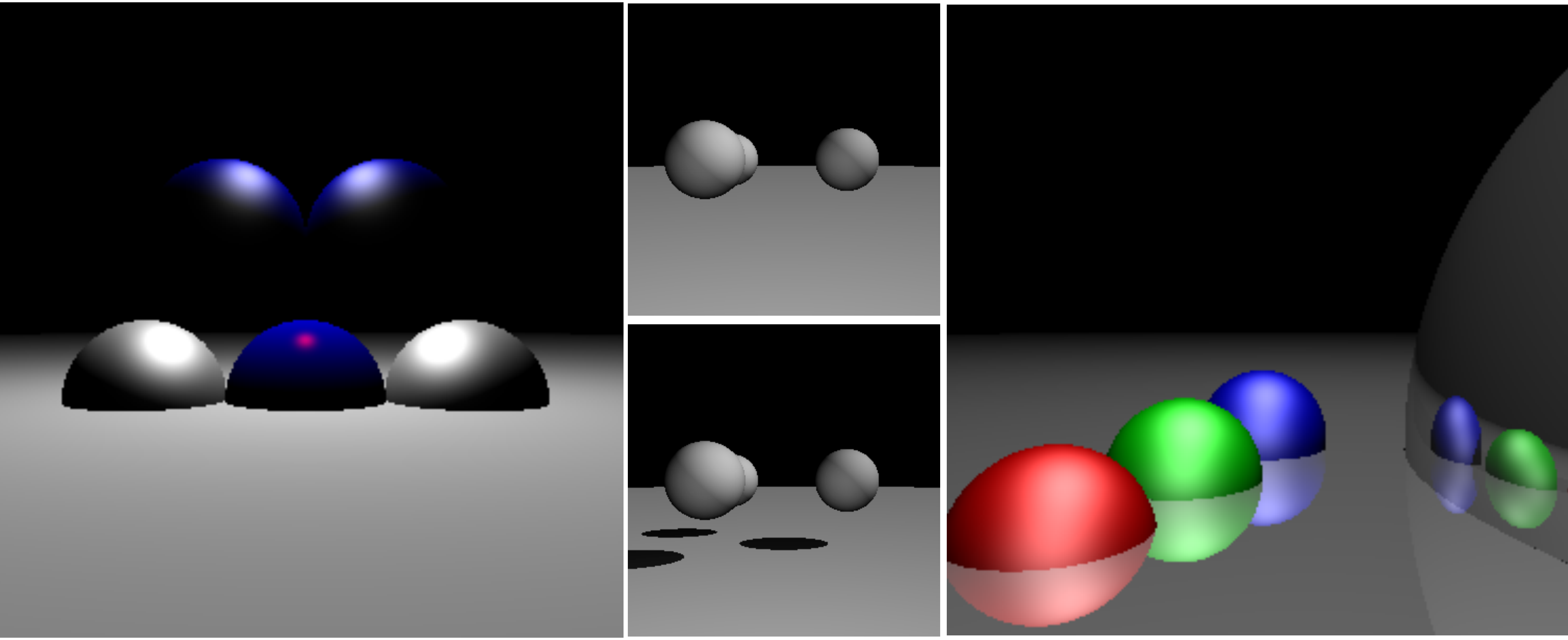

Computer Graphics

Lecture 8

Shading

Mirror Reflection

Shadows

Announcements

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- HW1 is out - due next Monday

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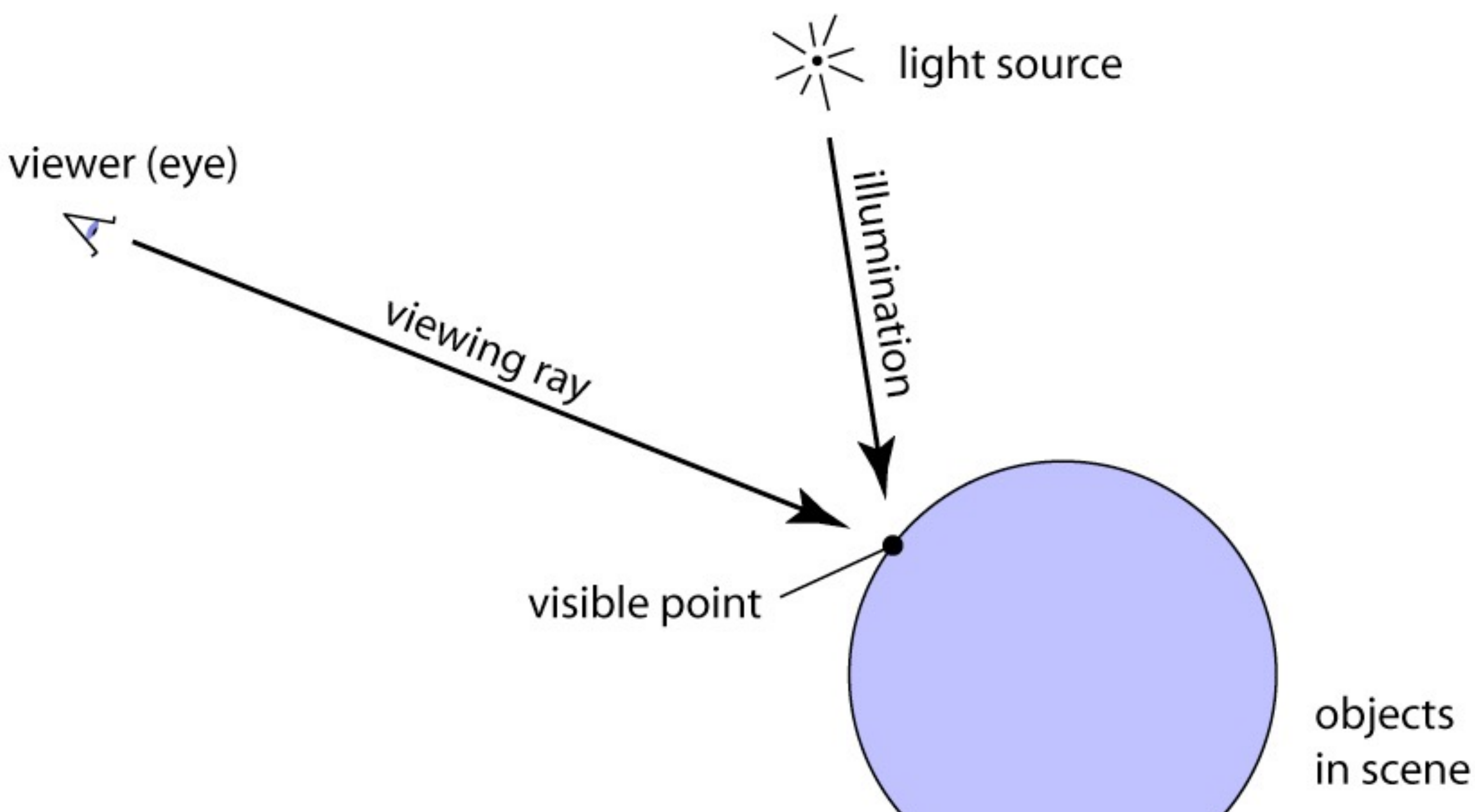
  - HW1 Problems 3 and 4 will help with A2 TODO 9 and 8.
- A2 is now due Friday 2/7

Ray Tracing: Pseudocode

```
for each pixel:
    generate a viewing ray for the pixel
    find the closest object it intersects
    determine the color of the object
```



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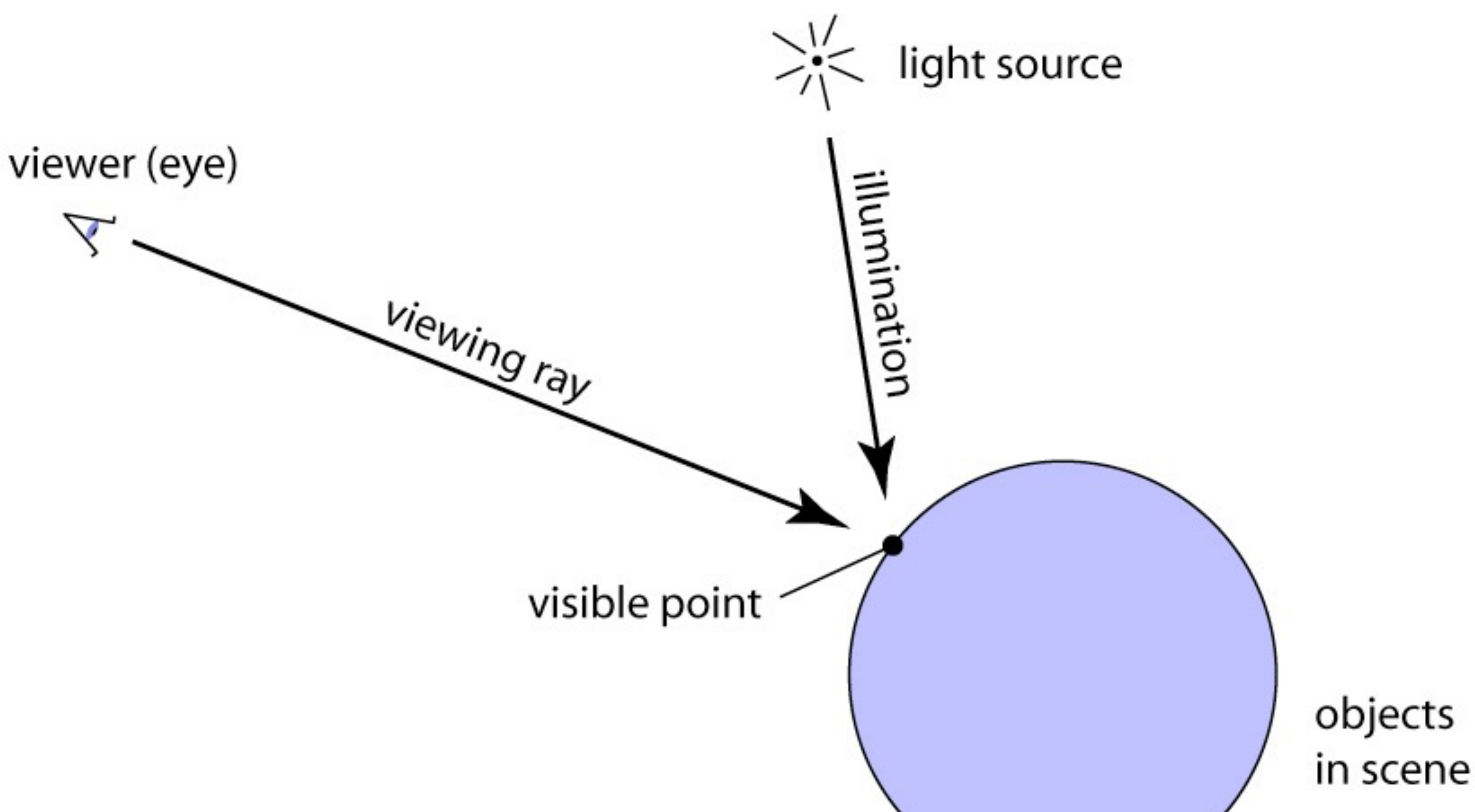

Shading

What does the color of a pixel depend on?

- surface normal *stored in or calculated from object*
- surface properties (color, shininess, ...) *stored in object*
- eye direction *calculated from viewing ray and intersection point*
- light direction (for each light) *calculated from light and intersection point*

Ray-Sphere: Code Sketch

```
function ray_intersect(ray, sphere, tmin, tmax):
```

- Use last lecture's math to find +/- *t*
- If no real solutions, return `nothing`
- Otherwise, return closest *t* that lies between `tmin` and `tmax`
- Also return info needed for shading - store in a `HitRecord` struct.

In A2: t, intersection point, normal, texture coordinate, object

Ray-Scene: Code Sketch

Brute force: check all objects.
There are better ways - more on this later.

```
find_intersection(ray, scene):
  closest_t = Inf # closest intersection t
  closest_rec = nothing # HitRecord for intersection
  for obj in scene:
    t, rec = ray_intersect(ray, obj, 1, closest_t)
    if rec != nothing:
      closest_t = t
      closest_rec = rec
  return closest_t, closest_rec
```

Ray Tracing: Code Sketch

```
scene = model_scene()
for each pixel (i,j):
    ray = get_view_ray(i, j)
    t, rec = find_intersection(ray, scene)
    if rec != nothing:
        canvas[i,j] = obj.color
    else:
        canvas[i,j] = scene.bgcolor
```

Ray Tracing: Code Sketch

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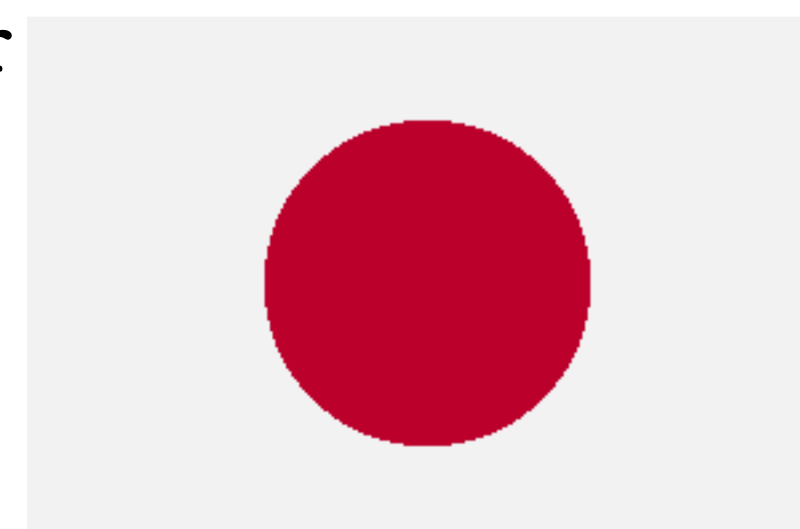
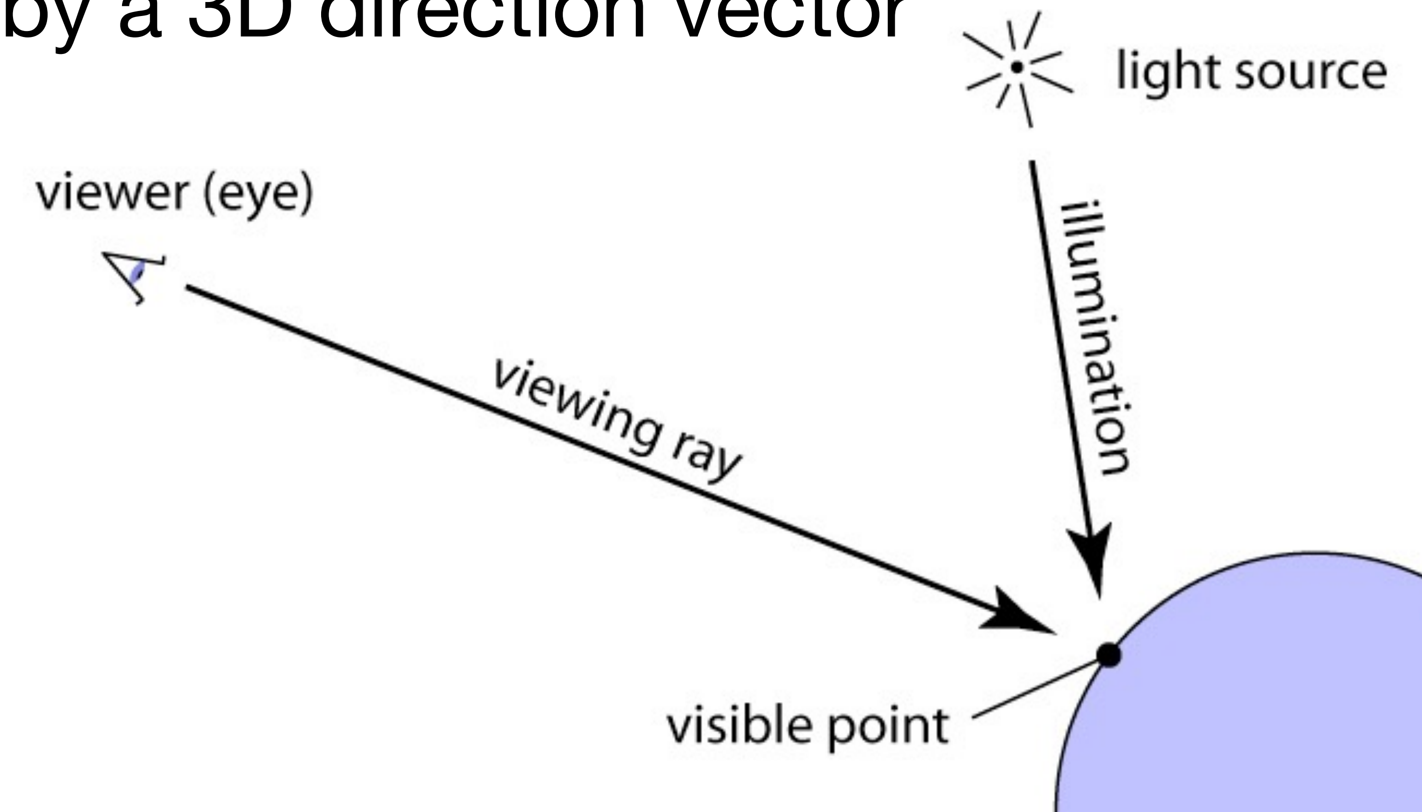
```

Let's work on this.



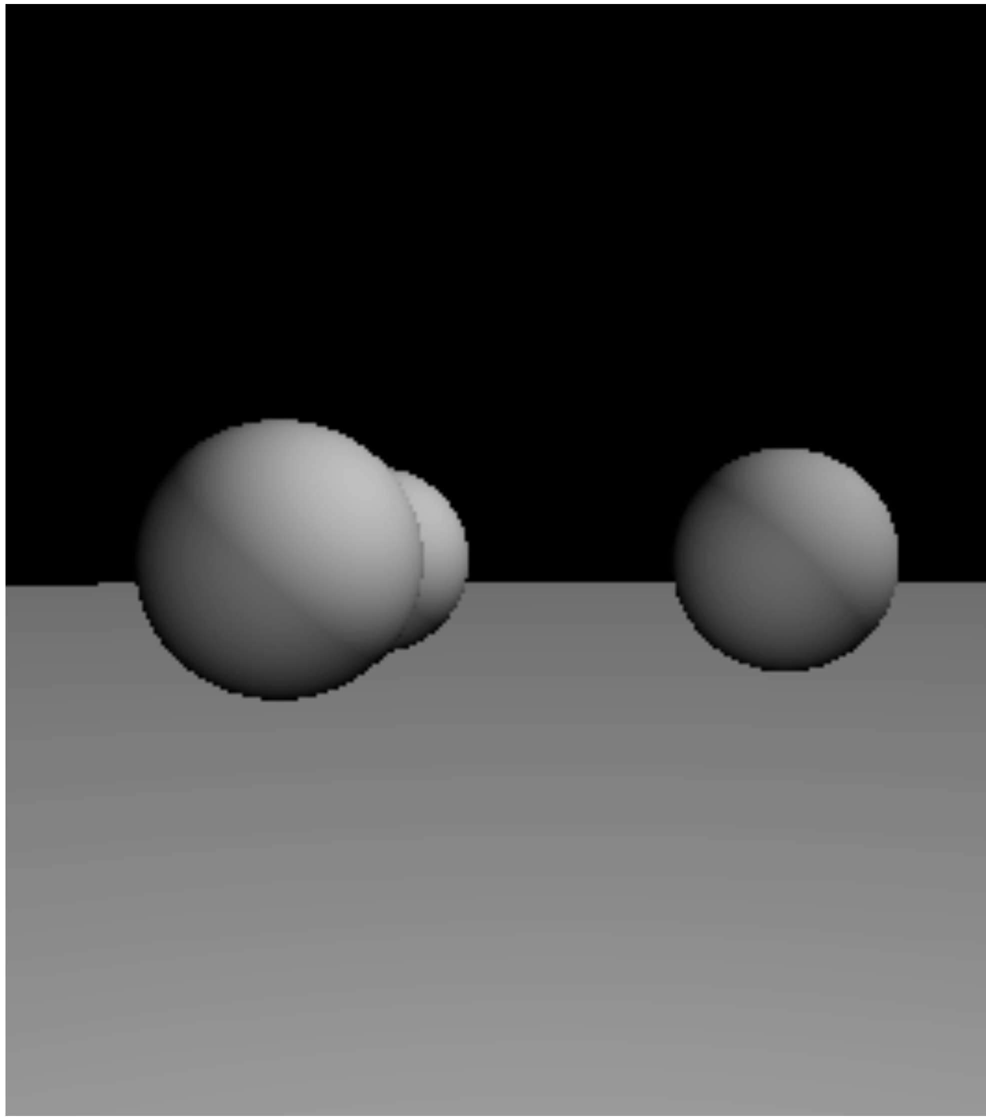
Light Sources

- Where does light come from?
- Two simple kinds of sources:
  - point source: defined by a 3D position
  - directional source: defined by a 3D direction vector



Diffuse (Lambertian) Reflection

- On a *diffuse* surface, light scatters uniformly in all directions.
- No dependence on view direction.
- Many surfaces are approximately diffuse:
  - matte painted surfaces, projector screens,
  - anything that doesn't look "shiny"

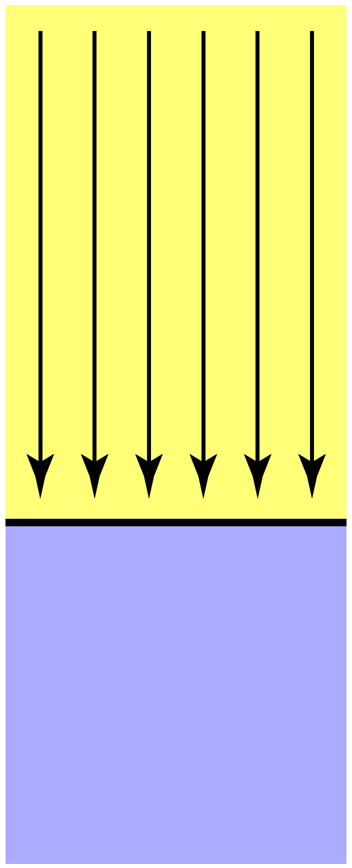


Diffuse (Lambertian) Reflection

- whiteboard

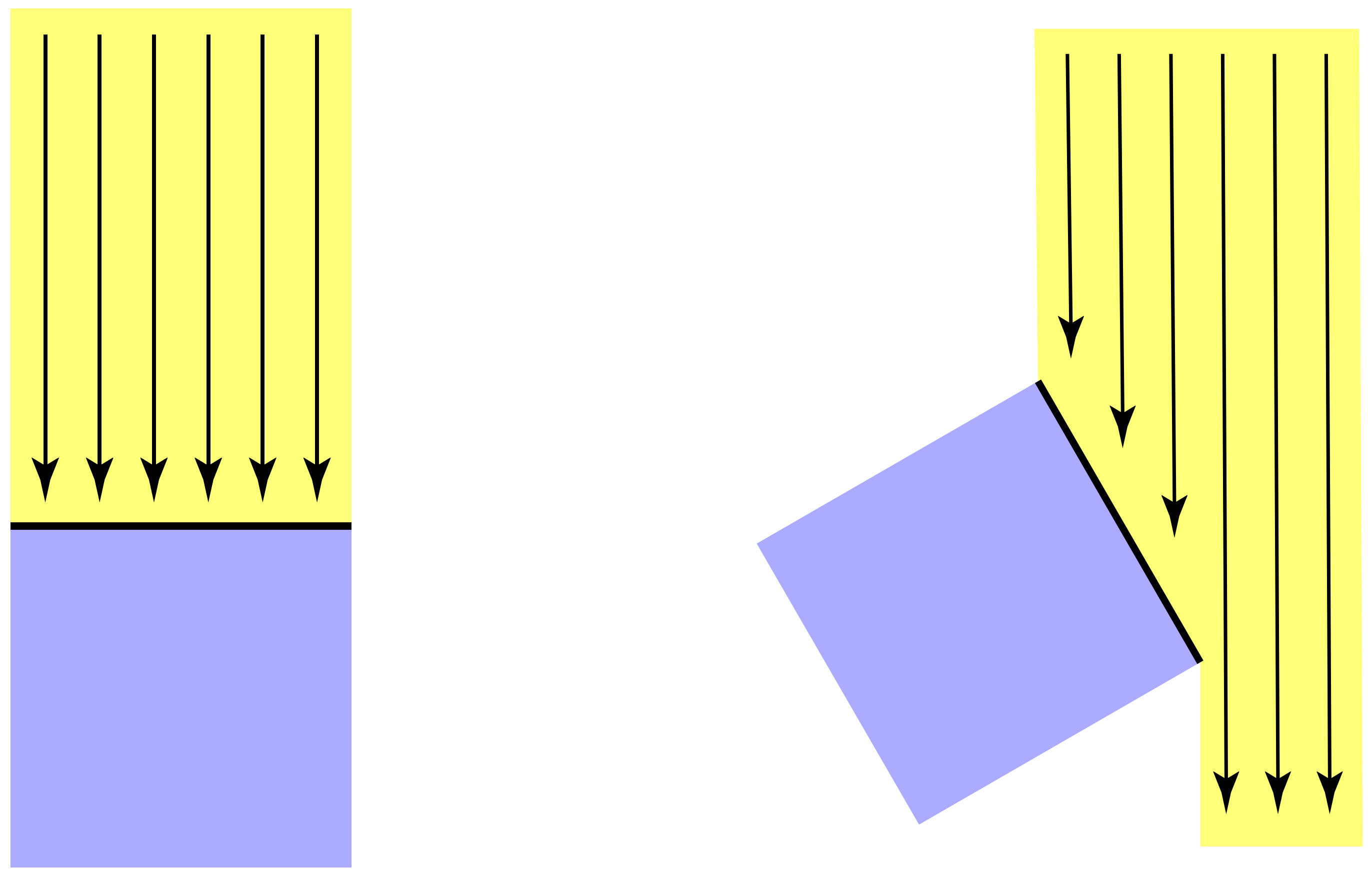
Diffuse (Lambertian) Reflection

Diffuse (Lambertian) Reflection



The top face of a cube receives some amount of light.

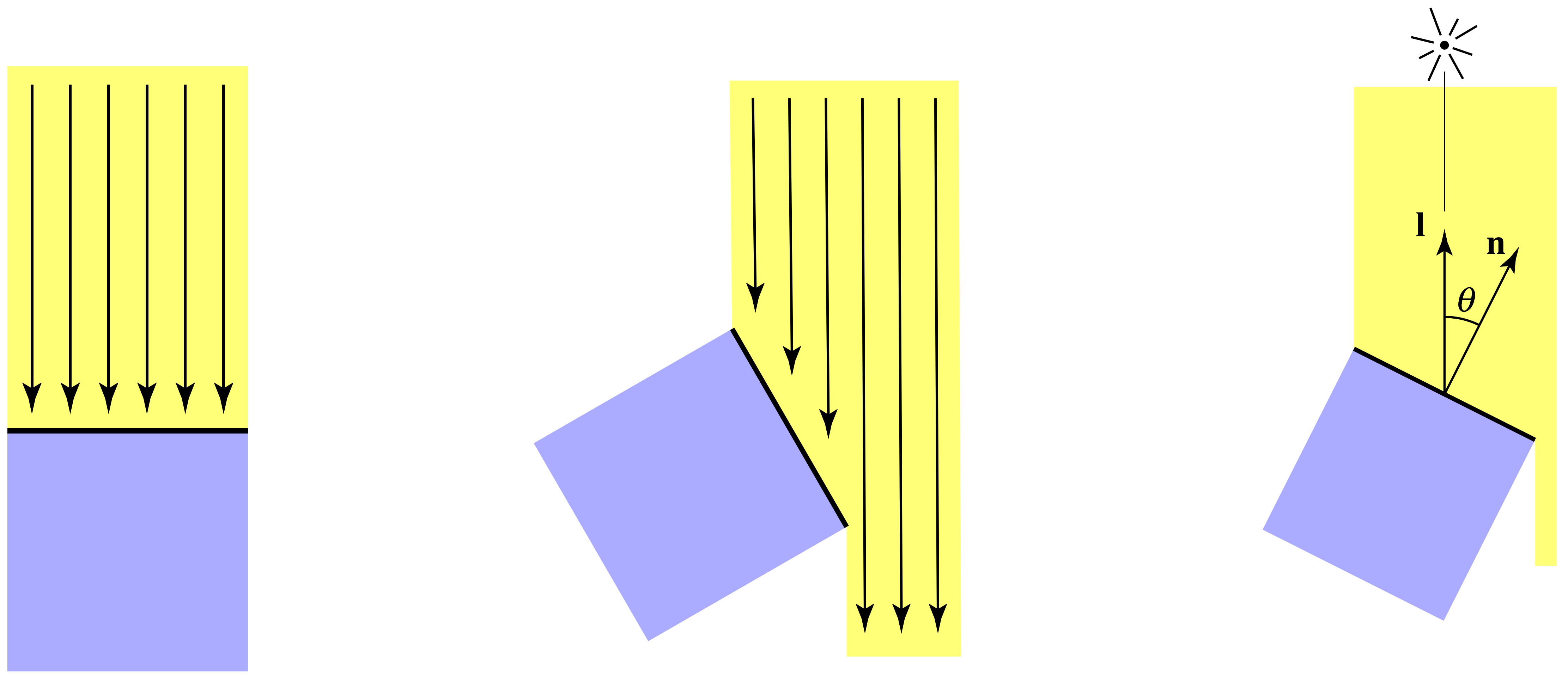
Diffuse (Lambertian) Reflection



The top face of a cube receives some amount of light.

Rotated 60°, the same face receives half the light.

Diffuse (Lambertian) Reflection



The top face of a cube receives some amount of light.

Rotated 60°, the same face receives half the light.

Light per unit area is proportional to $\cos\theta = \vec{n} \cdot \vec{\ell}$

Diffuse (Lambertian) Shading

- The full model:

$$L_d = k_d I \max(0, \vec{n} \cdot \vec{\ell})$$

why max?

diffuse
coefficient

diffusely
reflected light

light intensity

Diffuse (Lambertian) Shading

- The full model:

$$L_d = k_d I \max(0, \vec{n} \cdot \vec{\ell})$$

why max?

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diffusely reflected light

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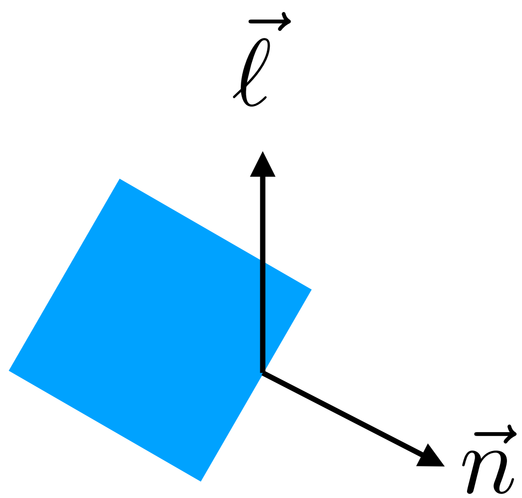
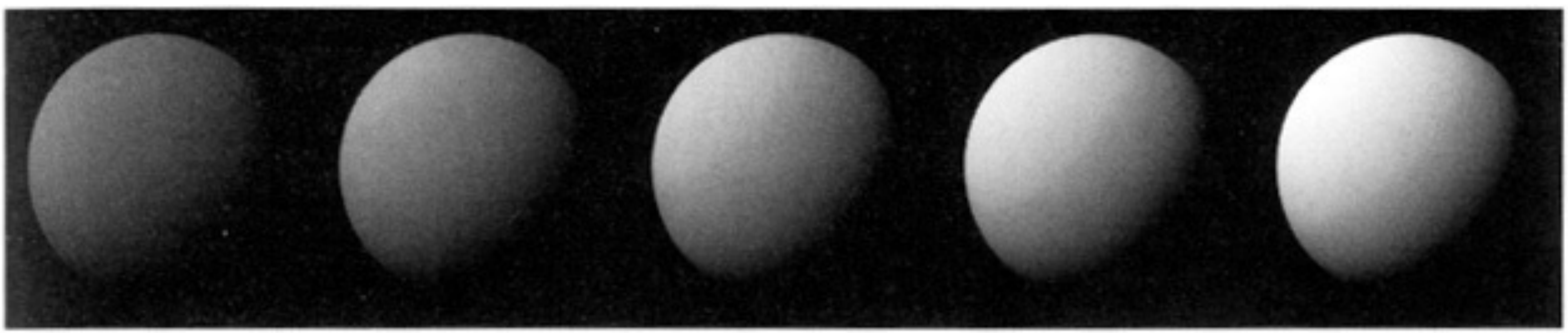


Diffuse (Lambertian) Shading

$$L_d = k_d I \max(\vec{n} \cdot \vec{\ell})$$



[Foley et al.]

k_d ⟶

For colored objects, k_d is a 3-vector of R, G, and B reflectances.

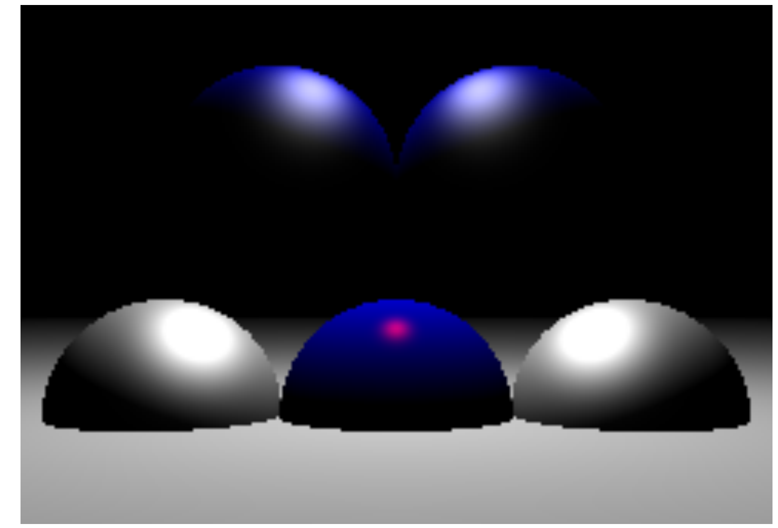
Exercise: Diffuse Reflection

Let's talk shinies.

- How does a mirror interact with light?

(whiteboard)

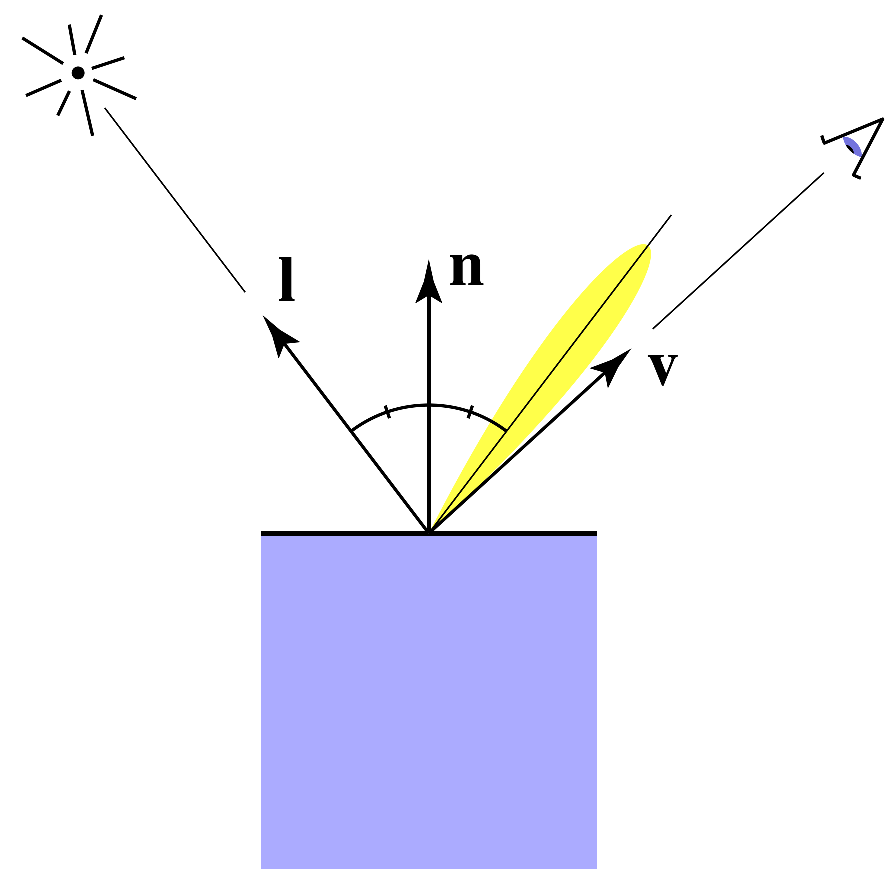
Specular Reflection



- What about non-mirror shiny surfaces?

- They appear brighter *near* "mirror" configuration

- Phong reflection: specular reflection is a function of angle between **r** and **v**.



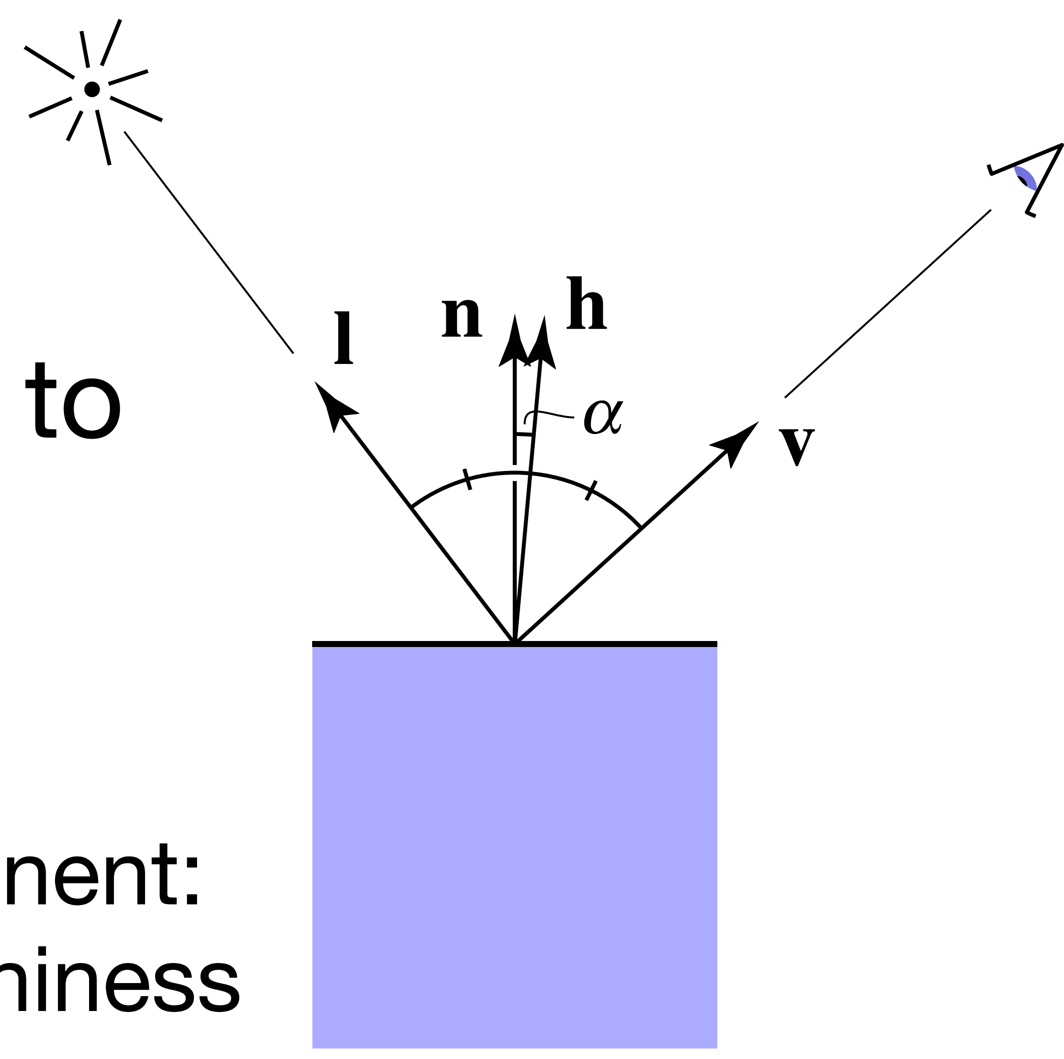
Specular Reflection

- Blinn-Phong: specular reflection is a function of angle between **half-way vector** between view and light and the **normal**.
- h = bisector(**v**, **l**)
- Reflected light proportional to

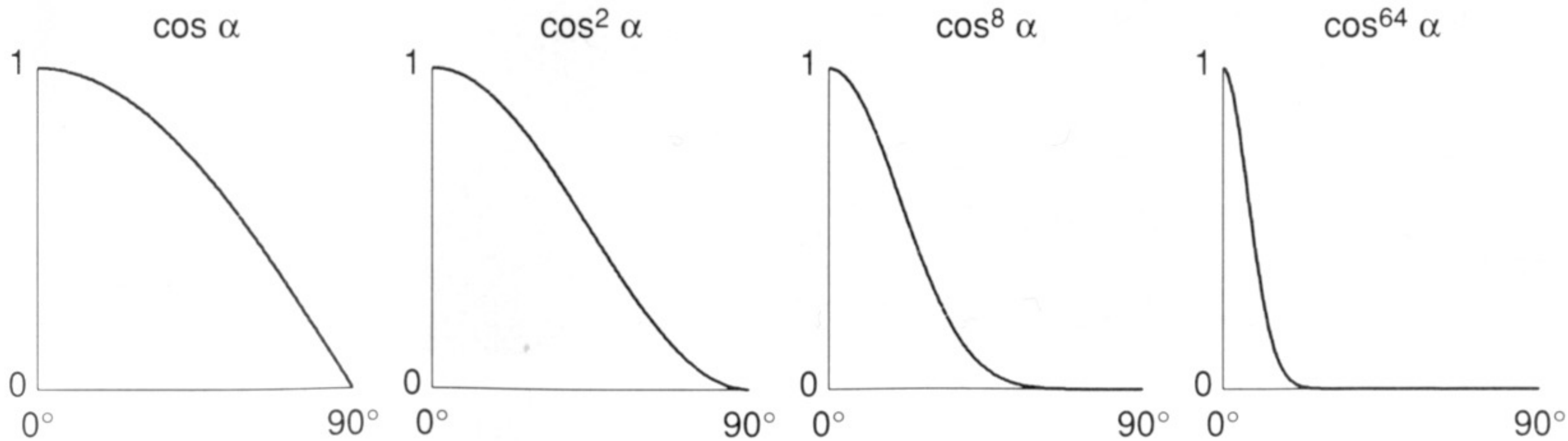
$$k_s \max(0, \vec{n} \cdot \vec{h})^p$$

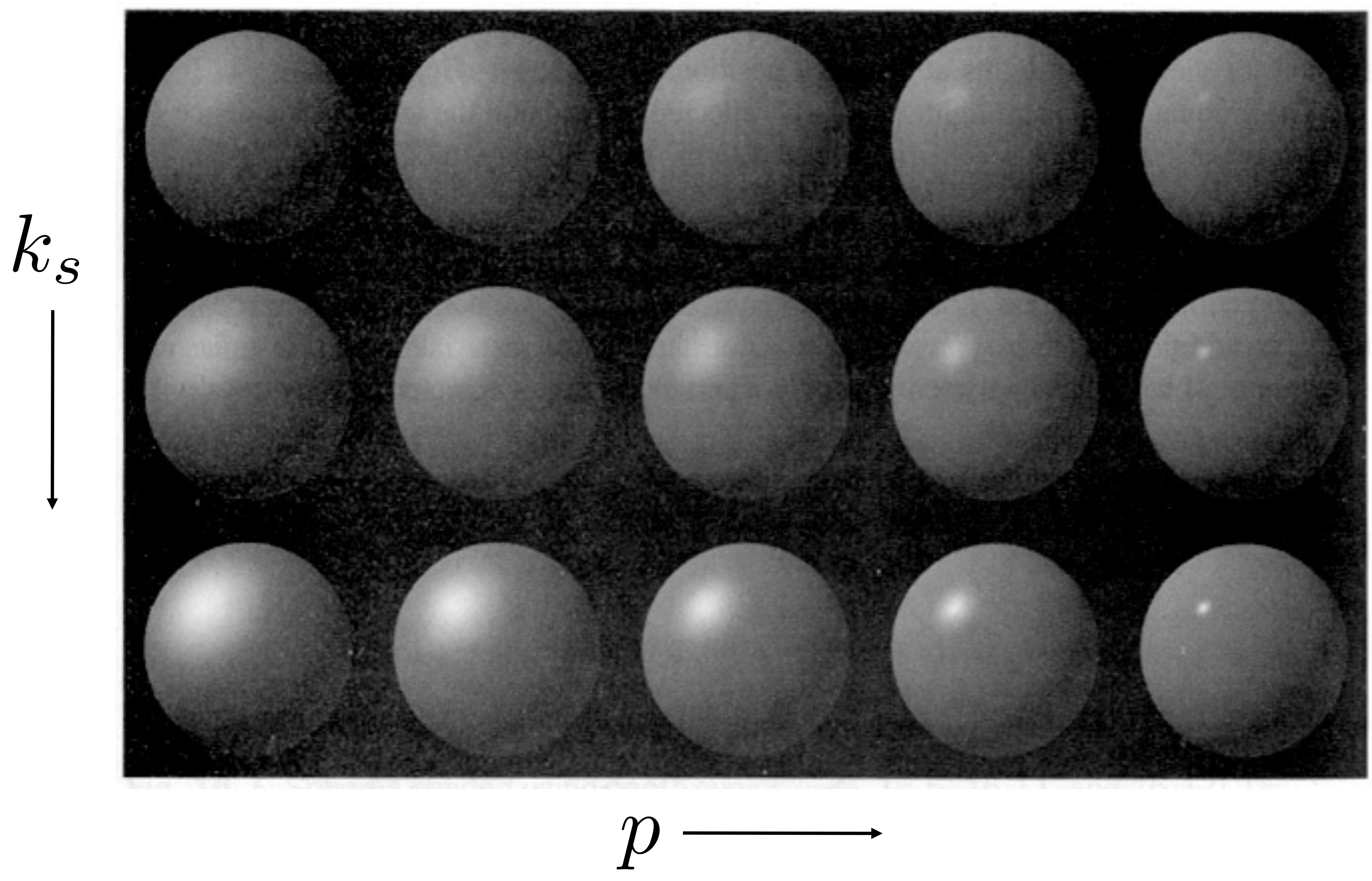
specular coefficient: determines strength of specularity term

specular exponent: determines shininess



Effect of *p*




k_s
p

Putting it all Together: Blinn-Phong Reflection Model

Usually surfaces have both diffuse *and* specular components, so we'll combine the two:

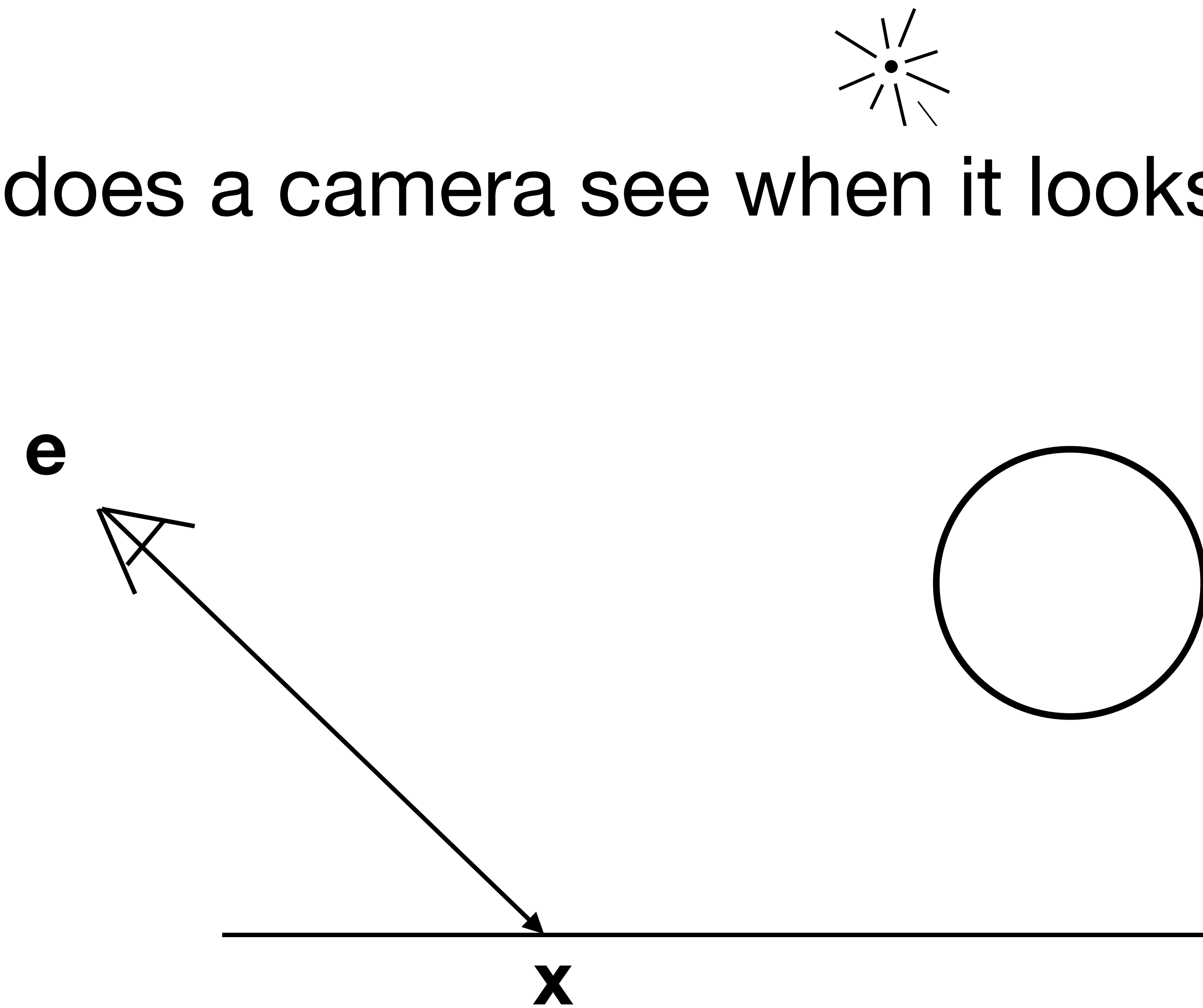
$$L = L_d + L_s$$

$$= k_d I \max(0, \vec{n} \cdot \vec{l}) + k_s I \max(0, \vec{n} \cdot \vec{h})^p$$

- L: light reflected
- L_d: diffuse reflection
- L_s: specular reflection
- k_d: diffuse coefficient (surface brightness and color)
- I: light intensity
- $\vec{n}$: normal
- $\vec{l}$: light direction
- k_s: specular coefficient (*strength* [and color] of specularity)
- $\vec{h}$: half-vector between **l** and **v**
- p: specular exponent (*sharpness* of specularity)

Mirror Reflection

What does a camera see when it looks at a mirror?

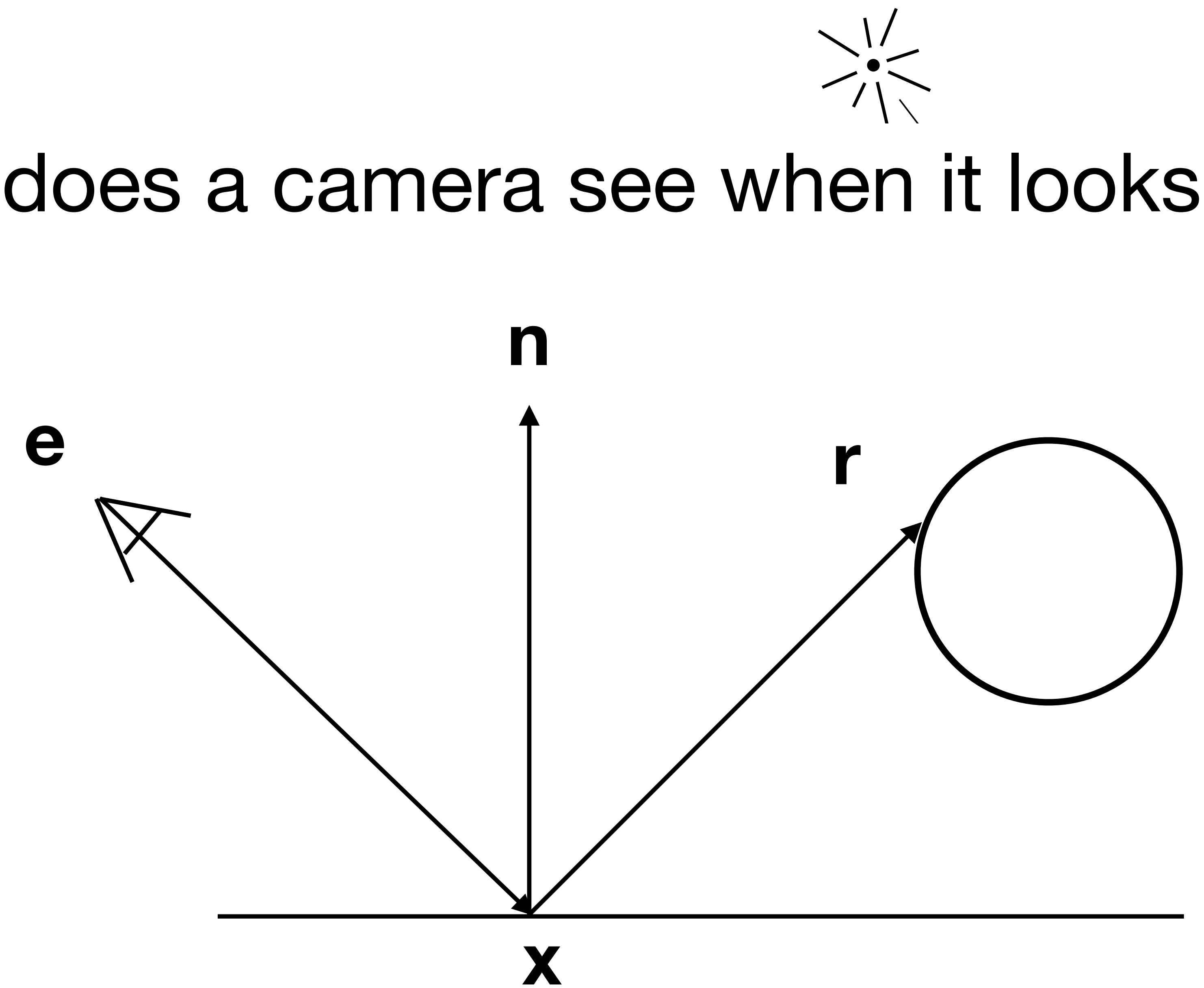


Can we do this using the tools we already have?

(Exercise 2)

Mirror Reflection

What does a camera see when it looks at a mirror?

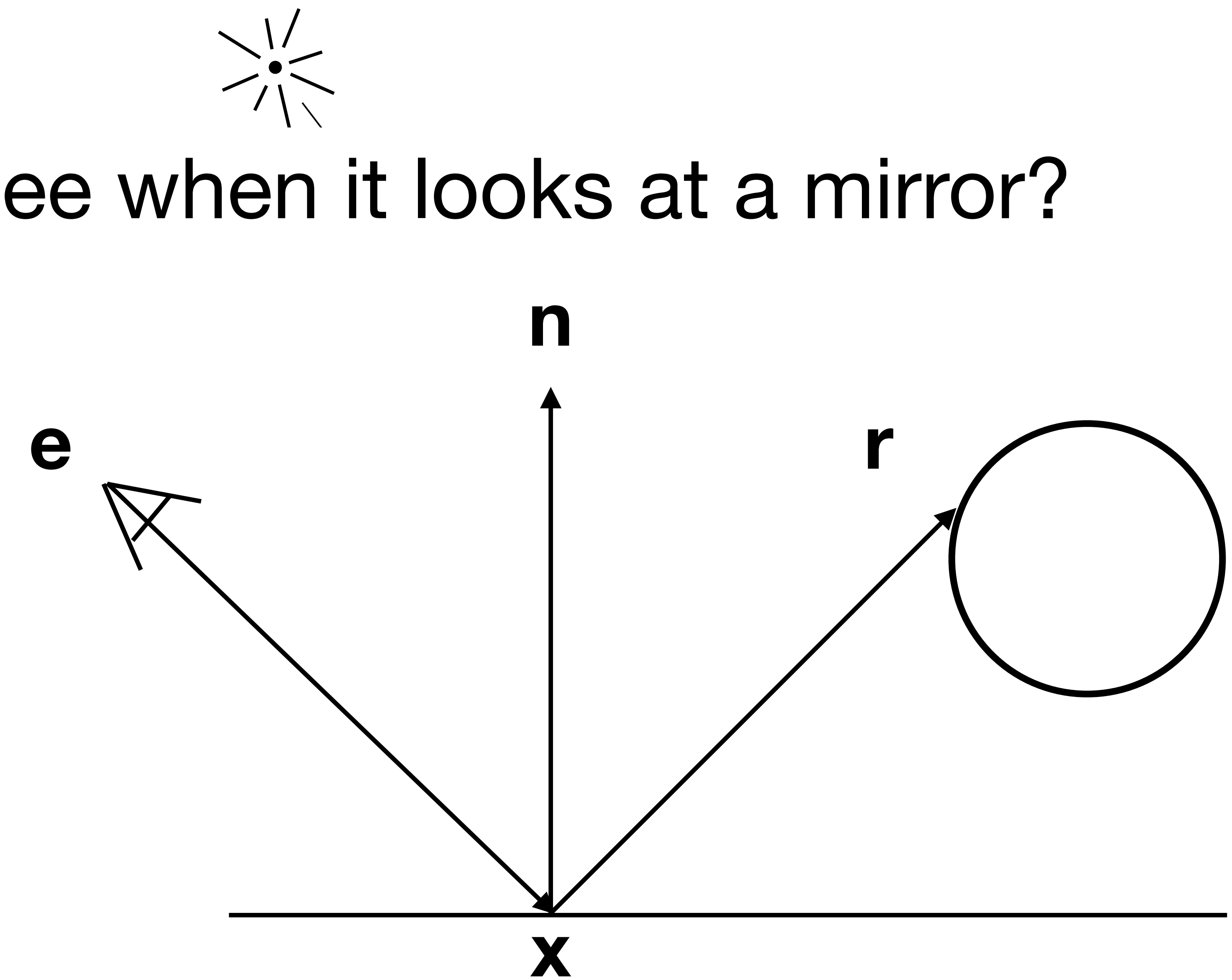


Can we do this using the tools we already have?

```
find_intersection(ray, scene)
```

Mirror Reflection

What does a camera see when it looks at a mirror?




```
compute r
ray = Ray(x, r)
find_intersection(ray, scene)
```

Recursion!?

```
traceray(ray, scene):
    t, rec = find_intersection(ray, scene)
    if rec.obj is a mirror:
        compute r, the reflection direction
        mirror_ray = Ray(rec.x, r)
        return traceray(mirror_ray, scene)
    # other cases, ...
```

Mirror Coefficient

- Most surfaces aren't perfect mirrors. Object stores a *mirror coefficient* k_m between 0 and 1.
- "Local color" computed as usual
- "reflected color" computed recursively
- Final color: $k_m * reflected + (1-k_m) * local$