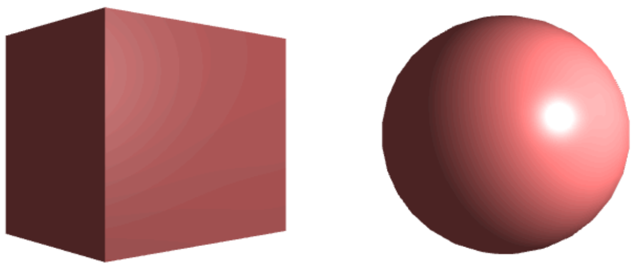


Computer Graphics

Lecture/Lab 23

WebGL, continued

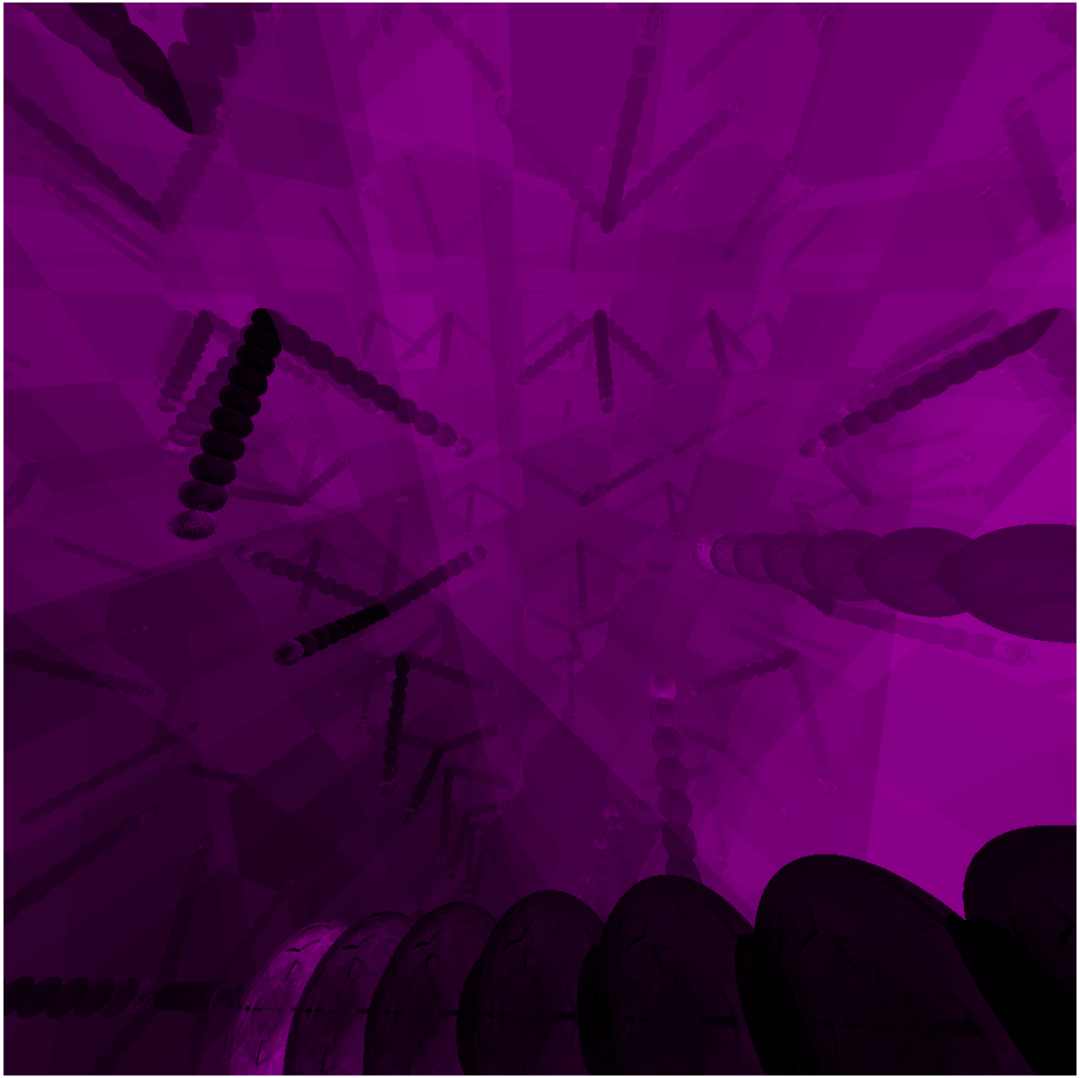
Flat, Gouraud, and Phong "shading"

Announcements

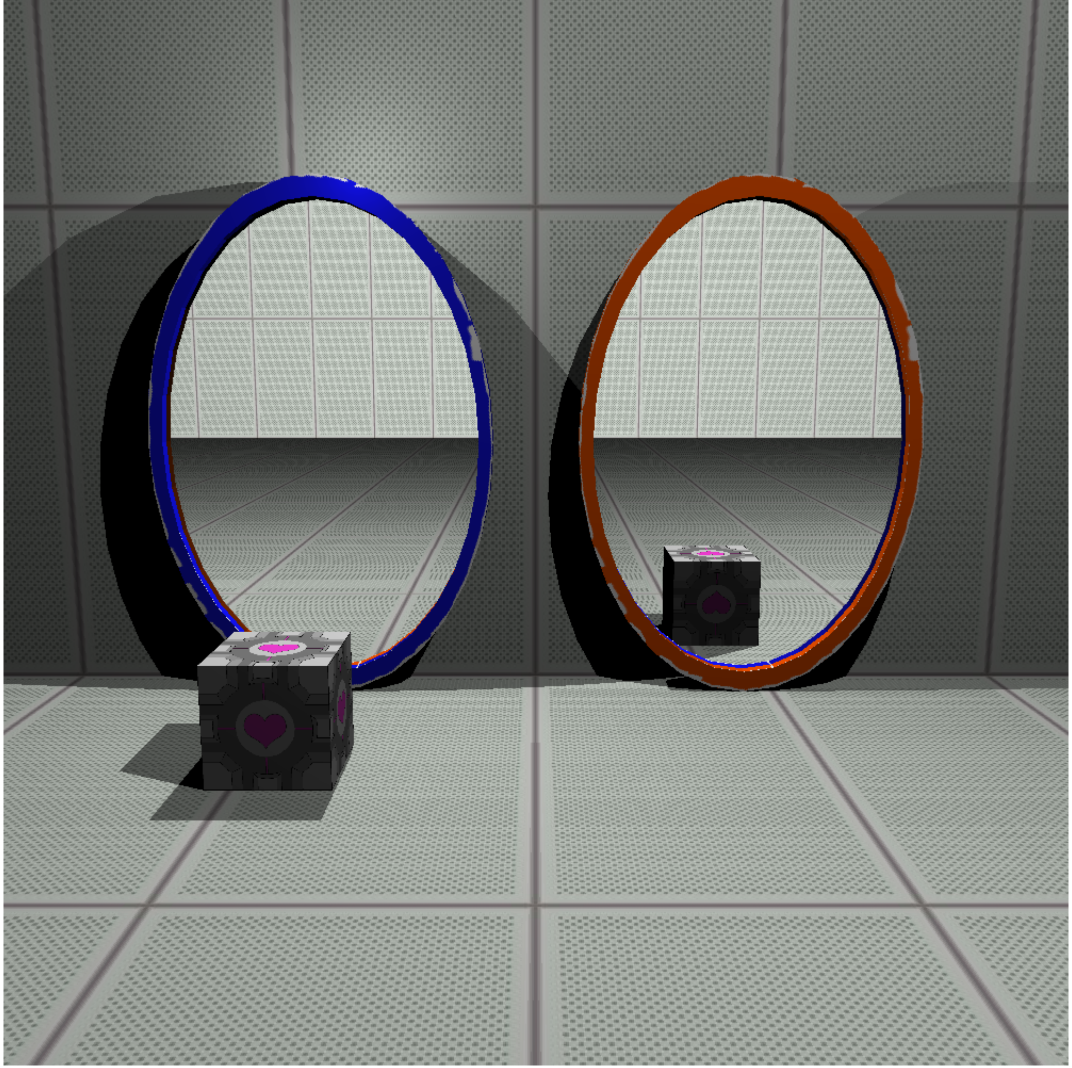
- Final project groups due tonight.
    - Still looking for a group? Let's meet up after class.
- HW3 graded
    - If you submit late (today or after), let me know so we can go back and grade it.
- Final project ~~report~~ due Friday
  proposal

A2 Artifact Results

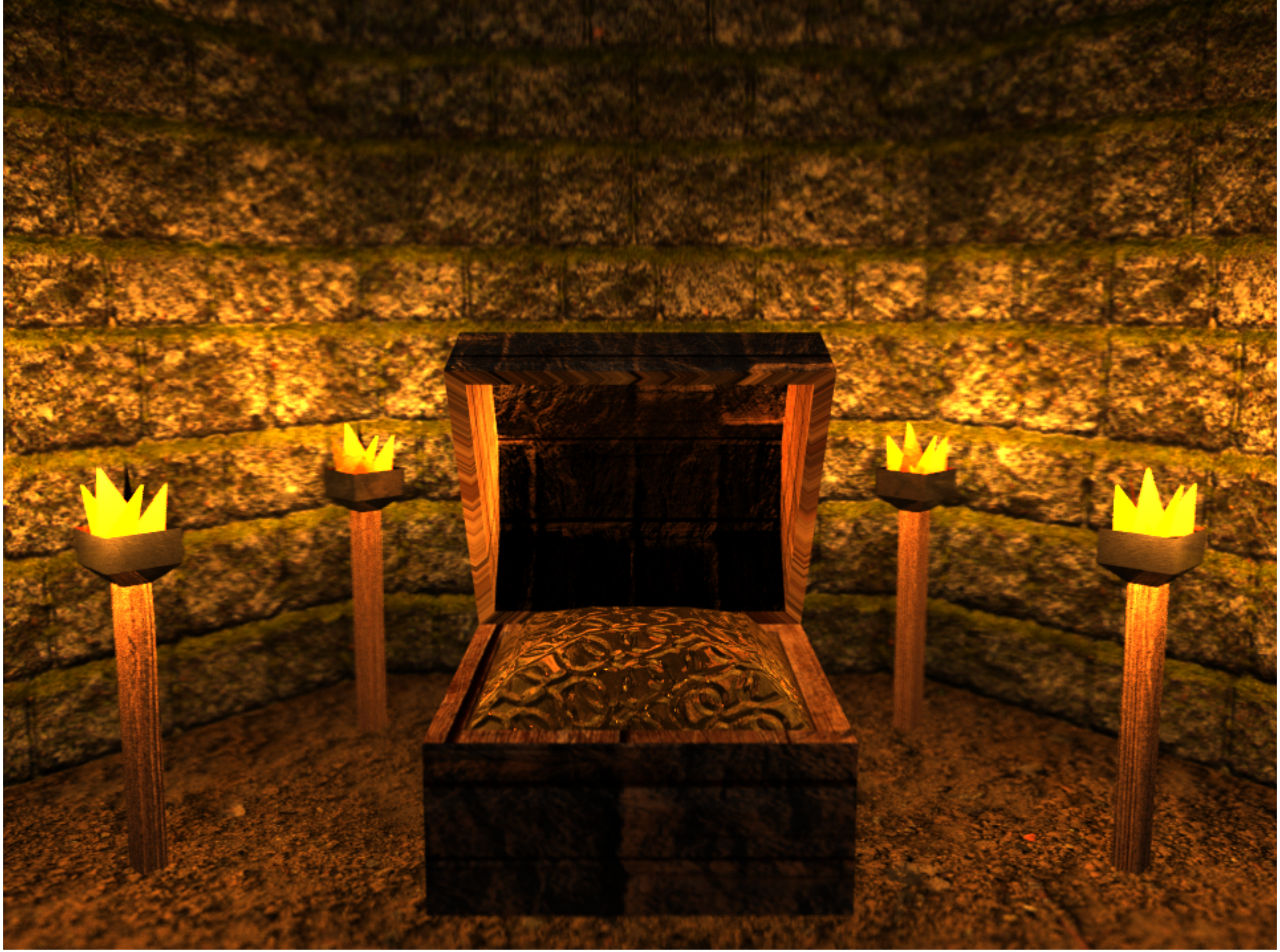
A 4-way tie for first place!



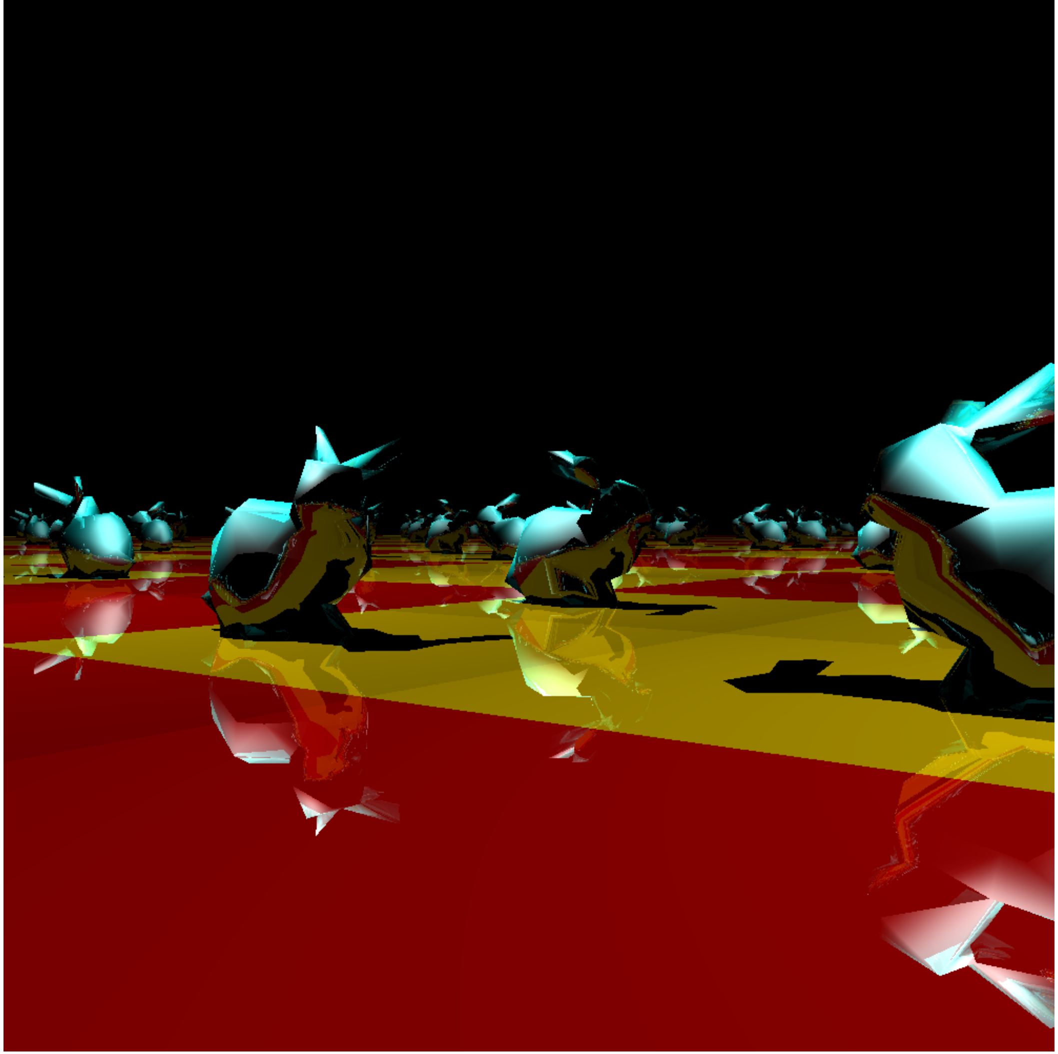
07 - Lucas Binder



12 - Jonathan Derr

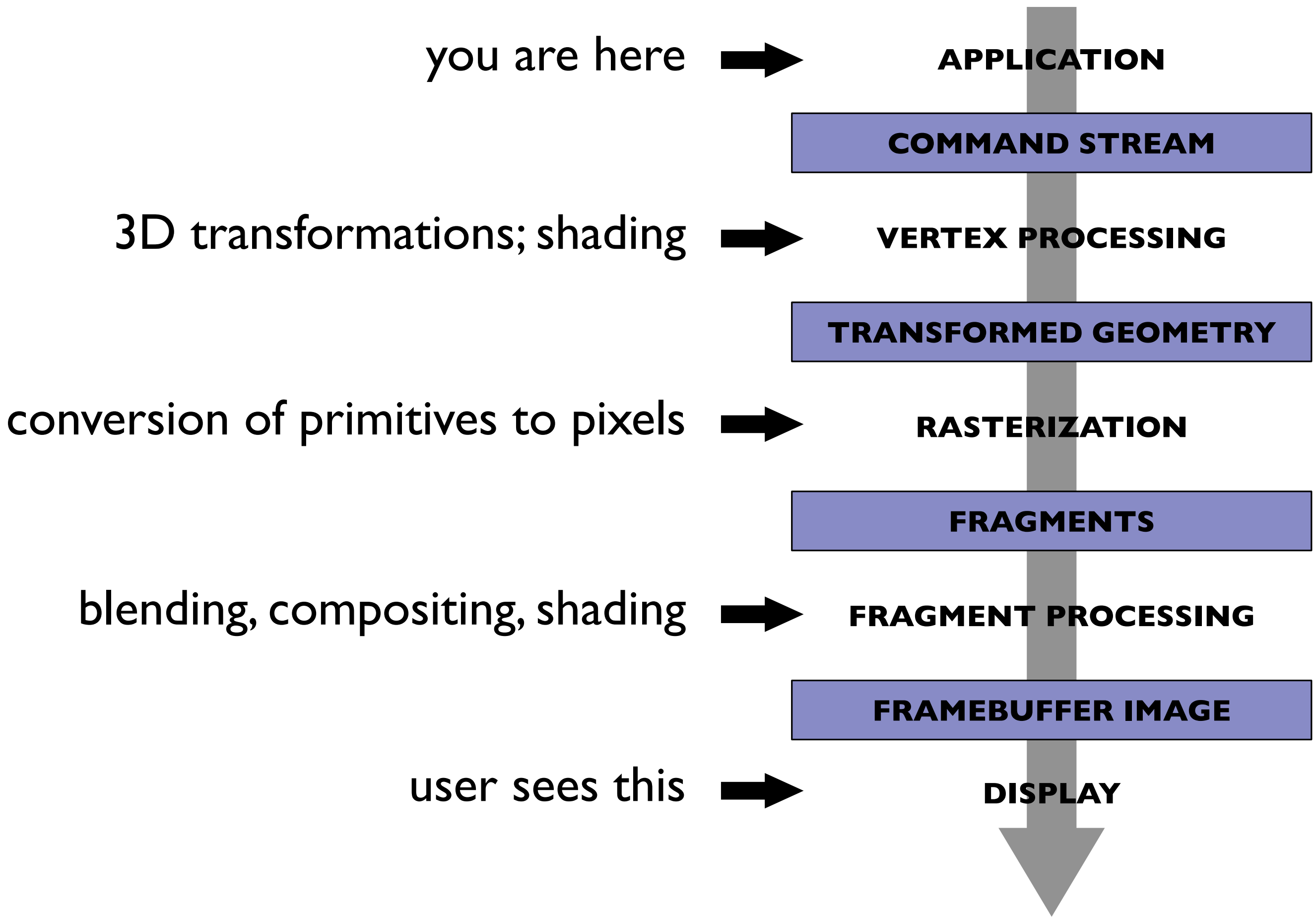


03 - Carter Schmidt



19 - Raiden Van Bronkhorst

Graphics Pipeline: Overview



OpenGL: Your job, conceptually

- Send buffers full of data to GPU up front.
- Tell GL how to interpret them (triangles, ...)
- GL executes custom-written **vertex shader** program on each vertex (to determine is **location in clip space**) *= normalized device coordinates*
- GL **rasterizes** primitives into pixel-shaped **fragments**
- Execute custom-written **fragment shader** program on each fragment to determine its color.
- GL writes fragment colors to framebuffer pixels; neat things appear on your screen.

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Last time: Hello, Triangle!

- Send geometry by calling `gl` functions
- Write a vertex shader
- Write a fragment shader

in **GLSL**, the GL shader language

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Shader Responsibilities

The **vertex shader's job** is to:

- assign a value to **`gl_Position`**, which specifies the vertex's position
- assign values to any **varying** parameters needed later

The **fragment shader's job** is to:

- assign a value to **`gl_FragColor`***, which specifies the fragment's color

deprecated

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Lab code so far:

```
gl_Position = vec4(Position, 1.0)
```

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rg ba ← transparency (a) α

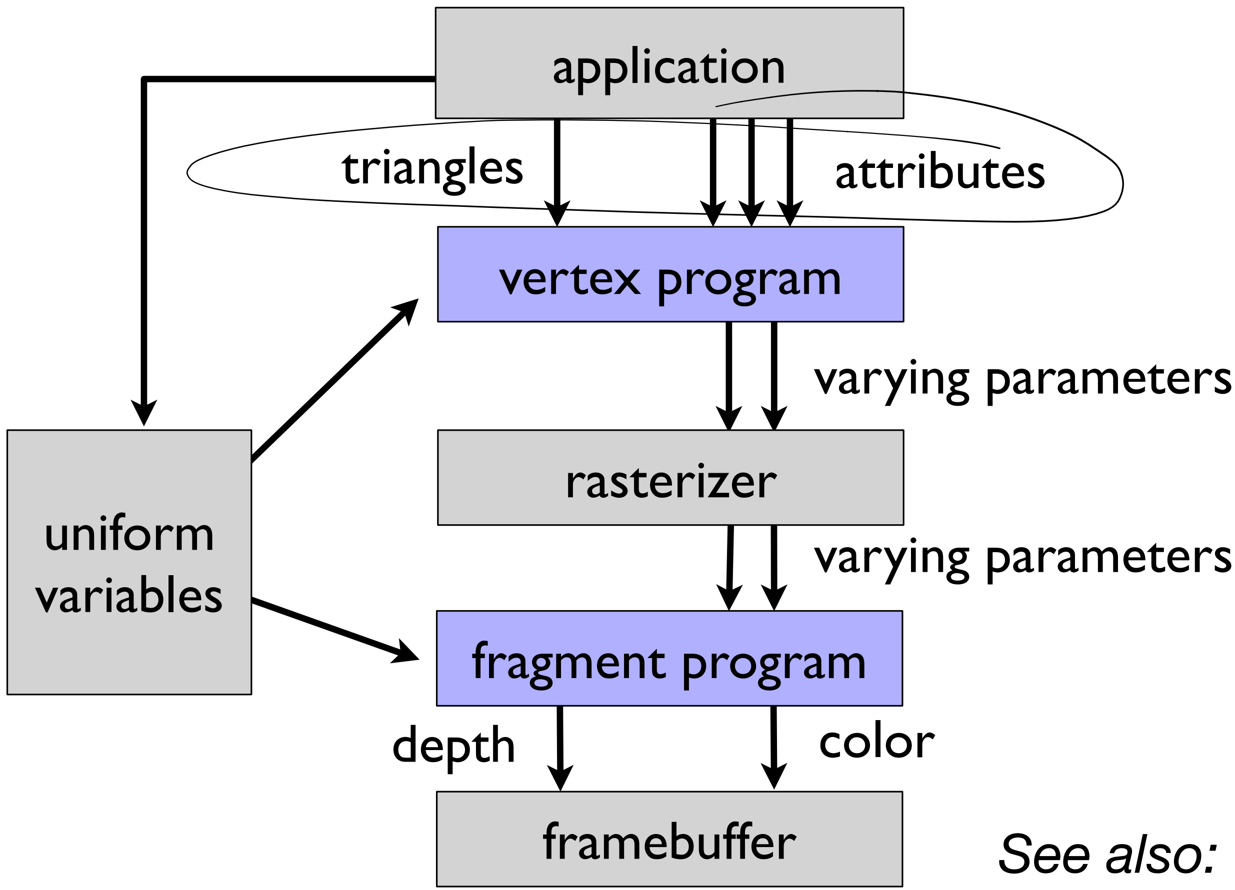
The **fragment shader's job** is to:

- assign a value to **`gl_FragColor`***, which specifies the fragment's color

Lab code so far:

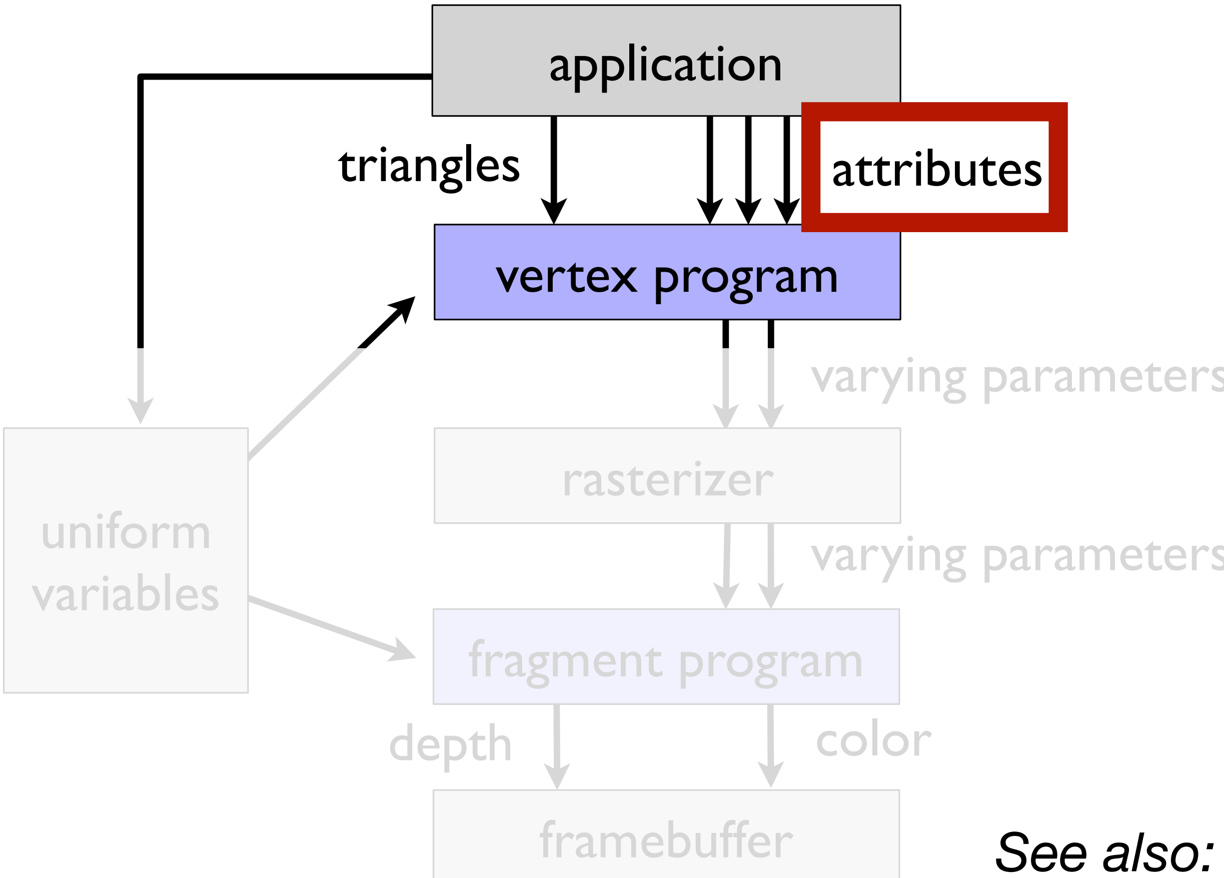
```
gl_FragColor = vec4(0.0, 0.0, 0.0, 1.0)
```

WebGL Data Plumbing: Overview



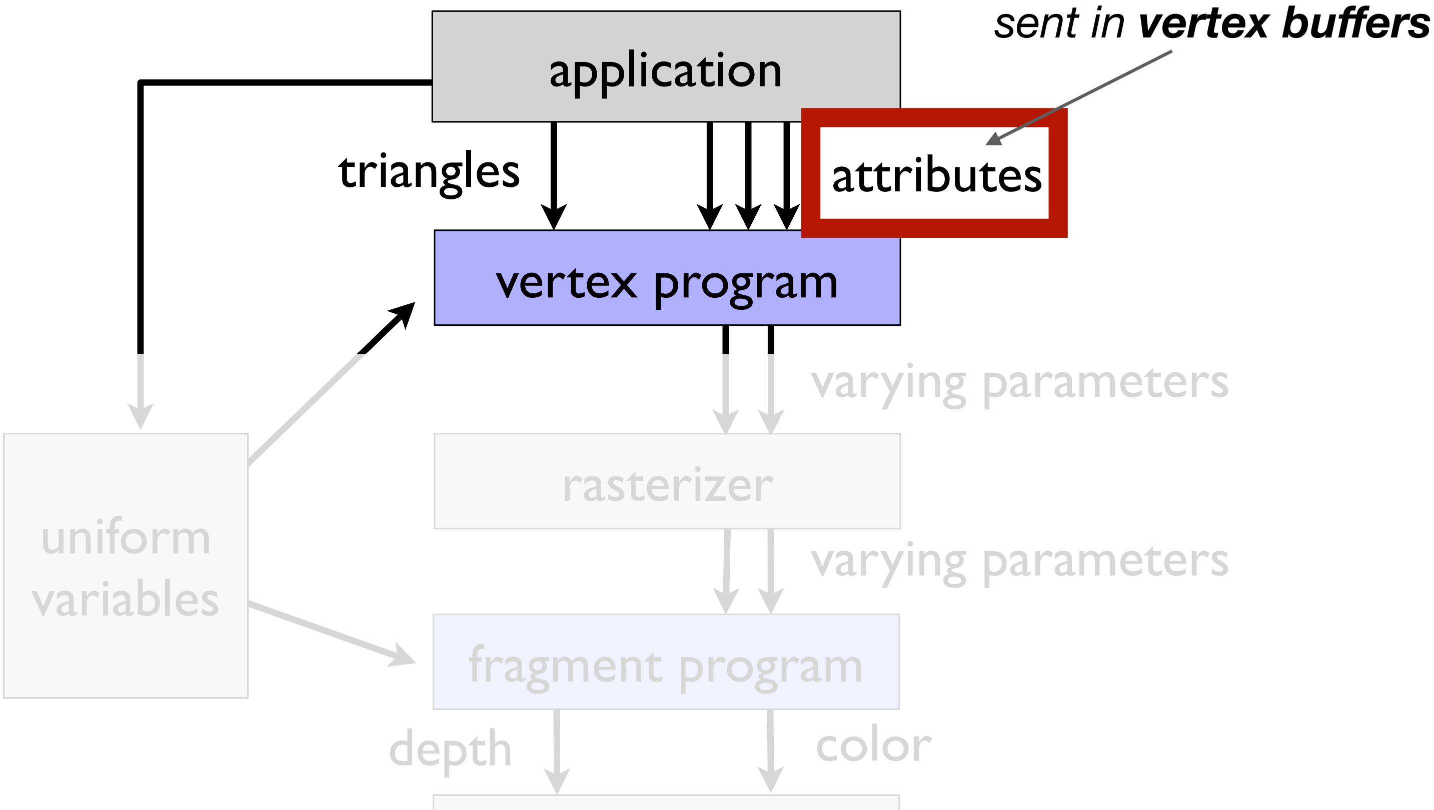
See also: Tuesday lecture notes

WebGL Data Plumbing



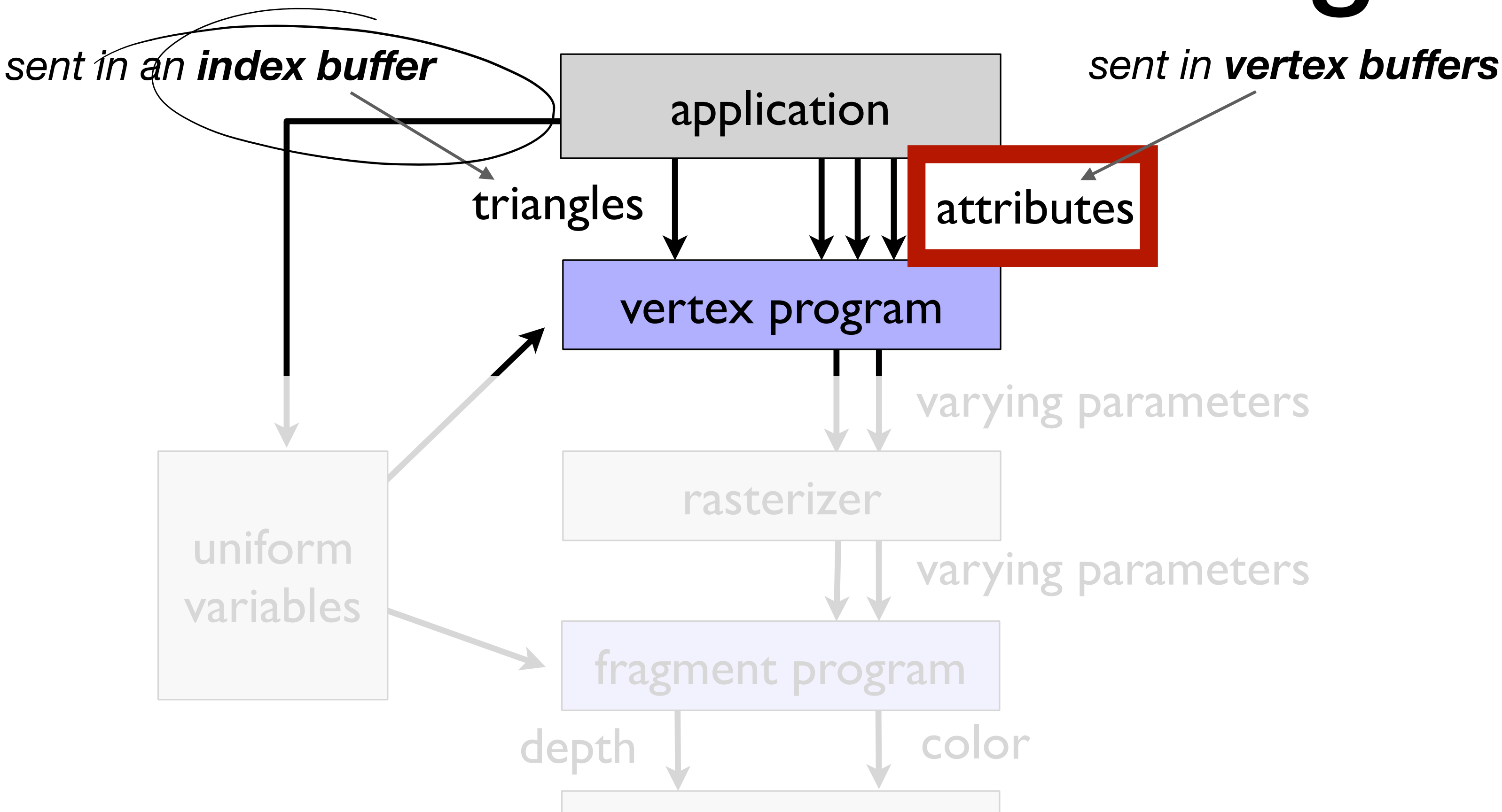
See also: Tuesday lecture notes

WebGL Data Plumbing



See also: Tuesday lecture notes

WebGL Data Plumbing



See also: Tuesday lecture notes

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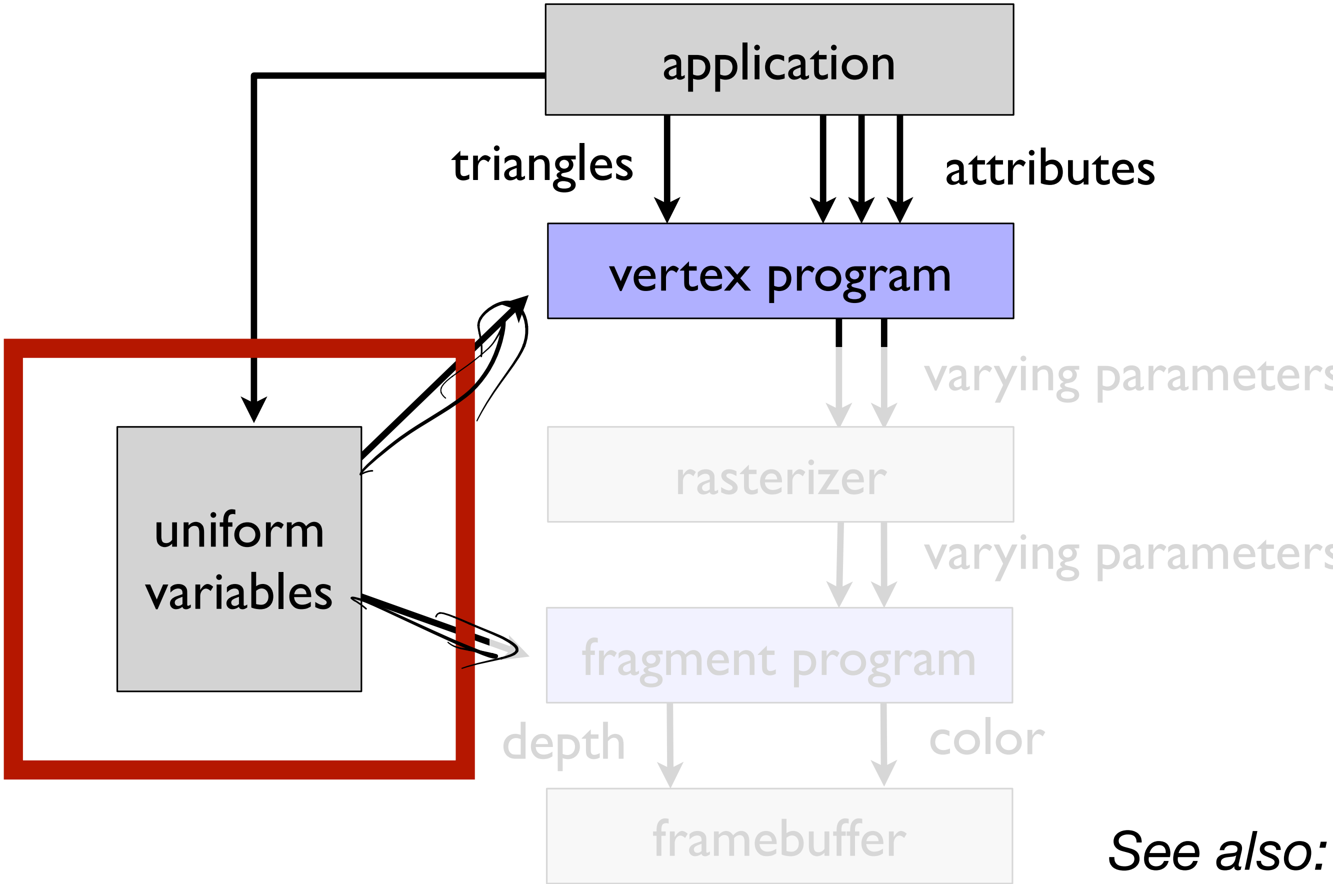


See also: Tuesday lecture notes

GLSL - GL Shader Language

- Built-in types for small vectors/matrices (e.g., `vec3`, `mat4`). They have friendly constructors:

```
vec3 a = vec3(1.0, 1.0, 1.0)
vec4 b = vec4(a, 1.0)
```

- Multiplication does matrix multiplication:

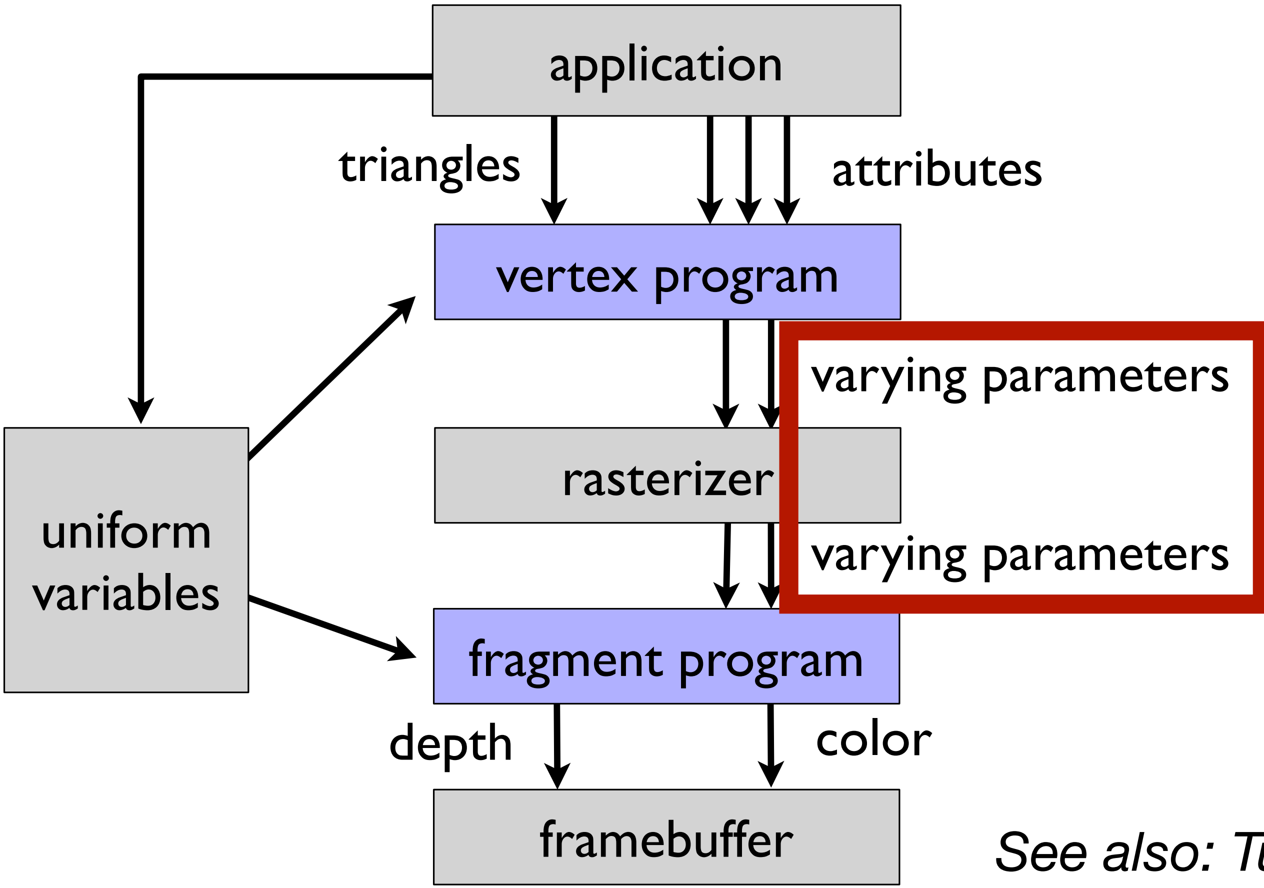
```
// GL matrices are in column-major order
mat2 A = mat2(1.0, 2.0, 3.0, 4.0);
vec2 x = vec2(1.0, 0.0);

vec2 a = A * x; // a = (1,2)
```

Task 2: Add a uniform

- Add a uniform variable called `Matrix` containing a 4x4 matrix
- In the vertex shader, multiply the `Position` attribute of the vertex by the `Matrix` to move the triangle vertices.

Terminology: data plumbing



See also: Tuesday lecture notes

GLSL - GL Shader Language

- `varyings` are declared in both the Vertex shader and in the Fragment shader.
  - The vertex shader sets their values for each vertex, then the rasterizer **interpolates** their values for each fragment and passes to the fragment shader.
- By convention, `varying` names are usually chosen to begin with `v`, such as `vColor` or `vNormal`

Task 3: Add a varying

- Set up a `varying` parameter to set the color at each vertex
- Use the interpolated values in the fragment shader to set each fragment's color.

Rendering Realistic Images

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- We have a pipeline that gives us access to the compute power of shaders and does a bunch of nice things for us.

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Rendering Realistic Images

- We have a pipeline that gives us access to the compute power of shaders and does a bunch of nice things for us.
- We know how to get data in and out
- How do we realistic-looking images using shading models like Lambertian and Blinn-Phong?

but first, a rant about terminology

Phong shading Lambertian shading in the fragment shader

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- Shade (v.): determine color of a pixel

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basically all of computer graphics...

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  flat shading, Gouraud shading, Phong shading

Flat shading (interpolation)

- Shade using the real normal of the triangle
  - same result as ray tracing a bunch of triangles without normal interpolation
- Leads to constant shading and faceted appearance
  - truest view of the mesh geometry

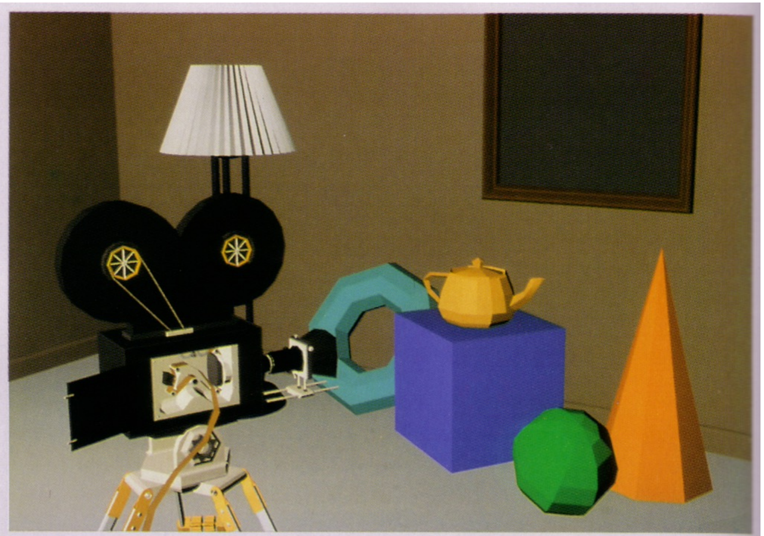


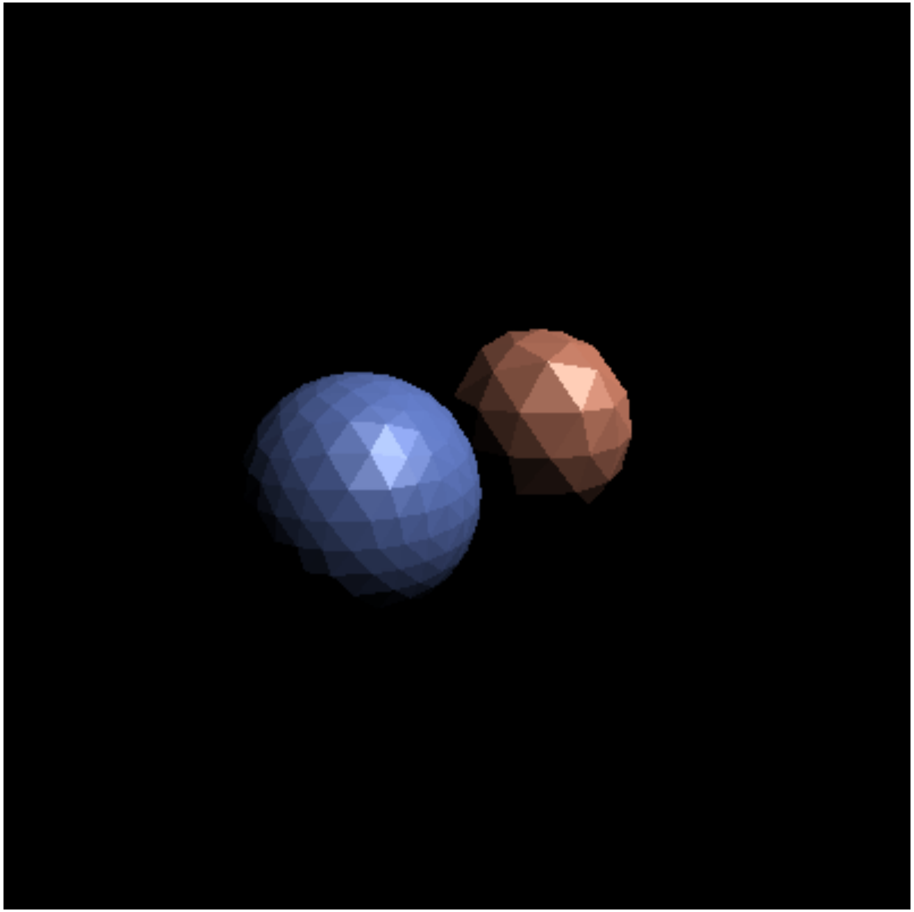
Plate II.29 *Shutterbug.* Individually shaded polygons with diffuse reflection (Sections 14.4.2 and 16.2.3). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

Pipeline for flat shading

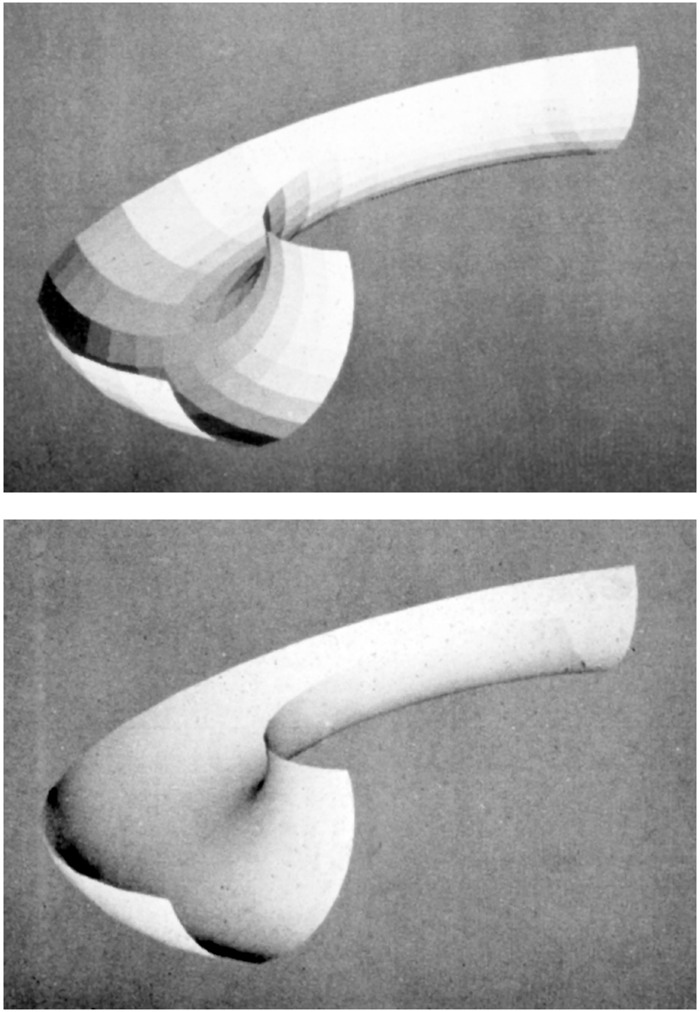
- Vertex stage (input: position / vtx; color and normal / tri)
  – transform position and normal (object to eye space)
  – compute shaded color per triangle using normal
  – transform position (eye to screen space)
- Rasterizer
  – interpolated parameters: z' (screen z)
  – pass through color
- Fragment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

Result of flat-shading pipeline



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"



[Gouraud thesis]

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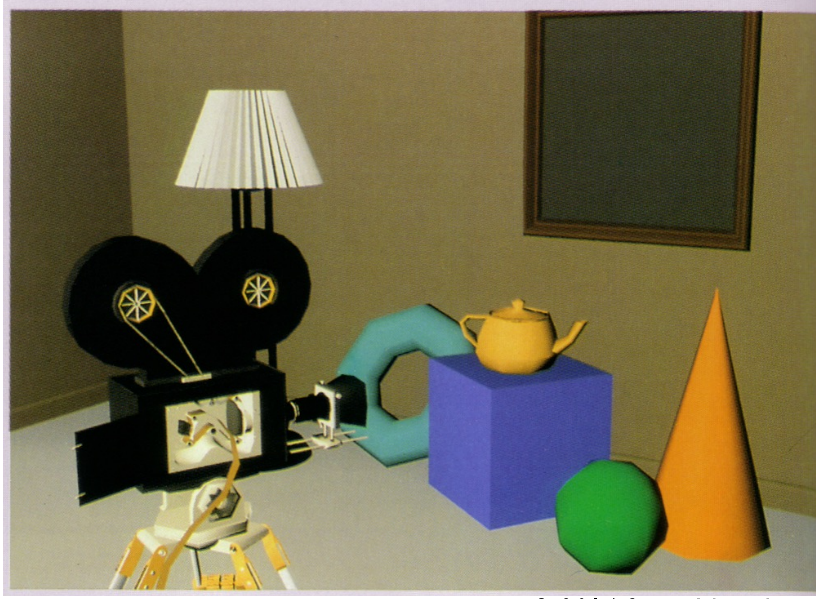
Plate II.30 *Shutterbug.* Gouraud shaded polygons with diffuse reflection (Sections 14.4.3 and 16.2.4). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

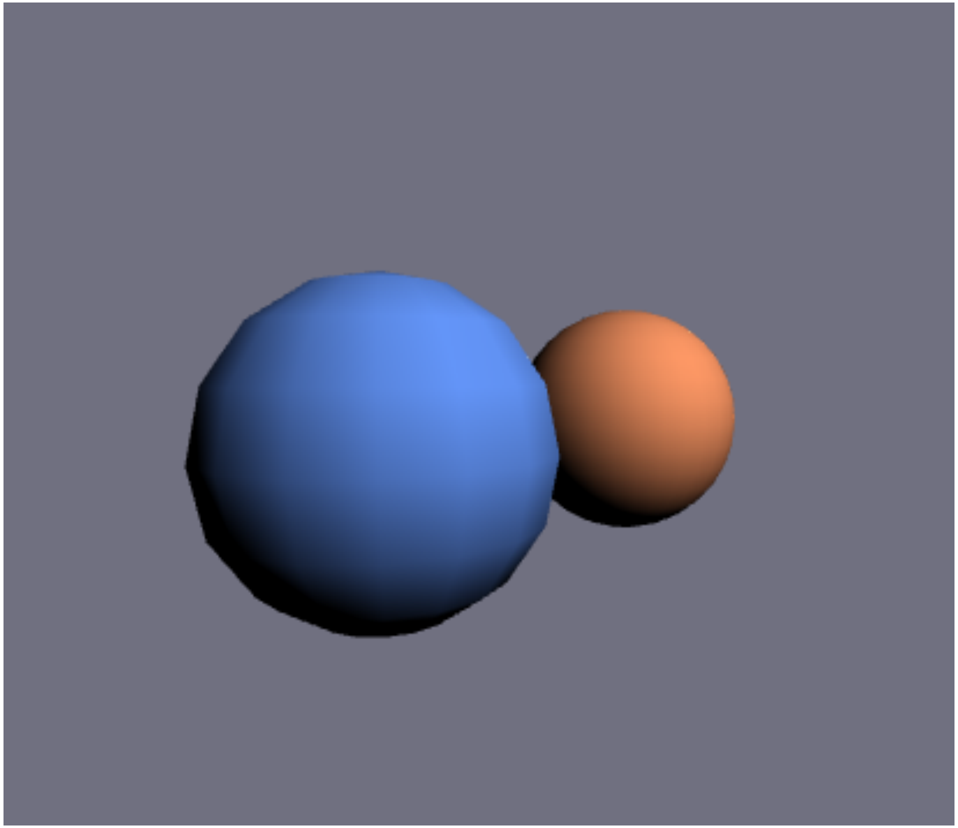


[Foley et al.]

Pipeline for Gouraud shading

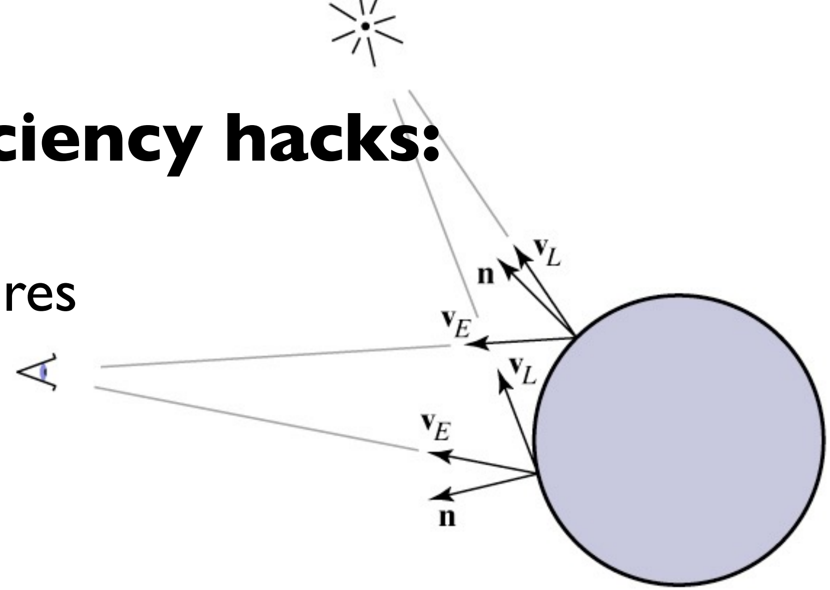
- Vertex stage (input: position, color, and normal / vtx)
  – transform position and normal (object to eye space)
  – compute shaded color per vertex
  – transform position (eye to screen space)
- Rasterizer
  – interpolated parameters: z' (screen z); r, g, b color
- Fragment stage (output: color, z')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

Result of Gouraud shading pipeline



Demo

Some possible efficiency hacks:



- Blinn-Phong model requires knowing
  - normal
  - light direction
  - view direction

- Hack: use directional lights so **l** doesn't change

- Hack: pretend viewer is infinitely distant so view direction doesn't change either.

Some possible efficiency hacks:

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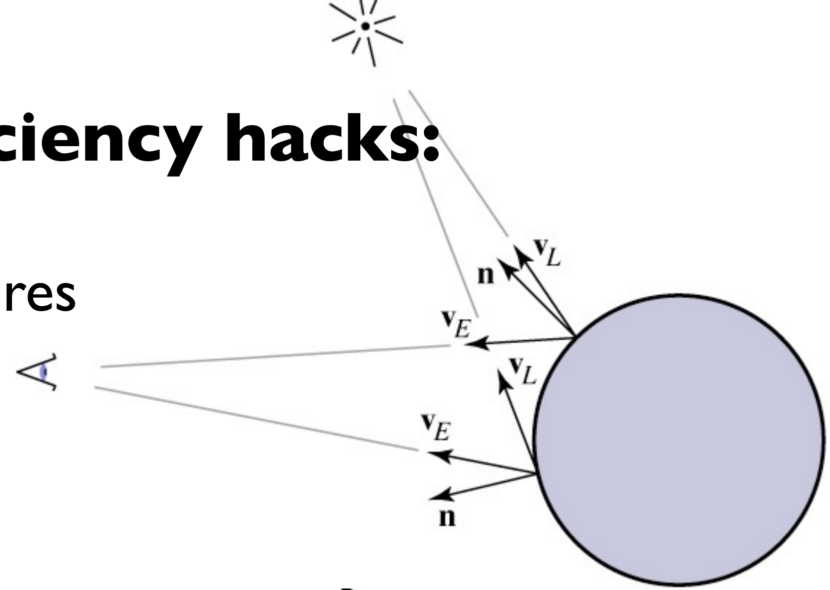

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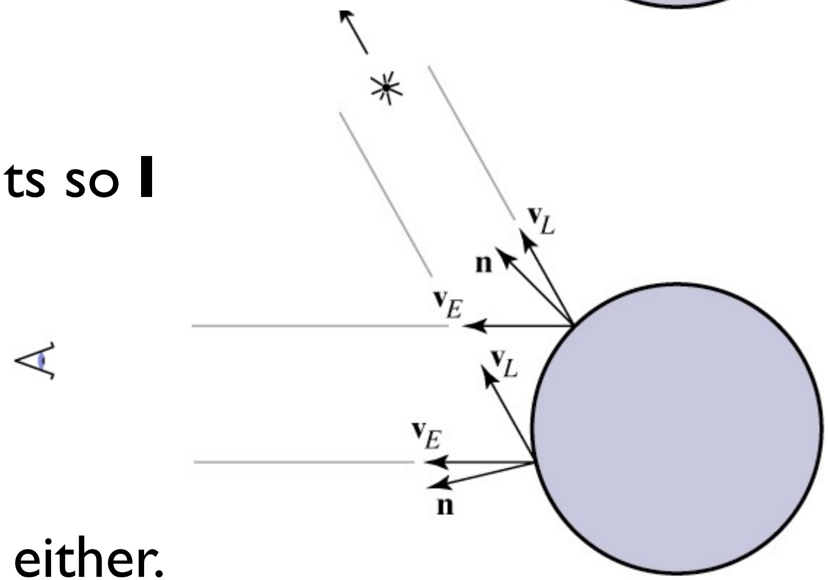


- Hack: pretend viewer is infinitely distant so view direction doesn't change either.

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
  - (demo)

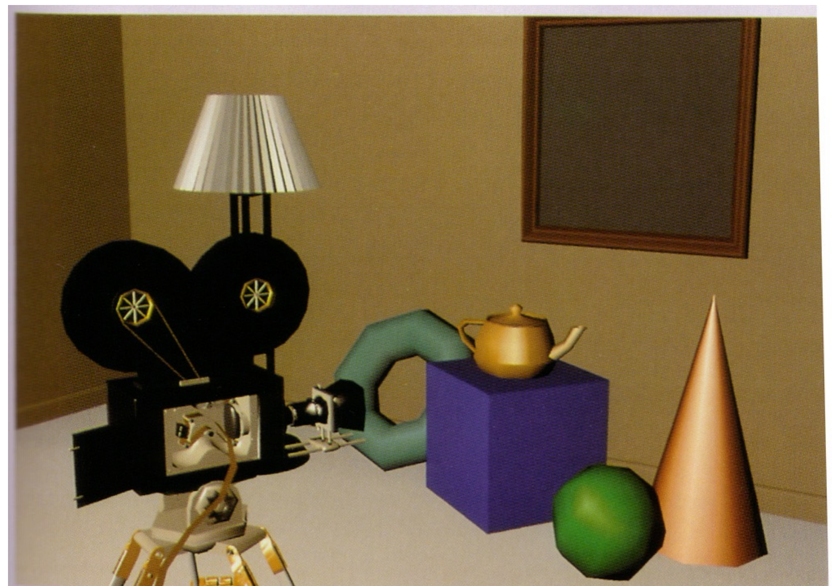


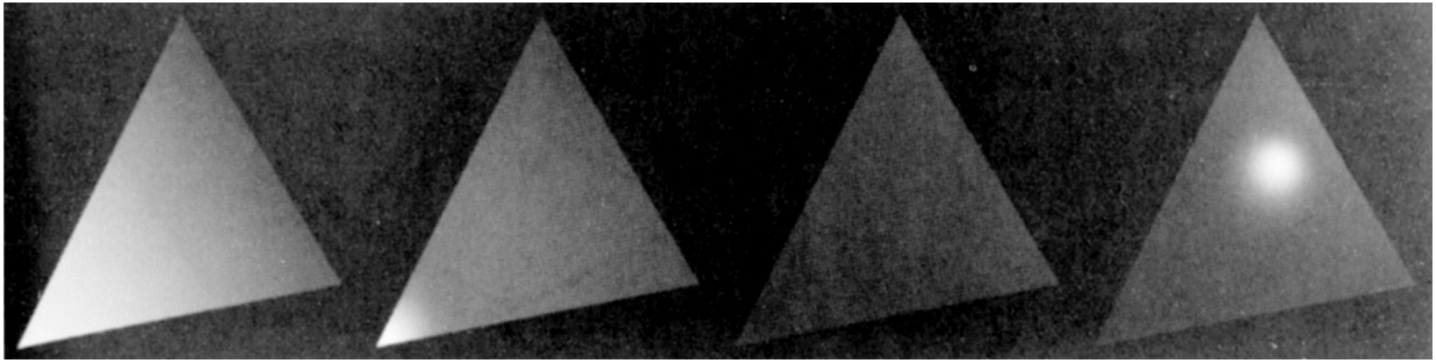
Plate II.31 *Shutterbug.* Gouraud shaded polygons with specular reflection (Sections 14.4.4 and 16.2.5). (Copyright © 1990, Pixar. Rendered by Thomas Williams and H.B. Siegel using Pixar's PhotoRealistic RenderMan™ software.)

[Foley et al.]

(*not the same thing as Blinn-Phong reflection)

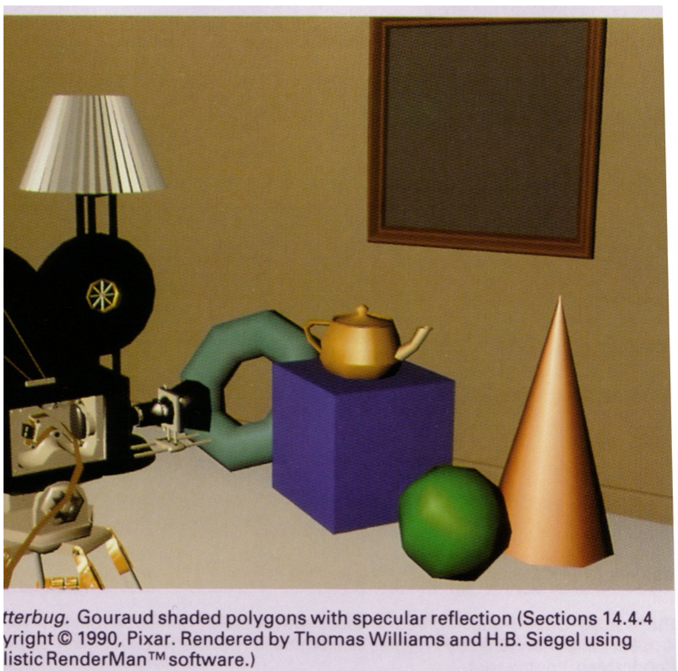
Per-pixel (Phong*) shading

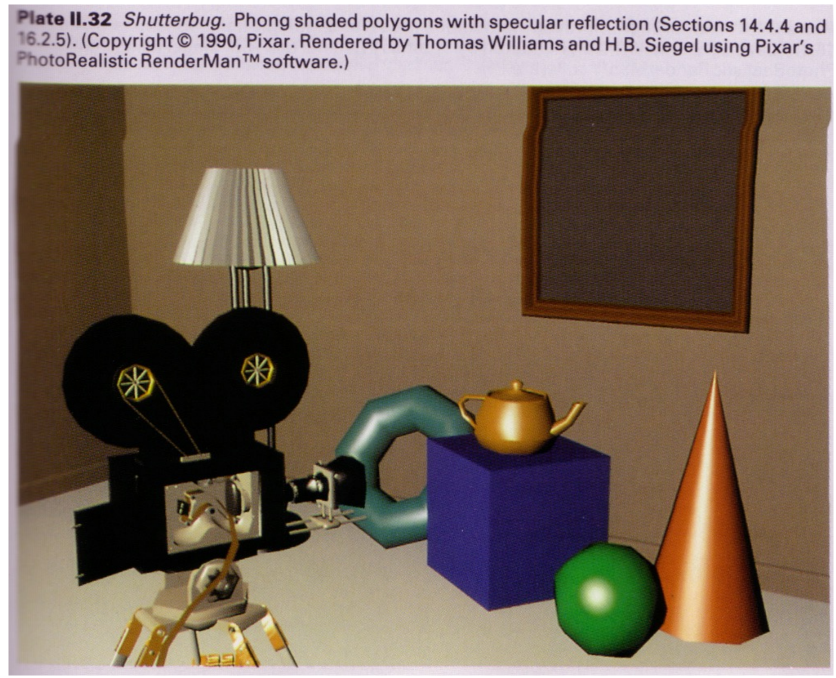
- Get higher quality by interpolating the normal
  - just as easy as interpolating the color
  - but now we are evaluating the illumination model per pixel rather than per vertex (and normalizing the normal first)
  - in pipeline, this means we are moving illumination from the vertex processing stage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



Per-pixel (Phong) shading

- Bottom line: produces much better highlights



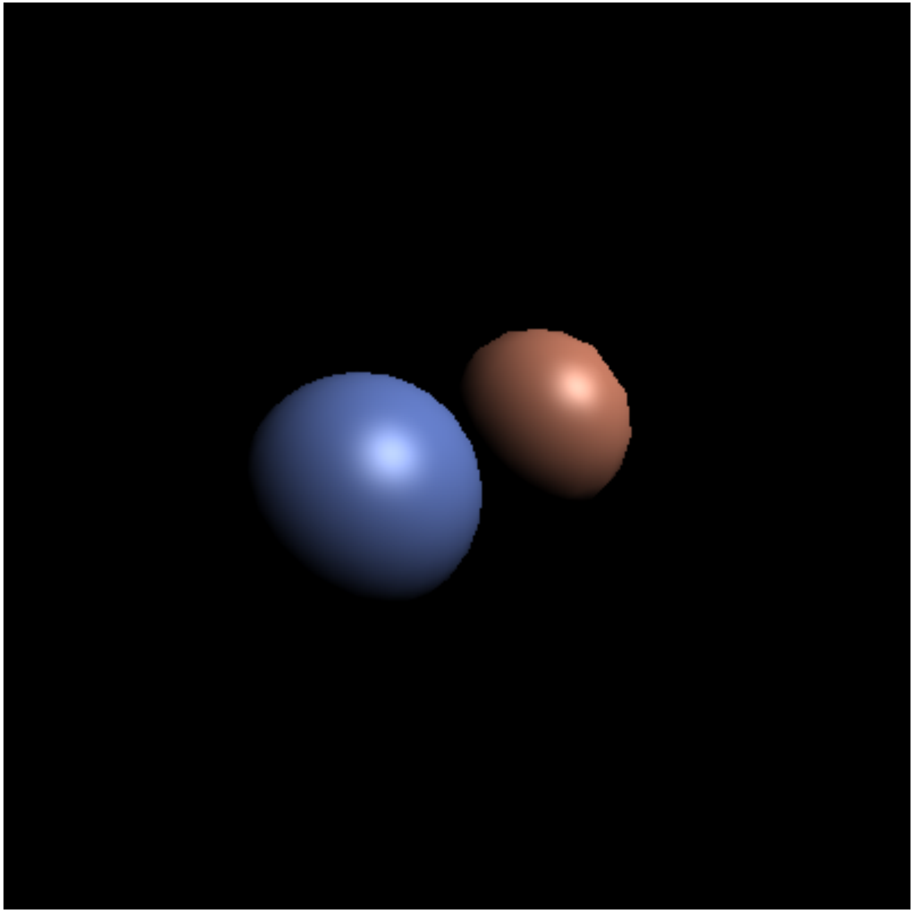


[Foley et al.]

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

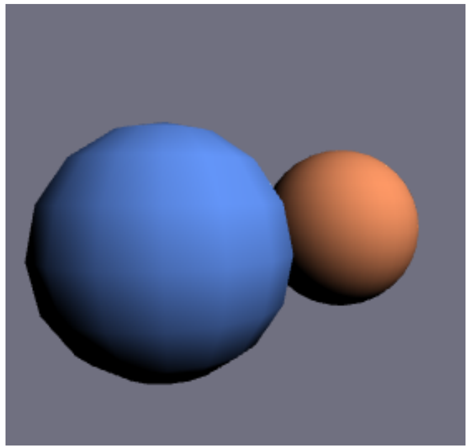
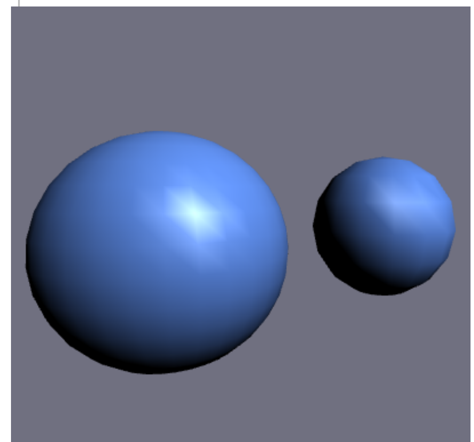


(demo)

Summary: Shading and Interpolation Techniques

reflection

interpolation

	Lambertian	Blinn-phong
Gouraud		
Phong