Shading

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Introduction to Computer Graphics
CMPT 361 – Lecture 13
Illumination vs. shading

- Illumination model (IM): determine the color of a surface point by simulating light-material interaction
  - Local IM: deals only with isolated surface (data) points and direct light sources, e.g., Phong LIM
  - Global IM: takes into account the relationships between all surfaces (points) in the environment

- Shading model: colors the whole scene after applying an illumination model at a set of point samples
Shading of surfaces

- We can shade a point on a surface using a LIM
- How about surfaces?
  - Flat (planar) polygons are computationally attractive
    - Normals, intersections, visibility, projections, etc., are all easier to compute than arbitrary surfaces
  - Hardware acceleration available
  - Curved surfaces are often tessellated into many small flat polygons in graphics – *polygonal meshes*
Polygonal meshes

- Composed of a set of polygons (often quadrilaterals or triangles) pasted along their edges
- Still the most dominant surface model for 3D shapes (esp. free-form shapes), e.g., in games
- Well, now there are points
Shading of flat polygons

- **Flat** (constant, faceted) *shading*
  - compute illumination once per polygon and apply it to whole polygon or take color of first vertex

- **Gouraud (interpolated, smooth)** *shading*
  - compute illumination at boundary (e.g. vertices) and interpolate over the interior

- **Accurate shading** – e.g., **Phong shading**
  - compute illumination at every point of the polygon
Flat shading

- Single color across polygon – efficient but approx.
- Intensity discontinuity across edges
- Flat shading would be correct if
  - Light source is at infinity, i.e., light vector \( l \) is constant, so \( n \cdot l \) is constant across polygon, and
  - viewer is at infinity, so \( r \cdot v \) is constant across polygon, and
  - polygons represent actual surface, not an approximation
- Also, when polygons are very small (e.g., pixel-size), faceting less obvious – spatial integration of our eyes
Results of flat shading
Mach band

- **Accentuation of intensity discontinuity** along edges of a mesh – quite visible in the case of flat shading
- **Caused by lateral inhibition** of the receptors in our eyes
  - perceived intensities overshoot near an edge
  - basis of our **edge detection** ability

http://serendip.brynmawr.edu/bb/latinhib.html
Why Mach banding?

- The more light a receptor receives, the more it makes neighboring receptors **insensitive** to light intensities (more inhibition).
- **A looks brighter** than **B** since the neighbors of **B**, which are brighter than those of **A**, make **B less sensitive** to light when compared with **A**.
- Similarly, **D should look darker** than **C**.
- **Perceived contrast > actual contrast**.
Gouraud shading

- Interpolative:
  - Given colors of the polygon vertices, interior points are colored through **bilinear interpolation**

- How to compute the normal at a mesh vertex?
  - Normalized average of normals of adjacent faces

\[
\mathbf{n} = \frac{\mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4}{\left| \mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4 \right|}
\]

- Typically **area/angle weighted** normals; angle average is best; see: http://meshlabstuff.blogspot.ca/2009/04/on-computation-of-vertex-normals.html
Color interpolation

- Interpolate colors along edges and scan-lines
- Can be done incrementally, i.e., via scan-lines

\[ l_a = l_1 - (l_1 - l_2) \frac{y_1 - y_3}{y_1 - y_2} \]
\[ l_b = l_1 - (l_1 - l_3) \frac{y_1 - y_3}{y_1 - y_3} \]
\[ l_p = l_b - (l_b - l_a) \frac{x_b - x_p}{x_b - x_a} \]
Flat vs. Gouraud shading

Flat Shading

Gouraud Shading
Phong shading

- Gouraud shading does not properly handle specular highlights because of color interpolation

- Phong shading or accurate shading
  - Interpolates normals at each point instead of colors
  - Apply LIM at each point using approximated normal
Phong vs. Gouraud shading

- Phong shading:
  - Handles specular highlights much better
  - But more expensive than Gouraud shading
Further problems with shading models so far (1)

- **Polygonal silhouette** – we are quite sensitive in picking up the low-res polygons there

- **Solution:** subdivide further
Refinement near silhouette

- Solution: subdivide further
Further problems with shading models so far (2)

- **Orientation dependence**
  - Note first that interpolation is done along *horizontal scanlines*
  - When orientation of the same polygon changes, the same point p may be colored differently

- **Solution:** triangulate
Further problems with shading models so far (3)

- Unrepresentative normals
  - Example: all vertex and interpolated normals are the same, but they are really not!
- Solution: subdivide
Physically based illumination

- Everything so far is highly heuristic. Cannot model:
  - Wavelength dependent phenomena
  - Anisotropic behaviors, e.g., "non-perfect" diffusers
  - Many other physical phenomena (real physics)

- More accurate solution: global illumination based on the rendering equation — next lecture

- Still ongoing research … Main early contributions: