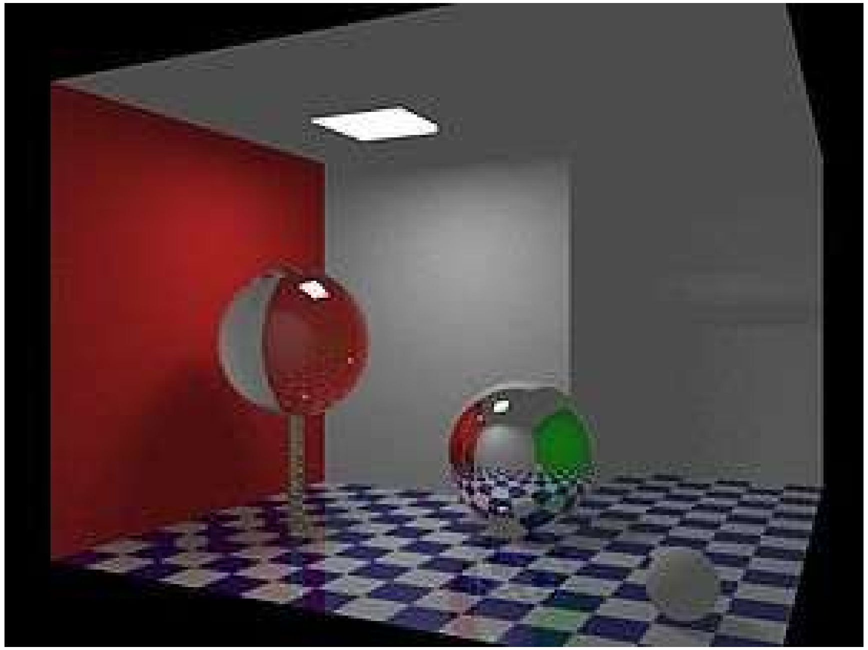
- Theoretically reflections, refractions, and shadows are all examples of global illumination, because when simulating them, one object affects the rendering of another object (as opposed to an object being affected only by a direct light).

- In practice, however, only the simulation of diffuse inter-reflection or caustics is called global illumination.

Global Illumination Model

- Rendering without global illumination. Areas that lie outside of the ceiling lamp's direct light lack definition. For example, the lamp's housing appears completely uniform.

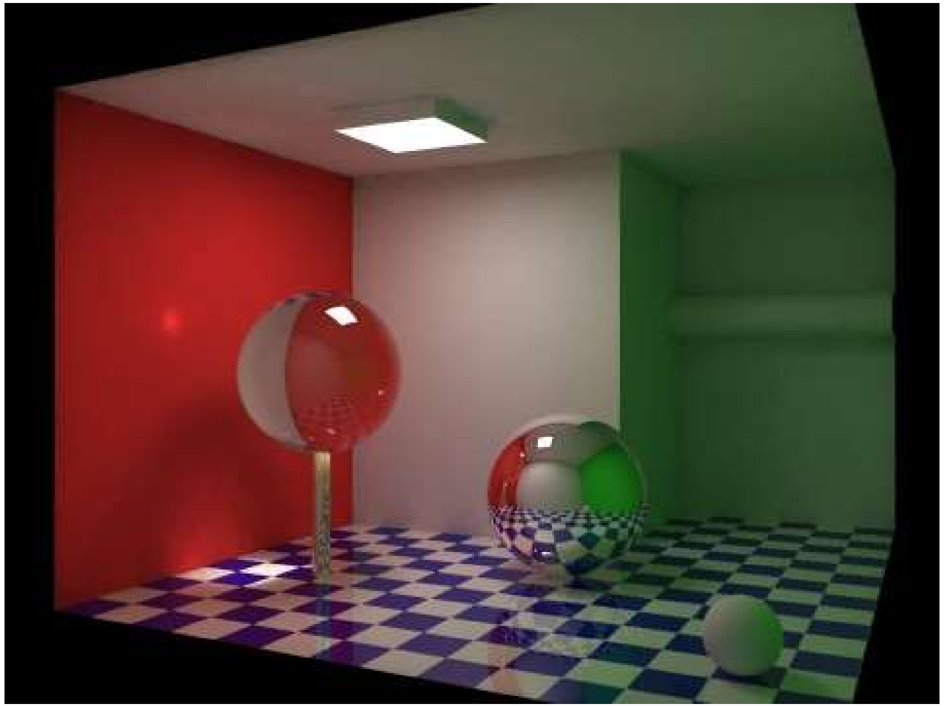
- Without the ambient light added into the render, it would appear uniformly black.



Global Illumination Model

- Rendering with global illumination. Light is reflected by surfaces, and coloured light transfers from one surface to another. Notice how colour from the red wall and green wall (not visible) reflects onto other surfaces in the scene.

- Also notable is the caustic projected onto the red wall from light passing through the glass sphere.



Global Illumination Model

- Images rendered using global illumination algorithms often appear more photorealistic than images rendered using only direct illumination algorithms.

- However, such images are computationally more expensive and consequently much slower to generate.

- One common approach is to compute the global illumination of a scene and store that information with the geometry, i.e., radiosity.

- That stored data can then be used to generate images from different viewpoints for generating walkthroughs of a scene without having to go through expensive lighting calculations repeatedly.

- LINK - Cryengine 3 - Global Illumination

Global Illumination Model

- Radiosity, ray tracing, beam tracing, cone tracing, path tracing, Metropolis light transport, ambient occlusion, photon mapping, and image based lighting are examples of algorithms used in global illumination, some of which may be used together to yield results that are not fast, but accurate.

- These algorithms model diffuse inter-reflection which is a very important part of global illumination; however most of these (excluding radiosity) also model specular reflection, which makes them more accurate algorithms to solve the lighting equation and provide a more realistically illuminated scene.

- The algorithms used to calculate the distribution of light energy between surfaces of a scene are closely related to heat transfer simulations performed using finite-element methods in engineering design.

Motion Blur

- When a camera creates an image, that image does not always represent a single instant of time. Because of technological constraints or artistic requirements, the image may represent the scene over a period of time.
- As objects in a scene move, an image of that scene must represent an integration of all positions of those objects, as well as the camera's viewpoint, over the period of exposure determined by the shutter speed.
- In such an image, any object moving with respect to the camera will look blurred or smeared along the direction of relative motion. This smearing may occur on an object that is moving or on a static background if the camera is moving.
- In a film or television image, this looks natural because the human eye behaves in much the same way.
- LINK - Motion blur in games - Modern Warfare 2 trailer with and without motion blur

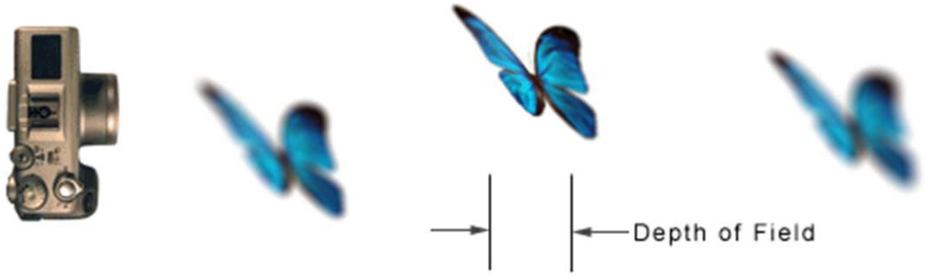
Depth of Field (DoF)

- In optics, particularly as it relates to film and photography, **depth of field** (DOF) is the distance between the nearest and farthest objects in a scene that appear acceptably sharp in an image.

- Although a lens can precisely focus at only one distance at a time, the decrease in sharpness is gradual on each side of the focused distance, so that within the DOF, the un-sharpness is imperceptible under normal viewing conditions.

- In some cases, it may be desirable to have the entire image sharp, and a large DOF is appropriate. In other cases, a small DOF may be more effective, emphasizing the subject while de-emphasizing the foreground and background. In cinematography, a large DOF is often called deep focus, and a small DOF is often called shallow focus.

- LINK - Depth of Field Wonderland



Real Time

- A system is said to be *real-time* if the total correctness of an operation depends not only upon its logical correctness, but also upon the time in which it is performed.

- Real-time systems, as well as their deadlines, are classified by the consequence of missing a deadline.

- **Hard** - Missing a deadline is a total system failure.

- **Firm** - Infrequent deadline misses are tolerable, but may degrade the system's quality of service. The usefulness of a result is zero after its deadline.

- **Soft** - The usefulness of a result degrades after its deadline, thereby degrading the system's quality of service.

Real Time Games

- In real-time games, game time progresses continuously according to the game clock.

- Players perform actions simultaneously as opposed to in sequential units or turns.

- Players must perform actions with the consideration that their opponents are actively working against them in real time, and may act *at any moment*.

- This introduces time management considerations and additional challenges (such as physical coordination in the case of video games).

Real Time Games

- Real-time game play is the dominant form of time-keeping found in simulation video games, and has to a large degree supplanted turn-based systems in other video game genres as well (for instance real-time strategy).

- Time is an important factor in most sports; and many, such as soccer or basketball, are almost entirely simultaneous in nature, retaining only a very limited notion of turns in specific instances, such as the free kick in soccer and the free throw and shot clock in basketball.

- While game time in video games is in fact subdivided into discrete units due to the sequential nature of computing, these intervals or units are typically so small as to be imperceptible to the player.

- LINK - Real Time Software Rendering - part 3 mountain

Ray Tracing

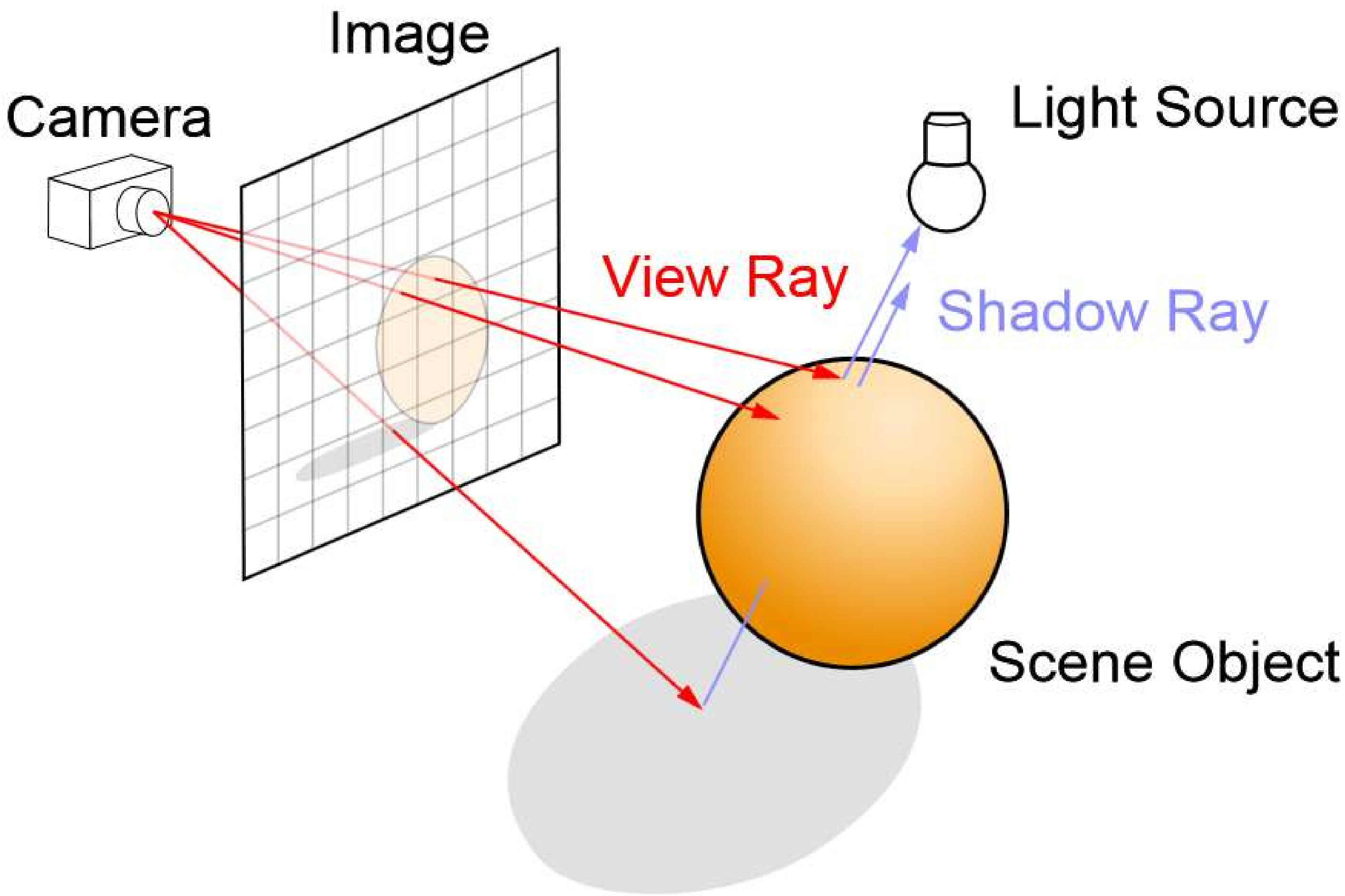
- This is a technique for generating an image by tracing the path of light through pixels in an image plane and simulating the effects of its encounters with virtual objects. The technique is capable of producing a very high degree of visual realism, usually higher than that of typical scanline rendering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

- This makes ray tracing best suited for applications where the image can be rendered slowly ahead of time, such as in still images and film and television special effects, and more poorly suited for real-time applications like video games where speed is critical.

- Ray tracing is capable of simulating a wide variety of optical effects, such as reflection and refraction, scattering, and dispersion phenomena (such as chromatic aberration).

Real Time Ray Tracing

- **Fast!**
- LINK - Real time Ray Tracing



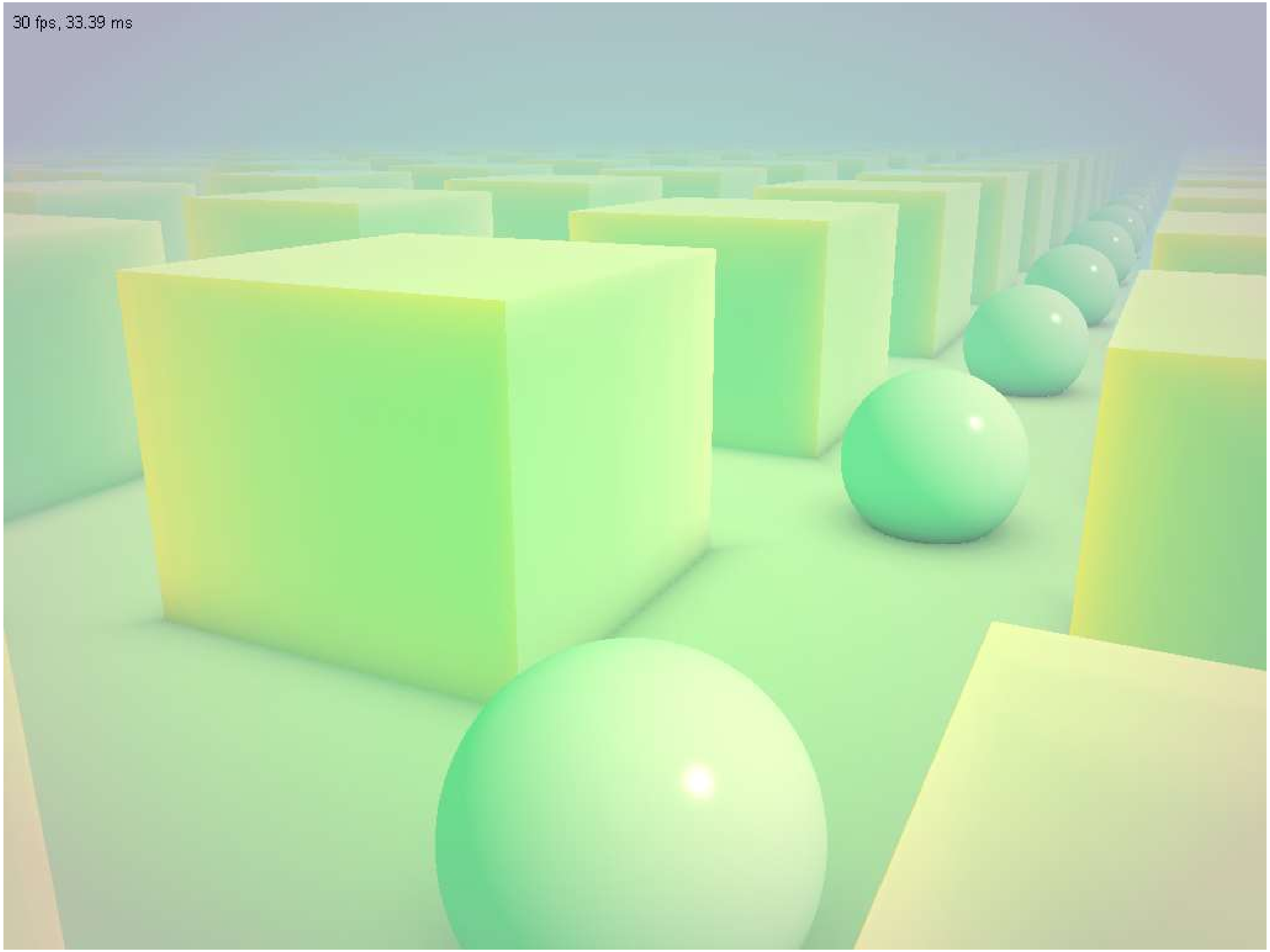
Real Time Distance Field Ray Tracing

- A distance field supplies the minimum distance to any surface in a scene from any point.
- A ray can therefore do a look up in the distance field at its position and step *at least* the returned distance in its direction before a new look up is necessary.
- The difficulty of course lies in defining a distance field that matches the geometry we want to render.
- Quílez proposed going the other way around, defining a distance field as a means to model a scene.
- LINK - Real-time distance field ray tracing on the GPU

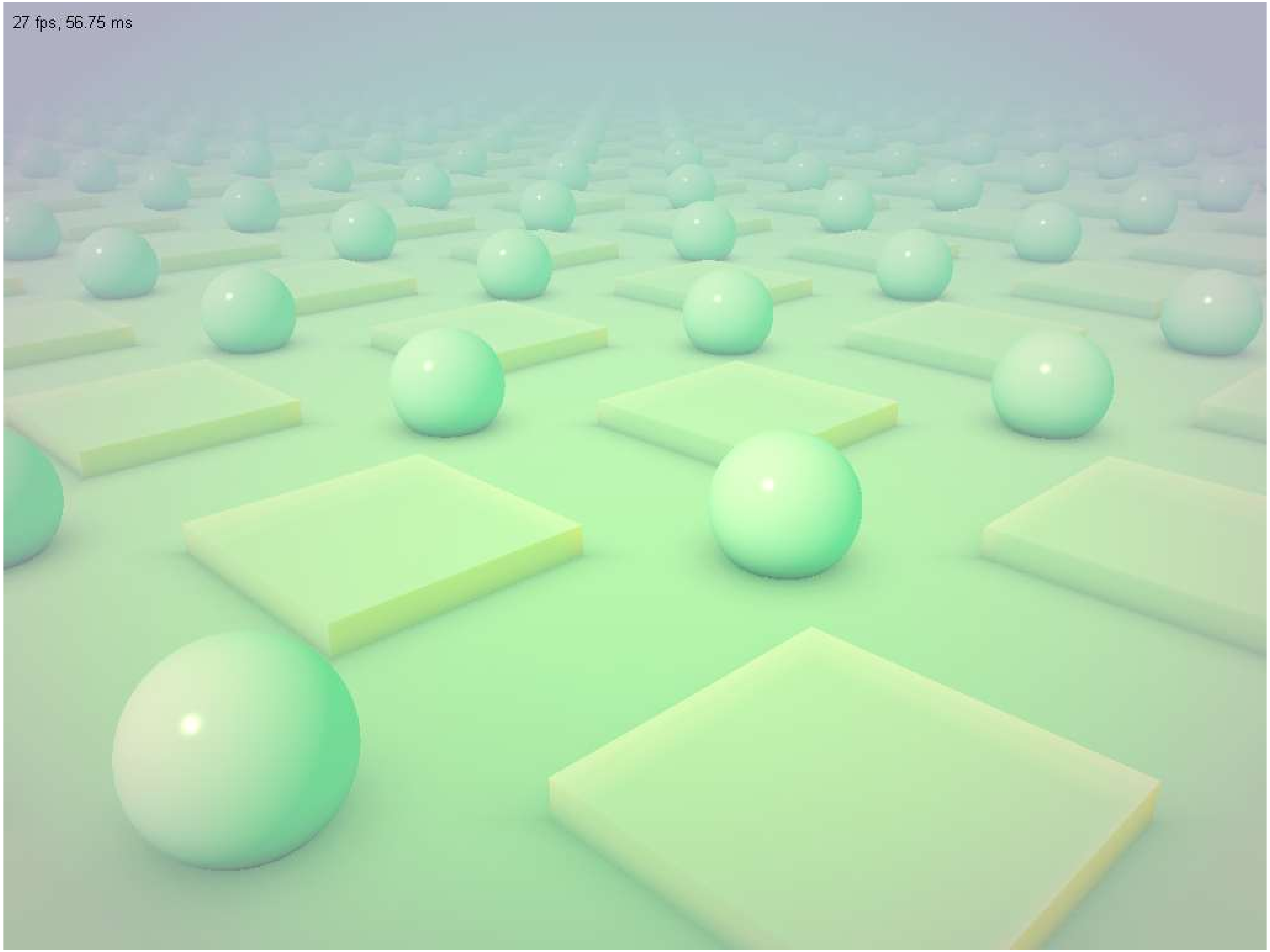
Real Time Distance Field Ray Tracing

- Legendary demo coder Iñigo Quílez’.
- ‘Rendering Worlds With Two Triangles’, describing the idea of optimizing ray marching (ray tracing done in discrete steps — perfect for scenes where intersections can’t be found analytically) by using distance fields.

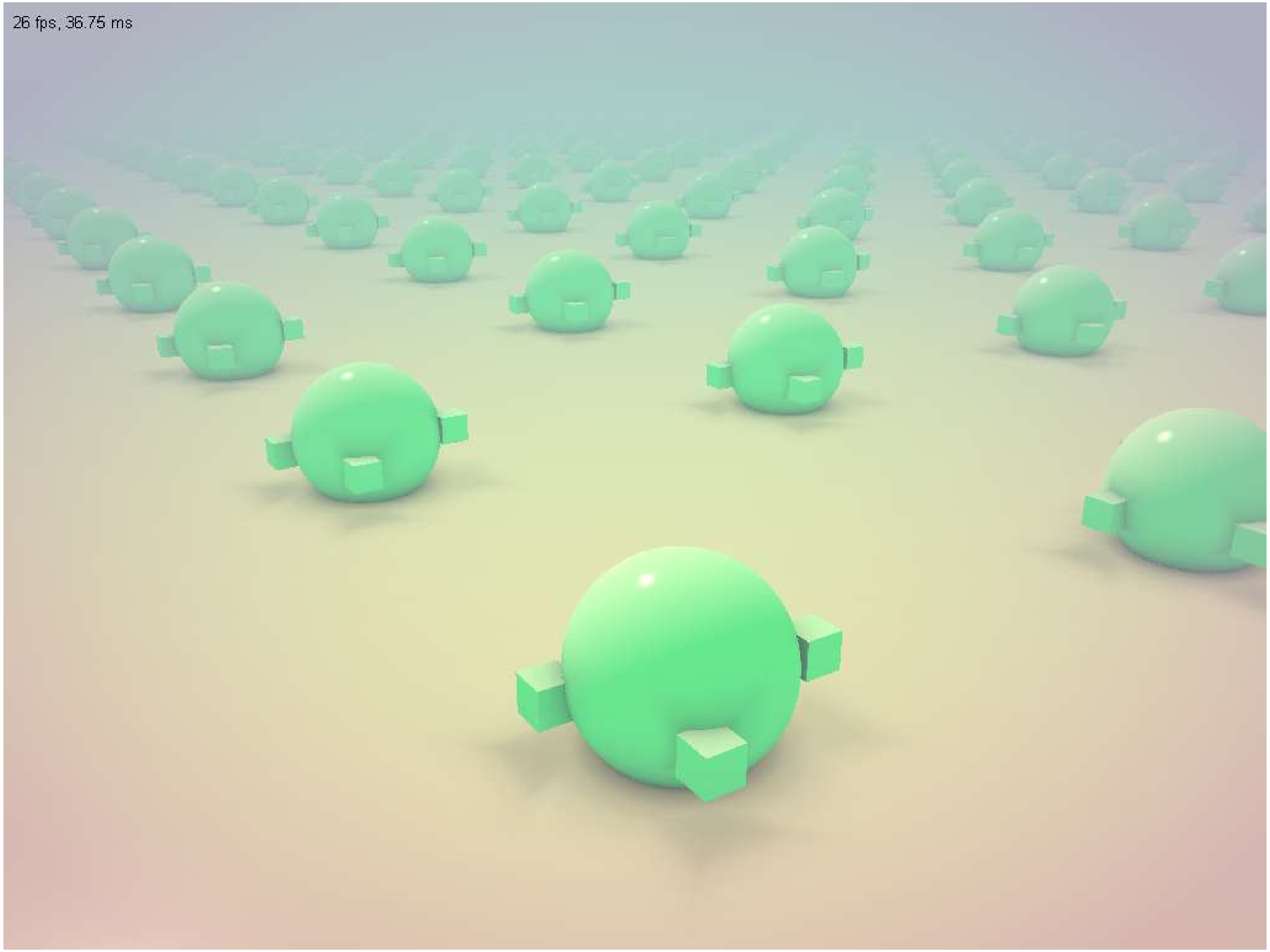
Real Time Distance Field Ray Tracing



Real Time Distance Field Ray Tracing



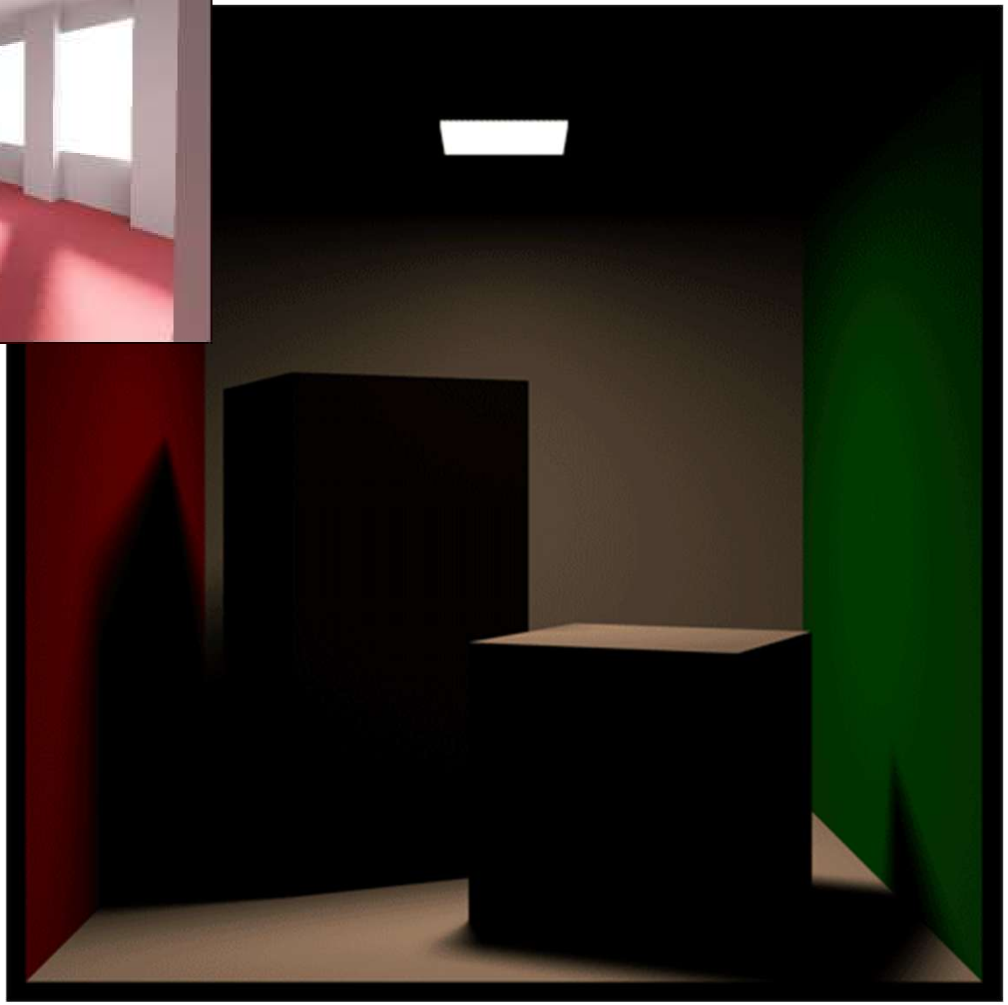
Real Time Distance Field Ray Tracing



Real Time Radiosity

- Radiosity is a global illumination algorithm used in 3D computer graphics rendering.
- Radiosity is an application of the finite element method to solving the rendering equation for scenes with purely diffuse surfaces.
- Unlike Monte Carlo algorithms (such as path tracing) which handle all types of light paths, typical radiosity methods only account for paths which leave a light source and are reflected diffusely some number of times (possibly zero) before hitting the eye.
- Such paths are represented as "LD*E". Radiosity calculations are viewpoint independent which increases the computations involved, but makes them useful for all viewpoints.

Real Time Radiosity



- LINK - NDK - Real-Time Radiosity in 1 minute

Scattered Light Rendering

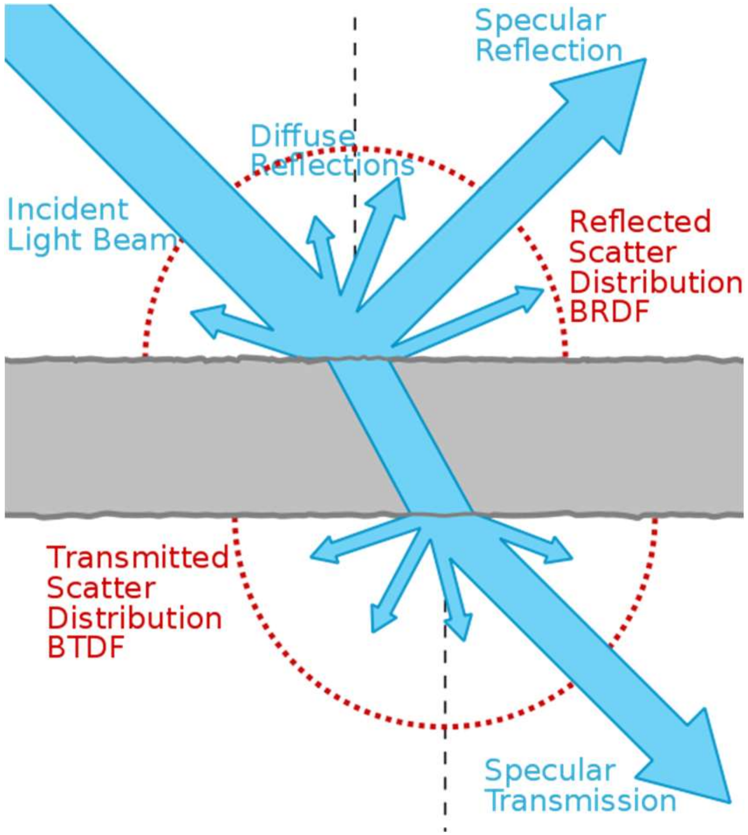
- Typically this terms refers to translucency — highly scattered transmission of light through solid objects.

- It can also refer to light moving through non-solid materials – such as water and air.

- LINK - TranceEngine - Refined Scattered Light Rendering

Path Tracing

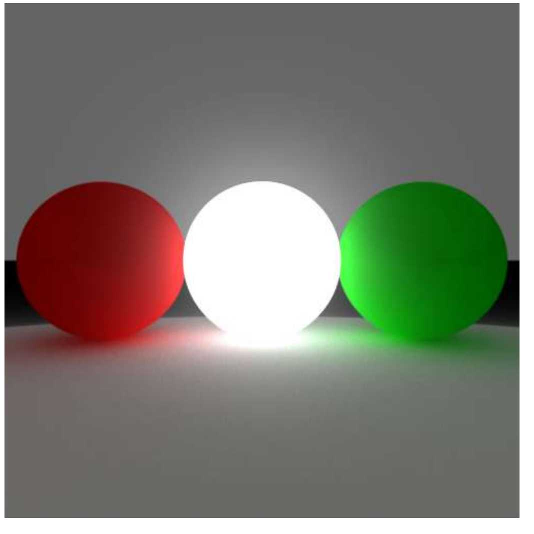
- **Path tracing** is a computer graphics rendering technique that attempts to simulate the physical behaviour of light as closely as possible. It is a generalisation of conventional ray tracing, tracing rays from the virtual camera through several bounces on or through objects. The image quality provided by path tracing is usually superior to that of images produced using conventional rendering methods at the cost of much greater computation requirements.



Path Tracing

- Path tracing naturally simulates many effects that have to be specifically added to other methods (conventional ray tracing or scan line rendering), such as soft shadows, depth of field, motion blur, caustics, ambient occlusion, and indirect lighting. Implementation of a renderer including these effects is correspondingly simpler.

- Due to its accuracy and unbiased nature, path tracing is used to generate reference images when testing the quality of other rendering algorithms. In order to get high quality images from path tracing, a large number of rays must be traced to avoid visible artefacts in the form of noise.



Path Tracing

- LINK - OpenCL path tracing renderer testing, animation (and Bullet Physics)

- LINK - Path Tracer Renders

Parallel Processing

- Shaders are written to apply transformations to a large set of elements at a time, for example, to each pixel in an area of the screen, or for every vertex of a model.
- This is well suited to parallel processing, and most modern GPUs have multiple shader pipelines to facilitate this, vastly improving computation throughput.
- LINK - Micro-Rendering for Scalable, Parallel Final Gathering

Scalable Parallel Processing

- Software is said to exhibit scalable parallelism if it can make use of additional processors to solve larger problems, i.e. this term refers to software for which Gustafson's law holds.

  - Gustafson's Law (also known as Gustafson-Barsis' law) is a law in computer science which says that computations involving arbitrarily large data sets can be efficiently parallelized.

Photon Mapping

- In computer graphics, **photon mapping** is a two-pass global illumination algorithm developed by Henrik Wand Jensen that solves the rendering equation.

- Rays from the light source and rays from the camera are traced independently until some termination criterion is met, then they are connected in a second step to produce a radiance value.

- It is used to realistically simulate the interaction of light with different objects.

- Specifically, it is capable of simulating the refraction of light through a transparent substance such as glass or water, diffuse interreflection between illuminated objects, the subsurface scattering of light in translucent materials, and some of the effects caused by particulate matter such as smoke or water vapour. It can also be extended to more accurate simulations of light such as spectral rendering.

Photon Mapping

- **Effects**
  - **Caustics -** A model of a wine glass ray traced with photon mapping to show caustics. Light refracted or reflected causes patterns called caustics, usually visible as concentrated patches of light on nearby surfaces.
  - **Diffuse interreflection - i**s apparent when light from one diffuse object is reflected onto another. Particularly adept at handling this effect because the algorithm reflects photons from one surface to another based on that surface's bidirectional reflectance distribution function (BRDF), and thus light from one object striking another is a natural result of the method.
  - **Subsurface scattering -** is the effect evident when light enters a material and is scattered before being absorbed or reflected in a different direction. Subsurface scattering can accurately be modelled using photon mapping. This

Photon Mapping

Photon Mapping

- **Construction of the photon map (1st pass)**

  - With photon mapping, light packets called *photons* are sent out into the scene from the light sources.

  - Whenever a photon intersects with a surface, the intersection point and incoming direction are stored in a cache called the *photon map*.

  - Typically, two photon maps are created for a scene: one especially for caustics and a global one for other light.

  - After intersecting the surface, a probability for either reflecting, absorbing, or transmitting/refracting is given by the material.

Photon Mapping

- **Rendering (2nd pass)**
  - In this step of the algorithm, the photon map created in the first pass is used to estimate the radiance of every pixel of the output image. For each pixel, the scene is ray traced until the closest surface of intersection is found.
  - At this point, the rendering equation is used to calculate the surface radiance leaving the point of intersection in the direction of the ray that struck it. To facilitate efficiency, the equation is decomposed into four separate factors: direct illumination, specular reflection, caustics, and soft indirect illumination.
  - For an accurate estimate of direct illumination, a ray is traced from the point of intersection to each light source. As long as a ray does not intersect another object, the light source is used to calculate the direct illumination. For an approximate estimate of indirect illumination, the photon map is used to calculate the radiance contribution.

Photon Mapping

- LINK - Visualizing Photon Mapping

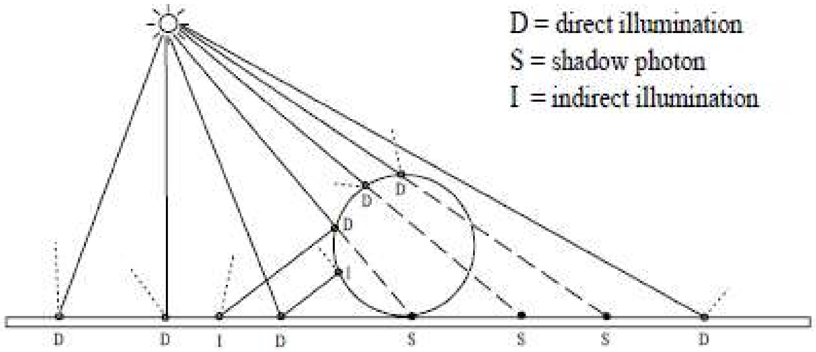


Figure 1: The photons in the global photon map are classified to optimize the rendering of shadows

Progressive Photon Mapping

- Progressive photon mapping is a multi-pass algorithm where the first pass is ray tracing followed by any number of photon tracing passes. Each photon tracing pass results in an increasingly accurate global illumination solution that can be visualized in order to provide progressive feedback.

- Progressive photon mapping uses a new radiance estimate that converges to the correct radiance value as more photons are used. It is not necessary to store the full photon map, and unlike standard photon mapping it possible to compute a global illumination solution with any desired accuracy using a limited amount of memory.

- Compared with existing Monte Carlo ray tracing methods progressive photon mapping provides an efficient and robust alternative in the presence of complex light transport such as caustics and in particular reflections of caustics.

- LINK - Progressive Photon Mapping with CUDA

Progressive Photon Mapping

- **Toshiya Hachisuka**
  UC San Diego

  Shinji Ogaki
  The University of Nottingham

  Henrik Wann Jensen
  UC San Diego

Path tracing | Bidirectional path tracing | Metropolis light transport | Photon mapping | Progressive photon mapping

Radiosity

- With the advent of powerful graphics hardware, people have begun to look beyond local illumination models toward more complicated global illumination models, such as those made possible by ray tracing and radiosity.

- Global illumination, which incorporates inter-object effects such as shadows and inter-reflections, attains a compelling level of visual realism that is difficult to achieve with local illumination models.

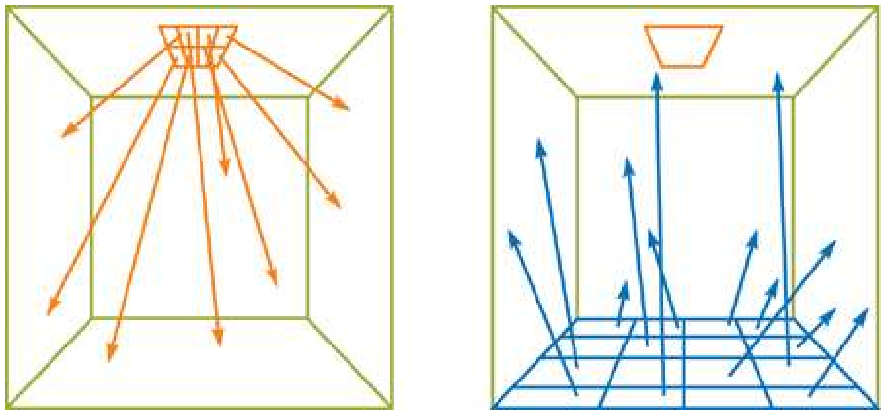
Progressive Radiosity

- A method for computing radiosity that performs all of the computation on the GPU. The radiosity energy is stored in texels, and fragment programs are used to compute the form factors and inter-object visibility.

- Avoid the problem of writing to arbitrary locations in memory by casting progressive refinement radiosity as a "gather" operation, which has a regular memory access pattern that is amenable to running on current GPUs.

Progressive Instant Radiosity

- Each element in the scene maintains two energy values: an *accumulated* energy value and *residual* (or "unshot") energy.
- Choose one of the elements in the scene as the "shooter" and test the visibility of every other element from this shooter.
- If a receiving element is visible, then we calculate the amount of energy transferred from the shooter to the receiving element, as described by the corresponding form factor and the shooter's residual energy.



- LINK - Progressive Instant Radiosity

Everything

- **Archee - Photon Race 2**
  - Pre-calculation may take 1-2 minute
  - Features:
    - Ray tracing
    - Photon tracing
    - Caustics
    - Constructive Solid Geometry(3dbool)
    - flare effect
    - using Shader Model 3.0
  - GeForce 8800 GTS 512
  - 15 FPS @ 1920 x 1080
- LINK - Archee - Photon Race 2

Showcase & Future Trends

- Faster – much faster – and then even faster - more complex – higher resolution – smaller hardware – less power consumption – real-time.... full global illumination.

- LINK - Siggraph 2011 Showreel

- LINK - Skyrim photo realistic graphic – Mods - Tweaks - Gameplay Ultra Setting @1080p

- LINK – World Building - Crysis Ultra High Quality - The Resort mod EIM v3.0.71 (EQM) HQ

- LINK - DirectX 11

- LINK - Transformers Audi Meconopsis Film Anniversaire 2011 HD

END