How do we draw a picture?

- Define geometry.
- Now what?
- We can draw the edges of the faces. Wireframe.
- We can only draw the edges of faces that are visible.
- We can fill in the faces. Giving each object a color (constant shading).
Flat Shading

- Assumes the object is faceted, and light and viewer at infinity.
- Illumination model is applied only once per polygon.
Flat Shading

• Assumes the object is faceted, and light and viewer at infinity.

• Illumination model is applied only once per polygon.

• What if the object represents a curved surface?
Flat Shading

- Works poorly if the model represents a curved surface.
- Adding more facets helps but...
  - Slows down the rendering.
  - Effectiveness is tempered by Mach banding.
Mach Bands

Perceived intensity change at edges are exaggerated by receptors in our eyes, making the dark facet look darker and the light facet look lighter.
Is A or B darker?

illusion by Ted Adelson
Are you sure?
Is A or B darker?

illusion by Ted Adelson
Are you sure?
Are the diamonds the same colour?
Are the diamonds the same colour?
Are the circles the same colour and size?
Harmann-grid illusion - See white circles?
Flat Shading
Gouraud Shading
Gouraud Shading

- Also called smooth shading, intensity interpolation shading or color interpolation shading.
- Discontinuities eliminated by interpolating intensity.
- Almost removes Mach bands (high curvature can still suffer).
- OpenGL implements Gouraud shading.
- Easily implemented in hardware.
Gouraud Shading: How it works

- Illumination is calculated per vertex.
- Average normals of polygons that share vertex.
- Vertex colors linearly interpolated per pixel, first along the edges, then between those for the scanline.
- Slower than flat shading, with much better results for curved surfaces.
Gouraud Shading: How it works
Gouraud Shading: Notice any problems?
Gouraud Shading: Problems

- Highlights are spread along edges.
- Highlights tend to be larger than they should.
- Highlights tend to be shaped funny (dependent on number of polys).
- Misses specular highlights contained within a polygon.
Gouraud Shading Problems
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Gouraud Shading Problems
Phong Shading

- Don’t confuse with Phong illumination (same guy different algorithm).
- Also called normal-vector interpolation shading.
- Interpolates the surface normals instead of the intensity values.
- Calculate illumination at every pixel, as well as a vector normalization. Much slower than Gouraud.
- Gives better results, especially for highlights.
- Can handle highlights within a polygon.
Phong Shading: How it works
Gouraud Shading
Phong Shading

Patrick Coleman
Shading Comparison

from Watt, 1989
Problems with Interpolation Shading

- Must store normals at each vertex.
- Silhouette edges not smoothed.
- Interpolation can mask regular changes.
- Interpolation in image space ignores perspective distortion.
- Crease edges should not have smooth shading.
- Orientation dependence.

from Watt, 1989
Interpolation Shading Problems

from Watt, 1989
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Fixes for Interpolation Shading

- Use triangles.
- Use more triangles.
- Use multiple normals (to get sharp edges)

from Watt, 1989