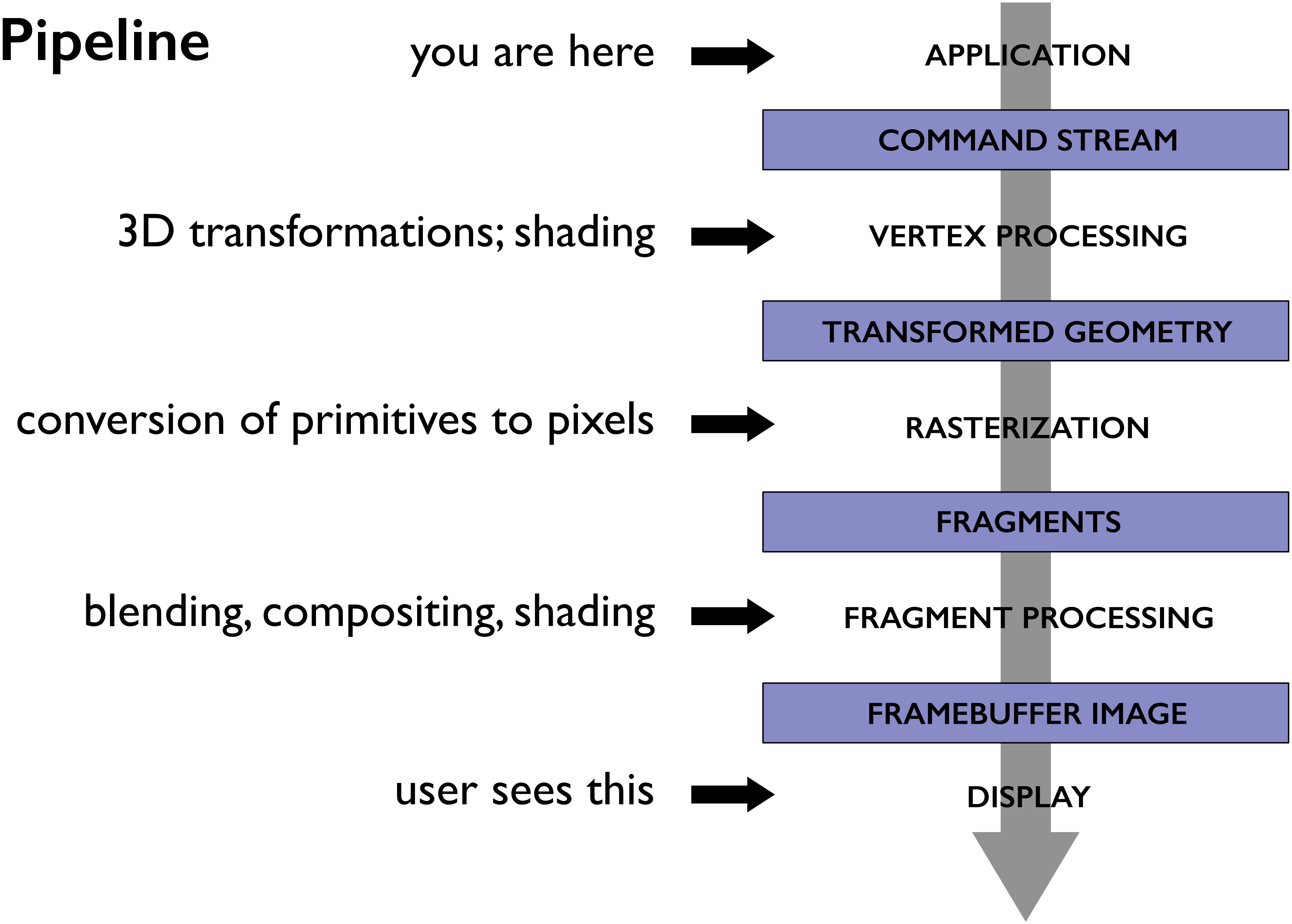
Pipeline

CS 4620 Lecture 17

Announcements

- A3 due on Thu
  - Will send mail about grading once finalized

Pipeline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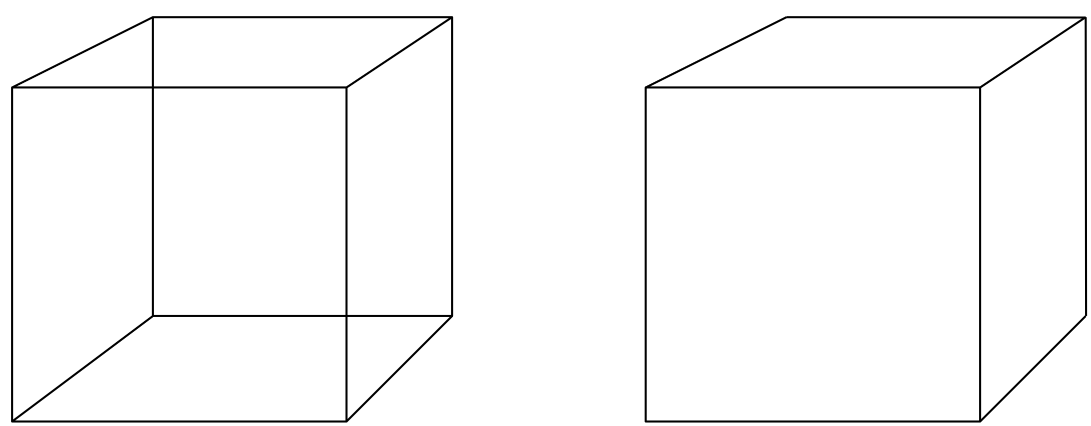
APPLICATION
COMMAND STREAM
3D transformations; shading
VERTEX PROCESSING
TRANSFORMED GEOMETRY
conversion of primitives to pixels
RASTERIZATION
FRAGMENTS
blending, compositing, shading
FRAGMENT PROCESSING
FRAMEBUFFER IMAGE
user sees this
DISPLAY

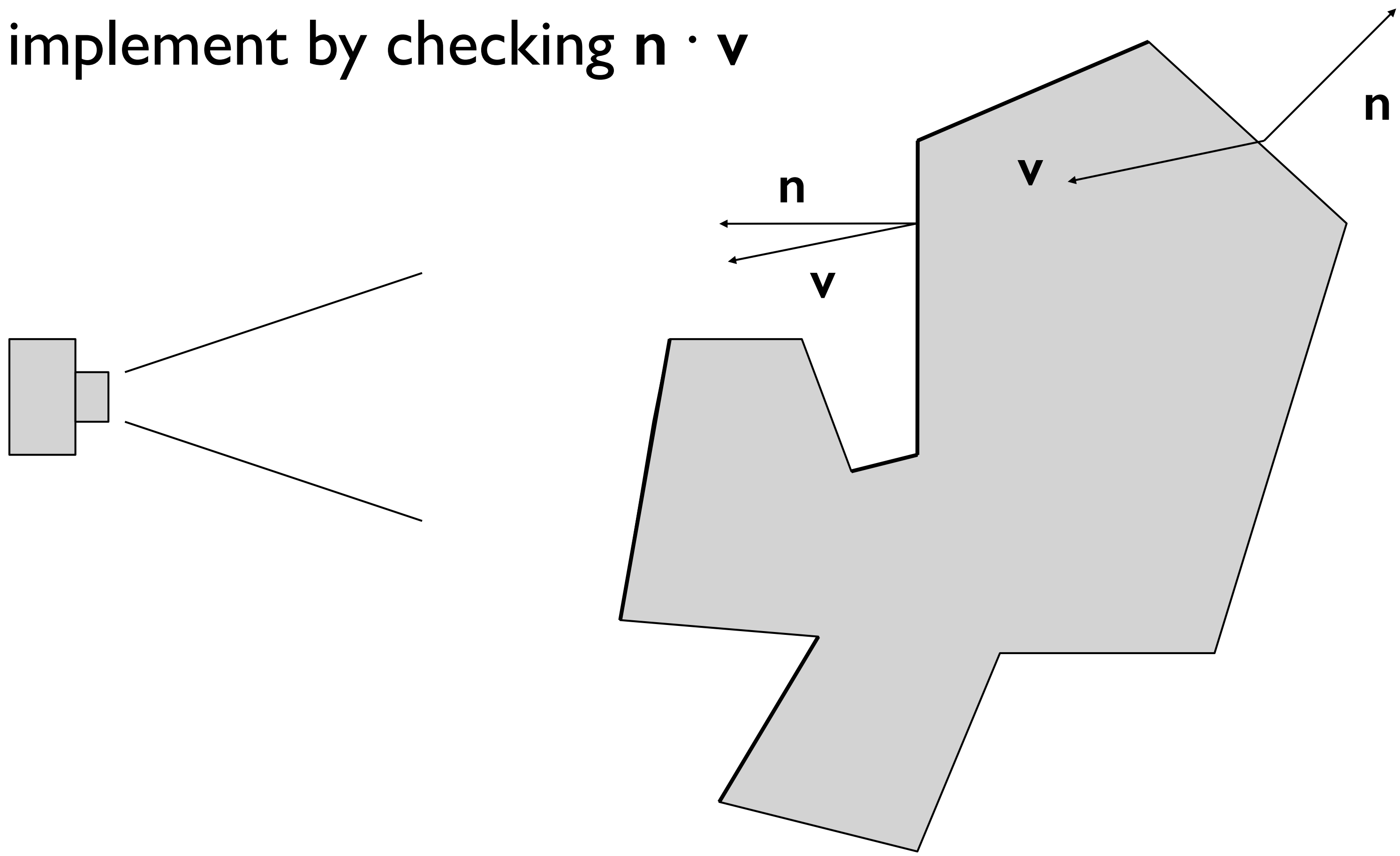
Hidden surface elimination

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



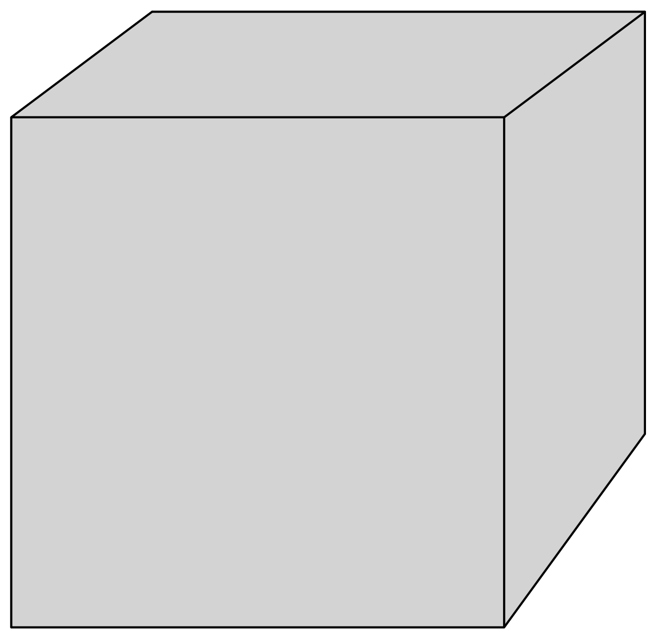
Back face culling

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



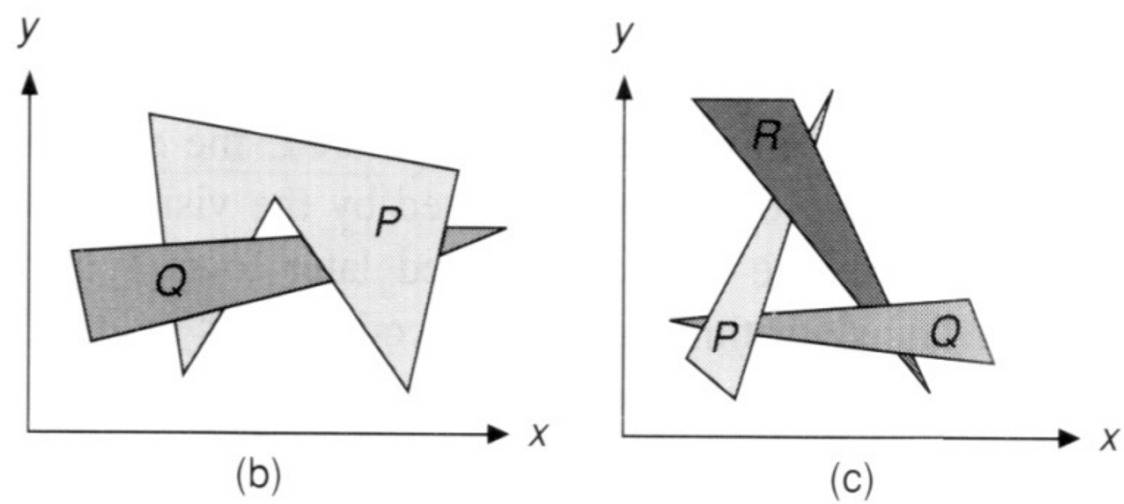
Painter's algorithm

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



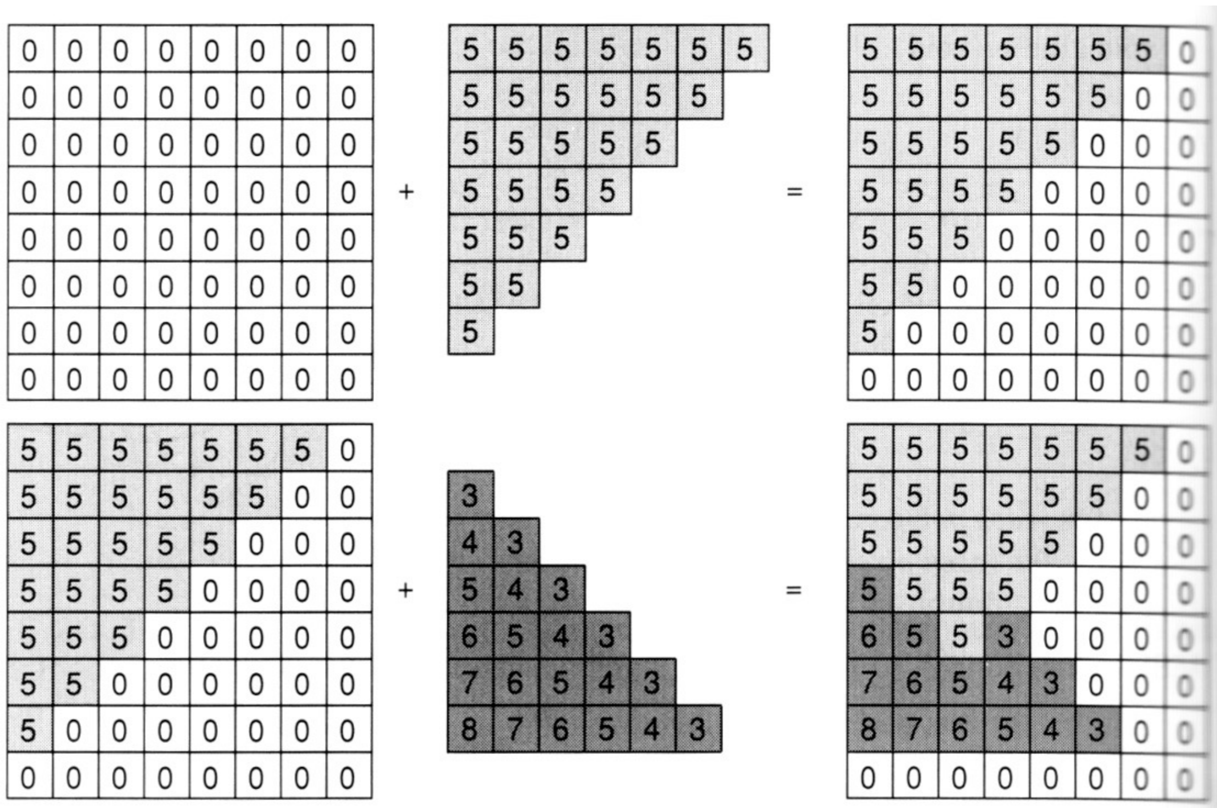
[Foley et al.]

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

The z buffer

- An example of a memory-intensive brute force approach that works and has become the standard
- Another one is texture mapping

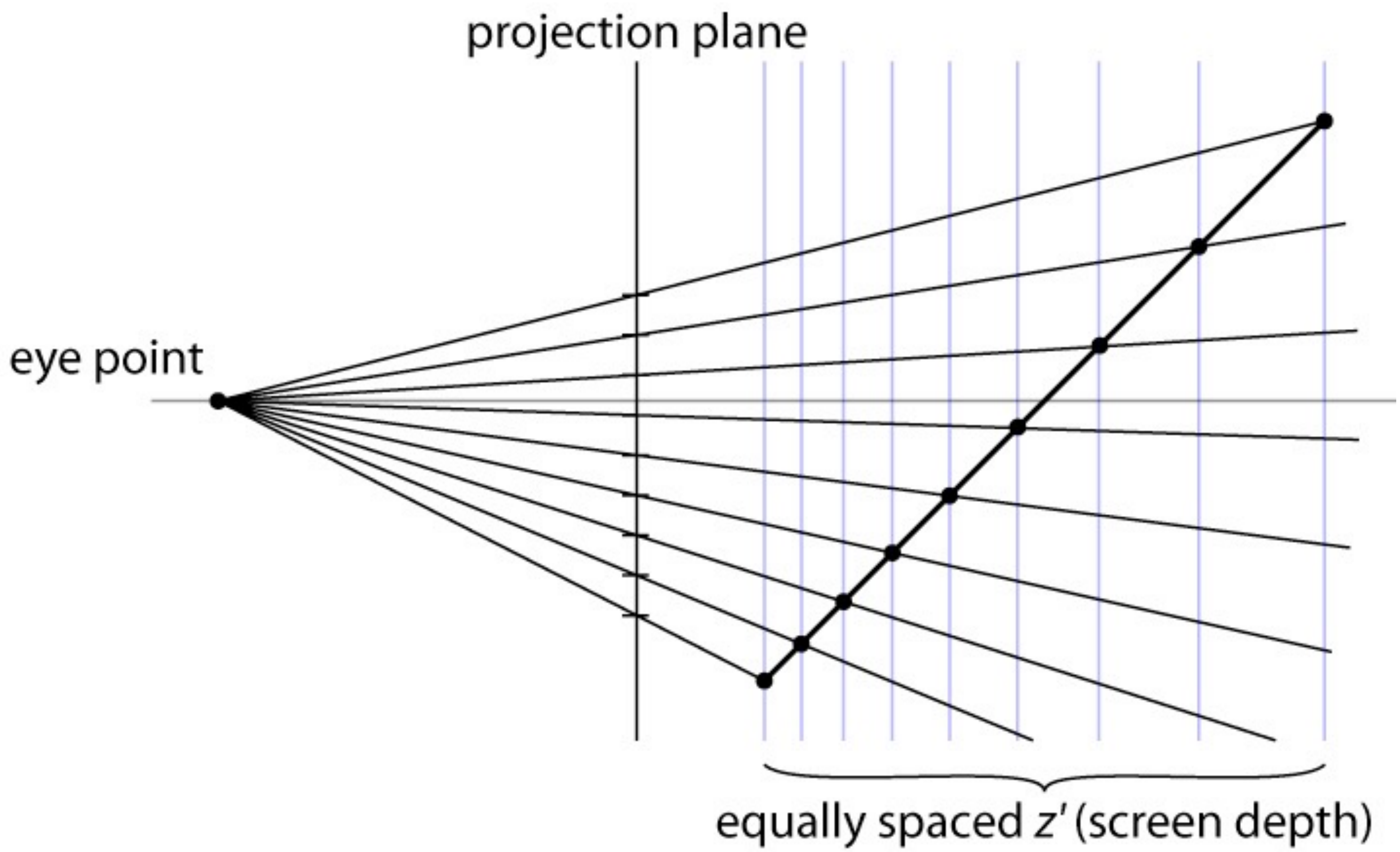


[Foley et al.]

Precision in z buffer

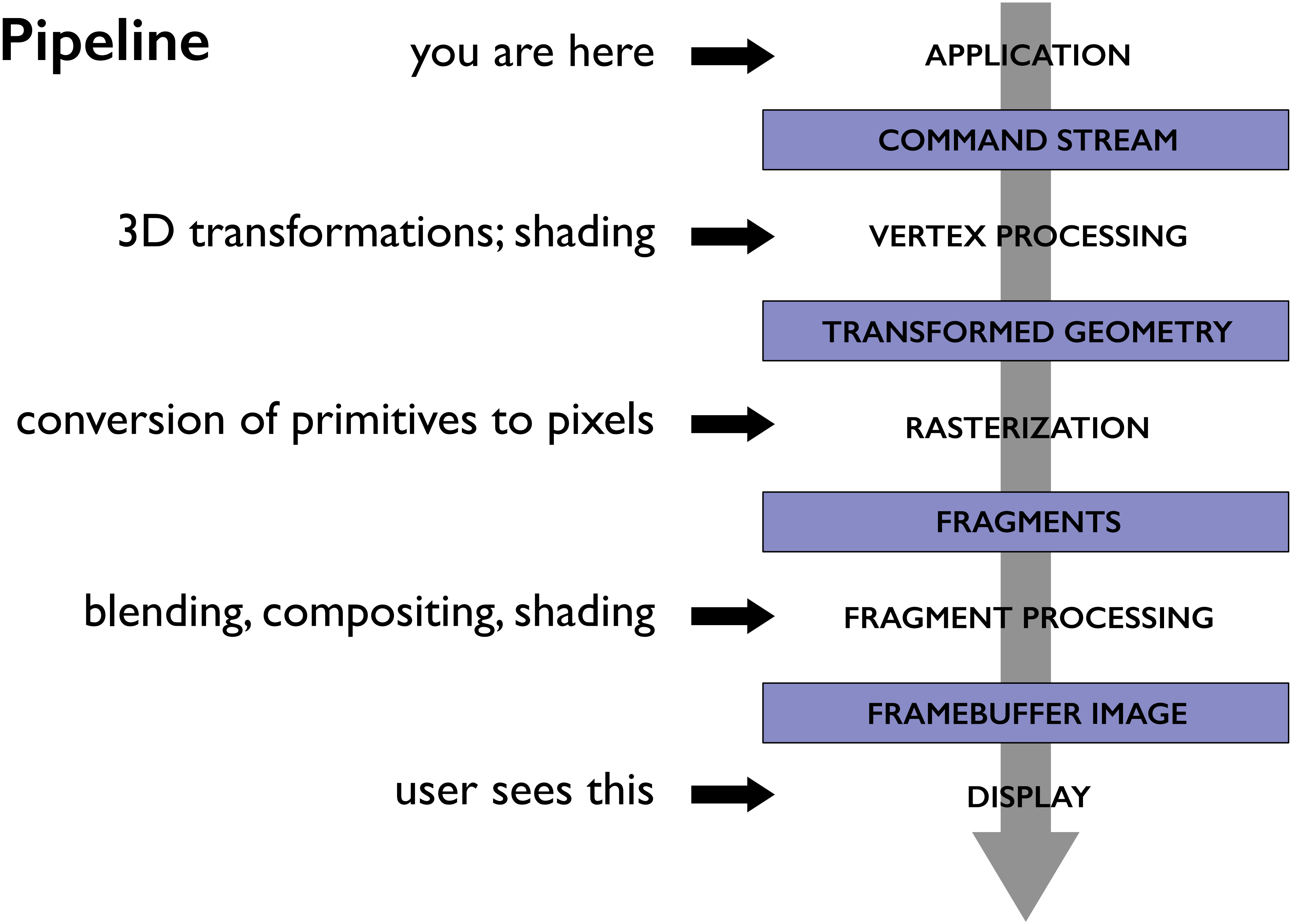
- The precision is distributed between the near and far clipping planes
  - this is why these planes have to exist
  - also why you can't always just set them to very small and very large distances
- Generally use *z'* (not world *z*) in *z* buffer

Interpolating in projection



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

Pipeline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Demos

Shader toy

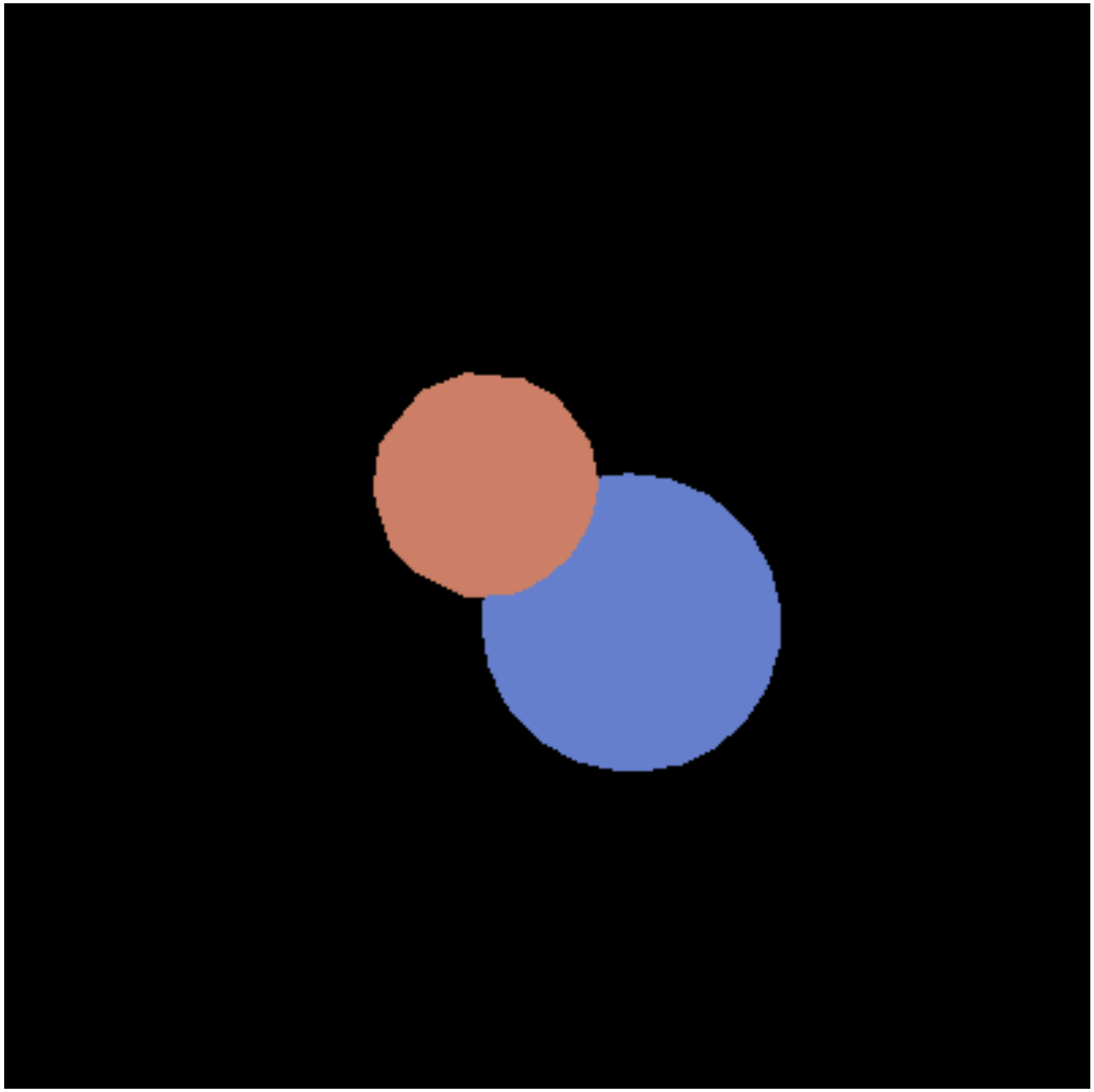
https://www.shadertoy.com/

http://acko.net/files/gltalks/pixelfactory/online.html

Pipeline for minimal operation

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

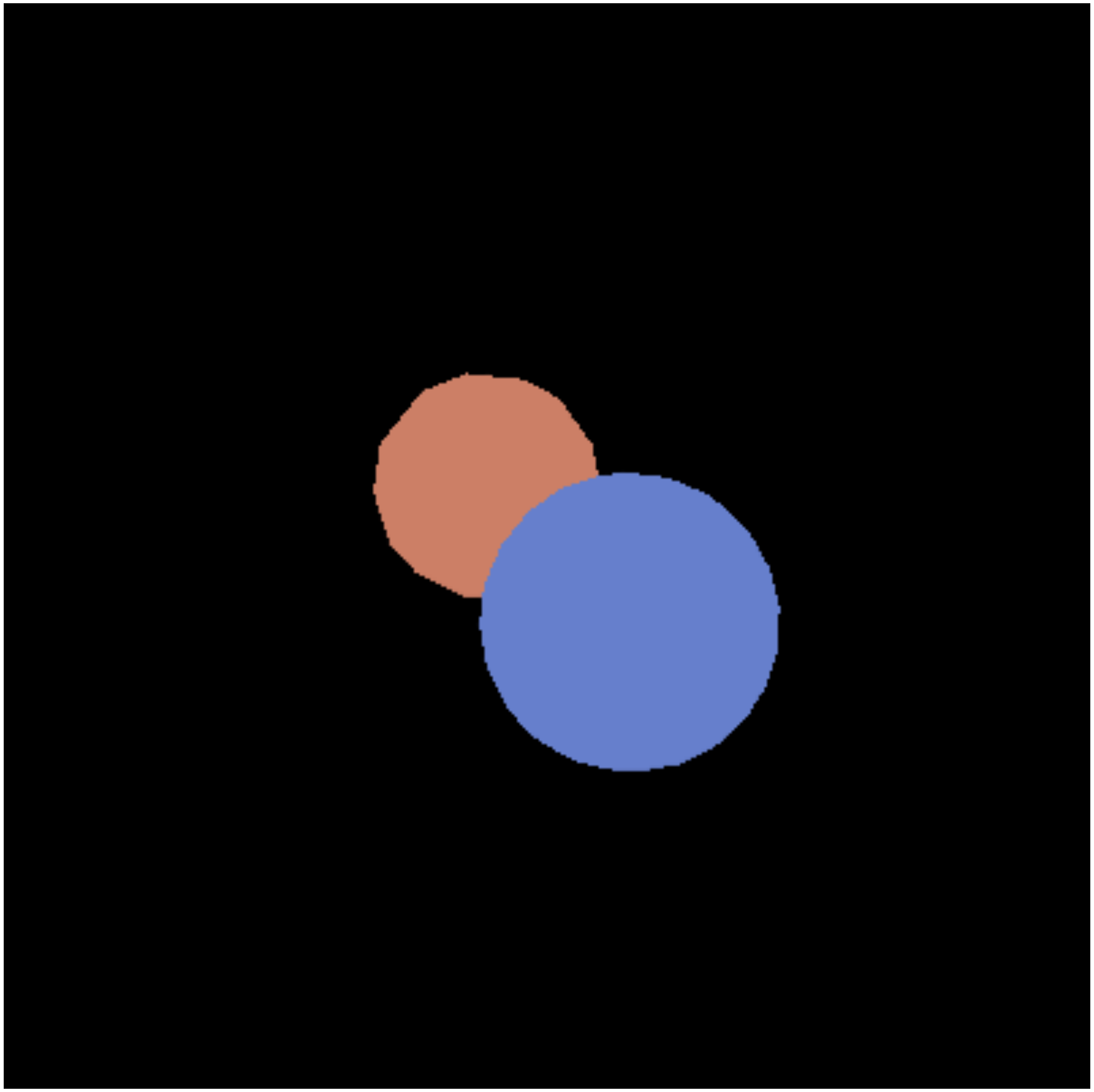
Result of minimal pipeline



Pipeline for basic *z* buffer

- Vertex stage (input: position / vtx; 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

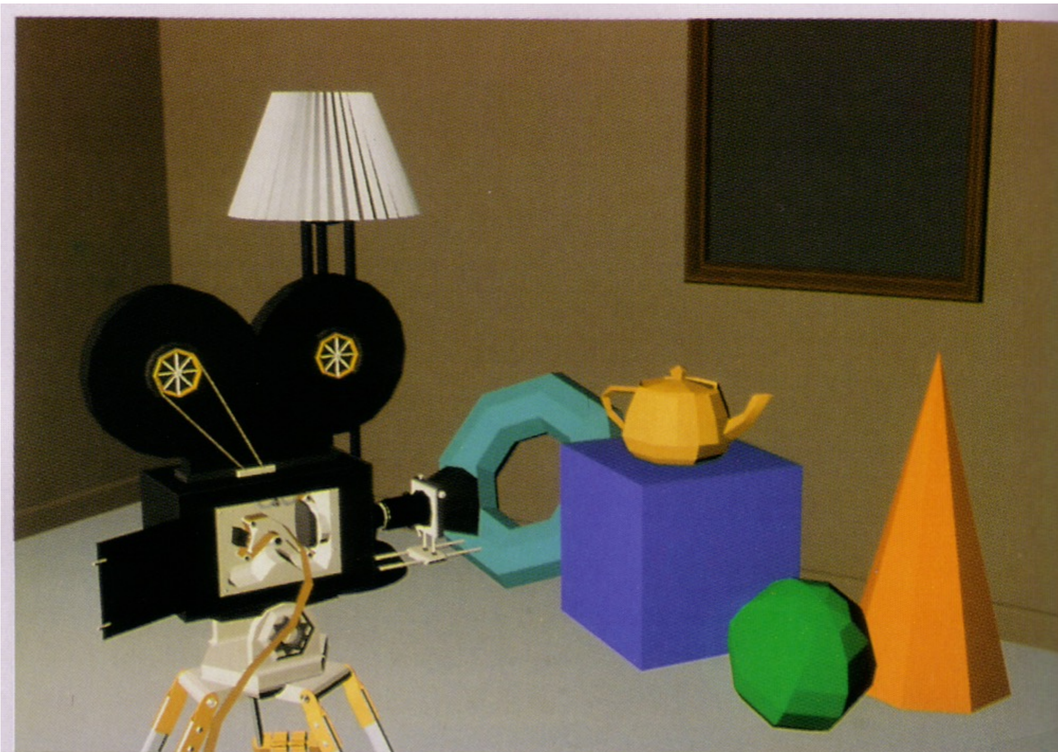


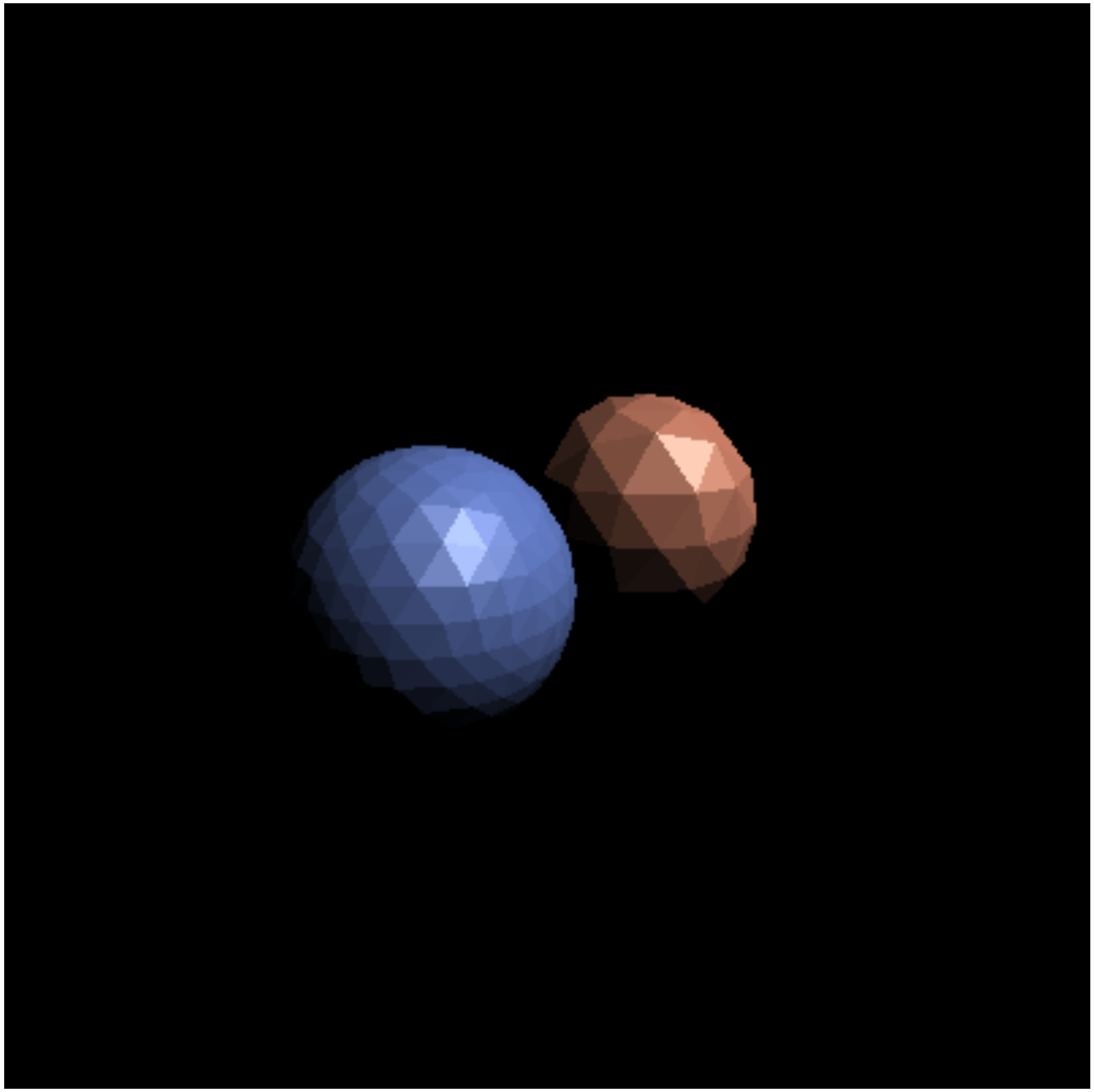
Plate II.29 *Shutterbug.* Individually shaded polygons with diffuse reflection (Sections 14.4.2 and 16.2.3). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Pipeline for flat shading

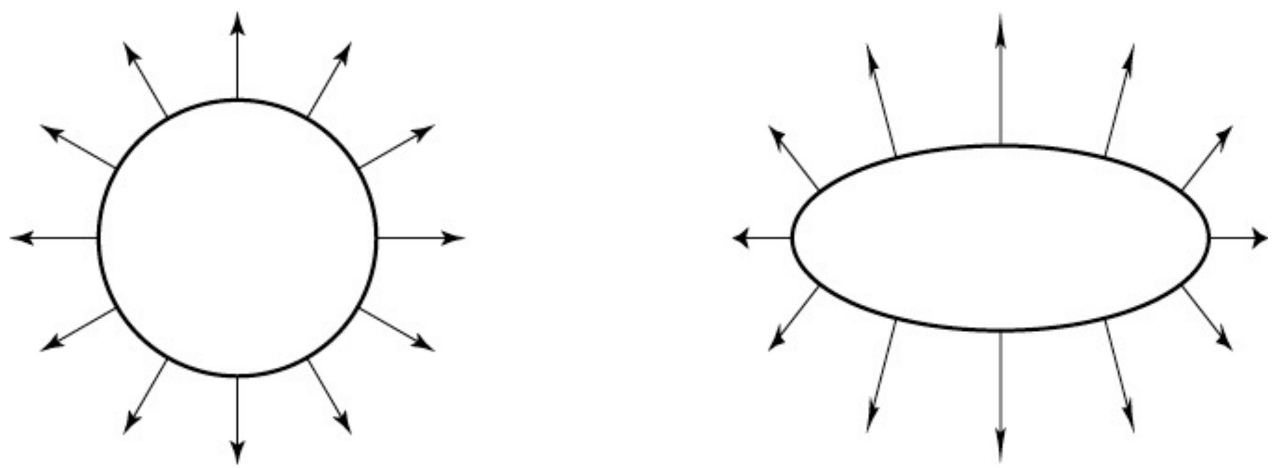
- Vertex stage (input: position / vtx; color and normal)
  - transform position and normal (object to eye space)
  - compute shaded color per triangle using normal
  - transform position (eye to screen space)
- Rasterizer
  - interpolated parameters: z' (screen z)
  - pass through color
- Fragment stage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

Result of flat-shading pipeline



Transforming normal vectors

- Transforming surface normals
  - differences of points (and therefore tangents) transform OK
  - normals do not --> use inverse transpose matrix



$$\text{have: } \mathbf{t} \cdot \mathbf{n} = \mathbf{t}^T \mathbf{n} = 0$$
$$\text{want: } M\mathbf{t} \cdot X\mathbf{n} = \mathbf{t}^T M^T X \mathbf{n} = 0$$
$$\text{so set } X = (M^T)^{-1}$$
$$\text{then: } M\mathbf{t} \cdot X\mathbf{n} = \mathbf{t}^T M^T (M^T)^{-1} \mathbf{n} = \mathbf{t}^T \mathbf{n} = 0$$

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"

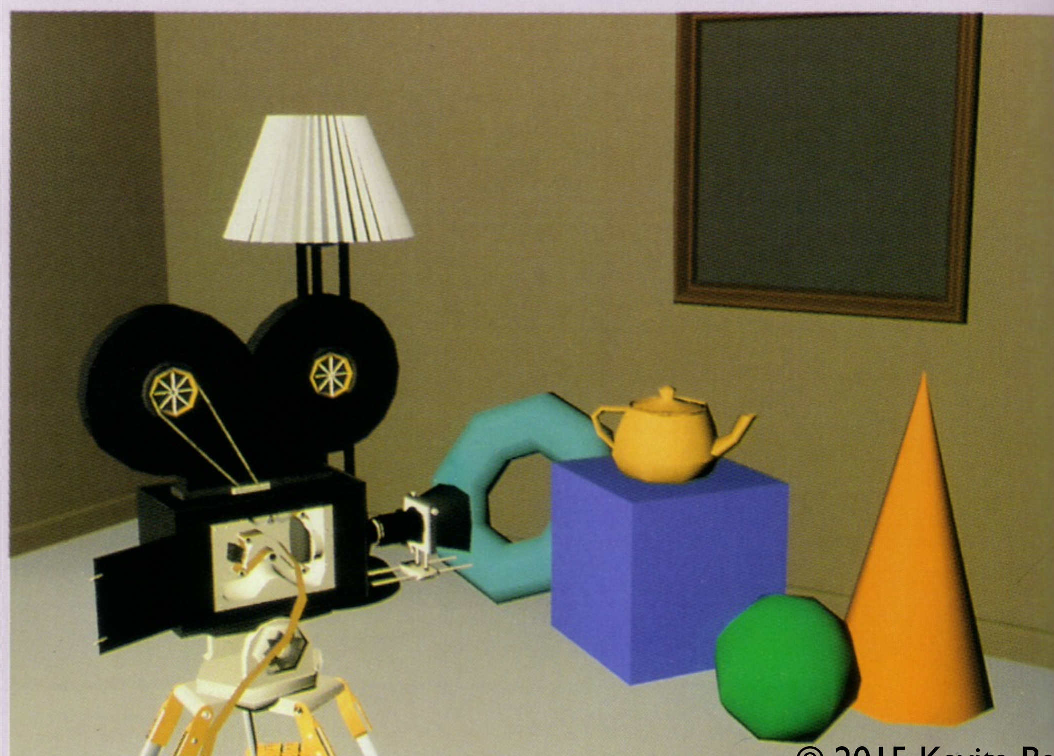


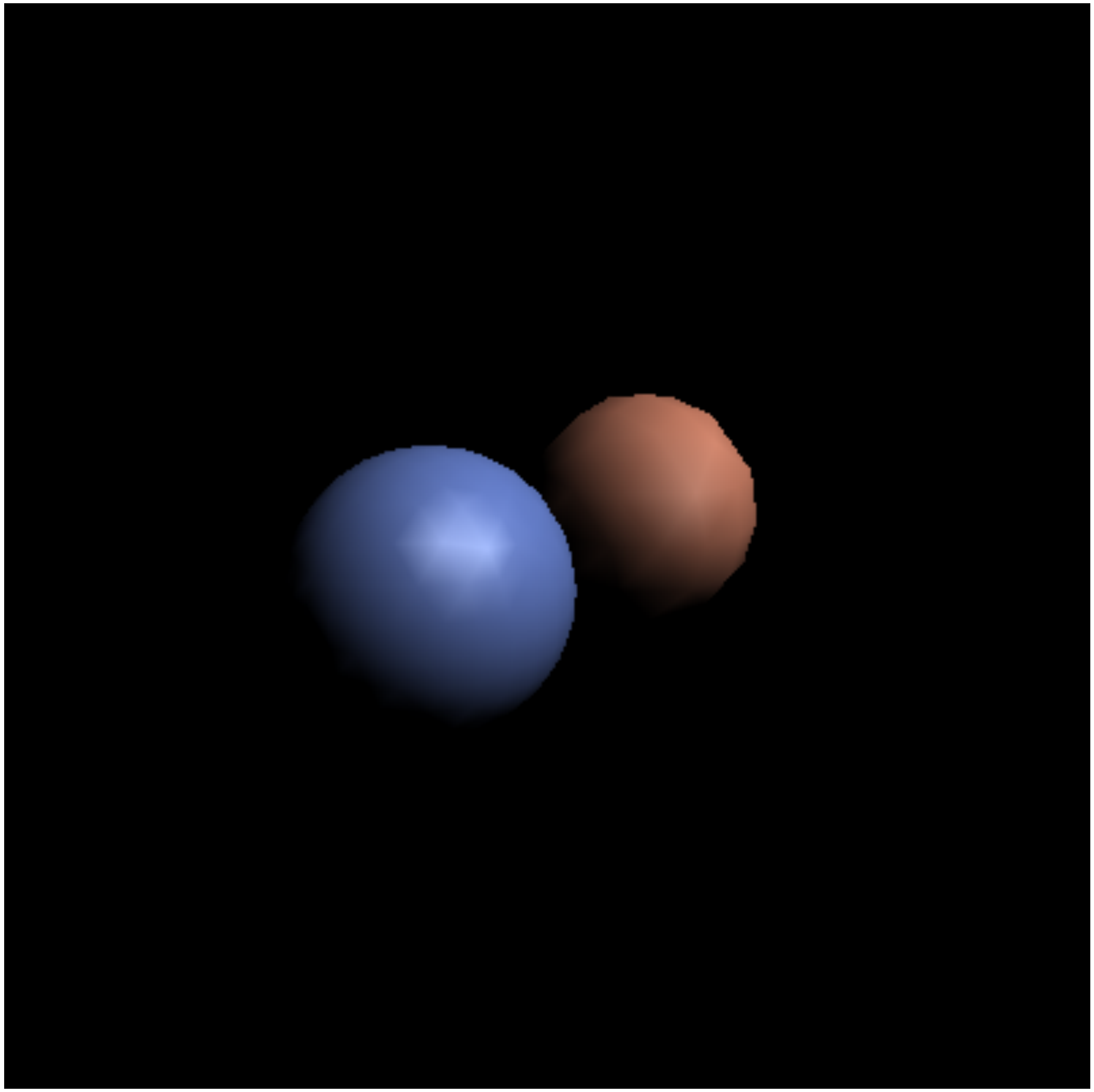
Plate II.30 *Shutterbug.* Gouraud shaded polygons with diffuse reflection (Sections 14.4.3 and 16.2.4). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Pipeline for Gouraud shading

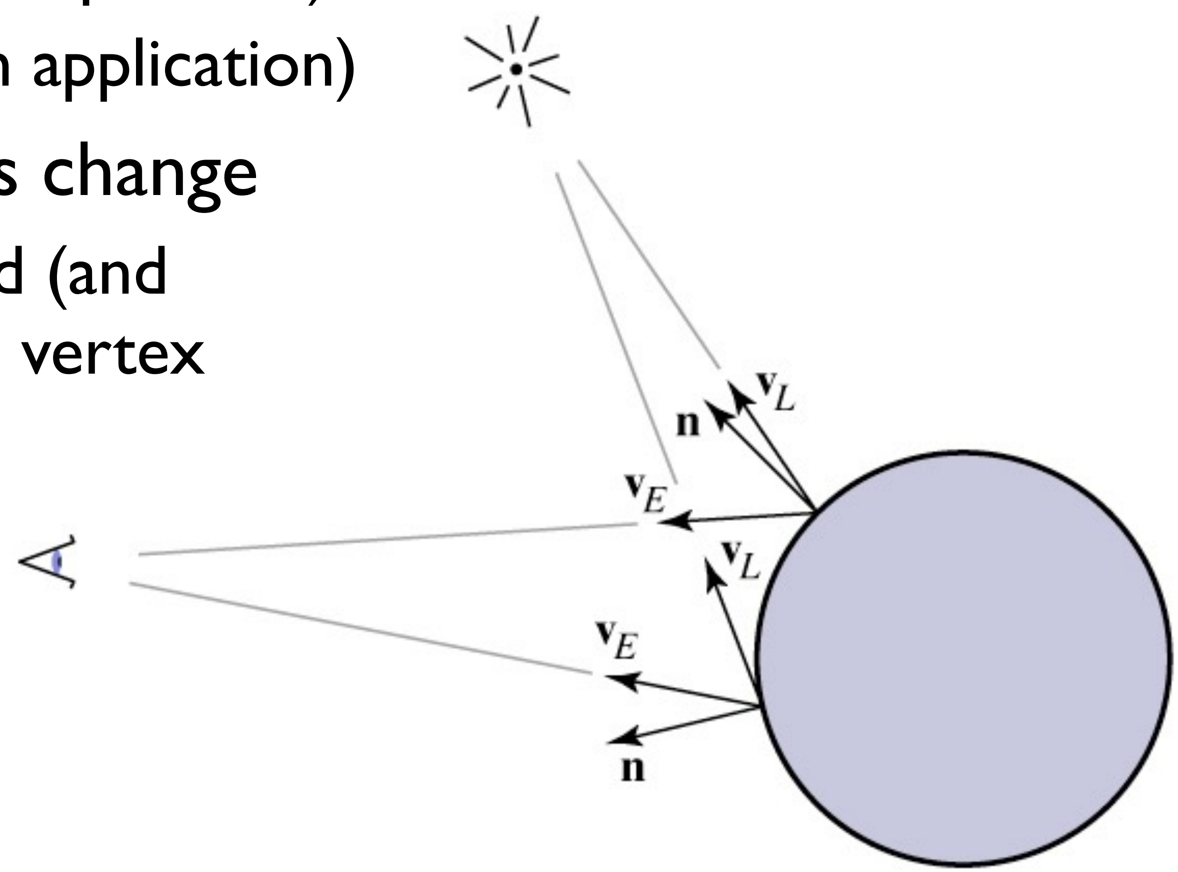
- Vertex stage (input: position, color, and normal / vtx)
  - transform position and normal (object to eye space)
  - compute shaded color per vertex
  - transform position (eye to screen space)
- Rasterizer
  - interpolated parameters: z' (screen z); r, g, b color
- Fragment stage (output: color, z')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

Result of Gouraud shading pipeline



Local vs. infinite viewer, light

- 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 vertex

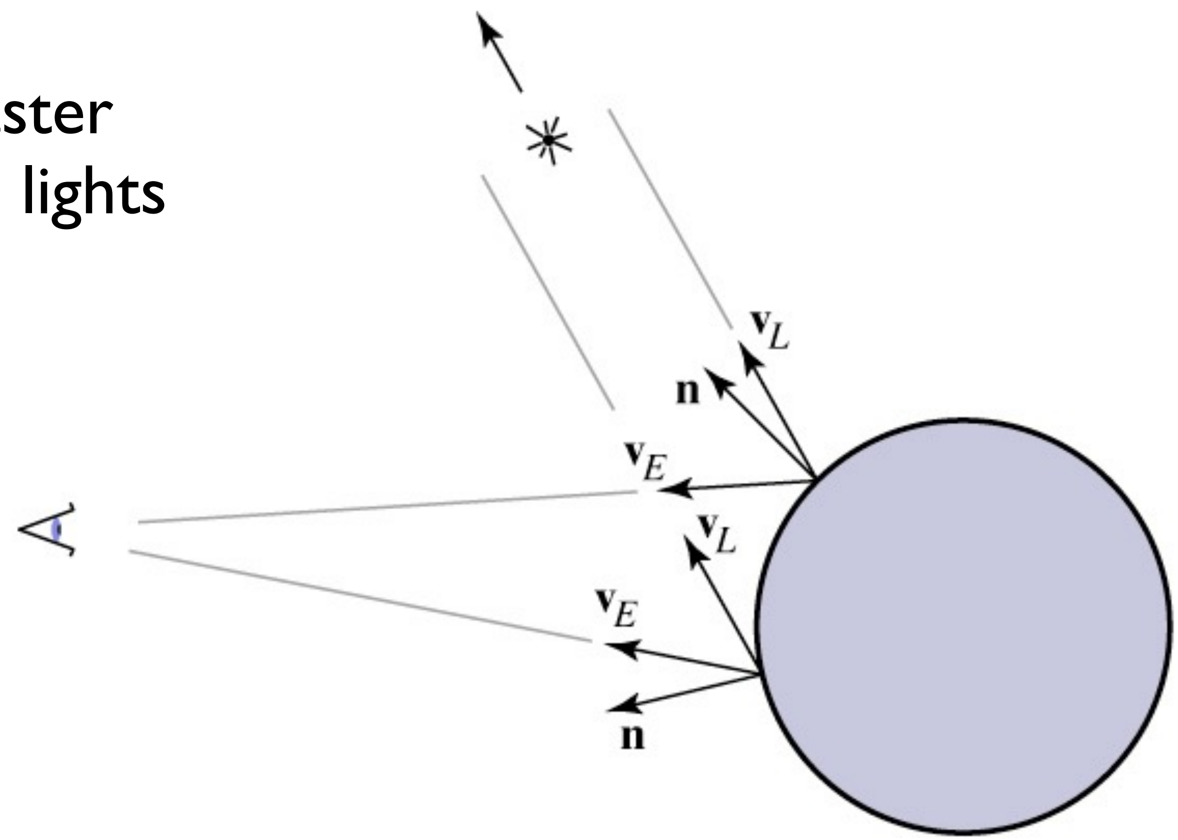


Local vs. infinite viewer, light

- 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

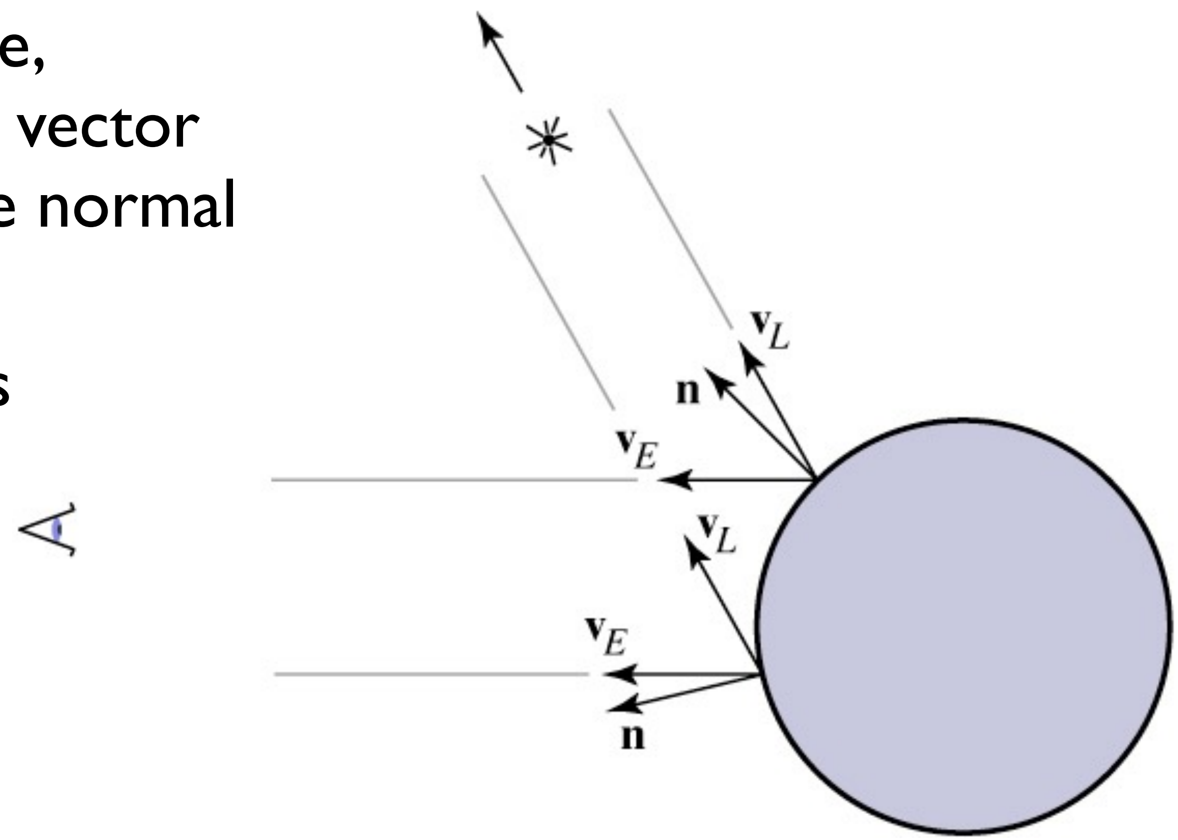
Directional light

- 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



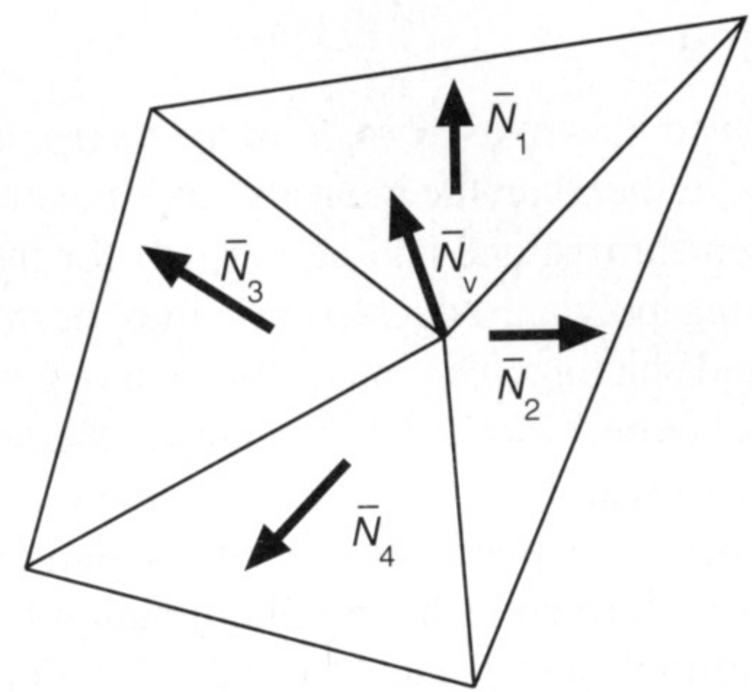
Infinite viewer

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



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

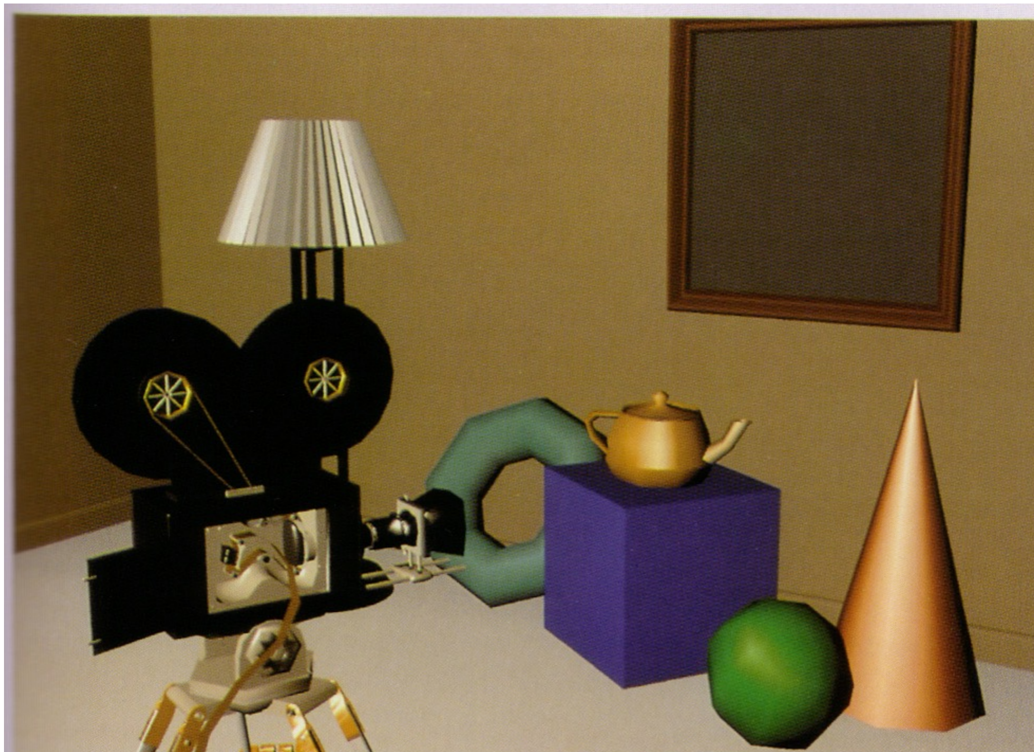
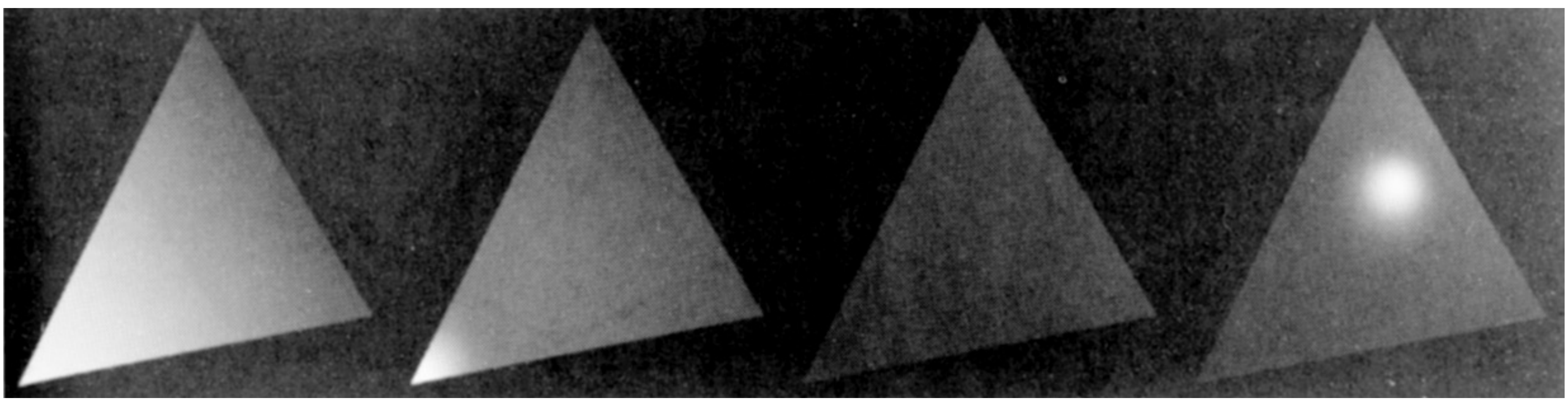


Plate II.31 *Shutterbug.* Gouraud shaded polygons with specular reflection (Sections 14.4.4 and 16.2.5). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

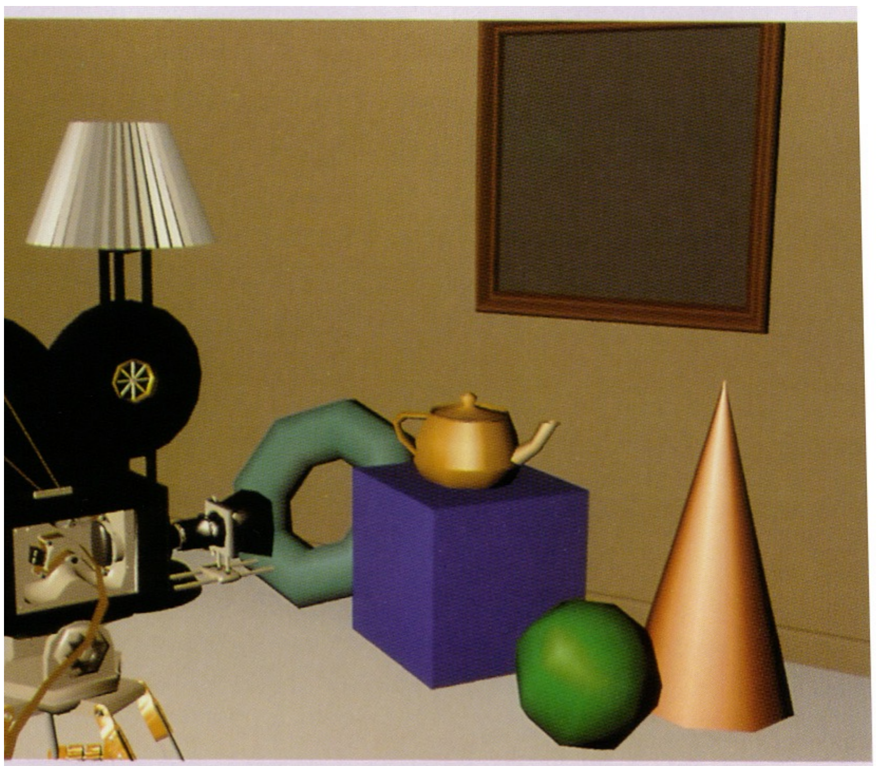
Per-pixel (Phong) shading

- 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



Per-pixel (Phong) shading

- Bottom line: produces much better highlights



tterbug. Gouraud shaded polygons with specular reflection (Sections 14.4.4
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listic RenderMan™ software.)

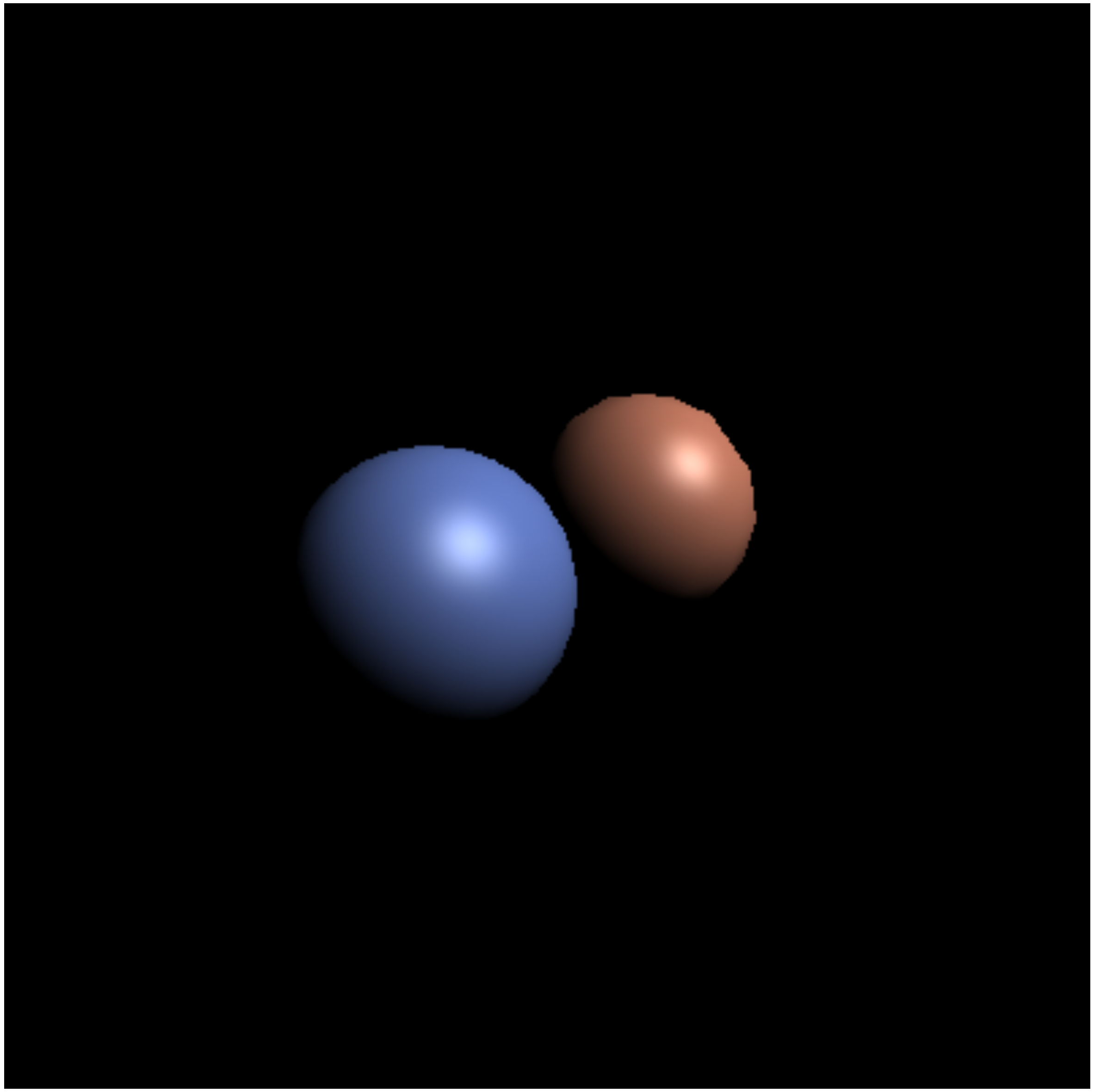
Plate II.32 *Shutterbug.* Phong shaded polygons with specular reflection (Sections 14.4.4 and 16.2.5). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Pipeline for per-pixel shading

- Vertex stage (input: position, color, and normal / vtx)
  - 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'*

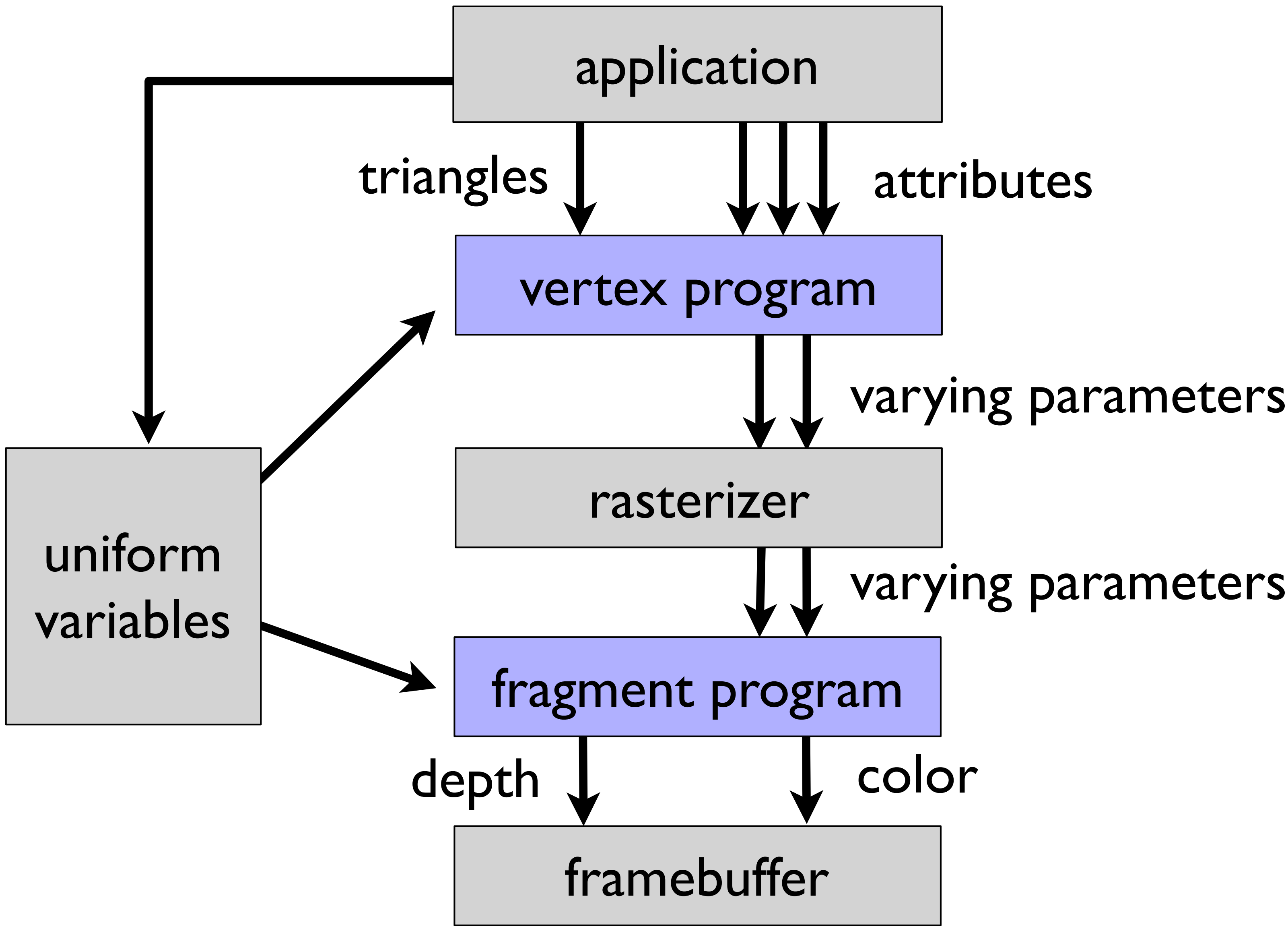
Result of per-pixel shading pipeline



Programming hardware pipelines

- Modern hardware graphics pipelines are flexible
  - programmer defines exactly what happens at each stage
  - do this by writing *shader programs* in domain-specific languages called *shading languages*
  - rasterization is fixed-function, as are some other operations (depth test, many data conversions, …)
- One example: OpenGL and GLSL (**GL S**hading **L**anguage)
  - several types of shaders process primitives and vertices; most basic is the *vertex program*
  - after rasterization, fragments are processed by a *fragment program*

GLSL Shaders



Demos

Shader toy
https://www.shadertoy.com/

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