### Geometric Transformations
- similar goal as in rendering pipeline:
  - modeling scenes more convenient using different coordinate systems for individual objects
- problem:
  - not all object representations are easy to transform
  - problem is fixed in rendering pipeline by restriction to polygons, which are affine invariant
  - ray tracing has different solution
  - ray itself is always affine invariant
  - thus: transform ray into object coordinates!

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<th>Ray-Tracing</th>
<th>Geometric Transformations</th>
<th>Total Internal Reflection</th>
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| - issues:
  - generation of rays
  - intersection of rays with geometric primitives
  - geometric transformations
  - lighting and shading
  - efficient data structures so we don't have to test intersection with every object |
| - method in book is elegant but a bit complex
- easier approach: triangle is just a polygon
- intersect ray with plane

![Ray-Triangle Intersection](image)

- normal: $\mathbf{n} = (\mathbf{b} - \mathbf{a}) \times (\mathbf{c} - \mathbf{a})$
- ray: $\mathbf{x} = \mathbf{e} + \lambda \mathbf{d}$
- plane: $(\mathbf{p} - \mathbf{x}) \cdot \mathbf{n} = 0$  
  
  $\mathbf{p} \cdot \mathbf{n} - \mathbf{e} \cdot \mathbf{n} + \lambda \mathbf{d} \cdot \mathbf{n} = 0$
- $\lambda = \frac{\mathbf{p} \cdot \mathbf{n} - \mathbf{e} \cdot \mathbf{n}}{\mathbf{d} \cdot \mathbf{n}}$
  
  $\lambda$ is a or b or c

- check if ray inside triangle

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<th>Global Shadows</th>
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- to test whether point is in shadow, send out shadow rays to all light sources
- if ray hits another object, the point lies in shadow

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<th>Global Reflections/Refractions</th>
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- send rays out in reflected and refracted direction to gather incoming light
- that light is multiplied by local surface color and added to result of local shading

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<thead>
<tr>
<th>Example Images</th>
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<td><img src="image" alt="Example Images" /></td>
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**Radiosity**
- radiosity definition
  - rate at which energy emitted or reflected by a surface
- radiosity methods
  - capture diffuse-diffuse bouncing of light
  - indirect effects difficult to handle with raytracing
- store and access only pixels
- no geometry, no light simulation...
- input: set of images
- output: image from new viewpoint

**Subsurface Scattering: Translucency**
- light enters and leaves at *different* locations on the surface
- bounces around inside
- technical Academy Award, 2003
- Jensen, Marschner, Hanrahan

**Subsurface Scattering: Marble**

**Subsurface Scattering: Milk vs. Paint**

**Subsurface Scattering: Skin**

**Non-Photorealistic Rendering**
- simulate look of hand-drawn sketches or paintings, using digital models
- store and access only pixels
- no geometry, no light simulation...
- input: set of images
- output: image from new viewpoint
- surprisingly large set of possible new viewpoints
- interpolation allows translation, not just rotation
  - lightfield, lumigraph: translate outside convex hull of object
  - QuickTime/VR: camera moves, no translation
- can point camera in or out

**Non-Photorealistic Shading**
- cool-to-warm shading

**Better Global Illumination**
- ray-tracing: great specular, approx. diffuse
- view dependent
- radiosity: great diffuse, specular ignored
- view independent, mostly-enclosed volumes
- photon mapping: superset of raytracing and radiosity

**Ray Tracing**
- photon mapping: superset of raytracing and radiosity

**Image-Based Modelling and Rendering**
- store and access only pixels
- no geometry, no light simulation...
- input: set of images
- output: image from new viewpoint
- surprisingly large set of possible new viewpoints
- interpolation allows translation, not just rotation
  - lightfield, lumigraph: translate outside convex hull of object
  - QuickTime/VR: camera moves, no translation
- can point camera in or out