# CS 543: Computer Graphics
# Lecture 12 (Part I): Raytracing (Part 3)

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# hit( ) Function for Sphere

- Recall that for generic sphere, there are two hit times, t1 and t2 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 $A = |\mathbf{c}|^2$ , $B = S.\mathbf{c}$ 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

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

```
A = dot3D(genRay.dir, genRay.dir);
B = dot3D(genRay.start, genRay.dir);
C = dot3D(genRay.start, genRay.start) – 1.0;

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

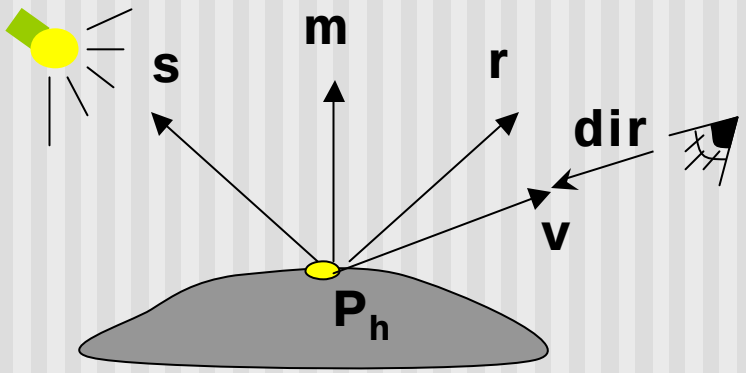
# Emissive shade( ) Function

```
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 14.7 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 **s** = Light positon – hit Point
- View vector **v = -dir**

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

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

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

- **h** is Blinn's halfway vector given by **h = s + 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 **m'**
- To get transformed object normal **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
```

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

## 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
    }
```

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

## 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

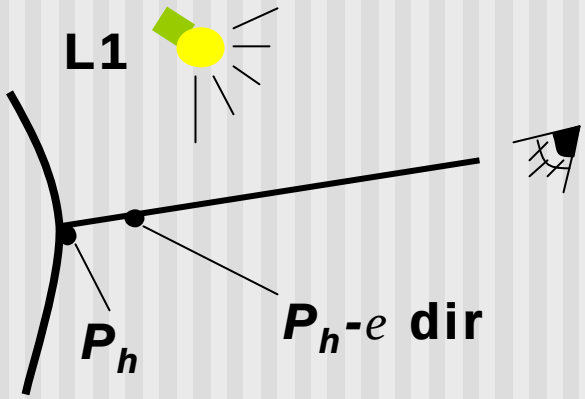
- Shadows are important visual cues for humans
- Previously discussed limited shadow algorithms
- Limited due to OpenGL
- Raytracing adds shadows with little programming effort
- So far, all hit points rendered with all shading components (ambient, diffuse, specular, emissive)
- If hit point is in shadow, 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 $\boldsymbol{P_h}$**-***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 - ε 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 14