Polygon Shading

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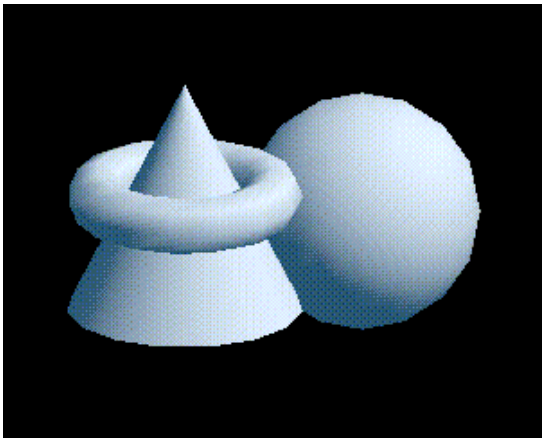
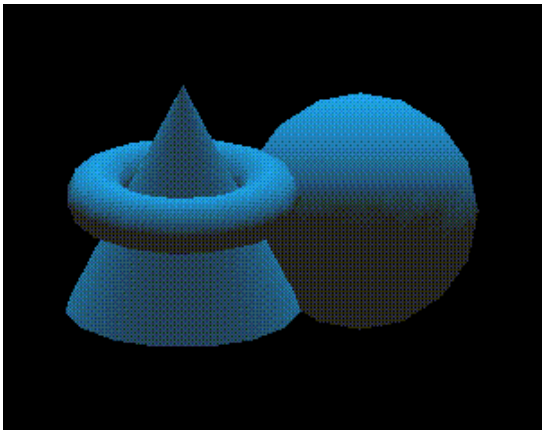
Illumination Revisited

$$I_\lambda = I_{a\lambda}k_a O_{d\lambda} + f_{att}I_{p\lambda}[k_d O_{d\lambda}(\hat{N} \bullet \hat{L}) + k_s O_{s\lambda}(\hat{R} \bullet \hat{V})^n]$$

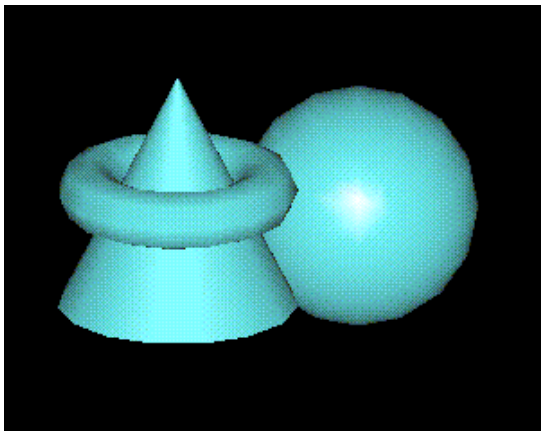
Objects drawn with gray material parameters and colored light sources.



pale blue ambient light and a white diffuse light source

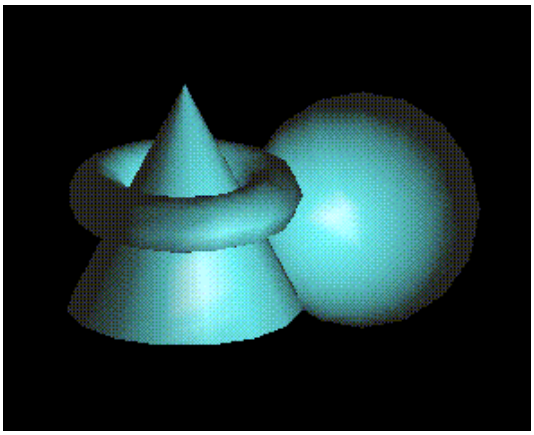


pale blue diffuse light source and almost **no** ambient light



an infinite diffuse light source and specularity

the highlight (specular reflection) is centered on both the cone and the sphere because the angle between the object and the line of sight is ignored



a local diffuse light source and specularity

the highlight is appropriately located on both the cone and the sphere because the angle is taken into account

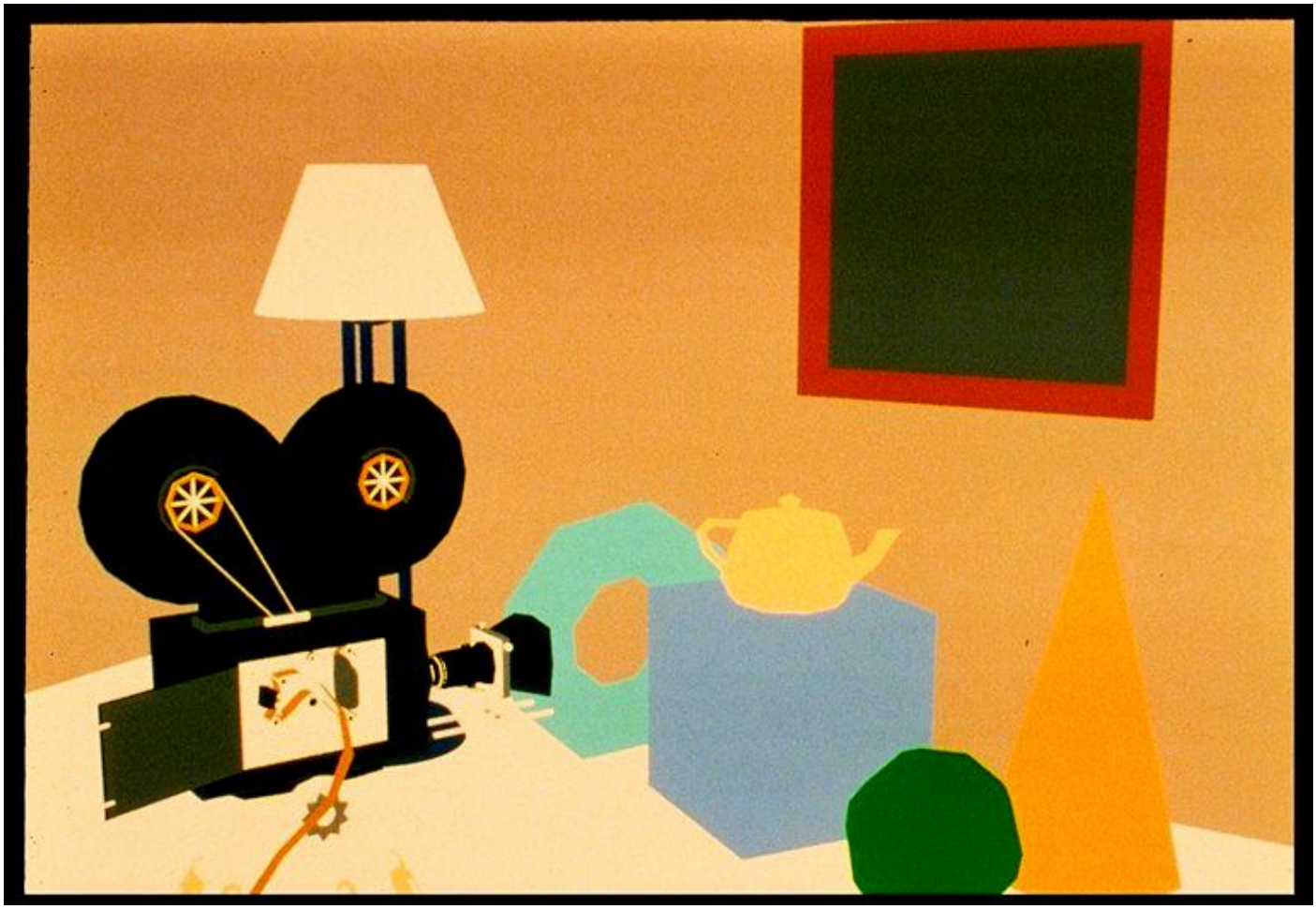
Illumination vs. Shading

Polygonal rendering

- Polygons (usually triangles) approximate actual geometry
- Non-global illumination model approximates physically-based *illumination/lighting* of each geometry point
- Speed: do not compute *illumination* at each point, only at vertices
- *Shading* (typically using some interpolation rule) approximates *lighting* of each sample point, typically an interior pixel during scan conversion. It's fast, and looks ok, especially for small triangles

Constant Shading

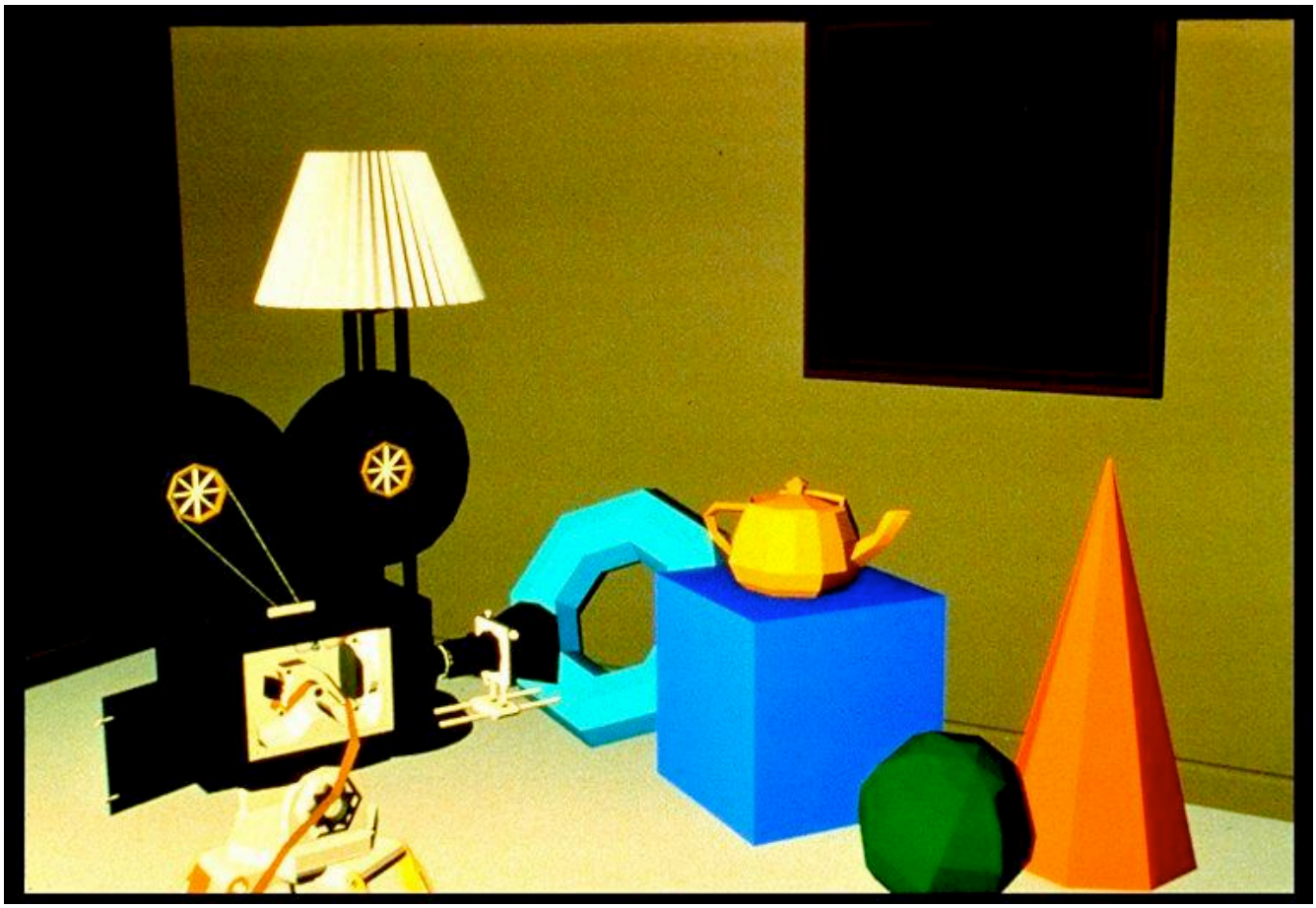
Constant shading: no interpolation, pick a single representative intensity and propagate it over entire object. Loses almost all depth cues.



Pixar "Shutterbug" images from:
www.siggraph.org/education/materials/HyperGraph/scanline/shade_models/shading.htm

Flat/Cartoon Shading

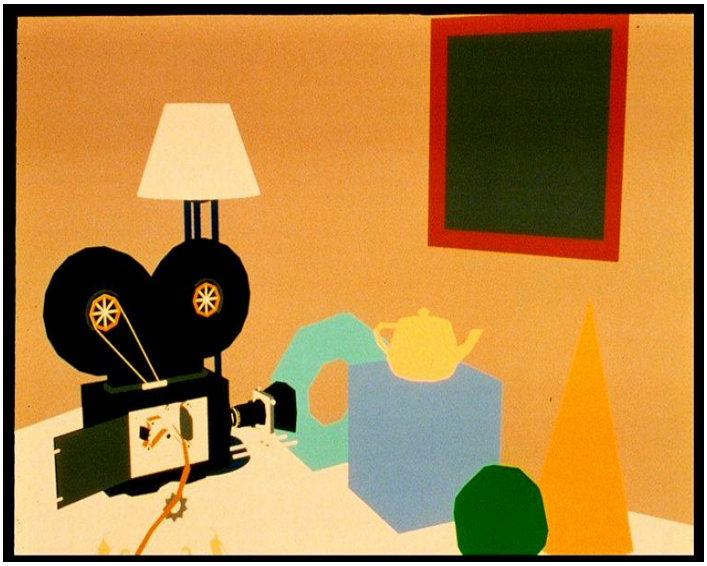
- Constant intensity over each face



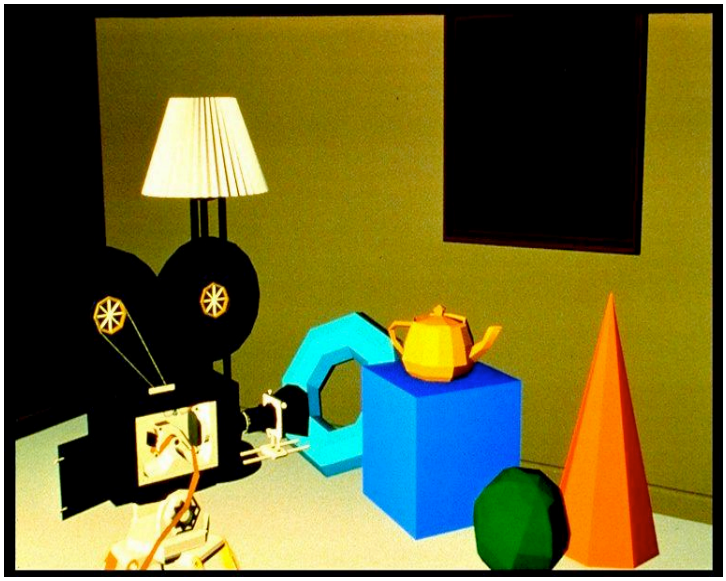
Shading Models Compared (cont.)

Constant Shading:

Constant intensity over each face



Flat/Cartoon Shading: Constant intensity over each face

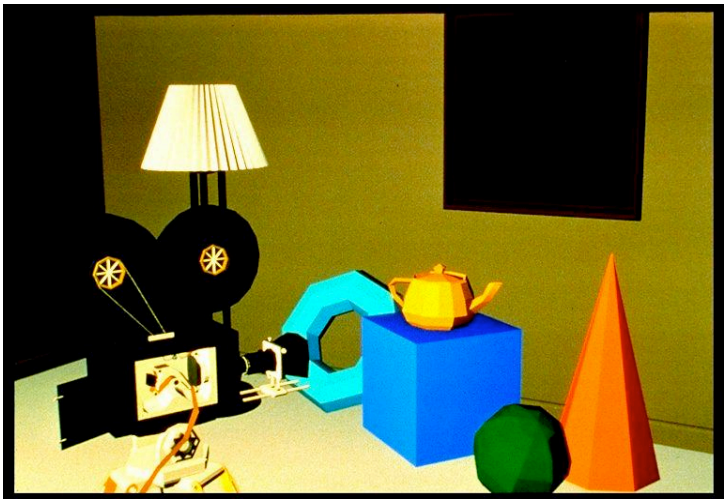


Gouraud Shading

Linear Interpolation of intensity across triangles to eliminate edge discontinuity

Shading Models Compared (cont.)

Flat/Cartoon Shading:
Constant intensity over each face



Gouraud Shading:
Linear Interpolation of intensity across triangles to eliminate edge discontinuity
Note: Silhouette edges may need special treatment

Vertex Normals

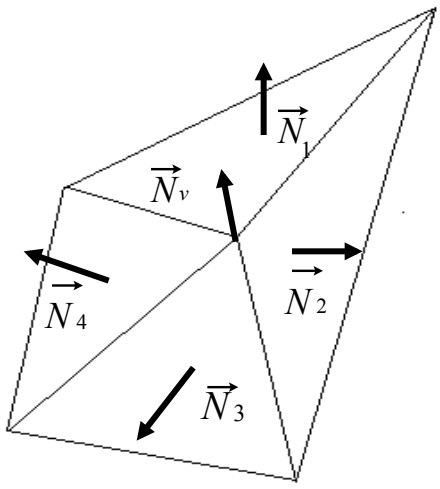
- Gouraud shading
  - use for polygon approximations to curved surfaces
- Linearly interpolate intensity along scan lines
  - eliminates intensity discontinuities at polygon edges; still have gradient discontinuities; largely ameliorated, not eliminated
  - must differentiate desired creases from tessellation artifacts (edges of a cube vs. edges on tessellated sphere)
- **Step 1**: since vertices don't have normals, calculate bogus vertex normals as average of surrounding polygons' normals:

$$\vec{N}_v = \frac{\vec{N}_1 + \vec{N}_2 + \vec{N}_3 + \vec{N}_4}{\| \vec{N}_1 + \vec{N}_2 + \vec{N}_3 + \vec{N}_4 \|}$$

More generally:

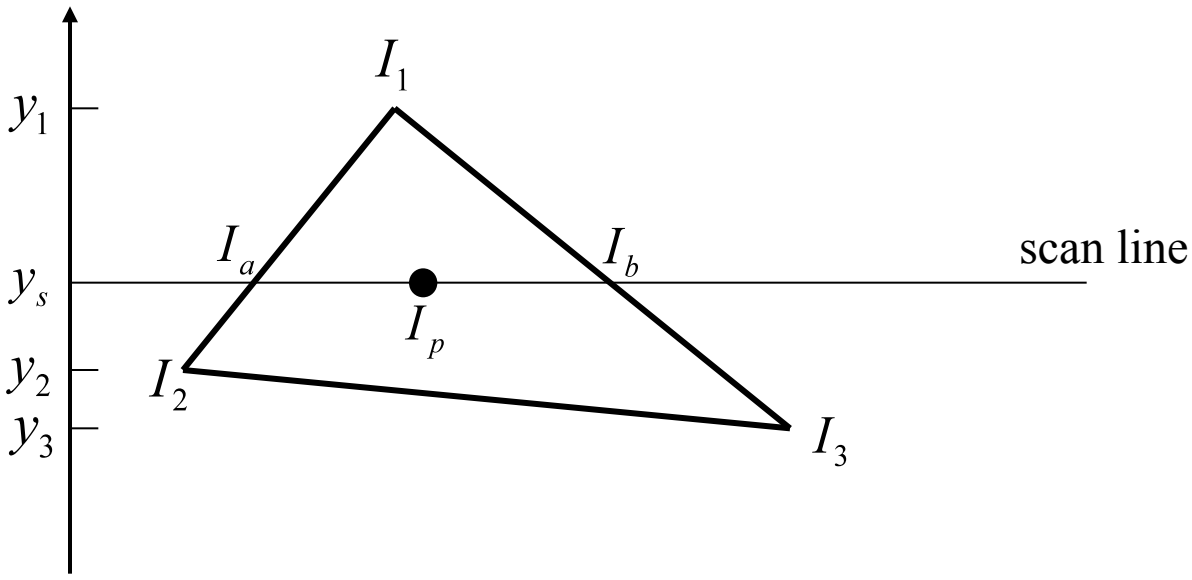
$$\vec{N}_v = \frac{\sum_{i=1}^{n} \vec{N}_i}{\left\| \sum_{i=1}^{n} \vec{N}_i \right\|}$$

n = 3 or 4 usually



Illumination Interpolation

- **Step 2**: interpolate intensity along polygon edges
- **Step 3**: interpolate along scan lines



$$I_a = I_1 \frac{y_s - y_2}{y_1 - y_2} + I_2 \frac{y_1 - y_s}{y_1 - y_2}$$

$$I_b = I_1 \frac{y_s - y_3}{y_1 - y_3} + I_3 \frac{y_1 - y_s}{y_1 - y_3}$$

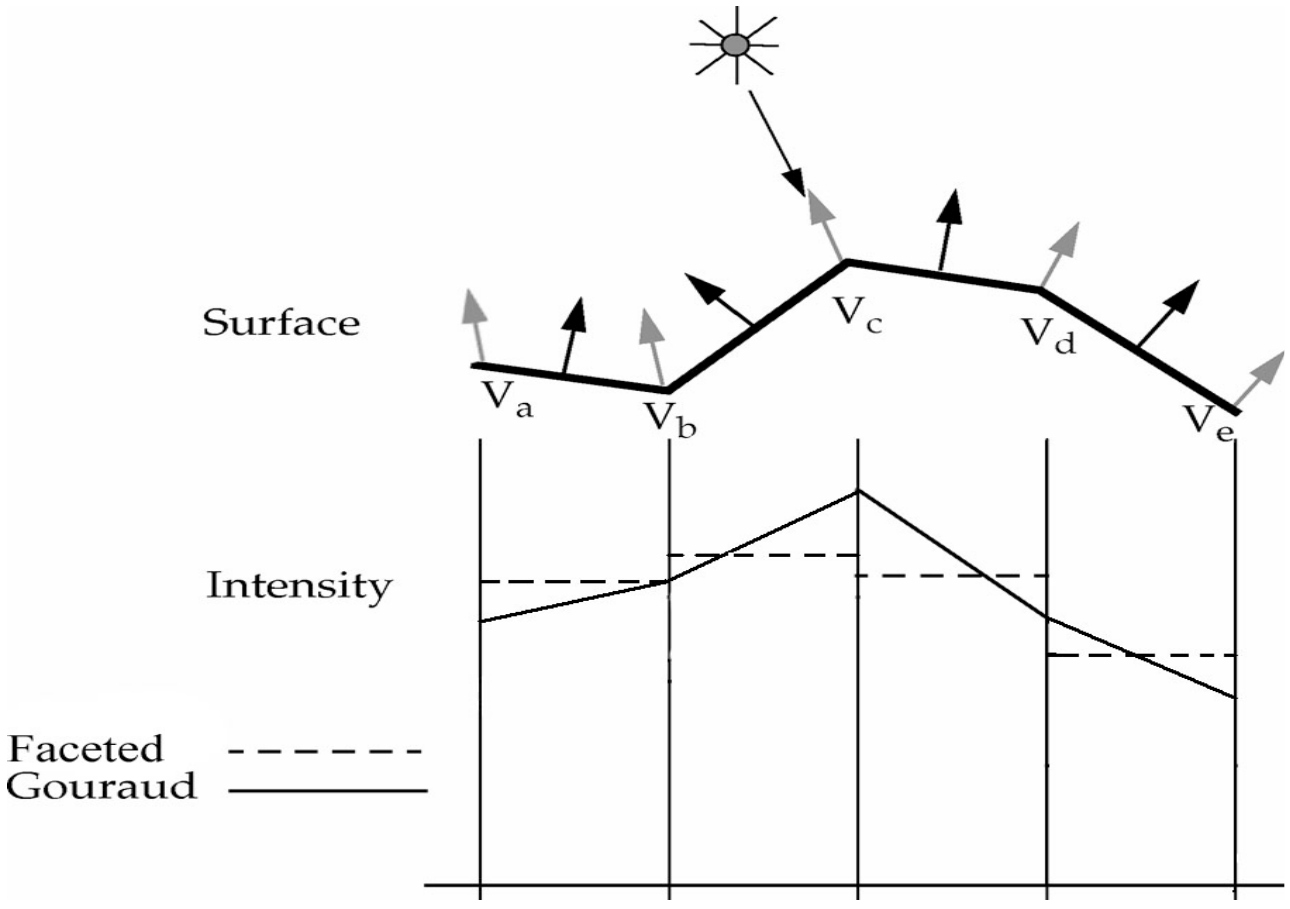
$$I_p = I_a \frac{x_b - x_p}{x_b - x_a} + I_b \frac{x_p - x_a}{x_b - x_a}$$

Polygon Mesh Shading

- Gouraud shading
  - Integrates nicely with scan line algorithm:

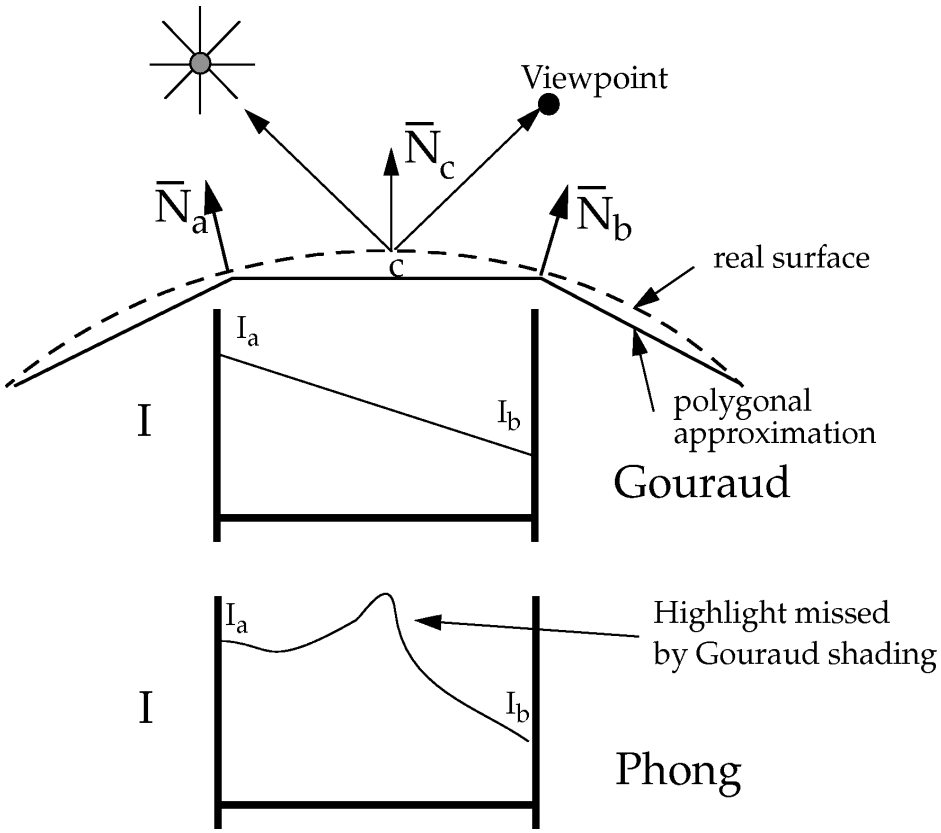
$$\frac{\Delta I}{\Delta Y} \text{ is constant along polygon edge}$$

- Gouraud versus flat/cartoon shading



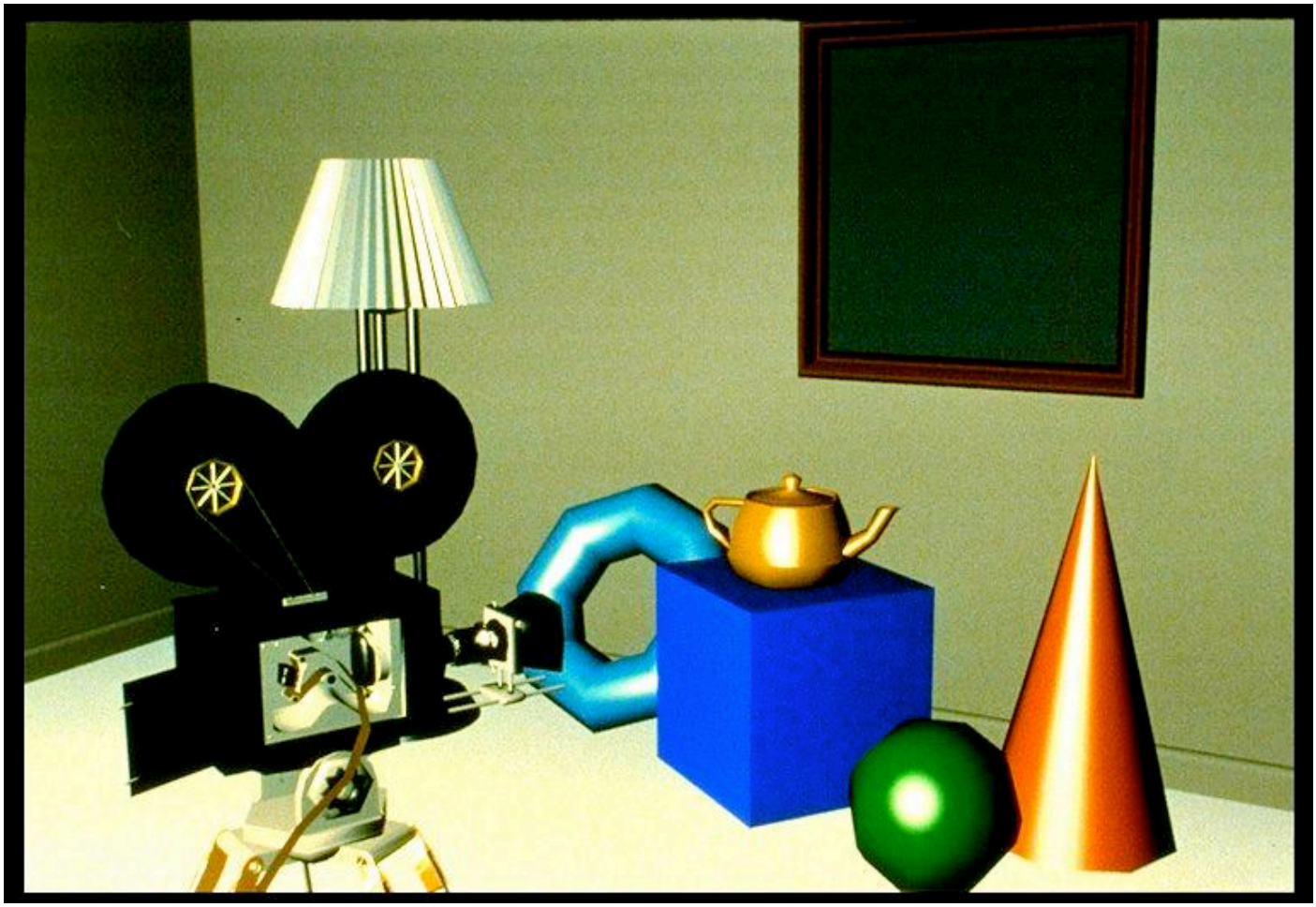
What Gouraud Shading Misses

- Gouraud shading can miss **specular highlights** because it interpolates *vertex colors* instead of calculating intensity directly at each point, or interpolating *vertex normals*
  - N_a and N_b would cause no appreciable specular component, whereas N_c would. Interpolating between I_a and I_b misses the highlight that evaluating I at c would catch



- Interpolating normal comes closer the actual normal of the surface being polygonally approximated
  - Reduces temporal "jumping" affect of highlight when rotating sphere during animation

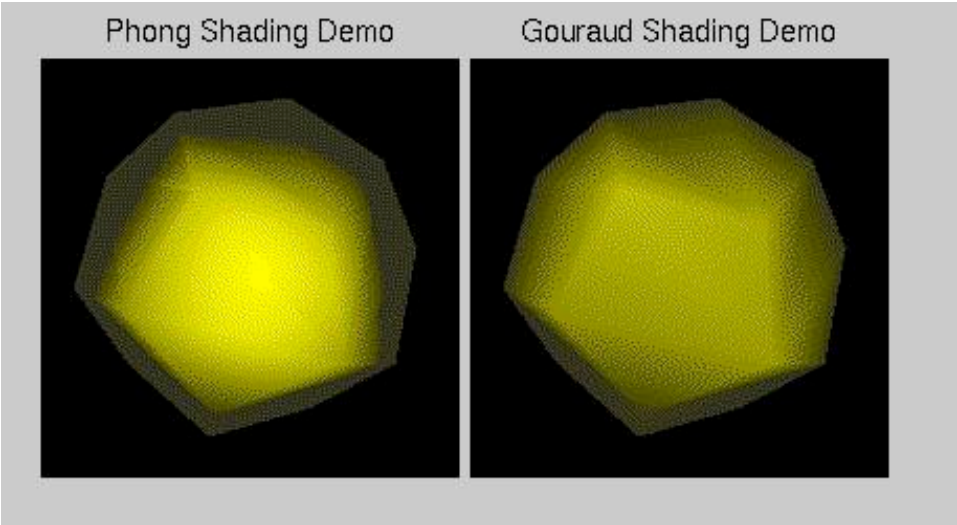
Phong Shading



Phong Shading

- Also called normal vector interpolation
  - interpolate *N* rather than *I*
  - especially important with specular reflection
  - computationally expensive at each pixel
    - recompute *N*; must normalize, requiring expensive square root
    - recompute I_λ
  - Bishop and Weimer developed fast approximation using Taylor series expansion (in SIGGRAPH '86)
- This looks much better and is now done in hardware
- Still, we don't have all the neat global effects that we'd get with recursive ray tracing

Temporal Effects

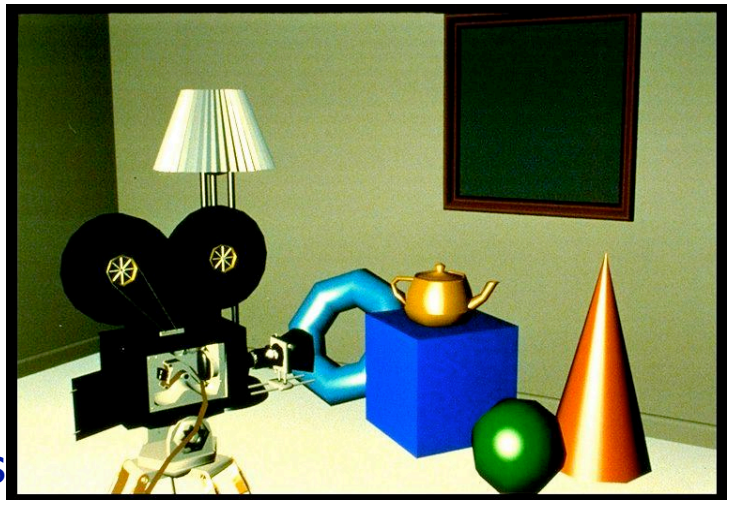


http://www.nbb.cornell.edu/neurobio/land/oldstudentprojects/cs490-95to96/guo/report.html

Shading Models Compared (cont.)

Gouraud Shading:

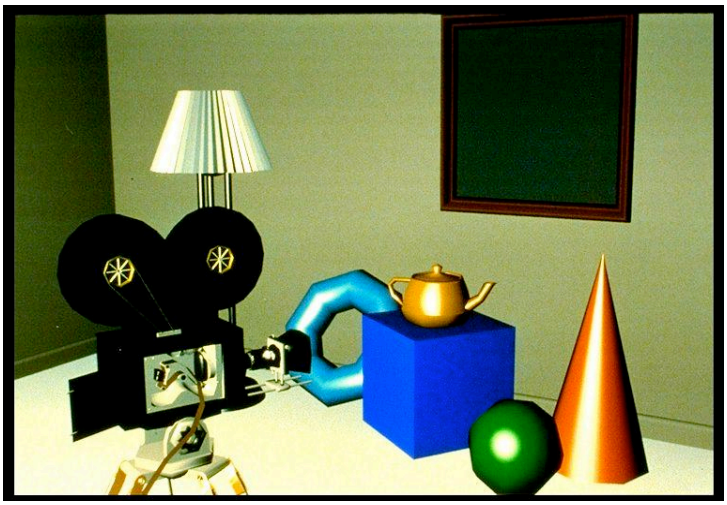
Phong Shading:
Interpolation of normals.
Smooth transitions from light to dark; specular highlights on plastic are white-ish, compact and elliptical
Note: specular highlights but no shadows – pure local illumination model



Global Illumination

Shading Models Compared (cont.)

Phong Shading:



Global Illumination:
Global illumination model with shadows, texture, bump, and reflection mapping

Summary

- Shading
  - Shading vs. illumination

- Shading models
    - Constant shading
      - one intensity per object
    - Flat/cartoon shading
      - one intensity per face
    - Gouraud shading
      - multiple intensities per face
      - color/intensity interpolation
      - vertex normals
    - Phong shading
      - multiple intensities per face
      - normal interpolation
      - captures specular highlights
      - more expensive

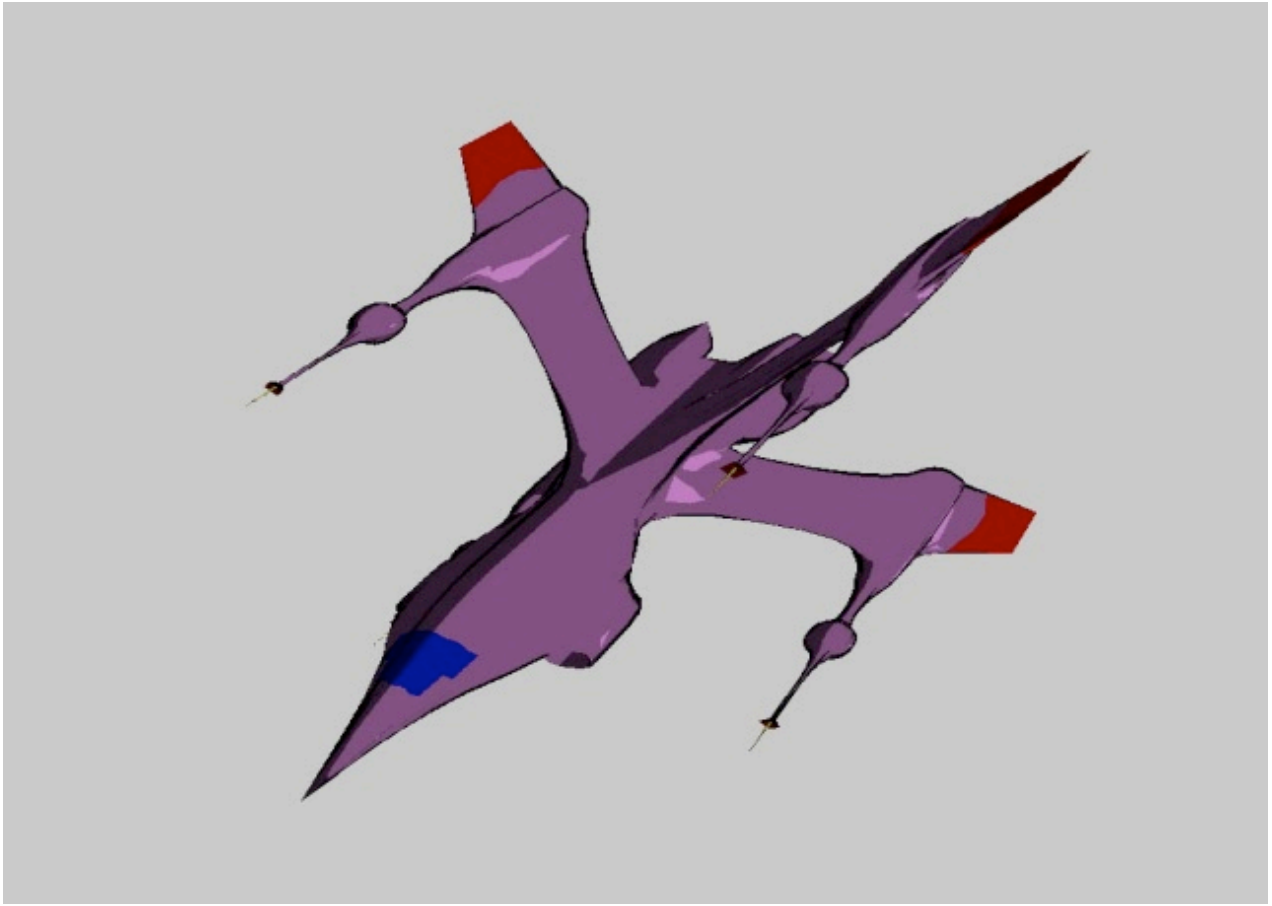
Recap: Shading

Constant shading

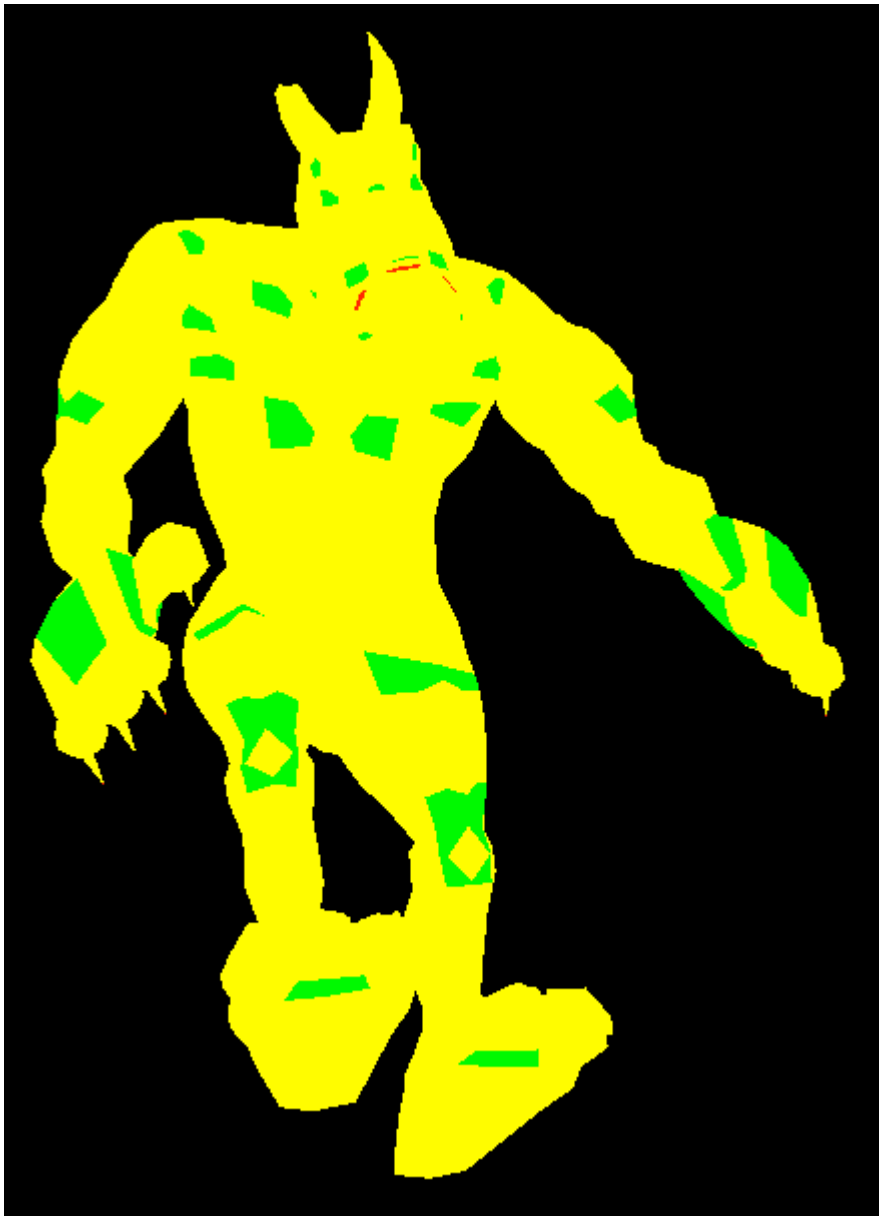
Cartoon/flat shading

Gouraud shading

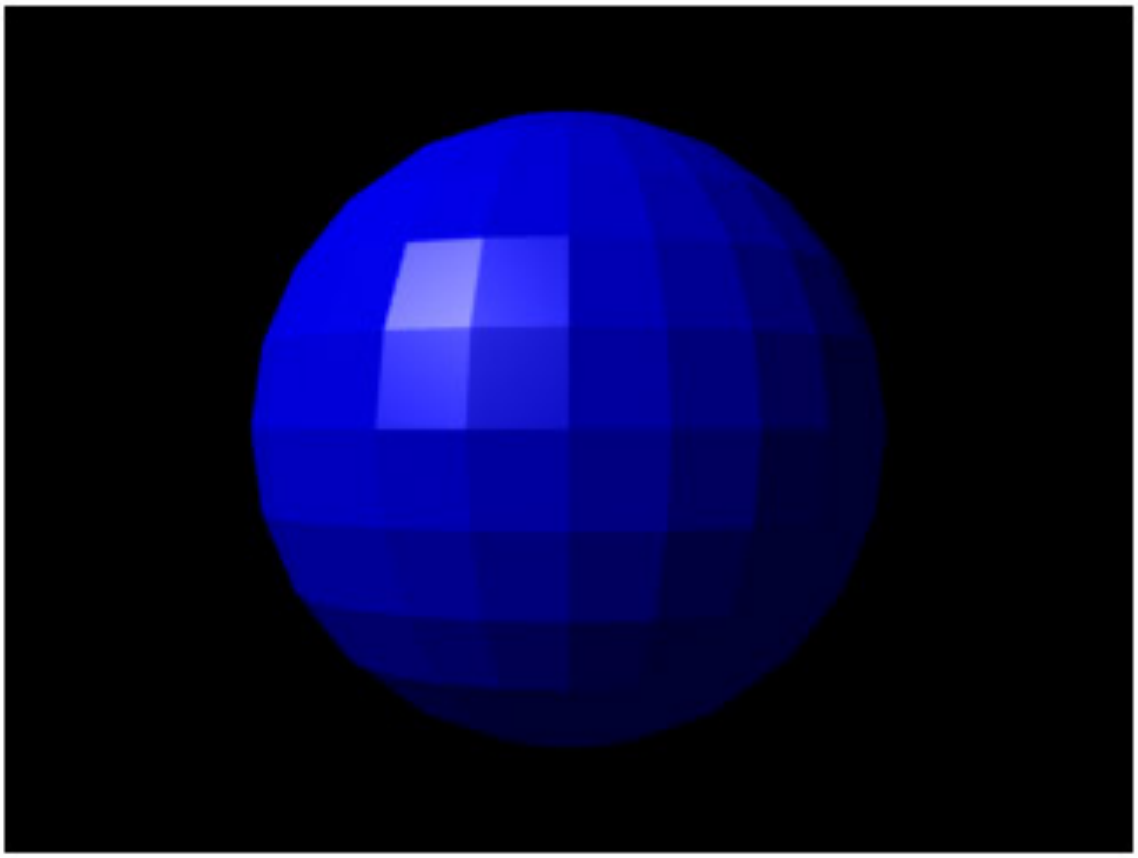
Phong shading



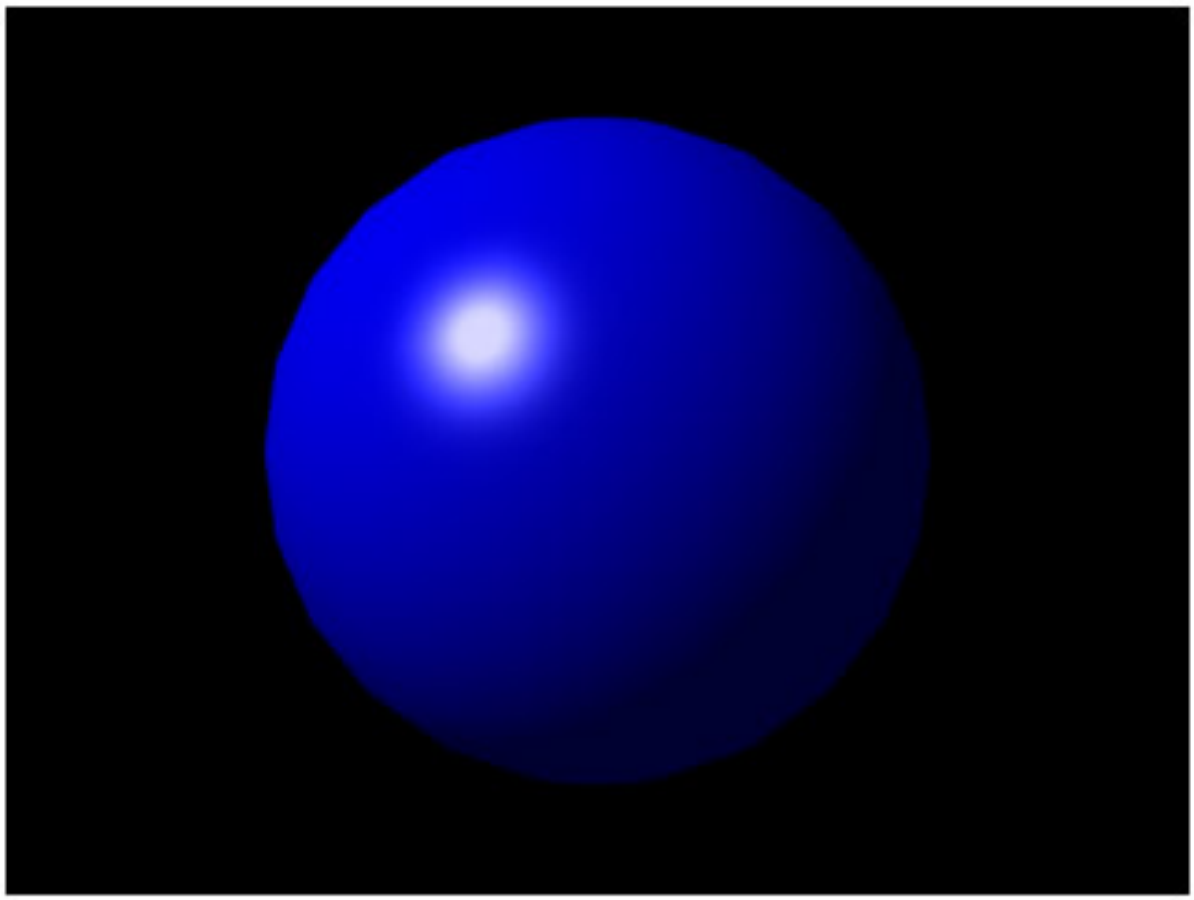
Constant shading – no light to dark transition; object appears flat, as if cut out from paper.



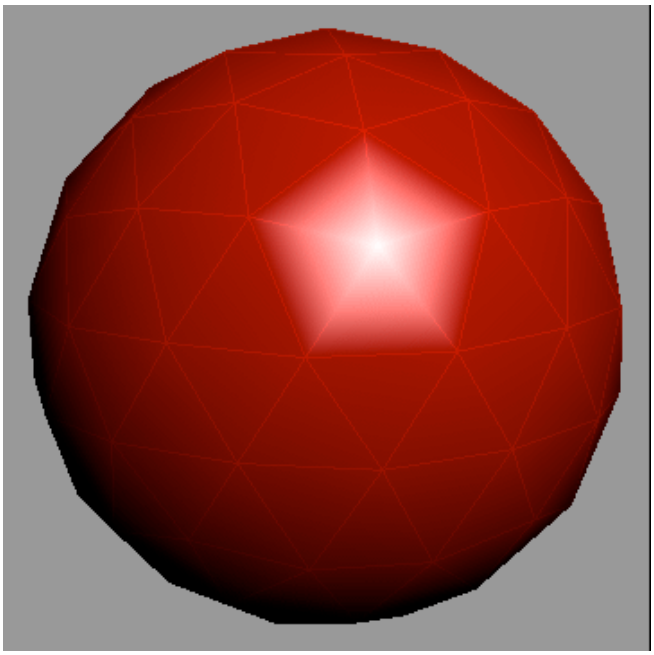
- Gouraud shading – more than one intensity per polygon (zoom in to see)

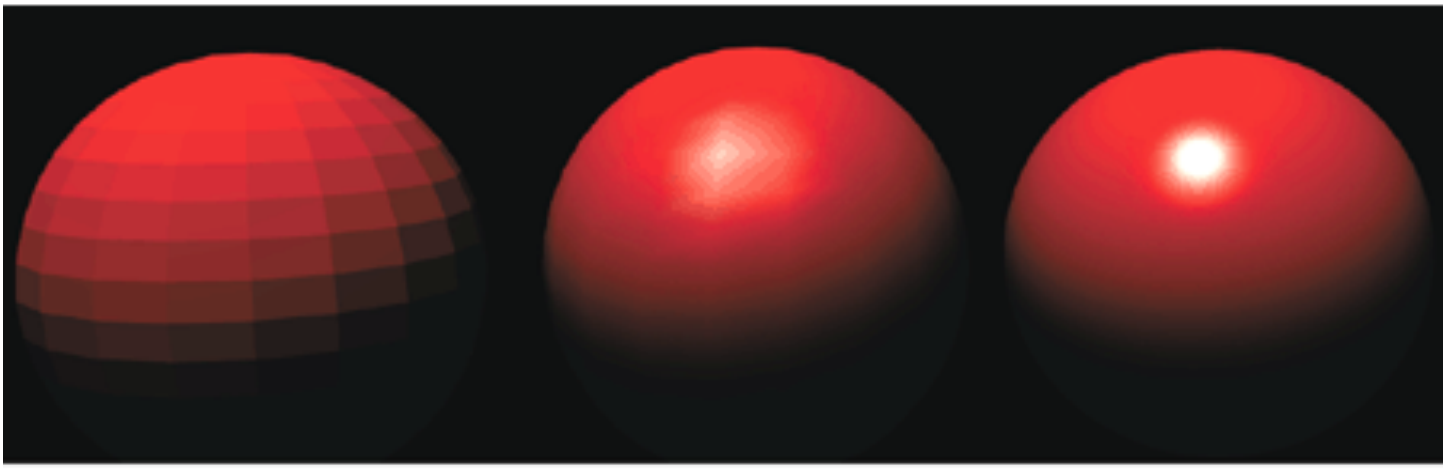


Phong shading – smooth transitions from light to dark; specular highlights on plastic are white-ish, compact and elliptical



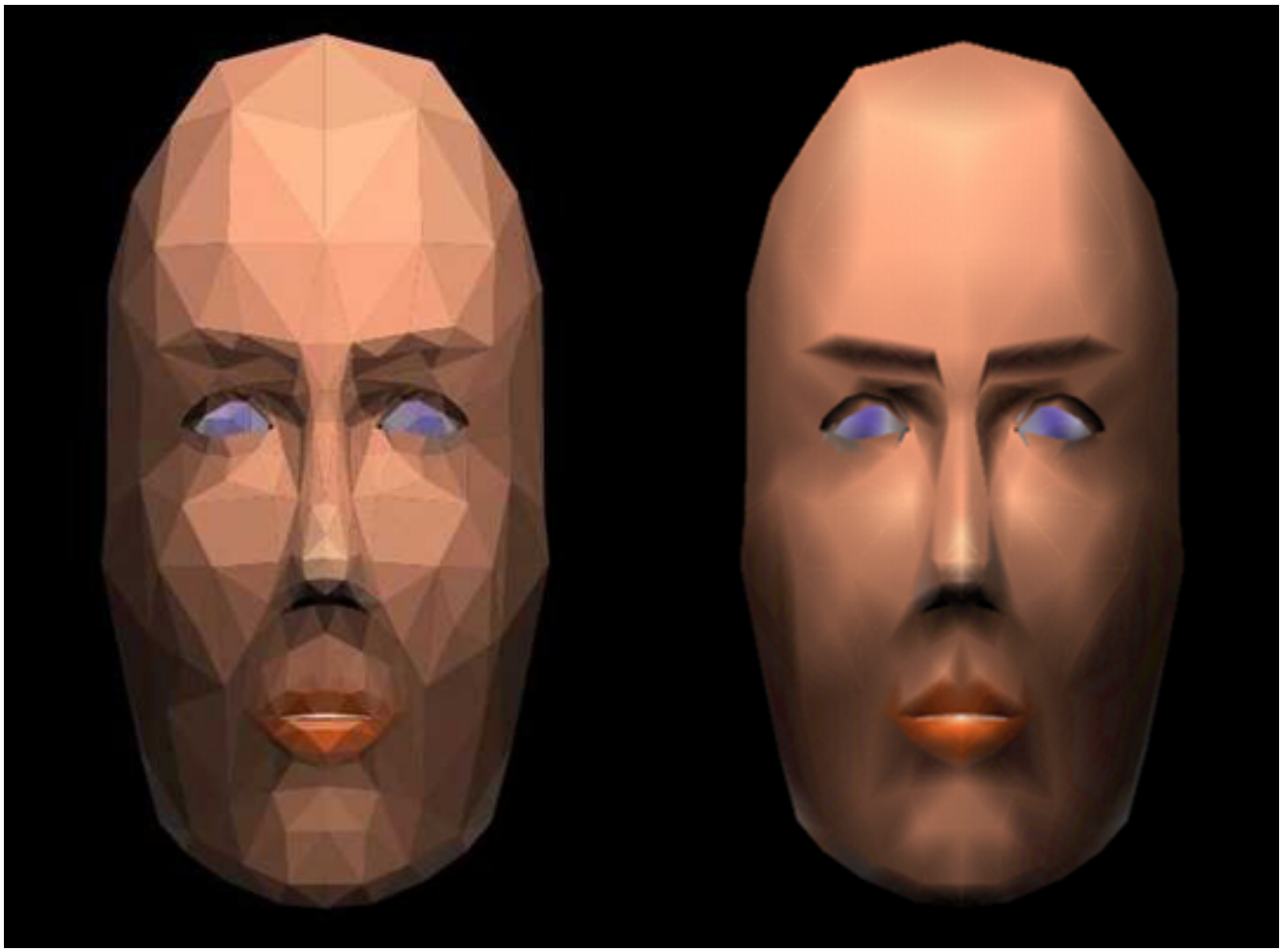
- Gouraud shading – smooth transitions from light to dark; specular highlights follow polygon edges



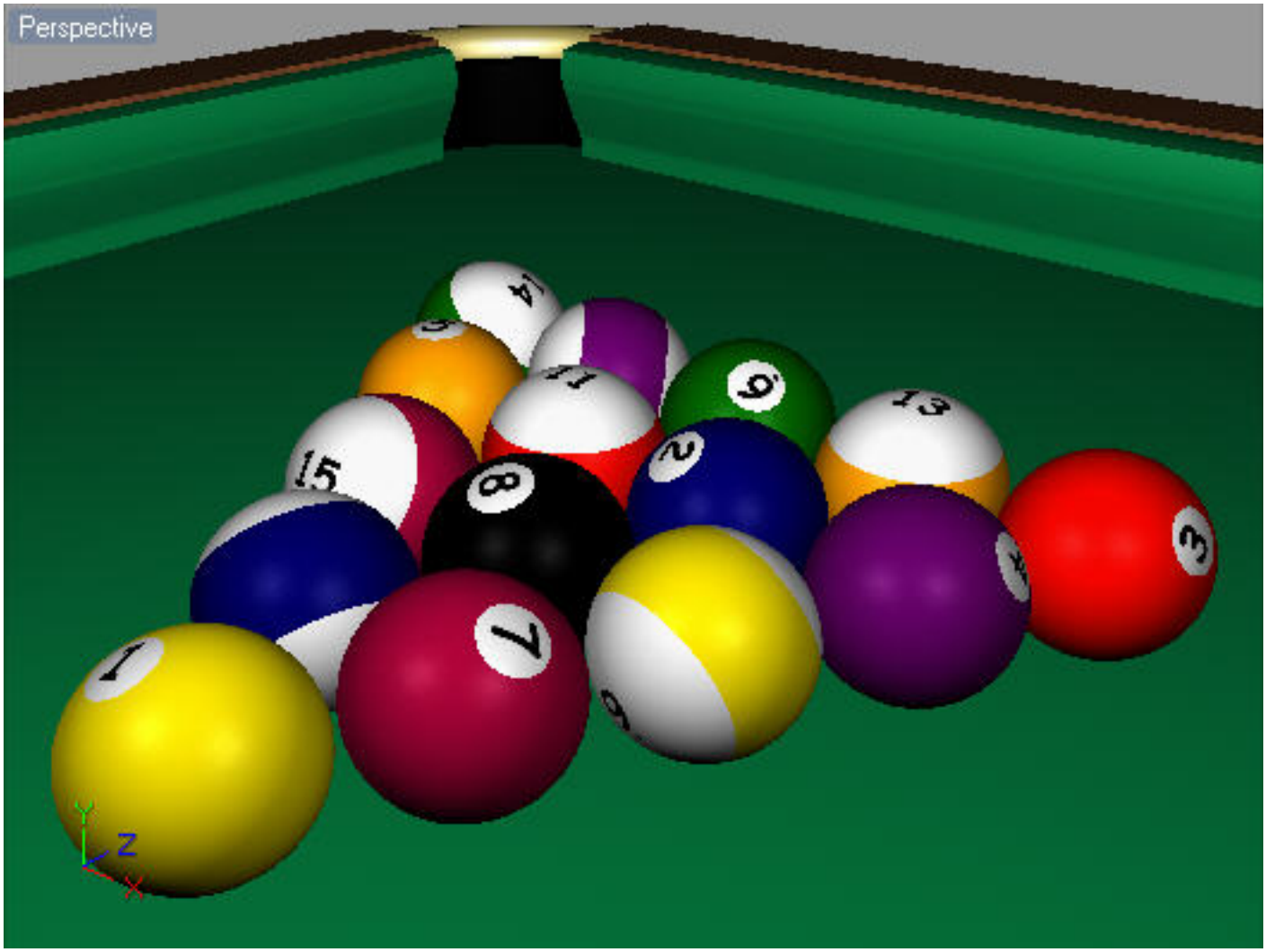


Flat Gouraud Phong

Flat Gouraud



Gouraud – looks good when tessellation fine enough; hint: specularities and billboard table edges (where there's few polygons)



Toon/Cell Shading

- How?

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