CS4620/5620: Lecture 33

Ray Tracing

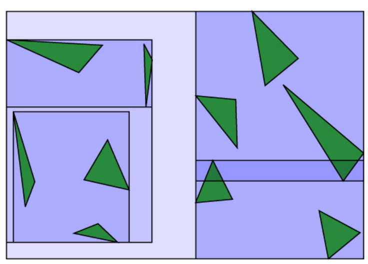
Announcements

- PPA 3 out
- HW 4 due on Tuesday (tomorrow)
- PA 3 is out tomorrow
- Prelim on Wed after TG in class

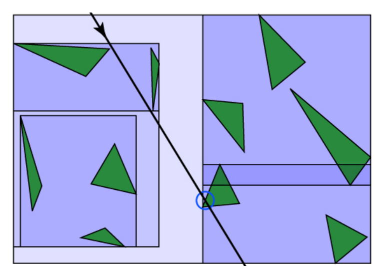
- Demo of performance capture (by Shyam Lenna)

http://www.youtube.com/watch?v=aL9wsEFohTw

BVH construction example



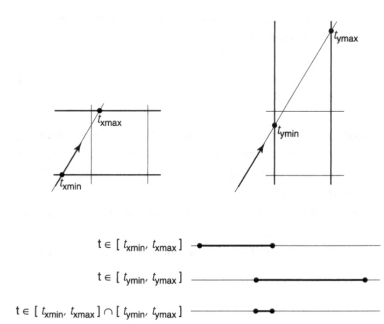
BVH ray-tracing example



Axis aligned bounding boxes

- Probably easiest to implement
- Computing for primitives
  – Cube: duh!
  – Sphere, cylinder, etc.: pretty obvious
  – Groups or meshes: min/max of component parts
- AABBs for transformed surface
  – Easy to do conservatively: bbox of the 8 corners of the bbox of the untransformed surface
- How to intersect them
  – Treat them as an intersection of slabs (see Shirley)

Intersecting boxes



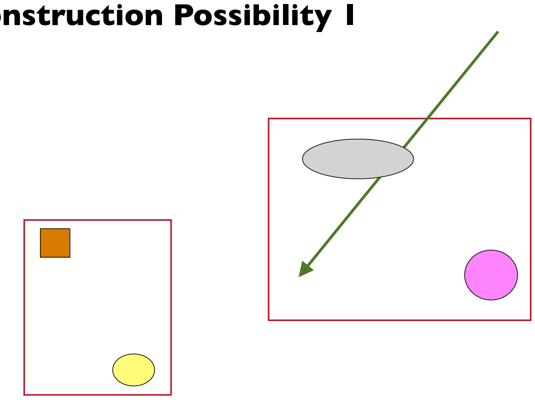
Building a hierarchy

- Can do it top down or bottom up
- Top down
  - Make bbox for whole scene, then split into parts
    - Recurse on parts
    - Stop when there are just a few objects in your box
      - Or if you are too deep (say max depth = 24)

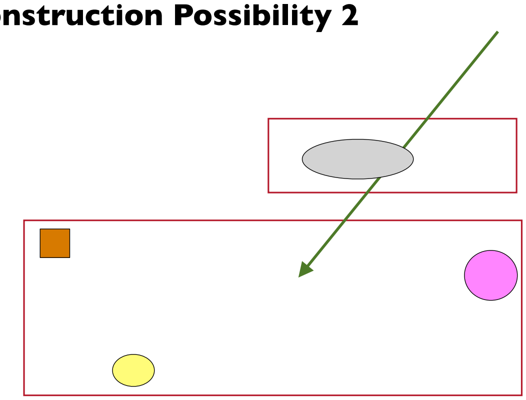
Building a hierarchy

- How to partition?
  - Practical: partition along axis
    - Center partition
      - Simple
      - Unbalanced tree
    - Median partition
      - More expensive
      - More balanced tree
- Objects that cross the median partition
  - Pick one of the sides to put the object on
  - Expand the bbox to cover that object

Construction Possibility 1

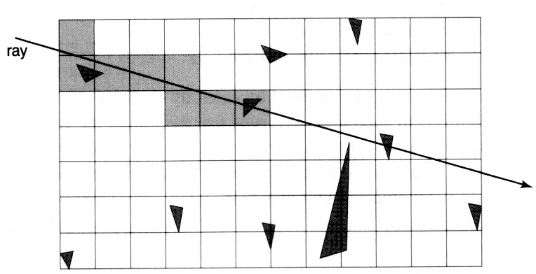


Construction Possibility 2



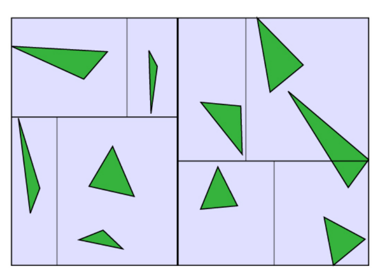
Regular space subdivision

- An entirely different approach: uniform grid of cells
  - Grid divides space, not objects



Non-regular space subdivision

- *k*-d Tree
  - subdivides space, like grid
  - adaptive, like BVH



Implementing acceleration structures

- Conceptually simple to build acceleration structure into scene structure
- Better engineering decision to separate them

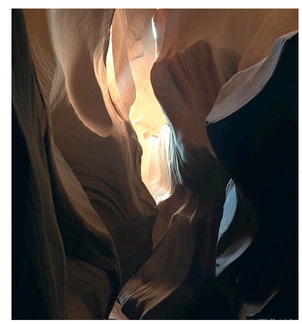
Light Reflection and Advanced Shading

Visual cues to 3D geometry

- size (perspective)
- occlusion
- shading

Shading

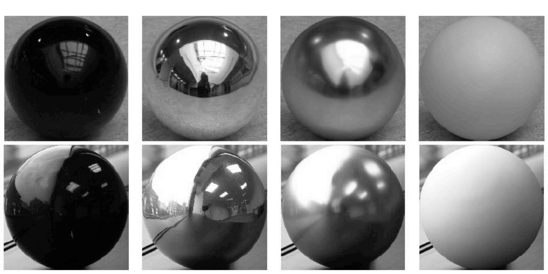
- Variation in observed color across an object
  - strongly affected by lighting
  - present even for homogeneous material
- caused by how a material reflects light
  - depends on
    - geometry
    - lighting
    - material
  - therefore gives cues to all 3



[Philip Greenspun]

Recognizing materials

- Human visual system is quite good at understanding shading



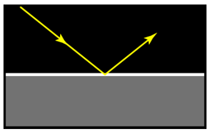
[Dror, Adelson, & Willsky]

Shading for Computer Graphics

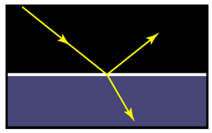
- Need to compute an image
  - of particular geometry
  - under particular illumination
  - from a particular viewpoint
- Basic question: how much light reflects from an object toward the viewer?

Simple materials

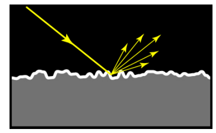
metal

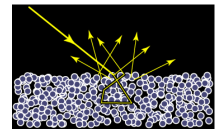


dielectric

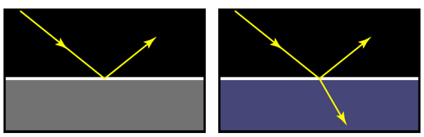


Adding microgeometry

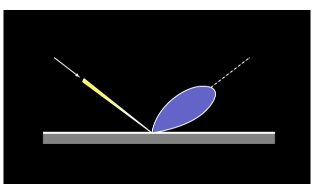




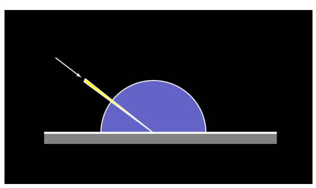
Classic reflection behavior



ideal specular (Fresnel)



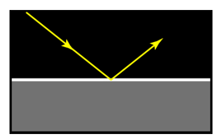
rough specular



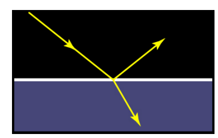
Lambertian

Specular reflection

- Smooth surfaces of pure materials have ideal specular reflection (said this before)
  - Metals (conductors) and dielectrics (insulators) behave differently
- Reflectance (fraction of light reflected) depends on angle



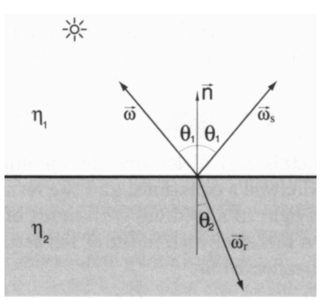
metal



dielectric

Snell's Law

- Tells us where the refracted ray goes
  - a.k.a. transmission vector
- Computation
  - ratio of sines is ratio of in-plane components
  - project to surface; scale by eta ratio; recompute normal-direction component
  - total internal reflection



$$\eta_1 \sin\theta_1 = \eta_2 \sin\theta_2$$

Example values of n:
air: 1.00;
water: 1.33–1.34;
window glass: 1.51;
optical glass: 1.49–1.92;
diamond: 2.42.

Computing the Transmission Vector, t

$$n \sin\theta = n_t \sin\phi.$$

Computing the sine of an angle between two vectors is usually not as convenient as computing the cosine, which is a simple dot product for the unit vectors such as we have here. Using the trigonometric identity $\sin^2\theta + \cos^2\theta = 1$, we can derive a refraction relationship for cosines:

$$\cos^2\phi = 1 - \frac{n^2\left(1-\cos^2\theta\right)}{n_t^2}.$$

Note that if n and n_t are reversed, then so are θ and ϕ as shown on the right of Figure 13.1.

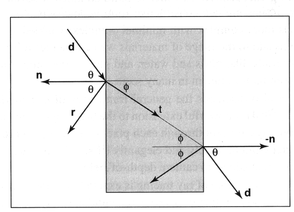


Figure 13.1. Snell's Law describes how the angle ϕ depends on the angle θ and the refractive indices of the object and the surrounding medium.

Computing the Transmission Vector, t

$$\mathbf{t} = \sin\phi\mathbf{b} - \cos\phi\mathbf{n}.$$

Since we can describe $\mathbf{d}$ in the same basis, and $\mathbf{d}$ is known, we can solve for $\mathbf{b}$:

$$\mathbf{d} = \sin\theta\mathbf{b} - \cos\theta\mathbf{n},$$
$$\mathbf{b} = \frac{\mathbf{d} + \mathbf{n}\cos\theta}{\sin\theta}.$$

This means that we can solve for $\mathbf{t}$ with known variables:

$$\mathbf{t} = \frac{n\,(\mathbf{d} + \mathbf{n}\cos\theta))}{n_t} - \mathbf{n}\cos\phi$$
$$= \frac{n\,(\mathbf{d} - \mathbf{n}(\mathbf{d}\cdot\mathbf{n}))}{n_t} - \mathbf{n}\sqrt{1 - \frac{n^2\,(1 - (\mathbf{d}\cdot\mathbf{n})^2)}{n_t^2}}.$$

Note that this equation works regardless of which of n and n_t is larger. An immediate question is, "What should you do if the number under the square root is negative?" In this case, there is no refracted ray and all of the energy is reflected. This is known as *total internal reflection*, and it is responsible for much of the rich appearance of glass objects.

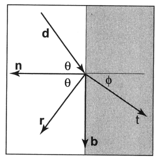


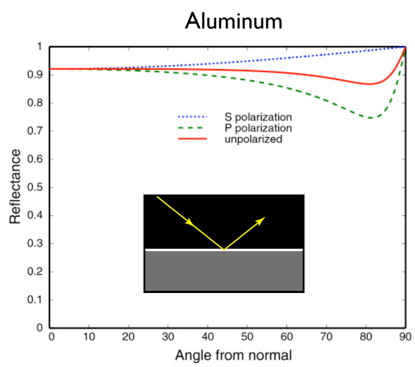
Figure 13.2. The vectors $\mathbf{n}$ and $\mathbf{b}$ form a 2D orthonormal basis that is parallel to the transmission vector $\mathbf{t}$.

Ray tracing dielectrics

- Like a simple mirror surface, use recursive ray tracing
- But we need two rays
  - One reflects off the surface (same as mirror ray)
  - The other crosses the surface (computed using Snell's law)
    - Doesn't always exist (total internal reflection)
- Splitting into two rays, recursively, creates a ray tree
  - Very many rays are traced per viewing ray
  - Ways to prune the tree
    - Limit on ray depth
    - Limit on ray attenuation

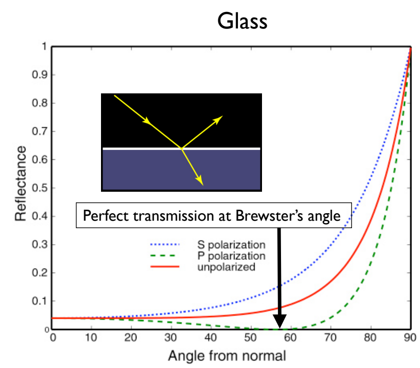
Specular reflection from metal

- Reflectance does depend on angle
  - but not much
  - safely ignored in basic rendering



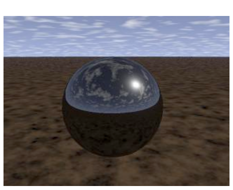
Specular reflection from glass/water

- Dependence on angle is dramatic!
  - about 4% at normal incidence
  - 100% at grazing
  - remaining light is transmitted
- Important for proper appearance

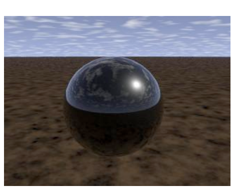


Fresnel reflection

- Black glazed sphere
  - reflection from glass surface
  - transmitted ray is discarded



Constant reflectance



Fresnel reflectance