

# How do we draw a picture?

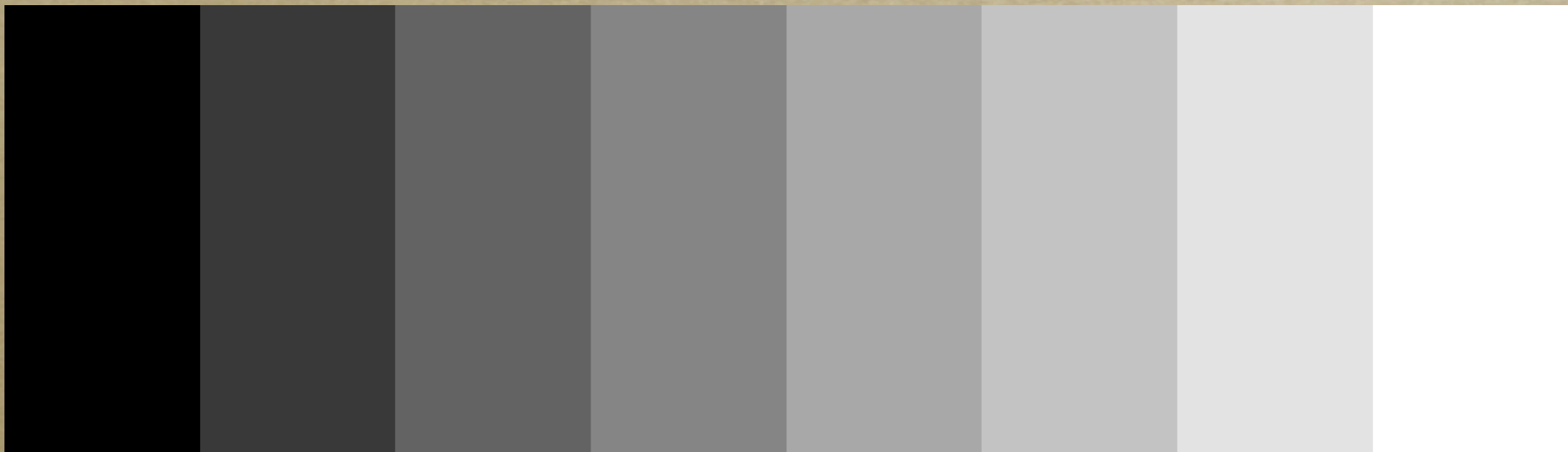
- *(Back to scan-line graphics!)*
- *Define geometry. Now what?*
- *We can draw the edges of the faces.*  
*Wireframe.*
- *We can only draw the edges of faces that are visible.*
- *We can fill in the faces. Giving each object a colour (constant shading).*

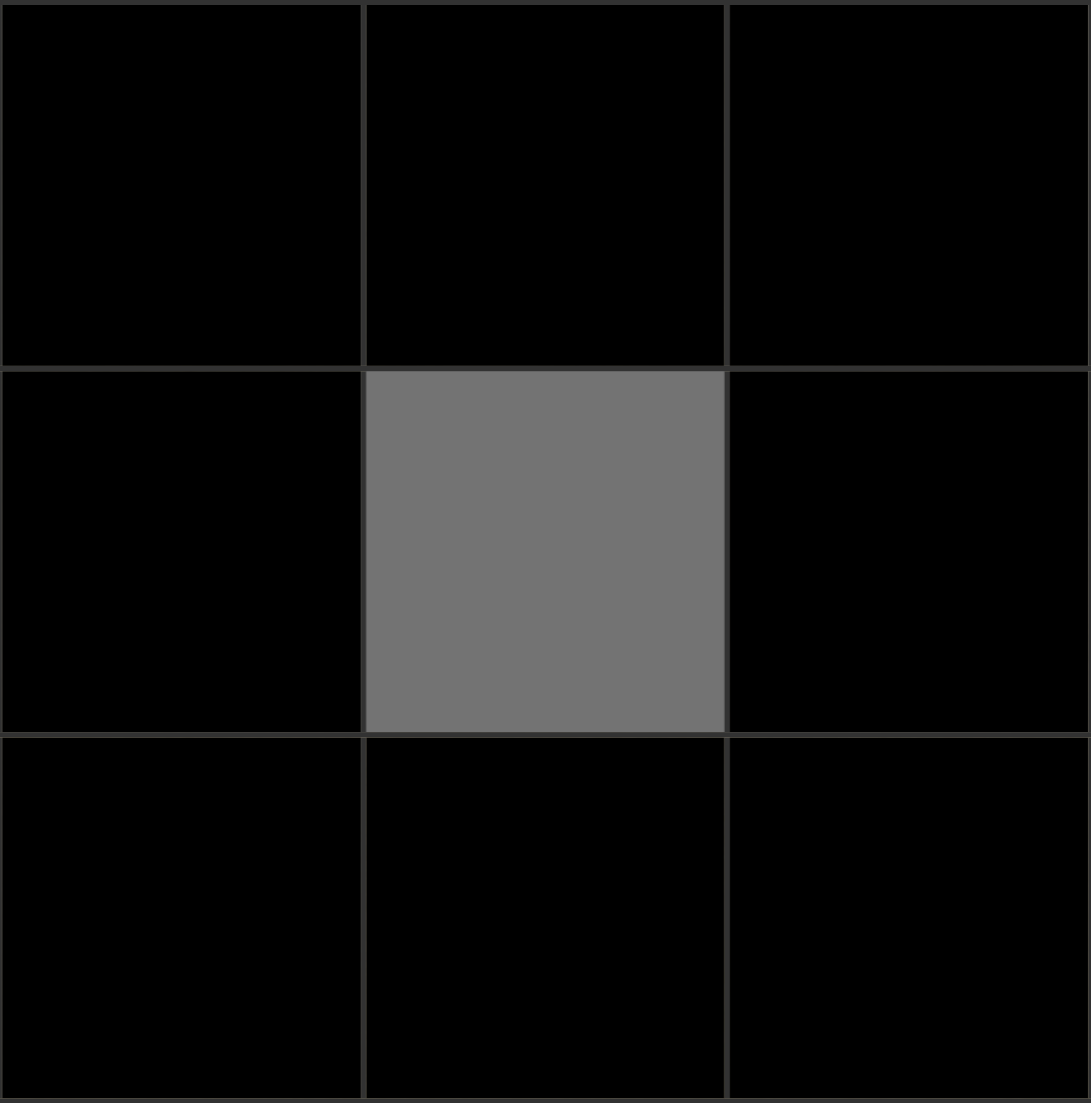
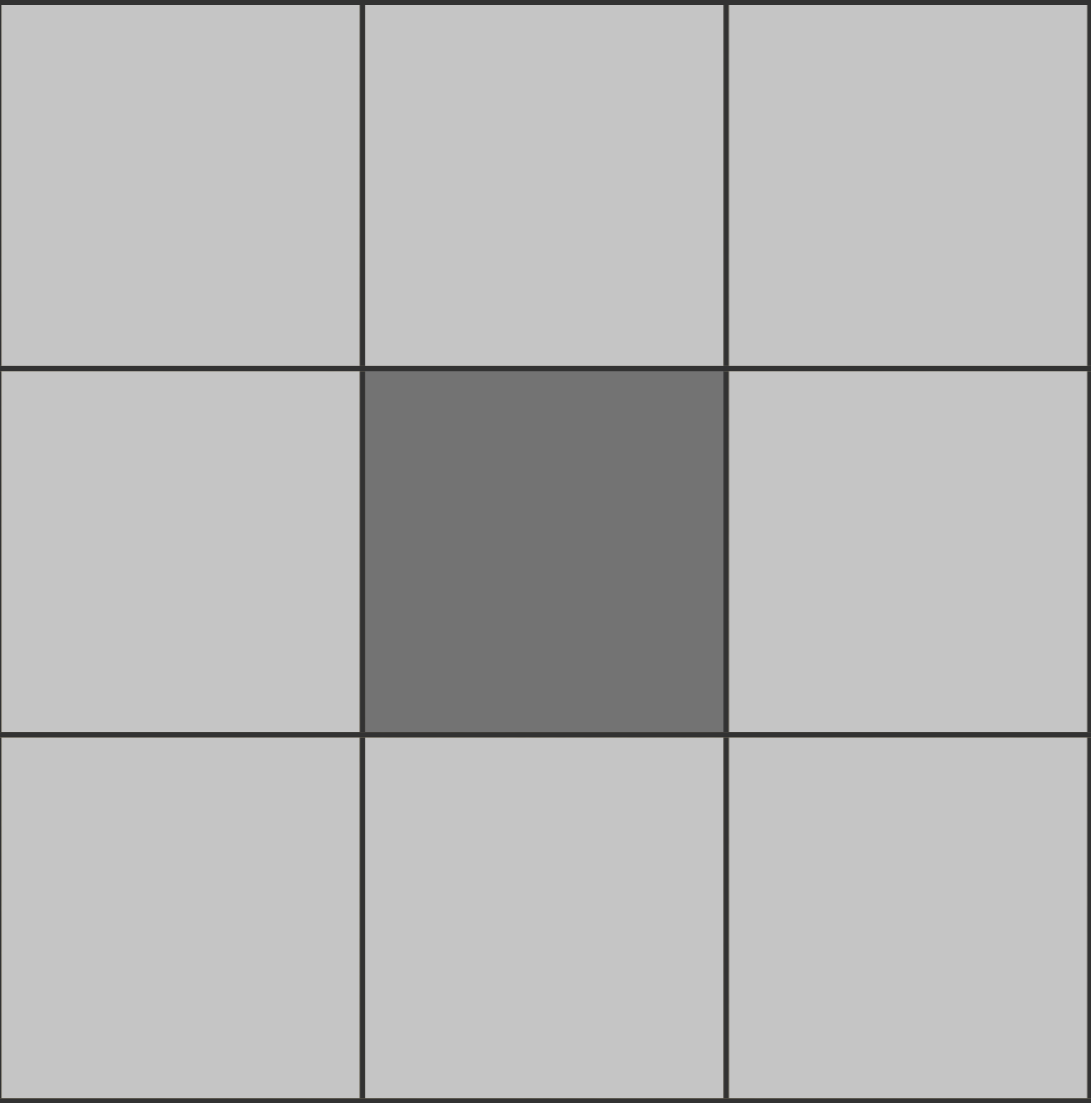
# Flat Shading

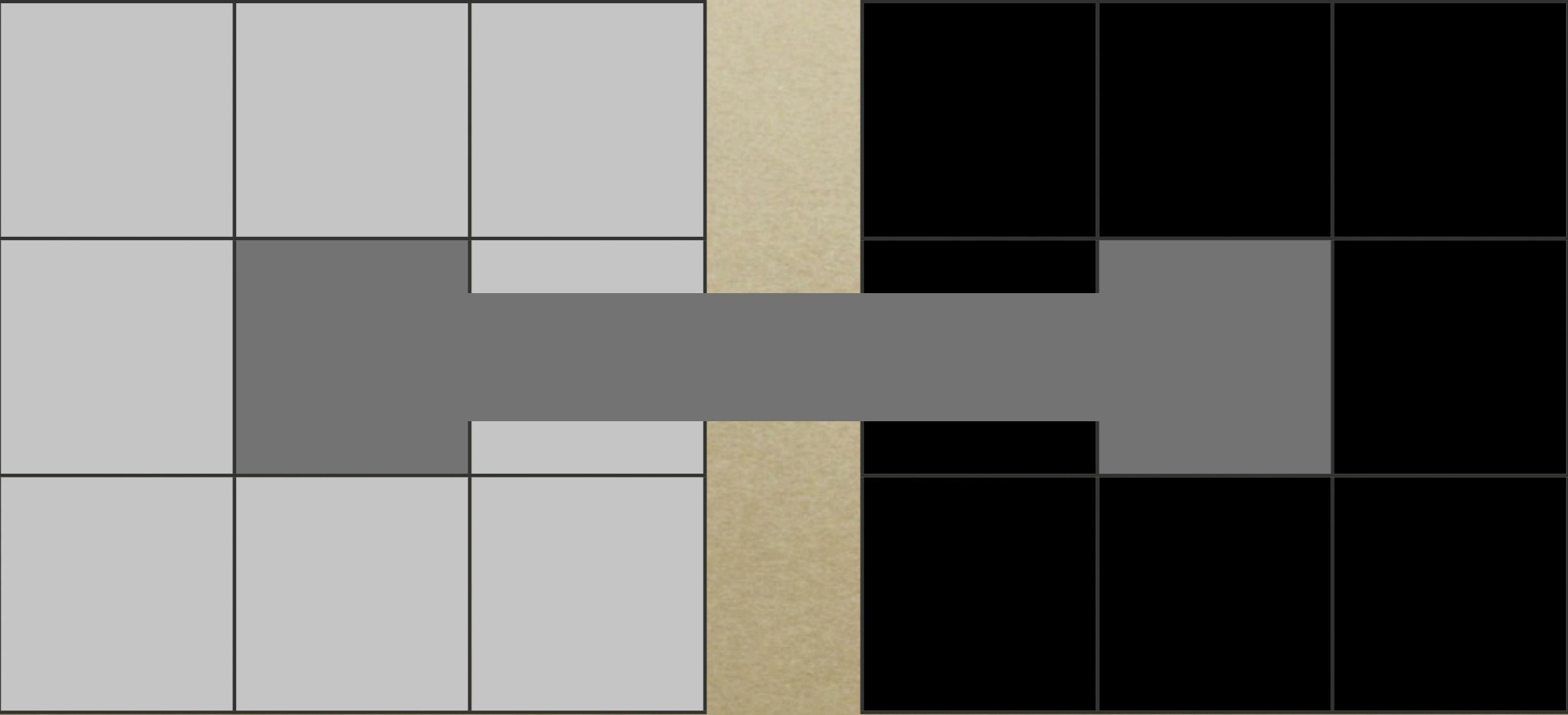
- *Assumes the object is faceted, and light and viewer at infinity.*
- *Illumination model is applied only once per polygon.*
- *What if the object represents a curved surface?*

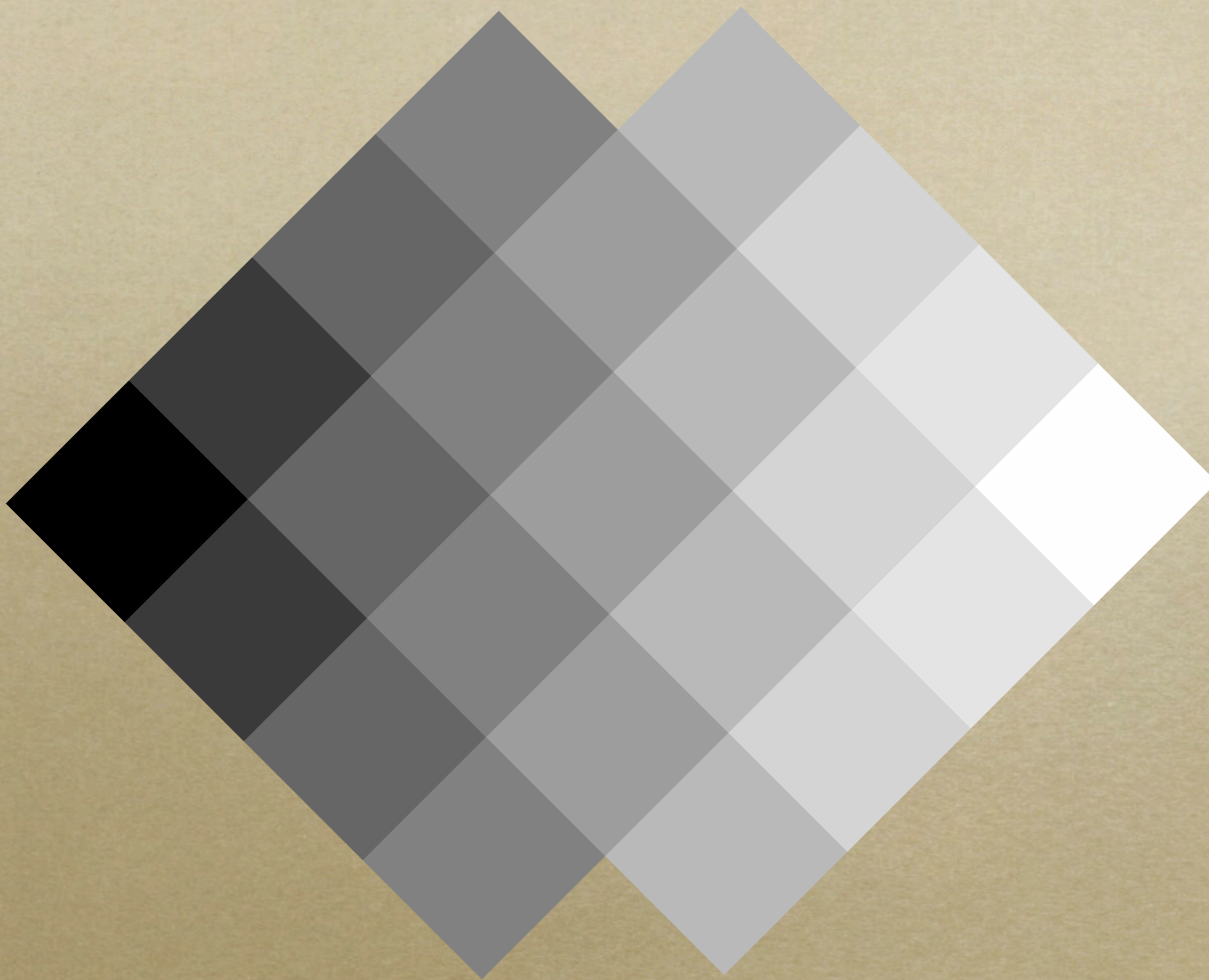
# Mach Bands

*Perceived intensity change at edges are exaggerated by receptors in our eyes, making the dark facet look darker and the light facet look lighter.*





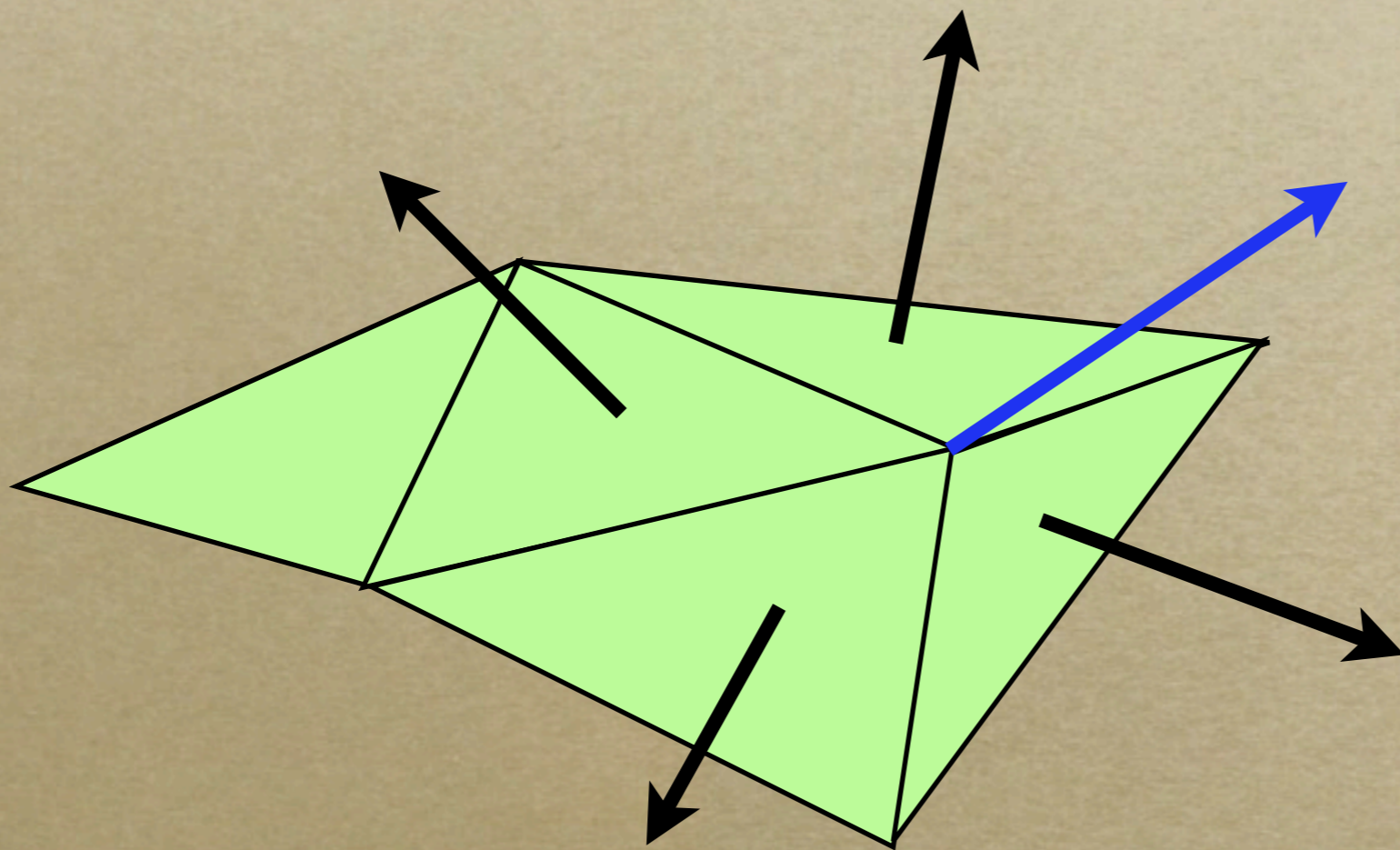




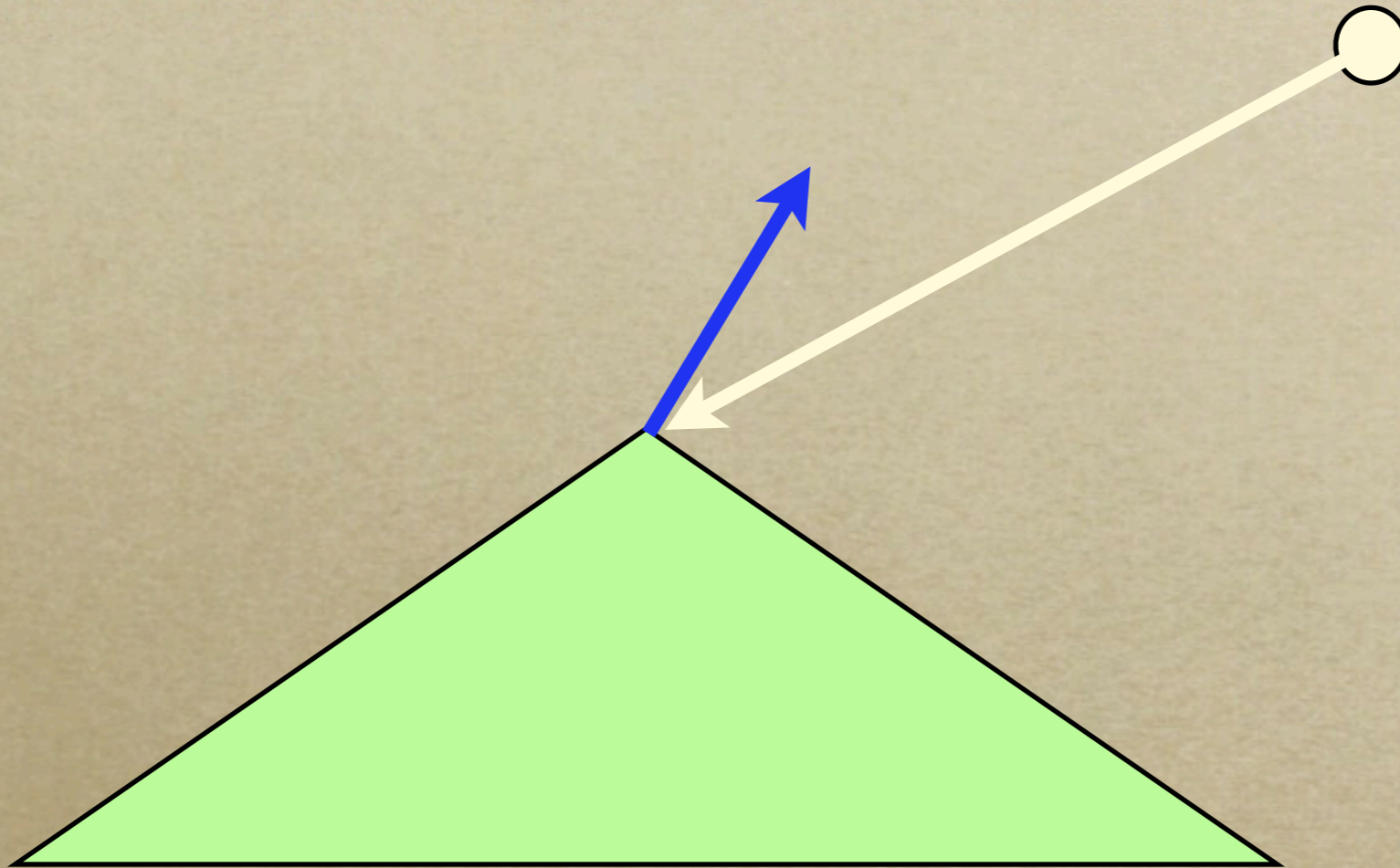
# Gouraud Shading

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

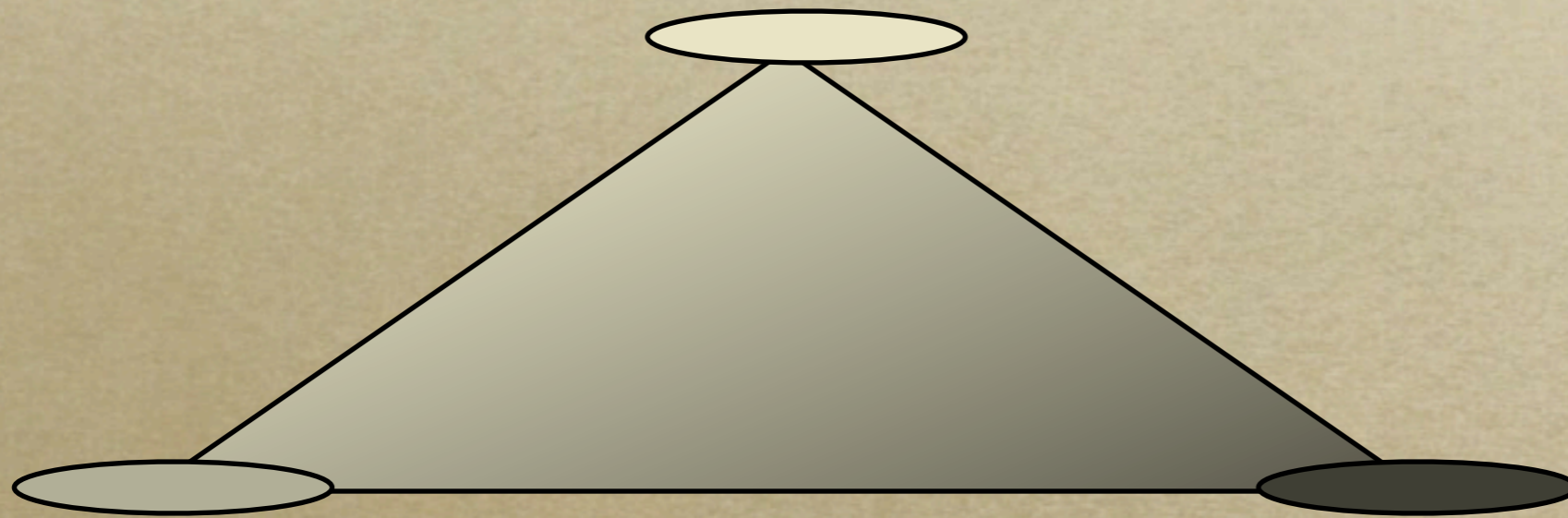
# How it works



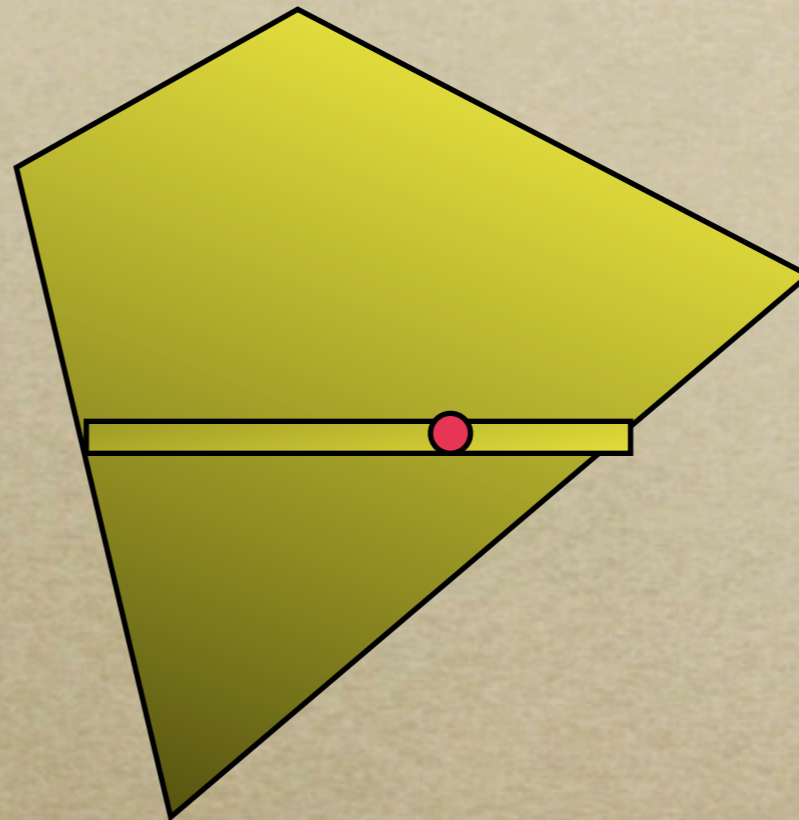
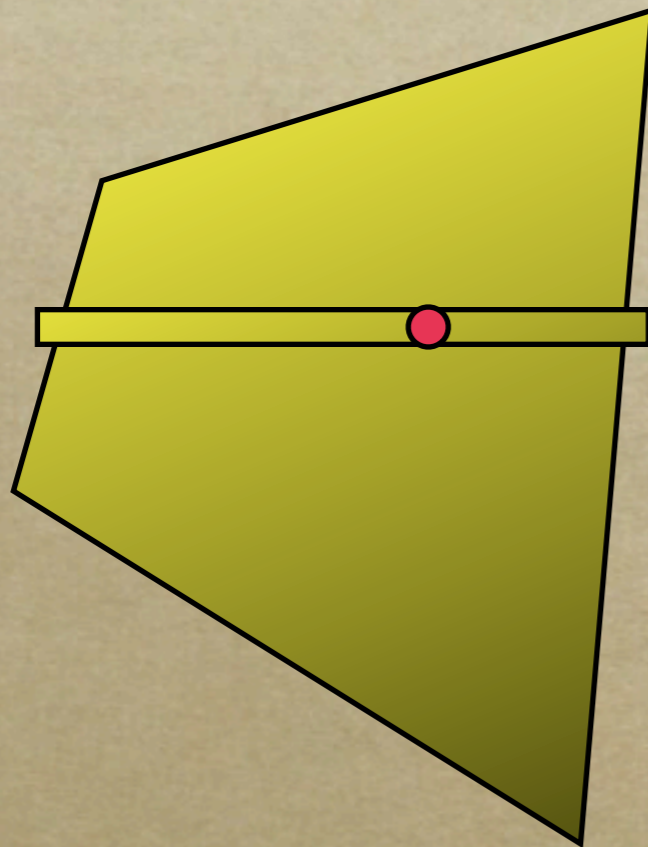
# Work out lighting



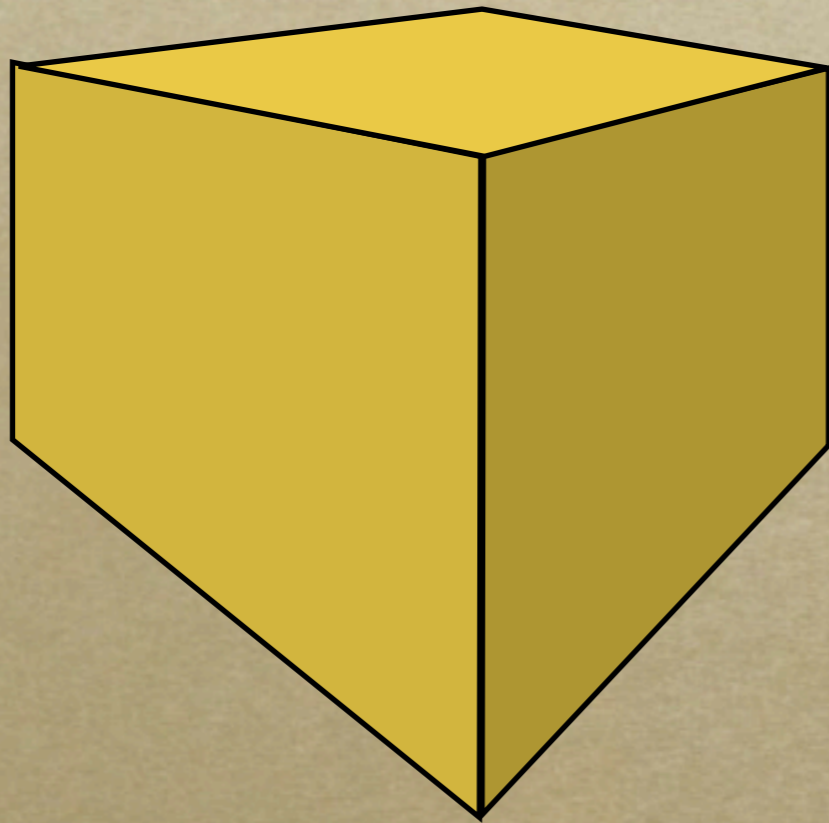
# Average across polygon



# Inconsistencies



# Sometimes want sharp edge



*Do you have more  
than one normal at a  
vertex?*

# Gouraud Shading

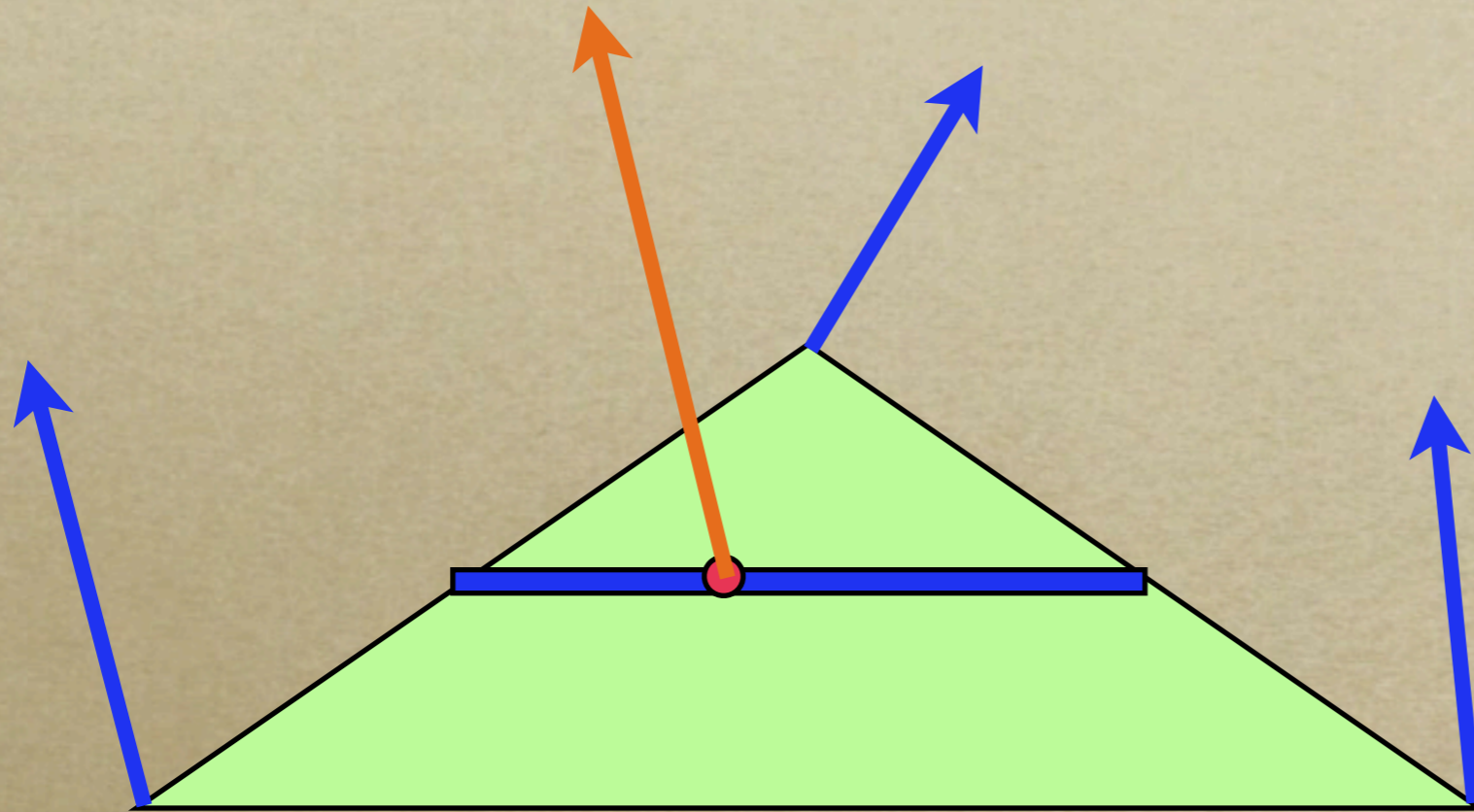


# Phong Shading

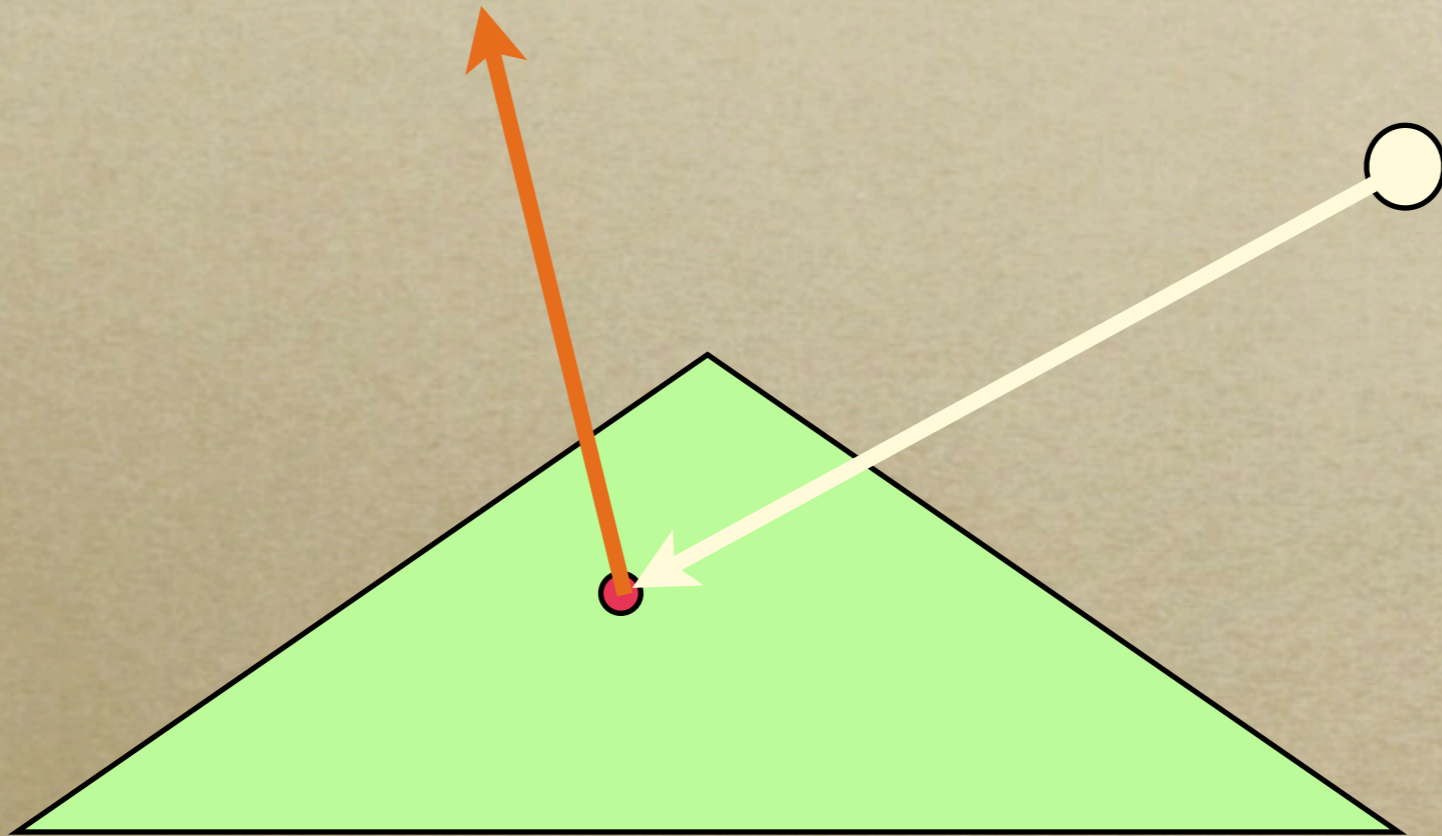
## *Not Phong Illumination*

- *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 normalisation. Much slower than Gouraud.*
- *Gives better results, especially for highlights.*
- *Can handle highlights within a polygon.*

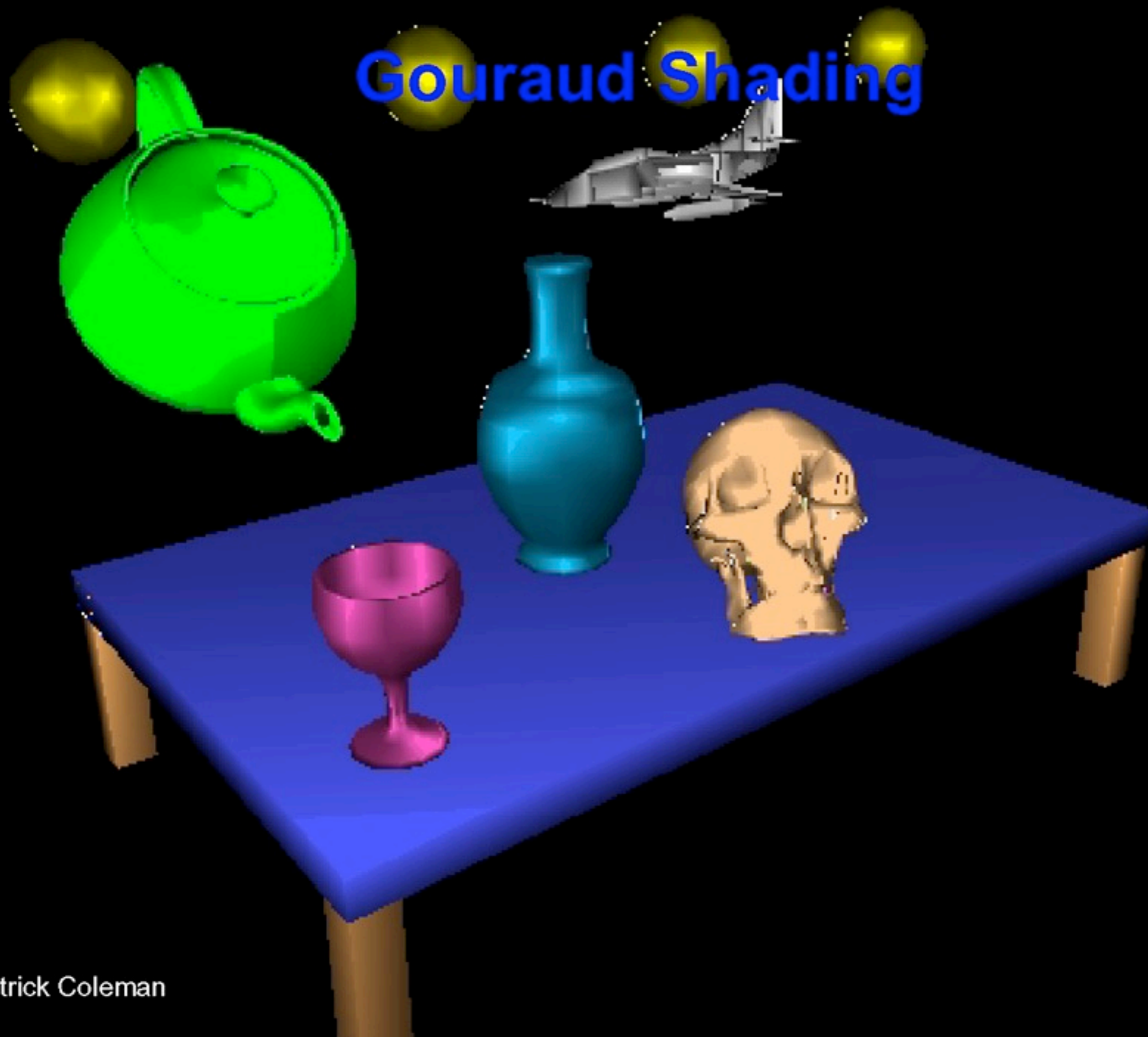
# Interpolate normal



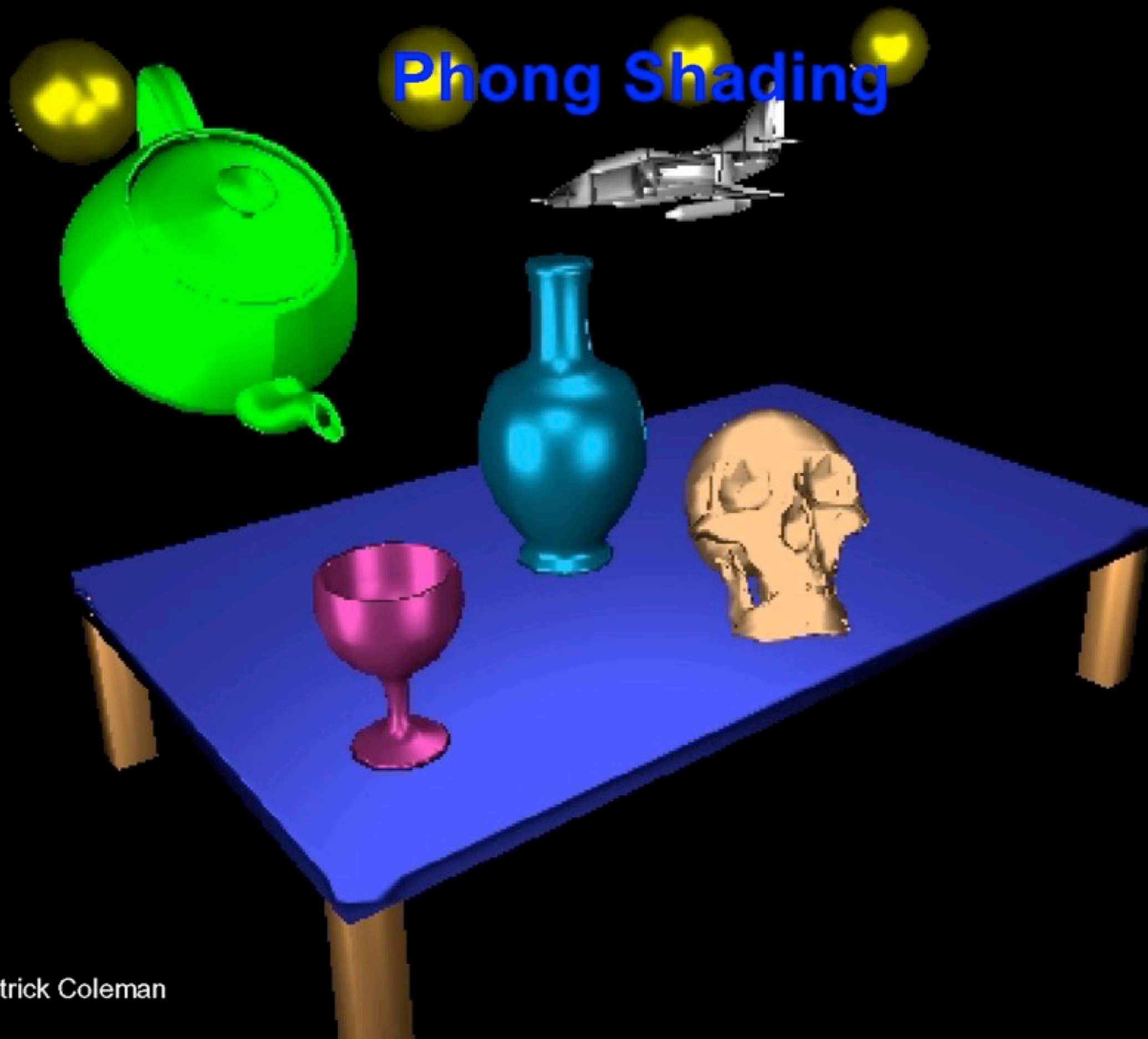
# Do lighting



# Gouraud Shading



# Phong Shading

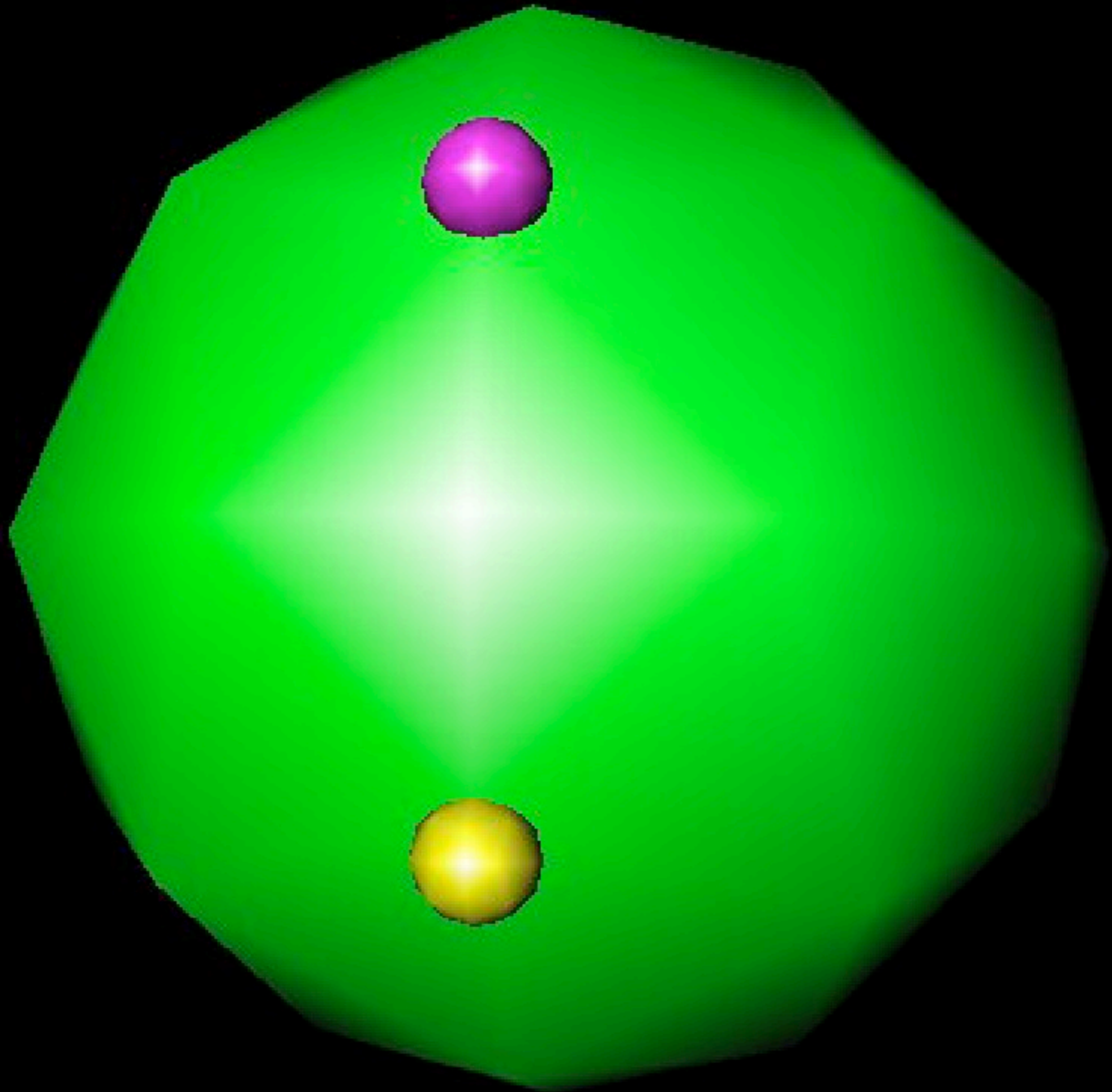


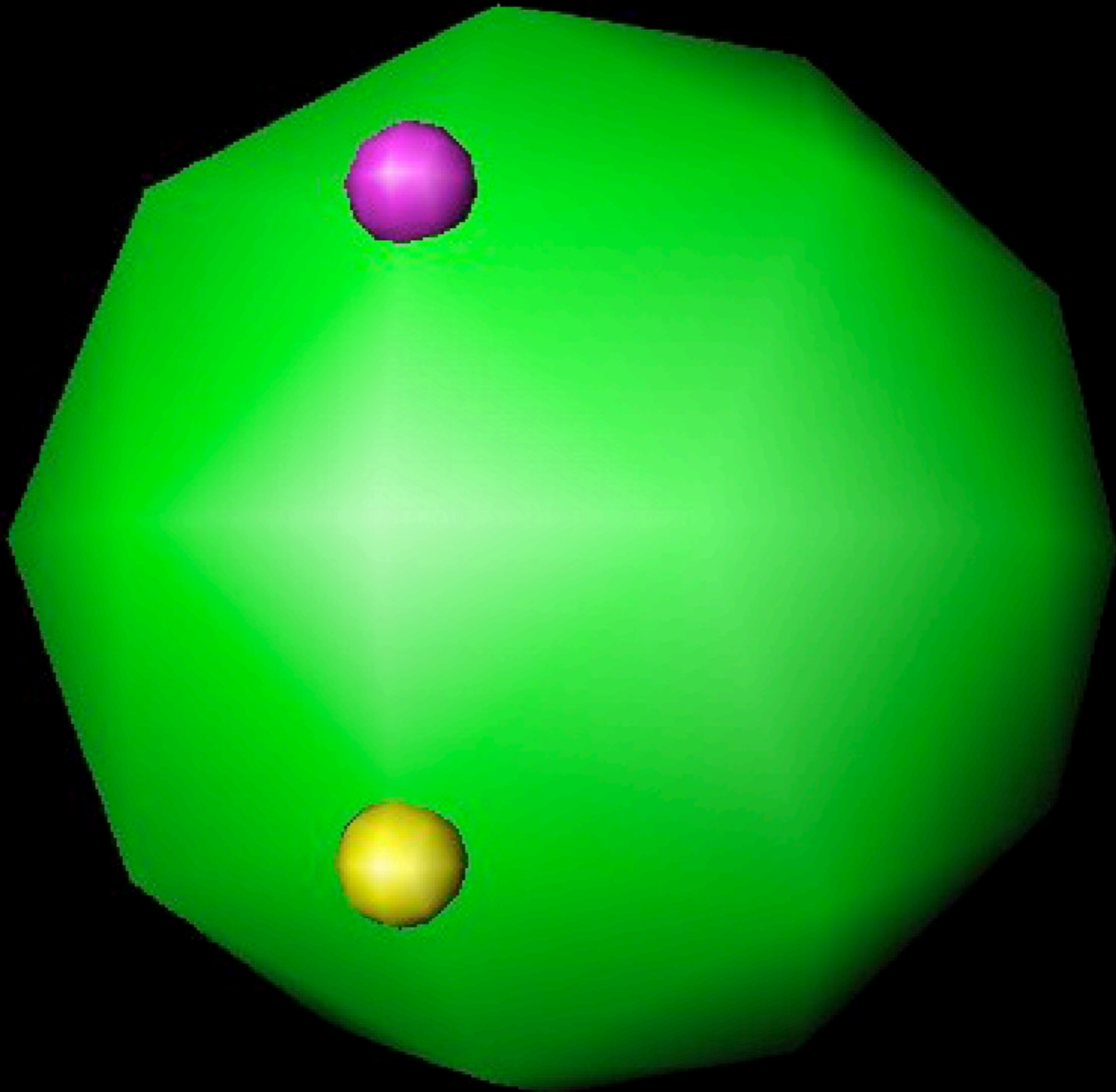
# Interpolation Shading Problems

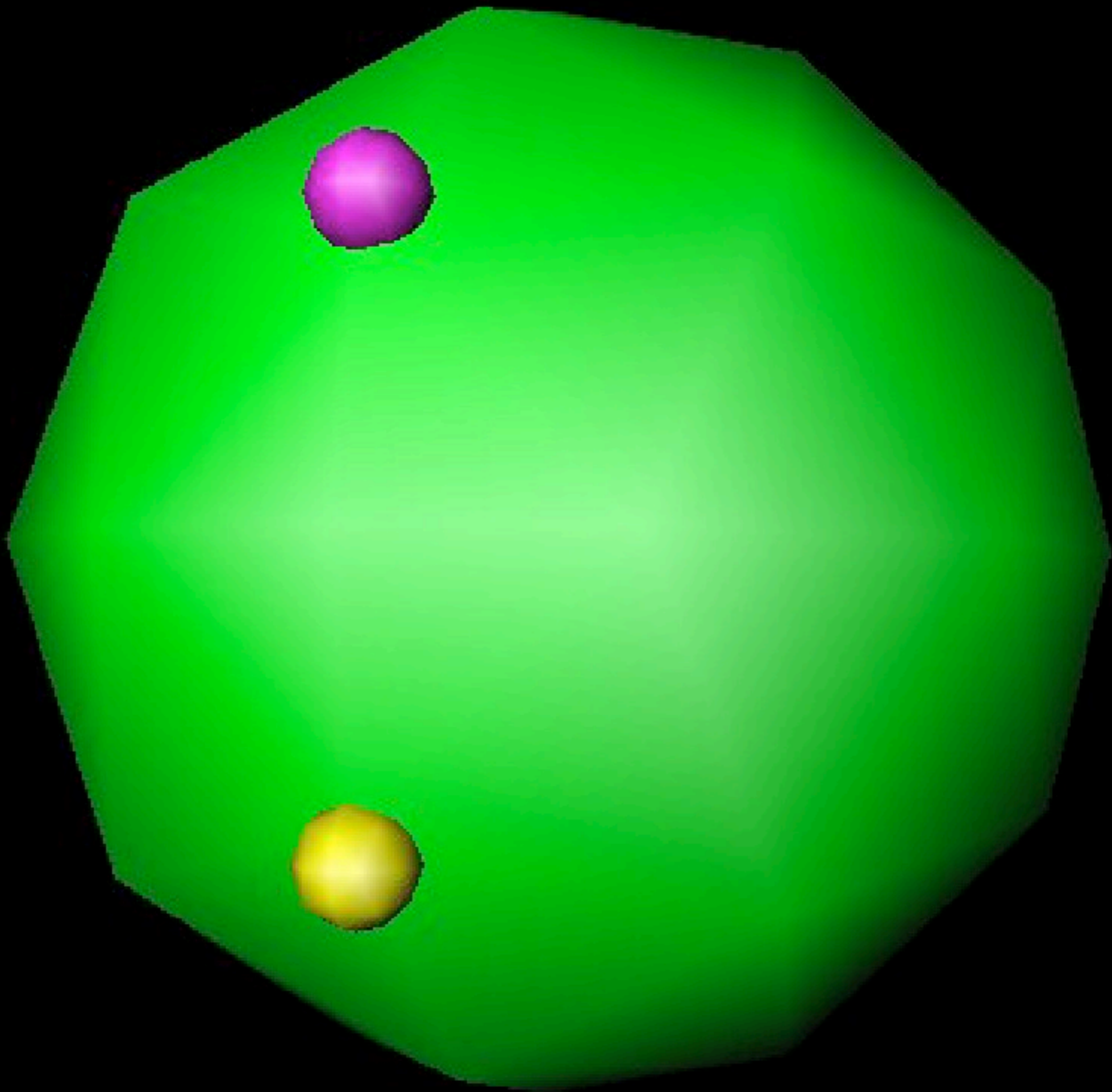
- *Must store normals at each vertex.*
- *Silhouette edges not smoothed.*
- *Interpolation can mask regular changes.*
- *Interpolation in image space ignores perspective distortion.*
- *Crease edges should not have smooth shading.*
- *Orientation dependence.*

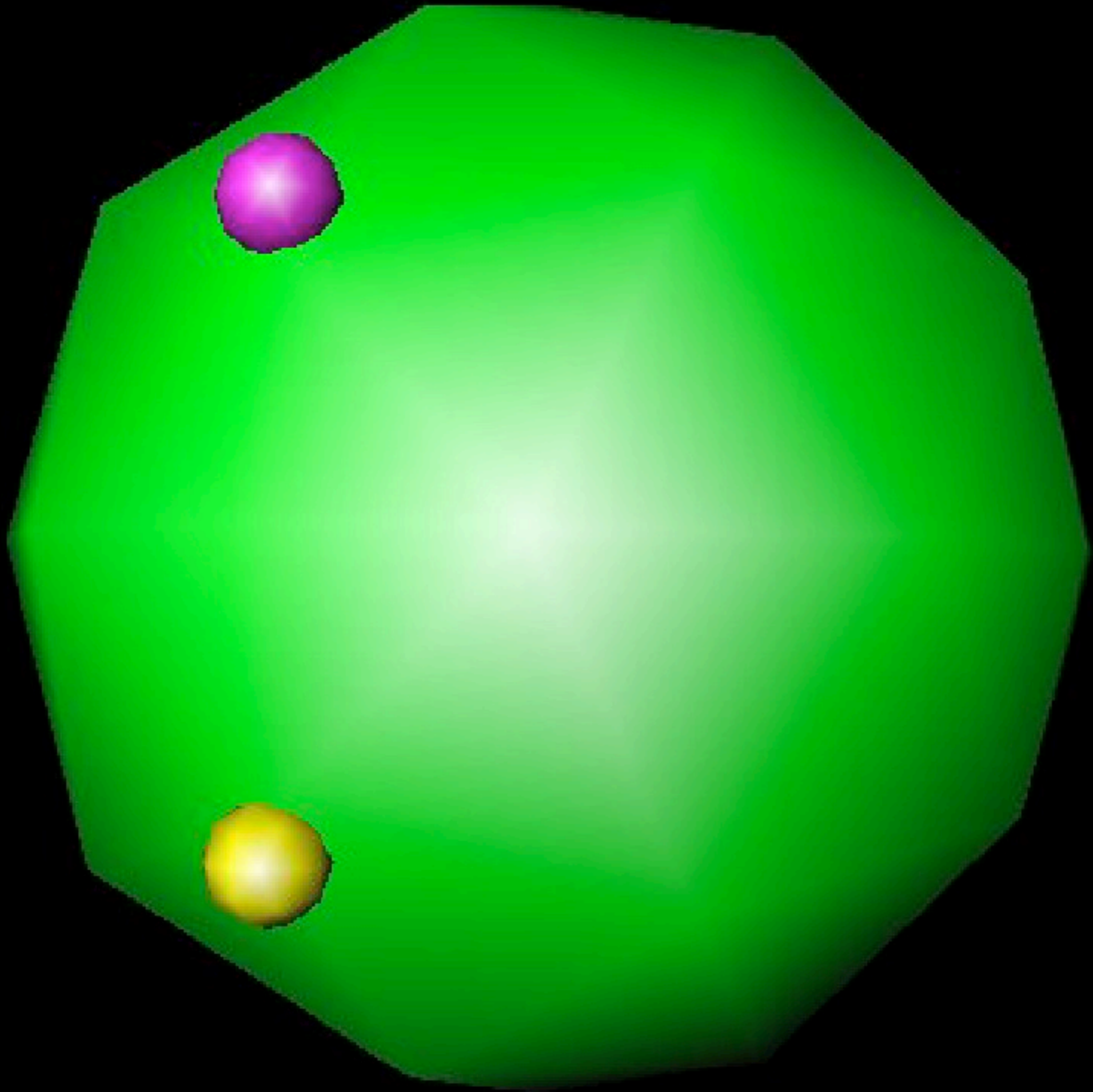
# Fixes for Interpolation Shading

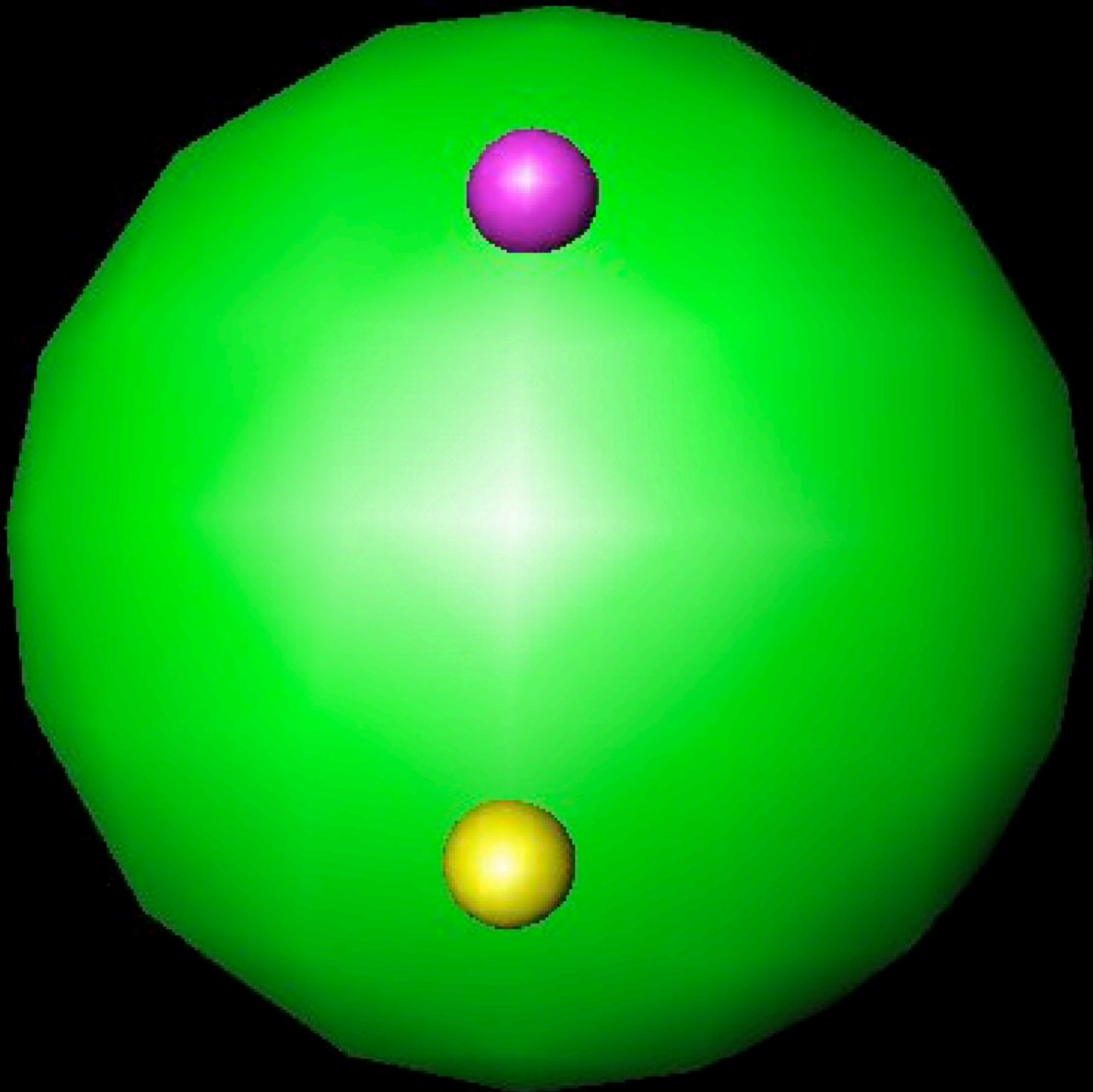
- *Use triangles.*
- *Use more triangles.*
- *Use multiple normals (to get sharp edges)*

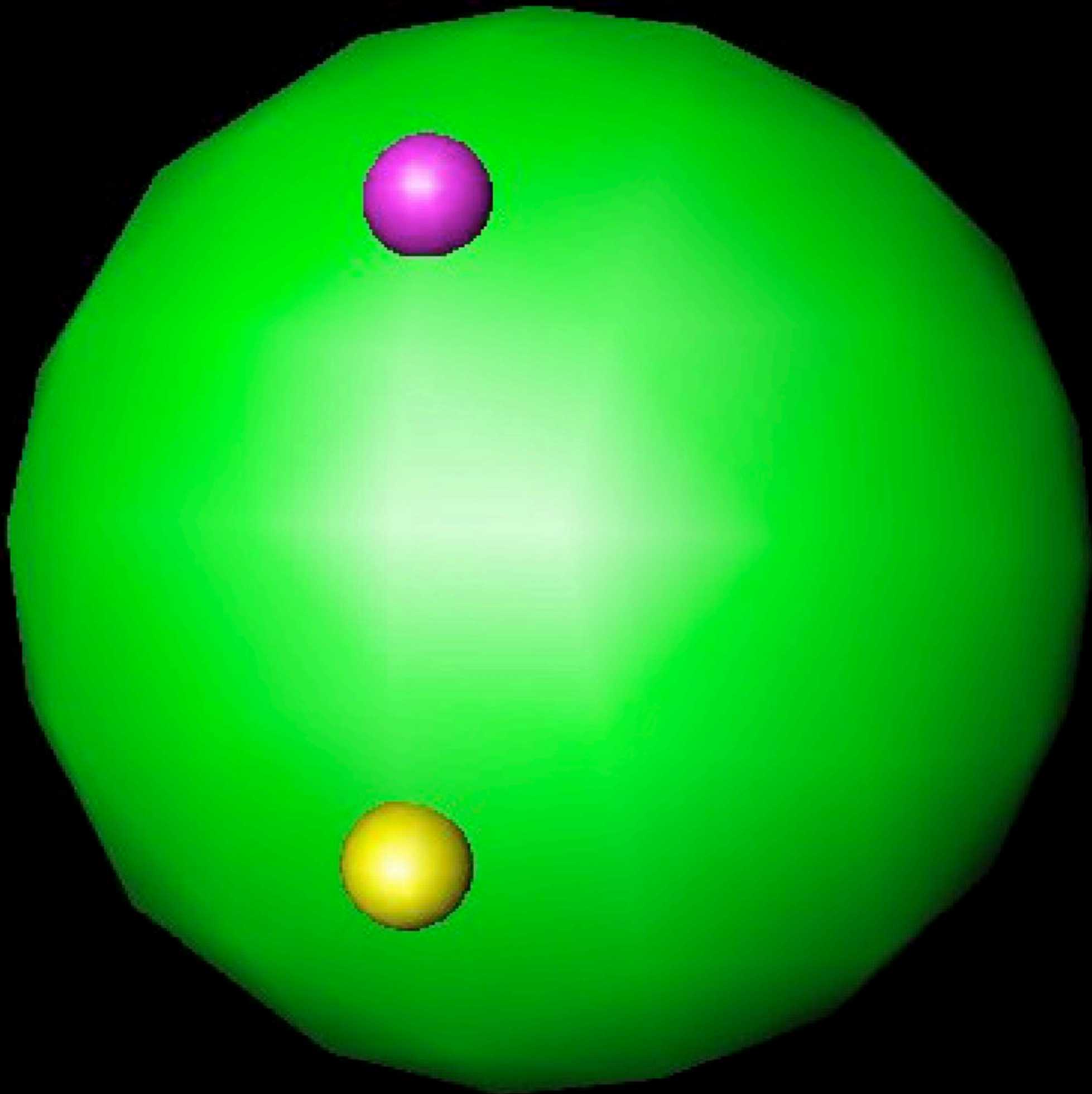


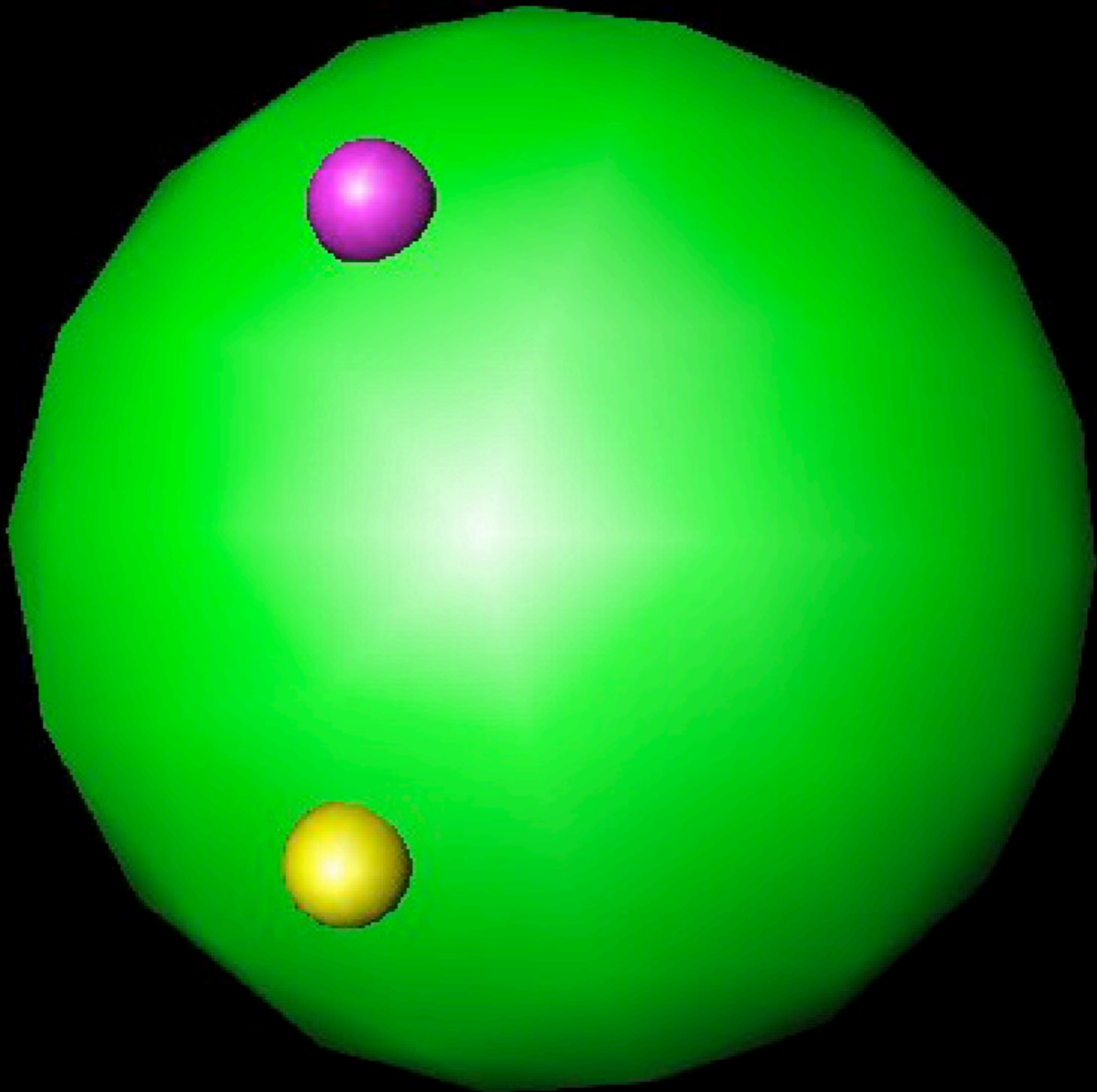


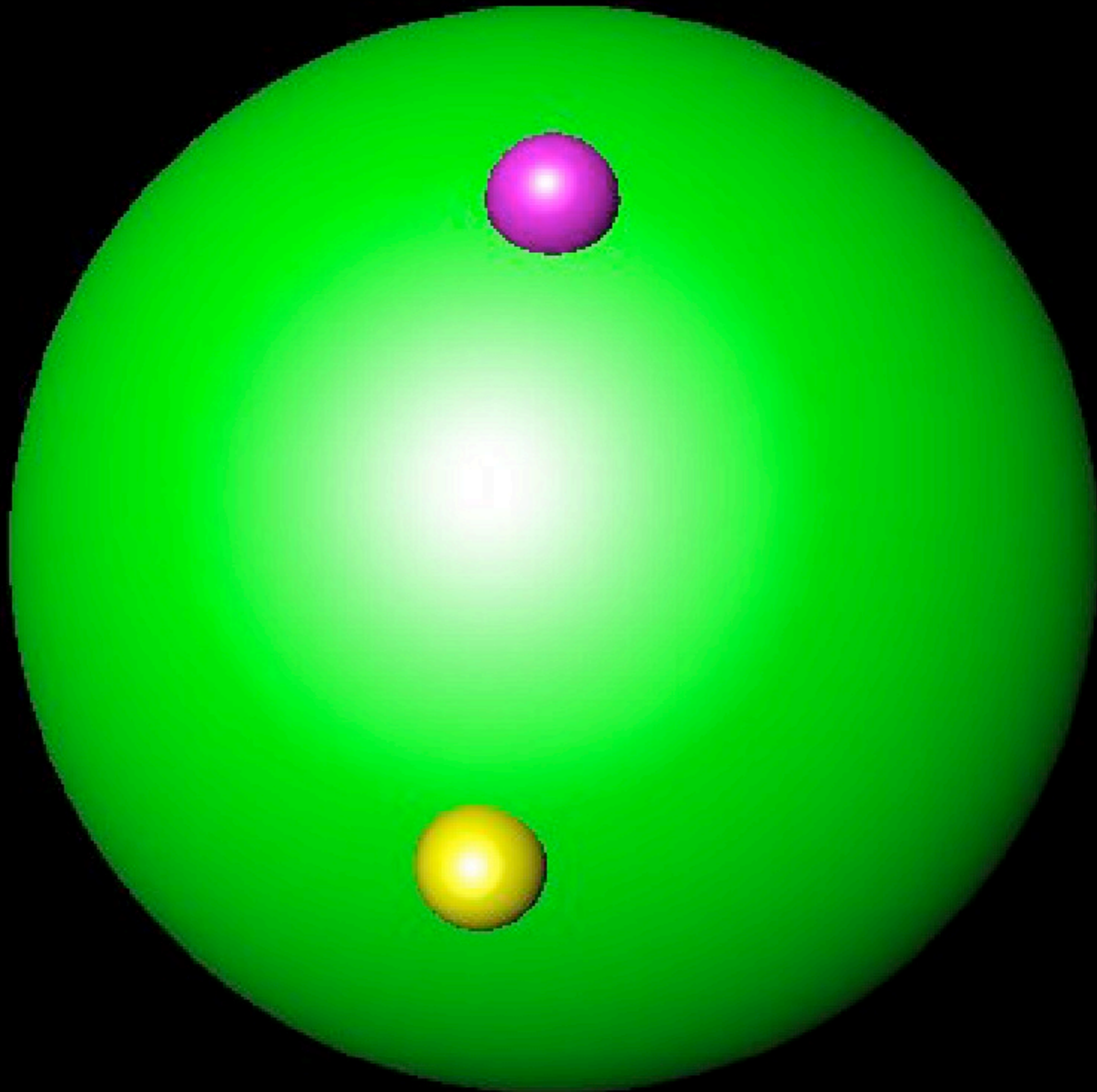


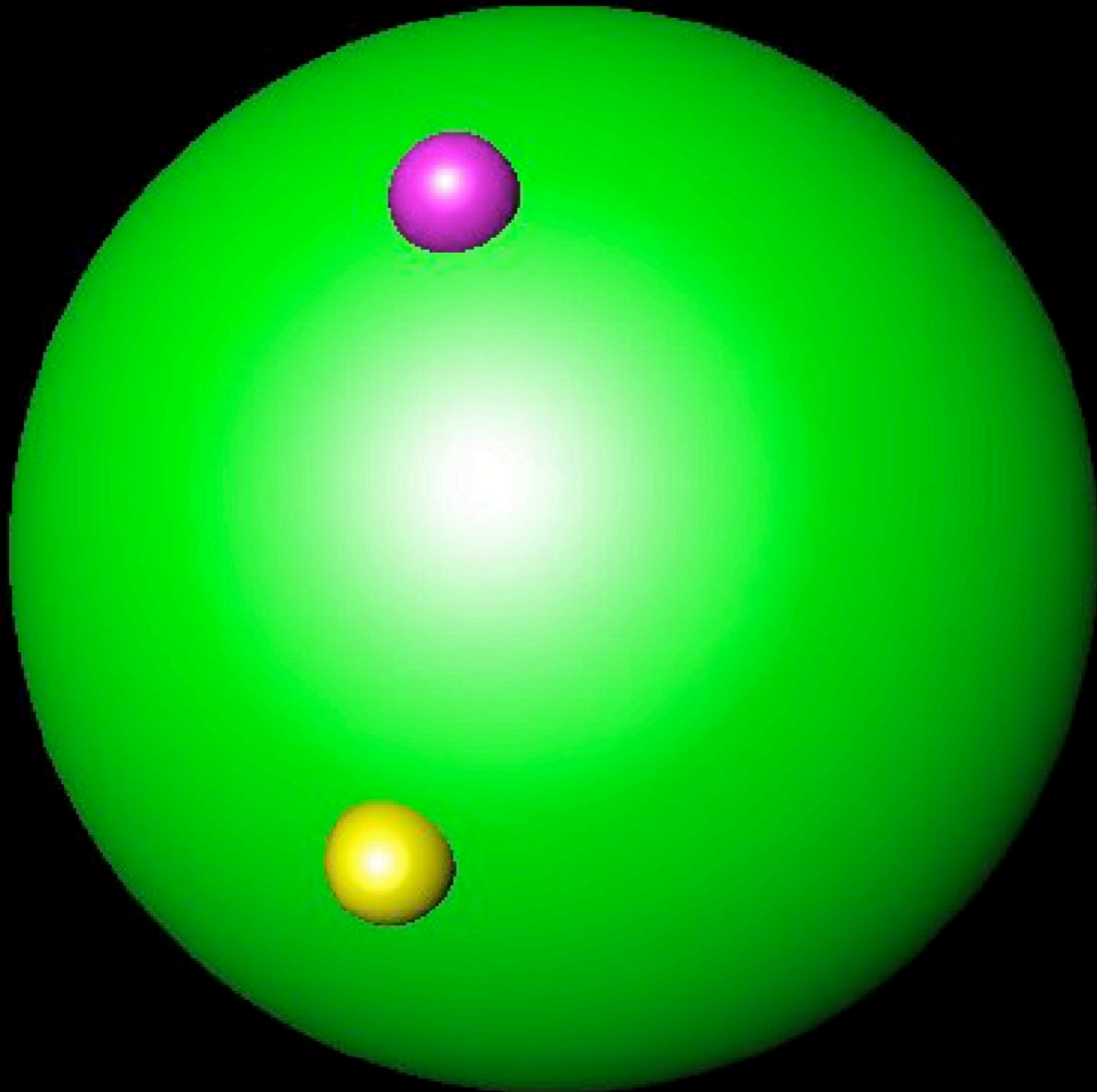


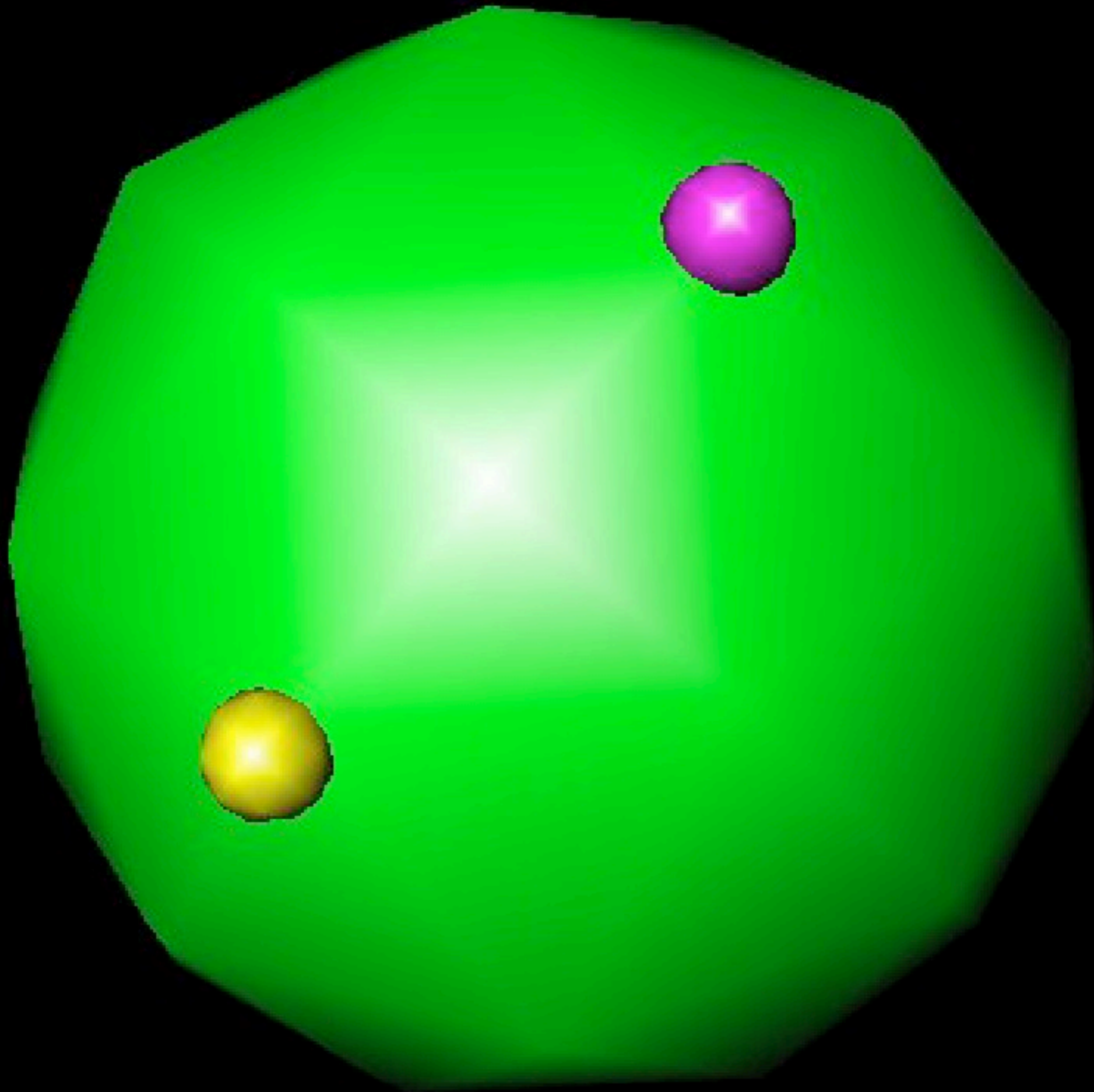


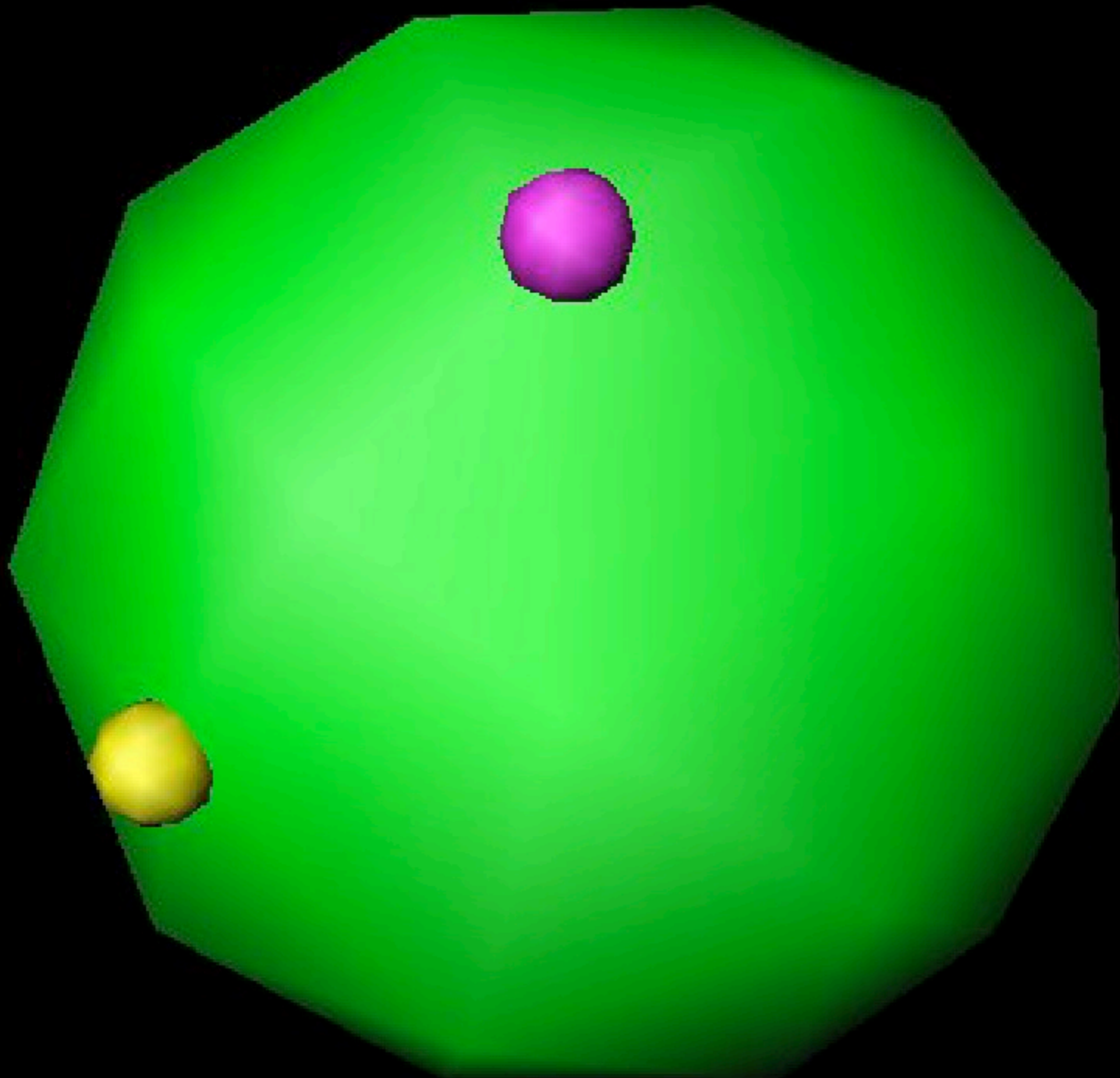


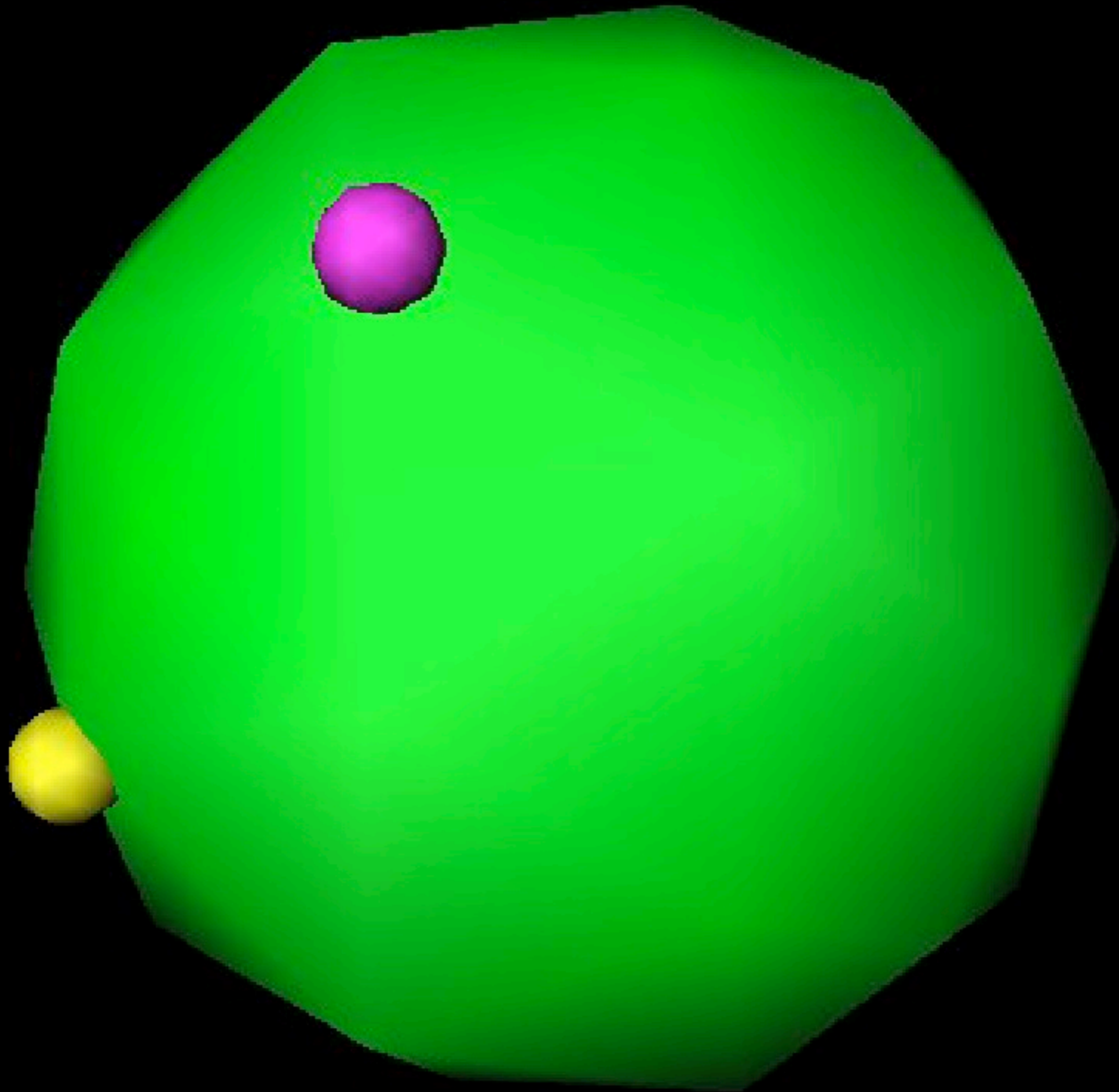


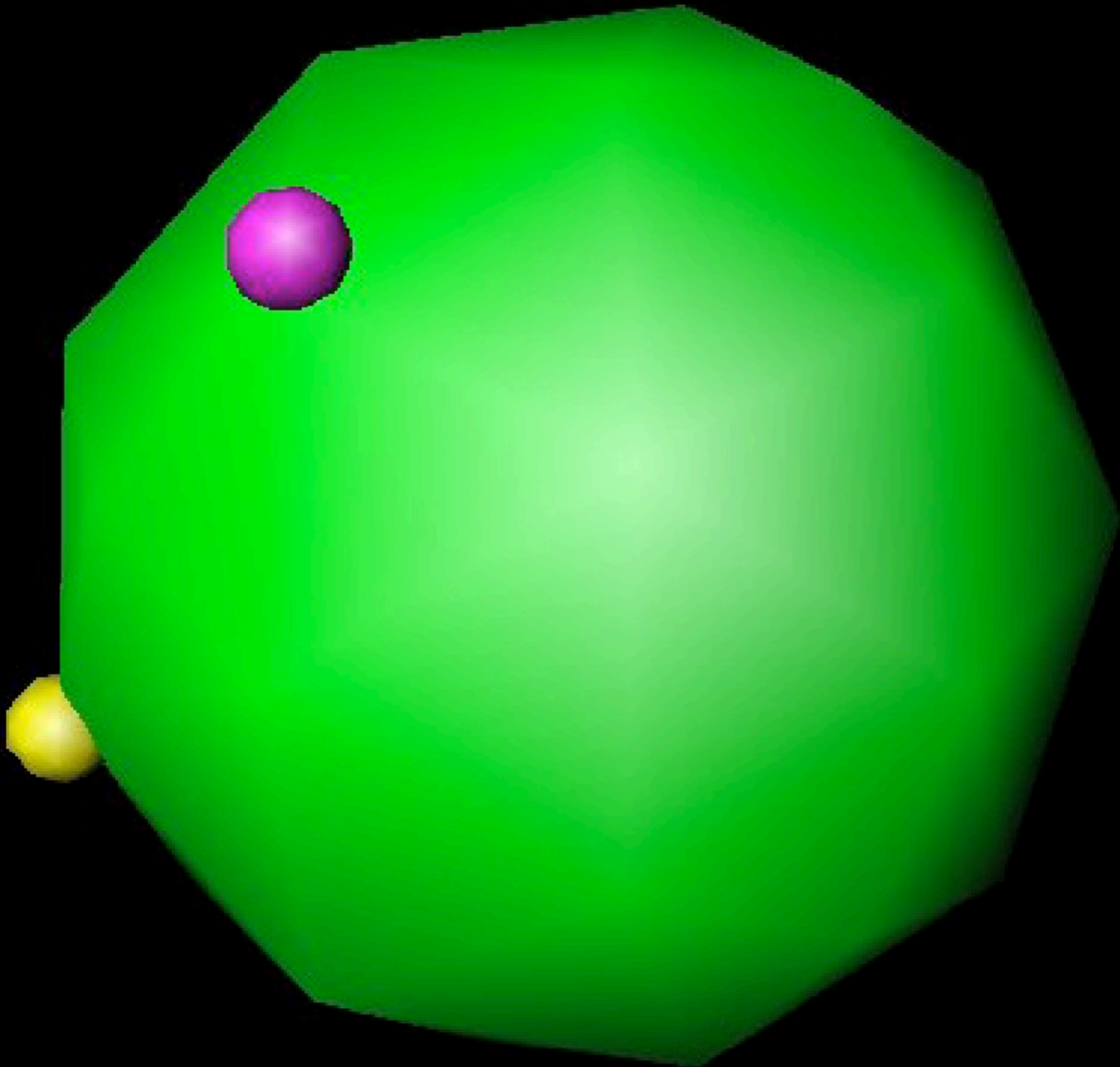


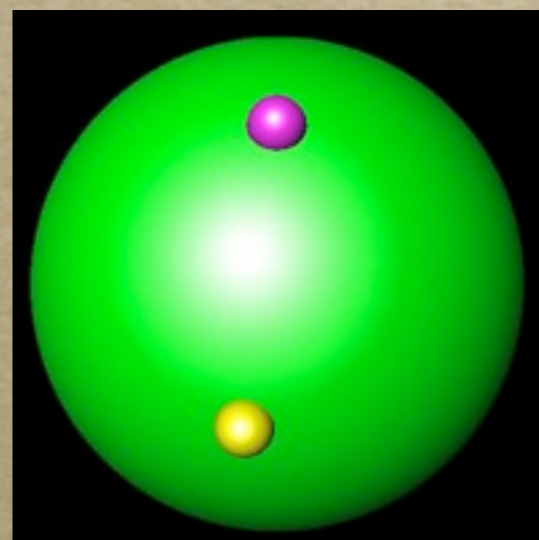
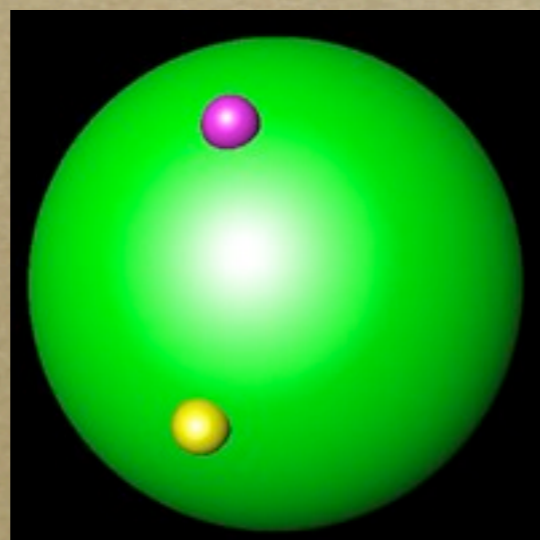
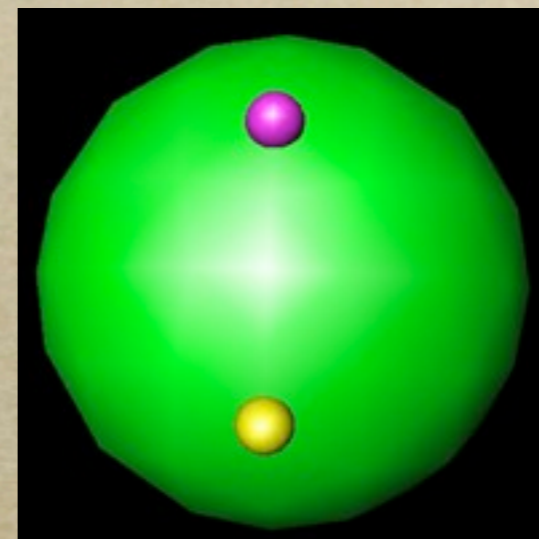
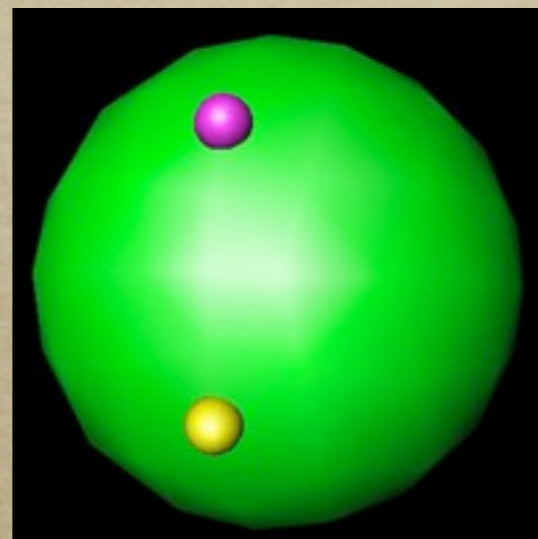
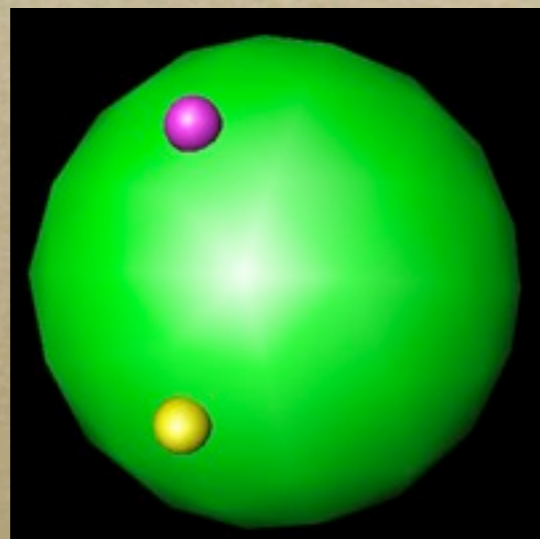
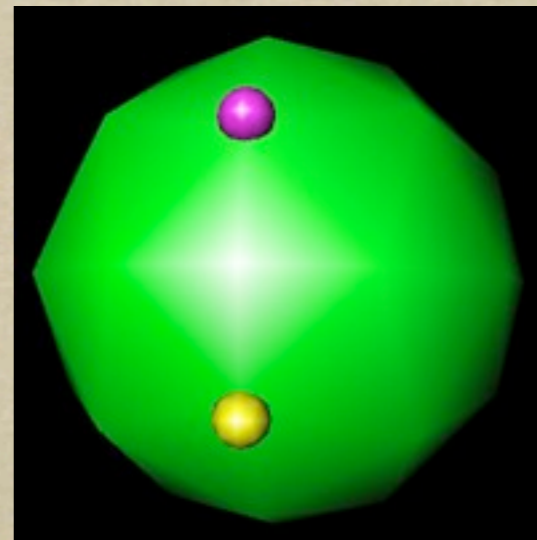
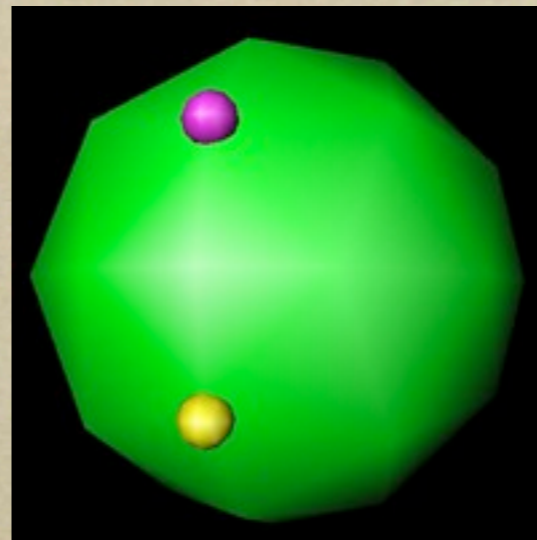
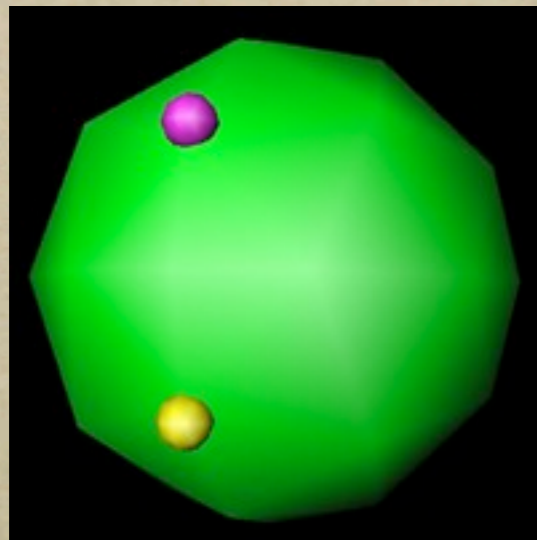


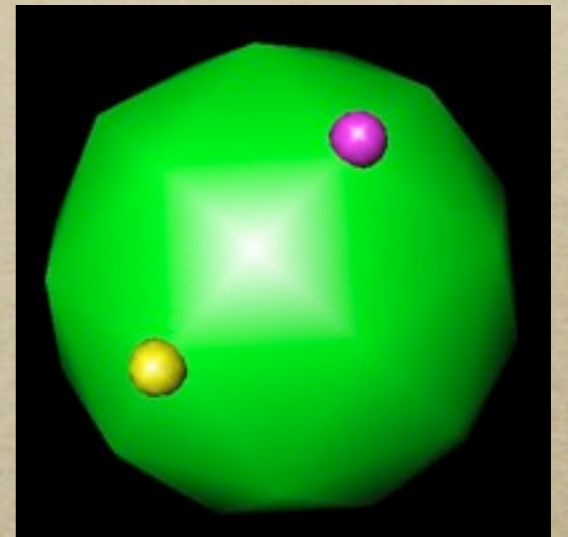
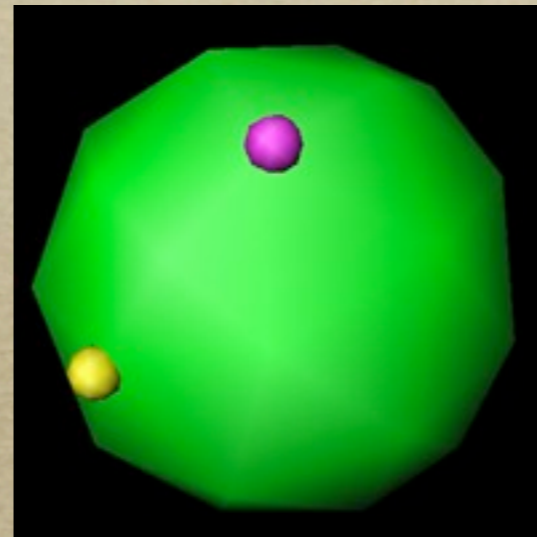
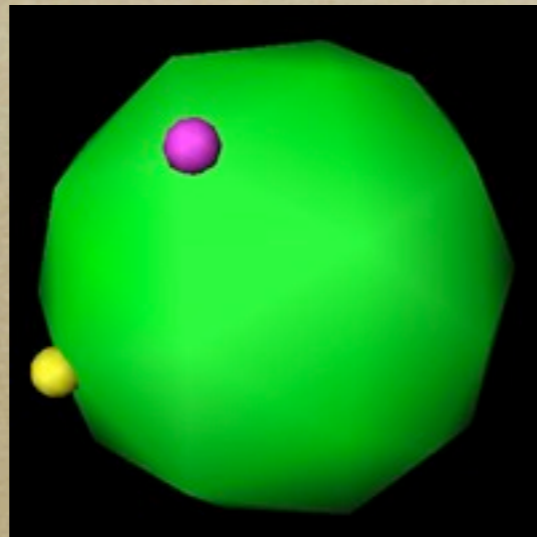
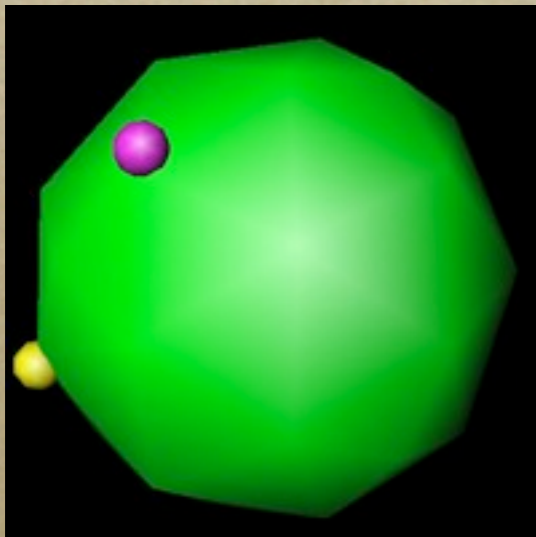












# Shading Comparison



from Watt, 1989



