Introduction to 2D and 3D Computer Graphics

Realistic Rendering

-- Ray Tracing--
Advanced Rendering

Ray Tracing

- Ray tracing...
  - ...allows the observer to see a point on a surface as a result of the interaction of the surface at that point with rays emanating from other places in the scene (so far, we have only considered illumination from light sources!)
  - ...allows light rays to be used that reach a surface indirectly via reflection or via transmission through transparent objects
  - ...uses global illumination: light that originates from the environment instead of just from direct light
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Ray Tracing

- Ray tracing combines...
  - ...hidden surface removal
  - ...shading due to direct illumination
  - ...shading due to global illumination from the environment
  - ...shadow computation
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Ray Tracing

- Ray tracing algorithm...
  - ...casts imaginary rays from the viewpoint to the objects in the scene
  - ...for each pixel, a ray is traced from the viewpoint through the pixel and into the scene
  - ...if this ray intersects an object, then the color of the pixel is a result of direct illumination on the object
  - ...if this object is reflective and/or transparent, the color of the point includes reflected and transmitted rays traced back to their origin to determine their effects
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Ray Tracing

- Ray tracing used for...hidden surface removal...
  - terminates ray traces at the first intersection
    ...the pixels' color is set to that of the object at the closest point of intersection
Invisible Rays cast from the viewpoint

Regular grid, corresponding to pixels:

View point

• A ray is fired from the viewpoint through each pixel to which the window maps

• The rays find the closest object intersected... rays are stopped at the first intersection...
Ray tracing used for...hidden surface removal

- For each scan line in the image
  » For each pixel in a scan line
    • Determine the ray from the viewpoint (or center of projection) through the pixel;
    • For each object in the scene
      – If the object is intersected and is closest found so far...then record the intersection and object's name;
    • Set the pixel's color to the closest object intersection;
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Ray Tracing

- Ray tracing used for...shading due to direct illumination...
  - ...takes into account the light source directly reflected on the surface in calculating the color of the pixel
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Ray Tracing

Light Source

Regular grid, corresponding to pixels:

Invisible Rays cast from the viewpoint

View point
Ray tracing used for...shading due to global illumination from the environment...

- ...uses the contribution from reflected and transmitted rays to determine the color of a pixel
Reflected rays must be traced backwards to discover their contribution; it may require ray tracing of additional rays at other intersections with objects.
Ray tracing used for...shadow computation

- ...casts an additional ray from the point of intersection to each of the light sources (called shadow rays)

- ...if one of these shadow rays intersects any object along the way, then the object is in the shadow at that point and the shading algorithm ignores the shadow ray's light source
- Shadow rays used to determine if an object is producing a shadow on the point of intersection...
  ...are not refracted
  ...are simply a straight line from the point of intersection and the light source

[Diagram showing view point, light source, and shadow ray]
Ray tracing used for...shadow computation...

- ...when an object lies in the path from the point of intersection to the light source, the point lies in a shadow
- ...when an opaque object lies in this path, the illumination at this point is reduced to simply be the ambient light
- ...when a semi-transparent object lies in this path, an attenuation factor affects the light at that point
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Ray Tracing

• Ray tracing is recursive since...
  – ...for each pixel a ray is traced backwards from the viewpoint into the scene, which might contain semi-transparent objects (those that reflect and refract)
  – ...the color seen along this ray is a result of the intersection with the first object encountered during the backwards trace of the ray ...the color is made up of local color due to illumination on the surface by direct or ambient light, the color from the reflection of a ray, and the color from the transmission of a ray coming from the refraction direction
The color from the reflection ray can be found by tracing this ray backwards to its first intersection with an object;
- its color is also made up of direct, reflected, and transmitted color....and so on...and so on...

Ray tracing is recursive...because the color of each pixel is based on three contributions...
...direct/ambient light
...reflected light ...transmitted light
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Ray Tracing

View point

Point where the ray from the viewpoint intersects the first object

Reflected ray

Refracted ray

Transmitted ray

Color seen from this direction is based on direct/ambient light, reflected light, & transmitted light
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Ray Tracing

- Ray tracing is recursive...
• Ray tracing is recursive...using a trace depth... ...which implies that beyond a certain number of intersections, any color contribution to the first level ray will be negligible

Assume the trace depth of 4
Ray tracing assumes that for each ray intersecting a surface...a reflected ray and a refracted ray are generated
– ...the reflection ray is \((Incident\ ray + 2*Normal*\cos(Angle))\)
– ...the refraction ray for a semi-transparent object is caused by a change in the light when it enters different media
– ...the transmitted ray's direction depends on how dense the material is
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Ray Tracing

Surface normal

Incident ray

Reflection

Reflected ray

Angle θ

Angle θ

Surface normal

Angle θ

Refraction

Transmitted ray

Angle β
The transmitted ray...
- ...traveling from a more to a less dense material may cause the refracted ray to be parallel to the surface
- ...causes internal reflection
- ...increases the internal reflection as the angle increases

Angle $\beta$ = critical angle for this material

Angle $\tilde{\beta}$ is greater than the critical angle
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Ray Tracing

- So...let's see how rays recursively create other rays...

Diagram showing:
- View point
- Primary ray
- Dense material
- Semi-transparent material
- Reflected ray
- Surface normal
- Refracted rays
- Transmitted ray
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Ray Tracing

- Direct illumination...
  - ...is light incident from light source(s)
  - ...means a surface receives light directly from a source
  - ...creates global illumination when it interacts with a surface and causes reflection and refraction
  - ...can be a combination of diffuse light, specular light, and ambient light

- Global illumination...
  - ...arises from the interaction of direct light with reflective and transparent surfaces
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Ray Tracing

- Scenes with multiple objects have reflection from...
  - ...ambient -- surfaces always receive ambient illumination
  - ...direct light -- surfaces receive illumination from light sources if they are visible to the source
  - ...traced rays of light due to the interaction between objects
• Since ray tracing traces all rays from the viewpoint...
  – ...shadow rays are cast only to direct light sources
  – ...the effects of reflected and refracted light sources, like mirrors and lenses, are not reproduced properly
  – ...shadows can be created from light rays bouncing off of mirrors, which in real life do not create shadows!
  – ...shadows of transparent objects do not refract light, which in real life do! (this is caused since shadow rays are cast in a straight line toward the light source)
Instead, ray tracing can be performed from light sources...

- ...to supplement the lighting information from regular ray tracing from the viewpoint
- ...allowing the light's rays to be traced recursively
Advanced Rendering
Ray Tracing

- Ray tracing side effects produce...
  - ...aliasing artifacts since rays are traced from intersection to intersection as infinitely thin beams
  - ...sharp shadows, sharp reflections, and sharp refractions resulting in surrealistic images since a perfect global reflection and transmission environment is assumed

- Ray tracing problems can be overcome...
  - ...by distributed ray tracing, which adds a large number of extra rays *(which even performs antialiasing!)*
Distributed ray tracing causes...

- ...reflective surfaces to have blurred reflections (simulating surface imperfections)
- ...transmitting surfaces to blur transmitted rays (simulating the type of material)
- ...blurred shadows and provides antialiasing
Distributed ray tracing...
- ...integrates antialiasing
- ...distributes reflected rays producing blurry reflections
- ...distributes transmitted rays producing translucency
- ...distributes shadow rays resulting in penumbras
- ...distributes ray origins over the viewpoint producing depth of field
- ...distributes rays in time to produce motion blur
Distributed ray tracing...
Advanced Rendering

Ray Tracing Pipeline

- With ray tracing... ...the rendering pipeline is very simple, since hidden surface removal, illumination, and antialiasing are combined.
Ray tracing...
- ...does an excellent job of modeling specular light
- ...still makes objects look surrealistic due to global illumination only using specular reflection and refraction, since tracing diffuse interaction would involve evaluating a very large number of rays at each surface intersection
- ...is limited since it makes use of directionless ambient light (*this is how diffuse light interactions are simulated*)
For example, using ray tracing to simulate diffuse light would cause a very large number of rays to be cast at each surface intersection.

As you can see...this is just the beginning! For just one point, an enormous number of rays would be cast!