INFOGR – Computer Graphics

Jacco Bikker & Debabrata Panja - April-July 2017

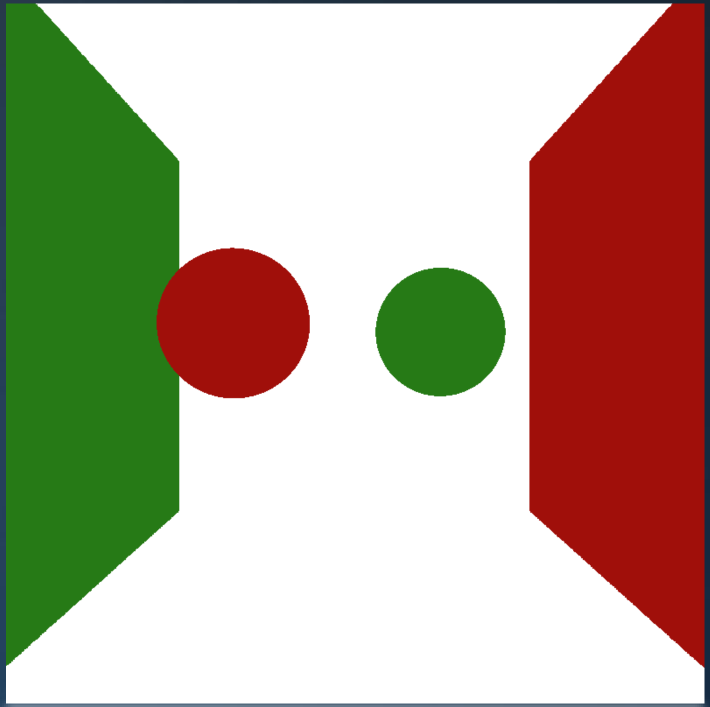
Lecture 3: “Ray Tracing (2)”

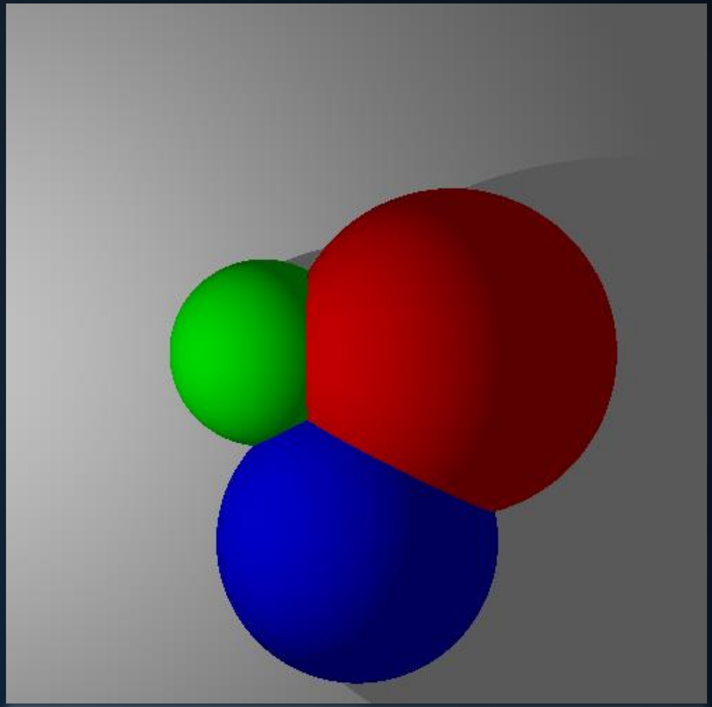
Welcome!

Today's Agenda:

- Recap
- Normals
- Assignment P2
- Reflections
- Recursion
- Shading models
- TODO

Recap





Recap

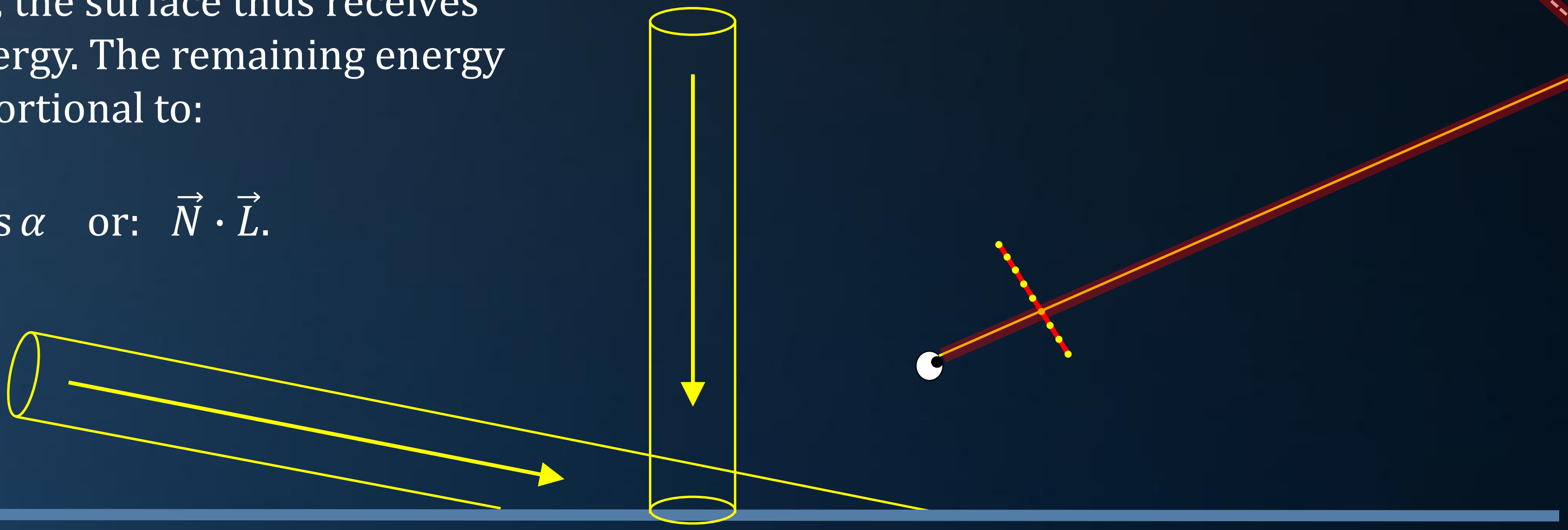
Transport

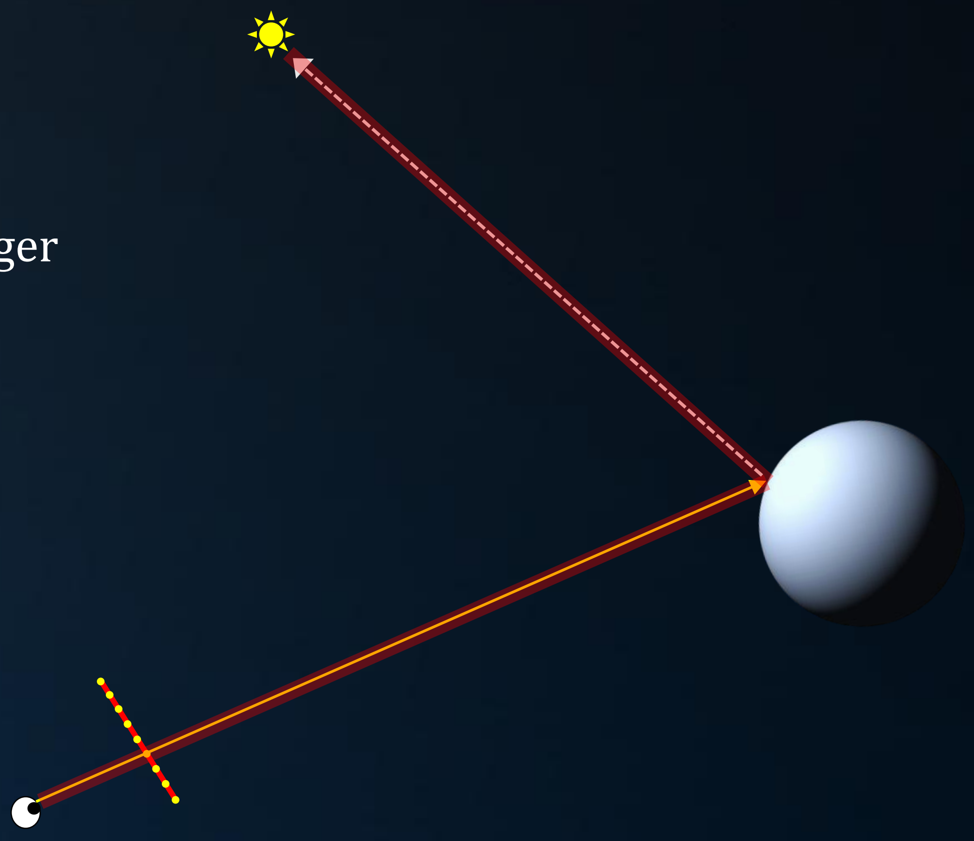
Energy arriving at an angle:

A small bundle of light arriving at a surface affects a larger area than the cross-sectional area of the bundle.

Per m^2, the surface thus receives less energy. The remaining energy is proportional to:

$$\cos\alpha \quad \text{or:} \quad \vec{N}\cdot\vec{L}.$$





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Normals

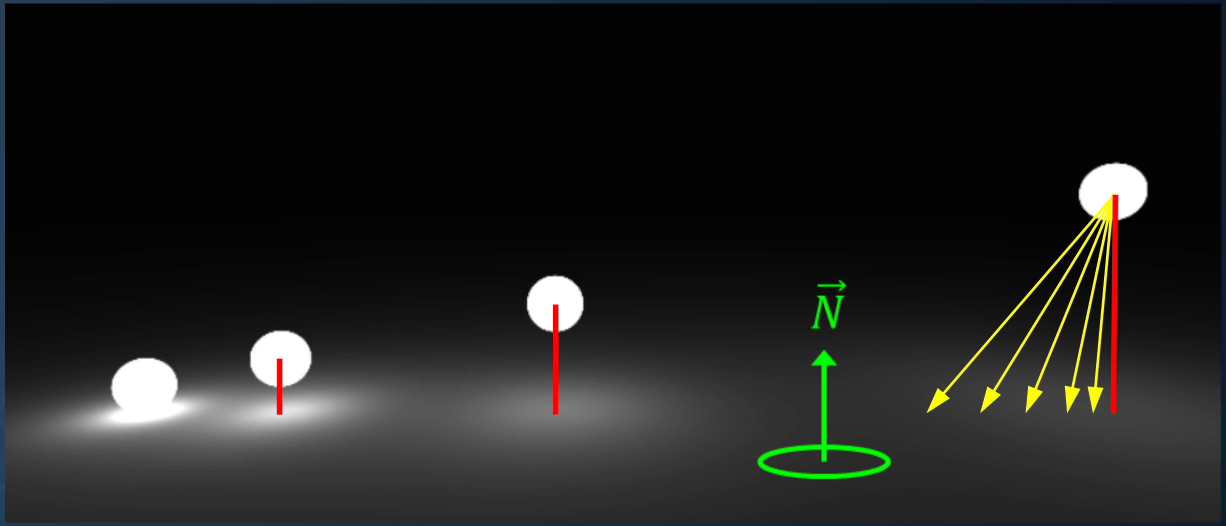
Fun fact: $\begin{pmatrix} A \\ B \\ C \end{pmatrix}$ *is* the normal.

A plane is the set of points that are at distance 0 from the plane.
Distance increases when we move away from the plane.
We move away from the plane my moving in the direction of the normal.

We Need a Normal

For a plane, we already have the normal.

$$Ax + By + Cz + D = 0 \quad \text{or} \quad \left(P \cdot \vec{N}\right) + D = 0$$



Distance attenuation: $1/r^2$

Angle of incidence: $N \cdot L$

Normals

We Need a Normal

Question:

How does light intensity relate to scene size?
i.e.: if I scale my scene by a factor 2, what should I do to my lights?

➔ Distance attenuation requires scaling light intensity by 2^2

➔ Scene scale does not affect $N \cdot L$.

Normals

We Need a Normal

Question:

What happens when a light is near the horizon?

➔ Angle approaches 90°; cos α approaches 0
(and so does $\vec{N} \cdot \vec{L}$)

➔ Light is distributed over an infinitely large surface
(so, per unit area it becomes 0)

Note: below the horizon, cos α becomes negative.
➔ Clamp $\vec{N} \cdot \vec{L}$ to zero.

Normals

We Need a Normal

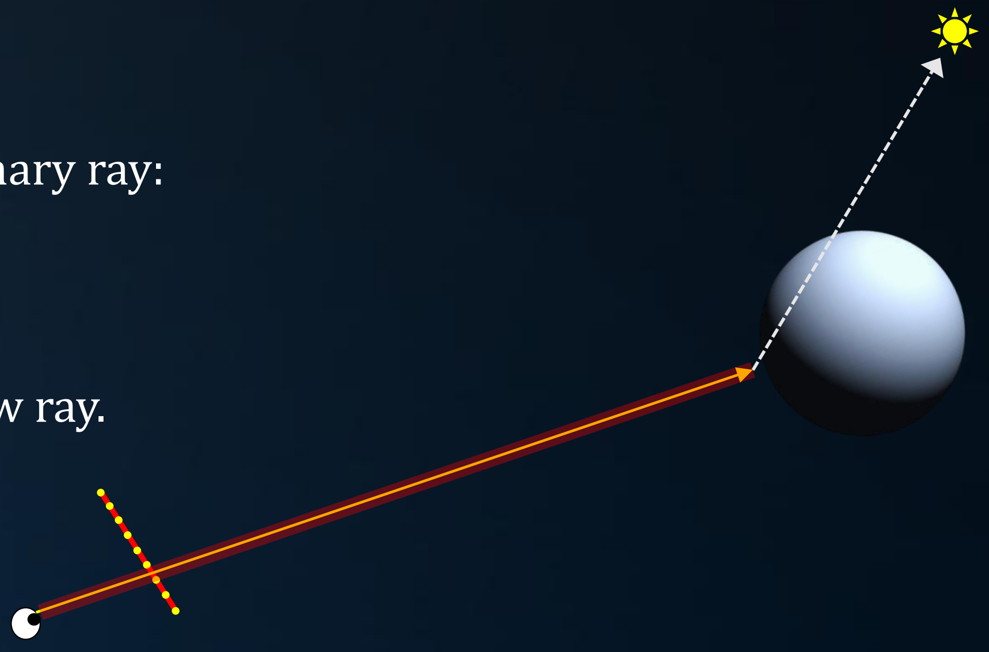
Normals are also used to *prevent* shadow rays.

Situation:

A light source is behind the surface we hit with the primary ray:

$$\vec{N} \cdot \vec{L} < 0$$

In this case, visibility is 0, and we do not cast the shadow ray.



Normals

We Need a Normal

Normals for spheres:

The normal for a sphere at a point P on the sphere is parallel to the vector from the center of the sphere to P.

$$\vec{N}_P = \frac{P - C}{||P - C||}$$

Normals

We Need a Normal

Normals for spheres:

When a sphere is hit from the inside, we need to *reverse* the normal.

$$\vec{N}_P = \frac{C - P}{||P - C||}$$

How to detect this situation when it is not trivial:

1. Calculate the normal in the usual manner $(P - C)$;
2. If $\vec{N}_P \cdot \vec{D}_{ray} < 0$ then $\vec{N}_P = -\vec{N}_P$.

Normals

Normal Interpolation

Simulating smooth surfaces using normal interpolation:

1. Generate *vertex normals*.

A vertex normal is calculated by averaging the normals of the triangles connected to the vertex and normalizing the result.

2. Interpolate the normals over the triangle.

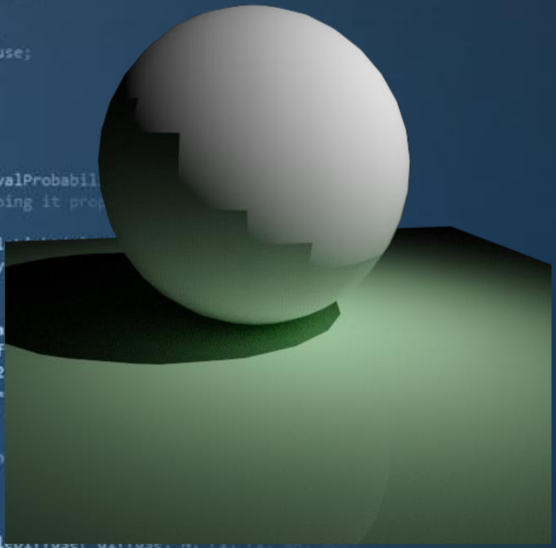
In a ray tracer, use barycentric coordinates to do this. Normalize the interpolated normal.

Normals

Normal Interpolation

Using the interpolated normal:

- Use the interpolated normal in the $\vec{N} \cdot \vec{L}$ calculation.
- Use the original face normal when checking if a light is visible.



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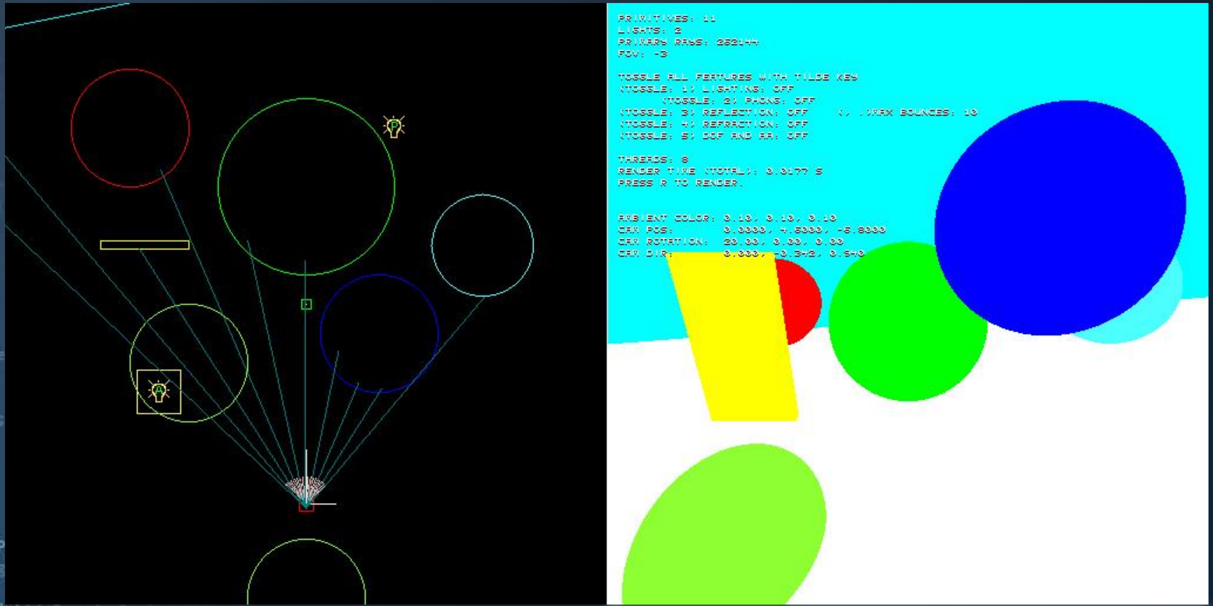
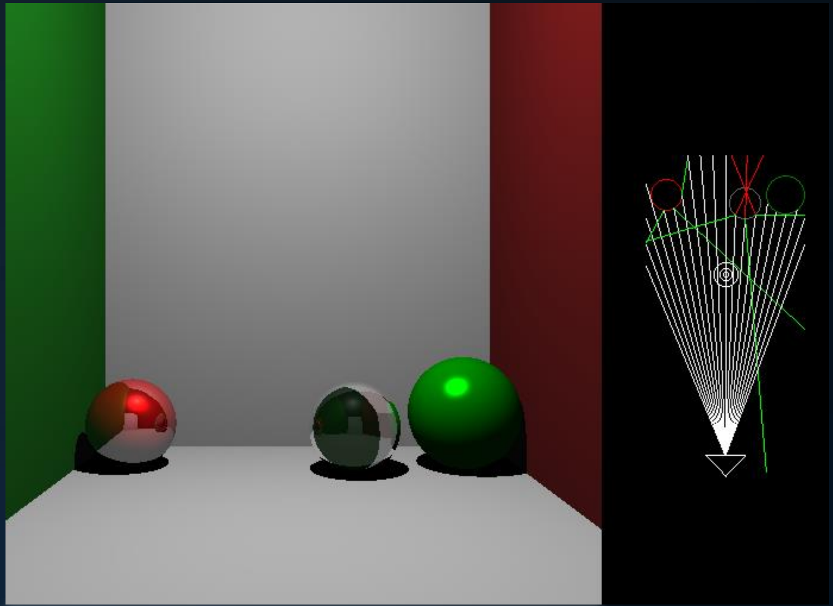
Assignment P2

1k-sw-raytrace'em all by Tristar & Red Sector Inc. (2004)

Assignment P2

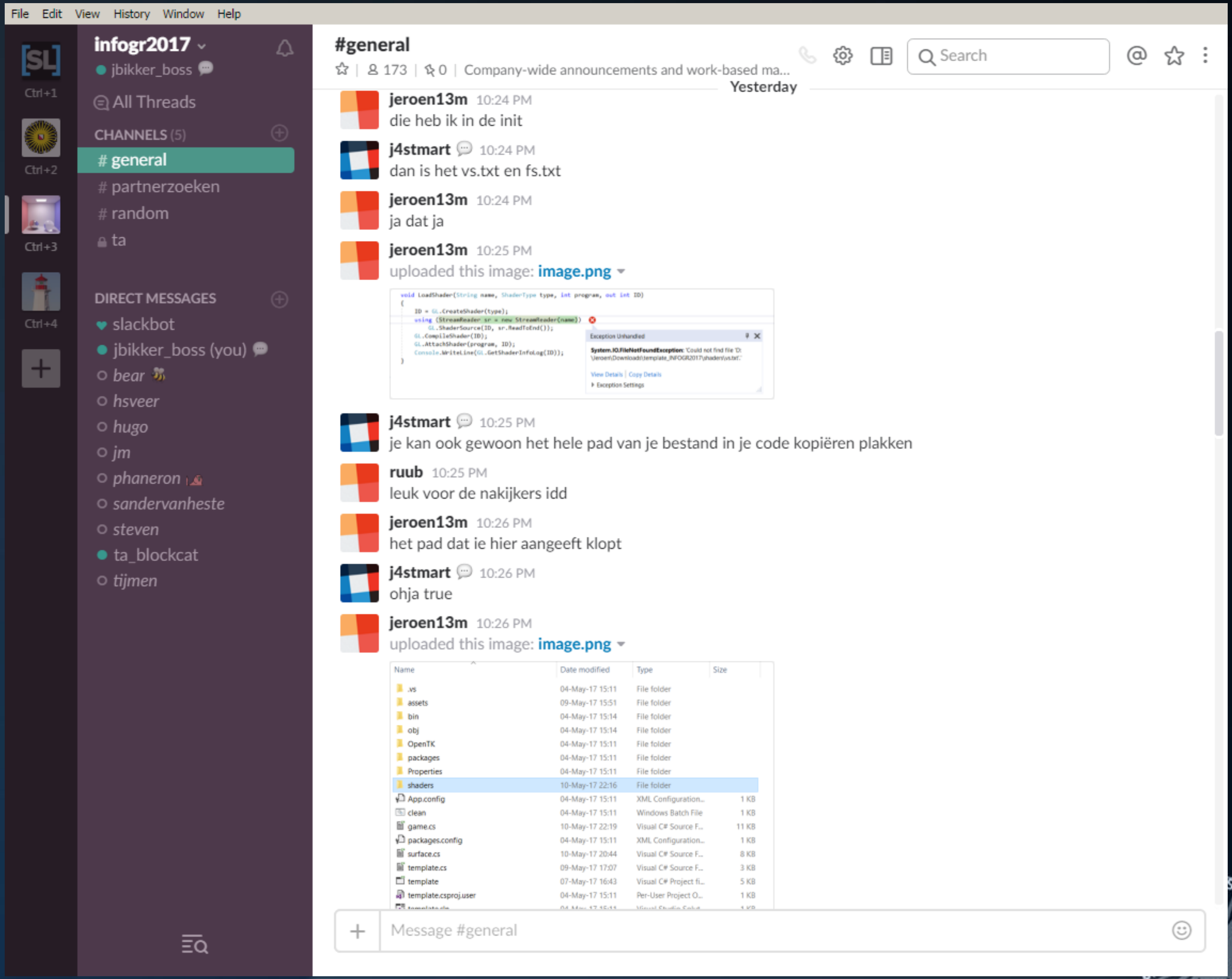
Use That Debug Output!





Assignment P2

Get on Slack!



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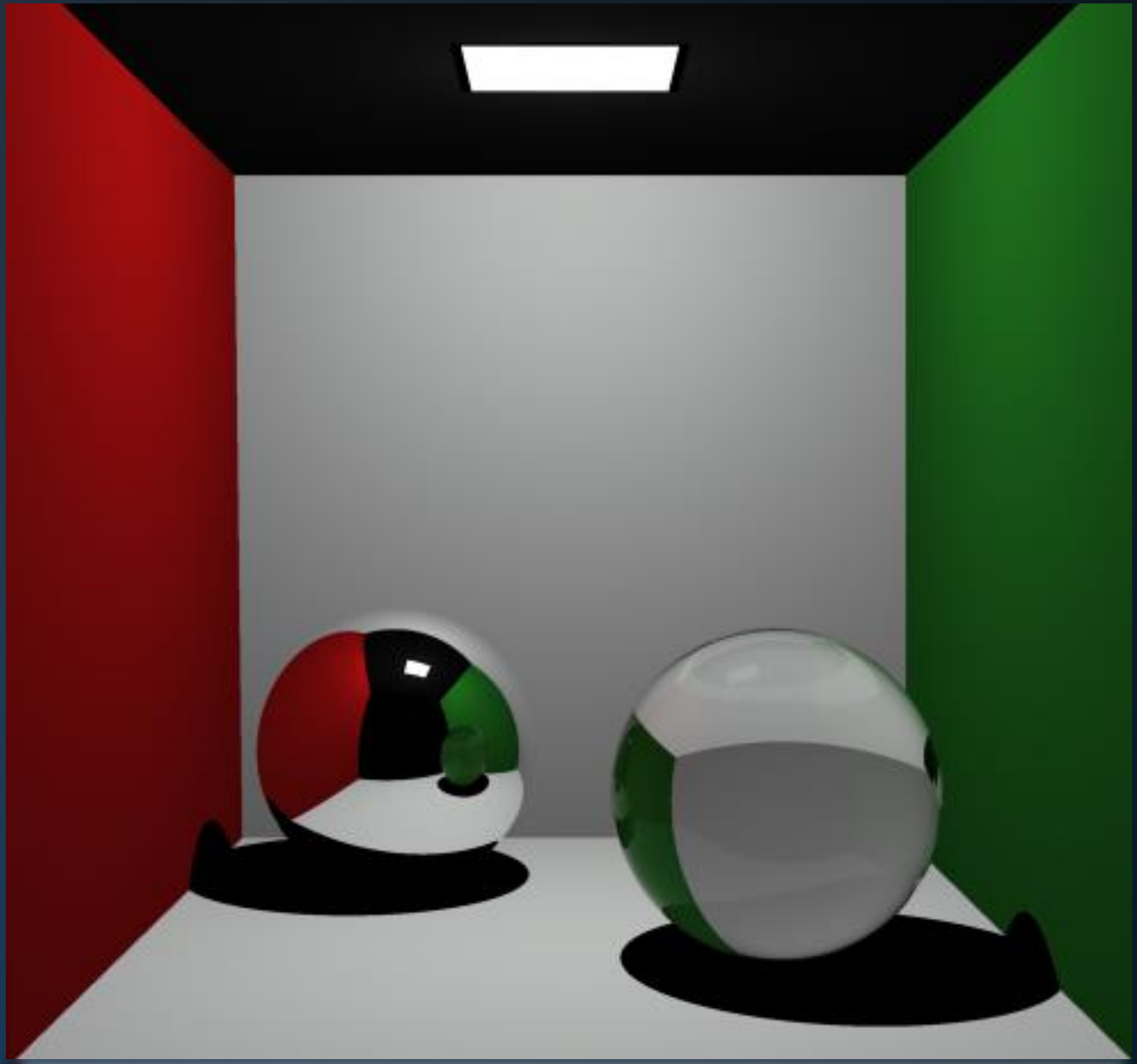
Reflections



Reflections

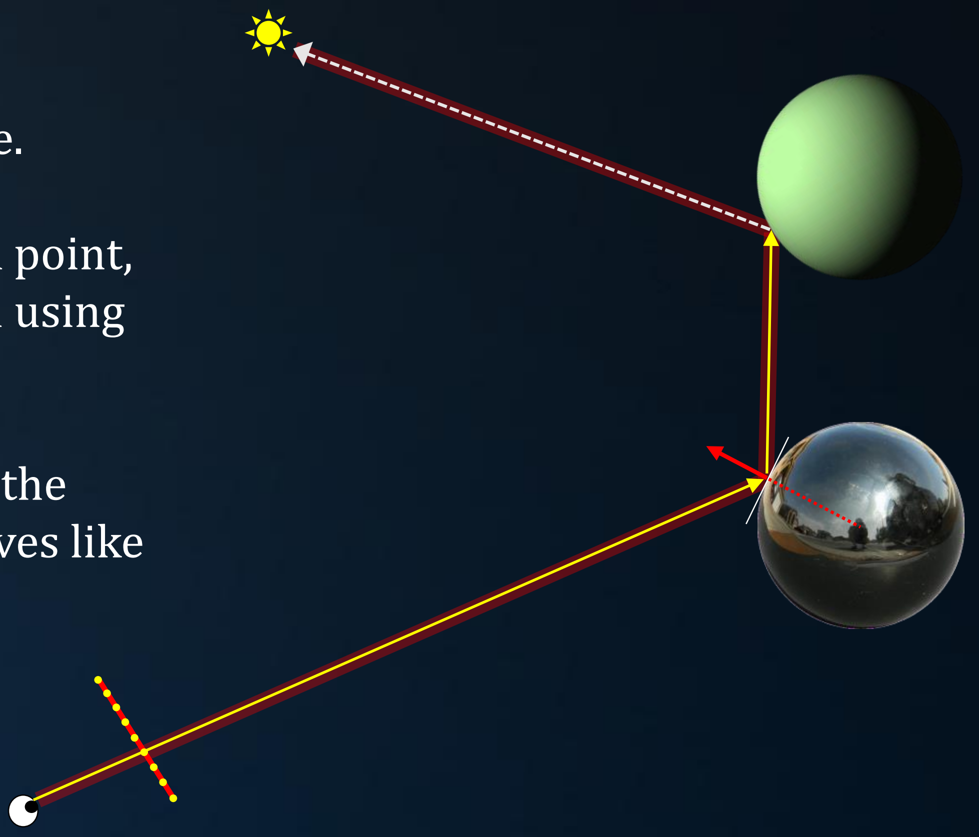
Light Transport

We introduce a *pure specular* object in the scene.

Based on the normal at the primary intersection point, we calculate a new direction. We follow the path using a *secondary ray*.

At the primary intersection point, we ‘see’ what the secondary ray ‘sees’; i.e. the secondary ray behaves like a primary ray.

We still need a shadow ray at the new intersection point to establish light transport.



Reflections

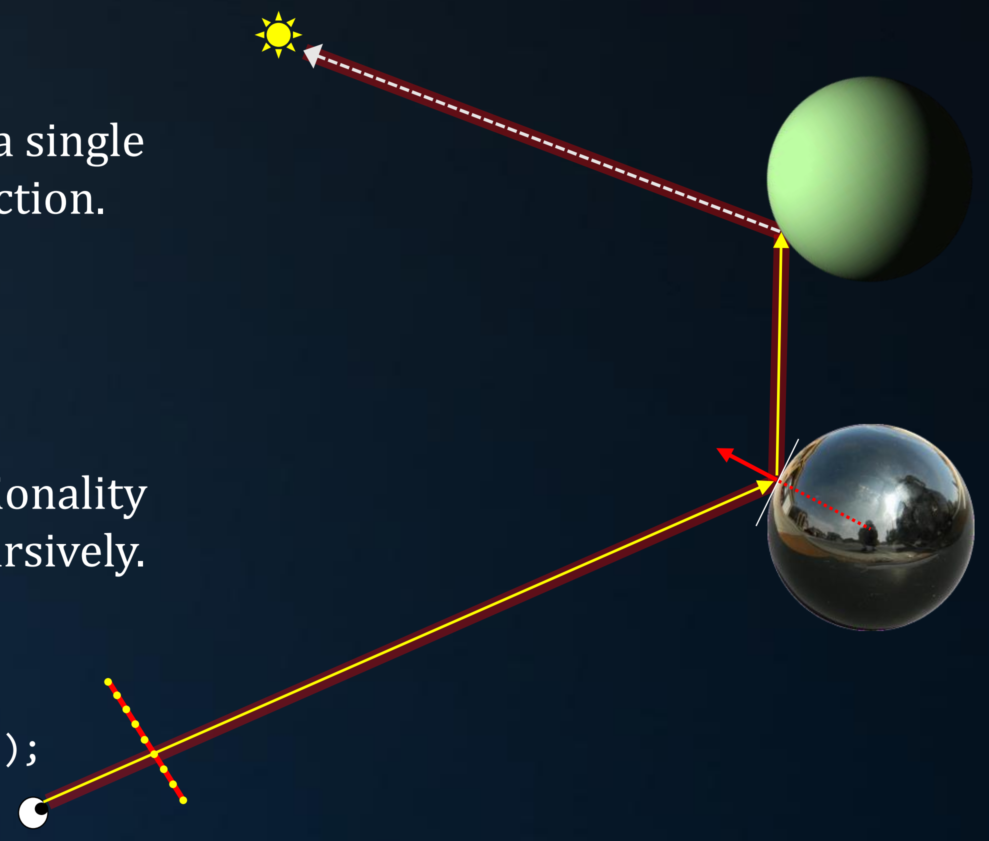
Light Transport

For a pure specular reflection, the energy from a single direction is reflected into a single outgoing direction.

- We do not apply $\vec{N} \cdot \vec{L}$
- We do apply absorption

Since the reflection ray requires the same functionality as a primary ray, it helps to implement this recursively.

```
vec3 Trace( Ray ray )
{
   I, N, material = scene.GetIntersection( ray );
   if (material.isMirror)
      return material.color * Trace( … );
   return DirectIllumination() * material.color;
}
```

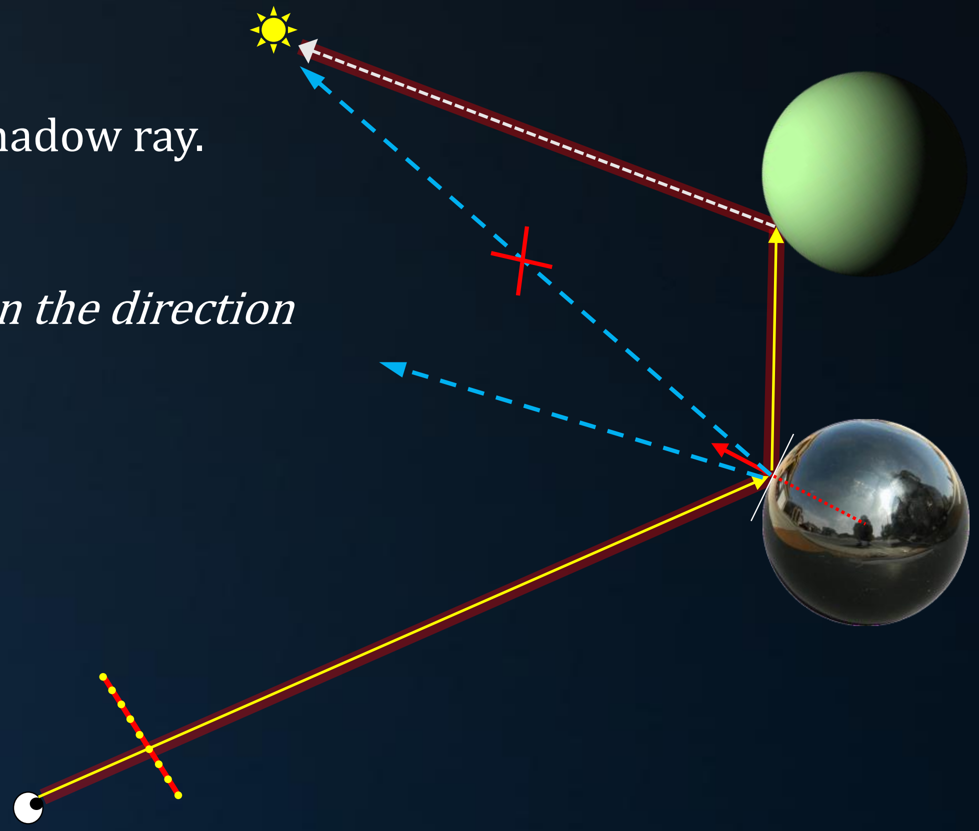


Reflections

Light Transport

For pure specular reflections we do not cast a shadow ray.

Reason:
Light arriving from that direction cannot leave in the direction of the camera.



Reflections

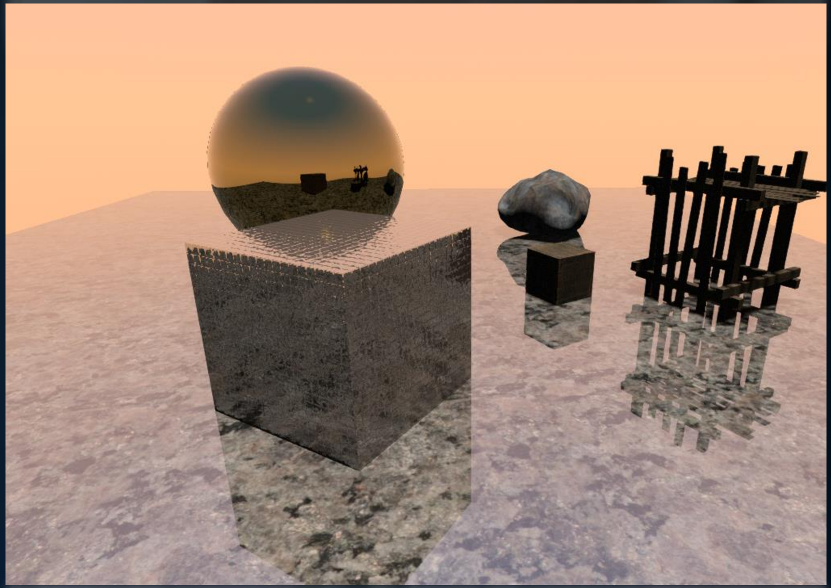
Reflections

Partially Reflective Surfaces

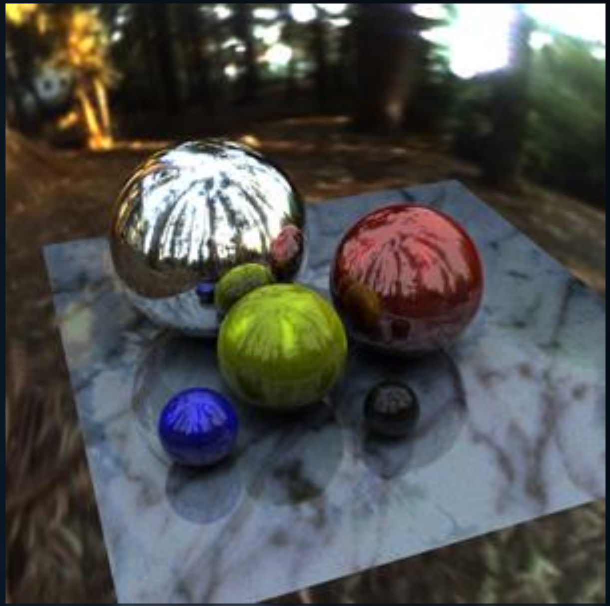
We can combine pure specularity and diffuse properties.

Situation: our material is only 50% reflective.

In this case, we send out the reflected ray, and multiply its yield by 0.5. We also send out a shadow ray to get direct illumination, and multiply the received light by 0.5.



Reflections



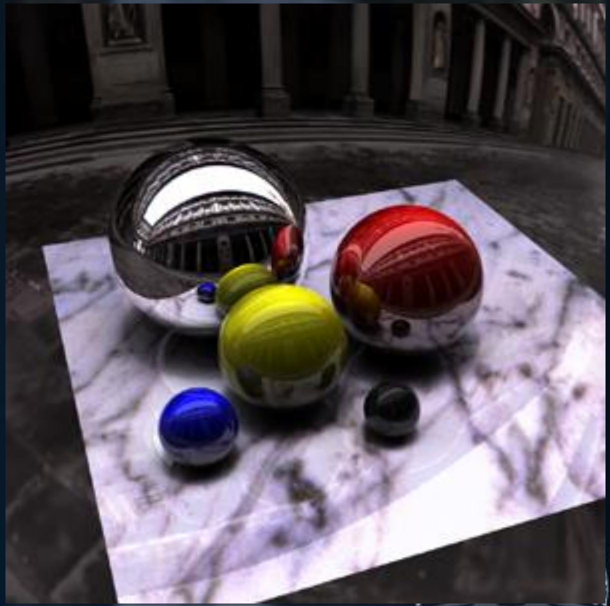
Reflecting a HDR Sky

A dark object can be quite bright when reflecting something bright.

E.g., a bowling ball, pure specular, color = (0.01, 0.01, 0.01); reflecting a 'sun' stored in a HDR skydome, color = (100, 100, 100).

For a collection of HDR probes, visit Paul Debevec's page:

http://www.pauldebevec.com/Probes



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Recursion

Whitted-style Ray Tracing, Pseudocode

```
Color Trace( vec3 O, vec3 D )
{
   I, N, mat = IntersectScene( O, D );
   if (!I) return BLACK;
   return DirectIllumination( I, N ) * mat.diffuseColor;
}

Color DirectIllumination( vec3 I, vec3 N )
{
   vec3 L = lightPos – I;
   float dist = length( L );
   L *= (1.0f / dist);
   if (!IsVisibile( I, L, dist )) return BLACK;
   float attenuation = 1 / (dist * dist);
   return lightColor * dot( N, L ) * attenuation;
}
```

Todo:

- Implement IntersectScene
- Implement IsVisible

Recursion

Whitted-style Ray Tracing, Pseudocode

```
Color Trace( vec3 O, vec3 D )
{
   I, N, mat = IntersectScene( O, D );
   if (!I) return BLACK;
   if (mat.isMirror())
   {
      return Trace( I, reflect( D, N ) ) * mat.diffuseColor;
   }
   else
   {
      return DirectIllumination( I, N ) * mat.diffuseColor;
   }
}
```

Todo:

Handle partially reflective surfaces.

Recursion

Whitted-style Ray Tracing, Pseudocode

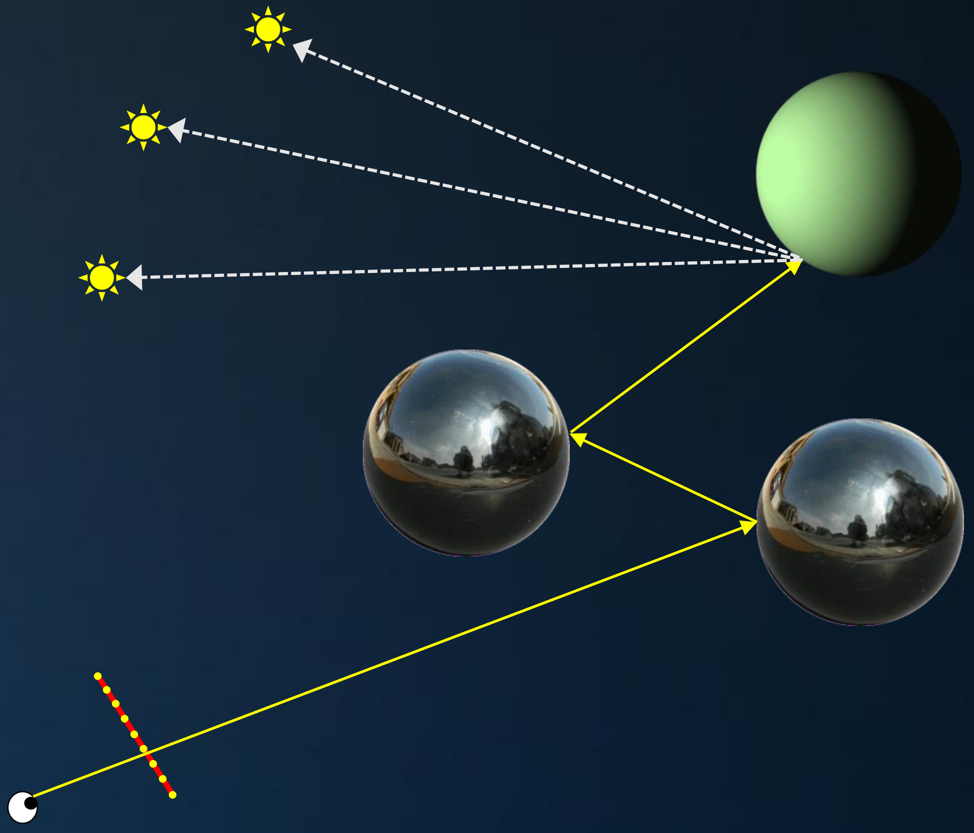
```
Color Trace( vec3 O, vec3 D )
{
   I, N, mat = IntersectScene( O, D );
   if (!I) return BLACK;
   if (mat.isMirror())
   {
      return Trace( I, reflect( D, N ) ) * mat.diffuseColor;
   }
   else if (mat.IsDielectric())
   {
      f = Fresnel( … );
      return (f * Trace( I, reflect( D, N ) )
        + (1-f) * Trace( I, refract( D, N, … ) ) ) * mat.DiffuseColor;
   }
   else
   {
      return DirectIllumination( I, N ) * mat.diffuseColor;
   }
}
```

Todo:

- Implement reflect
- Implement refract
- Implement Fresnel
- Cap recursion

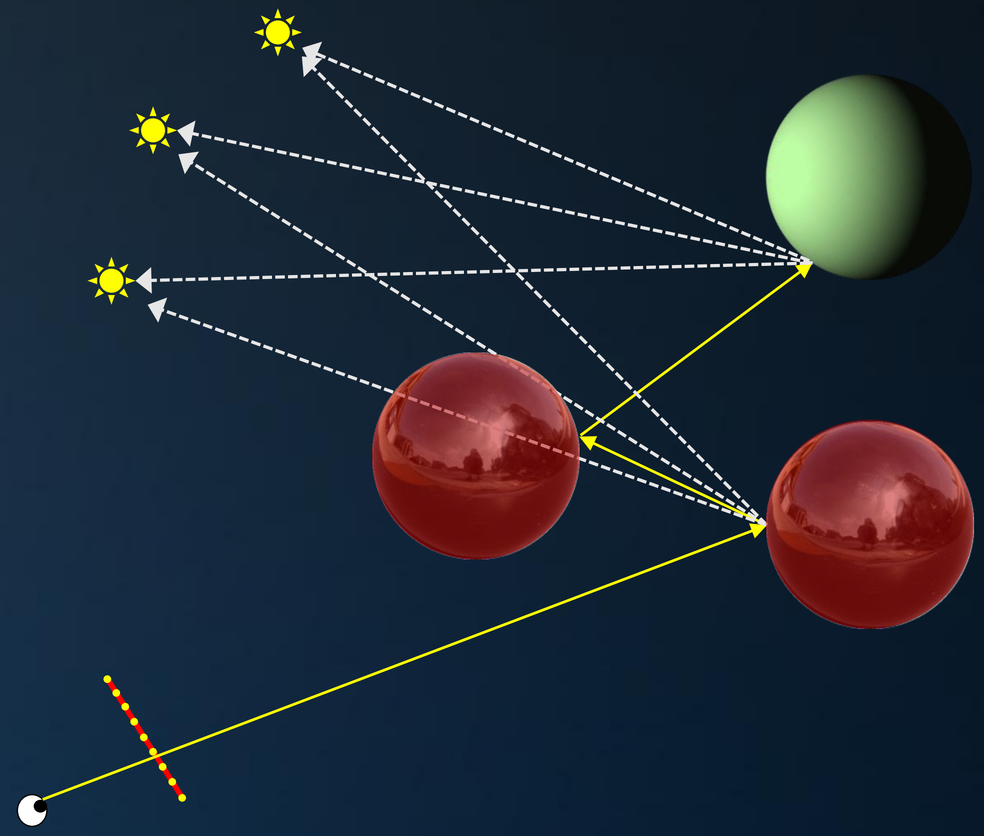
Recursion

Spheres: pure specular



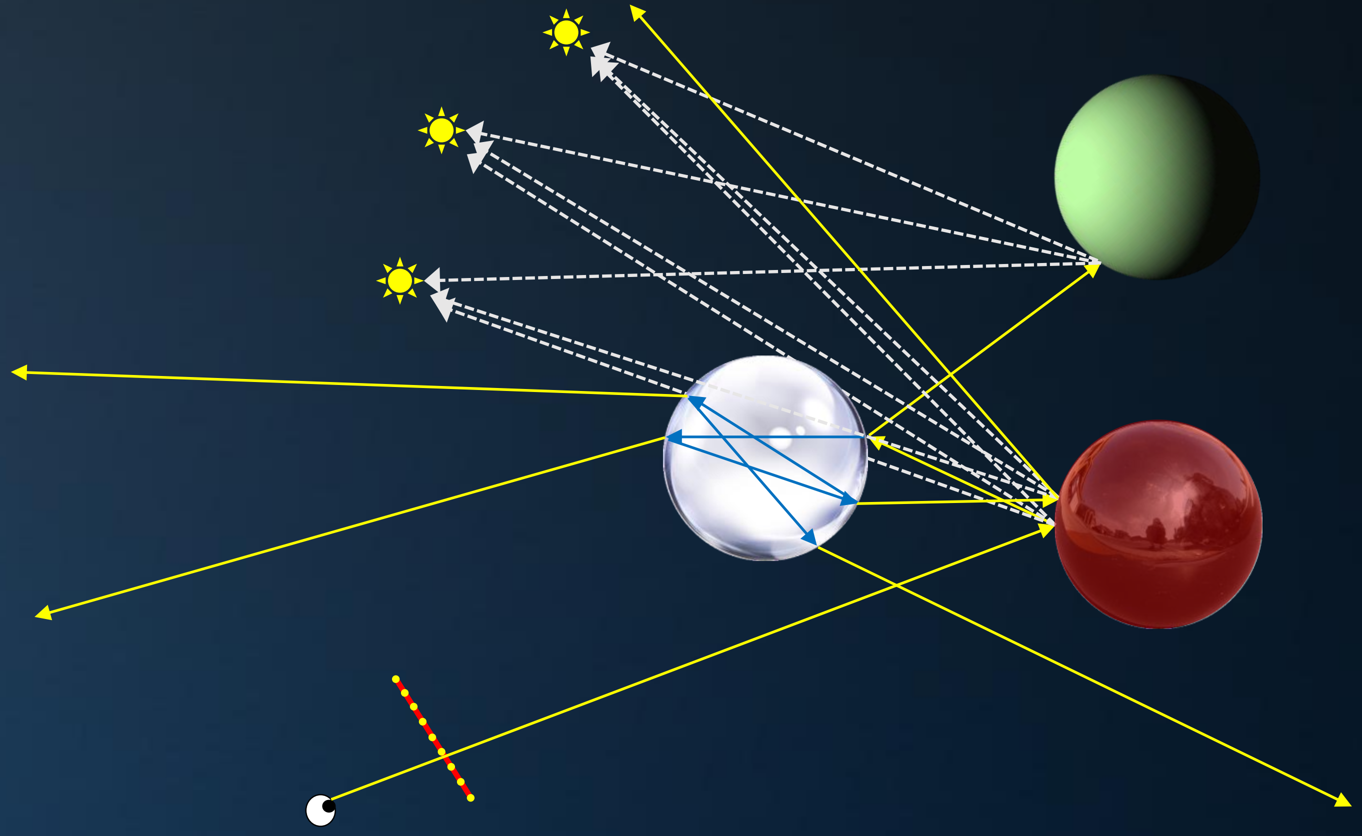
Recursion

Spheres: 50% specular



Recursion

Spheres: one 50% specular, one glass sphere



Recursion

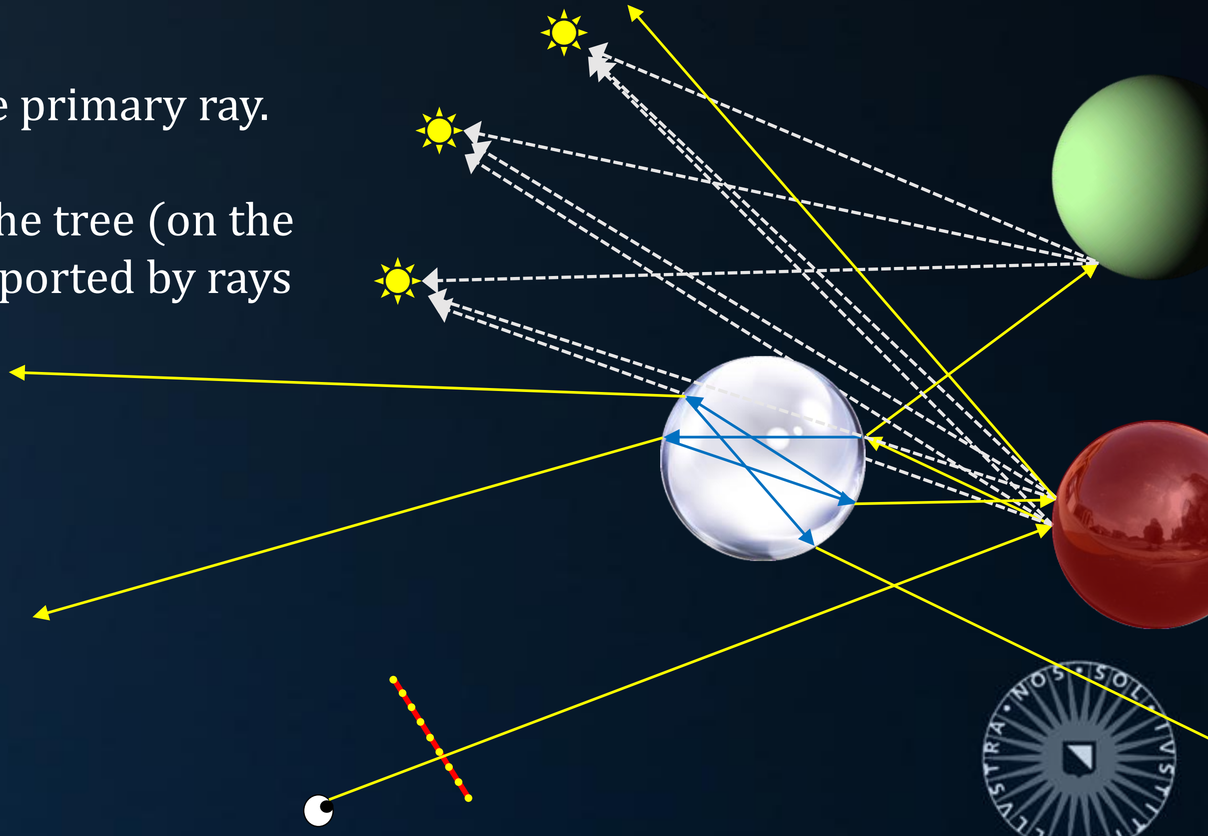
Recursion

Ray Tree

Recursion, multiple light sampling and path splitting in a Whitted-style ray tracer leads to a structure that we refer to as the *ray tree*.

All energy is ultimately transported by a single primary ray.

Since the energy does not increase deeper in the tree (on the contrary), the average amount of energy transported by rays decreases with depth.



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Shading

Diffuse Material

A diffuse material scatters incoming light in all directions.

Incoming: $E_{light} * \frac{1}{dist^2} * \vec{N} \cdot \vec{L}$

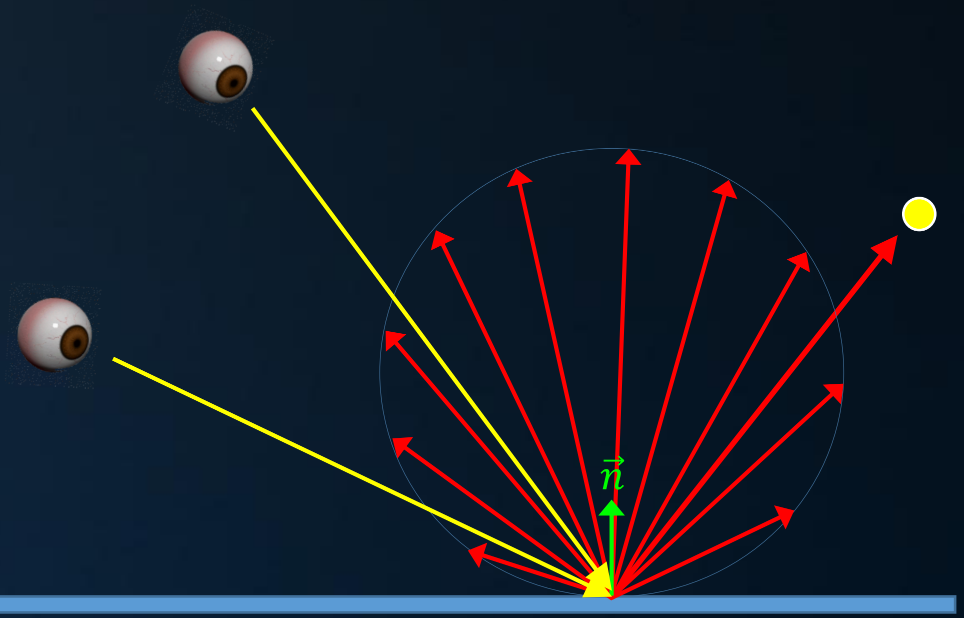
Absorption: $C_{material}$

Reflection: $(\vec{V} \cdot \vec{N})$

Eye sees: $\frac{1}{(\vec{V} \cdot \vec{N})}$

terms cancel out.

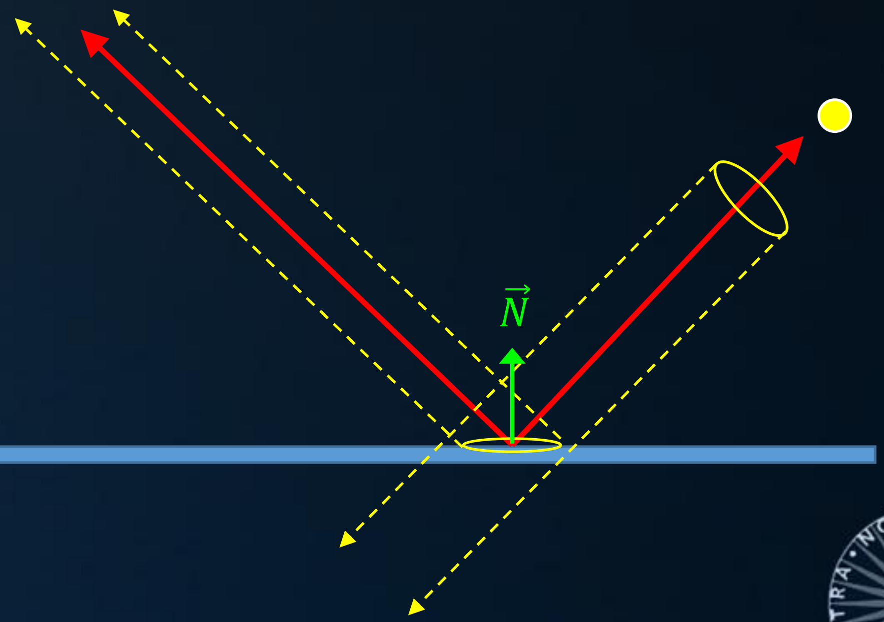
A diffuse material appears the same regardless of eye position.



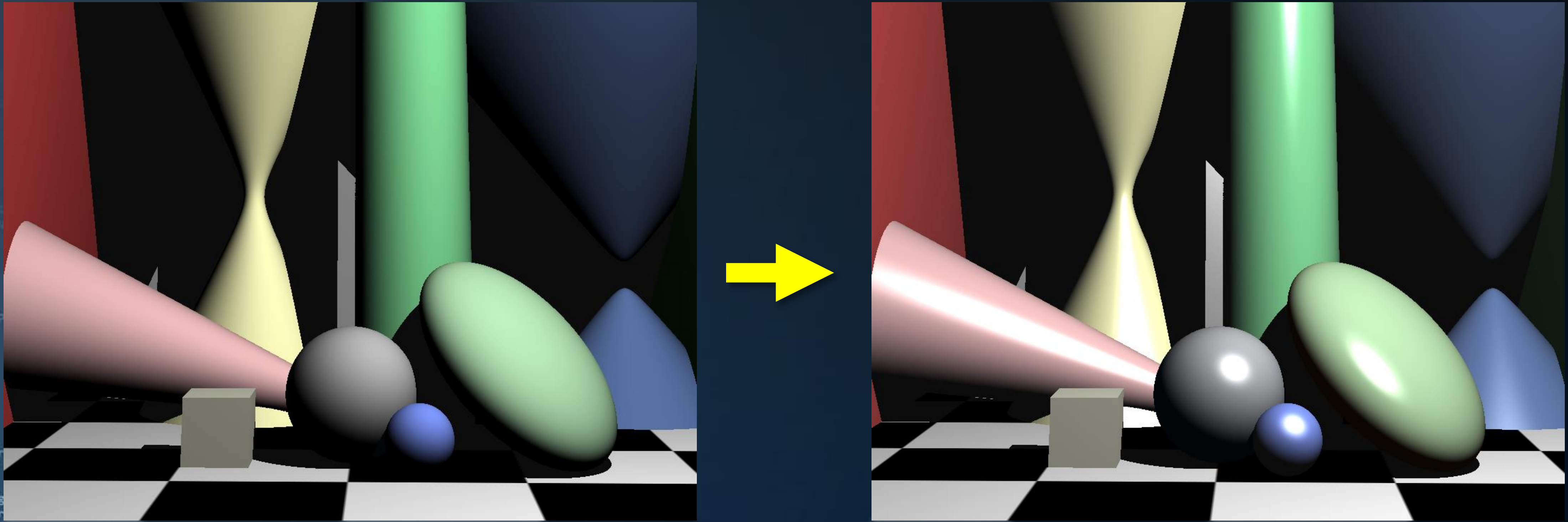
Shading

Specular Material

A specular material reflects light from a particular direction in a single outgoing direction.



Shading



Shading

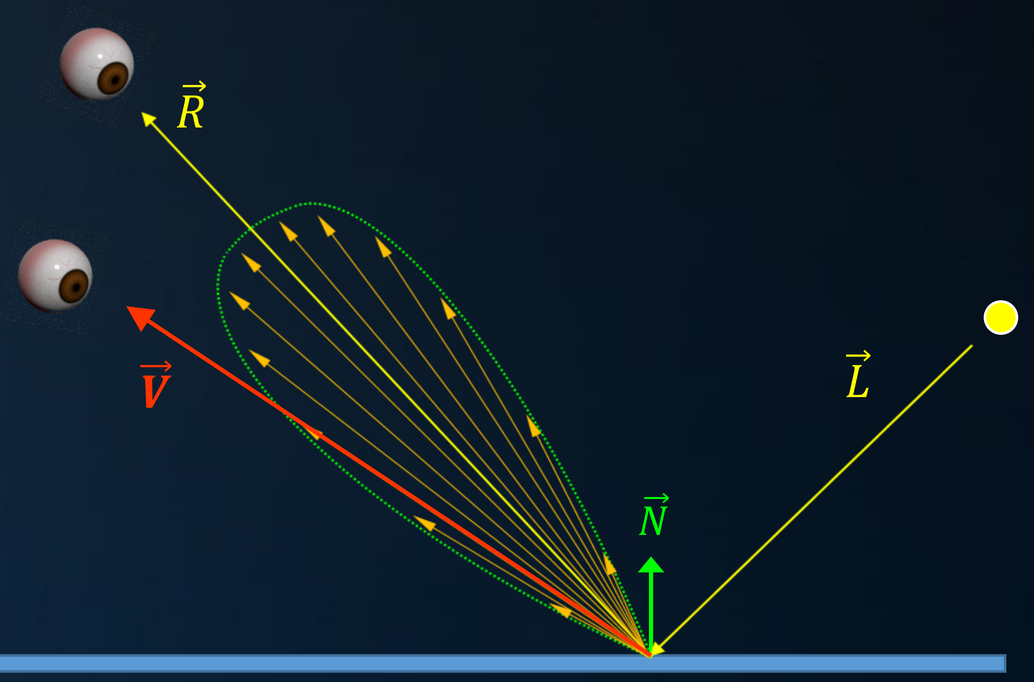
Glossy Material

A glossy material reflects *most* light along the reflected vector.

$$\vec{R} = \vec{L} - 2(\vec{L} \cdot \vec{N})\vec{N}$$

For other directions, the amount of energy is:

$(\vec{V} \cdot \vec{R})^{\alpha}$, where exponent α determines the specularity of the surface.



Shading

Phong Shading

Complex materials can be obtained by blending diffuse and glossy.

$$I = C_{material} * \left(\left(1 - f_{spec}\right)\left(\vec{N} \cdot \vec{L}\right) + f_{spec}\left(\vec{V} \cdot \vec{R}\right)^{\alpha} \right)$$

where

α is the specularity of the glossy reflection;
f_{spec} is the glossy part of the reflection;
$1 - f_{spec}$ is the diffuse part of the reflection.

Note that the glossy reflection *only* reflects light sources.

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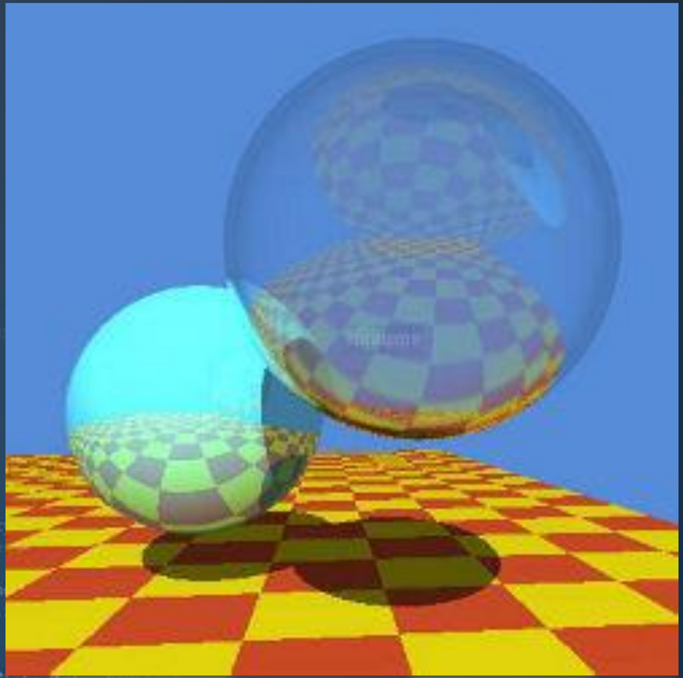
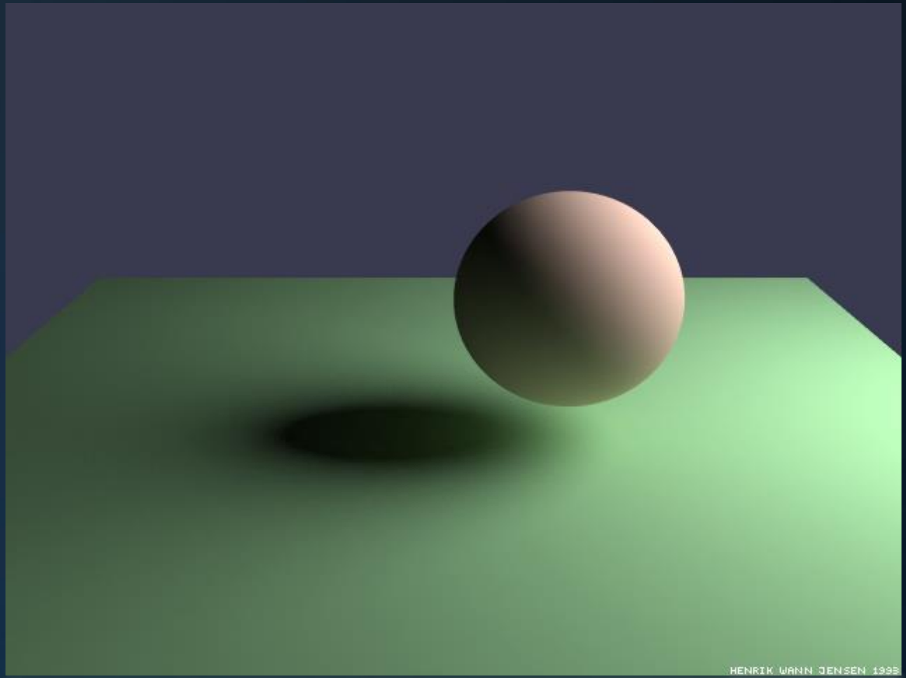
TODO

Limitations of Whitted-style



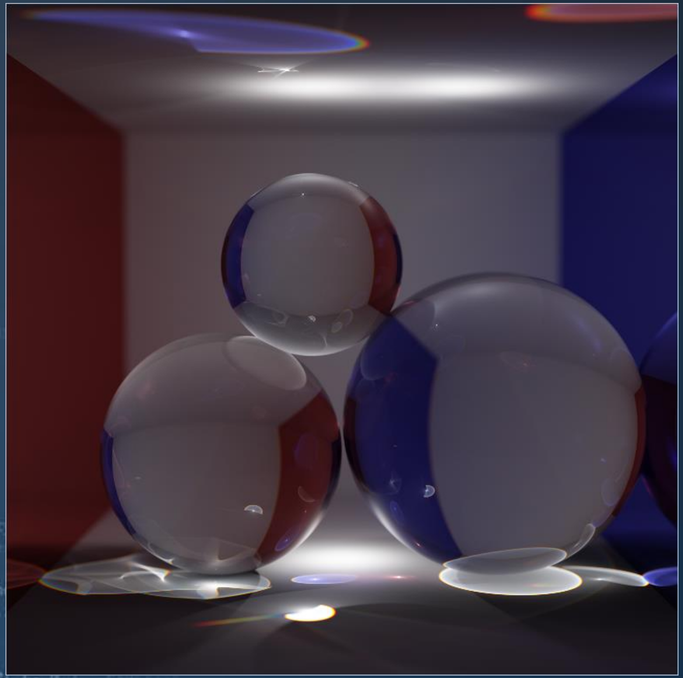


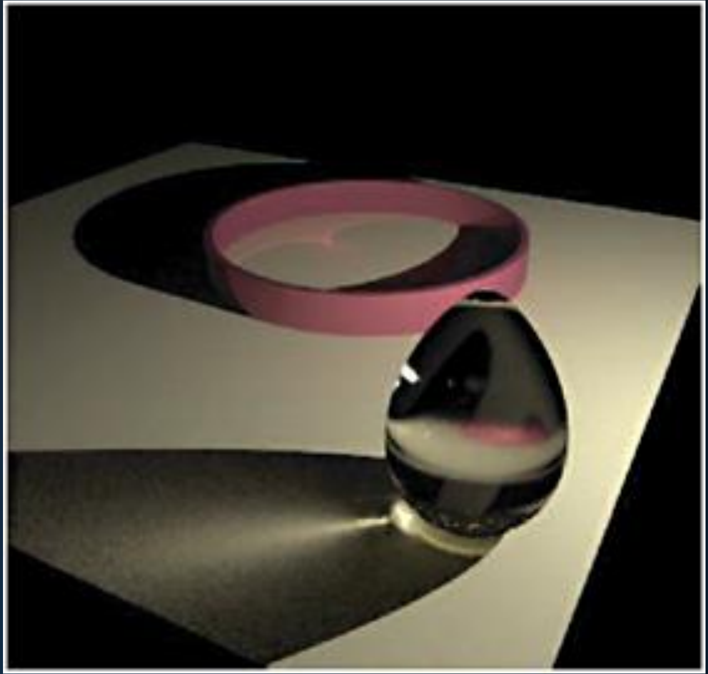
TODO

Limitations of Whitted-style

TODO

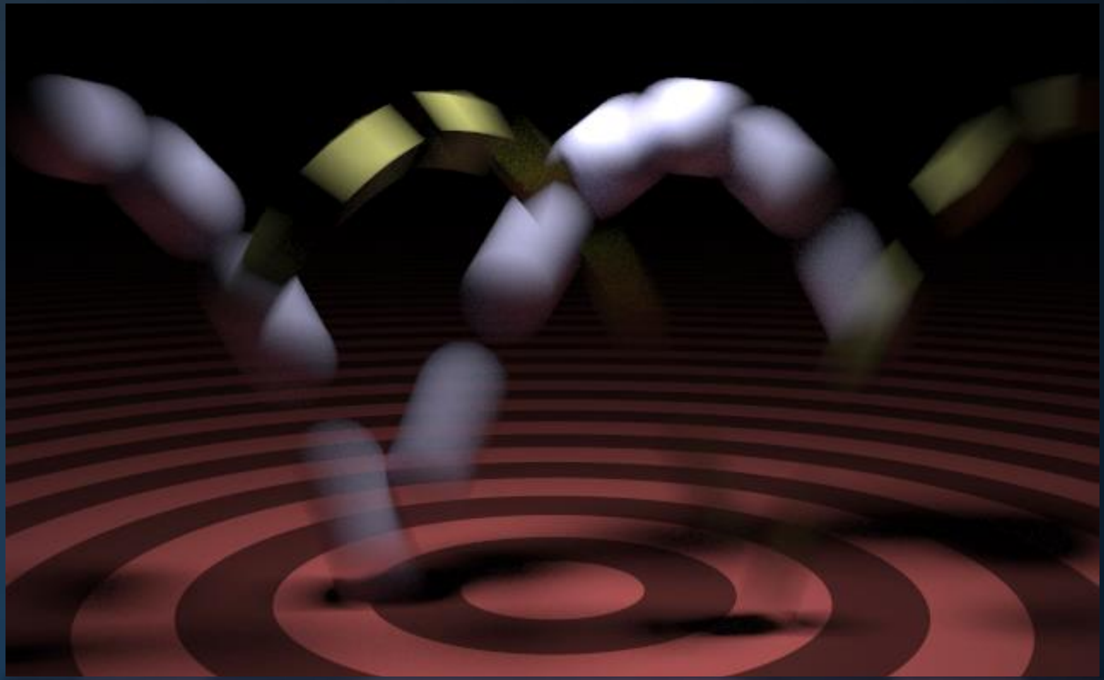
Limitations of Whitted-style





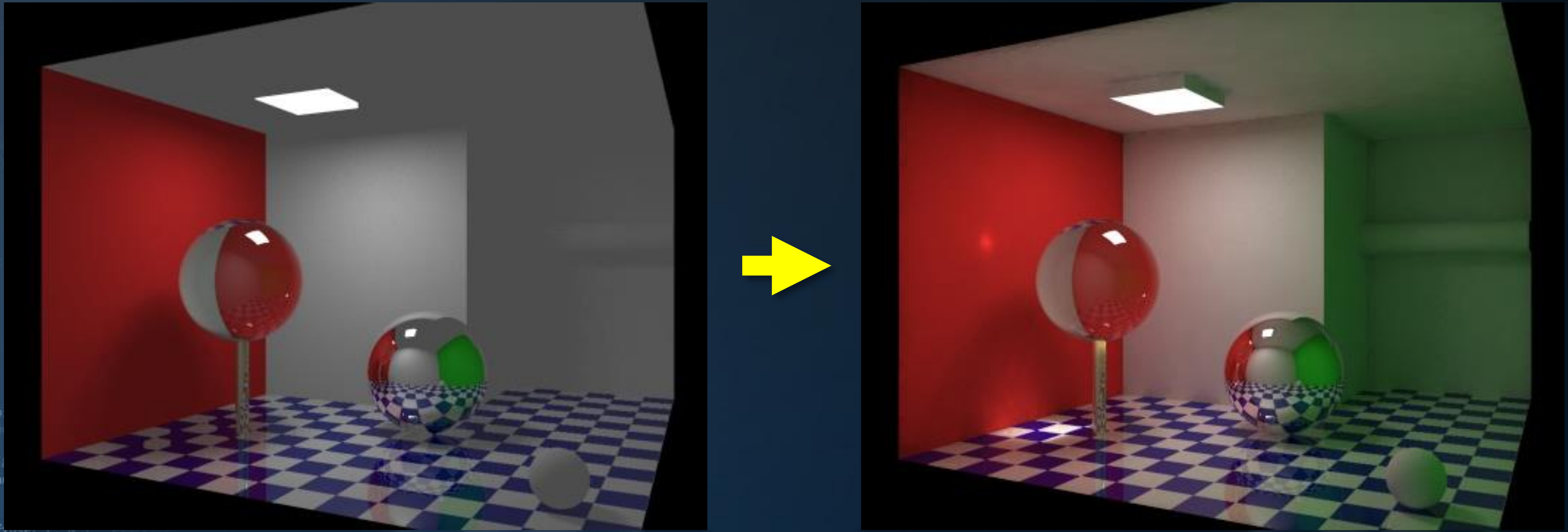
TODO

Limitations of Whitted-style



TODO

Limitations of Whitted-style



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END OF lecture 3: “Ray Tracing (2)”

Next lecture: “Accelerate”