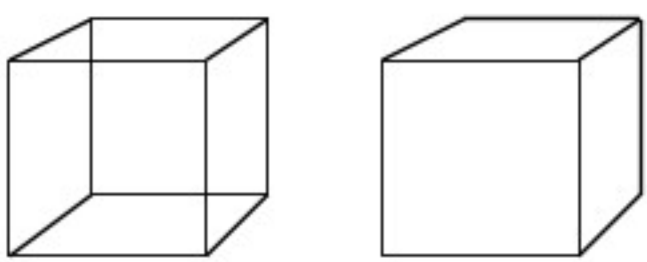
Buffers and Pipelines

Based on slides from Steve Marschner

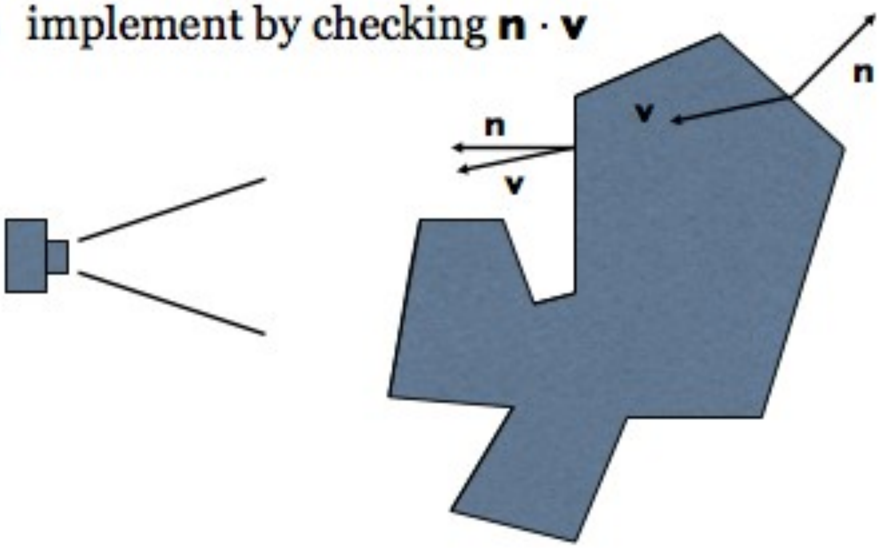
Hidden surface elimination

- We have discussed how to map primitives to image space
  - projection and perspective are depth cues
  - occlusion is the MOST important depth cue



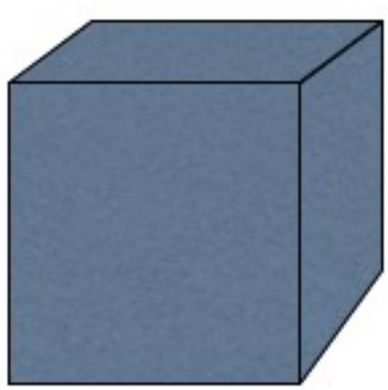
Back face culling

- For closed shapes you will never see the inside
  - therefore only draw surfaces that face the camera
  - implement by checking **n** · **v**



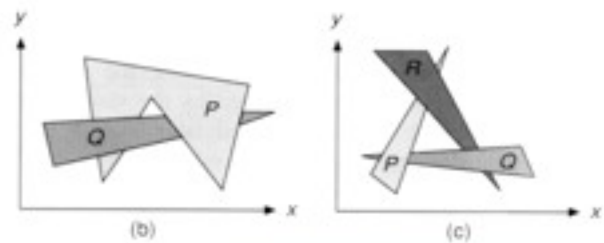
Painter's algorithm

- Simplest way to do hidden surfaces
- Draw from back to front, use overwriting in framebuffer



Painter's algorithm

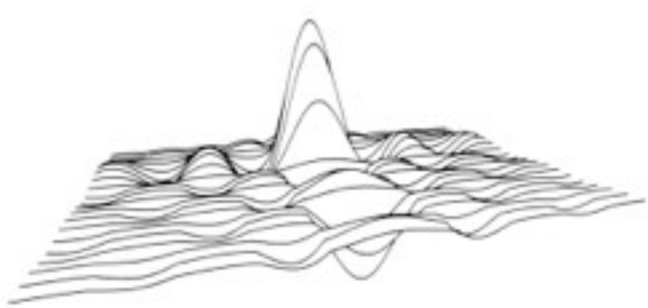
- Amounts to a topological sort of the graph of occlusions
  - that is, an edge from *A* to *B* means *A* is occluded by *B*
  - any sort is valid
    - ABCDEF
    - BADCFE
  - if there are cycles there is no sort



[Foley et

Painter's algorithm

- Useful when a valid order is easy to come by
- Compatible with alpha-blended transparency

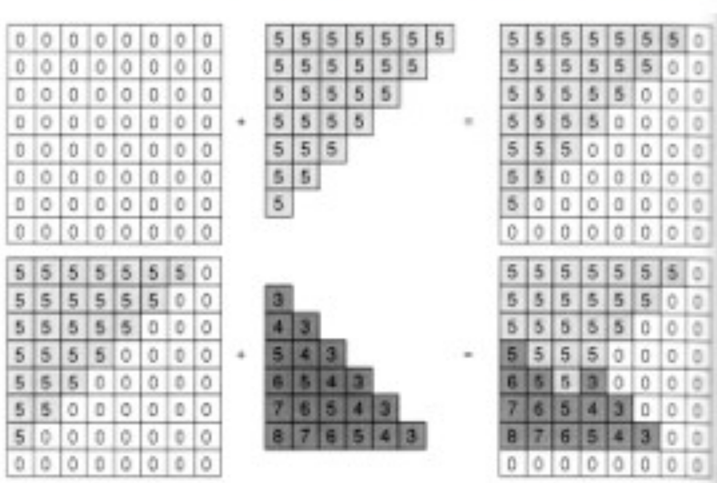


[Foley et al.]

The z buffer

- In many (most) applications maintaining a z sort is too expensive
  - changes all the time as the view changes
  - many data structures exist, but complex
- Solution: draw in any order, keep track of closest
  - allocate extra channel per pixel to keep track of closest depth so far
  - when drawing, compare object's depth to current closest depth and discard if greater
  - this works just like any other compositing operation

The z buffer



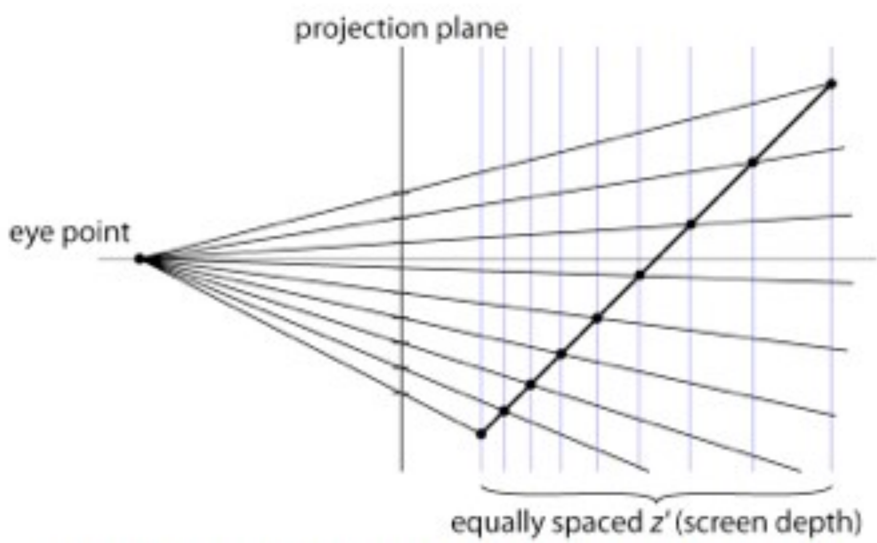
[Foley et al.]

- another example of a memory-intensive brute force approach that works and has become the standard

Precision in z buffer

- The precision is distributed between the near and far clipping planes
  - this is why these planes have to exist
  - also why you can't always just set them to very small and very large distances
- Generally use **z'** (not world **z**) in **z** buffer

Interpolating in projection

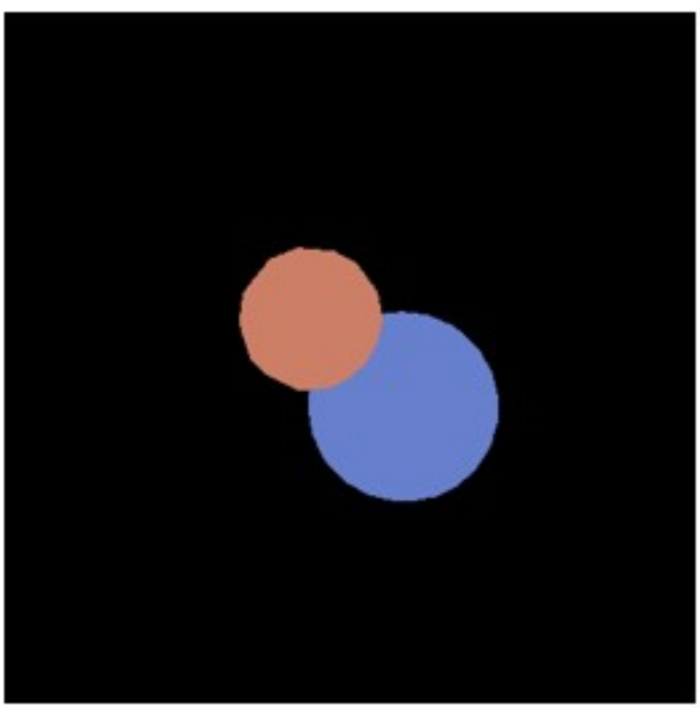


linear interp. in screen space ≠ linear interp. in world (eye) space

Pipeline for minimal operation

- Vertex stage (position and color)
  - transform position (object -> screen space)
- Rasterize stage
  - fill in shape color
- Fragment stage
  - write color to framebuffer

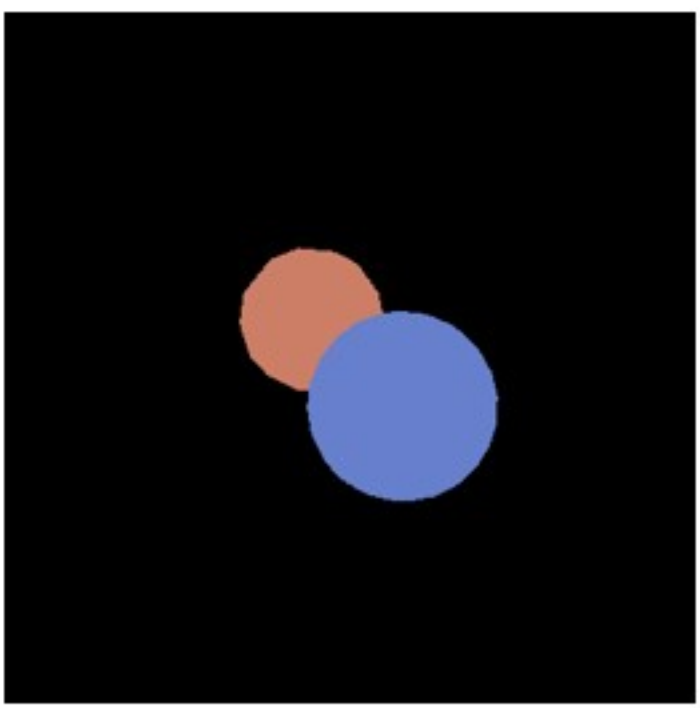
Result of minimal pipeline



Pipeline for basic z buffer

- Vertex stage (position and color)
  - transform position (object -> screen space)
- Rasterize stage
  - interpolate **z'** (screen **z**)
  - fill in shape color
- Fragment stage
  - write color to framebuffer if interpolated **z'** < current **z'**

Result of z-buffer pipeline



Flat shading

- Shade using the triangle normal
- Leads to constant shading and faceted appearance

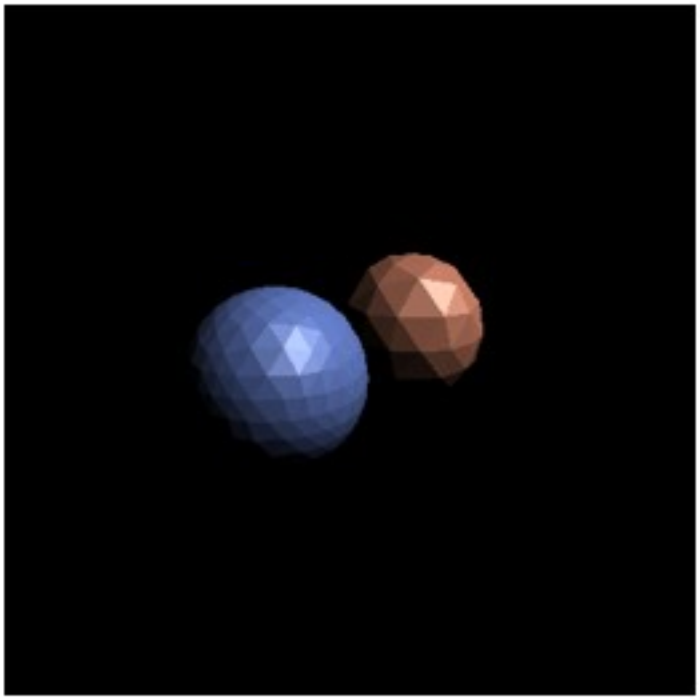
Plate II.29 *Shutterbug.* Individually shaded polygons with diffuse reflection (Sections 14.4.2 and 16.2.3). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Pipeline for flat shading

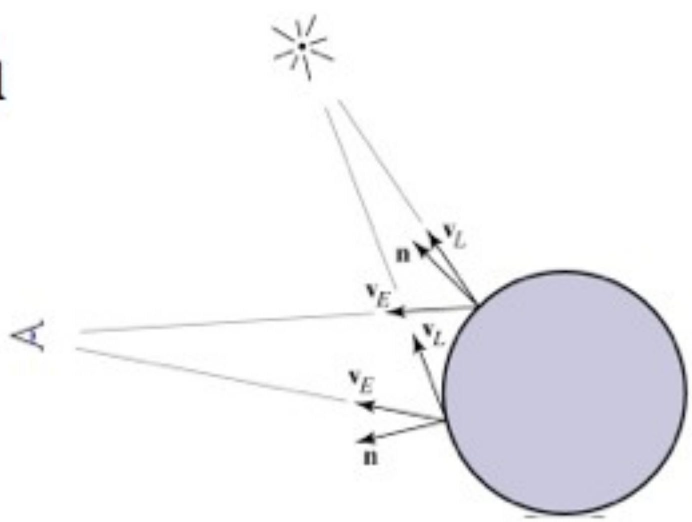
- Vertex stage (position and color)
  - transform position (object -> screen space)
  - compute shaded color per triangle using normal
- Rasterize stage
  - interpolate **z'** (screen **z**)
  - fill in shape color
- Fragment stage
  - write color to framebuffer if interpolated **z'** < current **z'**

Result of flat-shading pipeline



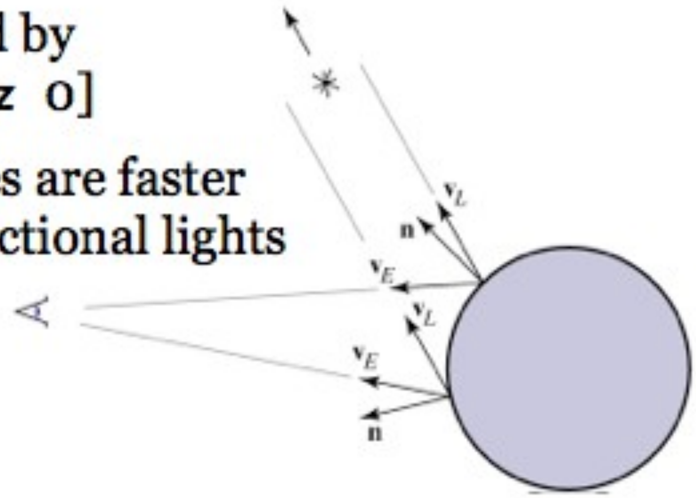
Lighting

- Phong illumination requires:
  - light vector
  - eye vector
  - surface normal



Directional light

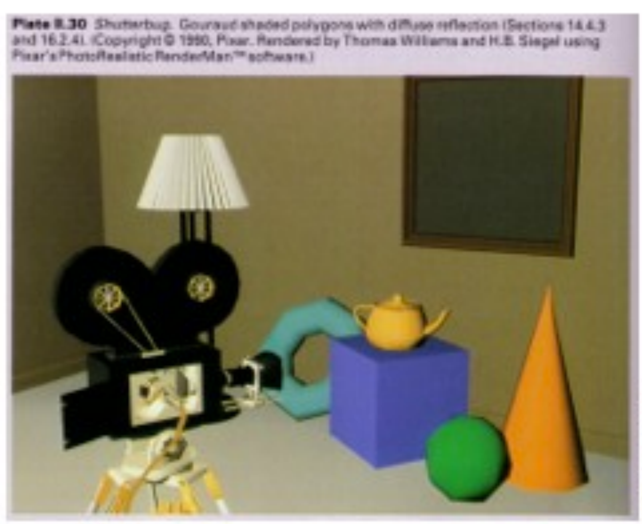
- Directional (infinitely distant) light source
  - light vector always points in the same direction
  - often specified by position [*x* *y* *z* 0]
  - many pipelines are faster if you use directional lights



Gouraud shading

*GL_SMOOTH

- Often draw smooth surfaces
  - compute colors at vertices using vertex normals
  - interpolate colors across triangles
  - "Gouraud shading"
  - "Smooth shading"

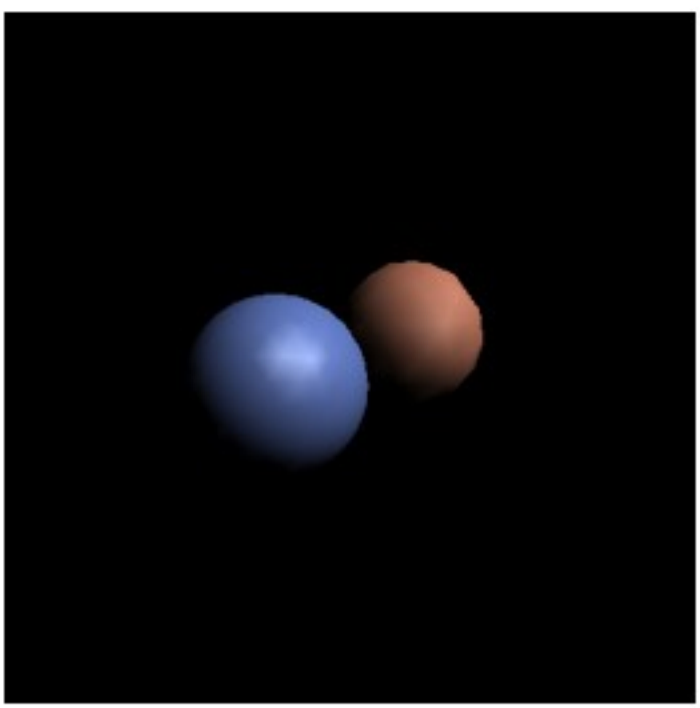


[Foley et al.]

Pipeline for Gouraud shading

- Vertex stage (position and color)
  - transform position and normal (object -> screen space)
  - compute shaded color per triangle using normal
- Rasterize stage
  - interpolate **z'** (screen **z**), and color
  - fill in shape color
- Fragment stage
  - write color to framebuffer if interpolated **z'** < current **z'**

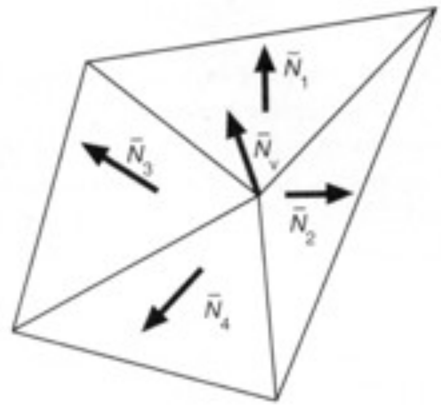
Result of Gouraud shading



Vertex normals

- Need normals at vertices to compute Gouraud shading
- Best to get vertex normals from the geometry
  - e. g. spheres
- Otherwise have to infer vertex normals from triangles
  - simple scheme: average surrounding face normals

$$N_v = \frac{\sum_i N_i}{\|\sum_i N_i\|}$$



[Foley et al.]

Non-diffuse Gouraud shading

- Results are not so good with fast-varying models like specular ones
  - problems with any highlights smaller than a triangle

Plate II.31 Shutterbug. Gouraud shaded polygons with specular reflection (Sections 14.4.4 and 16.2.5). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Phong shading

- Get higher quality by interpolating the normal
  - as easy as interpolating the color
  - evaluating the illumination model per pixel rather than per vertex
  - in pipeline, this means moving illumination from the vertex processing stage to the fragment processing stage

[Foley et al.]

Phong shading

- Produces much better highlights

...terbug. Gouraud shaded polygons with specular reflection (Sections 14.4.4 ...yright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using ...listic RenderMan™ software.)

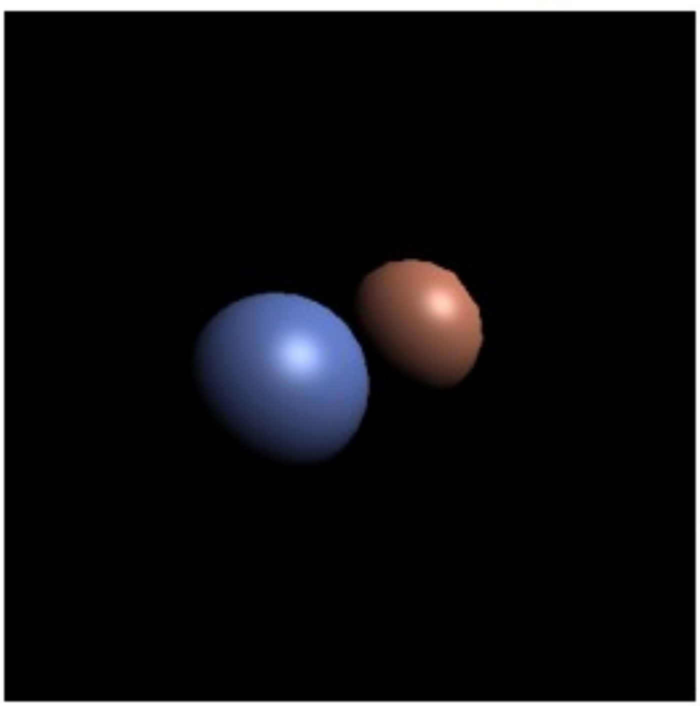
Plate II.32 Shutterbug. Phong shaded polygons with specular reflection (Sections 14.4.4 and 16.2.5). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Pipeline for Phong shading

- Vertex stage (position and color)
  - transform position and normal (object -> screen space)
  - compute shaded color per triangle using normal
- Rasterize stage
  - interpolate *z'* (screen z), color, and x, y, z normal
  - fill in shape color
- Fragment stage
  - compute shading using interpolated and color
  - write color to framebuffer if interpolated *z'* < current *z'*

Result of Phong shading



Not implemented in OpenGL. You must write your own shaders to do this.