Today

- Local Illumination & Shading
  - The BRDF
  - Simple diffuse and specular approximations
  - Shading interpolation: flat, Gouraud, Phong
  - Some miscellaneous tricks
Local Shading

- Local: consider in isolation
  - 1 light
  - 1 surface
  - The viewer
- Recall: lighting is linear
  - Almost always...

Counter example: photochromatic materials
## Local Shading

- Examples of non-local phenomena
  - Shadows
  - Reflections
  - Refraction
  - Indirect lighting

## The BRDF

- The Bi-directional Reflectance Distribution Function
  \[ \rho = \rho(\theta_V, \theta_L) \]
  \[ = \rho(v, l, n) \]

- Given
  - Surface material
  - Incoming light direction
  - Direction of viewer
  - Orientation of surface

- Return:
  - Fraction of light that reaches the viewer
- We’ll worry about physical units later...
The BRDF

\[ \rho(v, l, n) \]

- Spatial variation capture by “the material”
- Frequency dependent
  - Typically use separate RGB functions
  - Does not work perfectly
  - Better:
    \[ \rho = \rho(\theta_V, \theta_L, \lambda_{in}, \lambda_{out}) \]

Obtaining BRDFs

- Measure from real materials

Images from Marc Levoy
# Obtaining BRDFs

- Measure from real materials
- Computer simulation
  - Simple model + complex geometry
- Derive model by analysis
- Make something up

# Beyond BRDFs

- The BRDF model does not capture everything
  - e.g. Subsurface scattering (BSSRDF)

Images from Jensen et al, SIGGRAPH 2001
Beyond BRDFs

- The BRDF model does not capture everything
  - e.g. Inter-frequency interactions

\[
\rho = \rho(\theta_V, \theta_L, \lambda_{in}, \lambda_{out})
\]

A Simple Model

- Approximate BRDF as sum of
  - A diffuse component
  - A specular component
  - A “ambient” term
Diffuse Component

- Lambert’s Law
  - Intensity of reflected light proportional to cosine of angle between surface and incoming light direction
  - Applies to “diffuse,” “Lambertian,” or “matte” surfaces
  - Independent of viewing angle
- Use as a component of non-Lambertian surfaces

\[ k_d I(\hat{l} \cdot \hat{n}) \]
\[ \text{max}(k_d I(\hat{l} \cdot \hat{n}), 0) \]

Comment about two-side lighting in text is wrong..
Diffuse Component

• Plot light leaving in a given direction:

• Plot light leaving from each point on surface
<table>
<thead>
<tr>
<th>Diffuse Component</th>
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<tr>
<th>Specular Component</th>
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<tbody>
<tr>
<td>• Specular component is a mirror-like reflection</td>
</tr>
<tr>
<td>• Phong Illumination Model</td>
</tr>
<tr>
<td>• A reasonable approximation for some surfaces</td>
</tr>
<tr>
<td>• Fairly cheap to compute</td>
</tr>
<tr>
<td>• Depends on view direction</td>
</tr>
</tbody>
</table>
Specular Component

\[ k_s I (\hat{r} \cdot \hat{v})^p \]
\[ k_s I \max (\hat{r} \cdot \hat{v}, 0)^p \]

• Computing the reflected direction

\[ \hat{r} = -\hat{l} + 2(\hat{l} \cdot \hat{n})\hat{n} \]
\[ \hat{h} = \frac{\hat{l} + \hat{v}}{||\hat{l} + \hat{v}||} \]
### Specular Component

- Plot light leaving in a given direction:

- Plot light leaving from each point on surface
Specular Component

- Plot light leaving in a given direction:

- Plot light leaving from each point on surface

Specular Component

- Specular exponent sometimes called “roughness”
Ambient Term

- Really, it's a cheap hack
- Accounts for "ambient, omnidirectional light"
- Without it everything looks like it's in space

Summing the Parts

\[ R = k_a I + k_d I \max(\hat{\mathbf{I}} \cdot \hat{n}, 0) + k_s I \max(\hat{\mathbf{I}} \cdot \hat{\mathbf{v}}, 0) \]

- Recall that the \( k \)s are by wavelength
  - RGB in practice
  - Sum over all lights
Anisotropy

Metal -vs- Plastic
<table>
<thead>
<tr>
<th>Metal vs Plastic</th>
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| ![Metal 1](image1)
| ![Metal 2](image2) |
| ![Metal 3](image3)
| ![Metal 4](image4) |

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<tr>
<th>Other Color Effects</th>
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</table>
| ![Other Color 1](image5)
| ![Other Color 2](image6) |
| ![Other Color 3](image7)
| ![Other Color 4](image8) |
Other Color Effects

Images from Gooch et al. 1998

Measured BRDFs

BRDFs for automotive paint

Images from Cornell University Program of Computer Graphics
Measured BRDFs

BRDFs for aerosol spray paint

Images from Cornell University Program of Computer Graphics

Measured BRDFs

BRDFs for house paint

Images from Cornell University Program of Computer Graphics
Measured BRDFs

BRDFs for lucite sheet

Details Beget Realism

- The "computer generated" look is often due to a lack of fine/subtle details... a lack of richness.
Direction -vs- Point Lights

- For a point light, the light direction changes over the surface
- For “distant” light, the direction is constant
- Similar for orthographic/perspective viewer

Falloff

- Physically correct: $1/r^2$ light intensify falloff
- Tends to look bad (why?)
- Not used in practice
- Sometimes compromise of $1/r$ used
Spot and Other Lights

- Other calculations for useful effects
  - Spot light
  - Only light certain objects
  - Negative lights
  - etc.

Ugly....
Surface Normals

- The normal vector at a point on a surface is perpendicular to all surface tangent vectors.

- For triangles, normal given by right-handed cross product.
### Flat Shading

- Use constant normal for each triangle (polygon)
  - Polygon objects don’t look smooth
  - Faceted appearance very noticeable, especially at specular highlights
  - Recall mach bands...

### Smooth Shading

- Compute “average” normal at vertices
- Interpolate across polygons
- Use threshold for “sharp” edges
  - Vertex may have different normals for each face
### Smooth Shading

- Gouraud Shading
  - Compute shading at each vertex
  - Interpolate colors from vertices
  - Pros: fast and easy, looks smooth
  - Cons: terrible for specular reflections

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### Gouraud Shading

- Compute shading at each vertex
- Interpolate colors from vertices
- Pros: fast and easy, looks smooth
- Cons: terrible for specular reflections

Note: Gouraud was hardware rendered...
Phong Shading

- Compute shading at each pixel
  - Interpolate *normals* from vertices
  - Pros: looks smooth, better speculars
  - Cons: expensive

Note: Gouraud was hardware rendered...