Topics

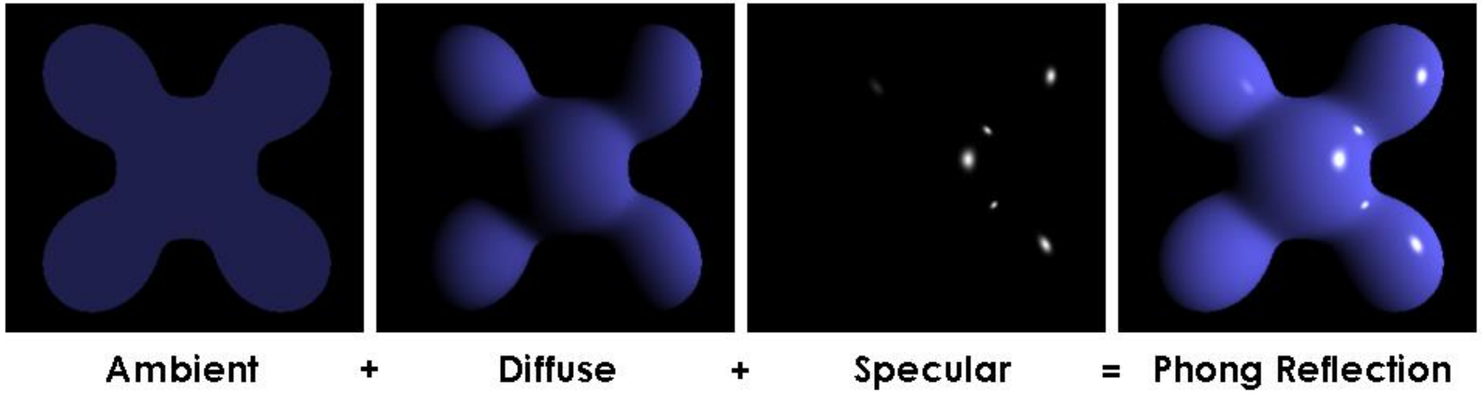
1. Introduction: What is Computer Graphics?
2. Raster Images (image input/output devices and representation)
3. Scan conversion (pixels, lines, triangles)
4. Ray Casting (camera, visibility, normals, lighting, Phong illumination)
5. Ray Tracing (shadows, supersampling, global illumination)
6. Spatial Data Structures (AABB trees, OBB, bounding spheres, octree)
7. Meshes (connectivity, smooth interpolation, uv-textures, subdivision, Laplacian smoothing)
8. 2D/3D Transformations (Translate, Rotate, Scale, Affine, Homography, Homogeneous coordinates)
9. Viewing and Projection (matrix composition, perspective, Z-buffer)
10. Shader Pipeline (Graphics Processing Unit)
11. Animation (kinematics, keyframing, Catmull-Romm interpolation, physical simulation)
12. 3D curves and objects (Hermite, Bezier, cubic curves, curve continuity, extrusion/revolve surfaces)
13. Advanced topics overview

Topic 5.

Ray Tracing

*Adapted from slides by Steve Marschner

Phong Illumination



Usually include ambient, diffuse, Phong in one model

$$
\begin{aligned}
L &= L_a + L_d + L_s \\
&= k_a\, I_a + k_d\, (I/r^2)\max(0, \mathbf{n}\cdot\mathbf{l}) + k_s\, (I/r^2)\max(0, \mathbf{n}\cdot\mathbf{h})^p
\end{aligned}
$$

The final result is the sum over many lights

$$
L = L_a + \sum_{i=1}^{N} [(L_d)_i + (L_s)_i]
$$

$$
\begin{aligned}
L = k_a\, I_a + \sum_{i=1}^{N} \big[& k_d\, (I_i/r_i^2)\max(0, \mathbf{n}\cdot\mathbf{l}_i) + \\
& k_s\, (I_i/r_i^2)\max(0, \mathbf{n}\cdot\mathbf{h}_i)^p \big]
\end{aligned}
$$

Mirror reflection

Consider perfectly specular/shiny surface

- there isn't a highlight
- instead there's a reflection of other objects

Can render this using recursive ray tracing

- to find out mirror reflection color, ask what color is seen from surface point in reflection direction
- already computing reflection direction for Phong…

"Glazed" material has mirror reflection and diffuse

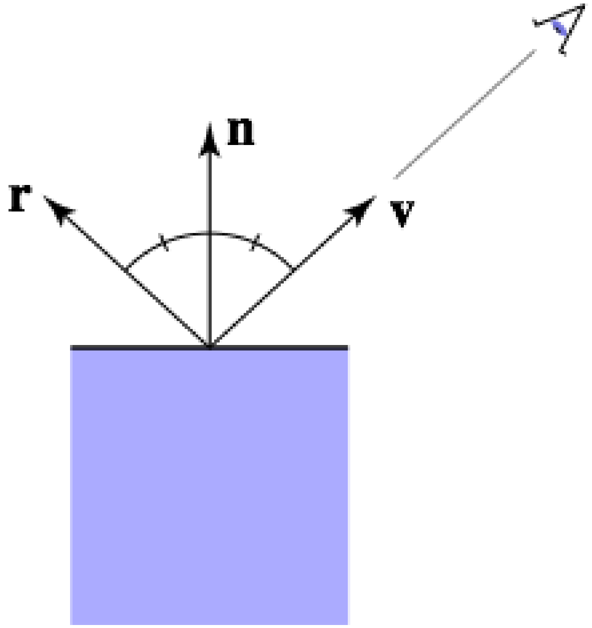
$$L = L_a + L_d + L_m$$

where L_m is evaluated by tracing a new ray

Mirror reflection

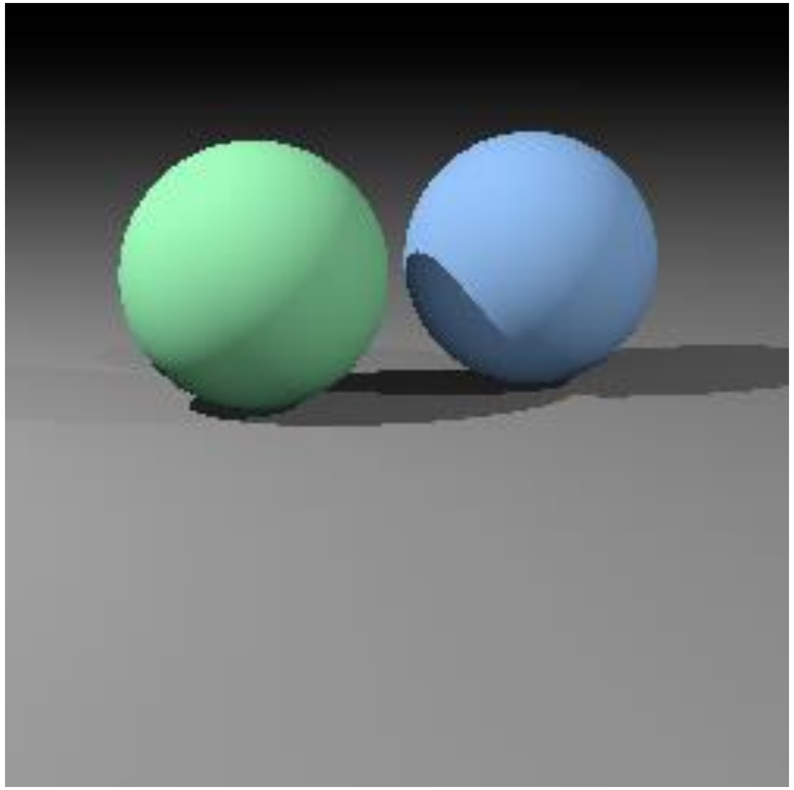
Intensity depends on view direction

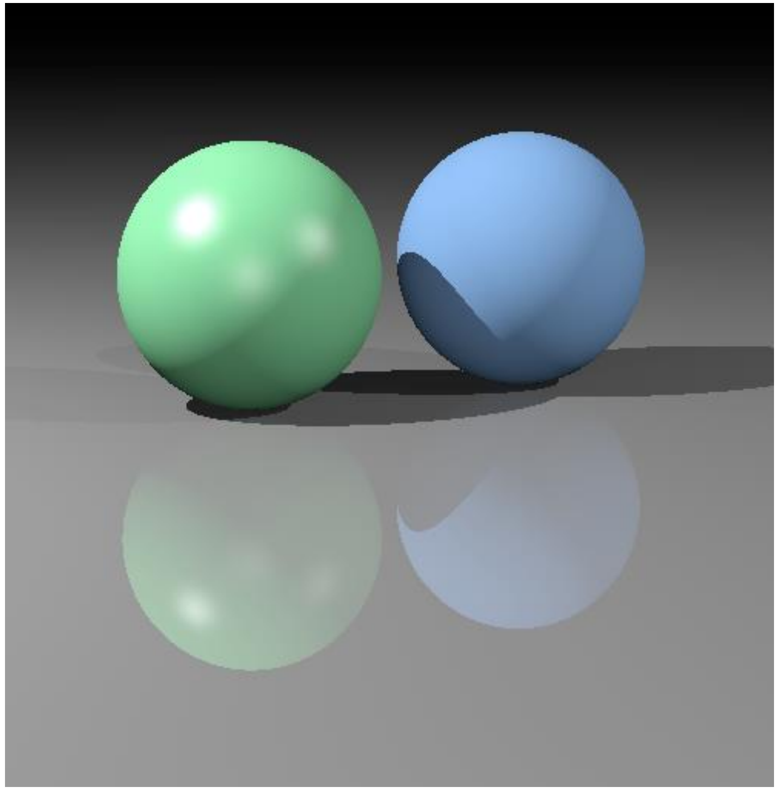
- reflects incident light from mirror direction



$$\mathbf{r} = \mathbf{v} + 2((\mathbf{n} \cdot \mathbf{v})\mathbf{n} - \mathbf{v})$$
$$= 2(\mathbf{n} \cdot \mathbf{v})\mathbf{n} - \mathbf{v}$$

Reflection





Local vs. Global Illumination

Local Illumination Models

- e.g. Phong
- Model source from a light reflected once off a surface towards the eye.
- Indirect light is included with an ad hoc “ambient” term which is normally constant across the scene.

Global Illumination Models

- e.g. recursive ray tracing (incomplete model).
- Try to measure light propagation in the scene.
- Model interaction between objects, other objects, and their environment

Categories of light transport

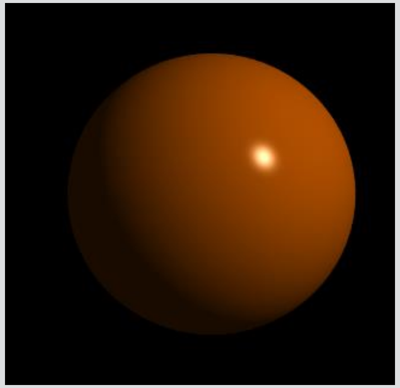
- Specular-Specular
- Specular-Diffuse
- Diffuse-Diffuse
- Diffuse-Specular

Ray Tracing

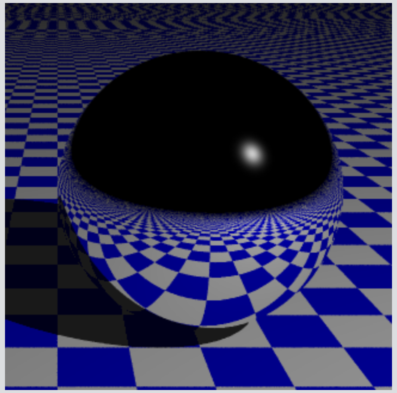
- Traces path of specularly reflected or transmitted/refracted rays through environment
- Rays are infinitely thin
- Don’t disperse
- Signature: shiny objects exhibiting sharp, multiple reflections

- Transport   E - S – S – S – D – L.

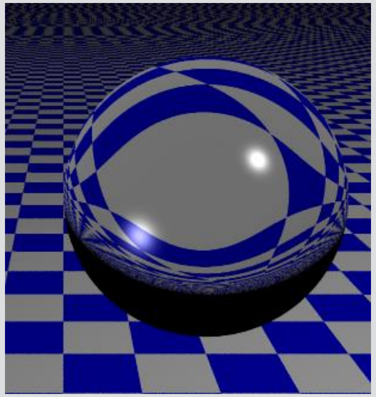
local illumination

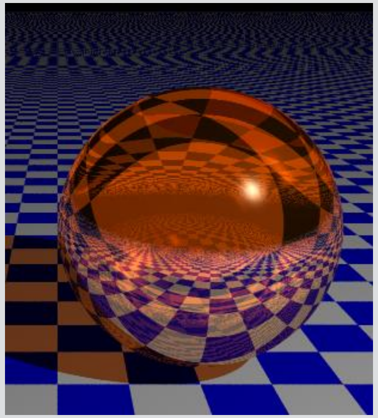


reflection

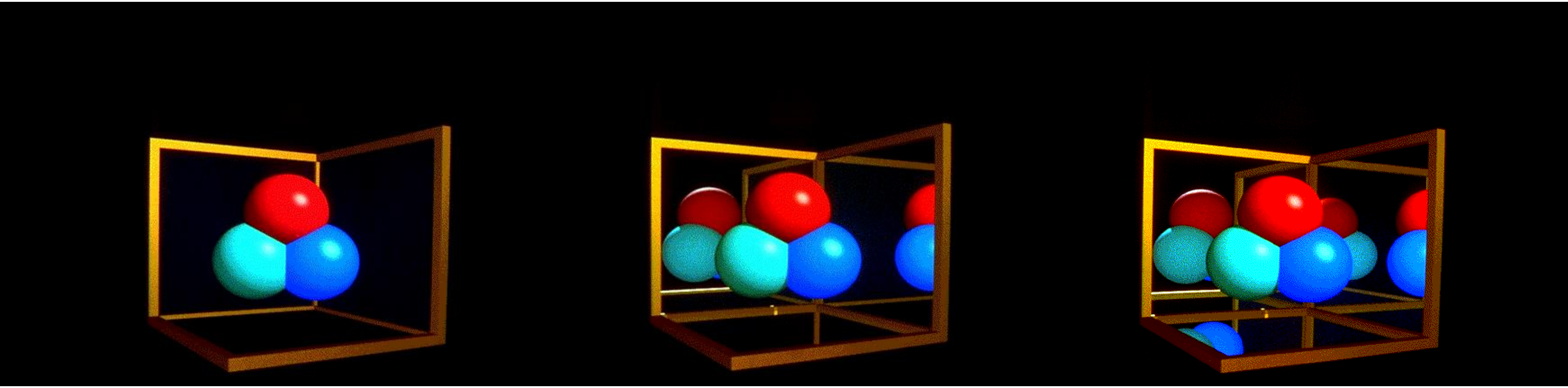


refraction

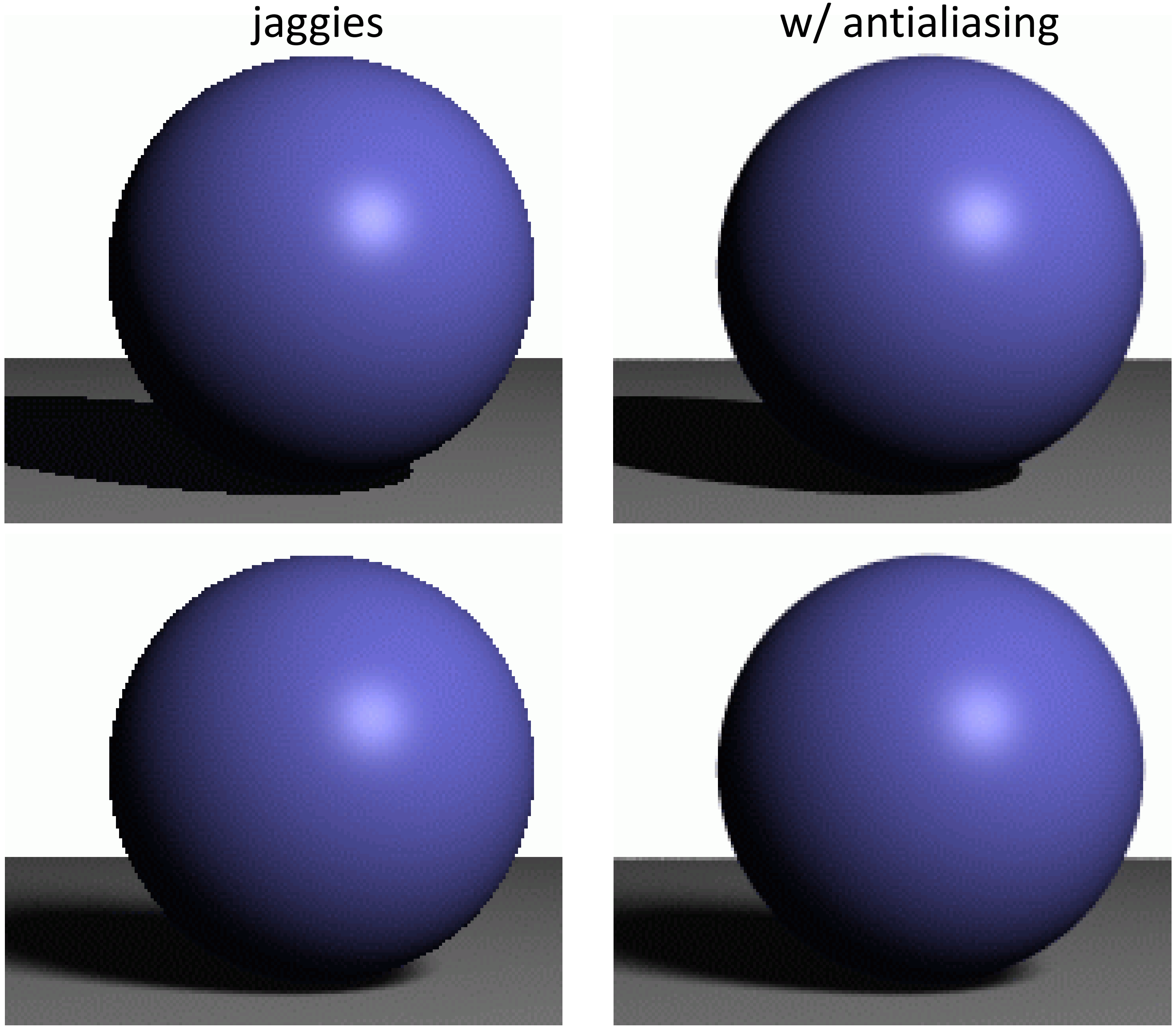




Ray Tracing recursion



Ray Tracing supersampling



Ray Tracing

- Unifies in one framework
  - Hidden surface removal
  - Shadow computation
  - Reflection of light
  - Refraction of light
  - Global **specular** interaction

Ray Tracing: Advantages

- **Customizable:** modular approach for ray sampling, ray object Intersections and reflectance models.

- **Variety of visual effects:** shadows, reflections, refractions, indirect illumination, depth of field etc.

- **Parallelizable:** each ray path is independent.

- **Speed vs. Accuracy trade-off:** # and recursive depth of rays cast.

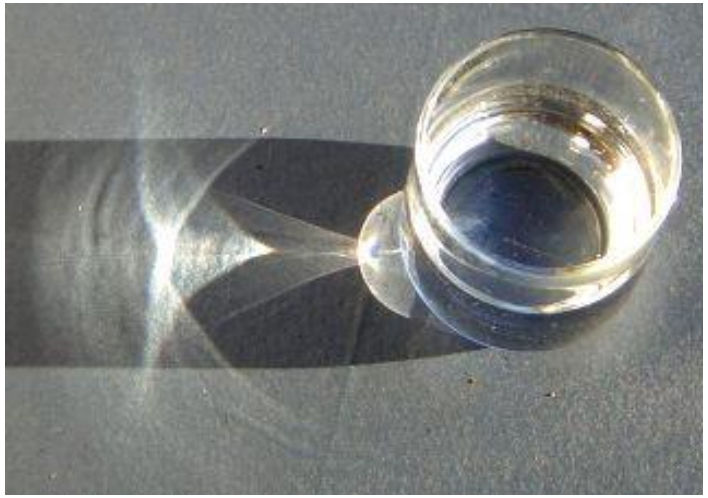
Ray Tracing Deficiencies

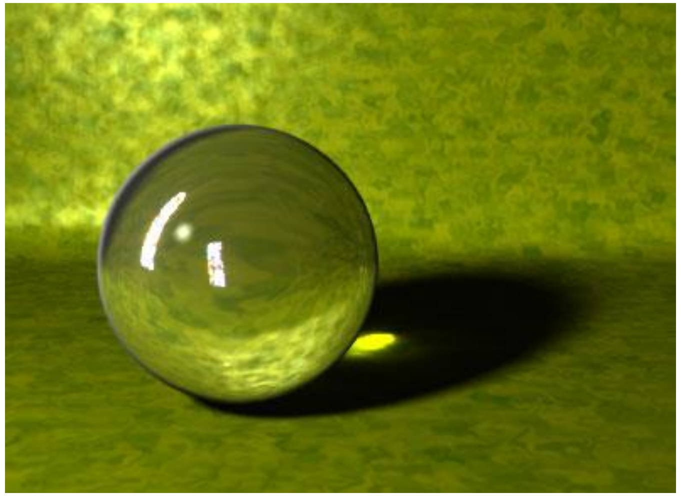
- Ignores light transport mechanisms involving diffuse surfaces.
- Intersection computation time can be long (solution: **bounding volumes**).
- Recursive algorithm can lead to exponential complexity (solution: stochastic sampling).

Ray Tracing Improvements: Caustics

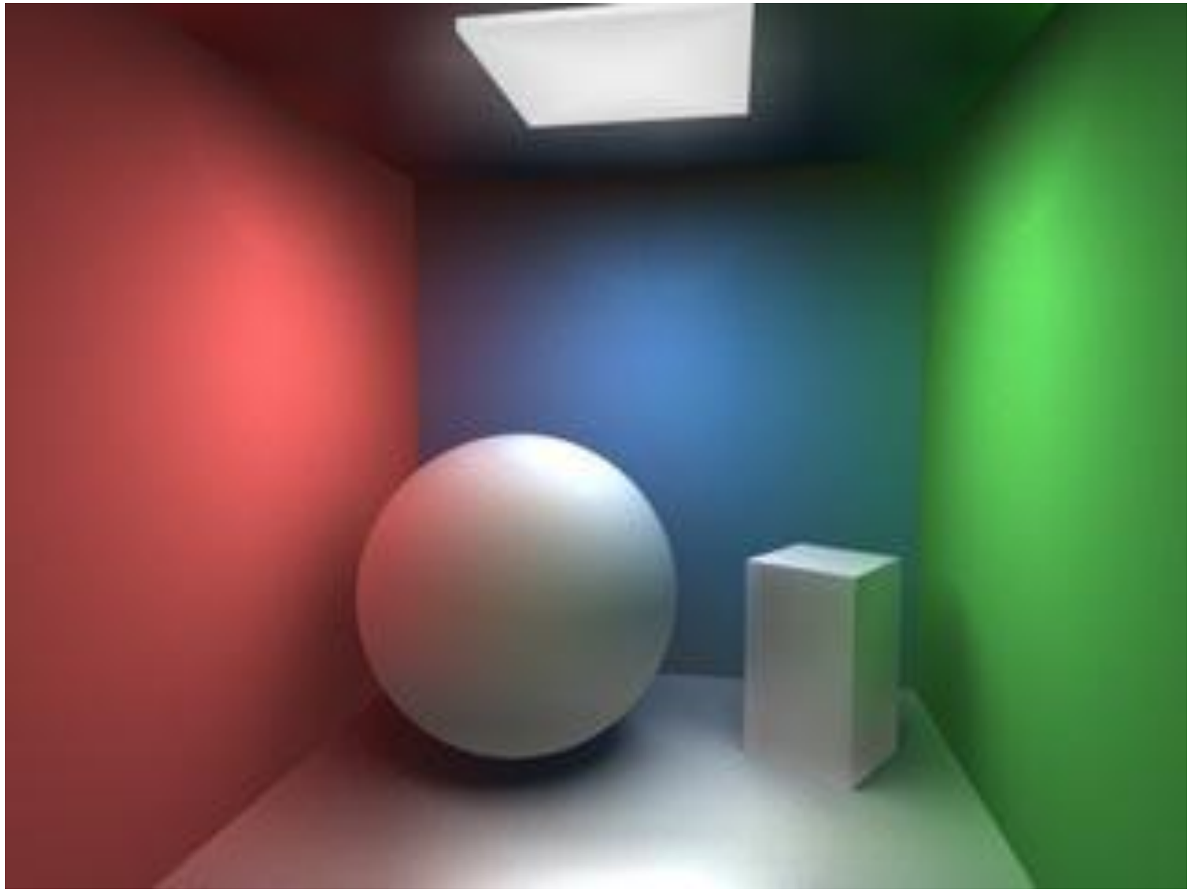
Backwards ray tracing

- Trace from the light to the surfaces and then from the eye to the surfaces
- “shower” scene with light and then collect it
- “Where does light go?” vs “Where does light come from?”
- Good for caustics
- Transport E – S – S – S - D – S – S – S - L





Radiosity: E – D – D – D - L



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