Lecture 20: All Together with Refraction

November 12, 2019

Translucence

- Some light passes through the material.
  - Typically, “passed through” light gets the diffuse reflection properties of the surface, unless object is 100% translucent (i.e. transparent)
- Speed of light is a function of the medium
  - This causes light to bend at boundaries
  - example: looking at the bottom of a pool

Refraction - With Trigonometry

Key is Snell's law …

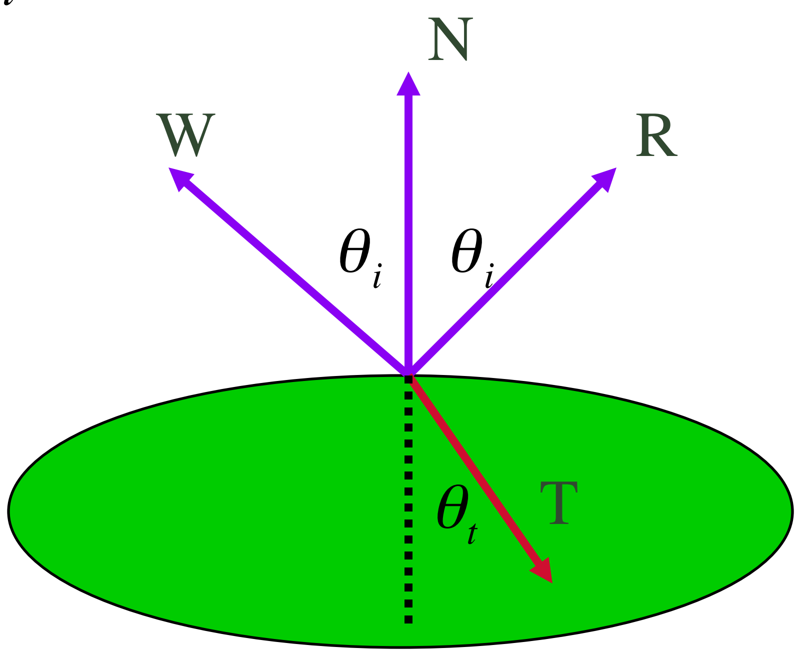
$$\sin(\theta_t) = \frac{\eta_i}{\eta_t}\sin(\theta_i)$$

θ_i Angle of incidence

θ_t Angle of refraction

η_i Index of refraction material #1

η_t Index of refraction material #2



The refraction ray is:

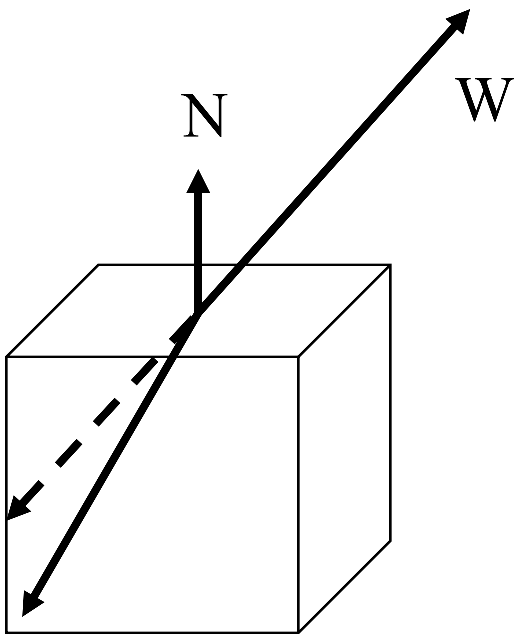
$$T = \left(\frac{\eta_i}{\eta_t}\cos(\theta_i) - \cos(\theta_t)\right)N - \frac{\eta_i}{\eta_t}W$$

Practical Refraction: Solids

- When light enters a solid glass object?

$\eta_{air} = 1.0$

$\eta_{glass} = 1.5$

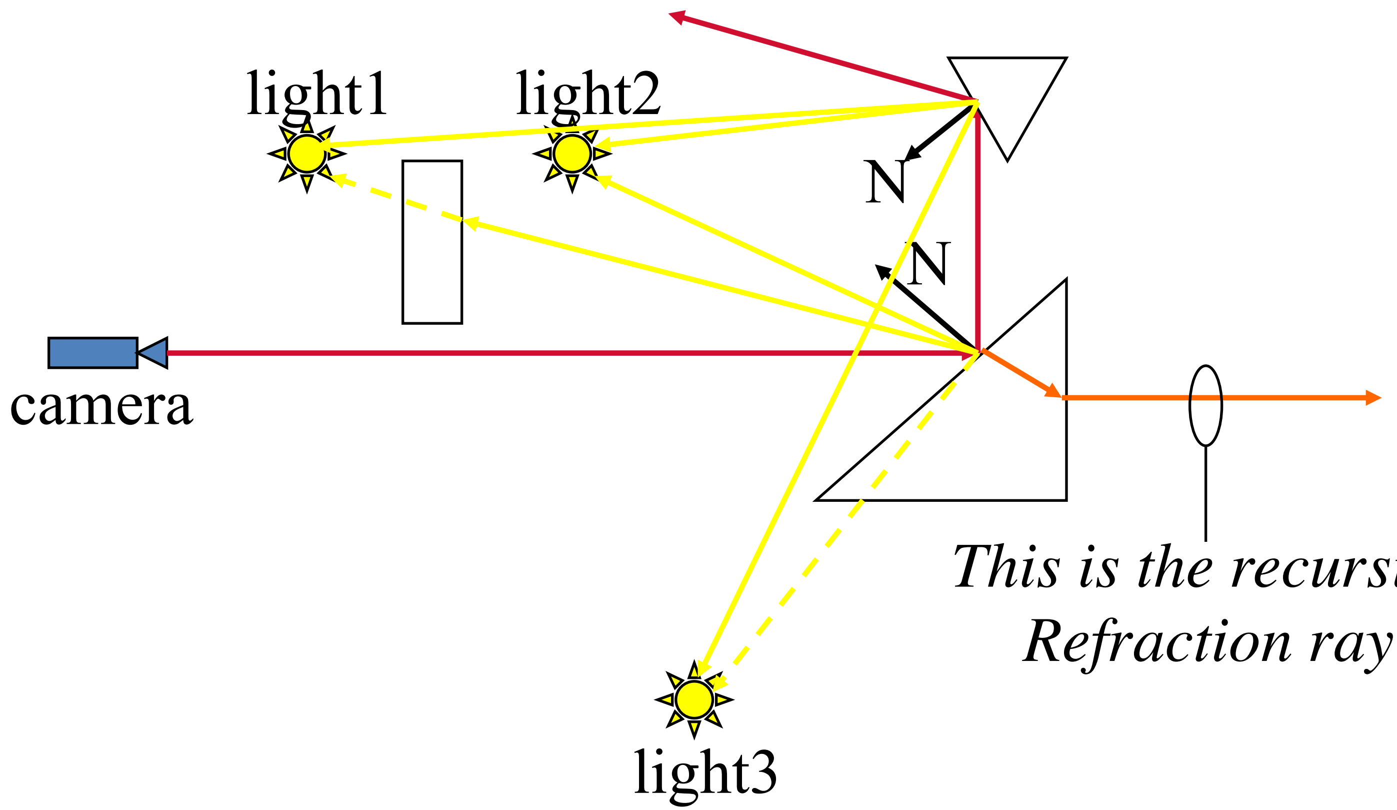


Theta i	Sin	mu	Theta r
0	0.00	0.67	0.00
10	0.17	0.67	6.67
20	0.34	0.67	13.33
30	0.50	0.67	20.00
40	0.64	0.67	26.67
50	0.77	0.67	33.33
60	0.87	0.67	40.00
70	0.94	0.67	46.67
80	0.98	0.67	53.33
90	1.00	0.67	60.00

$$\theta_r = \sin^{-1}\left(\frac{\eta_i}{\eta_r}\sin(\theta_i)\right) = \sin^{-1}\left(0.67 \cdot \sin(\theta_i)\right)$$

More Recursion

- This changes ray tracing from tail-recursion to double-recursion…



Practical Refraction: Surfaces

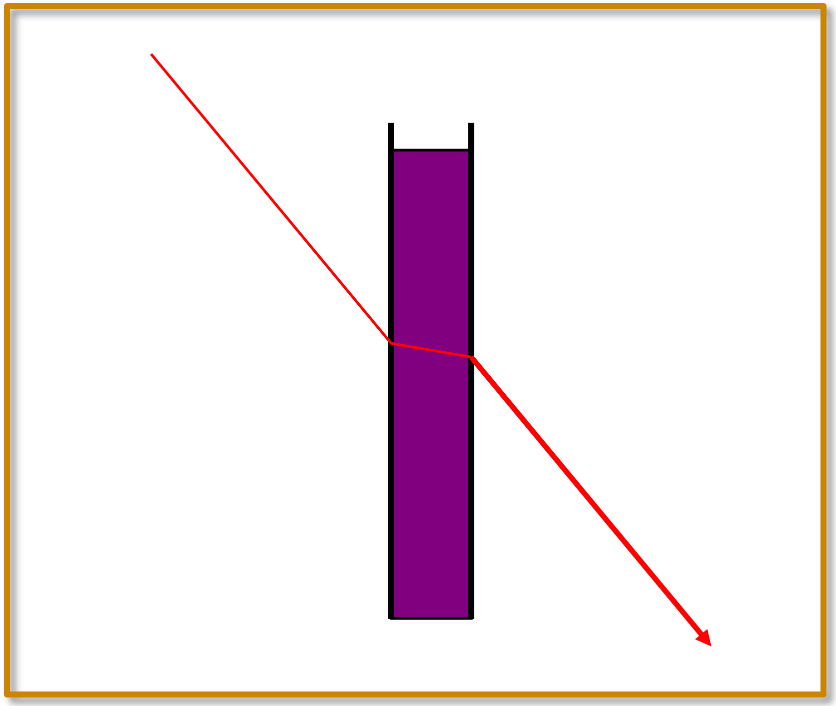
- What happens as it passes *through* a solid or surface?

$$\sin\theta_1 = \frac{\eta_i}{\eta_r}\sin\theta_i$$

$$\sin\theta_i = \frac{\eta_r}{\eta_i}\sin\theta_2$$

$$\sin\theta_1 = \frac{\eta_i}{\eta_r}\frac{\eta_r}{\eta_i}\sin\theta_2$$

$$= \sin\theta_2$$



➢ Overall effect: *displacement* of the incident vector

Note: this assumes the two surfaces of the solid are coplanar!

Refraction - No Trigonometry.

First Constraint: Snells Law

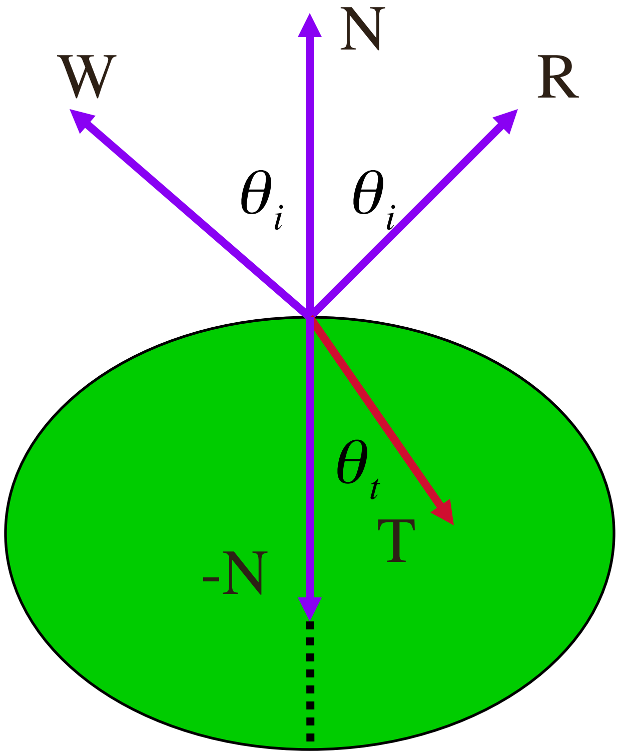
$$T = \alpha W + \beta N$$

$$\sin(\theta_i)^2 \mu^2 = \sin(\theta_t)^2 \quad \mu = \frac{\mu_i}{\mu_t}$$

$$\left(1 - \cos(\theta_i)^2\right)\mu^2 = 1 - \cos(\theta_t)^2$$

$$\left(1 - (W \cdot N)^2\right)\mu^2 = 1 - (-N \cdot T)^2$$

$$\left(1 - (W \cdot N)^2\right)\mu^2 = 1 - \left(-N \cdot (\alpha W + \beta N)\right)^2$$



Refraction - No Trigonometry

Second Constraint: Refraction ray is unit length.

$$T \cdot T = (\alpha W + \beta N) \cdot (\alpha W + \beta N) = 1$$

$$= \alpha^2 + 2\alpha\beta (W \cdot N) + \beta^2 = 1$$

Two quadratic equations in two unknowns.

Solving is a bit involved, …

Here is the answer.

$$\alpha = -\mu \quad \beta = \mu (W \cdot N) - \sqrt{1 - \mu^2 + \mu^2 (W \cdot N)^2}$$

A Wonderful Real Example

AAPT High School Physics Photo Contest (sample picture)

First Place - Contrived (2009)

Title: **Where Sand Meets Sea**
Student: **Kelsey Rose Weber**
School: **Wildwood School, Los Angeles, California**
Teacher: **Tengiz Bibilashvili**

This photo was contrived by placing a transparent sphere against the beach horizon. By matching the refraction from the sphere with the point where the shoreline and skyline meet, this photo demonstrates the physics of refraction. By means of refraction, lenses form an image. The glass sphere in this photo acted as a lens causing the inverted image. This photo was taken at the Venice beach in Los Angeles, California and shows the beauty of combining physics with ones own natural surroundings.

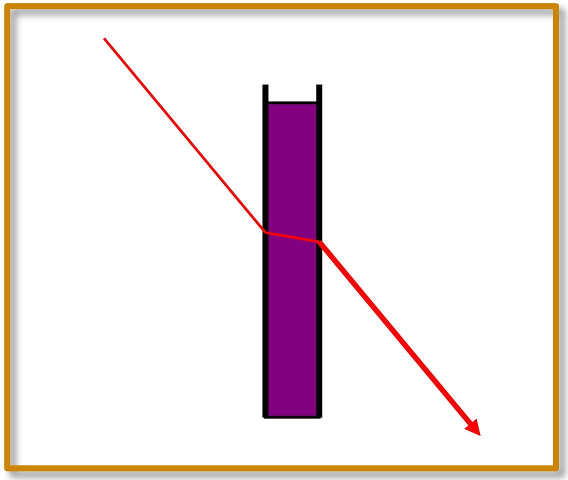
https://physicsb-2009-10.wikispaces.com

Yes, refraction typically makes everthing upside down and backwards.

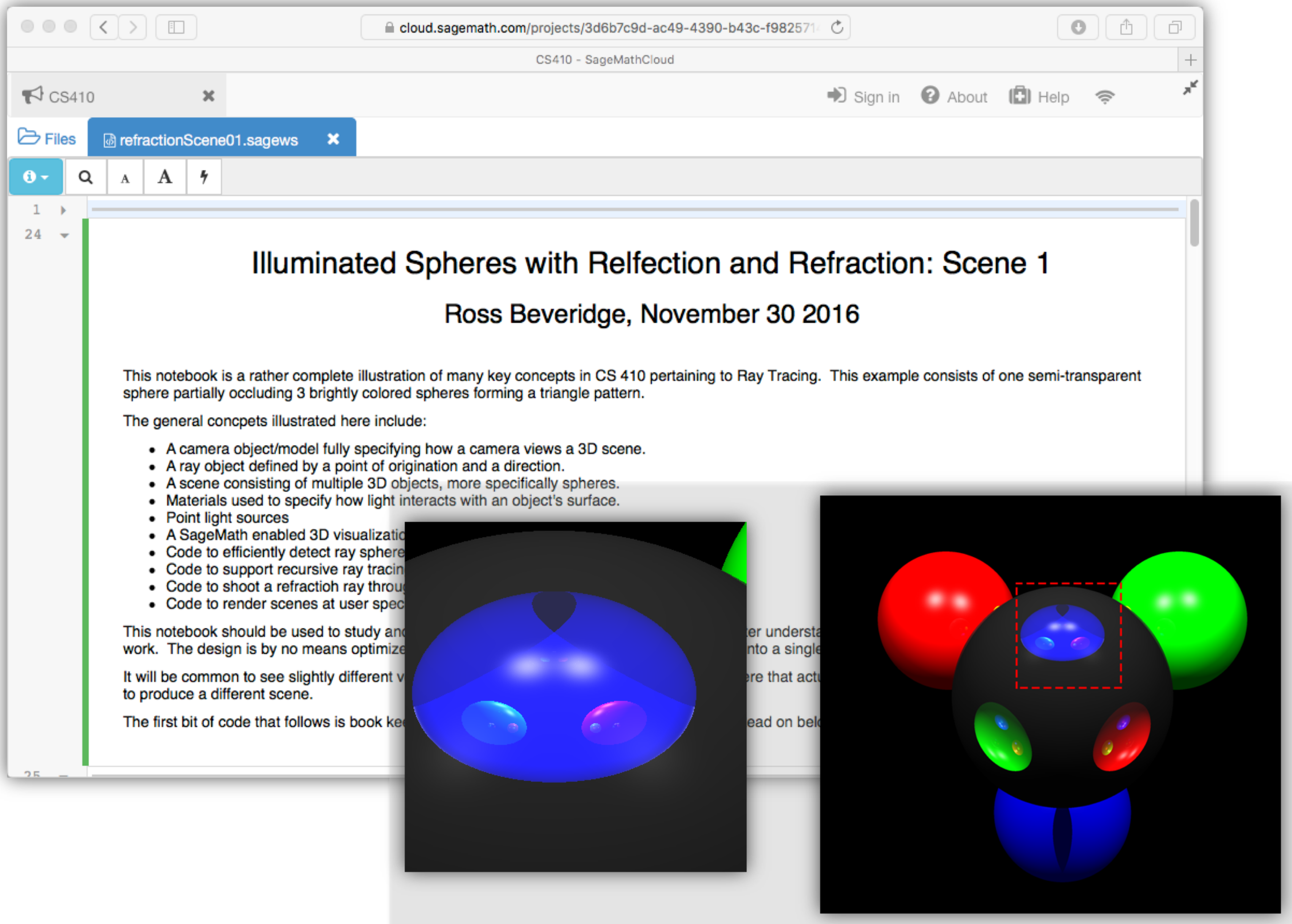
Refraction and Polygons

- It is entirely possible to implement refraction through complex solid models defined by polygons.
- But! Doing so requires the following:
  - Models must be complete: no holes!
  - All faces (triangles) must be tagged to a solid.
    - Needed to find where refraction ray exits the solid.
- There is a simpler special case
  - Thin faces with parallel sides (next slide).

Special Case: Thin Faces



- Consider entrance and exit
  - The are parallel (see picture)
- Refraction vectors
  - Pass through at a shifted angle
  - But exit in the same direction
- Result is an offset only
  - Offset depends on index of refraction
  - Offset depends on the thickness of the face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refractionScene01.sagews
Illuminated Spheres with Relfection and Refraction: Scene 1
Ross Beveridge, November 30 2016
This notebook is a rather complete illustration of many key concepts in CS 410 pertaining to Ray Tracing. This example consists of one semi-transparent sphere partially occluding 3 brightly colored spheres forming a triangle pattern.
The general concpets illustrated here include:
A camera object/model fully specifying how a camera views a 3D scene.
A ray object defined by a point of origination and a direction.
A scene consisting of multiple 3D objects, more specifically spheres.
Materials used to specify how light interacts with an object's surface.
Point light sources
A SageMath enabled 3D visualizatio
Code to efficiently detect ray sphere
Code to support recursive ray tracin
Code to shoot a refractioh ray throu
Code to render scenes at user spec
This notebook should be used to study an ... er understa
work. The design is by no means optimize ... nto a single
It will be common to see slightly different v ... re that act
to produce a different scene.
The first bit of code that follows is book ke ... ead on bel

The Complete Package

When you understand every line of code in the Sage Notebook creating this image you are will be in a position to write a truly compelling ray tracer.