# CS 4731/543: Computer Graphics
# Lecture 8 (Part II): Raytracing (Part 4)

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## Reflection and Transparency

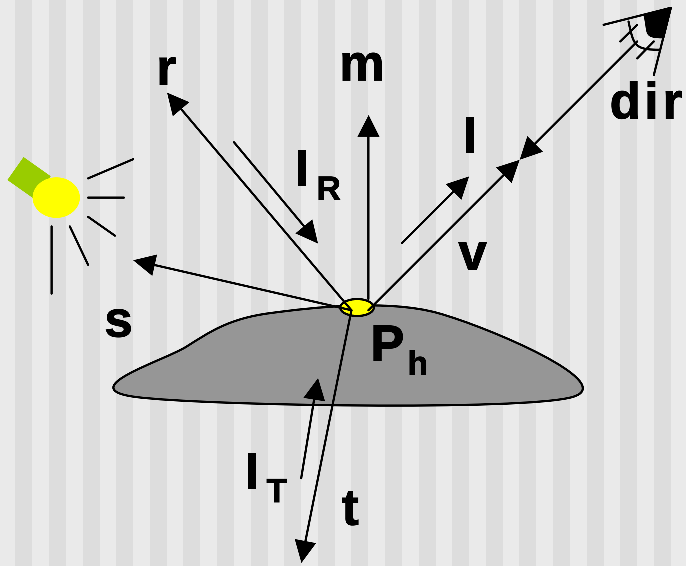
- Ray tracing also handles reflections and refraction of light well
- We can easily render realistic scenes with
  - mirrors,
  - martini glasses
- So, far, we have considered **Local components** (ambient, diffuse, specular)
- Local components are contributions from light sources which are visible from hit point
- To render reflection, and refraction we need to add reflection and refraction components of light

$$I = I_{amb} + I_{diff} + I_{spec} + I_{refl} + I_{tran}$$

## Reflection and Transparency

- First three components are local

$$I = I_{amb} + I_{diff} + I_{spec} + I_{refl} + I_{tran}$$



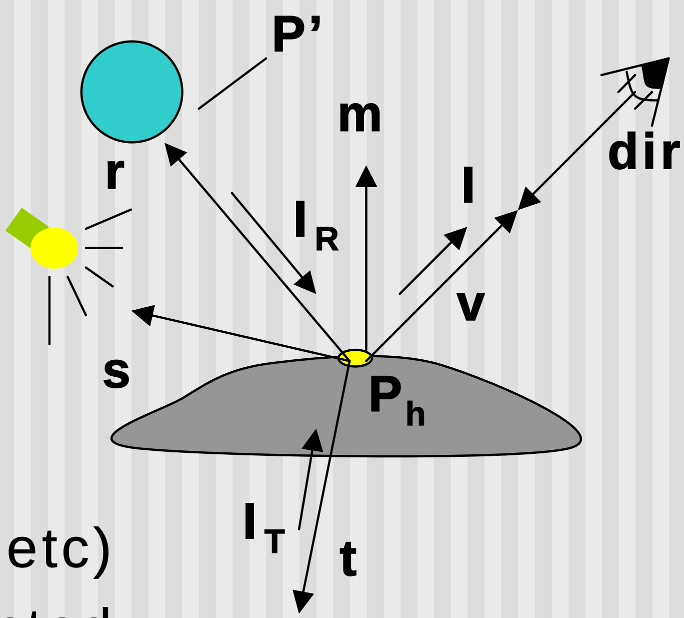

- Reflected component, $I_R$ is along mirror direction from eye **–r**

## Reflection and Transparency

- **r** is given as (see eqn 4.22) as

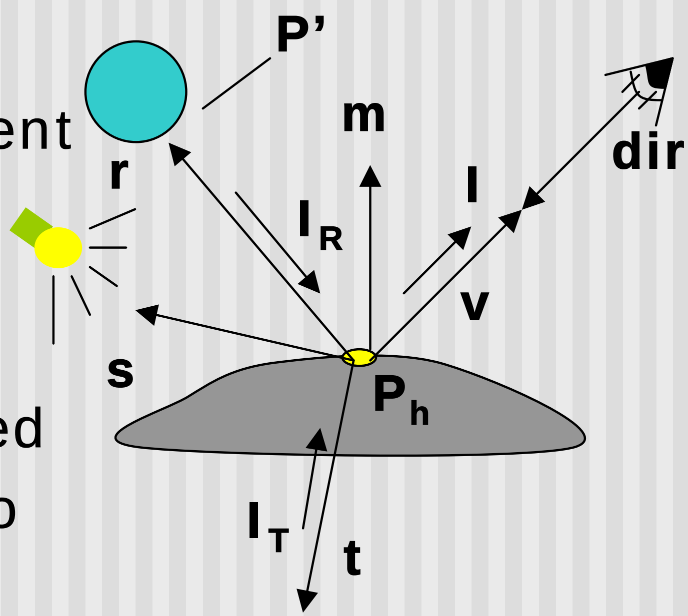
$$\mathbf{r} = \mathbf{dir} - 2(\mathbf{dir} \bullet \mathbf{m})\mathbf{m}$$

- Transmitted component $I_T$ is along transmitted direction **t**
- Portion of light coming in from direction **t** is bent along **dir**
- $I_R$ and $I_T$ each have their own five components (ambient, diffuse, etc)
- In some sense, point P' along reflected direction **r** serves as a light source to point $P_h$



# Reflection and Transparency

- To determine reflected component
  - Spawn reflected ray along direction **r**
  - Determine closest object hit
- To determine transmitted component
  - Cast transmitted ray along direction **t**
  - Determine closest object hit
- So, at each hit point, local, reflected and refracted components merge to form total contributions



## Reflection and Transparency: Ray Tree

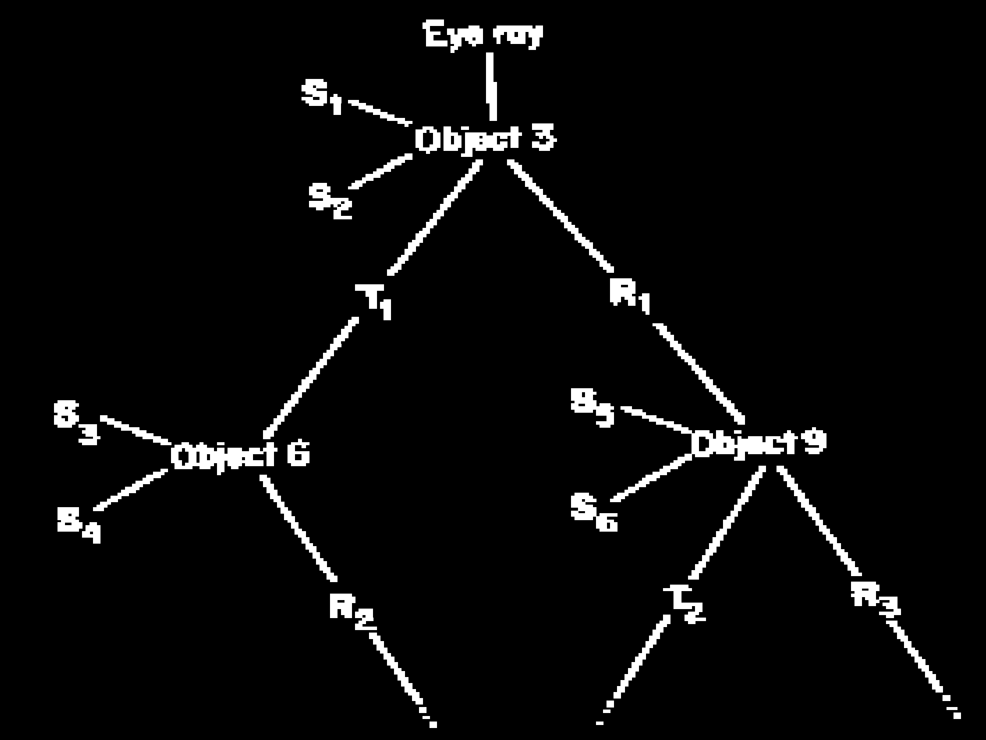



Fig. 12. The ray tree in schematic form.

- Local, reflected, transmitted and shadow rays form a tree

## Reflection and Transparency

- Tree structure suggest recursion at successive hit points
- Recurse forever? No!!
- At each point, only fraction of impinging reflected or refracted ray is lost
- Who determines fraction? Designer... sets transparency or reflectivity in SDL file.
- E.g reflectivity 0.8 means only 80% of impinging ray is reflected
- Thus, need to check reflected contribution by saying

  if (reflectivity > 0.6)...
- Also check if(transparency > threshold)
- Basically, do not want to work hard for tiny contributions. Drop (terminate shade) if contribution is too small

## Refraction and Transparency

- May also need to determine how many times you want to bounce (even if threshold is still high)
- For example, in room with many mirrors, do you want to bounce forever (your system may cry!!)
- Set **recurseLevel** (yup!! same as in shadows) to say how many bounces using (variable **maxRecursionLevel**)
- recurseLevel of 4 or 5 is usually enough to create realistic pictures
- Ray from eye to first hit point has recurseLevel of 0
- All rays from first hit point have recurseLevel = 1
- Need to modify shade function to handle recursion

## Recursive shade( ) skeleton

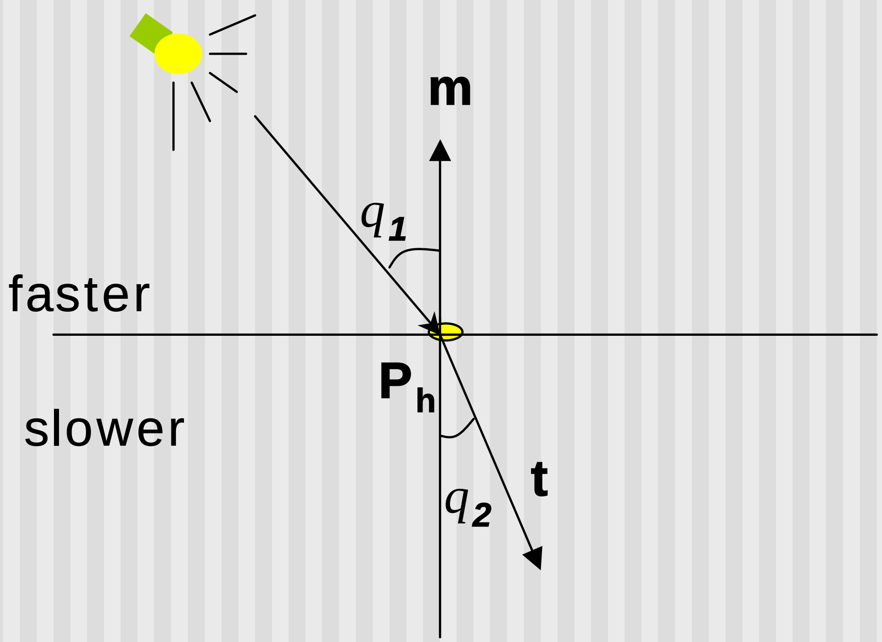
```
Color3 Scene::shade(Ray& )
{
    Get the first hit, and build hitInfo h
    Shape* myObj = (Shape*)h.hitObject; // ptr to hit obj
    Color3 color.set(the emissive component);
    color.add(ambient contribution);
    get normalized normal vector m at hit point
    for(each light source)
       add the diffuse and specular components
    // now add the reflected and transmitted components

    if(r.recurseLevel == maxRecursionLevel)
        return color; // don't recurse further
```

## Recursive shade( ) skeleton

```
if(hit object is shiny enough) // add reflected light
 {
      get reflection direction
      build reflected ray, refl
      refl.recurseLevel = r.recurseLevel + 1;
      color.add(shininess * shade(refl));
  }
  if(hit object is transparent enough)
  {
       get transmitted direction
       build transmitted ray, trans
       trans.recurseLevel = r.recurseLevel + 1;
       color.add(transparency * shade(trans));
  }
  return color;
}
```

# Finding Transmitted Direction

- So far, found reflected direction ray direction as mirror direction from eye
- Transmitted direction obeys **Snell's law**
- Snell's law: relationship holds in the following diagram




$$\frac{\sin(q_2)}{c_2} = \frac{\sin(q_1)}{c_1}$$

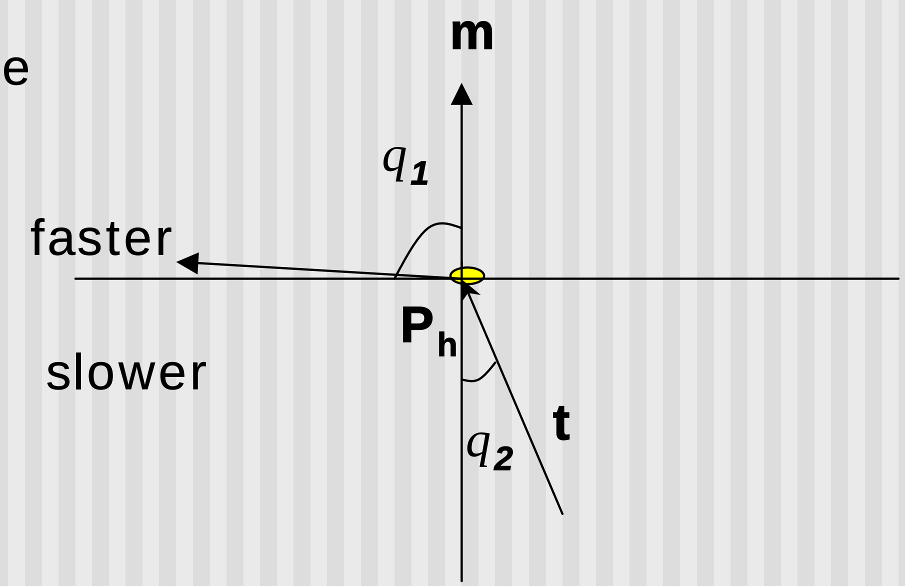
$c_1$, $c_2$ are speeds of light in medium 1 and 2

## Finding Transmitted Direction

- If ray goes from faster to slower medium, ray is bent **towards** normal
- If ray goes from slower to faster medium, ray is bent **away** from normal
- c1/c2 is important. Usually measured for medium-to-vacuum. E.g water to vacuum
- Some measured relative c1/c2 are:
  - Air: 99.97%
  - Glass: 52.2% to 59%
  - Water: 75.19%
  - Sapphire: 56.50%
  - Diamond: 41.33%

## Critical Angle

- There exists transmitted angle at which ray in faster medium (e.g. air) is bent along object surface
- That angle ($q_2$ in figure below) is known as the **critical angle**
- Increasing transmission angle beyond critical angle has "no effect"... transmitted ray still below object surface
- Physical significance:
  - Underwater in pond, can see enter world through small cone of angles



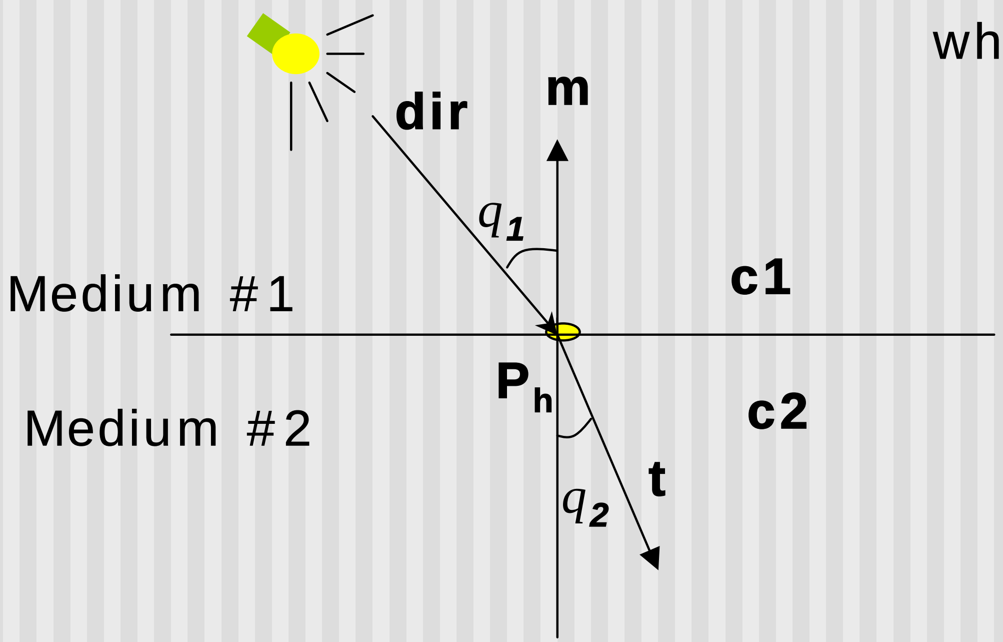
## Transmission Angle

- Vector for transmission angle can be found as

$$\mathbf{t} = \frac{c_2}{c_1}\mathbf{dir} + \left( \frac{c_2}{c_1}(\mathbf{m} \bullet \mathbf{dir}) - \cos(q_2) \right)\mathbf{m}$$

where

$$\cos(q_2) = \sqrt{1 - \left( \frac{c_2}{c_1} \right)\left(1 - (\mathbf{m} \bullet \mathbf{dir})^2\right)}$$



## For Project 5

- May read up hit (intersection) functions for shapes, add to your ray tracer
  - Cube
  - Cylinder
  - Mesh, ... etc

## References

- Hill, chapter 12