INFOGR – Computer Graphics

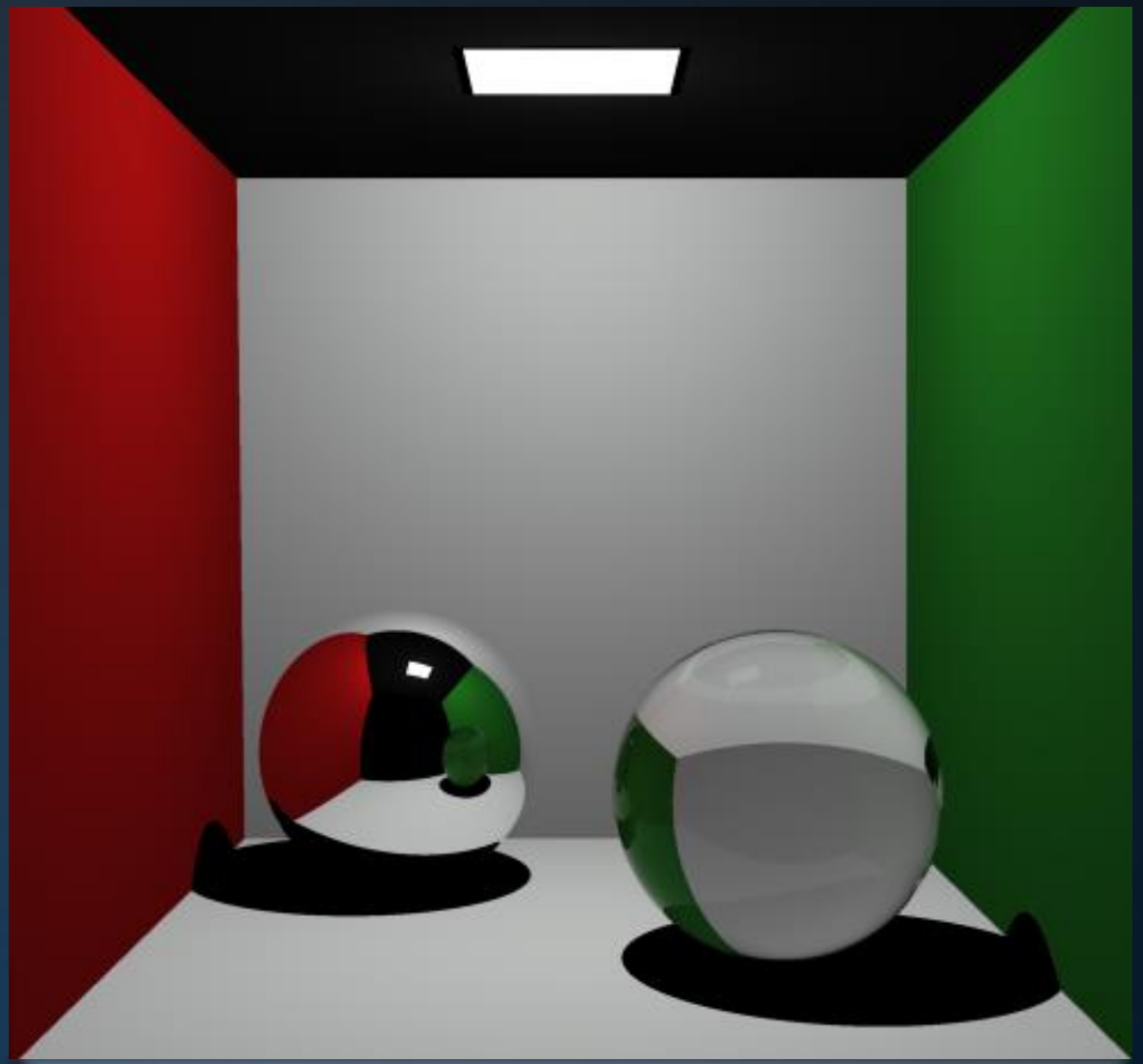
Jacco Bikker - April-July 2016 - Lecture 5: “Ray Tracing (3)”

Welcome!

Today’s Agenda:

- Reflections
- Refraction
- Recursion
- Shading models
- TODO

Reflections



Reflections

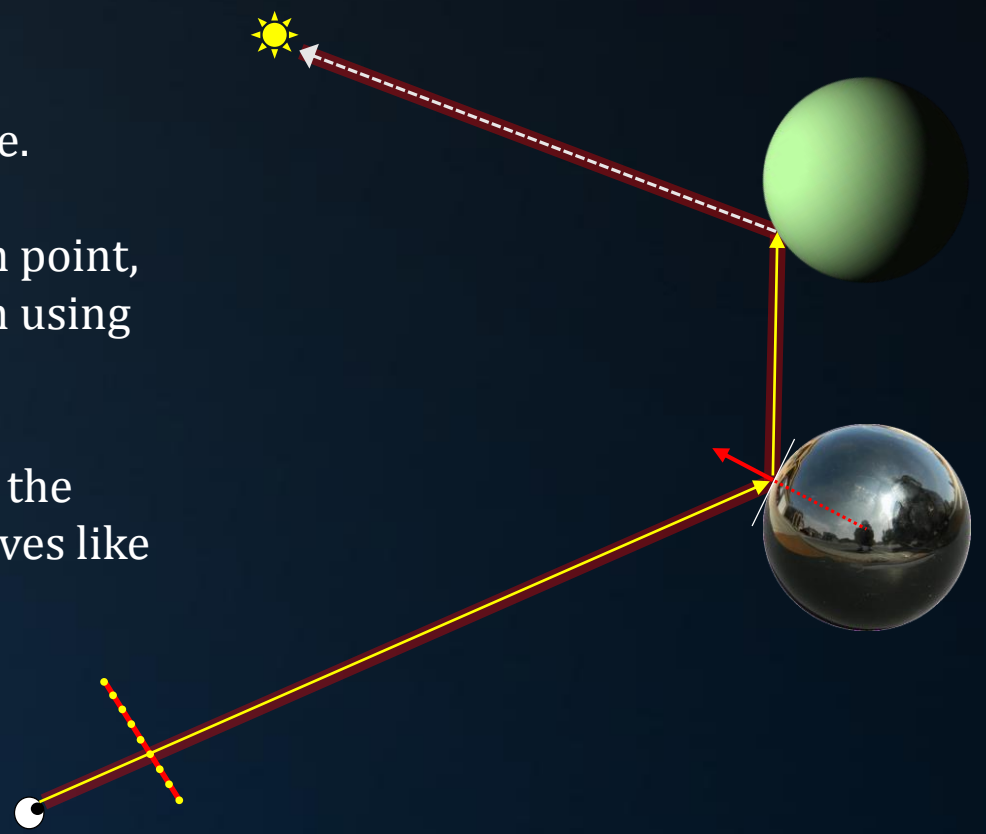
Light Transport

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.



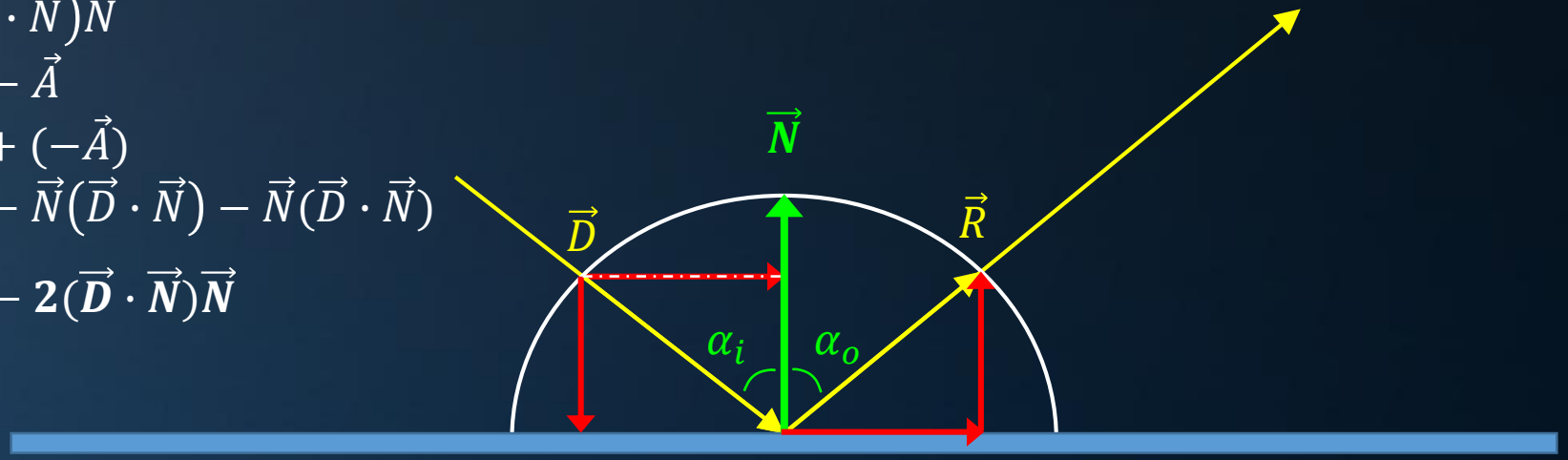
Reflections

Reflected Vector

Reflection: *angle of incidence* equals *angle of reflection*.

Using normalized vector $\vec{D}$:

$$\vec{A} = (\vec{D} \cdot \vec{N})\vec{N}$$
$$\vec{B} = \vec{D} - \vec{A}$$
$$\vec{R} = \vec{B} + (-\vec{A})$$
$$\vec{R} = \vec{D} - \vec{N}(\vec{D} \cdot \vec{N}) - \vec{N}(\vec{D} \cdot \vec{N})$$
$$\boldsymbol{\vec{R} = \vec{D} - 2(\vec{D} \cdot \vec{N})\vec{N}}$$



Reflections

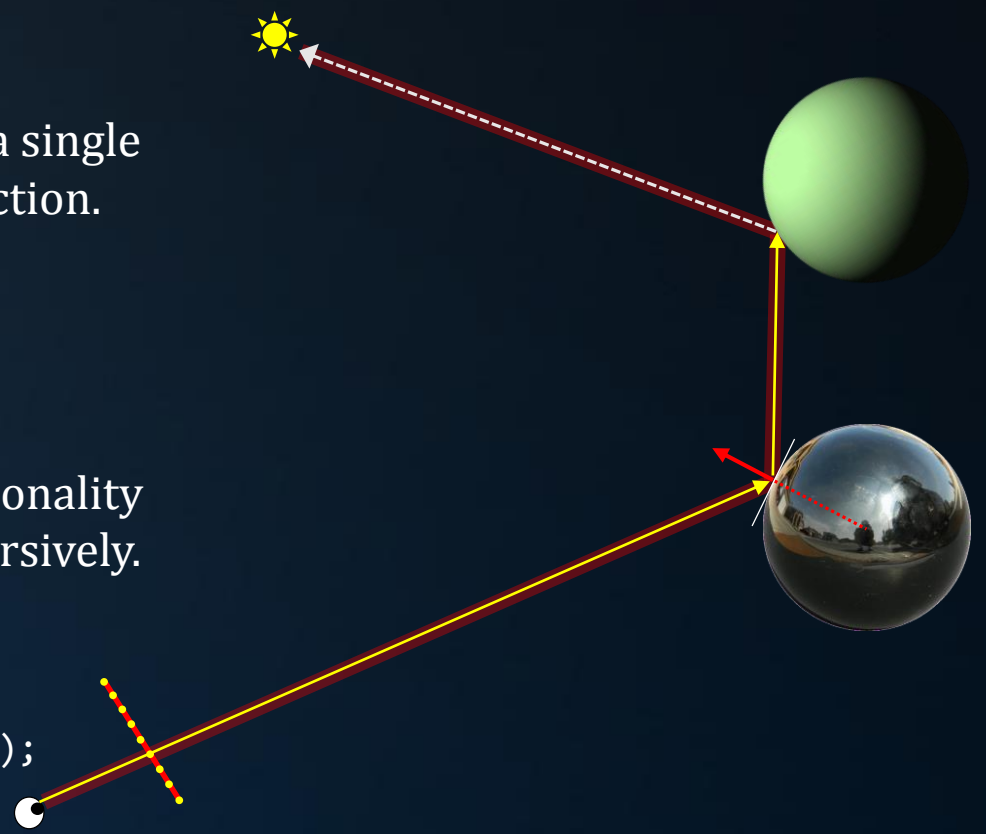
Light Transport

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

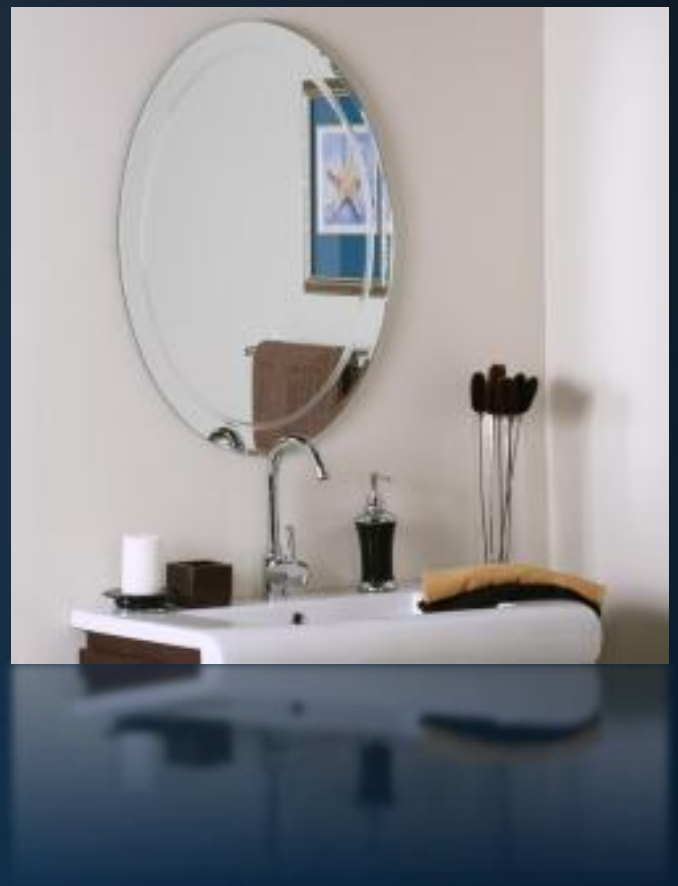
Since the reflection ray requires the same functionality as a primary ray, it helps to implement this recursively.

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



Reflections

What is the color of a bathroom mirror?



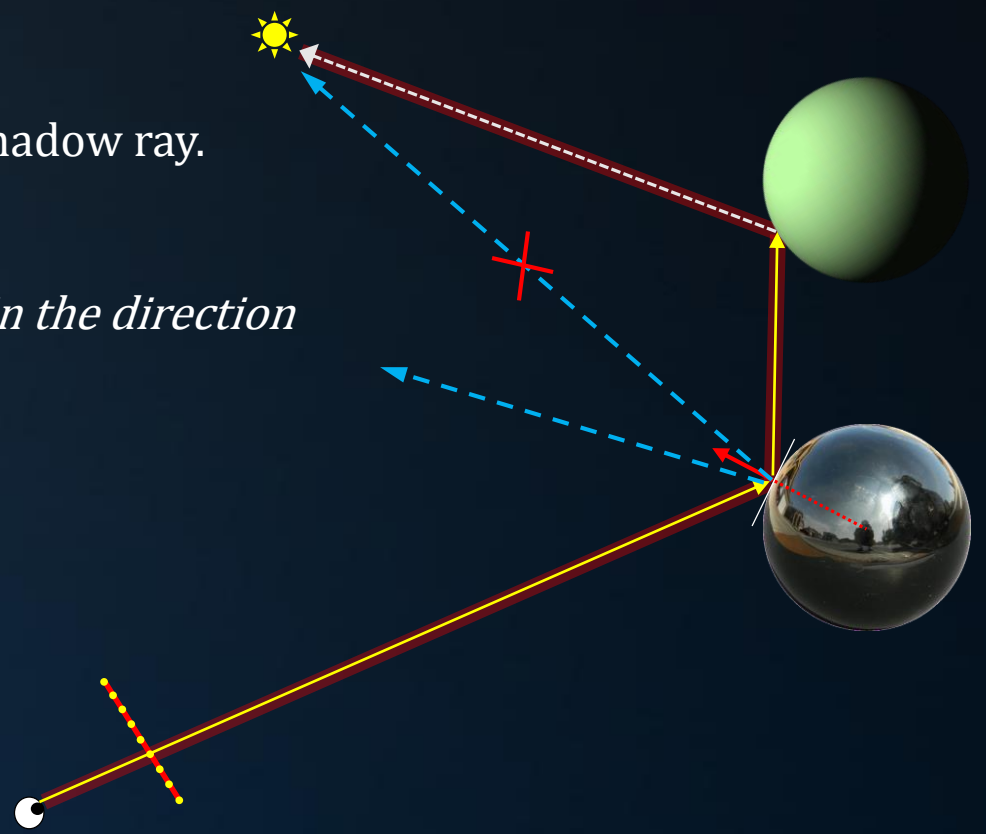
(In a ray tracer, it’s white.)

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

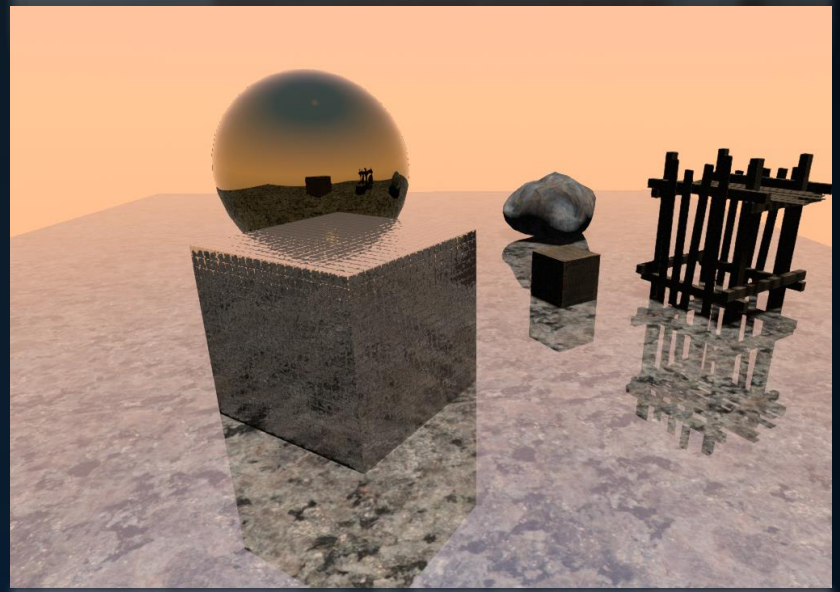
Reflections

Partially Reflective Surfaces

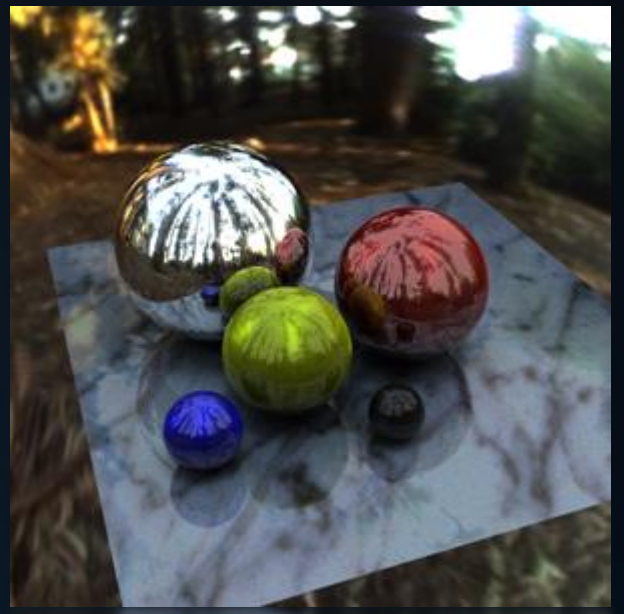
We can combine pure specularity and diffuse properties.

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.



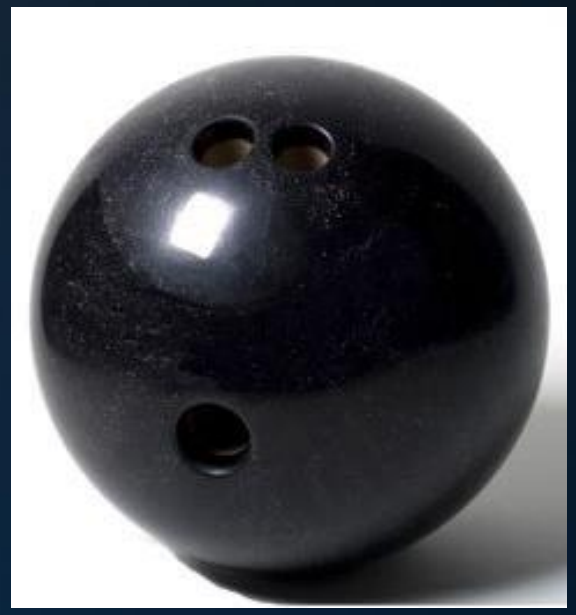
Reflections

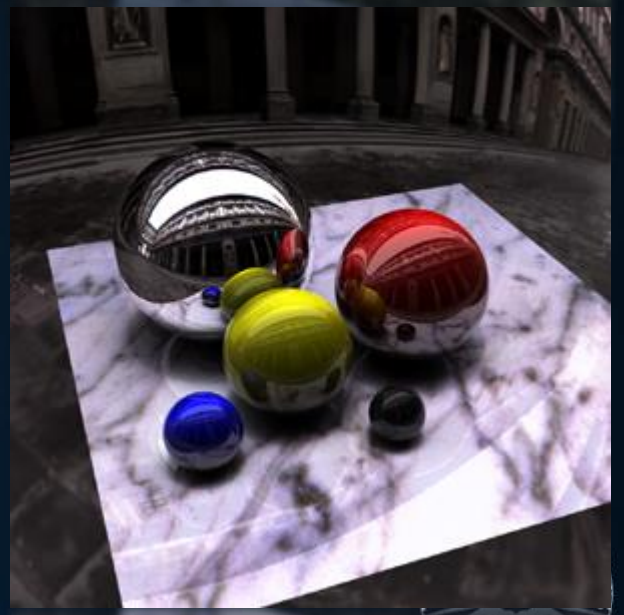


Reflecting a HDR Sky

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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Refraction

Dielectrics

Materials such as water and glass require two types of light transport:

1. Transmission
2. Reflection

Both of these happen at each *medium boundary*.

Refraction

Dielectrics

The direction of the transmitted vector $\vec{T}$ depends on the refraction indices n_1, n_2 of the media separated by the surface. According to Snell’s Law:

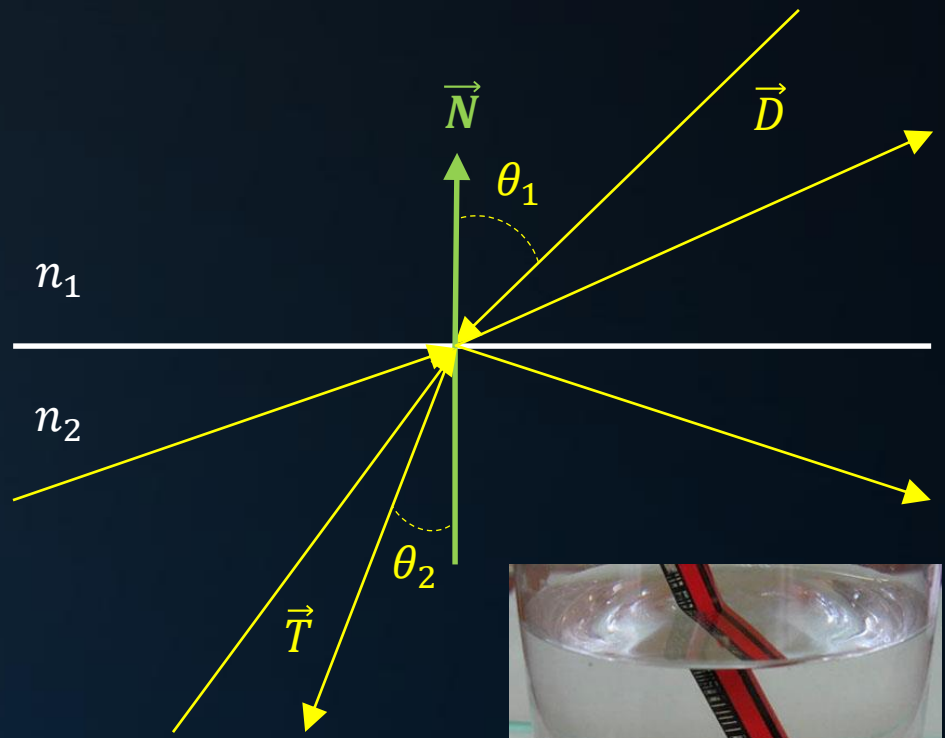
$$n_1 sin\theta_1 = n_2 sin\theta_2$$

or

$$\frac{n_1}{n_2} sin\theta_1 = sin\theta_2$$

Note: left term may exceed 1, in which case θ_2 cannot be computed. Therefore:

$$\frac{n_1}{n_2} sin\theta_1 = sin\theta_2 \Leftrightarrow sin\theta_1 \leq \frac{n2}{n1} \rightarrow \theta_{critical} = \arcsin\left(\frac{n_2}{n_1}\sin\theta_2\right)$$



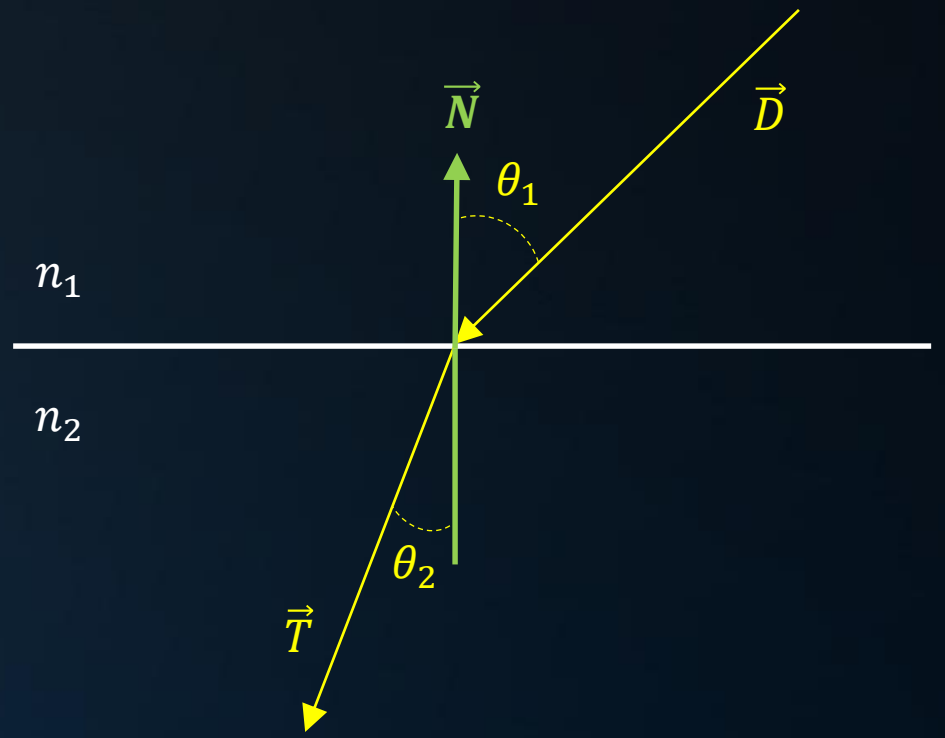
Refraction

Dielectrics

$$\frac{n_1}{n_2} sin\theta_1 = sin\theta_2 \Leftrightarrow sin\theta_1 \leq \frac{n2}{n1}$$

$$k = 1 - \left(\frac{n_1}{n_2}\right)^2 \left(1 - cos\theta_1{}^2\right)$$

$$\vec{T} = \begin{cases} TIR, & for\ k < 0 \\ \frac{n_1}{n_2}\vec{D} + \vec{N}\left(\frac{n_1}{n_2} cos\theta_1 - \sqrt{k}\right), & for\ k \geq 0 \end{cases}$$



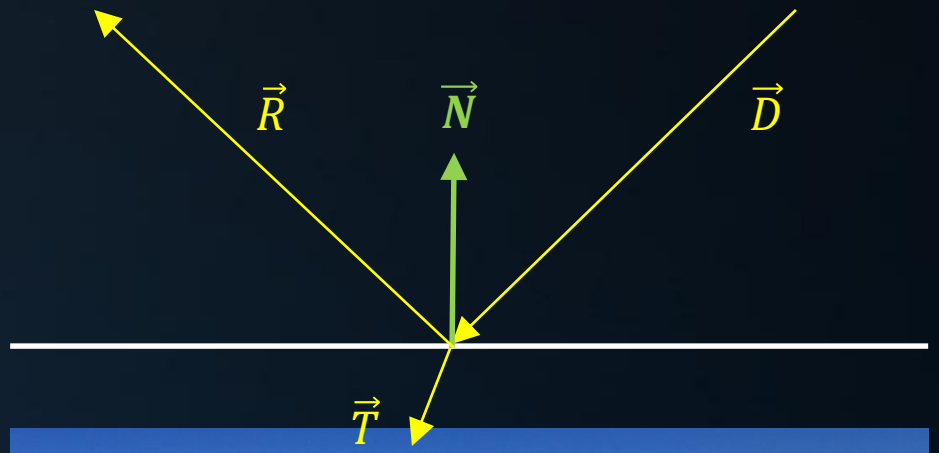
Note: $cos\theta_1 = \vec{N} \cdot -\vec{D}$, and $\frac{n_1}{n_2}$ should be calculated only once.

* For a full derivation, see http://www.flipcode.com/archives/reflection_transmission.pdf

Refraction

Dielectrics

A typical dielectric transmits *and* reflects light.



Refraction

Dielectrics

A typical dielectric transmits *and* reflects light.

Based on the *Fresnel equations*, the reflectivity of the surface for non-polarized light is formulated as:

$$F_r = \frac{1}{2}\left(\left|\frac{n_1 cos\theta_i - n_2\sqrt{1-\left(\frac{n_1}{n_2}sin\theta_i\right)^2}}{n_1 cos\theta_i + n_2\sqrt{1-\left(\frac{n_1}{n_2}sin\theta_i\right)^2}}\right| + \left|\frac{n_1 cos\theta_i - n_2\sqrt{1-\left(\frac{n_1}{n_2}sin\theta_i\right)^2}}{n_1 cos\theta_i + n_2\sqrt{1-\left(\frac{n_1}{n_2}sin\theta_i\right)^2}}\right|\right)$$

Refraction

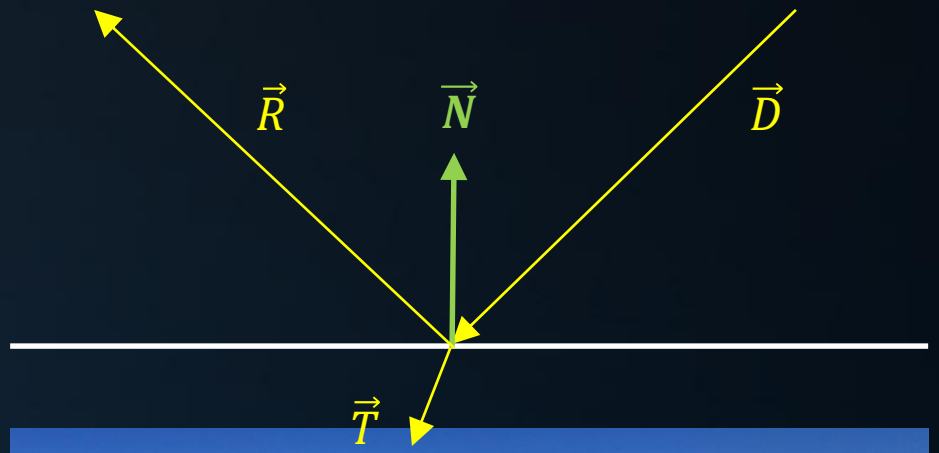
Dielectrics

In practice, we use Schlick’s approximation:

$F_r = R_0 + (1 - R_0)(1 - cos\theta)^5$, where $R_0 = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$.

Based on the law of conservation of energy:

$F_t = 1 - F_r$



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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.

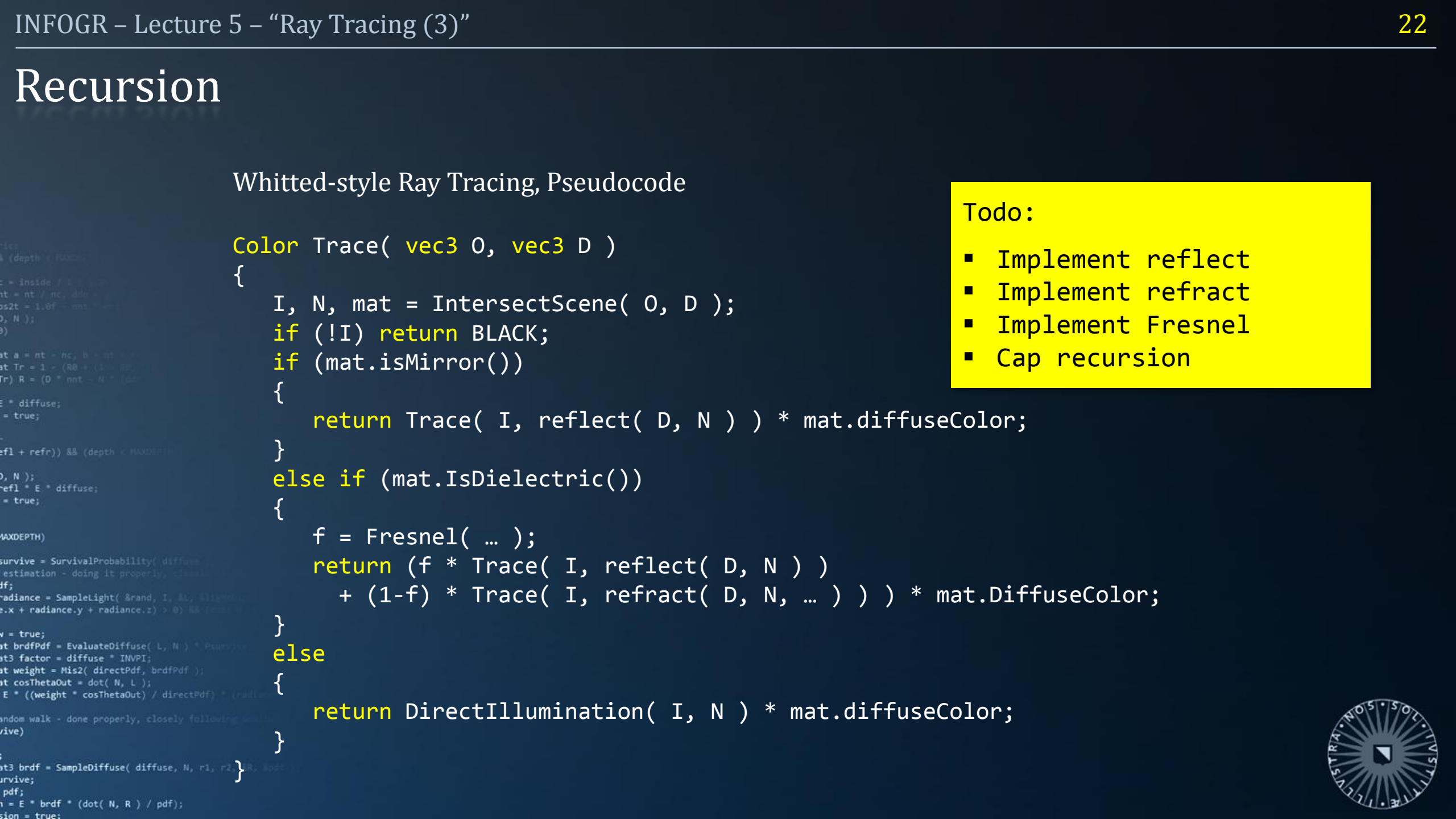
Recursion

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;
   }
}
```

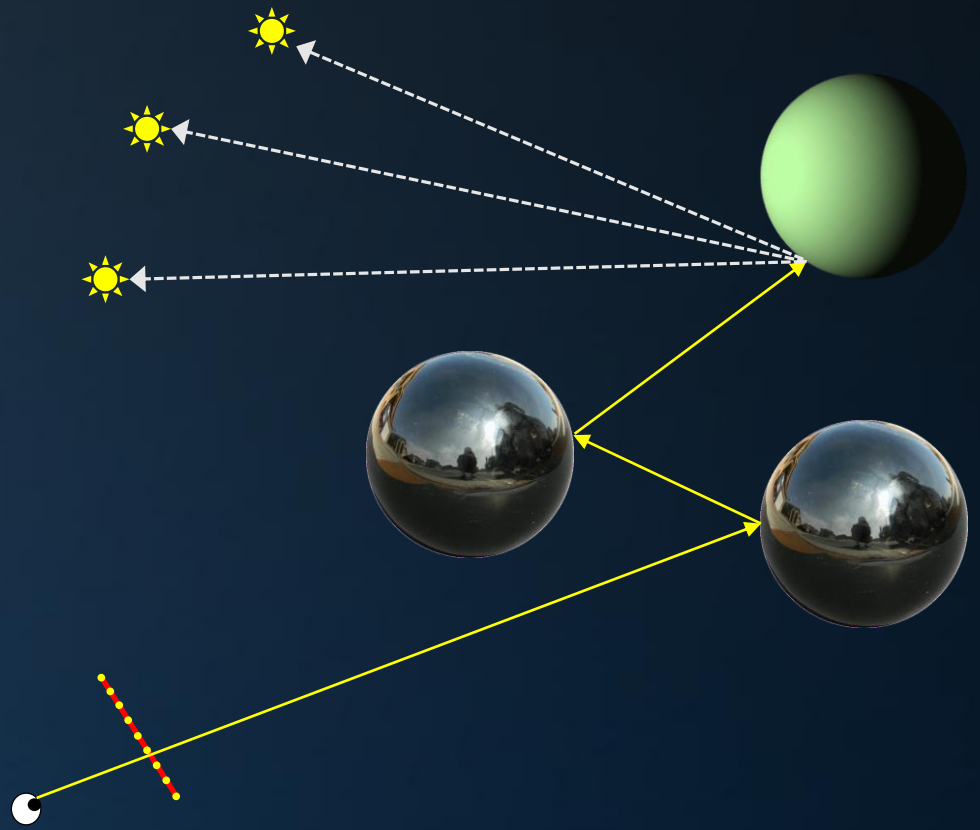
Todo:

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



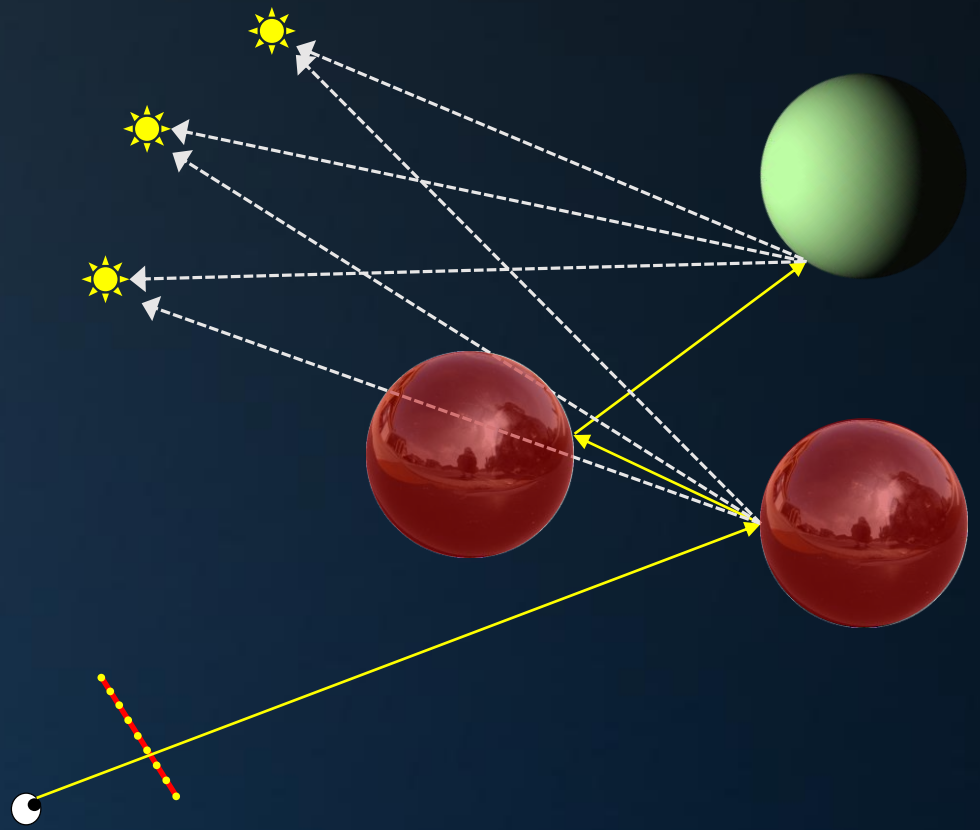
Recursion

Spheres: pure specular



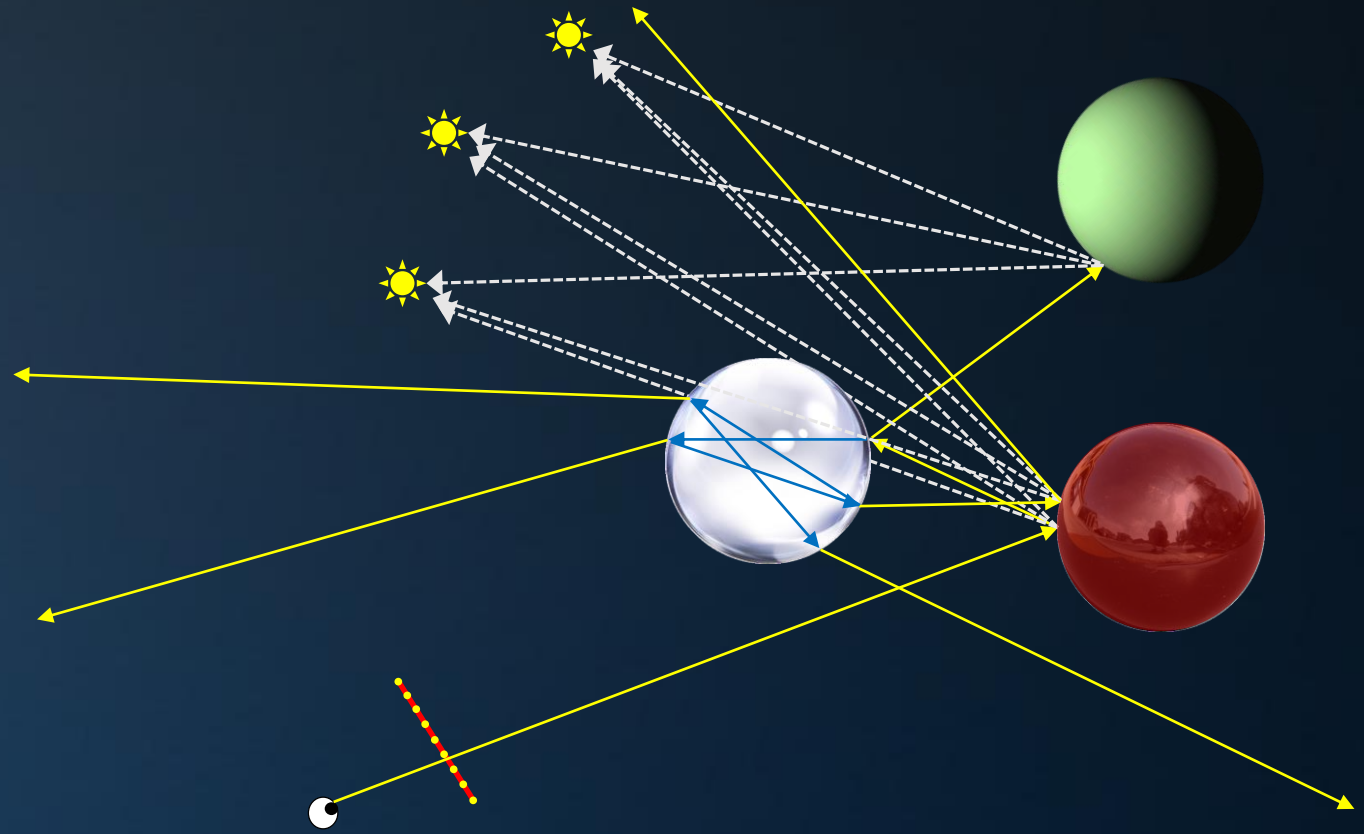
Recursion

Spheres: 50% specular



Recursion

Spheres: one 50% specular, one glass sphere



Recursion

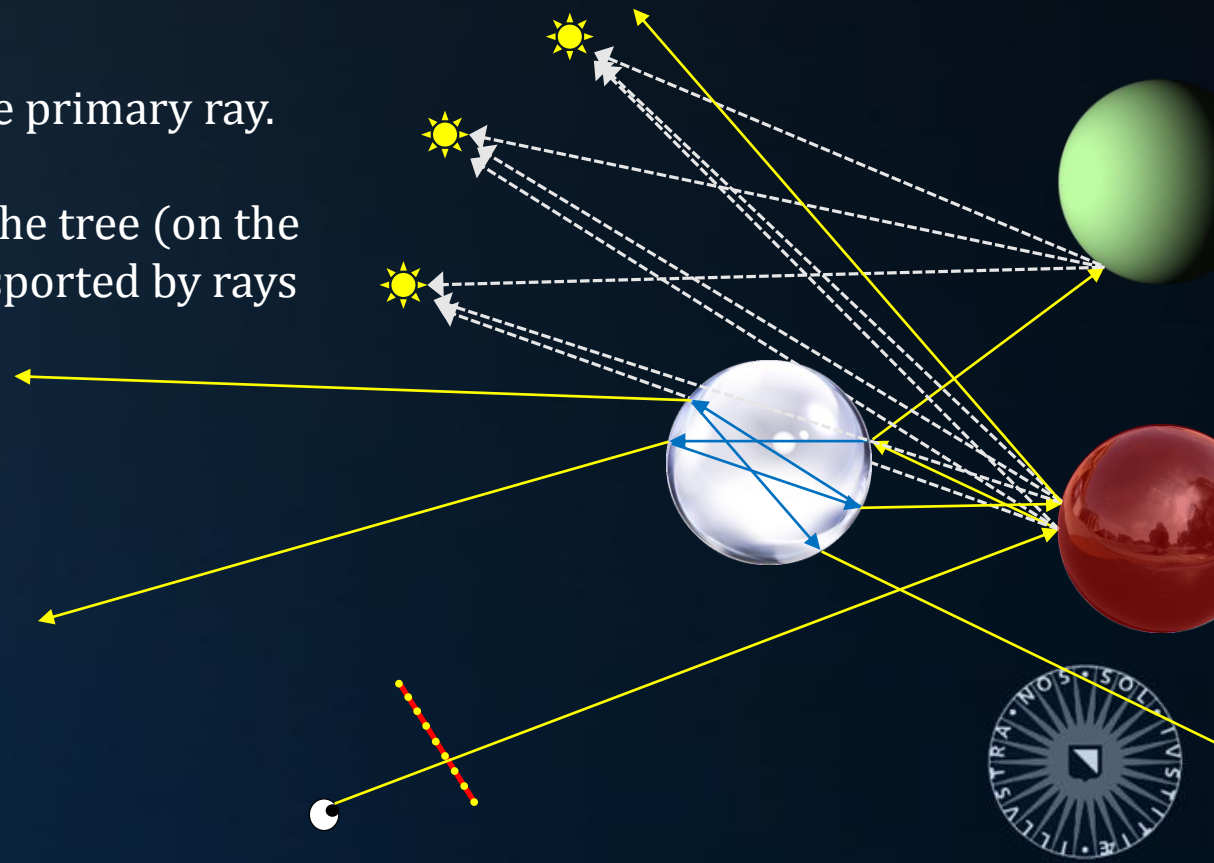
Recursion

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

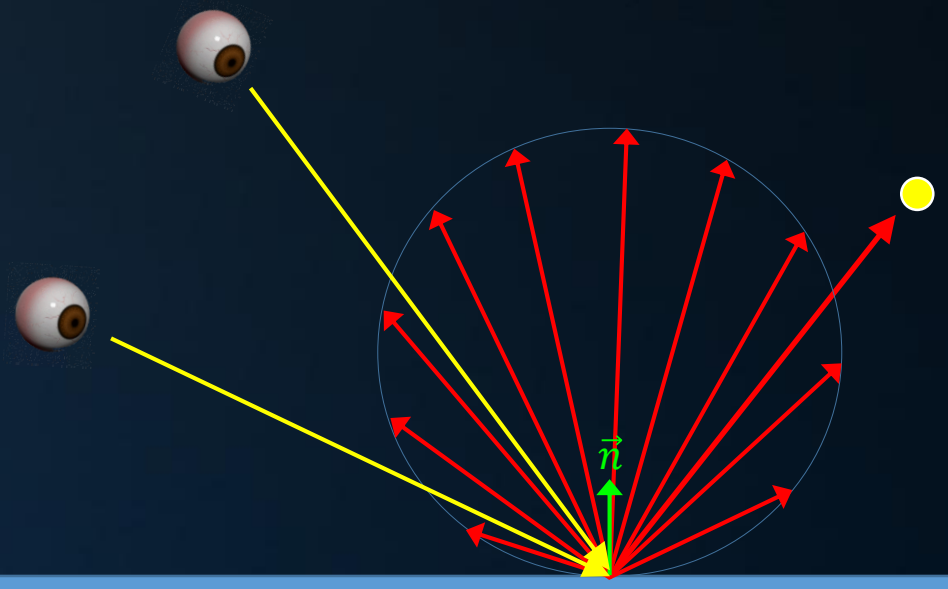
Absorption: $C_{material}$

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

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

terms cancel out.

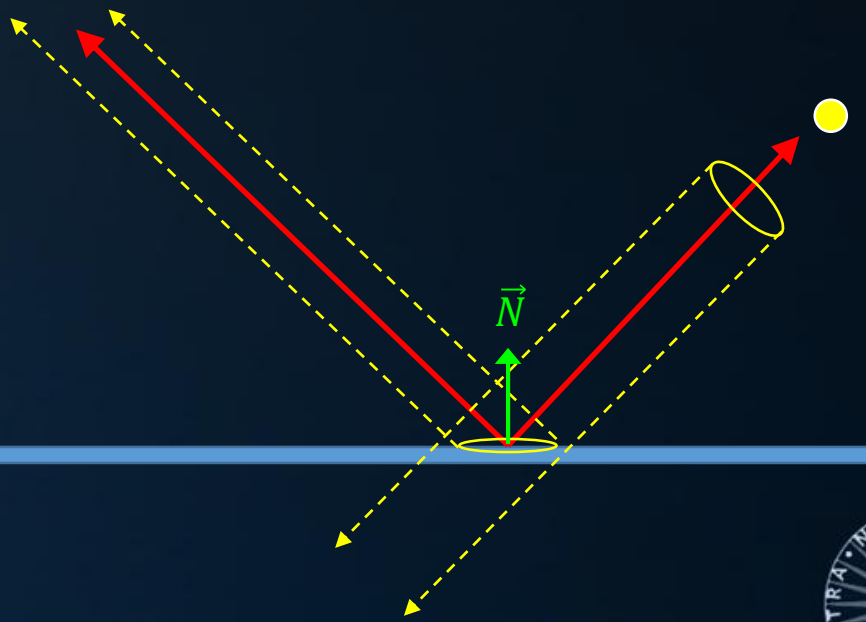
A diffuse material appears the same regardless of eye position.



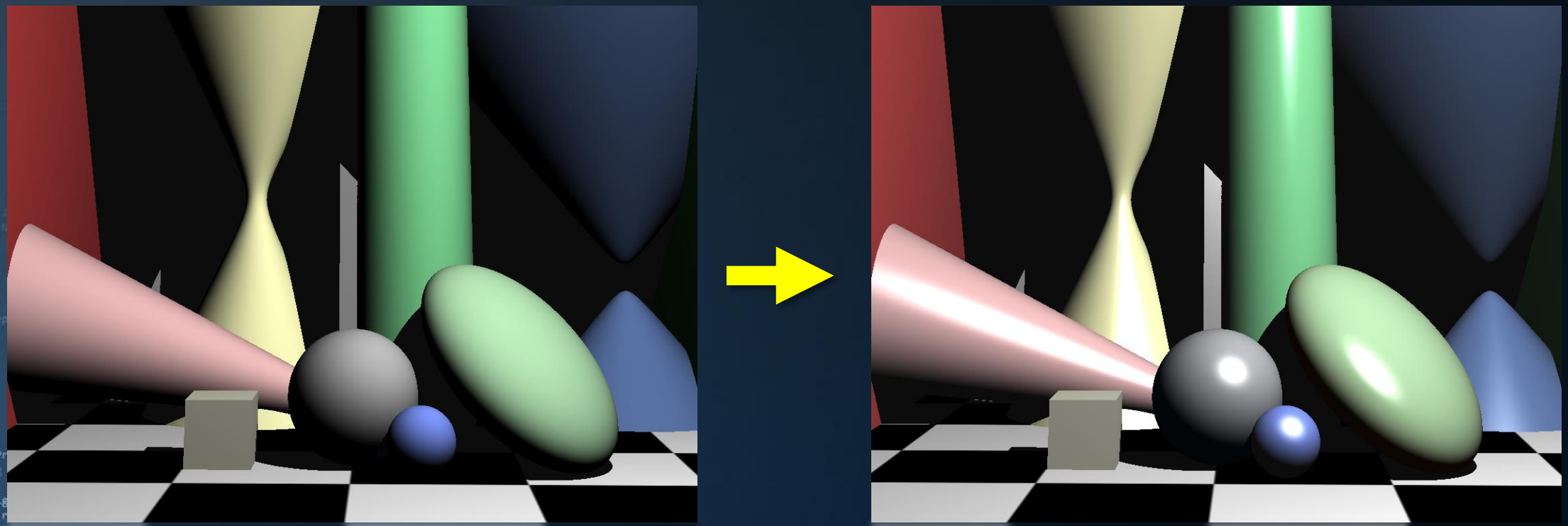
Shading

Specular Material

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



Shading



Shading

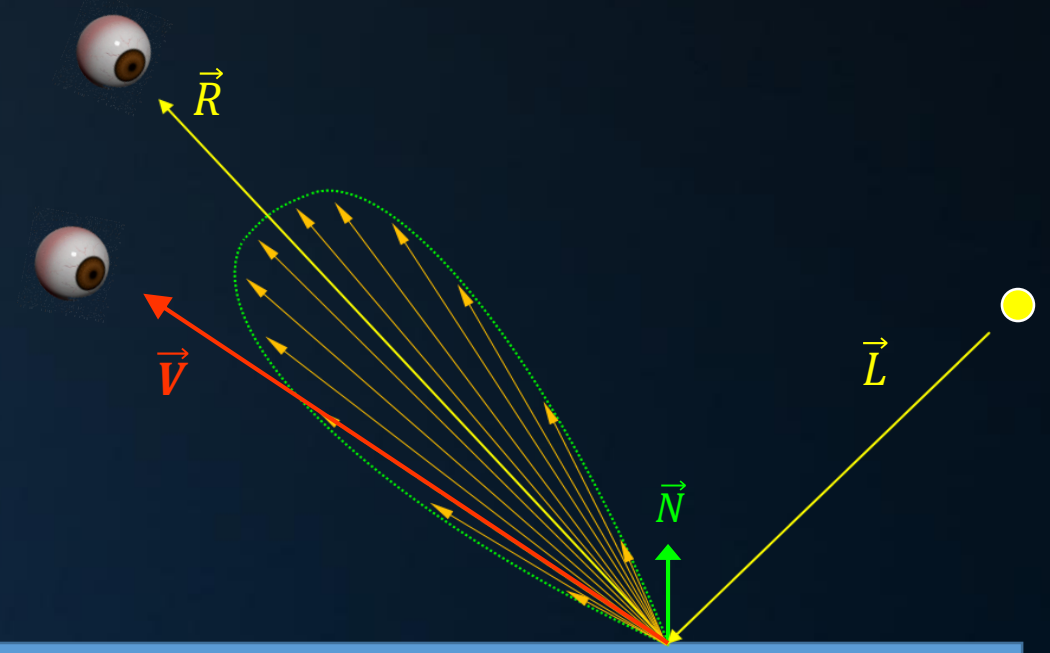
Glossy Material

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

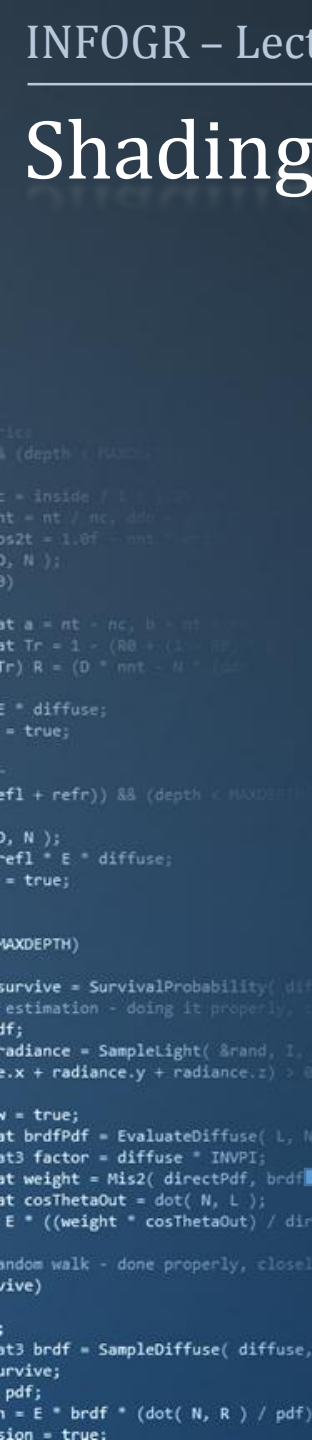
Complex materials can be obtained by blending diffuse and glossy.

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

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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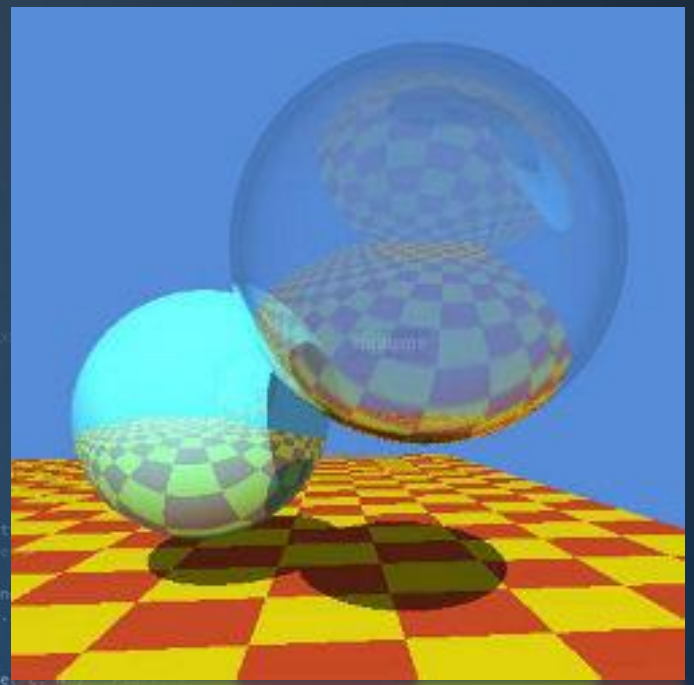
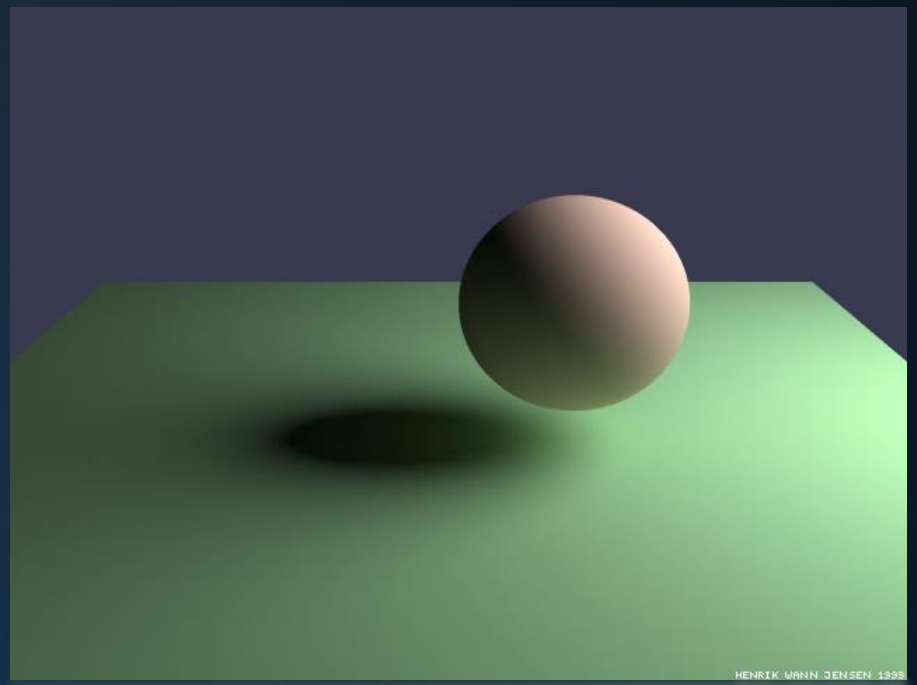
TODO

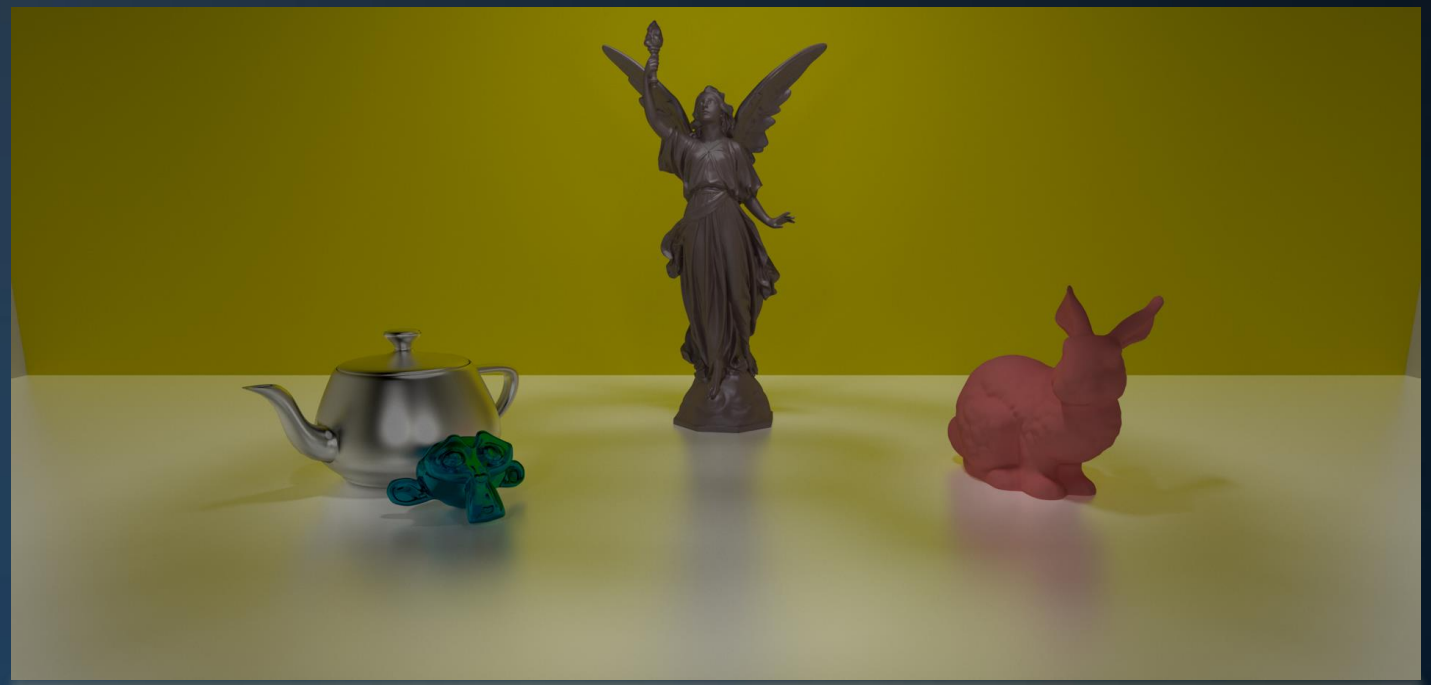
Limitations of Whitted-style





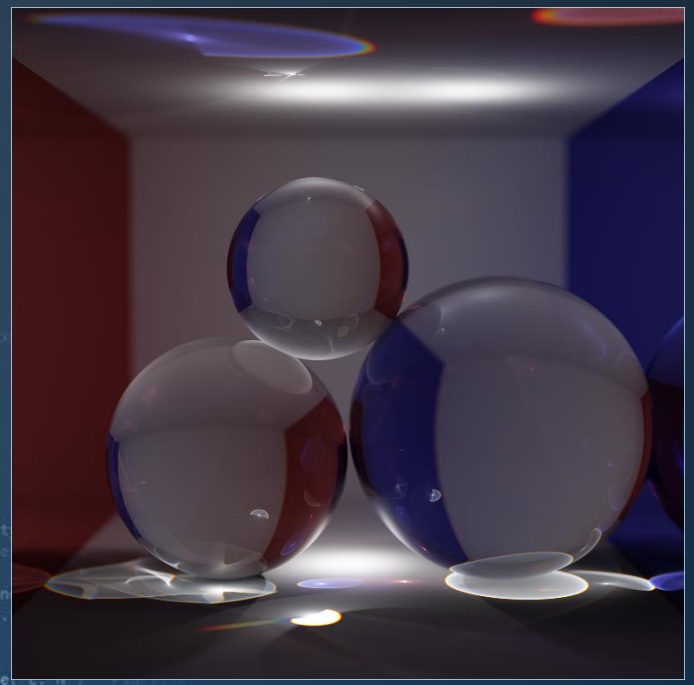
TODO

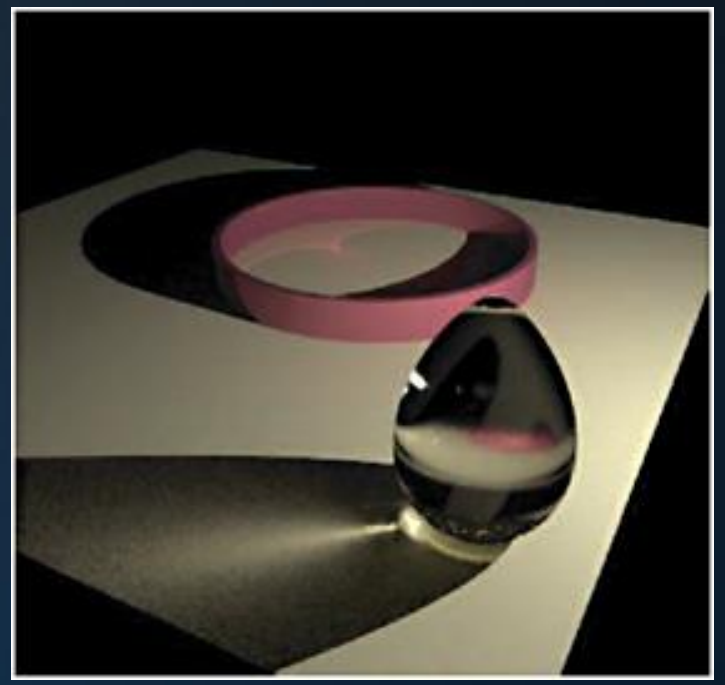
Limitations of Whitted-style



TODO

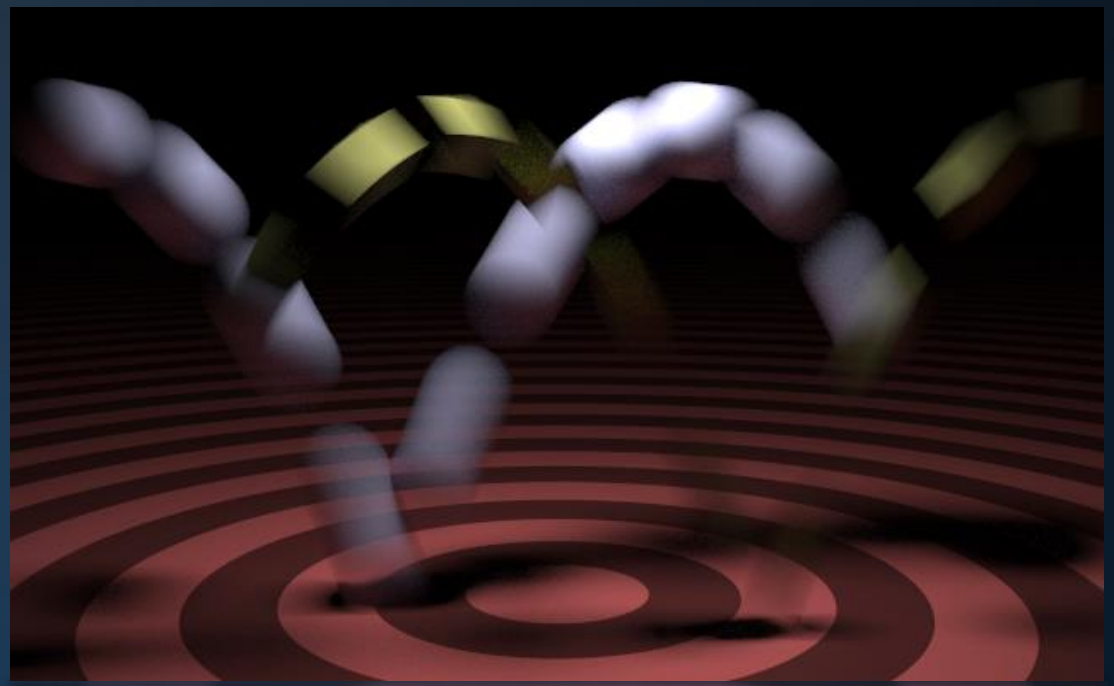
Limitations of Whitted-style





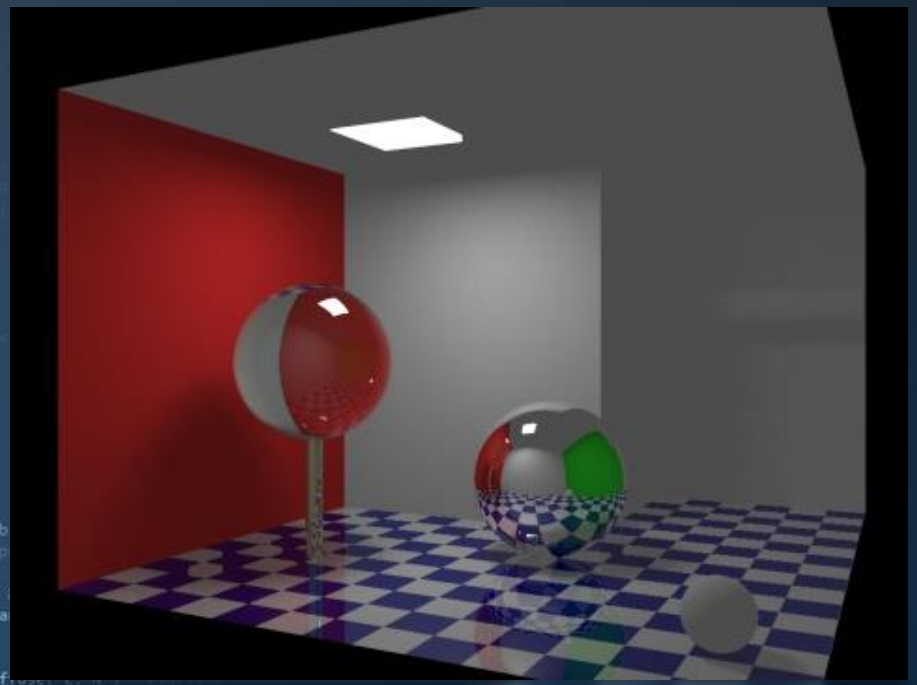
TODO

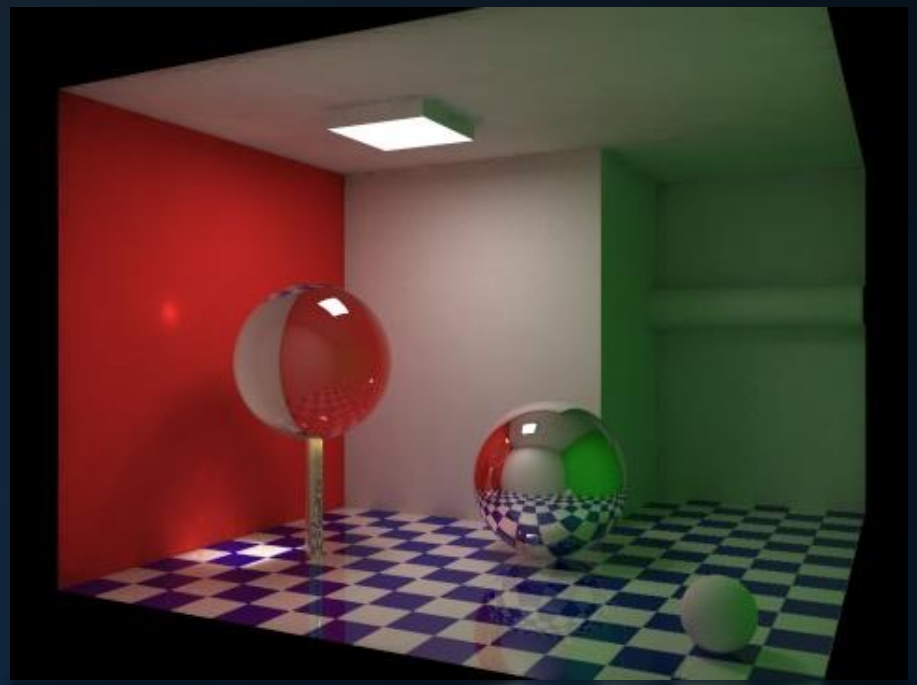
Limitations of Whitted-style



TODO

Limitations of Whitted-style





Tutorial 2 - Geometry

Basic geometric entities

Exercise 1.

Given: a line in $\mathbb{R}^2$ through two points (-3,0) and (2,2).

a) What is the slope-intersect form of this line?
b) Verify your answer for a) for the two given points.
c) What is the implicit form of the line?
d) Determine two normals for the line, with different directions.
e) What is the relation between the distance of the line to the origin, 'C' in the general representation, and the magnitude of the normal?

Exercise 2.

Let l be a line in $\mathbb{R}^2$ through the origin, and let $\vec{n}$ be a normal vector for l.

a) Show geometrically that all points p that lie on the line satisfy $\vec{n} \cdot \vec{p} = 0$.

Now, let l be a line in $\mathbb{R}^2$ that does not go through the origin, and let $\vec{n}$ be a normal vector for l.

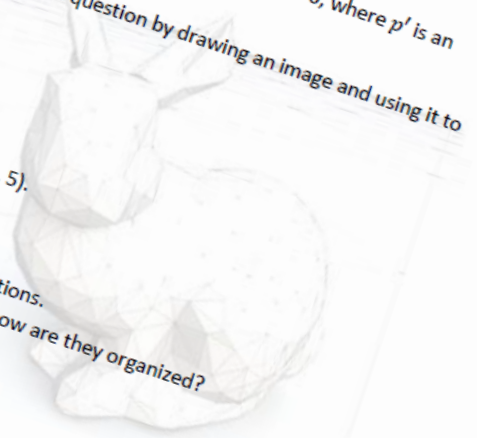
b) Show geometrically that all points p that lie on the line satisfy $\vec{n} \cdot \vec{p} - \vec{n} \cdot \vec{p'} = 0$, where p' is an arbitrary point on the line.

Note: "geometrically" here means that you can solve this question by drawing an image and using it to explain the solution.)

Exercise 3.

Given: a line in $\mathbb{R}^3$ through two points, (-4,1,1) and (2, 2, 5).

a) What is the length of this line segment?
b) What is the *parametric* representation of this line?
c) Determine two normals for the line, with different directions.
d) How many normals of unit length exist for this line, and how are they organized?



INFOGR – Computer Graphics

Jacco Bikker - April-July 2016 - Lecture 5: “Ray Tracing (3)”

END of “Ray Tracing (3)”

next lecture: “Boxes”