Announcements

Written Assignment 2 out (due March 8)
Advanced Ray Tracing

(Recursive) Ray Tracing
Antialiasing
Motion Blur
Distribution Ray Tracing
Ray Tracing and Radiosity
Assumptions

• Simple shading (OpenGL, z-buffering, and Phong illumination model) assumes:
  – direct illumination (light leaves source, bounces at most once, enters eye)
  – no shadows
  – opaque surfaces
  – point light sources
  – sometimes fog

• (Recursive) ray tracing relaxes those assumptions, simulating:
  – specular reflection
  – shadows
  – transparent surfaces (transmission with refraction)
  – sometimes indirect illumination (a.k.a. global illumination)
  – sometimes area light sources
  – sometimes fog
Ray Types for Ray Tracing

Four ray types:
- Eye rays: originate at the eye
- Shadow rays: from surface point toward light source
- Reflection rays: from surface point in mirror direction
- Transmission rays: from surface point in refracted direction
Ray Tracing Algorithm

send ray from eye through each pixel  
compute point of closest intersection with a scene surface  
shade that point by computing shadow rays  
spawn reflected and refracted rays, repeat
Ray Genealogy

RAY PATHS (BACKWARD)

RAY TREE
Ray Genealogy

RAY PATHS (BACKWARD)

RAY TREE

EYE
L1
Obj1
Obj2
Obj3
L2

Eye
Obj1
Obj2
Obj3
L1
L2
T
R
Ray Genealogy

RAY PATHS (BACKWARD)

RAY TREE
When to stop?

When a ray leaves the scene

When its contribution becomes small—at each step the contribution is attenuated by the K’s in the illumination model.

\[ I = k_a I_a + f_{att} I_{light} \left[ k_d \cos \theta + k_s (\cos \phi)^{n_{shiny}} \right] \]
Ray Casting vs. Ray Tracing

Ray Casting -- 1 bounce

Ray Tracing -- 2 bounces

Ray Tracing -- 3 bounces
Ray Tracing—Demo program

http://www.siggraph.org/education/materials/HyperGraph/raytrace/rt-java/raytrace.html
Writing a Simple Ray Tracer

Raytrace() // top level function
   for each pixel x,y
      color(pixel) = Trace(ray_through_pixel(x,y))

Trace(ray) // fire a ray, return RGB radiance
   object_point = closest_intersection(ray)
   if object_point return Shade(object_point, ray)
   else return Background_Color
Shade(point, ray) /* return radiance along ray */
  radiance = black; /* initialize color vector */
  for each light source
    shadow-ray = calc_shadow-ray(point,light)
    if !in_shadow(shadow-ray,light)
      radiance += phong_illumination(point,ray,light)
    if material is specularly reflective
      radiance += spec_reflectance * Trace(reflected-ray(point,ray))
    if material is specularly transmissive
      radiance += spec_transmittance * Trace(refracted-ray(point,ray))
  return radiance

Closest_intersection(ray)
  for each surface in scene
    calc_intersection(ray,surface)
  return the closest point of intersection to viewer
  (also return other info about that point, e.g., surface
   normal, material properties, etc.)
Raytracing Example

http://www.med.osaka-u.ac.jp/pub/cl-comp/saito/raytr/saturn-img.html
Raytracing Example
What problems do you see?

Images are VERY clean
Alignment of objects and sampling can lead to unintended patterns

Solution:
more rays
more randomness
Problem with Simple Ray Tracing: Aliasing
Aliasing

Ray tracing gives a color for every possible point in the image

But a square pixel contains an \textit{infinite} number of points

These points may not all have the same color

Sampling: choose the color of one point (center of pixel)

Regular sampling leads to \textit{aliasing}

- jaggies
- moire patterns

\textit{Aliasing} means one frequency (high) masquerading as another (low)

e.g. wagon wheel effect
Anti-aliasing

Supersampling

Fire more than one ray for each pixel (e.g., a 4x4 grid of rays)

Average the results (perhaps using a filter)
Anti-aliasing: Supersampling

Can be done *adaptively*

– divide pixel into 2x2 grid, trace 5 rays (4 at corners, 1 at center)
– if the colors are similar then just use their average
– otherwise recursively subdivide each cell of grid
– keep going until each 2x2 grid is close to uniform or limit is reached
– filter the result
Adaptive Supersampling

• Is adaptive supersampling the answer?
  – Areas with fairly constant appearance are sparsely sampled (good)
  – Areas with lots of variability are heavily sampled (good)

• But...
  – even with massive supersampling visible aliasing is possible when the sampling grid interacts with regular structures
  – problem is, objects tend to be almost aligned with sampling grid
  – noticeable beating, moire patterns are possible

• So use *stochastic sampling*
  – instead of a regular grid, subsample randomly
  – then adaptively subsample
Supersampling

No antialiasing

3x3 supersampling
3x3 unweighted filter
Temporal Aliasing: Motion Blur

Aliasing happens in time as well as space
  – the sampling rate is the frame rate, 30Hz for NTSC video, 24Hz for film
  – fast moving objects move large distances between frames
  – if we point-sample time, objects have a jerky, strobed look

Real media (film and video) automatically do temporal anti-aliasing
  – photographic film integrates over the exposure time
  – video cameras have persistence (memory)
  – this shows up as motion blur in the photographs

To avoid temporal aliasing we need to filter in time too
  – so compute frames at 120Hz and average them together (with appropriate weights)?
  – a bit expensive
Motion Blur

Apply stochastic sampling to time as well as space
Assign a time as well as an image position to each ray
The result is still-frame motion blur and smooth animation

Jitter time: $T = T_0 + \delta(T_1 - T_0)$ for each ray
Example of Motion Blur

From Foley et al. Plate III.16

Rendered using distribution ray tracing at 4096x3550 pixels, 16 samples per pixel.

Note motion-blurred reflections and shadows with penumbrae cast by extended light sources.
Glossy Reflection

Simple ray tracing spawns only one reflected ray—perfect reflection
But Phong illumination models a cone of rays
  Produces fuzzy highlights
  Change fuzziness (cone width) by varying the shininess parameter

Can we generate fuzzy highlights?
  Yes
  But there’s a catch
    we can’t do light reflected from the fuzzy highlight onto other objects

A more accurate model is possible using stochastic sampling
  Stochastically sample rays within the cone
  Sampling probability drops off sharply away from the specular angle
  Highlights can be soft, blurred reflections of other objects
Soft Shadows

Point light sources produce sharp shadow edges
  – the point is either shadowed or not
  – only one ray is required

With an extended light source the surface point may be partially visible to it
  – only part of the light from the sources reaches the point
  – the shadow edges are softer
  – the transition region is the *penumbra*

Accomplish this by
  – firing shadow rays to random points on the light source
  – weighting them by the brightness
  – the resulting shading depends on the fraction of the obstructed shadow rays
Soft Shadows

firing shadow rays to random points on the light source
weighting them by the brightness
the resulting shading depends on the fraction of the obstructed shadow rays
Soft Shadows

fewer rays, more noise

more rays, less noise
Depth of Field

The camera model only approximates real optics
  – real cameras have lenses with focal lengths
  – only one plane is truly in focus
  – points away from the focus project as disks
  – the further away from the focus the larger the disk

The range of distances that appear in focus is the depth of field

Simulate this using stochastic sampling through different parts of the lens
Distribution Ray Tracing

distribute rays throughout a pixel to get spatial antialiasing

distribute rays in time to get temporal antialiasing (motion blur)

distribute rays in reflected ray direction to simulate gloss

distribute rays across area light source to simulate penumbras
  (soft shadows)

distribute rays across eye to simulate depth of field

distribute rays across hemisphere to simulate diffuse
  interreflection

also called: “distributed ray tracing” or stochastic ray tracing

aliasing is replaced by less visually annoying noise.

powerful idea! (but requires significantly more computation)
Examples

Including texture map and bump map

http://www.graphics.cornell.edu/online/tutorial/raytrace/
Examples

Semi-transparent glass with etched image.

http://www.graphics.cornell.edu/online/tutorial/raytrace/