

Ray Tracing

Forward & Backward Ray Tracing
Ray Tracing
Ray-Surface Intersection Testing
Shadows
Reflections
Transmission
Next time: efficient ray tracing

Shirley, Chapter 4

Ray Tracing



Ray Tracing



Real-time Ray traced Bugatti Veyron with reflected reflections, adaptive FSAA and realistic shadows. [Source: Nvidia]

Object-oriented vs. Pixel-oriented Rendering

OpenGL rendering:

walk through objects, transforming and then drawing each one unless the z buffer says that it is not in front

Ray tracing

walk through each pixel looking for what object (if any) should be shown there

Light is Bouncing Photons

Light sources send off photons in all directions

- Model these as particles that bounce off objects in the scene

- Each photon has a wavelength and energy (color and intensity)

- When photons bounce, some energy is absorbed, some reflected, some transmitted

If we can model photon bounces we can generate images

Technique: follow each photon from the light source until:

- All of its energy is absorbed (after too many bounces)

- It departs the known universe (not just the part of the world that is within the viewing volume!)

- It strikes the image and its contribution is added to appropriate pixel

Forward Ray Tracing

Rays are the paths of these photons

This method of rendering by following photon paths is called *ray tracing*

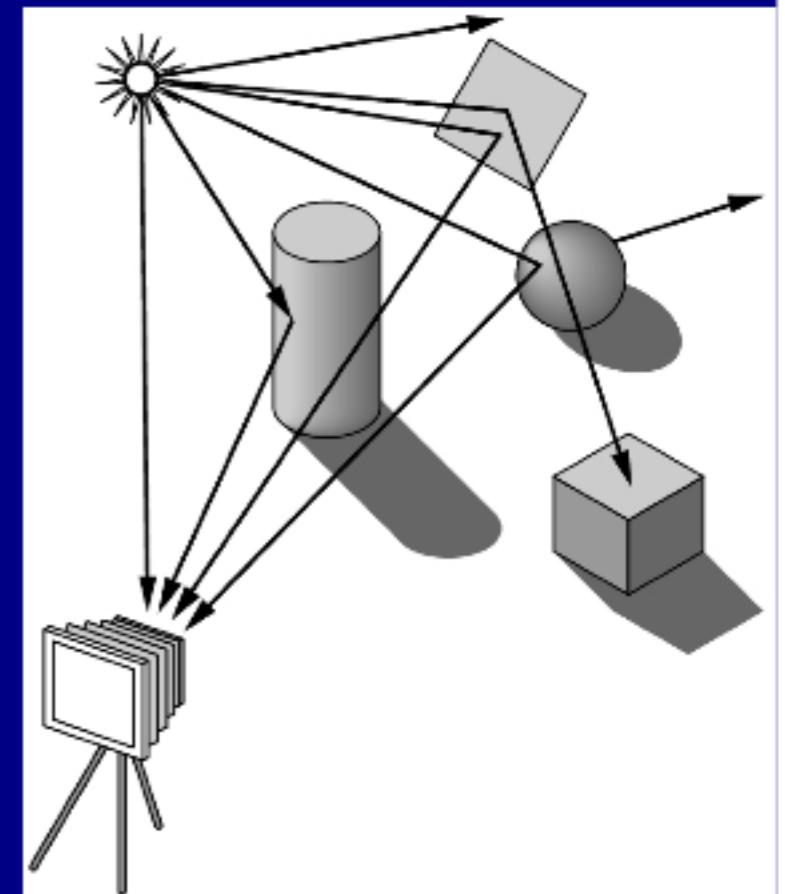
Forward ray tracing follows the photon in direction that light travels (from the source)

BIG problem with this approach:

- Only a tiny fraction of rays reach the image
- Many, many rays are required to get a value for each pixel

Ideal Scenario:

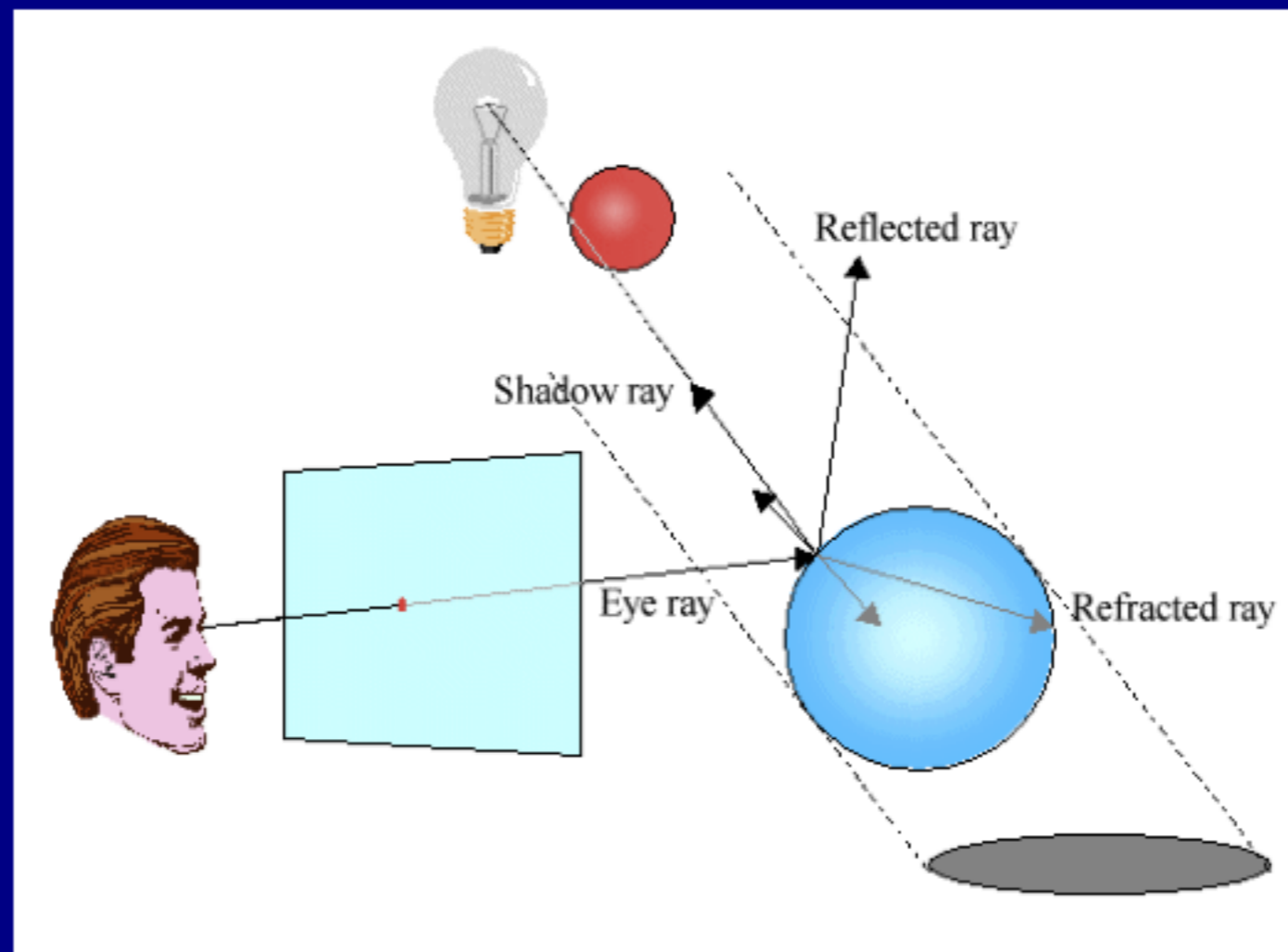
- We'd like to magically know which rays will eventually contribute to the image, and trace only those



Backward Ray Tracing

The solution is to start from the image and trace backwards—*backward* ray tracing

Start from the image and follow the ray until the ray finds (or fails to find) a light source



Backward Ray Tracing

Basic idea:

Each pixel gets light from just one direction—the line through the image point and focal point

Any photon contributing to that pixel's color has to come from this direction

So head in that direction and see what is sending light

If we hit a light source—done

If we find nothing—done

If we hit a surface—see where that surface is lit from

At the end we've done forward ray tracing, but **ONLY** for the rays that contribute to the image

Ray Tracing

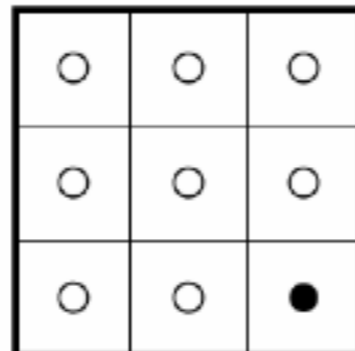
The basic algorithm is

compute u, v, w basis vectors

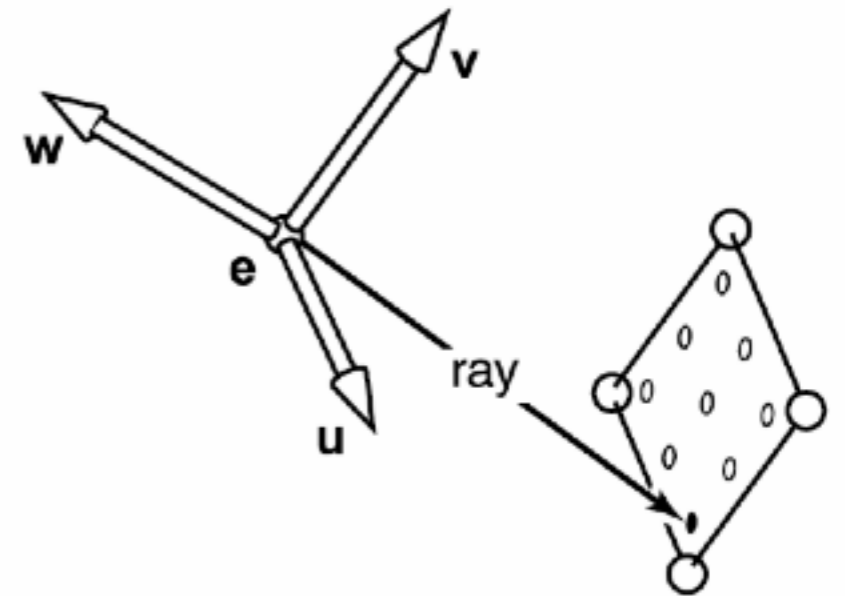
for each pixel do

shoot ray from eye point through pixel (x,y) into scene

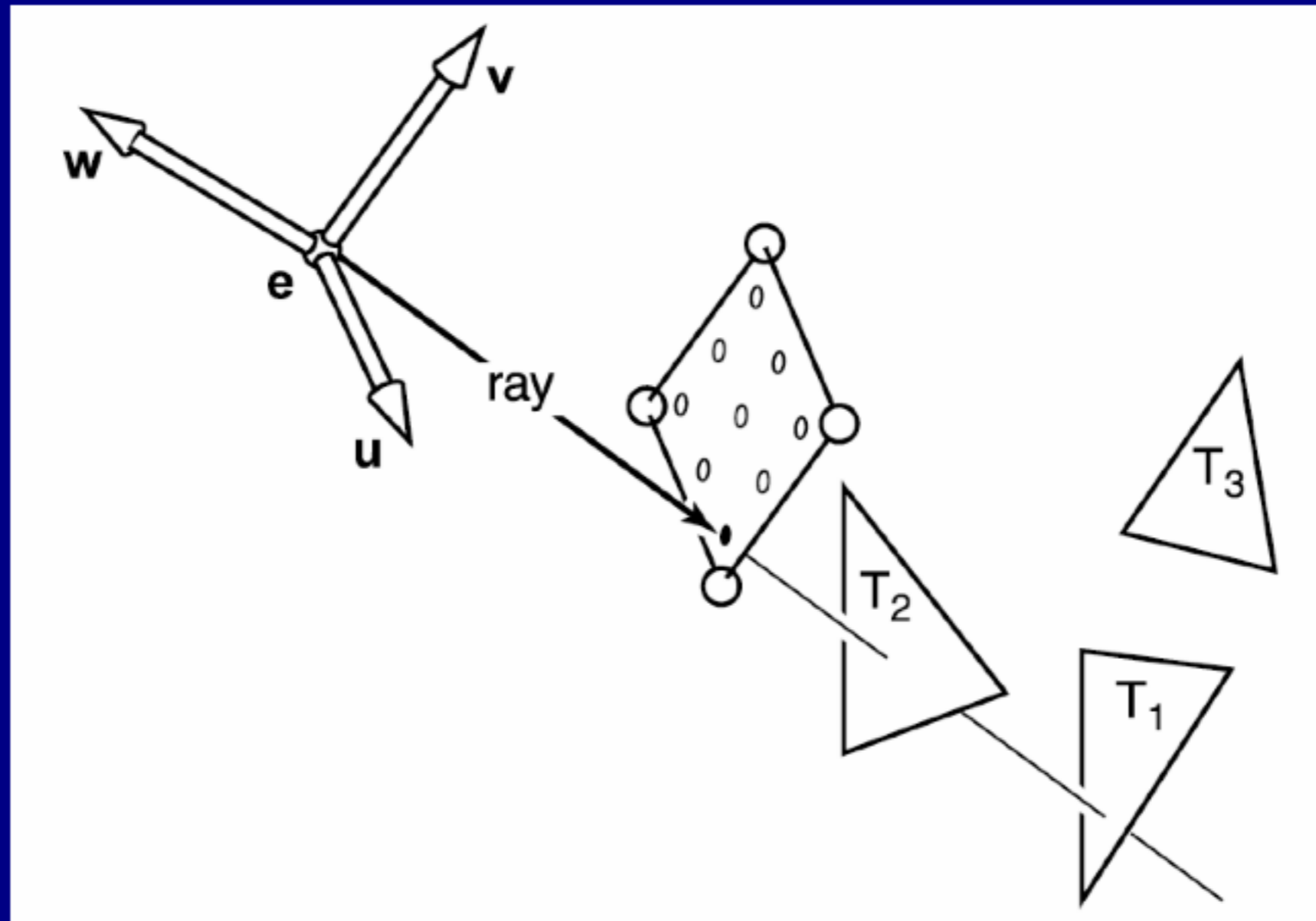
intersect with all surfaces, find first one the ray hits
shade that point to compute pixel (x,y) 's color



screen



Ray Tracing



Computing Rays

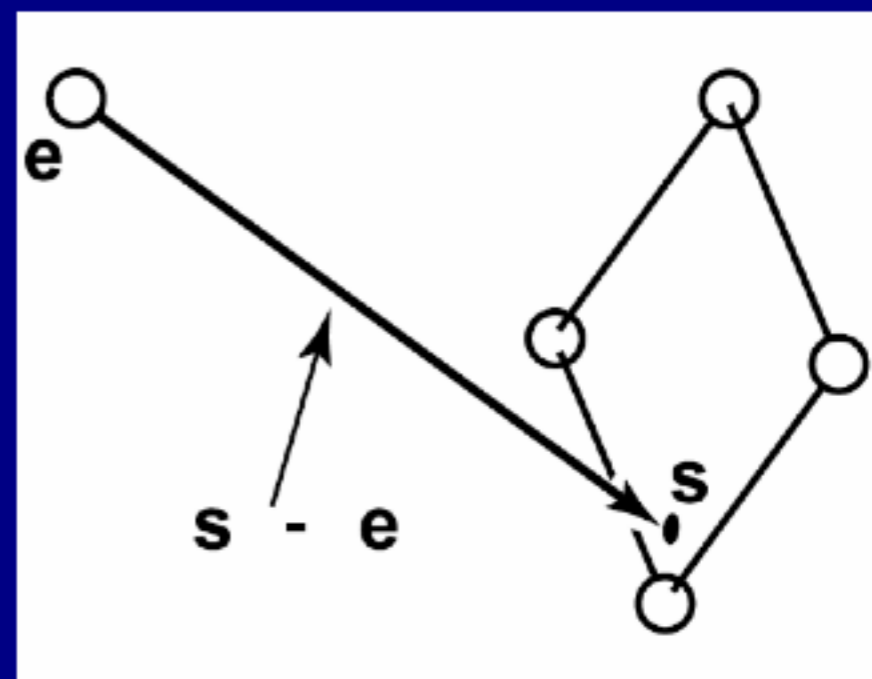
$$p(t) = e + t(s - e)$$

$t = 0$ origin of the ray

$t > 0$ in positive direction of ray

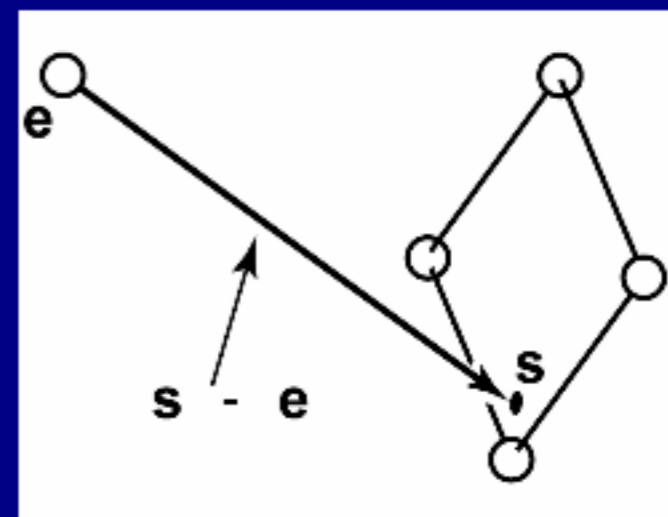
$t < 0 \Rightarrow$ then $p(t)$ is behind the eye

$t_1 < t_2 \Rightarrow p(t_1)$ is closer to the eye than $p(t_2)$

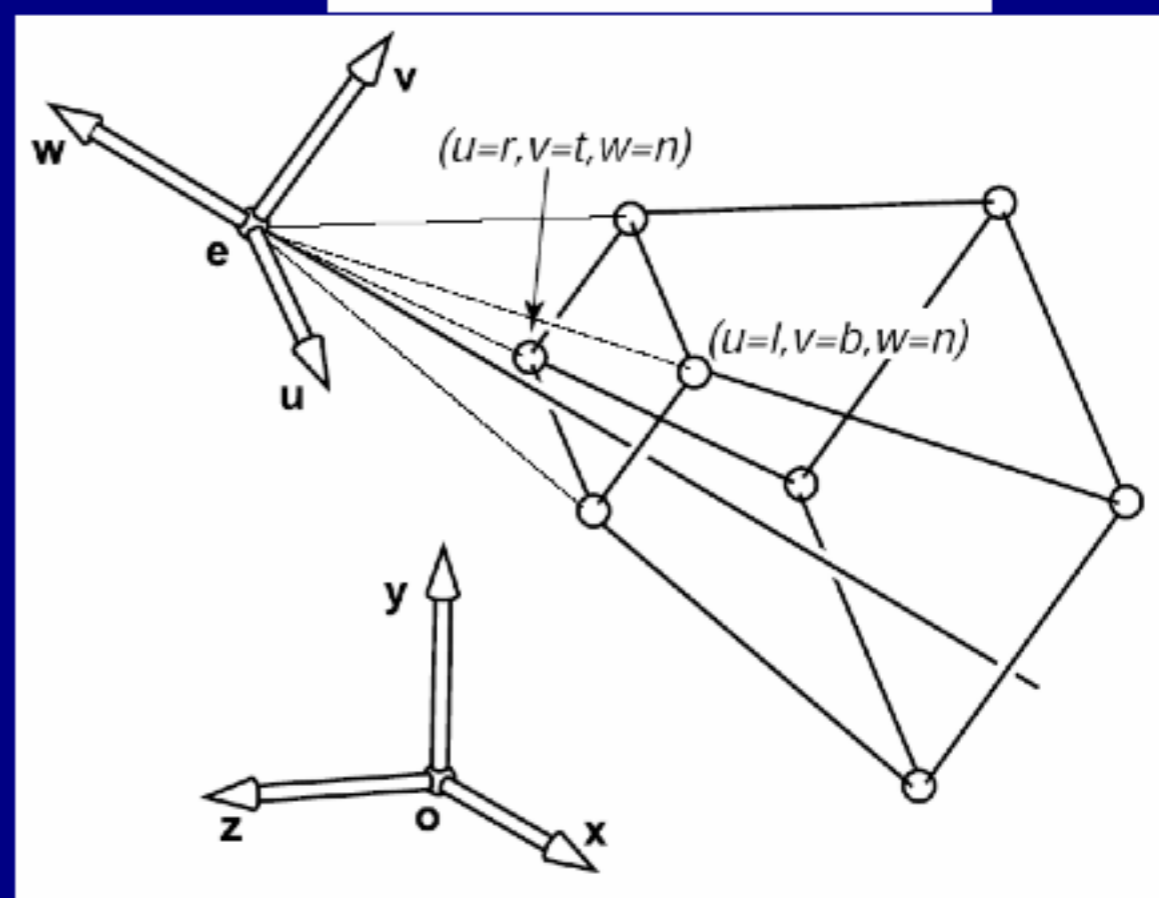


Computing Rays

Where is s ? (x, y of image)
Intersection of ray with image plane

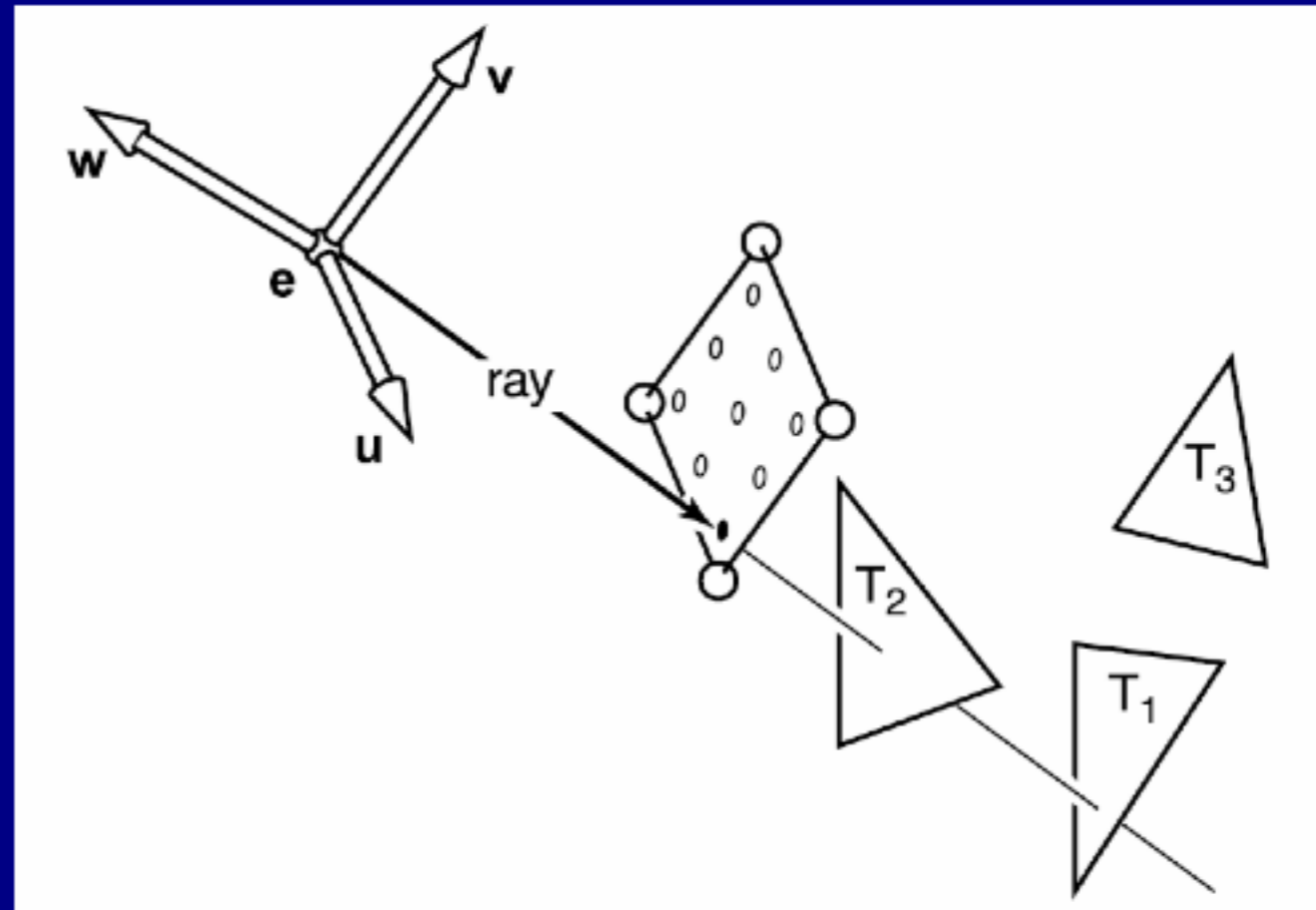


Details in book.
Derived using viewing transformations



Ray Object Intersection

Sphere
Triangle
Polygon

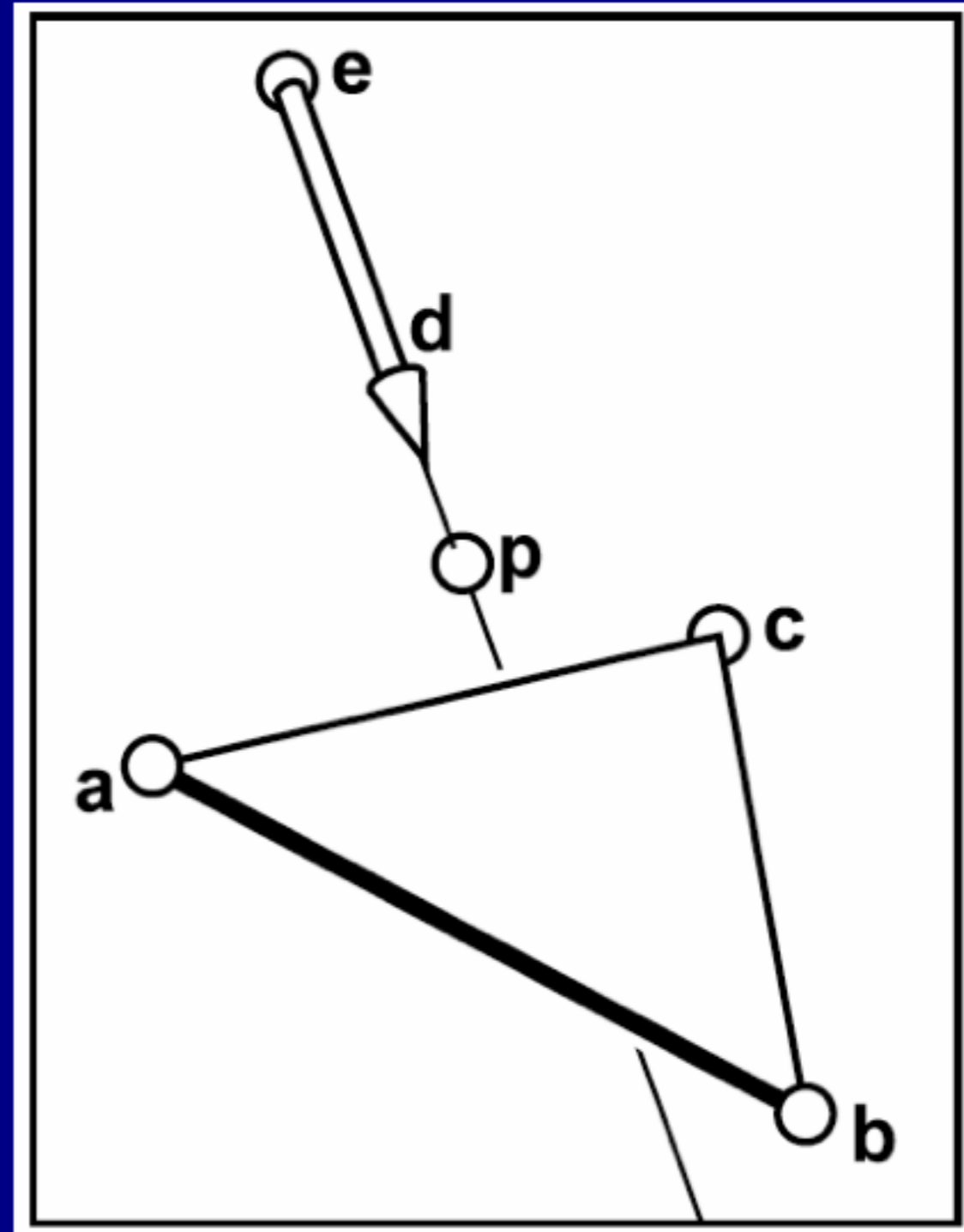


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Ray Object Intersection

Sphere
Triangle
Polygon

blackboard



Ray Object Intersection

Sphere
Triangle
Polygon

Ray-polygon—in book
Intersection with plane of polygon
in/outside of polygon determination

Ray-triangle—3D models composed of triangles

Ray-sphere—early models for raytracing, and now bounding volumes

Global vs. Local Rendering Models

Local rendering models: the color of one object is independent of its neighbors (except for shadows)

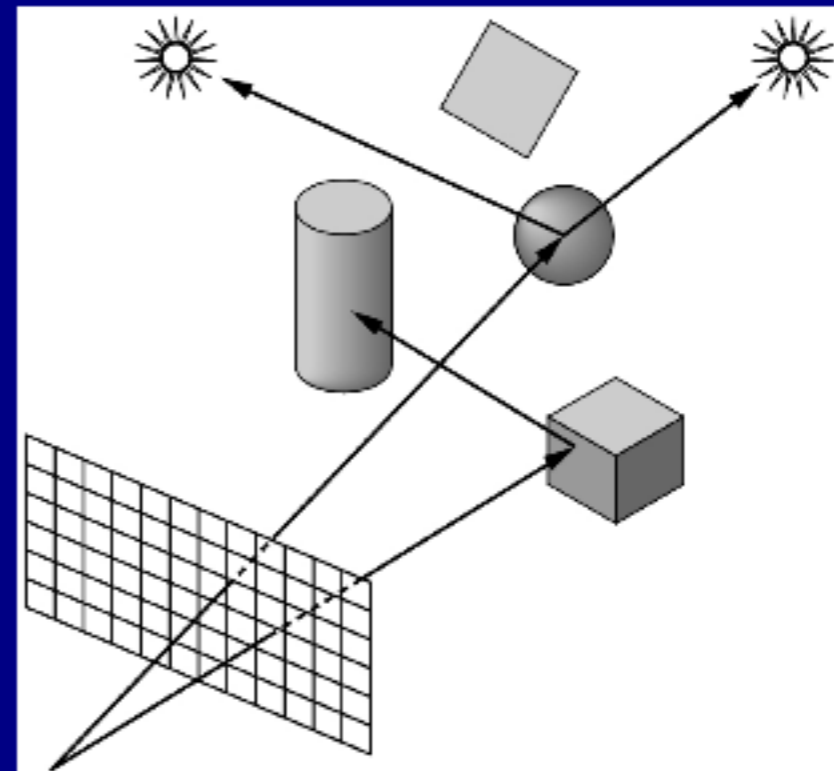
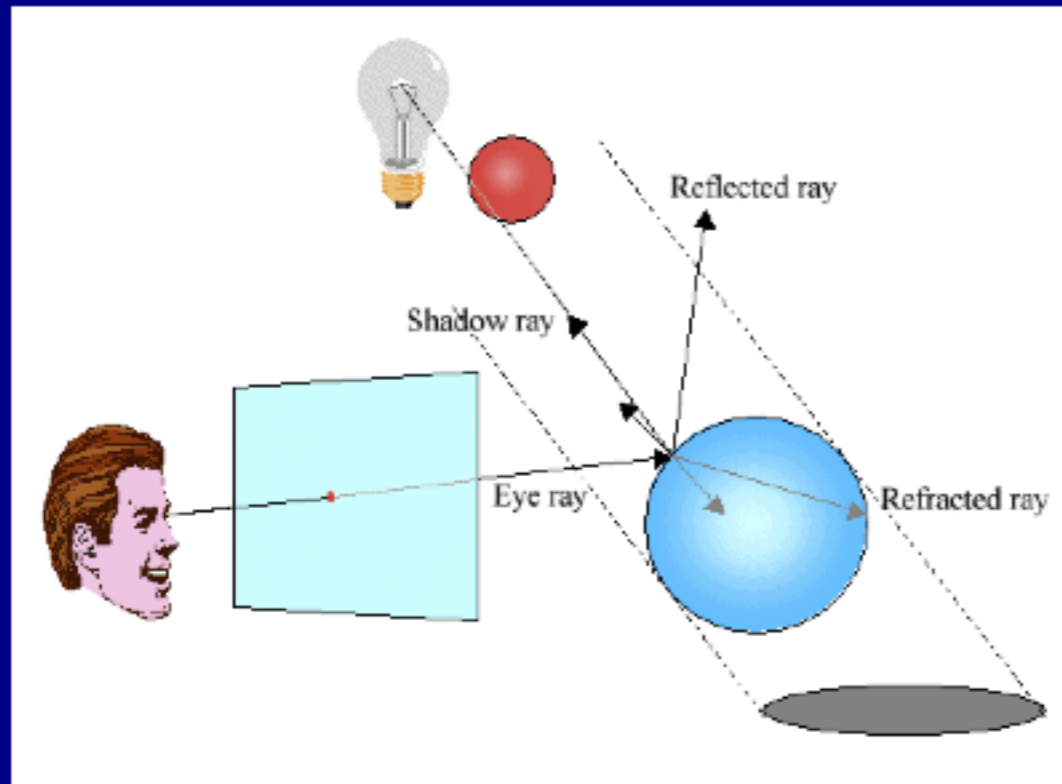
Missing scattering of light between objects, real shadowing

Global Rendering Models

Raytracing—specular highlights

Radiosity—diffuse surfaces, closed environments

Recursive Ray Tracing



Four ray types:

Eye rays: originate at the eye

Shadow rays: from surface point toward light source

Reflection rays: from surface point in mirror direction

Transmission rays: from surface point in refracted direction

Writing a Simple Ray Caster (no bounces)

```
Raycast () // generate a picture
  for each pixel x,y
    color(pixel) = Trace(ray_through_pixel(x,y))

Trace(ray) // fire a ray, return RGB radiance
           // of light traveling backward along it
  object_point = Closest_intersection(ray)
  if object_point return Shade(object_point, ray)
  else return Background_Color

Closest_intersection(ray)
  for each surface in scene
    calc_intersection(ray, surface)
  return the closest point of intersection to viewer
  (also return other info about that point, e.g., surface
  normal, material properties, etc.)

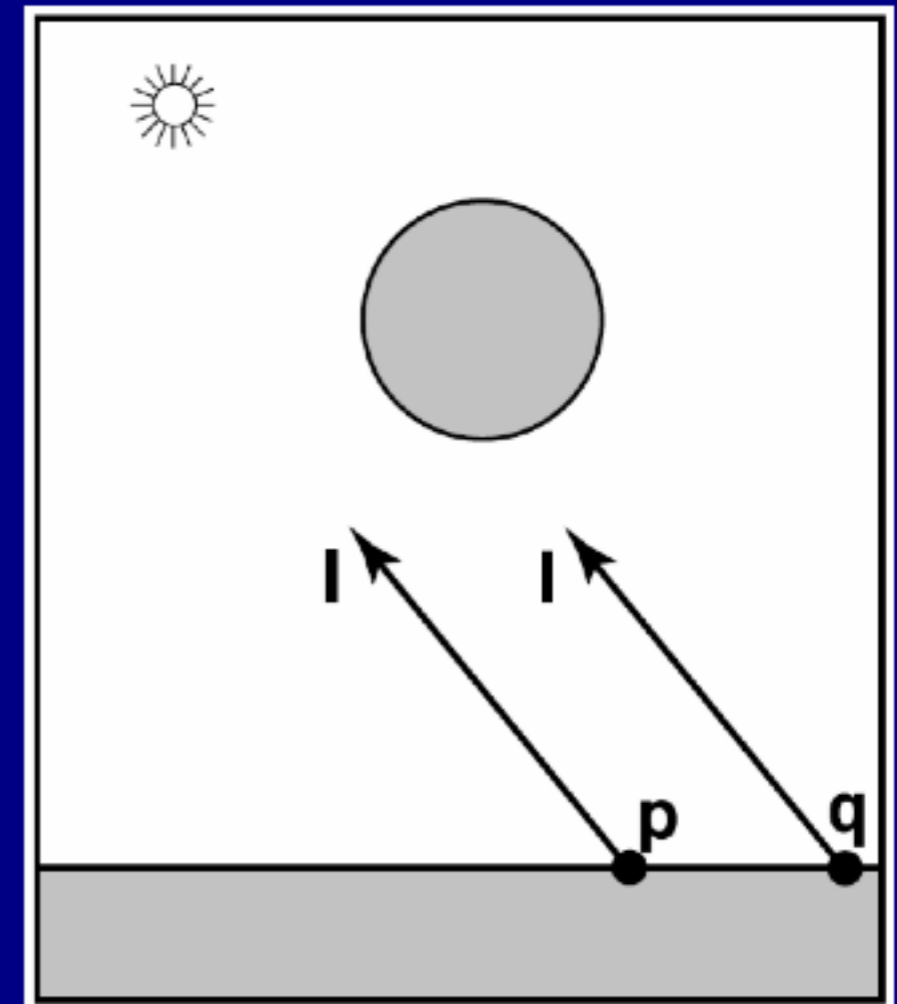
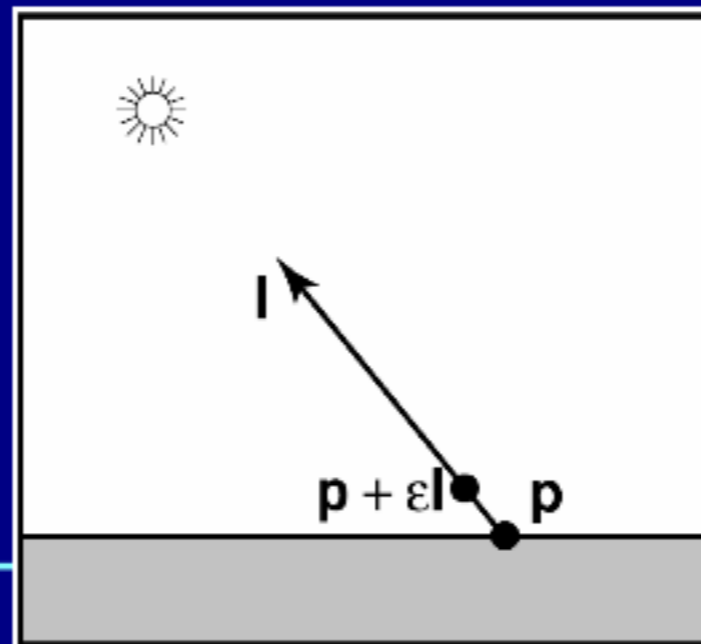
Shade(point, ray) // return radiance of light leaving
                 // point in opposite of ray direction
  calculate surface normal vector
  use Phong illumination formula (or something similar)
  to calculate contributions of each light source
```

Shadow Rays

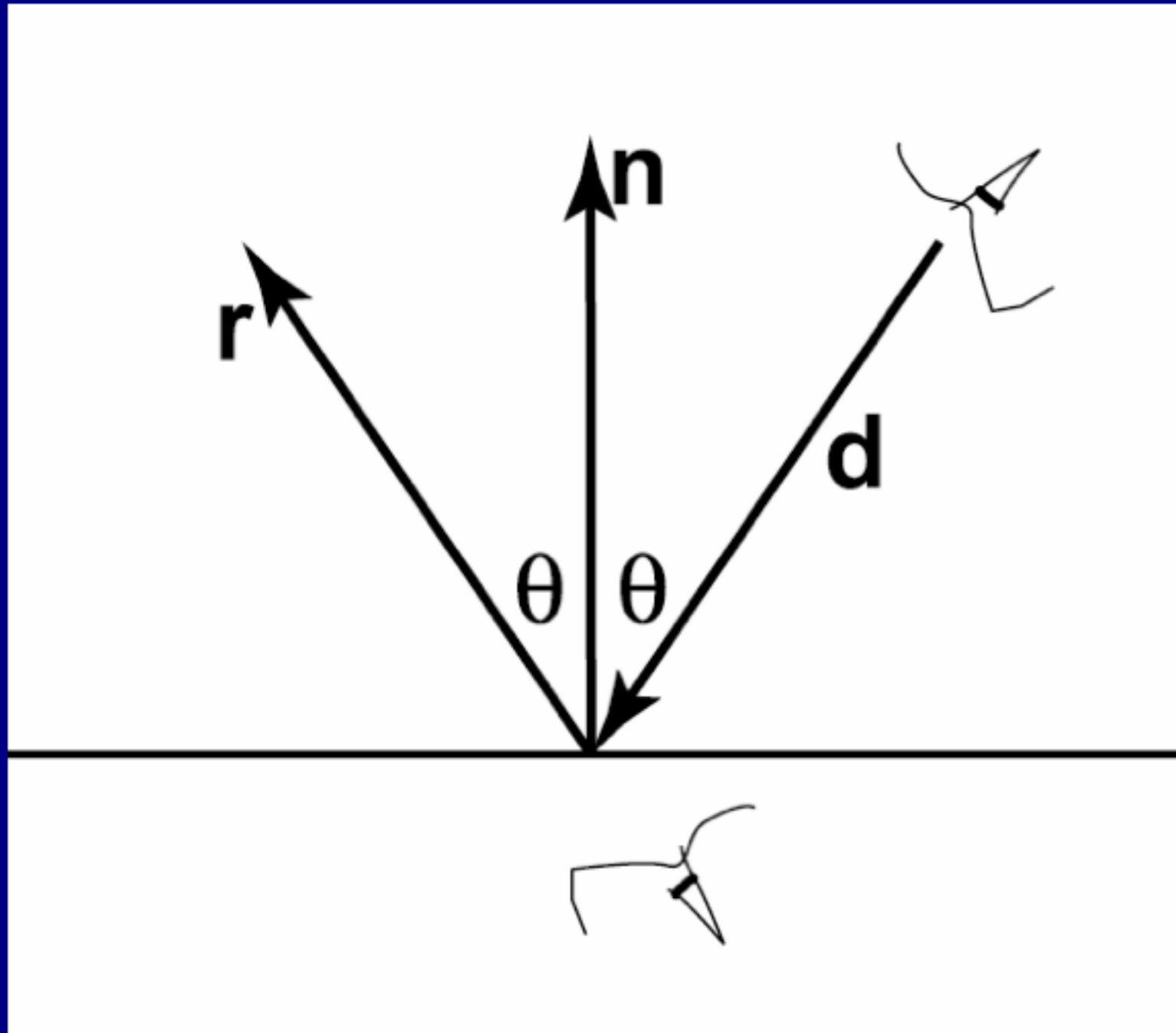
$p + t\mathbf{l}$ does not hit any objects

$q + t\mathbf{l}$ does hit an object and is shadowed

1 the same for both points
because this is a directional light
(infinitely far away)



Specular Reflection Rays



blackboard

Transmission Rays

Dielectrics—transparent material that refracts (and filters) light. Diamonds, glass, water, and air.

Light bends by the physics *principle of least time*

light travels from point A to point B by the fastest path

when passing from a material of one index to another *Snell's law* gives the angle of refraction

When traveling into a denser material (larger n), light bends to be more perpendicular (eg air to water) and vice versa

MATERIAL	INDEX OF REFRACTION
air/vacuum	1
water	1.33
glass	about 1.5
diamond	2.4

Refraction



Transmission Rays

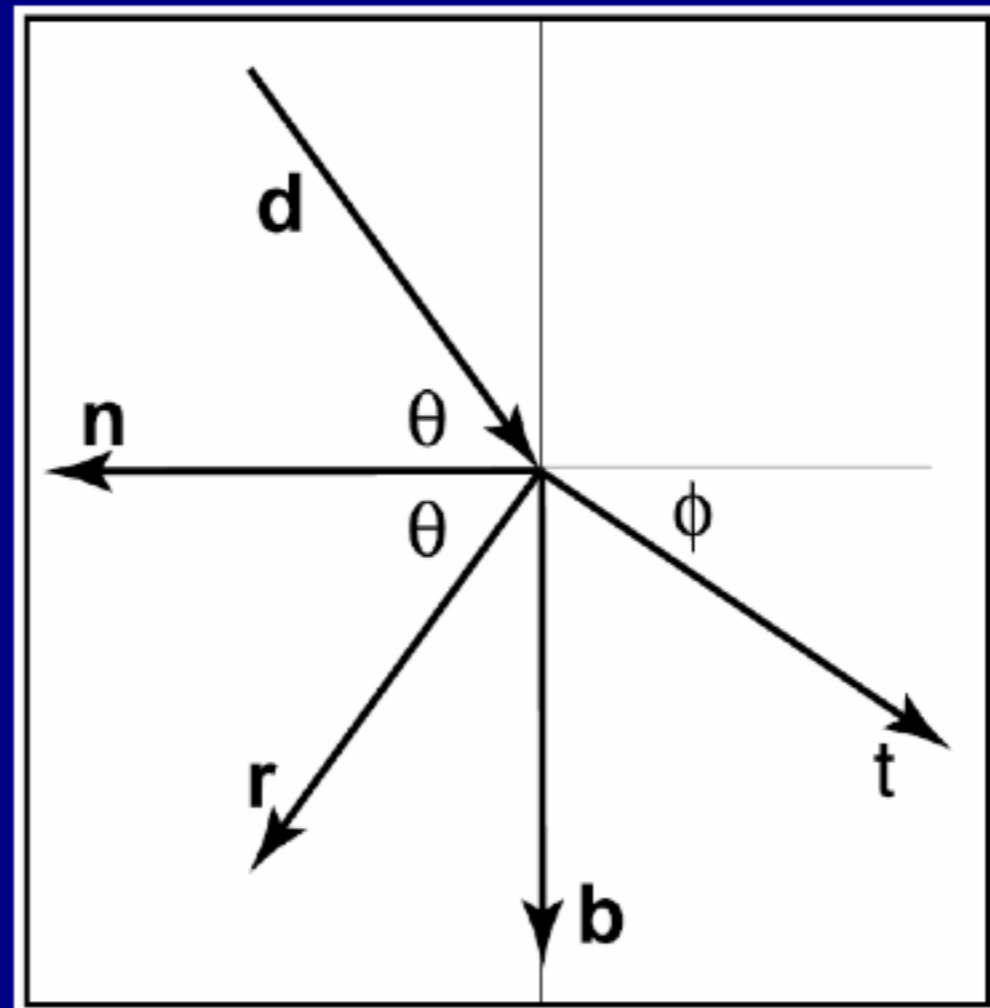
Dielectrics—transparent material that refracts (and filters) light. Diamonds, glass, water, and air.

Snell's law:

$$n \sin \theta = n_t \sin \phi$$

n is the refractive index
of the first material.
 n_t is the refractive index
of the second material

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Transmission Rays

Dielectrics—transparent material that refracts (and filters) light. Diamonds, glass, water, and air.

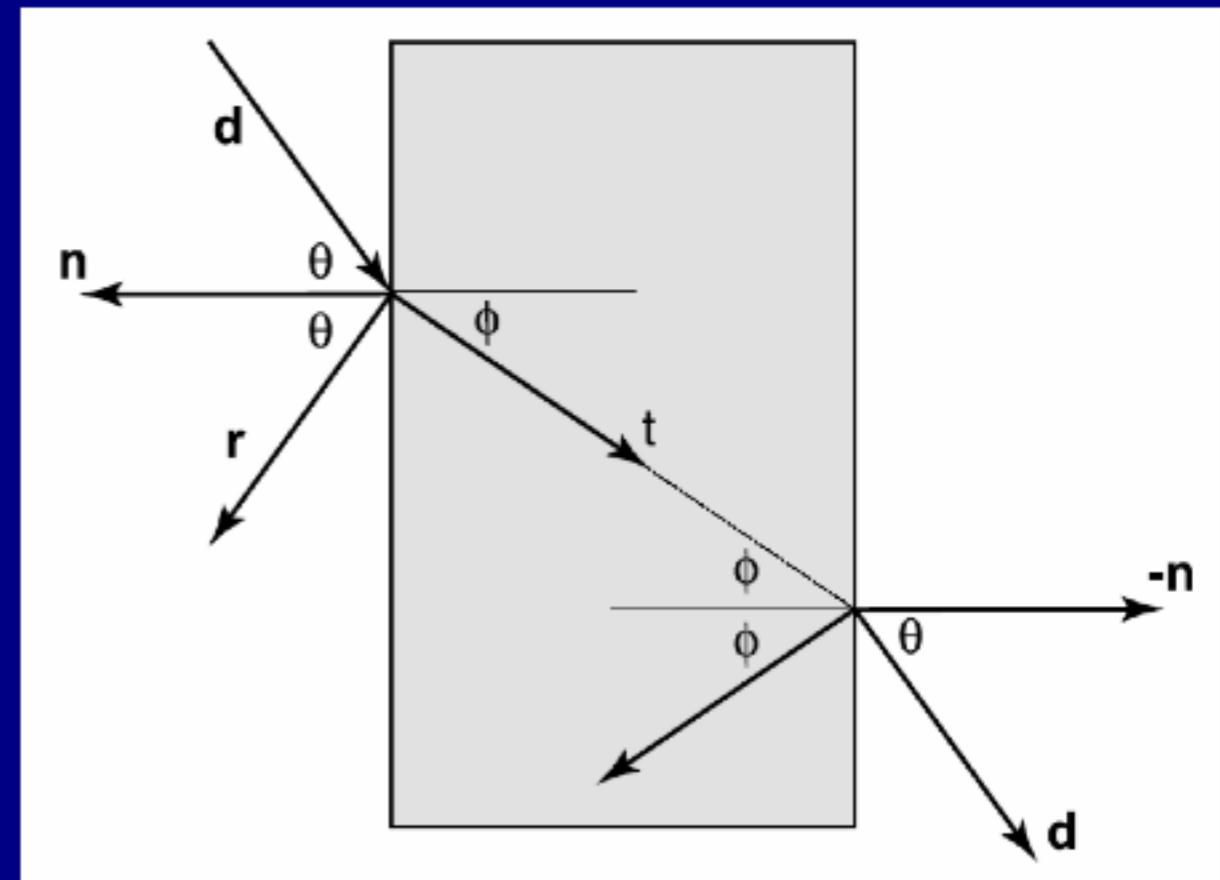
Snell's law:

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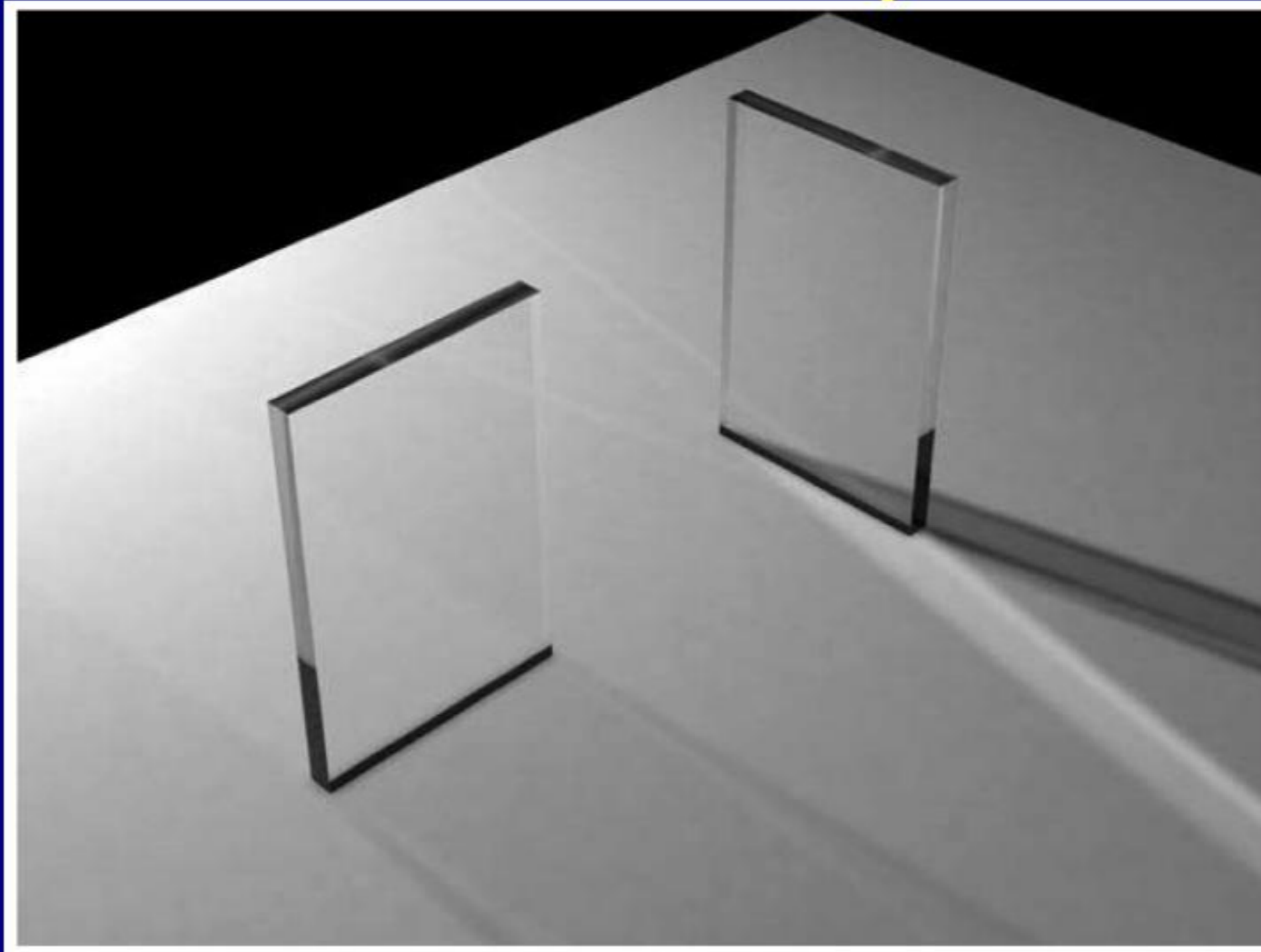
n is the refractive index of the first material.

n_t is the refractive index of the second material

blackboard



Transmission Rays



Total Internal Reflection



Practice Problems

In a backwards ray tracing algorithm that follows rays through a single bounce only, the color rendered at a pixel is a sum of what components? Write an equation for computing pixel color and label the terms. Include direct lighting, specular reflection, and specular refraction.

Now suppose you follow rays through two bounces (i.e., a ray can bounce off two objects in succession). What new terms are added? What effects can we capture in two bounces that cannot be captured in one?

Practice Problems

Read about the algorithm for ray-triangle intersection in the Shirley text. Draw up an example and work it out to test your understanding of how to solve for the intersection in this manner.

Create a numerical example problem where total internal reflection is demonstrated.