Computer Graphics

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Fall 2021

http://www.cs.pdx.edu/~fliu/courses/cs447/

11/29/2021

Last time

- Splines

Today

- Raytracing
- Final Exam
  - To-know list available
  - December 06 (Monday) 17:30-19:00

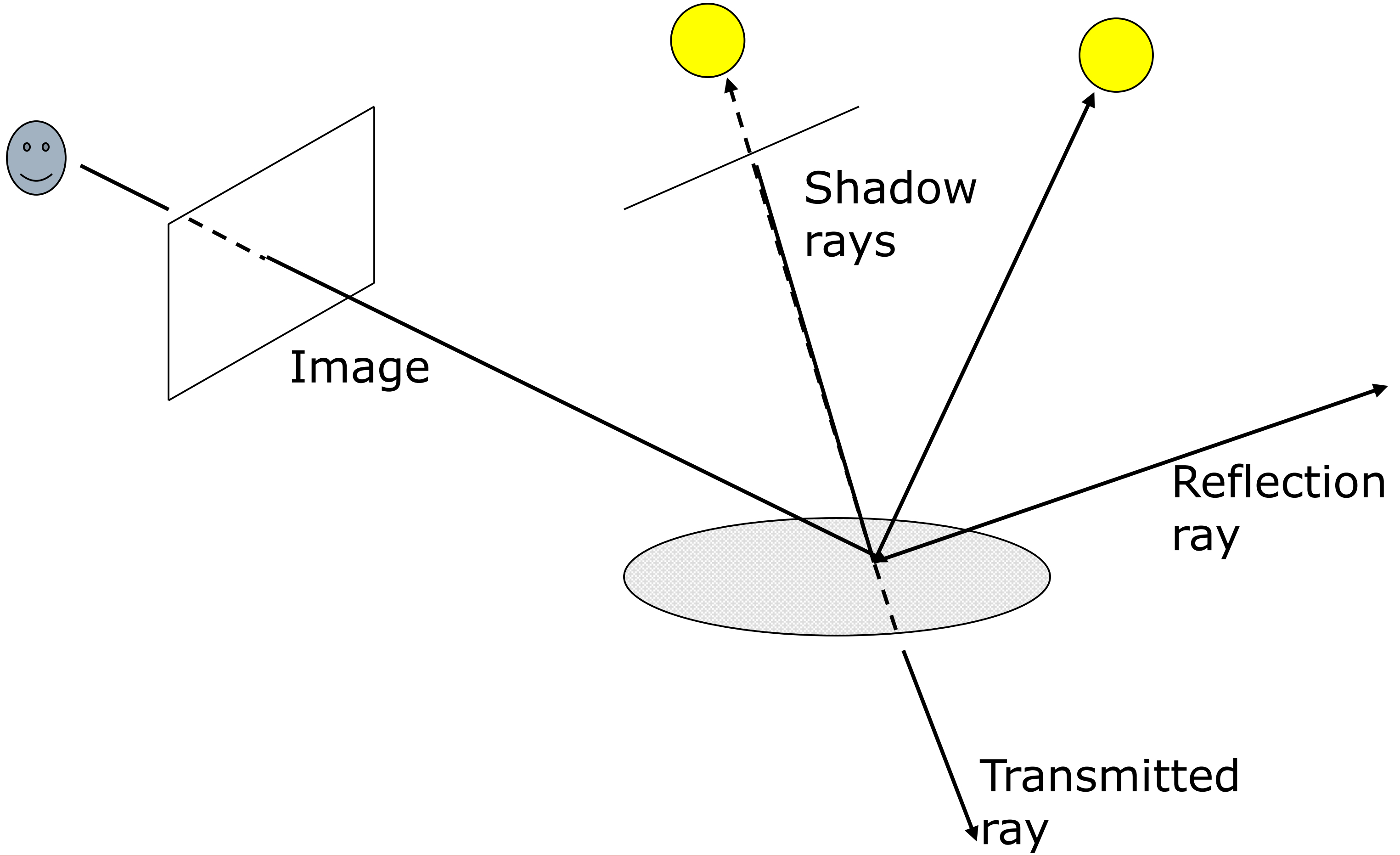
OpenGL Limitations

- Stream processing of geometry
  - No random access to geometric information
  - Can’t do any computation that requires all the geometry at once
- Rasterization is limited
  - We saw many ways to represent objects – not all can be rasterized
  - Cannot provide rasterizers for every form of geometry
- Everything get rasterized and drawn
  - Figuring out what you can see before rasterizing is possible but hard
- Computation loops over geometry, then pixels
  - for all objects { for all pixels in object … }

Raytracing

- Cast rays out from the eye, through each pixel, and determine what the rays hit
  - Builds the image pixel by pixel, one at a time
- Cast additional rays from the hit point to determine the pixel color
- Rays test visibility – what do I see from this point in this direction?
  - Ray casting is widely used in graphics to test visibility

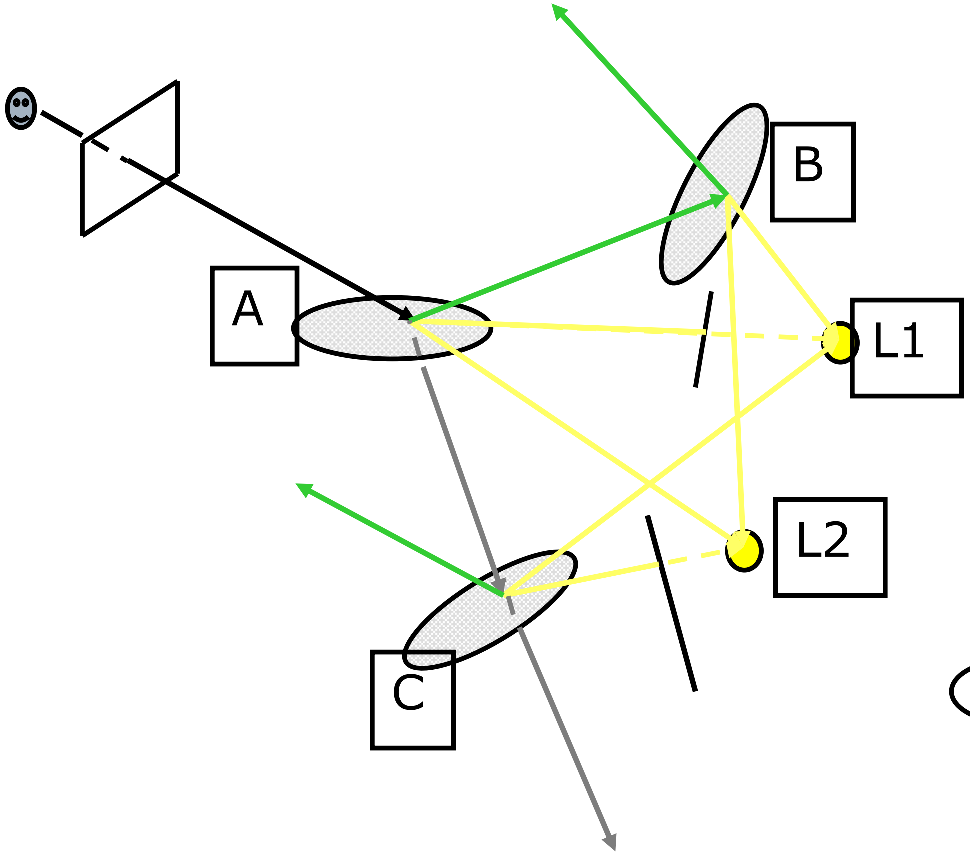
Raytracing

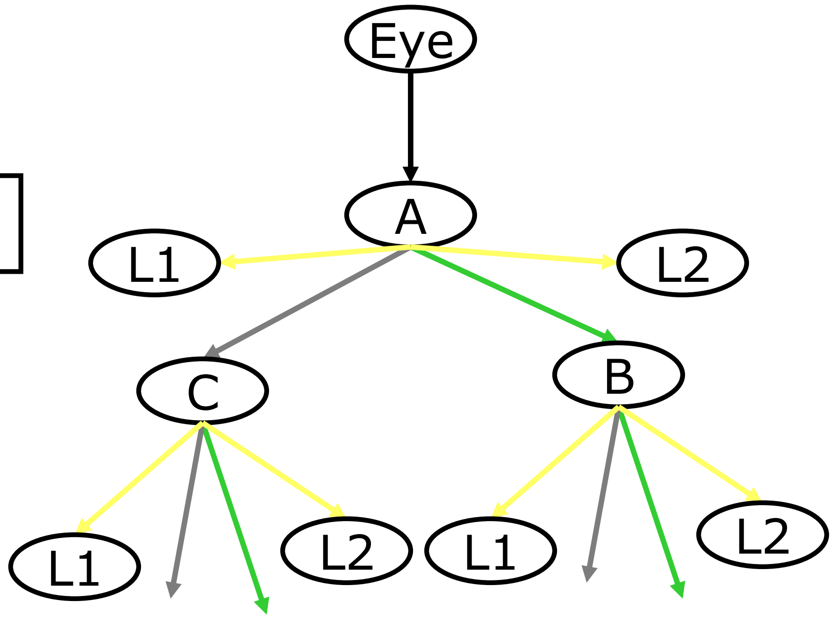


Recursive Ray Tracing

- When a reflected or refracted ray hits a surface, repeat the whole process from that point
  - Send out more shadow rays
  - Send out new reflected ray (if required)
  - Send out a new refracted ray (if required)
  - Generally, reduce the weight of each additional ray when computing the contributions to surface color
  - Stop when the contribution from a ray is too small to notice
- The result is a *ray tree*

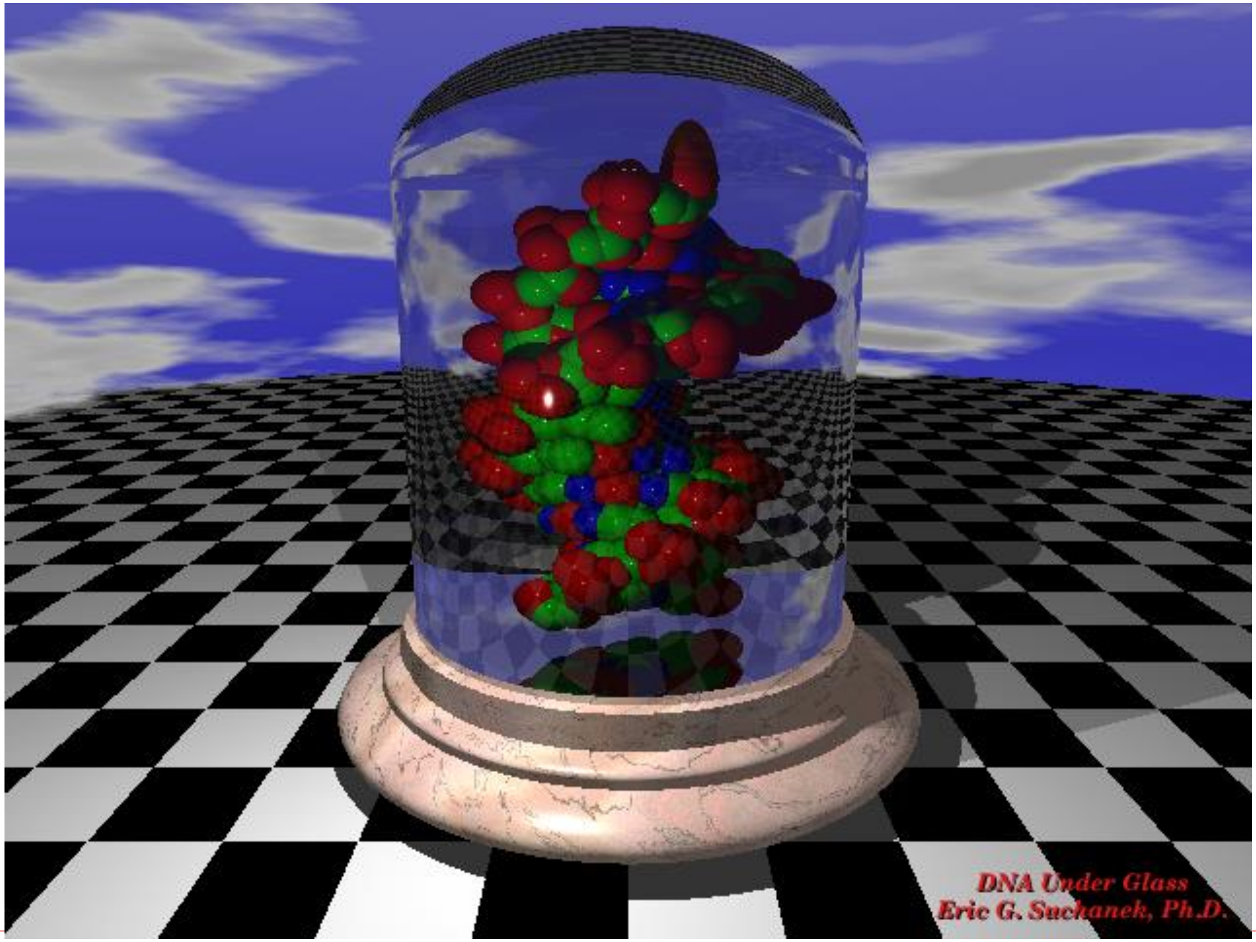
Ray Tree





PCKTWTCH by Kevin Odhner, POV-Ray

Kettle,
Mike Miller,
POV-Ray


DNA Under Glass
Eric G. Suchanek, Ph.D.

Raytracing Implementation

- Raytracing breaks down into two tasks:
  - Constructing the rays to cast
  - Intersecting rays with geometry
- The former problem is simple vector arithmetic
- The intersection problem arises in many areas of computer graphics
  - Collision detection
  - Other rendering algorithms
- Intersection is essentially root finding (as we will see)
  - Any root finding technique can be applied

Constructing Rays

- Define rays by an initial point and a direction
- Eye rays: Rays from the eye through a pixel
- Shadow rays: Rays from a point on a surface to a light
  - If the ray hits something before it gets to the light, then the point is in shadow
- Reflection rays: Rays from a point on a surface in the reflection direction
  - Only for reflective surfaces
- Transmitted rays: Rays from a point on a transparent surface through the surface
  - Use Snell's law to get refraction direction

Eye Rays

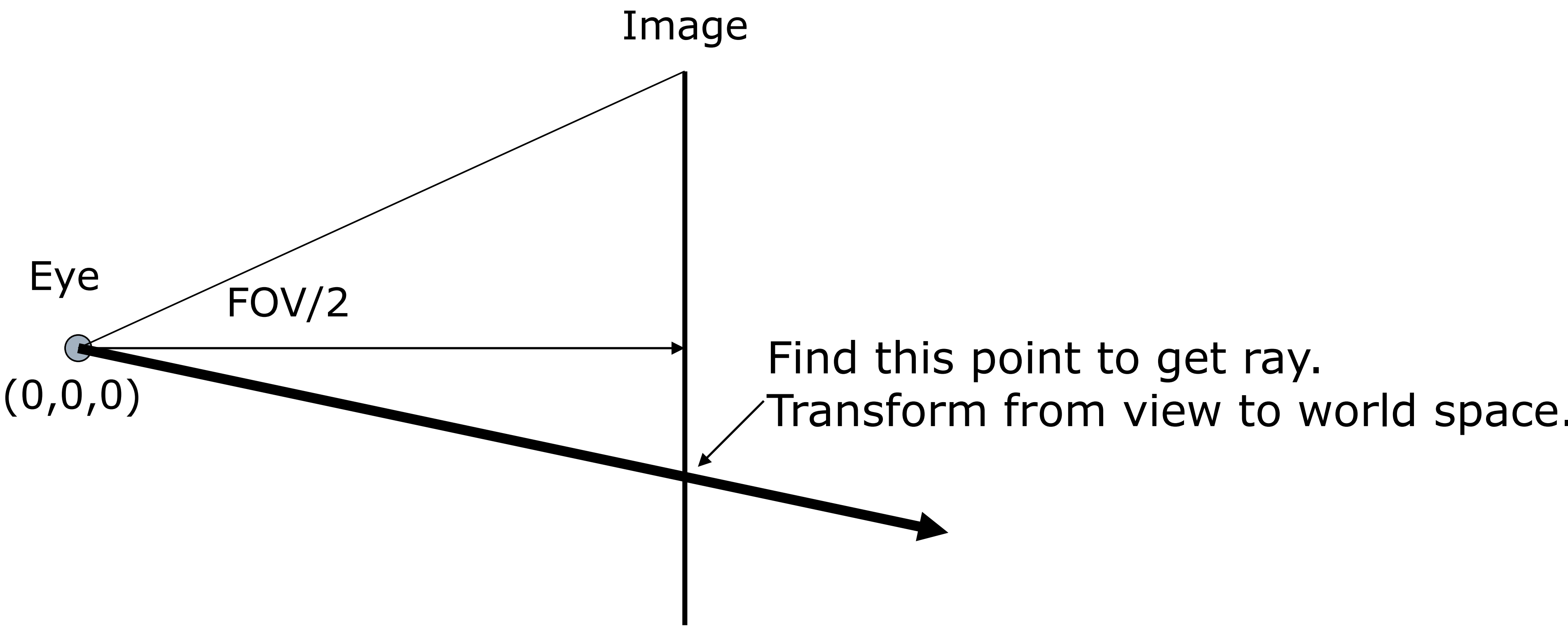


Image
Eye
FOV/2
(0,0,0)
Find this point to get ray.
Transform from view to world space.

Ray-Object Intersections

- Aim: Find the parameter value, t_i, at which the ray first meets object *i*
- Transform the ray into the object's local coordinate system
  - Makes ray-object intersections generic: ray-sphere, ray-plane, …
- Write the surface of the object implicitly: $f(\mathbf{x})=0$
  - Unit sphere at the origin is $\mathbf{x} \bullet \mathbf{x} - 1 = 0$
  - Plane with normal **n** passing through origin is: $\mathbf{n} \bullet \mathbf{x} = 0$
- Put the ray equation in for **x**
  - Result is an equation of the form $f(t)=0$ where we want *t*
  - Now it's just root finding

Ray-Sphere Intersection

$$\text{Ray}: \ \boldsymbol{x}(t) = \boldsymbol{x}_0 + t\boldsymbol{d}$$

$$\text{Sphere}: \ \boldsymbol{x} \bullet \boldsymbol{x} - 1 = 0$$

$$\text{Substitute}: \ (\boldsymbol{x}_0 + t\boldsymbol{d}) \bullet (\boldsymbol{x}_0 + t\boldsymbol{d}) - 1 = 0$$

$$: (\boldsymbol{d} \bullet \boldsymbol{d}) t^2 + 2(\boldsymbol{x}_0 \bullet \boldsymbol{d}) t + (\boldsymbol{x}_0 \bullet \boldsymbol{x}_0 - 1) = 0$$

- Quadratic in t
  - 2 solutions: Ray passes through sphere - take minimum value that is > 0
  - 1 solution: Ray is tangent - use it if >0
  - 0 solutions: Ray does not hit sphere

Ray-Plane Intersections

$$\text{Ray}: \ \boldsymbol{x}(t) = \boldsymbol{x}_0 + t\boldsymbol{d}$$

$$\text{Plane}: \ \boldsymbol{n} \bullet \boldsymbol{x} = 0$$

$$\text{Substitute}: \ \boldsymbol{n} \bullet \left(\boldsymbol{x}_0 + t\boldsymbol{d}\right) = 0$$

$$: \left(\boldsymbol{n} \bullet \boldsymbol{d}\right) t + \boldsymbol{n} \bullet \boldsymbol{x}_0 = 0$$

$$: t = \frac{-\boldsymbol{n} \bullet \boldsymbol{x}_0}{\boldsymbol{n} \bullet \boldsymbol{d}}$$

- To do polygons, intersect with plane then do point-in-polygon test…
- Faster tests for triangles, but this is the start point

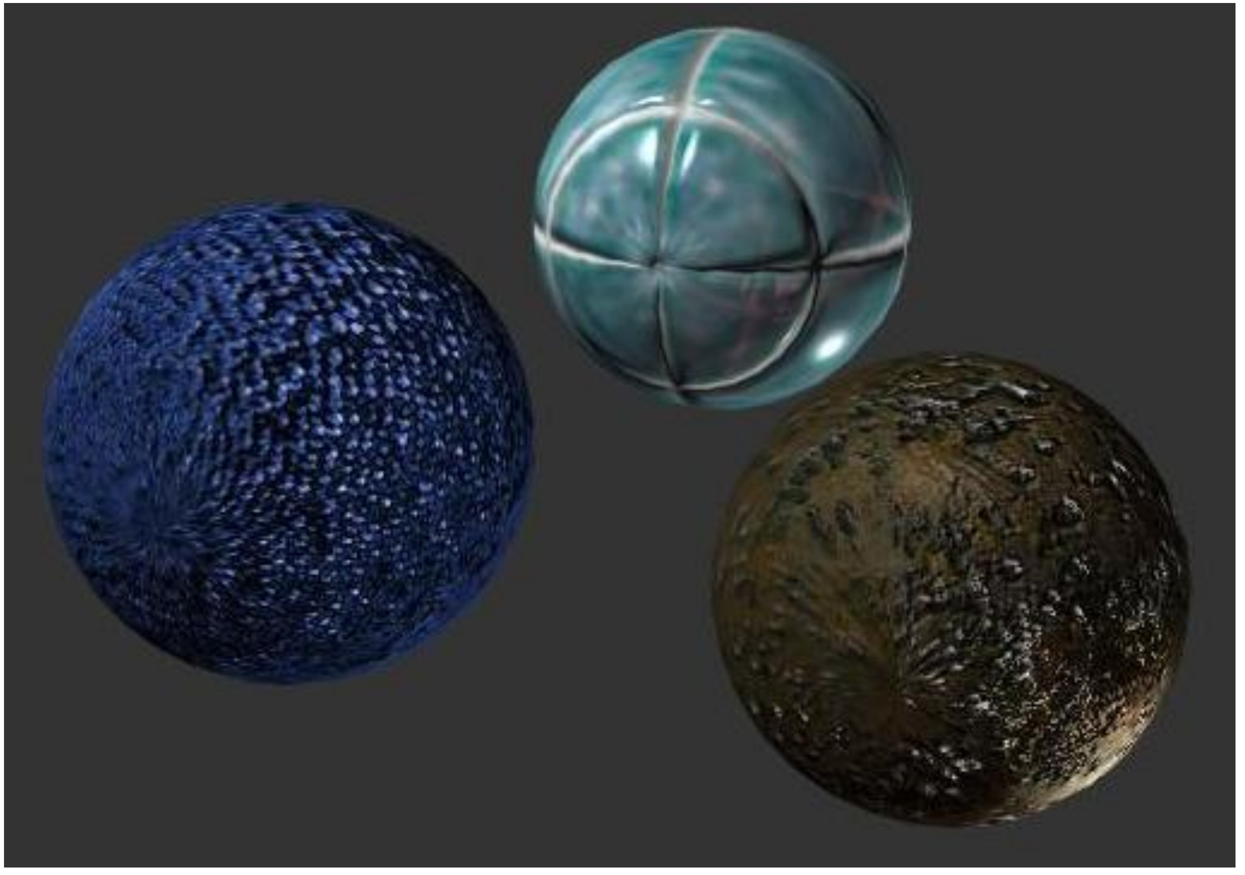
Details

- Must find *first* intersection of ray from the eye
  - Find all candidate intersections, sort them and take soonest
  - Techniques for avoiding testing all objects
    - Bounding boxes that are cheap to test
    - Octrees for organizing objects in space
  - Take care to eliminate intersections behind the eye
  - Same rules apply for reflection and transmission rays
- Shadow ray just has to find *any* intersection shadowing the light source
  - Speedup: Keep a cache of shadowing objects - test those first

Mapping Techniques

- All raytracing calculations are done for every pixel
- Raytracing provides a wealth of information about the visible surface point:
  - Position, normal, texture coordinates, illuminants, color…
- Raytracing also has great flexibility
  - Every point is computed independently, so effects can easily be applied on a per-pixel basis
  - Reflection and transmission and shadow rays can be manipulated for various effects
  - Even the intersection point can be modified

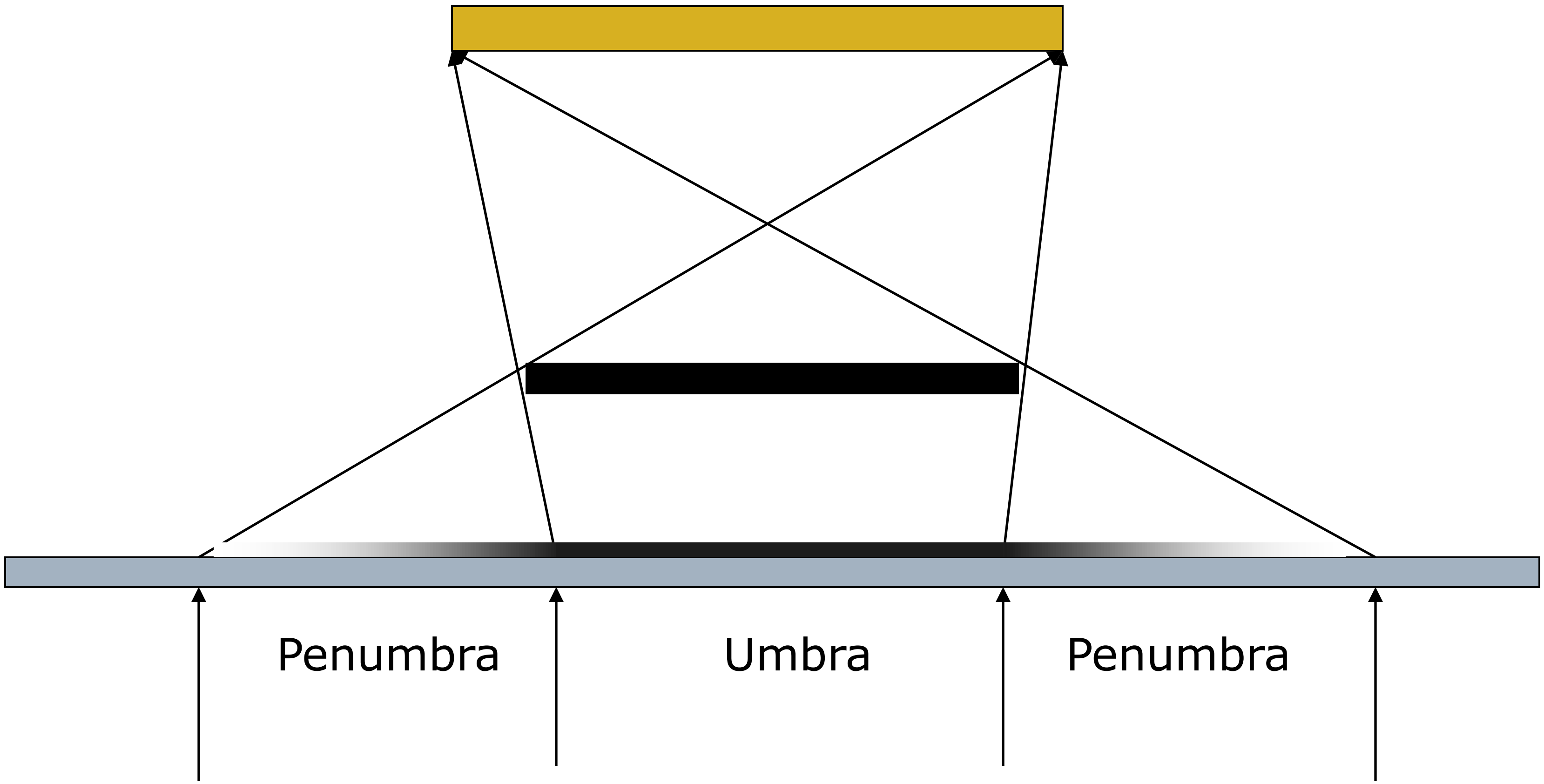
Bump Mapping Examples



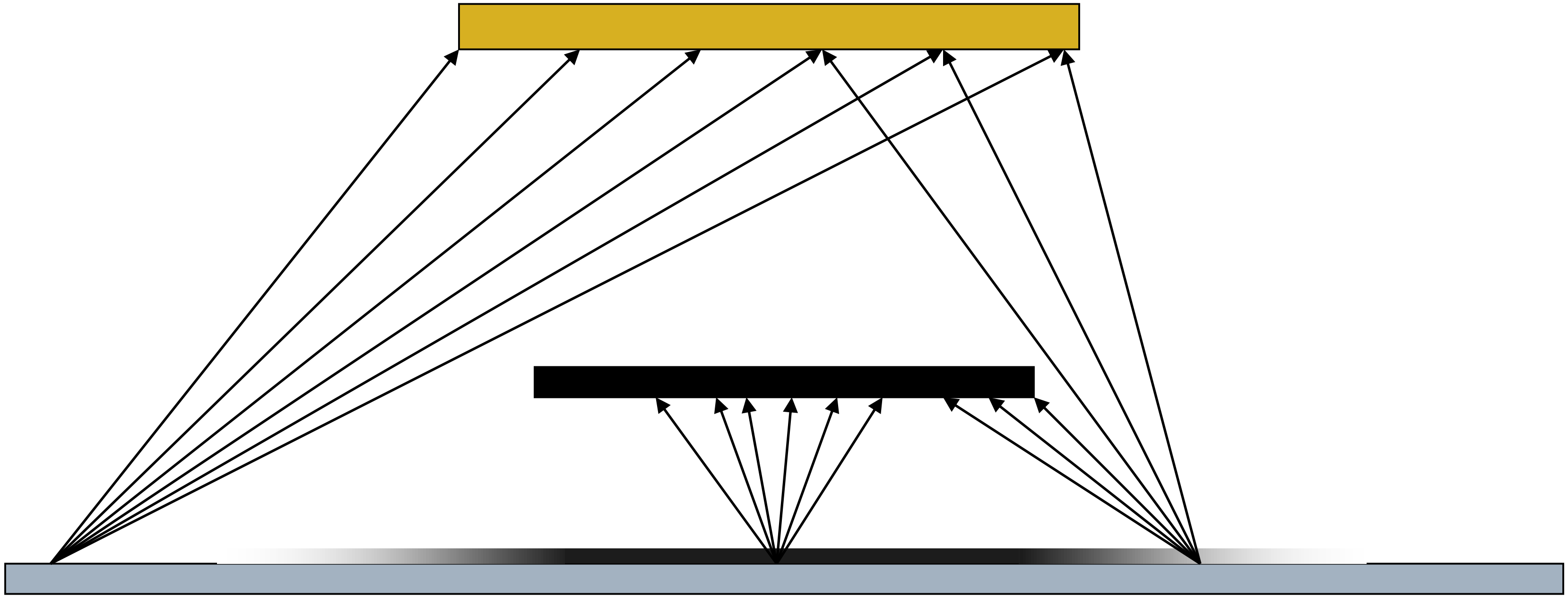
Soft Shadows

- Light sources that extend over an area (*area light sources*) should cast soft-edged shadows
  - Some points see all the light - fully illuminated
  - Some points see none of the light source - the *umbra*
  - Some points see part of the light source - the *penumbra*
- To ray-trace area light sources, cast multiple shadow rays
  - Each one to a different point on the light source
  - Weigh illumination by the number that get through

Soft Shadows



Soft Shadows



All shadow rays go through

No shadow rays go through

Some shadow rays go through

Ray-Tracing and Sampling

- Basic ray-tracing casts one ray through each pixel, sends one ray for each reflection, one ray for each point light, etc
- This represents a single sample for each point, and for an animation, a single sample for each frame
- Many important effects require more samples:
  - Motion blur: A photograph of a moving object smears the object across the film (longer exposure, more motion blur)
  - Depth of Field: Objects not located at the focal distance appear blurred when viewed through a real lens system
  - Rough reflections: Reflections in a rough surface appear blurred

Distribution Raytracing

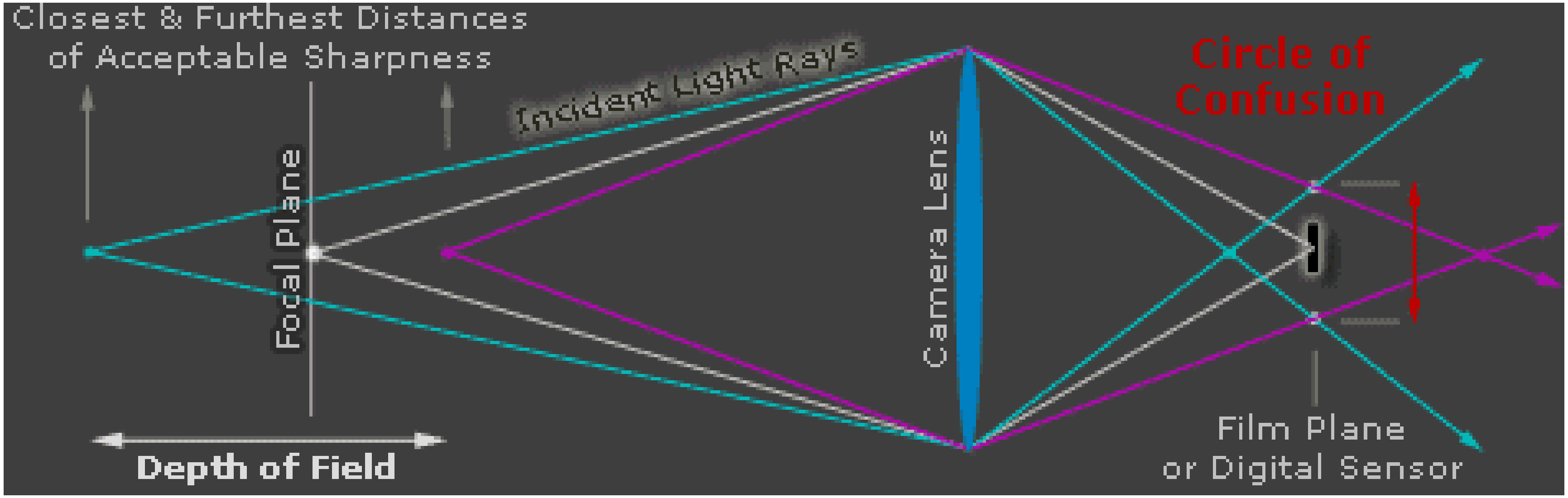
- Distribution raytracing casts more than one ray for each sample
  - Originally called *distributed raytracing*, but the name's confusing
- How would you sample to get motion blur?
- How would you sample to get rough reflections?
- How would you sample to get depth of field?

Distribution Raytracing

- Multiple rays for each pixel, distributed in time, gives you *motion blur*
  - Object positions have to vary continuously over time
- Casting multiple reflection rays at a reflective surface and averaging the results gives you rough, blurry reflections
- Simulating multiple paths through the camera lens system gives you *depth of field*

Motion Blur

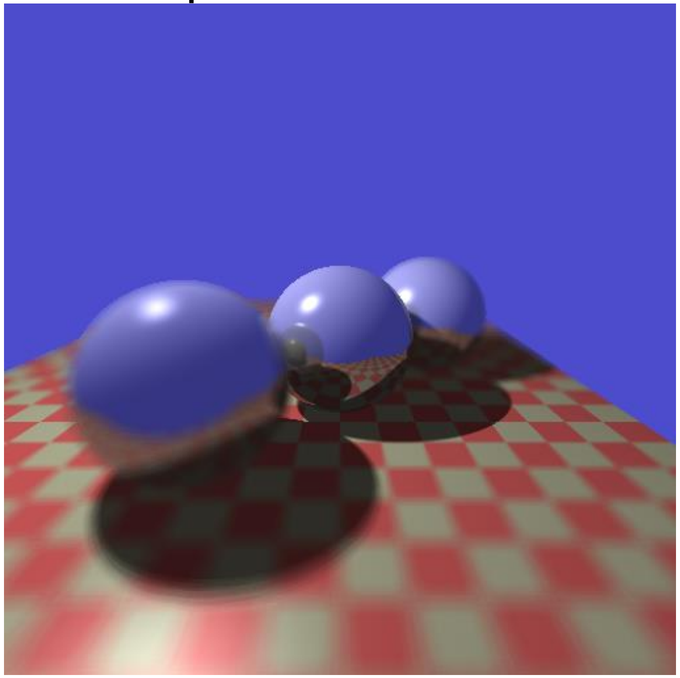
Depth of Field

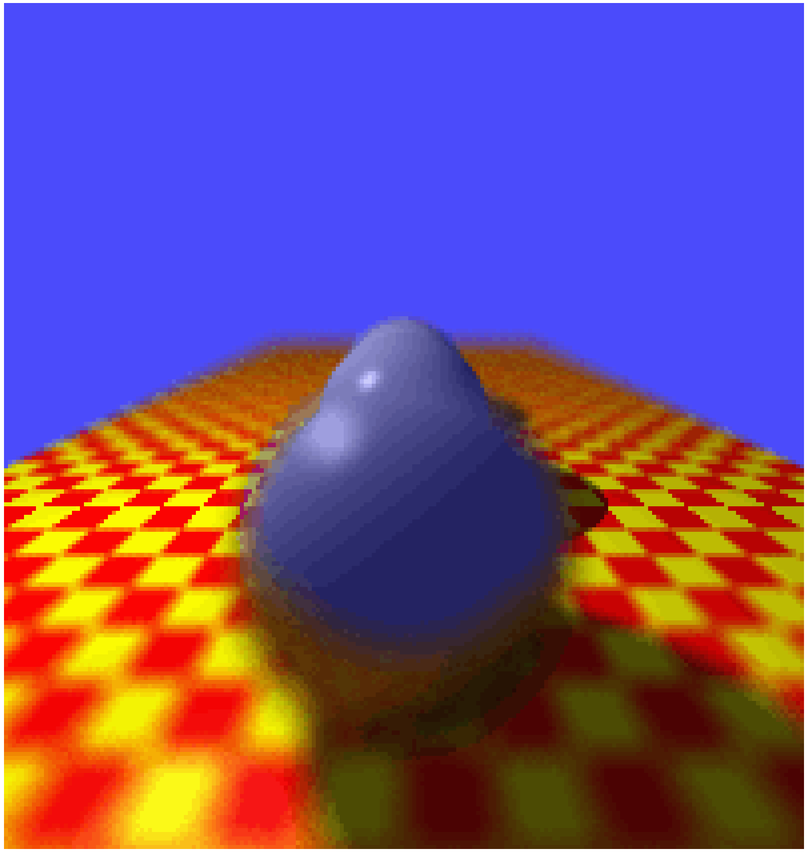


http://www.cambridgeincolour.com/tutorials/depth-of-field.htm

Distribution Raytracing

Depth of Field





From Alan Watt, “3D Computer Graphics”

Next Time

- Animation