

Ray Tracing

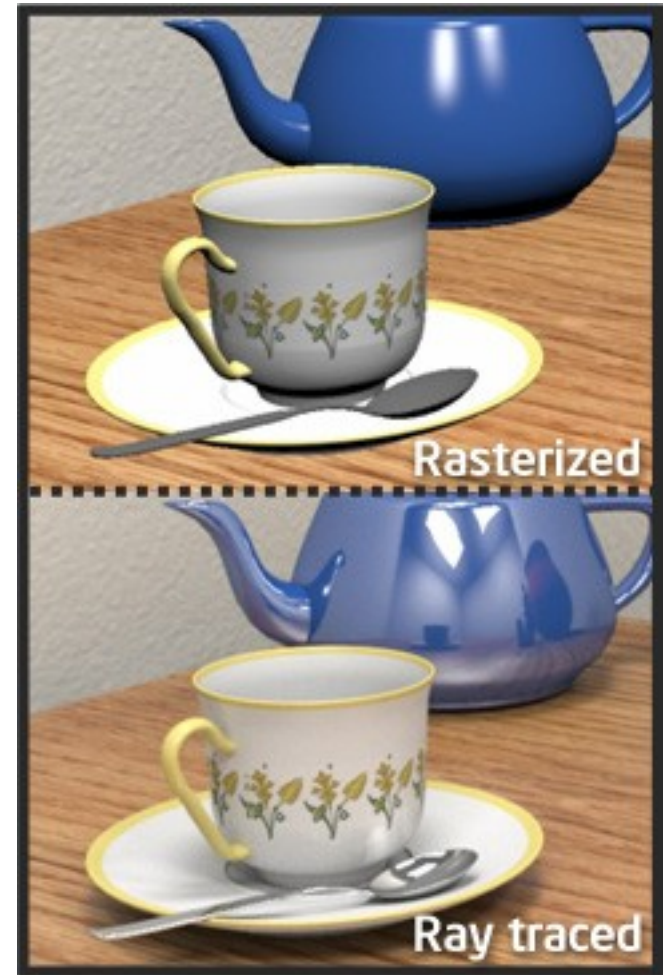
CSCI 4239/5239

Advanced Computer Graphics

Spring 2021

What is it?

- Method for rendering a scene using the concept of optical rays bouncing off objects
 - More realistic
 - Reflections
 - Shadows



How does it work?

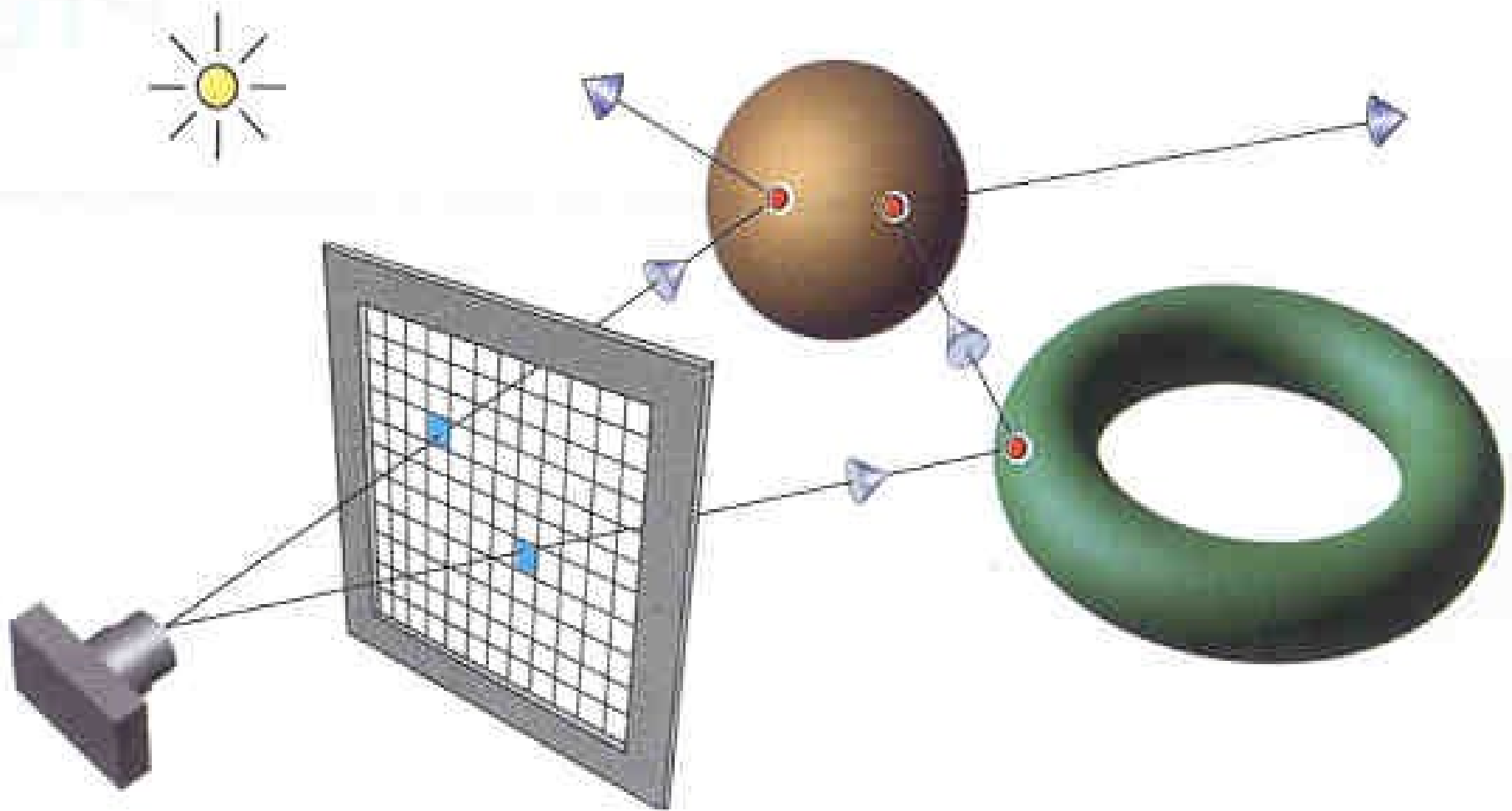


Figure 1. The ray-tracing process.

Sources

- Ray Tracing from the Ground Up
 - Kevin Suffern
 - Excellent tutorial
 - Some working examples
 - <http://www.raytracegroundup.com/>
- nVidia
- Intel
- PBRT (Physically Based Ray Tracing)

Interactive Ray Tracing

- True ray tracing is VERY compute intensive
- Global problem – scene complexity adds effort
- Generally there is no upper limit to computation
- Solutions are generally software based
 - Dedicated hardware provides 3-5x speedup
 - <http://www.caustic.com/>
 - OpenRL
 - Maya Plugins
- Compare nVidia RTX



nVidia Quadra Plex
1920x1024@30fps



nVidia Quadra Plex
1920x1024@30fps

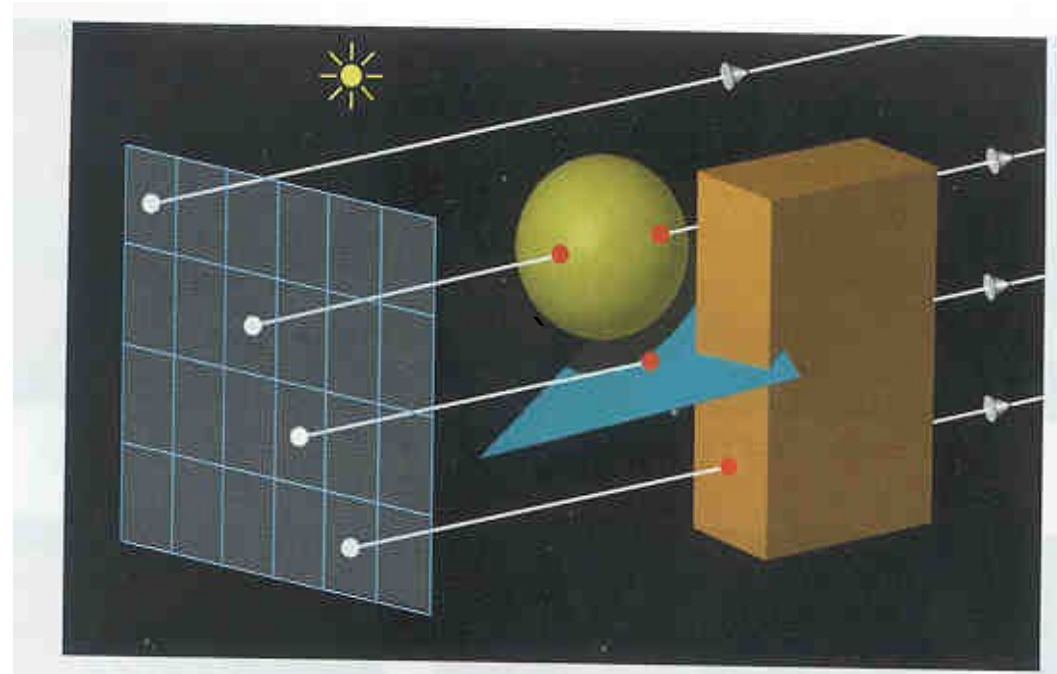


How is it Done?

- Scene Description Language
 - Defines objects in scene
 - Geometry and properties
 - Lights
 - Eye position
- Determine color of individual pixels using ray tracing algorithms
 - Very hard to do real time

How ray tracing works

- Define scene and view
 - objects
 - lights
 - eye
- For each pixel
 - Shoot ray from pixel
 - Find nearest hit
 - Use object properties and lights to calculate color, or set to black if no hits



True Global Ray Tracing

- Light can bounce many times
 - Color changes at each bounce
 - Each bounce attenuates light
 - Light scatters in complex ways
 - Objects block light
- This simple scene took 2 CPU years to render
 - Cornell Box
 - Area light and three boxes



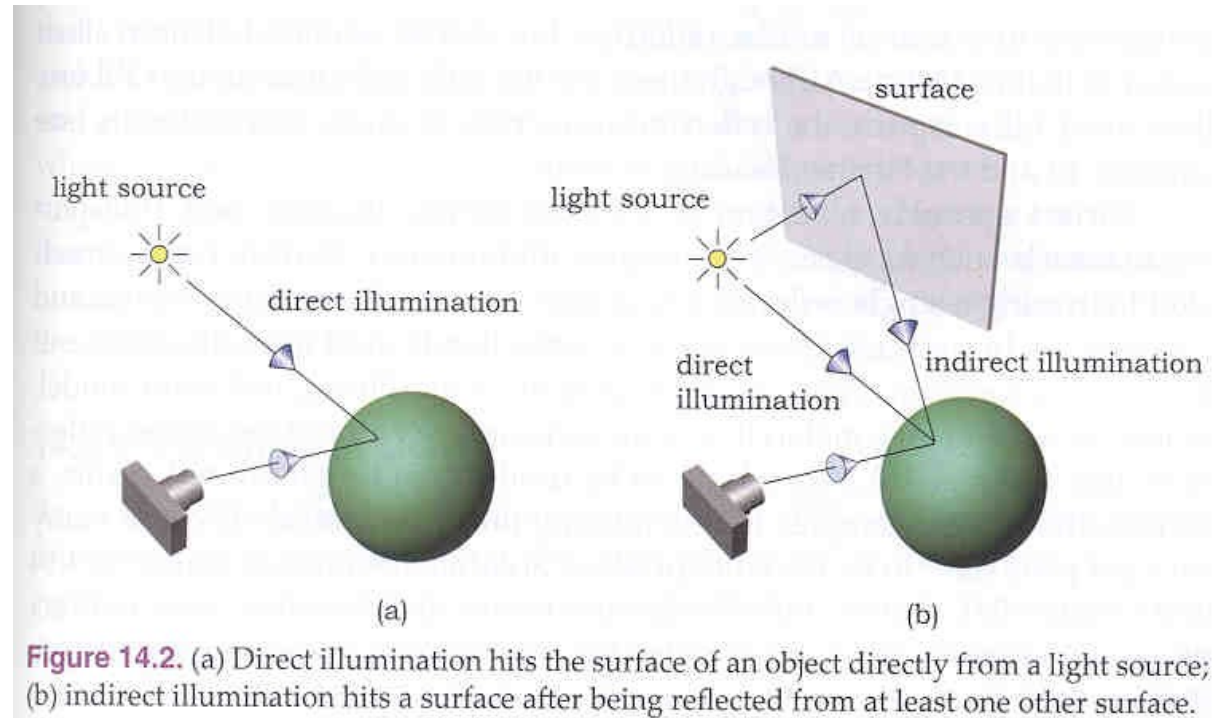
Image courtesy of Steven Parker

Efficiency and Complexity

- Most ray tracers written in C++
 - Object Oriented paradigm for objects, rays, colors
 - Good efficiency/readability trade-off
- Efficiency is a HUGE deal
 - Pushing the envelope of hardware
 - Algorithm is global by definition
- Recursion and complexity
 - Need clean interface on objects

What is a Ray?

- $\mathbf{p} = \mathbf{o} + t \mathbf{d}$
- Types of rays
 - Primary rays
 - Secondary rays
 - Shadow rays
 - Light rays
- Rays are one directional



Intersections

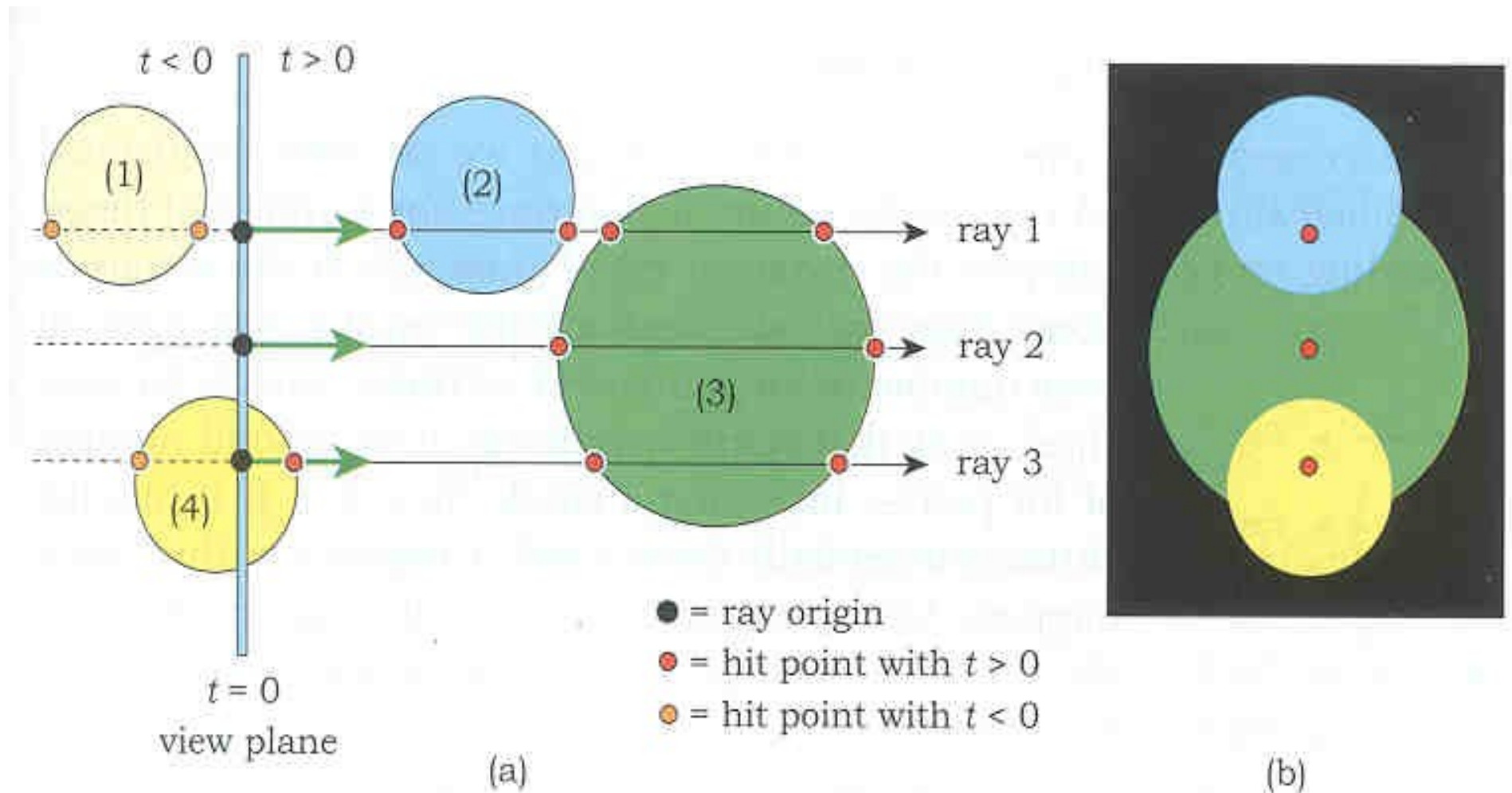


Figure 3.4. (a) Rays and their intersections with spheres; (b) ray-traced image of the spheres.

Intersecting a Sphere

- Simplest 3D object

- Center
- Radius

- Smooth normal

- Intersections

- none

- once

- tangent

- internal

- twice

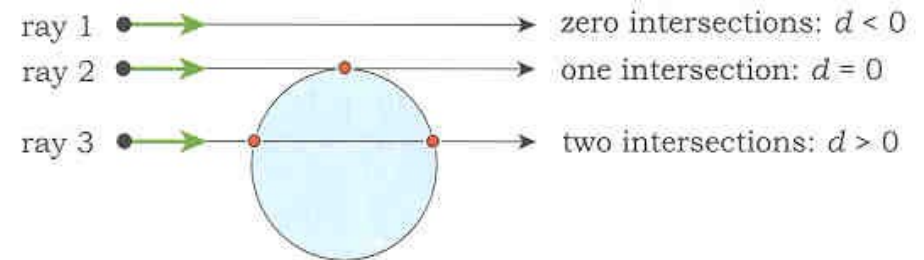


Figure 3.7. Ray-sphere intersections.

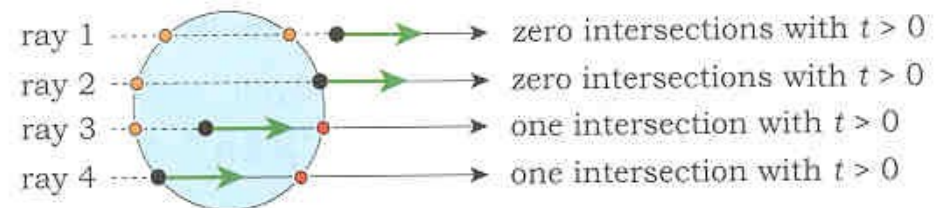


Figure 3.8. Further ray-sphere intersections.

Implicit Surfaces

- General
 - $f(x,y,z) = 0$
- Plane: Point **a** and Normal **n**
 - $(p-a) \bullet n = 0$
- Sphere
 - $(\mathbf{p}-\mathbf{a}) \bullet (\mathbf{p}-\mathbf{a}) - r^2 = 0$
- Triangle
 - Limit plane

Interaction between Lights and Objects

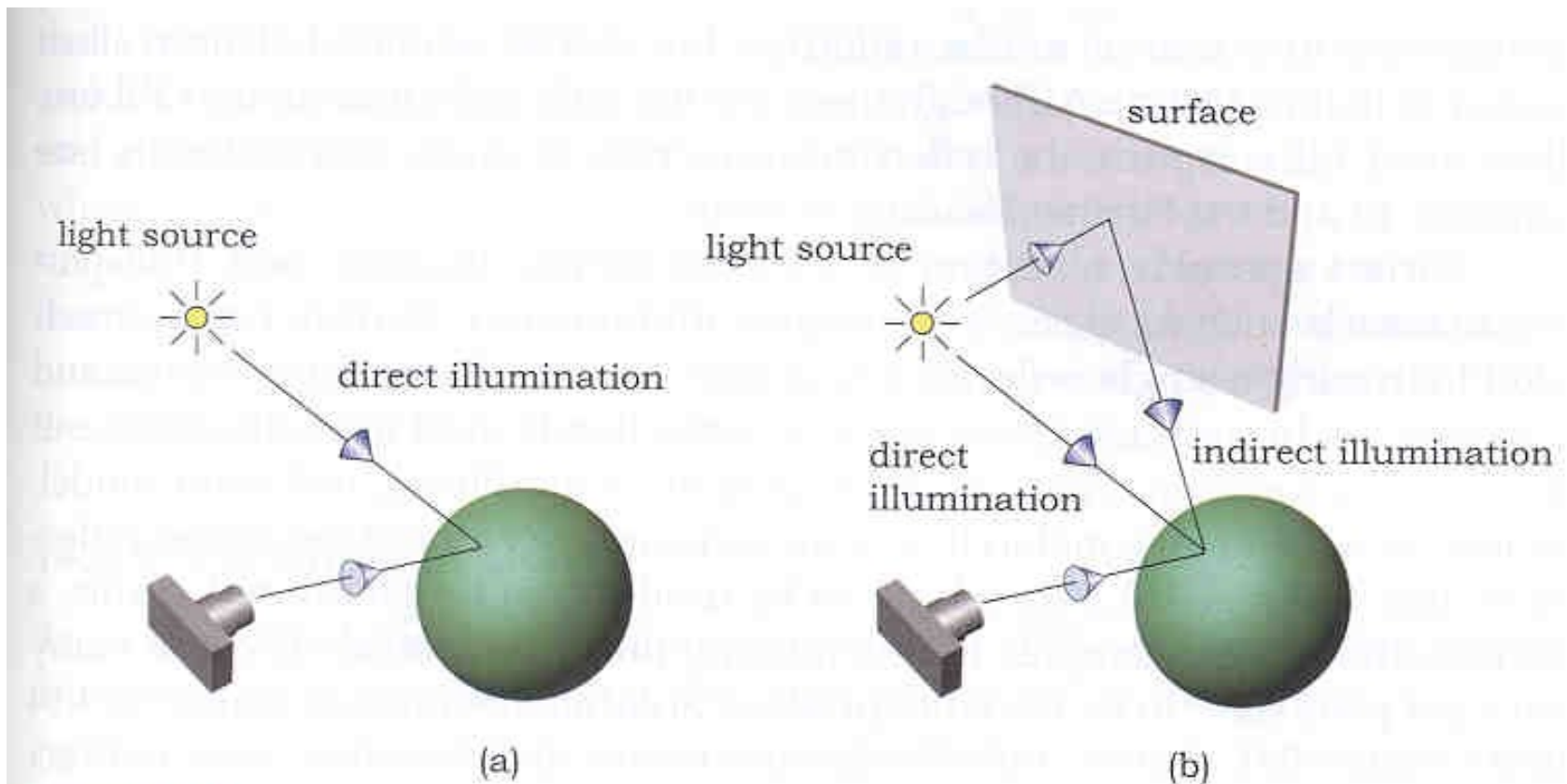


Figure 14.2. (a) Direct illumination hits the surface of an object directly from a light source; (b) indirect illumination hits a surface after being reflected from at least one other surface.

Bouncing Rays from Surfaces

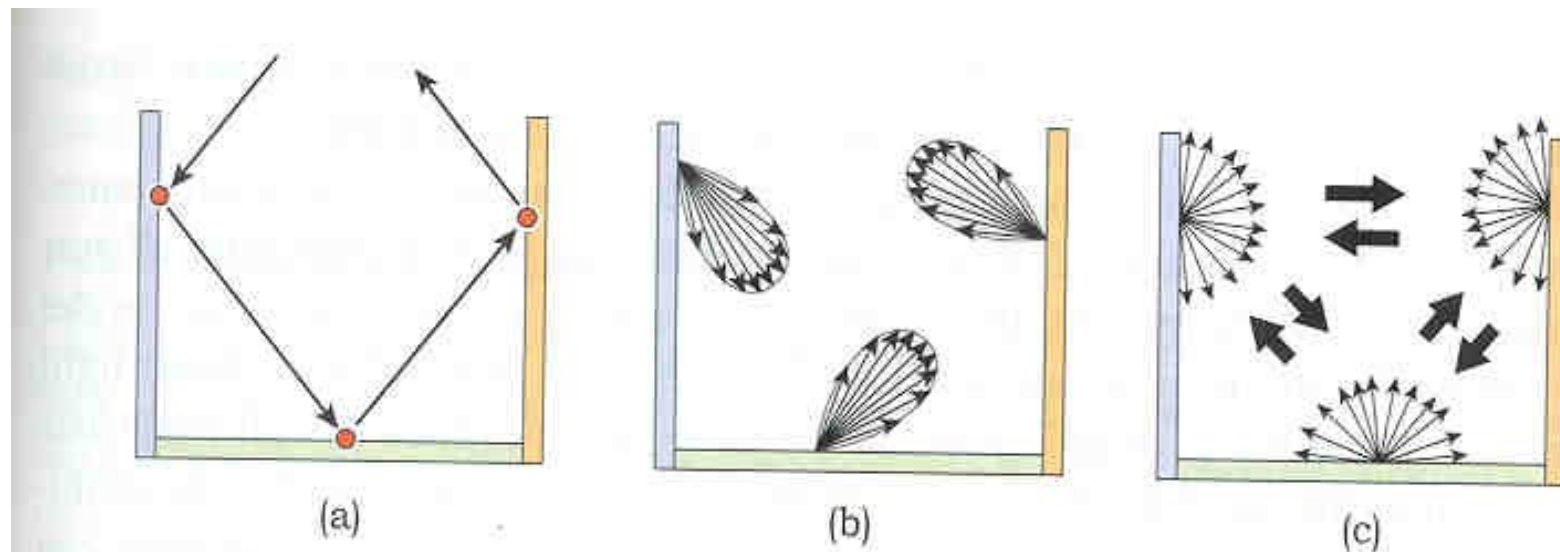


Figure 14.4. (a) Mirror reflection can be modeled by tracing a single reflected ray at each hit point; (b) modeling glossy specular light transport between surfaces requires many rays to be traced per pixel; (c) modeling perfect diffuse light transport between surfaces also requires many rays to be traced per pixel.

Light Reflection

- Diffuse (Lambertian) reflection
 - Intensity Factor $N \cdot L$

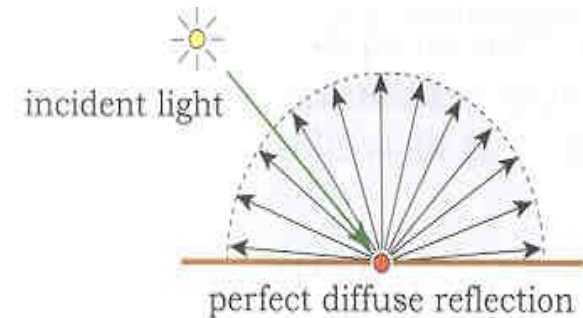


Figure 13.6. Light being scattered from a perfectly diffuse surface.

- Specular reflection
 - $R = 2(N \cdot L)N - L$
 - Intensity Factor

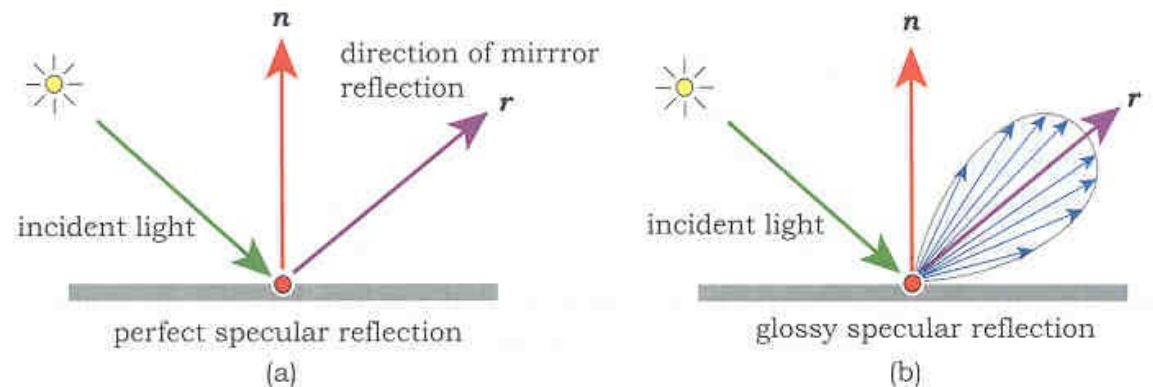


Figure 14.3. (a) Perfect specular reflection; (b) glossy specular reflection.

Specular Reflected Light

- Assume the ray (from the eye) hits objects 1,2,3,... with reflection coefficients $\alpha_1, \alpha_2, \alpha_3, \dots$
- Specular Reflection Color
$$\alpha_1(C_1 + \alpha_2(C_2 + \alpha_3(C_3 + \dots)))$$
$$= \alpha_1 C_1 + \alpha_1 \alpha_2 C_2 + \alpha_1 \alpha_2 \alpha_3 C_3 + \dots$$
- Since light is assumed to be linearly additive, just keep track of α and add light along successive bounces of the ray
- White specular means α can be a scalar

Simple Ray Tracing Algorithm

- Initialize ray (\mathbf{O}, \mathbf{d})
 - color = black
 - coef = 1
- Find closest intersection \mathbf{P}
 - color += coef*ambient*material
 - *if not in shadow* color += coef* $\mathbf{N} \cdot \mathbf{L}$ *diffuse*material
 - coef *= reflectivity
 - redirect ray from \mathbf{P} to $\mathbf{d} - 2(\mathbf{d} \cdot \mathbf{N})\mathbf{N}$
- Stop when no intersection, or coef $\ll 1$, or maximum number of bounces

Ex 23: Three Ray Traced Spheres

- Simple scene
 - Three highly reflective spheres
 - Two white lights (one close, one far)
 - OpenMP for parallel processing
- Support classes
 - Vec3, Mat3, Color
- Base classes
 - Ray, Material, Light
- Object classes
 - Sphere

Implementation Notes

- Written in **very bad** C++
 - *KISS*
 - No object abstraction
- Use STL `vector<>` class for lists
- Calculate array of pixel values *width x height*
 - View by transforming pixel location
 - OpenMP parallel calls to `RayTracePixel()`
 - Copy to screen using *glDrawPixels*
- All calculations in **global** coordinates
 - Preprocess scene as needed

Building a real Ray Tracer in C++

- Base classes
 - Ray
 - Object
 - Light
 - Material
- Derived Object Classes
 - Sphere
 - Cube
 - Triangle
 - Triangle Mesh

Object Class

- Type of object
 - Implicit Surface
 - Sphere
 - Torus, cylinder, cube, ...
 - Compound objects
 - Triangular mesh
- Intersection with a ray
 - Point of intersection
 - Normal
 - Textures, etc

Virtual Methods

- Base class
 - hit
 - sample
 - color
- Each object class overrides the base class

Intersecting a Complex Object

- Defining a complex object
 - Triangle mesh on vertexes
 - Gouraud shading
- Expensive to ray trace
 - Test every ray against every triangle in the object
 - Test bounding box of entire object
- Intersections
 - Plane
 - Axis-aligned box
 - Generic triangle

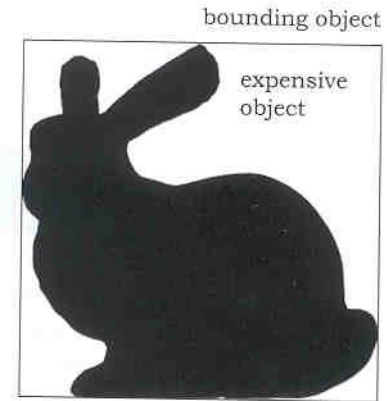


Figure 19.1. The Stanford bunny and a bounding box.

Perspective Ray Tracing

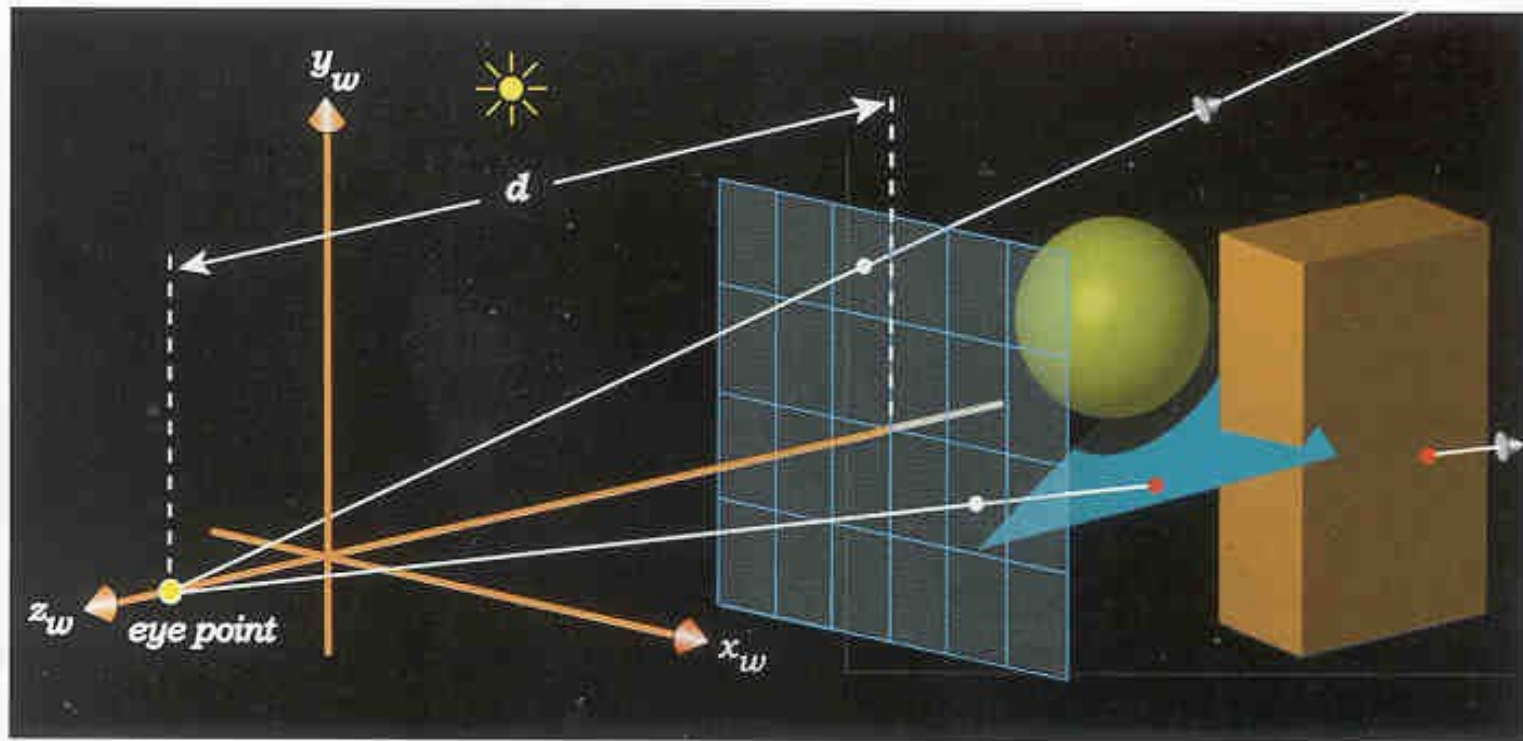
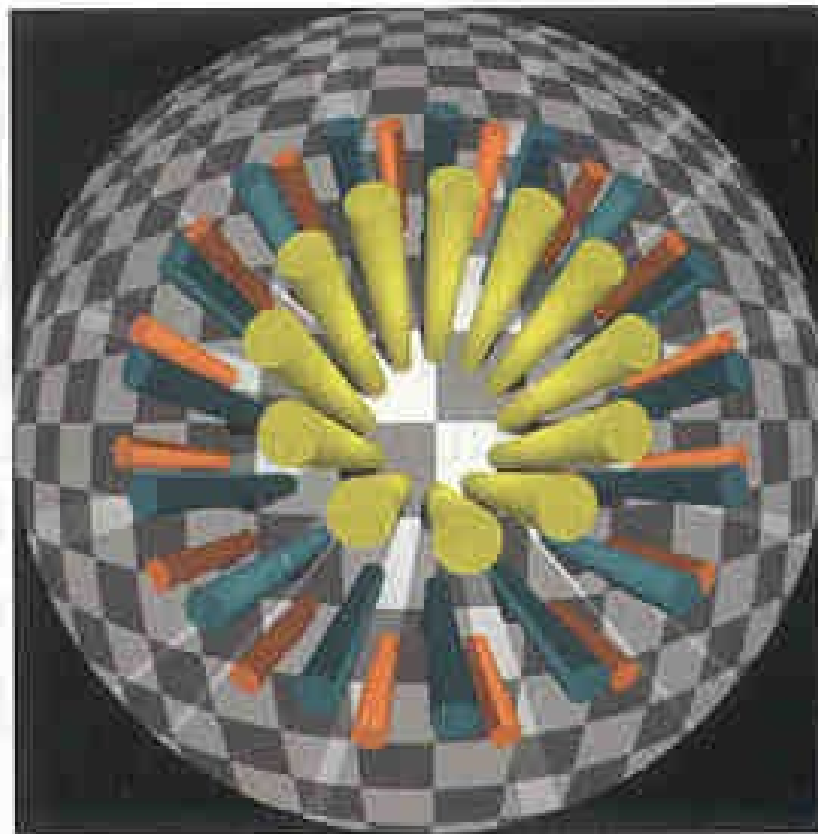
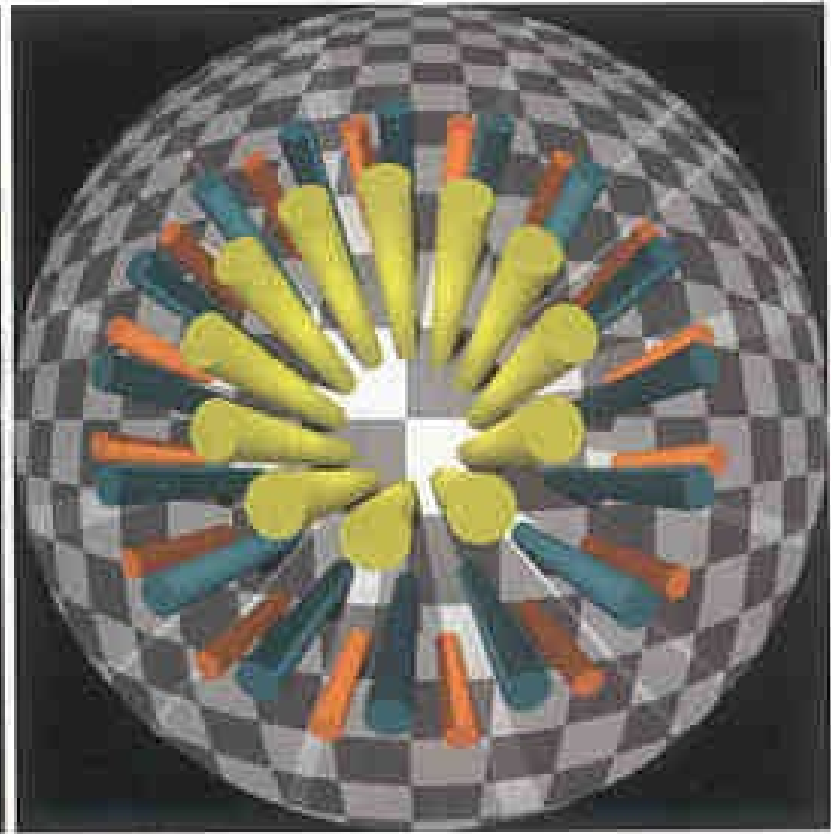


Figure 8.14. Set-up for axis-aligned perspective viewing with the eye point and two rays going through pixel centers.

Stereoscopy



left-eye view



right-eye view

Installing PBRT3

- Build code from github

```
- git clone --recursive https://github.com/mmp/pbrt-  
  v3.git  
- git clone git://git.pbrt.org/pbrt-v3-scenes  
- apt-get install openexr-viewers  
- cd pbrt-v3  
- mkdir build  
- cd build  
- cmake ..  
- make -j8  
- sudo make install
```

- Run using pbrt ??????.pbrt

- exrdisplay *.exr

- PBRT4 similar but syntax changed