Imatge Sintètica

Ray Tracing for Realistic Image Synthesis

Ricardo Marques
(ricardo.marques@upf.edu)

Group de Tecnologies Interactives (GTI)
Departament de Tecnologies de la Informació i les Comunicacions (DTIC)
Universitat Pompeu Fabra (UPF)

Edifici Tànger - Office 55.106

Lecture 4 - Perfect Reflections, Refractions and Intersections

2017/2018

Class Outline

Lecture 4 - Perfect Reflections, Refractions and Intersections

Last Class Summary

- Learned how to account for the contribution of point light sources to the illumination at a point
- Learned different lighting effects (light material interaction)
- Used the Phong reflection model (empirical) to model reflections at the surface (diffuse and glossy)

Section 2

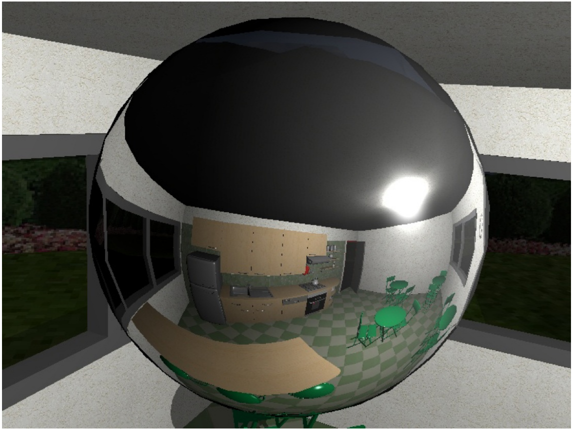
Perfect Specular Reflections and Refractions

Subsection 1

Perfect Specular Reflection

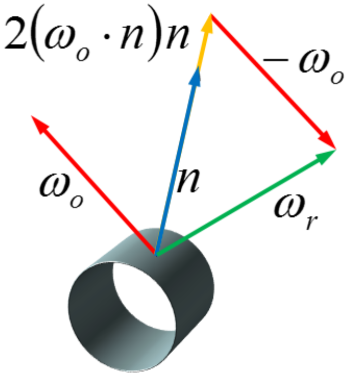
Perfect Specular Reflection

- A perfect specular reflection is a mirror-like reflection



- Light arriving at a surface from a given direction is reflected in a single reflection direction

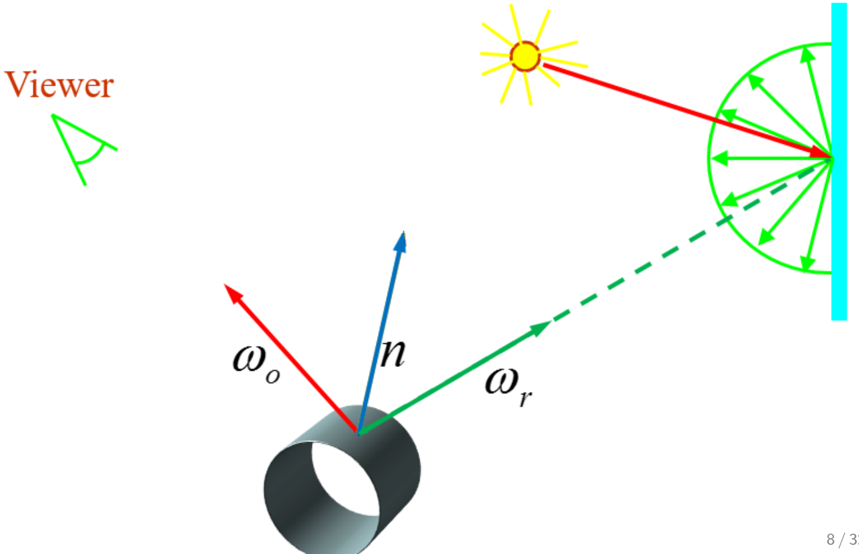
Perfect Specular Reflection



$\boxed{\omega_o \cdot \mathbf{n} = \omega_r \cdot \mathbf{n}}$ and $\boxed{\omega_r = 2\left(\omega_o \cdot \mathbf{n}\right)\mathbf{n} - \omega_o}$

Perfect Specular Reflection

- The color reflected in the $\boldsymbol{\omega}_o$ direction is given by the light arriving from direction $-\boldsymbol{\omega}_r$



Perfect Specular Reflection
Pseudo Code

Algorithm 1 Computing the perfect specular reflection

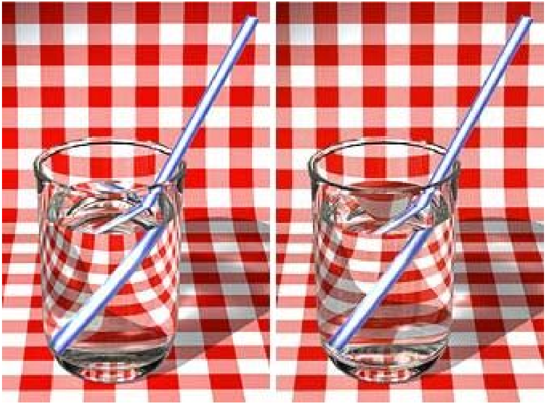
```
function ComputeColor(ray, objList, LSList)
    color ← (0, 0, 0)
    (...)
    if (material().hasSpecular()) then
        ω_r ← computeReflectionDirection(ray.d, its.normal)
        reflectionRay ← Ray(itsPoint, ω_r, ray.depth+1)
        color ← ComputeColor(reflectionRay, objList, lsList)
    end if
    (...)
    return color
end function
```

Subsection 2

Perfect Specular Refraction

Refraction

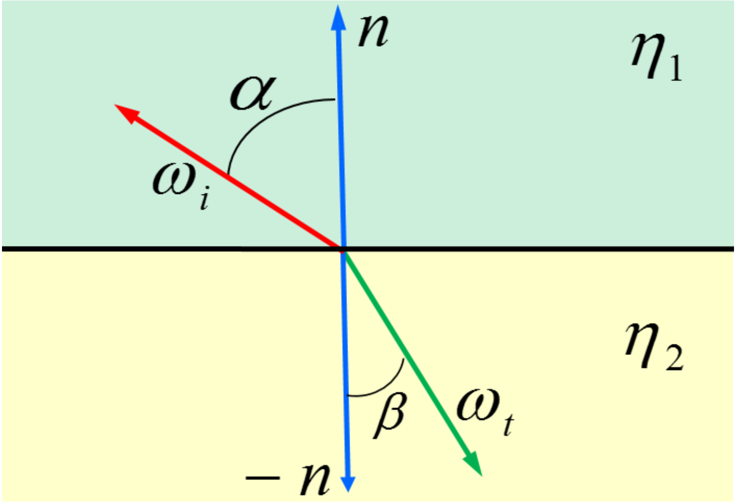
- Refraction: change of direction of light propagation due to a change of medium



- The angle of refraction depends on the densities of both mediums

Perfect Specular Refraction

- When changing medium, light is refracted in a single direction

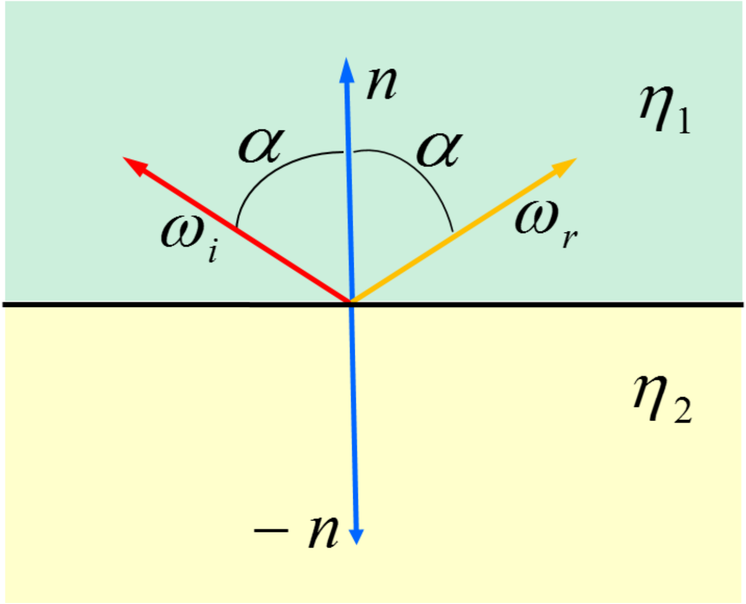


Snell's Law

- The Snell's law relates the angle of incidence with the angle of refraction
$$\frac{\sin\alpha}{\sin\beta} = \frac{\eta_1}{\eta_2} = \eta_t$$
- Using Snell's law, we can show that:
$$\boldsymbol{\omega}_t = -\boldsymbol{\omega}_i\,\eta_t + \mathbf{n}\left(\eta_t\cos\alpha - \cos\beta\right),$$
where
$$\cos\beta = \sqrt{1 + \eta_t^2\left(\cos^2\alpha - 1\right)}$$
- **Attention:** if the radicand is negative, then the incident light from $\boldsymbol{\omega}_i$ is reflected along $\boldsymbol{\omega}_r$!
  - We the say we are in *total internal reflection* conditions

Perfect Specular Refraction

Total Internal Reflection



Perfect Specular Refraction

Pseudo Code

Algorithm 2 Computing the perfect specular refraction

```
function COMPUTECOLOR(ray, objList, LSList)
    color ← (0, 0, 0)
    (...)
    if (material().hasTransmission()) then
        (...)
        if !isTotalInternalReflection(...) then
            ω_t ← computeTransmissionDirection(...)
            refracRay ← Ray(itsPoint, ω_t, ray.depth+1)
            color ← COMPUTECOLOR(refracRay, objList, lsList)
        else
            color ← Specular reflection
        end if
    end if
    (...)
    return color
end function
```

Section 3

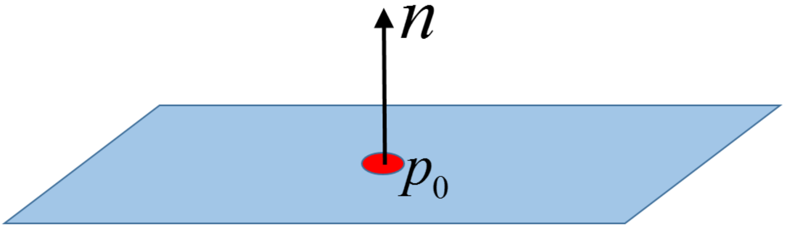
Ray-Object Intersections

Subsection 1

Ray-Plane Intersection

Infinite Plane Definition

- An infinite plane is defined by:
  - a normal $\mathbf{n}$ (perpendicular to the plane)
  - a point $\mathbf{p}_0$

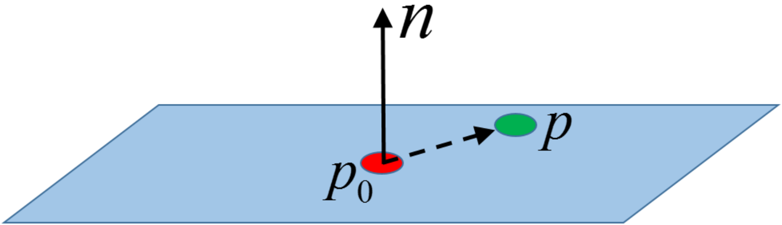


Infinite Plane Definition

- All points verifying the equation

$$(\mathbf{p} - \mathbf{p}_0) \cdot \mathbf{n} = 0$$

belong to the plane defined by $\mathbf{n}$ and $\mathbf{p}_0$

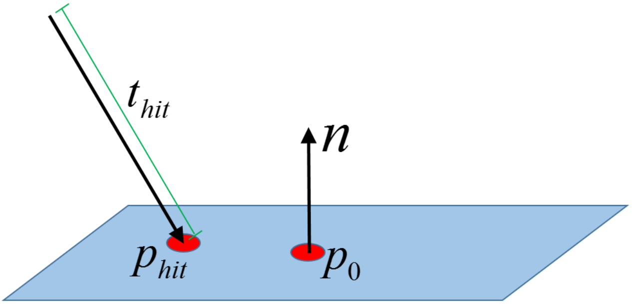


Ray-Plane Intersection

- Recall the expression of a ray

$$r = \mathbf{o} + t\,\mathbf{d}$$

- Intersecting a ray with a plane amounts to finding the points belonging to the plane which also belong to the ray



Ray-Plane Intersection

- Intersecting a ray with a plane amounts to finding the points belonging to the plane which also belong to the ray:

$$
\begin{aligned}
&(r - \mathbf{p}_0) \cdot \mathbf{n} = 0 \\
\Leftrightarrow &(\mathbf{o} + t\,\mathbf{d} - \mathbf{p}_0) \cdot \mathbf{n} = 0 \\
\Leftrightarrow &t = \frac{(\mathbf{p}_0 - \mathbf{o}) \cdot \mathbf{n}}{\mathbf{d} \cdot \mathbf{n}}
\end{aligned}
$$

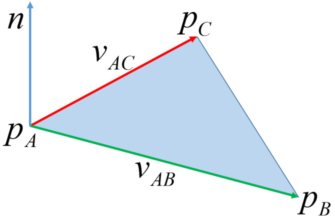
- If $\mathbf{d} \cdot \mathbf{n} = 0$ then the ray is parallel to the plane
  - Either infinite of zero solutions
  - We'll assume there is no solution

Subsection 2

Ray-Triangle Intersection

Triangle Definition

- A triangle is defined by three points ($\mathbf{p}_A$, $\mathbf{p}_B$, $\mathbf{p}_C$)



- Let $\mathbf{v}_{AB} = \mathbf{p}_B - \mathbf{p}_A$ and $\mathbf{v}_{AC} = \mathbf{p}_C - \mathbf{p}_A$
- Convention: the triangle normal $\mathbf{n}$ is given by

$$\mathbf{n} = \mathbf{v}_{AC} \times \mathbf{v}_{AB}$$

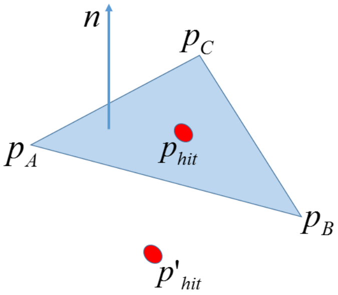
- The triangle is facing the viewer if it reads in anti-clockwise vertexes order

Ray-Triangle Intersection

- The triangle ($\mathbf{p}_A$, $\mathbf{p}_B$, $\mathbf{p}_C$) is contained in a plane defined by:
  - A normal, given by $\mathbf{n} = \mathbf{v}_{AC} \times \mathbf{v}_{AB}$
  - A point belonging to the triangle. By convention we'll use $\mathbf{p}_A$
- Computing the ray-triangle intersection (2-step solution):
  1. Compute the intersection of the ray with the plane defined by the triangle
  2. Check if the intersection point belongs to the triangle

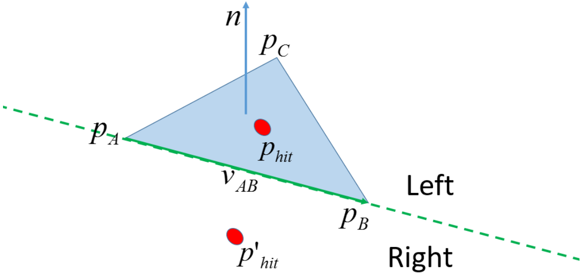
Ray-Triangle Intersection

- Let $\mathbf{p}_{hit} = \mathbf{o} + t_{hit}\,\mathbf{d}$ be the intersection point of a ray with a plane defined by a triangle $(\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C)$
- $\mathbf{p}_{hit} \in (\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C)$? $\quad \mathbf{p}'_{hit} \in (\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C)$?



Ray-Triangle Intersection

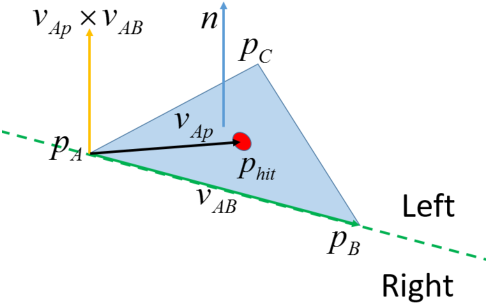
- Approach: use the cross product to determine if $\mathbf{p}_{hit}$ is at the left or at the right of the triangle edges



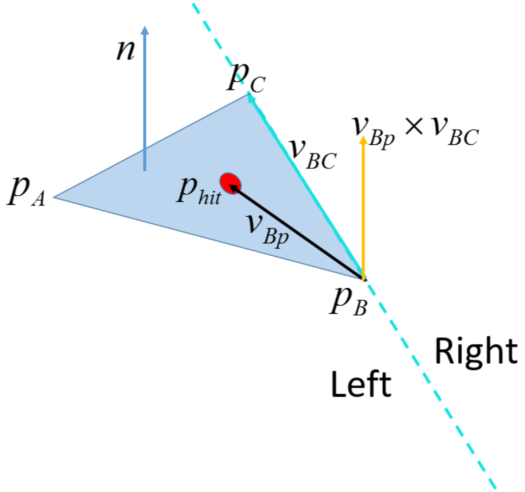
- If $\mathbf{p}_{hit}$ is at the left of all edges, then $\mathbf{p}_{hit} \in (\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C)$

Ray-Triangle Intersection

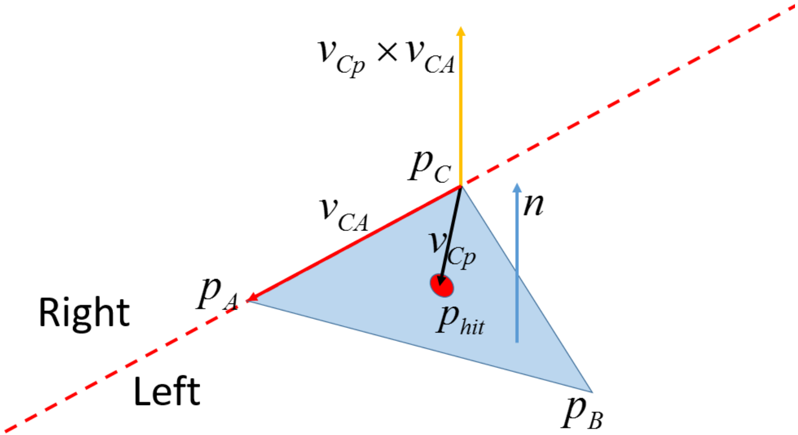
- The cross product can be used to determine if $\mathbf{p}_{hit}$ is at the left or at the right of a given triangle edge
- $\mathbf{v}_{\mathbf{Ap}} \times \mathbf{v}_{AB}$ yields a vector perpendicular to the plane defined by $\mathbf{v}_{\mathbf{Ap}}$ and $\mathbf{v}_{AB}$
- **If** $(\mathbf{v}_{AB} \times \mathbf{v}_{\mathbf{Ap}_{hit}}) \cdot \mathbf{n} > 0$ **then** $\mathbf{p}_{hit}$ is at the left of $\mathbf{v}_{AB}$



Ray-Triangle Intersection

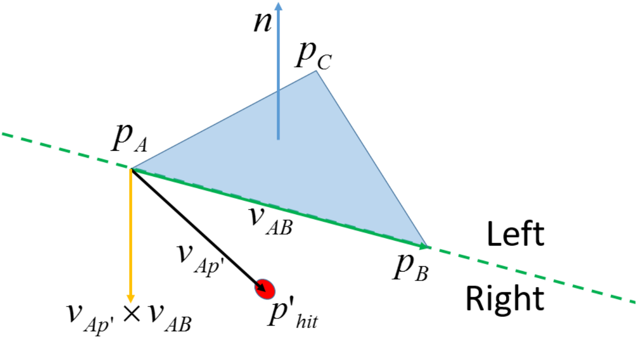


Ray-Triangle Intersection



Ray-Triangle Intersection

- **If** $(\mathbf{v}_{AB} \times \mathbf{v}_{\mathbf{Ap}_{hit}}) \cdot \mathbf{n} < 0$ **then** $\mathbf{p}_{hit}$ is at the right of $\mathbf{v}_{AB}$



Lecture Summary

- We have learned new light-matter interactions
  - Perfect specular reflections
  - Perfect specular refractions
- We have learned new types of ray-object intersections
  - Ray-plane intersection (infinite plane)
  - Ray-triangle intersection

A Glance on the Next Classes

- Global Illumination
- Anti-aliasing