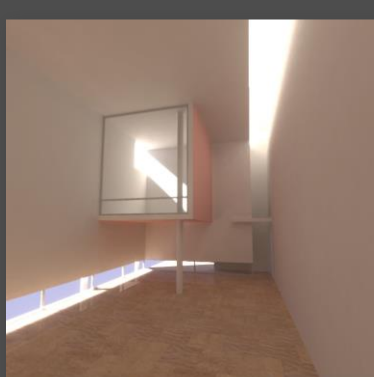
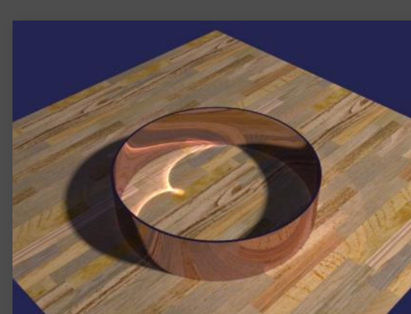
Ray-Tracing

Photorealism

Objective: To generate images that are as close as possible to those perceived by the human eye.

Method: Accurate simulation of optical phenomena.





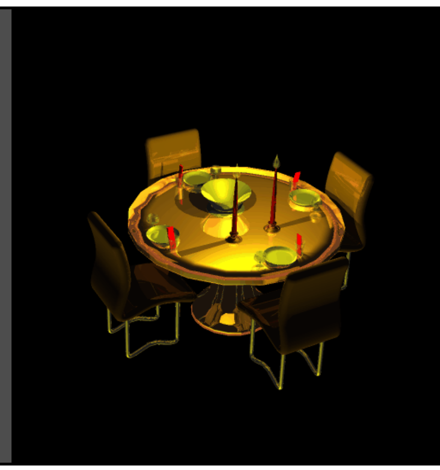
Illumination Models

Local: Depends only on the model, the light sources and the viewer. Easy to simulate.

Examples: Diffuse and specular illumination models. Flat, Gourard and Phong shading of polyhedra.

Global: Depends on the *entire* scene, the light sources and the viewer. Complex to simulate.

Examples: Shadow algorithms, ray-tracing, radiosity methods.



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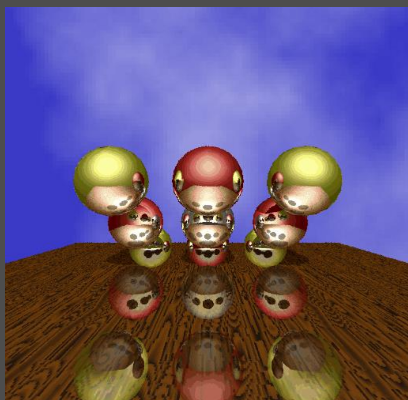

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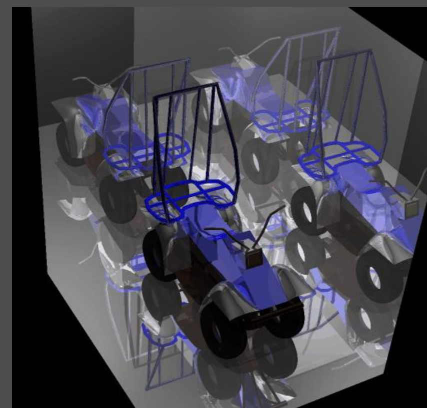

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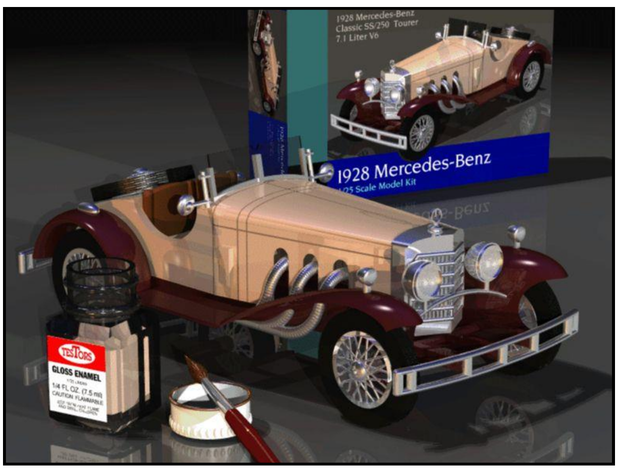

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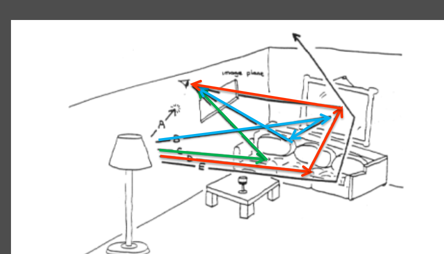
The Physics
Basic Illumination Model

Light rays are emitted from light sources and bounce (reflect) in the scene until they reach the eye



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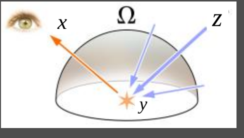
Rendering Equation

$$I(x,y) = g(x,y)[e(x,y) + \int_{Surf} s(x,y,z)I(y,z)dz]$$



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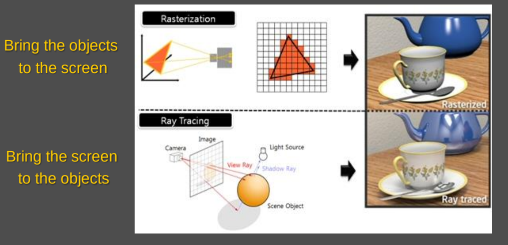

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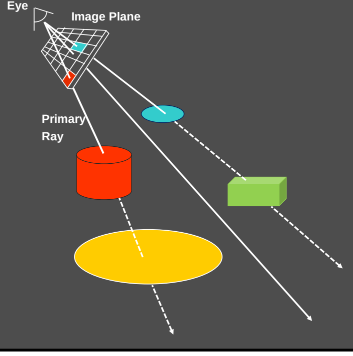
Ray-Casting Algorithm



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A Basic Ray-Casting Algorithm

```
RayCast (r, scene)

        <obj, p> := FirstIntersection(r, scene);
        if (no obj)
                return BackgroundColor;
        else
                return Shade(p, obj);
        end;
```

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Ray-Object Intersection

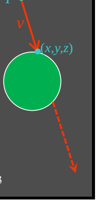
- In the kernel of every ray-tracer
- Ray-object intersections are computed millions of times for a single image, hence must be very efficient
- **Example**: Ray-Sphere intersection

ray: $x(t) = p_x + v_x t, \quad y(t) = p_y + v_y t, \quad z(t) = p_z + v_z t$

(unit) **sphere**: $x^2 + y^2 + z^2 = 1$

Solve a quadratic equation in t :

$$\begin{aligned} 0 &= (p_x + v_x t)^2 + (p_y + v_y t)^2 + (p_z + v_z t)^2 - 1 \\ &= t^2(v_x^2 + v_y^2 + v_z^2) + 2t(p_x v_x + p_y v_y + p_z v_z) \\ &\quad + (p_x^2 + p_y^2 + p_z^2) - 1 \end{aligned}$$



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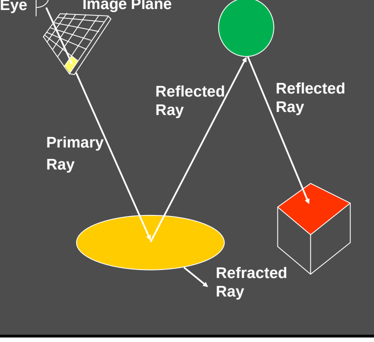
Ray-Tracing Algorithm



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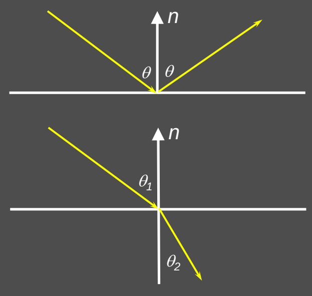
Reflection and Refraction



Snell's law

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$$

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A Basic Ray-Tracing Algorithm

```
RayTrace(r, scene)
<obj, p> := FirstIntersection(r, scene);
if (no obj)  return BackgroundColor;
else begin
   if ( Reflect(obj) ) then
      ReflectColor := RayTrace(ReflectRay(r, p, obj));
   else
      ReflectColor := Black;
   if ( Transparent(obj) ) then
      RefractColor := RayTrace(RefractRay(r, p, obj));
   else
      RefractColor := Black;
   return Shade(ReflectColor, RefractColor, p, obj);
end;
```

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Termination in Ray-Tracing

- Possible termination criteria:
  - No intersection
  - Contribution of secondary ray attenuated below a threshold
  - Maximal depth

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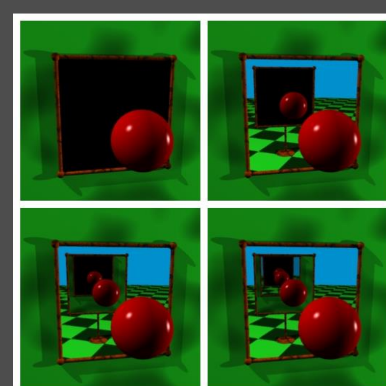

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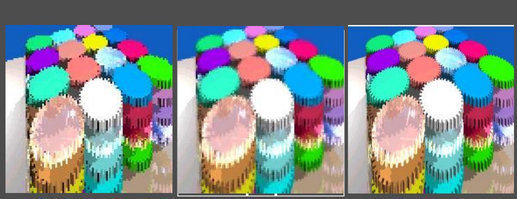
Ray-Tracing as a Sampling Process



1 ray/pixel   16 rays/pixel   64 rays/pixel

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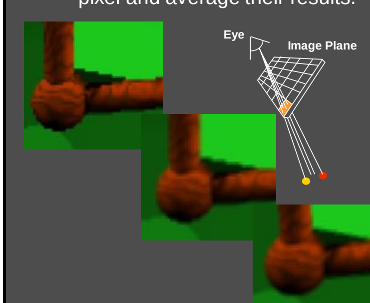
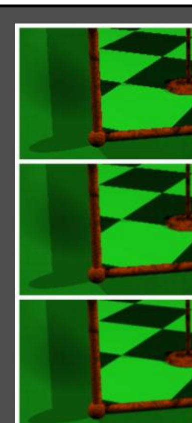
Supersampling

Trace multiple primary rays per pixel and average their results.





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Optimized Ray-Tracing

- Basic algorithm is simple but VERY expensive.
- Optimized ray-tracing is critical
  - Reduce number of rays traced
  - Reduce number of ray-object intersection calculations
- Methods
  - Bounding Boxes
  - Object Hierarchies
  - Spatial Subdivision (Octrees/BSP)
  - Tree Pruning (Randomized)

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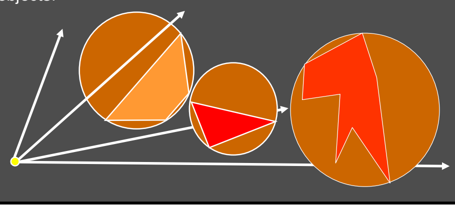
Bounding Volumes

- Bound each scene object by a simple volume (e.g. sphere). This enables *fast reject* of non-intersections. More work is performed when there *is* an intersection (or near intersection).
- Since, on the average, a typical ray will not intersect the vast majority of the scene objects, this results in a significant speedup.
- The time complexity is still linear in the number of scene objects.



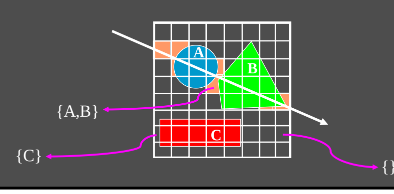
Choosing Bounding Volumes

Bounding volume should be:

- As tight-fitting as possible
- As simple as possible

Uniform Spatial Partition

- 3D space is divided into voxels of identical size. Each voxel contains a list of objects it intersects. A tradeoff exists between voxel size and list length.
- **Disadvantage:** The subdivision is totally independent of the scene structure.
- **Advantages:**
  - Simple !
  - The voxels pierced by a ray may be accessed very efficiently by incremental calculation. A 3D version of Bresenham's algorithm is used.



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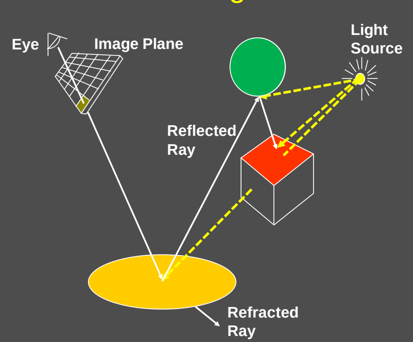
Simulating Shadows



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Simulating Shadows

- Trace ray from each ray-object intersection point to light source(s)
  - If no line-of-sight ⇒ point is shadowed
- Shadow computation routine:

shadow = **RayTrace**(**LightRay**(p,obj,light));

to be included in the final shading:

return **Shade**(shadow, ReflectColor, RefractColor, p, obj);

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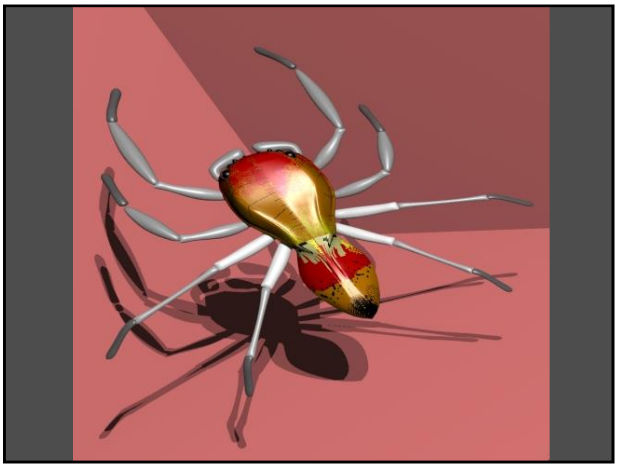


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