CS4620/5620: Lecture 17

Pipeline Operations

Clipping

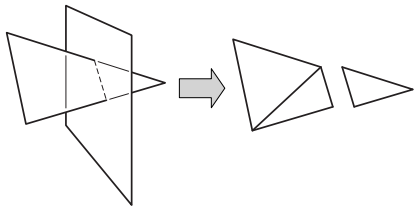
- Rasterizer tends to assume triangles are on screen
  - particularly problematic to have triangles crossing the plane $z = 0$
- After projection, before perspective divide
  - clip against the planes $x, y, z = 1, -1$ (6 planes)
  - primitive operation: clip triangle against axis-aligned plane

Official perspective matrix

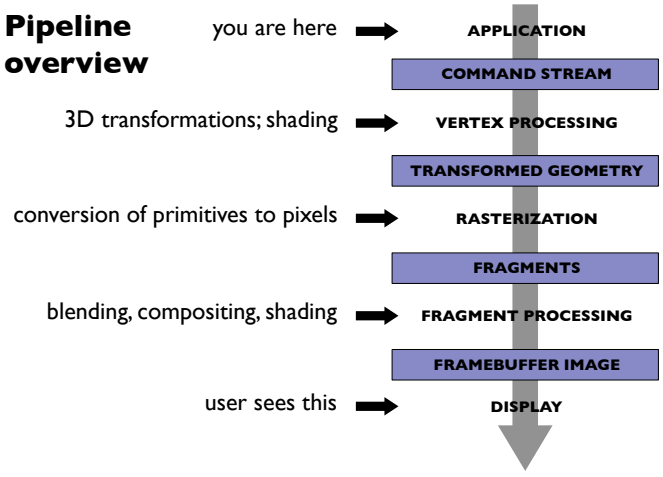
$$\mathbf{P} = \begin{bmatrix} n & 0 & 0 & 0 \\ 0 & n & 0 & 0 \\ 0 & 0 & n+f & -fn \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Clipping a triangle against a plane

- 4 cases, based on sidedness of vertices
  - all in (keep)
  - all out (discard)
  - one in, two out (one clipped triangle)
  - two in, one out (two clipped triangles)

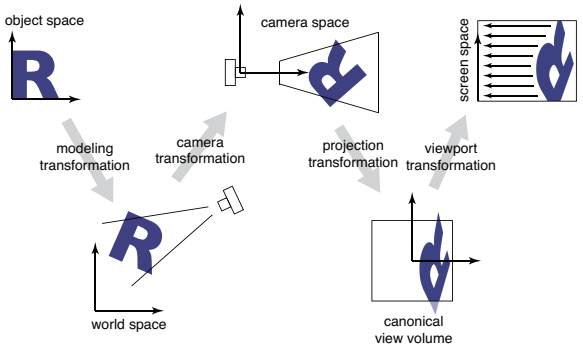


Pipeline overview



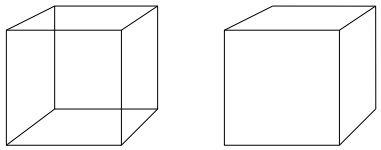
Pipeline of transformations

- Standard sequence of transforms



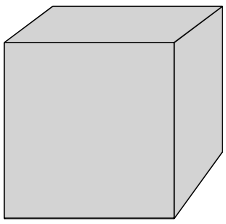
Hidden surface elimination

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



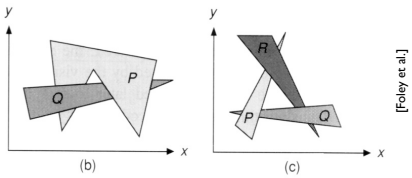
Painter's algorithm

- 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 sometimes occludes B
  - any sort is valid
    - ABCDEF
    - BADCFE
  - if there are cycles there is no sort



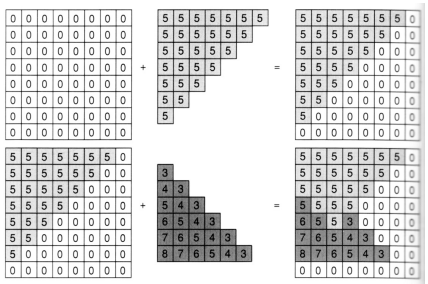
[Foley et al.]

- Works when valid sort is easy to come by

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

The z buffer



[Foley et al.]

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

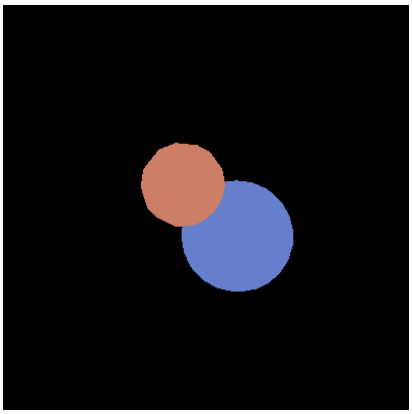
Precision in z buffer

- 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

Pipeline for minimal operation

- Vertex stage (input: position,color)
  - transform position (object to screen space)
  - pass through color
- Rasterizer
  - pass through color
- Fragment stage (output: color)
  - write to color planes

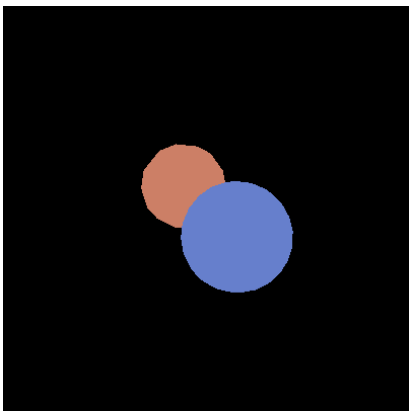
Result of minimal pipeline



Pipeline for basic z buffer

- Vertex stage (input: position,color)
  - transform position (object to screen space)
  - pass through color
- Rasterizer
  - interpolated parameter: z' (screen z)
  - pass through color
- Fragment stage (output: color, z')
  - write to color planes only if interpolated z' < current z'

Result of z-buffer pipeline



Flat shading

- Shade using the real normal of the triangle
  - same result as ray tracing a bunch of triangles
- Leads to constant shading and faceted appearance
  - truest view of the mesh geometry

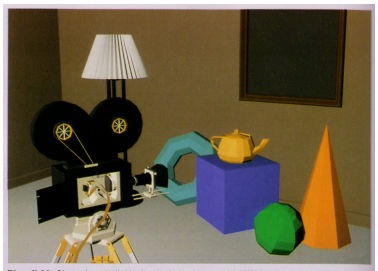


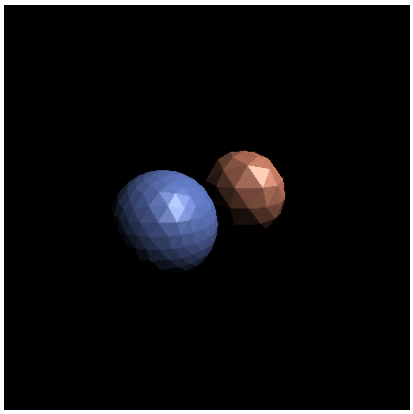
Plate II.29 *Shutterbug.* Individually shaded polygons with diffuse reflection (Sections 14.4.2 and 16.2.3). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Pipeline for flat shading

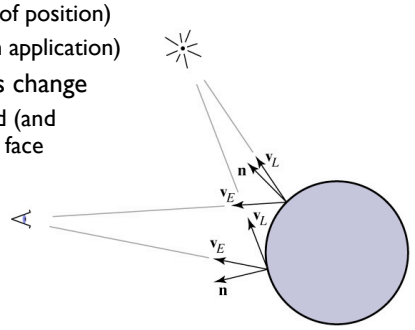
- Vertex stage (input: position, color and normal)
  - transform position and normal (object to eye space)
  - compute shaded color per triangle using normal
  - transform position (eye to screen space)
- Rasterizer
  - interpolated parameters: z' (screen z)
  - pass through color
- Fragment stage (output: color, z')
  - write to color planes only if interpolated z' < current z'

Result of flat-shading pipeline



Beyond flat shading

- Phong illumination requires geometric information:
  - light vector (function of position)
  - eye vector (function of position)
  - surface normal (from application)
- Light and eye vectors change
  - need to be computed (and normalized) for each face
- In which space?
  - Eye, world

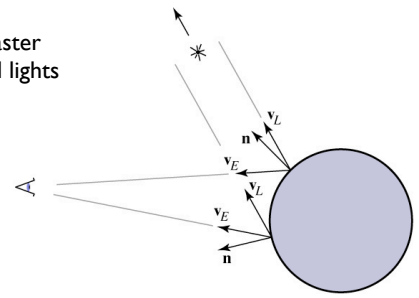


Local vs. infinite viewer, light

- Look at case when eye or light is far away:
  - distant light source: nearly parallel illumination
  - distant eye point: nearly orthographic projection
  - in both cases, eye or light vector changes very little
- Optimization: approximate eye and/or light as infinitely far away

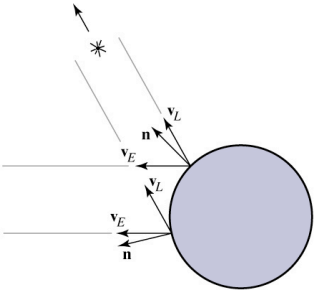
Directional light

- 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



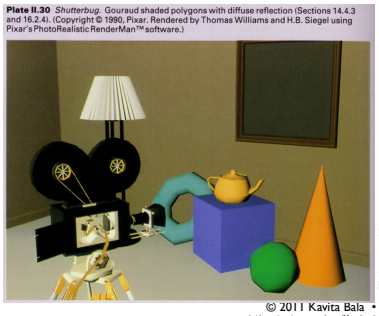
Infinite viewer

- Orthographic camera
  - projection direction is constant
- "Infinite viewer"
  - even with perspective, can approximate eye vector using the image plane normal
  - can produce weirdness for wide-angle views
  - Blinn-Phong: light, eye, half vectors all constant!



Gouraud shading

- Often we're trying to draw smooth surfaces, so facets are an artifact
  - compute colors at vertices using vertex normals
  - interpolate colors across triangles
  - "Gouraud shading"
  - "Smooth shading"

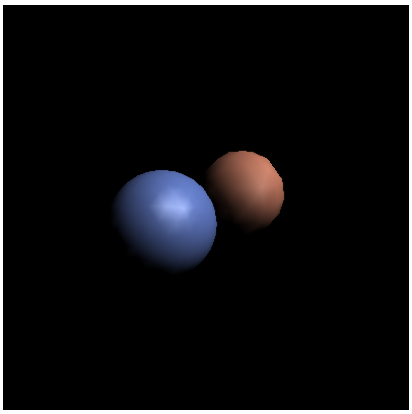


[Foley et al.]

Pipeline for Gouraud shading

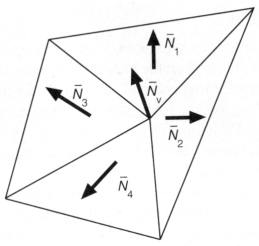
- Vertex stage (input: position, color, and normal)
  - transform position and normal (object to eye space), pass along
  - compute shaded color per vertex
  - transform position (eye to screen space)
- Rasterizer
  - interpolated parameters: *z'* (screen *z*); *r, g, b* color
- Fragment stage (output: color, *z'*)
  - write to color planes only if interpolated *z'* < current *z'*

Result of Gouraud shading pipeline



Vertex normals

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



[Foley et al.]

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

Non-diffuse Gouraud shading

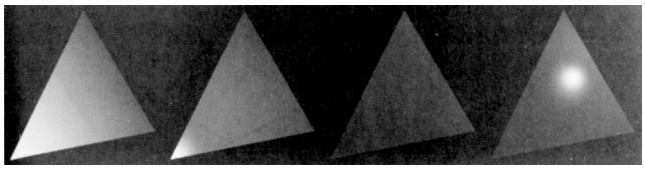
- Can apply Gouraud shading to any illumination model
  - it's just an interpolation method
- Results are not so good with fast-varying models like specular ones
  - problems with any highlights smaller than a triangle

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 PhotoRealisticRenderMan™ software.)

[Foley et al.]

Phong shading

- Get higher quality by interpolating the normal
  - just as easy as interpolating the color
  - but now we are evaluating the illumination model per pixel rather than per vertex (and normalizing the normal first)
  - in pipeline, this means we are moving illumination from the vertex processing stage to the fragment processing stage



Phong shading

- Bottom line: produces much better highlights

tterbug. 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.)

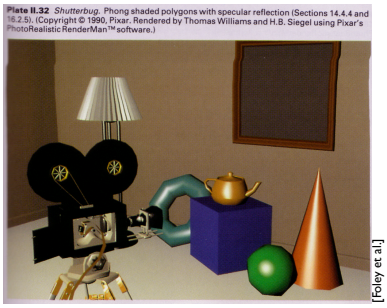


Plate II.32 *Shutterbug.* Phong shaded polygons with specular reflection (Sections 14.4.4 and 16.2.5). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealisticRenderMan™ software.)

[Foley et al.]

Pipeline for Phong shading

- Vertex stage (input: position, color, and normal)
  - transform position and normal (object to eye space)
  - transform position (eye to screen space)
  - pass through color
- Rasterizer
  - interpolated parameters: z' (screen z); r, g, b color; x, y, z normal
- Fragment stage (output: color, z')
  - compute shading using interpolated color and normal
  - write to color planes only if interpolated z' < current z'

Result of Phong shading pipeline