

**CS 4731/543: Computer Graphics**  
**Lecture 8 (Part I): Raytracing (Part 3)**

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## hit() Function for Sphere

- Recall that for generic sphere, there are two hit times,  $t_1$  and  $t_2$  corresponding to the solutions

$$t_h = -\frac{B}{A} \pm \frac{\sqrt{B^2 - AC}}{A}$$

- which are the solutions to the quadratic equation  $At^2 + 2Bt + C = 0$  where  $A = |\mathbf{c}|^2$ ,  $B = \mathbf{S} \cdot \mathbf{c}$  and  $C = |S|^2 - 1$
- Thus the hit() function for a sphere is as follows:

```
Bool Sphere::hit(Ray &r, Intersection inter)
{
    Ray genRay;    // need to make the generic ray
    xfrmRay(genRay, invTransf, r);
    double A, B, C
    .....
```

## hit() Function for Sphere

```
A = dot3D(genRay.dir, genRay.dir);
```

```
B = dot3D(genRay.start, genRay.dir);
```

```
C = dot3D(genRay.start, genRay.start) - 1.0;
```

$$t_h = -\frac{B}{A} \pm \frac{\sqrt{B^2 - AC}}{A}$$

```
double discrim = B * B - A * C;
```

```
if(discrim < 0.0) // ray misses
```

```
    return false;
```

```
int num = 0; // the # of hits so far
```

```
double discRoot = sqrt(discrim);
```

```
double t1 = (-B - discRoot)/A; // the earlier hit
```

```
..... • •
```

## Hit() Function for Sphere

```
If(t1 > 0.00001) // is hit in front of the eye?  
{  
    inter.hit[0].hitTime = t1;  
    inter.hit[0].hitObject = this;  
    inter.hit[0].isEntering = true;  
    inter.hit[0].surface = 0;  
    Point3 P(rayPos(genRay, t1)); // hit spot  
    inter.hit[0].hitPoint.set(P);  
    inter.hit[0].hitNormal.set(P);  
    num = 1;    // have a hit  
}
```

$$t_h = -\frac{B}{A} \pm \frac{\sqrt{B^2 - AC}}{A}$$

## Hit() Function for Sphere

```
double t2 = (-B + discRoot)/A; // the later hit

If(t2 > 0.00001) // is hit in front of the eye?
{
    inter.hit[num].hitTime = t2;
    inter.hit[num].hitObject = this;
    inter.hit[num].isEntering = false;
    inter.hit[num].surface = 0;
    Point3 P(rayPos(genRay, t2)); // hit spot
    inter.hit[num].hitPoint.set(P);
    inter.hit[num].hitNormal.set(P);
    num++; // have a hit
}
inter.numHits = num;
return (num > 0); // true of false
}
```

$$t_h = -\frac{B}{A} \pm \frac{\sqrt{B^2 - AC}}{A}$$

## Final words on Sphere hit() Function

- Function **xfrmRay()** inverse transforms the ray
- Test for t2 is structured such that if t1 is negative, t2 is returned as first hit time
- **rayPos** converts hit time to a 3D point (x, y, z)

```
Point3 rayPos(Ray &r, float t); //returns ray's location at t
```

- rayPos is based on equation

$$P_{hit} = eye + \mathbf{dir}_{rc} t_{hit}$$

- We can finish off a ray tracer for emissive sphere
- Emissive?
  - Yes... no ambient, diffuse, specular
  - If object is hit, set to emissive color (from SDL file) else set to background

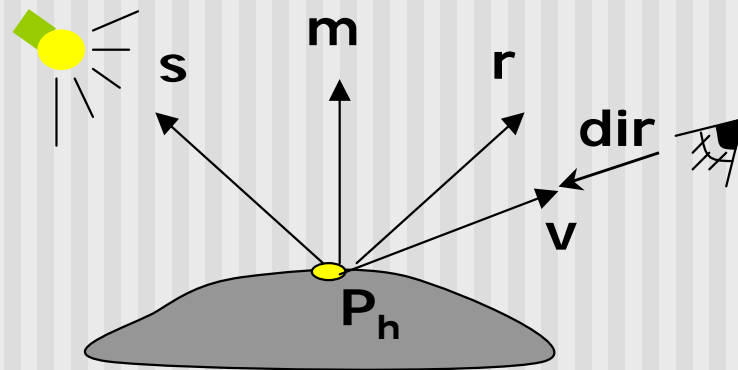
## Emissive shade() Function

```
Color3 Scene :: shade(Ray& ray) // is hit in front of the eye?
{
    Color3 color;
    Intersection best;
    getFirstHit(ray, best);
    if(best.numHits == 0) return background;
    Shape* myObj = (Shape*)best.hit[0].hitObject; // hit object
    color.set(myObj->mtrl.emissive);
    return color;
}
```

- Need hit functions for more shapes (cube, square, cylinder, etc)
- At this point, will take things out of order..
- Jump to section 12.7 to add ambient diffuse, specular
- Return later to do more intersections

## Adding Ambient, Diffuse, Specular to shade() Function

- Recall Phong's illumination model



$$I = I_a k_a + I_d k_d \times \mathbf{lambert} + I_{sp} k_s \times \mathbf{phong}^f$$

- Where light vector  $\mathbf{s} = \text{Light position} - \text{hit Point}$
- View vector  $\mathbf{v} = -\mathbf{dir}$

$$\mathbf{lambert} = \max\left(0, \frac{\mathbf{s} \cdot \mathbf{m}}{|\mathbf{s}| |\mathbf{m}|}\right)$$

$$\mathbf{phong} = \max\left(0, \frac{\mathbf{h} \cdot \mathbf{m}}{|\mathbf{h}| |\mathbf{m}|}\right)$$



## Adding Ambient, Diffuse, Specular to shade( ) Function

- **h** is Blinn's halfway vector given by  $\mathbf{h} = \mathbf{s} + \mathbf{v}$
- To handle colored lights and object surfaces, we separate the equation

$$I = I_a k_a + I_d k_d \times \mathbf{lambert} + I_{sp} k_s \times \mathbf{phong}^f$$

into separate R G and B parts so that

$$I_r = I_{ar} k_{ar} + I_{dr} k_{dr} \times \mathbf{lambert} + I_{spr} k_{sr} \times \mathbf{phong}^f$$

$$I_g = I_{ag} k_{ag} + I_{dg} k_{dg} \times \mathbf{lambert} + I_{spg} k_{sg} \times \mathbf{phong}^f$$

$$I_b = I_{ab} k_{ab} + I_{db} k_{db} \times \mathbf{lambert} + I_{spb} k_{sb} \times \mathbf{phong}^f$$

- Lambert and phong terms use transformed object normal **m** at hit point
- *How do we get transformed normal?*

## Finding Normal at Hit Spot

- *How do we get transformed normal?*
- We set generic object normal at hit point
- E.g. in sphere hit function, set hit point normal = hit point for generic sphere, we did

```
inter.hit[0].hitNormal.set(P);
```

- So, we have normal for generic object  $\mathbf{m}'$
- To get transformed object normal  $\mathbf{m}$ , simply (see section 6.5.3)

$$\mathbf{m} = M^{-T} \mathbf{m}'$$

## Adding Ambient, Diffuse, Specular to shade( ) Function

- You specify ambient, diffuse and specular values of materials in your SDL file
- Each cylinder, cube is a GeomObj class
- GeomObj class has material **mtrl** as member
- Your ray tracer can then access ka, kd ... as **mtrl.ambient**, **mtrl.diffuse** and **mtrl.specular**
- For more realistic look, can use carefully measure values from McReynolds and Blythe.

**! first define values**

```
def Copper{ ambient 0.19125 0.0735 0.0225
             diffuse 0.7038 0.27048 0.0828
             specular 0.256777 0.137622 0.086014 exponent 12.8}
```

**!then use defined values**

Use Copper sphere

## Adding Ambient, Diffuse, Specular to shade( ) Function

- Can now define full shade function with ambient, diffuse and specular contributions

```
Color3 Scene :: shade(Ray& ray) // is hit in front of the eye?
{
    Get the first hit using getFirstHit(r, best);
    Make handy copy h = best.hit[0]; // data about first hit
    Form hitPoint based on h.hitTime
    Form v = -ray.dir; // direction to viewer
    v.normalize( );

    Shape* myObj = (Shape *)h.hitObject; // point to hit object
    Color3 color(myObj->mtrl.emissive)*; // start with emissive
    color.add(ambient contribution); // compute ambient color
}
```

$$\text{lambert} = \max\left(0, \frac{\mathbf{s} \cdot \mathbf{m}}{|\mathbf{s}| |\mathbf{m}|}\right)$$

## Adding Ambient, Diffuse, Specular to shade() Function

```
Vector3 normal;
```

```
// transform the generic normal to the world normal
```

```
xfrmNormal(normal, myObj->invTransf, h.hitNormal);
```

```
normal.normalize( ); // normalize it
```

```
for(each light source, L) // sum over all sources
```

```
{
```

```
    if(isInShadow(..)) continue; // skip L if it's in shadow
```

```
    Form s = L.pos - hitPoint; // vector from hit pt to src
```

```
    s.normalize( );
```

```
    float mDotS = s.dot(normal); // Lambert term
```

```
    if(mDotS > 0.0){ // hit point is turned toward the light
```

```
        Form diffuseColor = mDotS * myObj->mtrl.diffuse * L.color
```

```
        color.add(diffuseColor); // add the diffuse part
```

```
    }
```

$$\text{phong} = \max\left(0, \frac{\mathbf{h} \cdot \mathbf{m}}{|\mathbf{h}| |\mathbf{m}|}\right)$$

## Adding Ambient, Diffuse, Specular to shade() Function

```
Form h = v + s; // the halfway vector
```

```
h.normalize( );
```

```
float mDotH = h.dot(normal); // part of phong term
```

```
if(mDotH <= 0) continue; // no specular contribution
```

```
float phong = pow(mDotH, myObj->mtrl.specularExponent);
```

```
specColor = phong * myObj->mtrl.specular * L.color;
```

```
color.add(specColor);
```

```
}
```

```
return color;
```

```
}
```

- isInShadow( ) is function to tests if point is in shadow. Implement next!

## Adding Shadows to Raytracing

- Shadows are important visual cues for humans
- Previously discussed limited shadow algorithms
- Limited due to OpenGL
- Raytracing adds shadows with little programming effort
- So far, all hit points rendered with all shading components (ambient, diffuse, specular, emissive)
- If hit point is in shadow, render using only ambient (and emissive). Leave out specular and diffuse
- 3 possible cases
  - A: no other object between hit point and light source
  - B: another object between hit point and light source (occlusion)
  - C: object blocks itself from light source (back face)

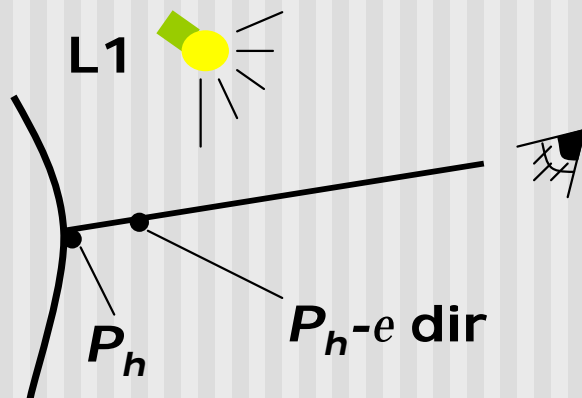
## Adding Shadows

- Need routine `isInShadow( )` which tests to see if hit point is in shadow
- `isInShadow( )` returns
  - `true` if hit point is in shadow
  - `false` otherwise
- `isInShadow( )` spawns new ray called **shadow feeler** emanating from hit point at time  $t=0$  and reaching light source at  $t=1$
- So, parametric equation of shadow feeler is  $P_h + (L - P_h)t$
- So, shadow feeler is built and each object in object list is scanned for intersection (just like eye ray)
- If any valid intersection in time range  $t=[0,1]$  **isInShadow** returns true, otherwise returns false



## Adding Shadows

- **Note:** since we made hit function general, takes ray as argument, once we build shadow feeler, reuse hit( ) functions
- One more sticky point: self-shadowing!!
- How? Since shadow feeler starts at hit point at  $t=0$ , **isInShadow** always intersects with object itself (returns true)
- Can fix this by starting shadow ray slightly away from hit point. E.g. in figure, start shadow feeler starts at  $P_h - e$  dir



**Note: feeler is  $e$  toward eye NOT light**

## Adding Shadows

- How to put this back into shade( ) function?
- After **getFirstHit( )** returns closest hit point, add ambient component
- Next, build shadow feeler (per light source) with start point of  $P_n$ -e dir
- Feeler direction is set to **(Light position – feeler start)**
- Call **isInShadow(feeler)** to determine object intersections (and hit times)
- If any valid intersections with object (t between 0 and 1), diffuse and specular components are skipped else add them
- Variable recurseLevel is used to control how many times hit( ) function can call itself. Set it to 1 for shadow ray
- More on recurseLevel when we discuss reflection

## Shade Function with Shadow Pseudocode

```
feeler.start = hitPoint - e ray.dir;
feeler.recurseLevel = 1;
color = ambient part;
for(each light source, L)
{
    feeler.dir = L.pos - hitPoint;
    if(isInShadow(feeler)) continue;
    color.add(diffuse light);
    color.add(specular light);
}
```

## isInShadow() Implementation

```
bool Scene:: isInShadow(Ray& f)
{
    for(GeomObj* p = obj; p; p = p->next)
        if(p->hit(f)) return true;
    return false;
}
```

- Above, we use simplified hit( ) function
  - Only tests for hit time between 0 and 1
  - If valid hit, return, don't fill hit record, hit object, etc

## References

- Hill, chapter 12