CS4620/5620: Lecture 8

Ray Tracing Basics

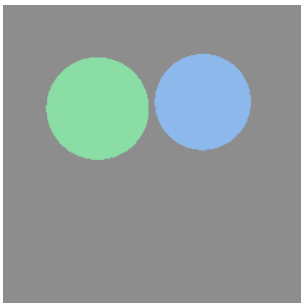
Announcements

- PA1 out
  - In pairs: PA0 (find partners), stay after class to find partners, or post on piazza, or contact the TAs, ...
  - capped cylinder, cone
- Staff list
  - cs4620-staff-l@cornell.edu

Image so far

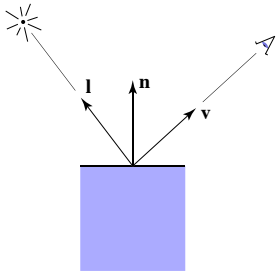
- With eye ray generation and scene intersection

```
for 0 <= iy < ny
   for 0 <= ix < nx {
      ray = camera.getRay(ix, iy);
      c = scene.trace(ray, 0, +inf);
      image.set(ix, iy, c);
   }

...

Scene.trace(ray, tMin, tMax) {
   surface, t = surfs.intersect(ray, tMin, tMax);
   if (surface != null) return surface.color();
   else return black;
}
```



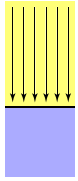
Shading

- Compute light reflected toward camera
- Inputs:
  - eye direction
  - light direction (for each of many lights)
  - surface normal
  - surface parameters (color, shininess, …)

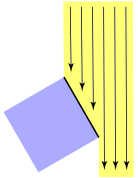


Diffuse reflection

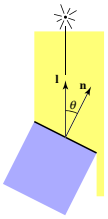
- Light is scattered uniformly in all directions
  - the surface color is the same for all viewing directions
- Lambert's cosine law



Top face of cube receives a certain amount of light



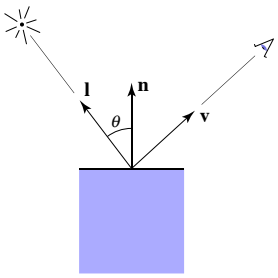
Top face of 60° rotated cube intercepts half the light



In general, light per unit area is proportional to $\cos\theta = \mathbf{l} \cdot \mathbf{n}$

Lambertian shading

- Shading independent of view direction



illumination from source

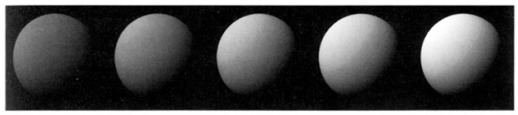
$$L_d = k_d \, I \max(0, \mathbf{n} \cdot \mathbf{l})$$

diffuse coefficient

diffusely reflected light

Lambertian shading

- Produces matte appearance



$k_d \longrightarrow$

[Foley et al.]

Diffuse shading

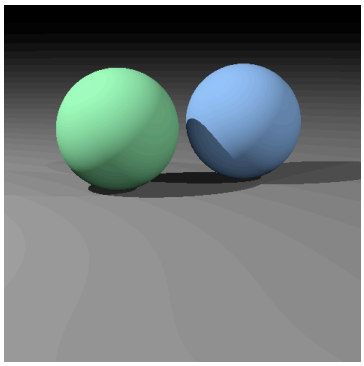
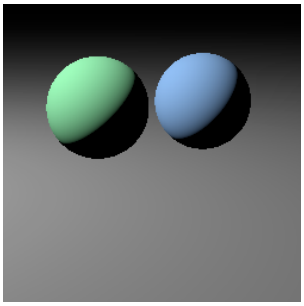


Image so far

```
Scene.trace(Ray ray, tMin, tMax) {
   surface, t = hit(ray, tMin, tMax);
   if surface is not null {
      point = ray.evaluate(t);
      normal = surface.getNormal(point);
      return surface.shade(ray, point,
          normal, light);
   }
   else return backgroundColor;
}

...

Surface.shade(ray, point, normal, light) {
   v = –normalize(ray.direction);
   l = normalize(light.pos – point);
   // compute shading
}
```



Light

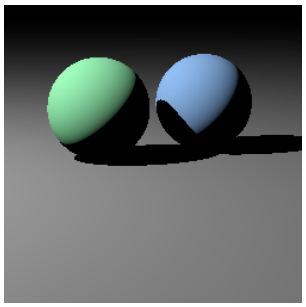
- Local light
  - Position
- Directional light (e.g., sun)
  - Direction, no position

Shadows

- Surface is only illuminated if nothing blocks its view of the light
- With ray tracing it's easy to check
  - just intersect a ray with the scene!

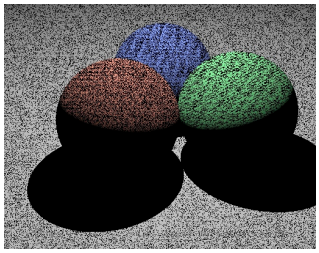
Image so far

```
Surface.shade(ray, point, normal, light) {
   shadRay = (point, light.pos – point);
   if (shadRay not blocked) {
      v = –normalize(ray.direction);
      l = normalize(light.pos – point);
      // compute shading
   }
   return black;
}
```



Shadow rounding errors

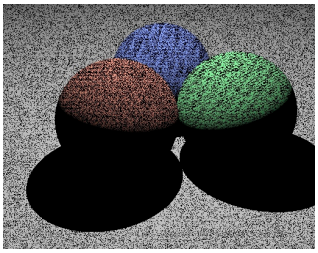
- Sounds like it should work, but hmm....



- What's going on?

Shadow rounding errors

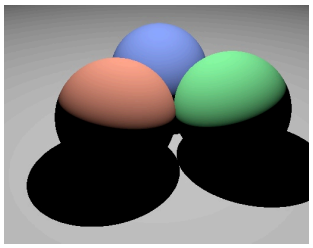
- Sounds like it should work, but hmm....



- What's going on?
  - hint: at what *t* does the shadow ray intersect the surface you're shading?

Shadow rounding errors

- Solution: shadow rays start a tiny distance from the surface



- Do this by moving the start point, or by limiting the *t* range

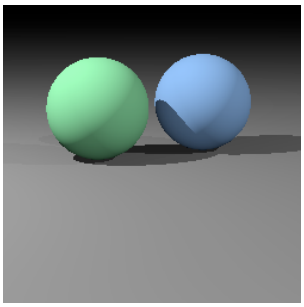
Multiple lights

- Just loop over lights, add contributions
- Important to fill in black shadows

- Ambient shading
  - black shadows are not really right
  - one solution: dim light at camera
  - alternative: add a constant "ambient" color to the shading…

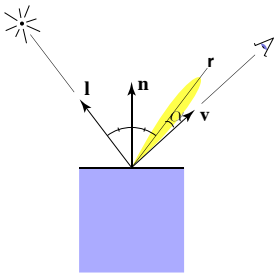
Image so far

```
shade(ray, point, normal, lights) {
   result = ambient;
   for light in lights {
      if (shadow ray not blocked) {
         result += shading contribution;
      }
   }
   return result;
}
```



Specular shading (Phong)

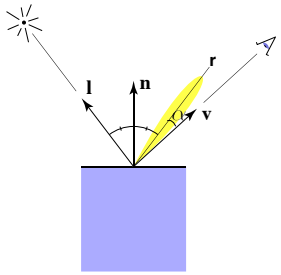
- Intensity depends on view direction
  - bright near mirror configuration
  - measure "near" by dot product of unit vectors



$\cos(\alpha) = \mathbf{v} \cdot \mathbf{r}$

Specular shading (Phong)

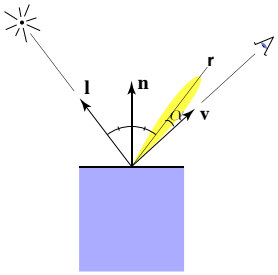
- Intensity depends on view direction
  - bright near mirror configuration



$$L_s = k_s I \max(0, \cos\alpha)^n$$
$$\cos(\alpha) = \mathbf{v}.\mathbf{r}$$
$$L_s = k_s I \max(0, \mathbf{v}.\mathbf{r})^n$$

Reflected direction

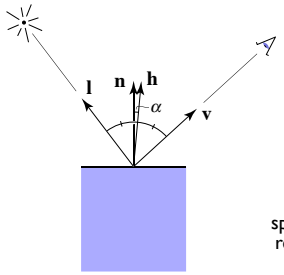
- Intensity depends on view direction
  - reflects incident light from mirror direction



$$\mathbf{r} = 2(\mathbf{n}.\mathbf{l})\mathbf{n} - \mathbf{l}$$

Specular shading (Blinn-Phong)

- Close to mirror ⇔ half vector near normal



$$\mathbf{h} = \text{bisector}(\mathbf{v}, \mathbf{l}) = \frac{\mathbf{v}+\mathbf{l}}{\|\mathbf{v}+\mathbf{l}\|}$$

$$L_s = k_s I \max(0, \cos\alpha)^n = k_s I \max(0, \mathbf{n}\cdot\mathbf{h})^n$$

specularly reflected light

specular coefficient

Phong model—plots

- Increasing *n* narrows the lobe

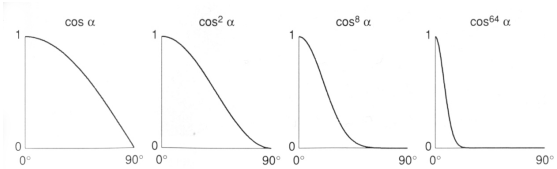
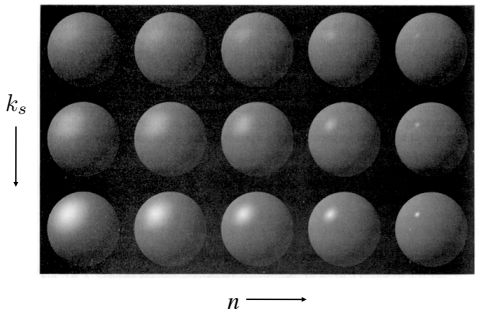


Fig. 16.9 Different values of $\cos^n \alpha$ used in the Phong illumination model.

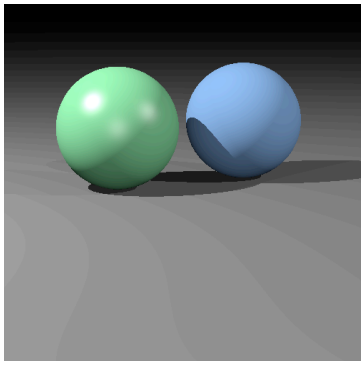
[Foley et al.]

Specular shading



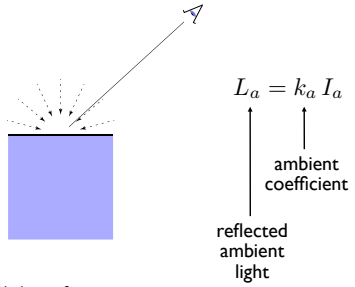
[Foley et al.]

Diffuse + Phong shading



Ambient shading

- Shading that does not depend on anything
  - add constant color to account for disregarded illumination and fill in black shadows



Putting it together

- Usually include ambient, diffuse, Phong in one model

$$L = L_a + L_d + L_s$$
$$= k_a\, I_a + k_d\, I \max(0, \mathbf{n} \cdot \mathbf{l}) + k_s\, I \max(0, \mathbf{n} \cdot \mathbf{h})^{\,n}$$

- The final result is the sum over many lights

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

$$L = k_a\, I_a + \sum_{i=1}^{N} [k_d\, I_i \max(0, \mathbf{n} \cdot \mathbf{l}_i) + k_s\, I_i \max(0, \mathbf{n} \cdot \mathbf{h}_i)^{\,n}]$$

Mirror reflection

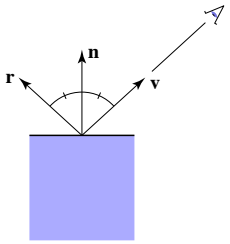
- Consider perfectly shiny surface (a mirror)
  - there isn't a highlight
  - instead there's a reflection of other objects
- Can render this using recursive ray tracing
  - to find out mirror reflection color, ask what color is seen from surface point in reflection direction
  - already computing reflection 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

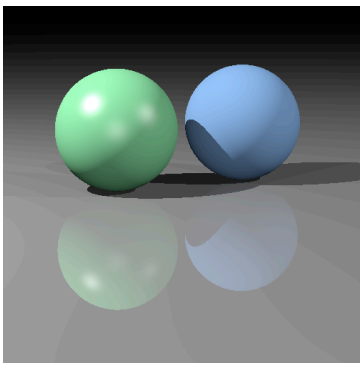
Mirror reflection

- Intensity depends on view direction
  - reflects incident light from mirror direction



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

Diffuse + mirror reflection (glazed)



(glazed material on floor)

Ray tracer architecture 101

- You want a class called Ray
  - point and direction; evaluate(t)
  - possible: tMin, tMax
- Some things can be intersected with rays
  - individual surfaces, groups of surfaces (acceleration goes here), the whole scene
  - make these all subclasses of Surface
  - limit the range of valid *t* values (*e.g.* shadow rays)
- Once you have the visible intersection, compute the color
  - may want to separate shading code from geometry
  - separate class: Material (each Surface holds a reference to one)
  - its job is to compute the color

Architectural practicalities

- Return values
  - surface intersection tends to want to return multiple values
    - *t*, surface or shader, normal vector, maybe surface point
  - in many programming languages (*e.g.* Java) this is a pain
  - typical solution: an *intersection record*
    - a class with fields for all these things
    - keep track of the intersection record for the closest intersection

Architectural practicalities

- Efficiency
  - in Java the (or, a) key to being fast is to minimize creation of objects
  - what objects are created for every ray? try to find a place for them where you can reuse them.
  - Shadow rays can be cheaper (any intersection will do, don't need closest)
  - but: "First Get it Right, Then Make it Fast"