VGP351 – Week 9

- Agenda:
  - Quiz #4
  - Framebuffer blending
    - Transparency
    - Multipass rendering
  - Stencil buffer
  - Fog
  - Assignments:
    - #2 due
    - Start #3

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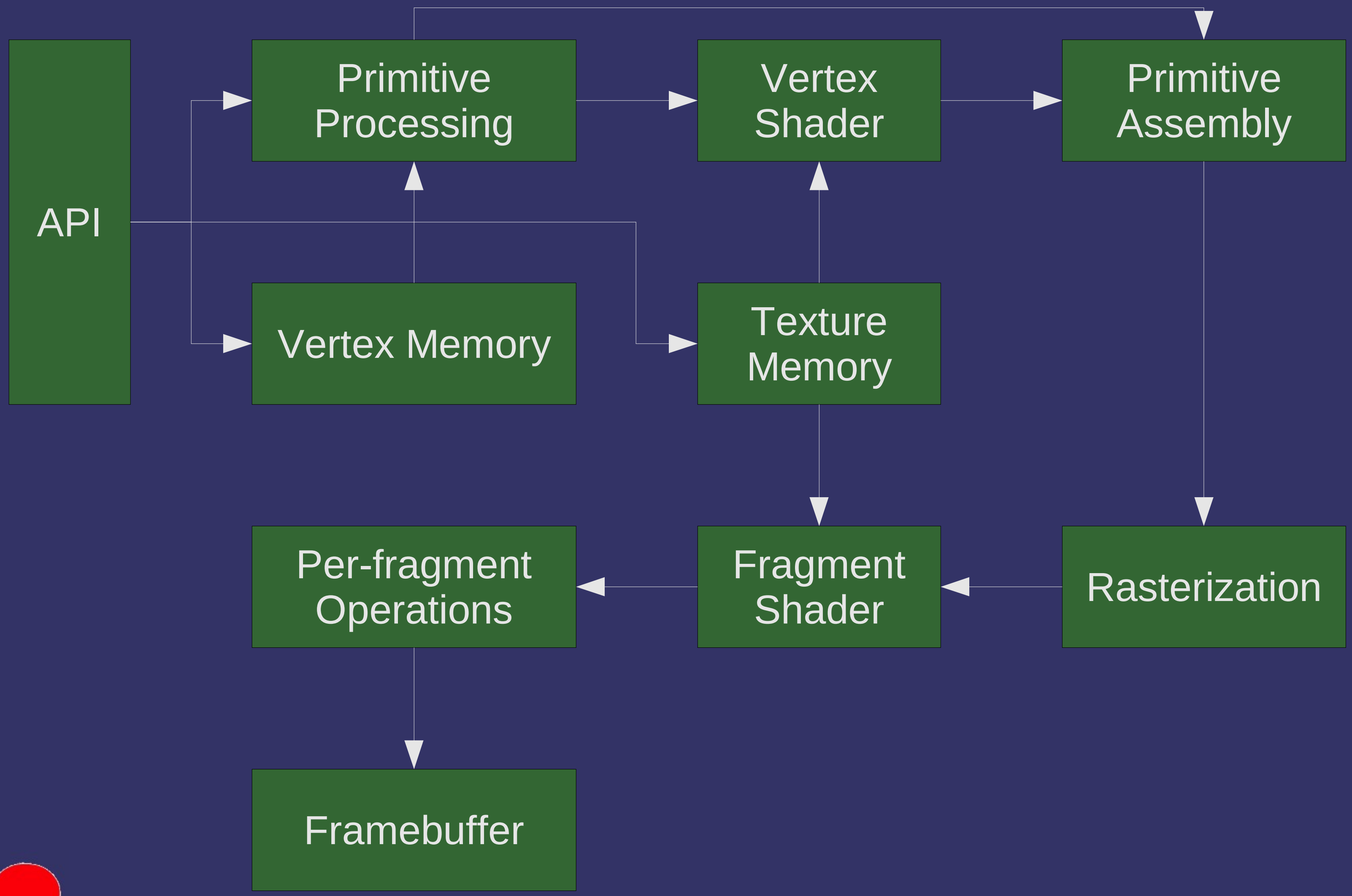
Graphics Pipeline



API

Primitive Processing

Vertex Shader

Primitive Assembly

Vertex Memory

Texture Memory

Per-fragment Operations

Fragment Shader

Rasterization

Framebuffer

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Blending

- Last of the “per-sample” operations
  - Color output from fragment shader is combined with color already in the framebuffer
- *Many* uses!
  - Translucent / transparent objects
    - Difficult problem in the general case...objects must be rendered in the correct order and cannot intersect
  - Anti-aliasing
    - Especially useful for fonts and 2D “stroked” objects
  - 2D compositing
    - Quartz (Mac OS X), Aero (Vista), compiz (X Windows)
  - Multi-pass rendering

Blending

$$C_{src} \times F_{src} + C_{dst} \times F_{dst}$$

Color from the fragment shader

Color already in the framebuffer

Blending Function

$$C_{src} \times F_{src} + C_{dst} \times F_{dst}$$

Source blending function

Destination blending function

- `GL_SRC_ALPHA`
- `GL_SRC_COLOR`
- `GL_DST_ALPHA`
- `GL_DST_COLOR`
- `GL_CONSTANT_COLOR`
- `GL_CONSTANT_ALPHA`
  - The above have a “one minus” form: `GL_ONE_MINUS_SRC_ALPHA`
- `GL_ZERO`, `GL_ONE`
- `GL_SRC_ALPHA_SATURATE`
  - Only available as a source factor
  - $F_{src} = \min(A_s, 1 - A_d)$

Blending Function

- Blend function set with:

```
void glBlendFuncSeparate(
    GLenum srcRGB,    GLenum dstRGB,
    GLenum srcAlpha, GLenum dstAlpha);
```

- Blend constant color set with:

```
void glBlendColor(GLclampf red,
    GLclampf green,
    GLclampf blue,
    GLclampf alpha);
```

Blending Equation

$$C_{src} \times F_{src} + C_{dst} \times F_{dst}$$

Blending equation

- `GL_FUNC_ADD`
- `GL_FUNC_SUBTRACT`
- `GL_FUNC_REVERSE_SUBTRACT`
- `GL_MIN`
- `GL_MAX`
  - Min and max equations do *not* modulate with the blend functions

Blending Equation

- Blending equation set with

```
void glBlendEquationSeparate(GLenum modeRGB,
    GLenum modeAlpha);
```

Alpha Buffer

- If the desired blend modes use destination alpha, the color buffer must have alpha bits
  - As usual, ask SDL to allocate an appropriate buffer

```
SDL_GL_SetAttribute(SDL_GL_ALPHA_SIZE, 8);
```

  - If there is no explicit destination alpha value, the destination alpha value is implicitly 1.0

Transparency

- Want to see through certain objects

Image from Enemy Territory: Quake Wars, © Copyright 2007 id Software, Inc.

Transparency

- Transparent / translucent objects affect the appearance of objects behind them
  - Multiple levels of transparent objects accumulate additional effects

Transparency

- Rendering must be performed in a specific order
  - Render all non-transparent objects first
  - Render transparent objects in back-to-front order

Alpha Test

- Sometimes transparency is used to simulate holes in objects

Image from Enemy Territory: Quake Wars, © Copyright 2007 id Software, Inc.

Alpha Test

- *Much* faster to draw a single polygon with a texture than to draw many lines or small polygons
  - Observe that each fragment is either completely opaque ($\alpha = 1.0$) or completely transparent ($\alpha = 0.0$)

Alpha Test

- Optimize by killing fragments with α below a certain threshold
  - Used to be performed in an extra per-sample operation call *alpha test*

```
if (calculated_color.a <= threshold)
    discard;
```

Multi-pass Rendering

- What do you do when the desired shading effect requires more resources than the hardware has available?

Multi-pass Rendering

- What do you do when the desired shading effect requires more resources than the hardware has available?
  - Use a different effect...probably with lower quality
  - Render in multiple passes

Multi-pass Rendering

- Divide the shader into multiple parts
  - Partition at places where blending can combine partial results
  - Example: Perform diffuse textured pass. Configure blender to add fragment color to framebuffer. Finally, perform specular-only pass.

Multi-pass Rendering

- Why do we want to render in as few passes as possible?

Multi-pass Rendering

- Why do we want to render in as few passes as possible?
  - Multiple passes are almost always slower
    - Memory for each pixel must be accessed multiple times
    - Geometry must be processed multiple times
    - Usually have to change state (e.g., textures, blend modes) between passes

Multi-pass Rendering

- Why do we want to render in as few passes as possible?
  - Less accurate
    - Framebuffer usually only has 8 bits per component
      - Can work around this at the cost of an extra post-process pass
    - Shader math is *at least* 24-bit floating point per component

Multi-pass Rendering

- Why do we want to render in as few passes as possible?
  - Can't always achieve the desired result
    - Doesn't work well with translucent objects
    - Can't always partition into parts that can be combined with the blender

References

http://en.wikipedia.org/wiki/Alpha_compositing

- Good background on general alpha blending theory

http://developer.nvidia.com/object/order_independent_transparency.html

- Solves the ordering problem, but is complex to implement
- We'll come back to it next term :)

Peltzer, K. “Rendering Countless Blades of Waving Grass.” In GPU Gems. Ed. Randima Fernando. Upper Saddle River, NJ: Addison-Wesley Professional, April 1, 2004. http://developer.download.nvidia.com/books/HTML/gpugems/gpugems_ch07.html

Stencil Buffer

- Extra per-pixel buffer containing integer values
  - Values in stencil buffer can be used to control drawing
  - Often interleaved with depth buffer
    - 24-bit depth and 8-bit stencil is most common
- To use stencil buffer, ask SDL to create one:

```
SDL_GL_SetAttribute(SDL_GL_STENCIL_SIZE, 1);
```

Stencil Test

- Drawing can be controlled via stencil test
  - If the test passes, drawing proceeds
  - If the test fails, the fragment is not drawn
  - Enable stencil test with:

```
glEnable(GL_STENCIL_TEST);
```

  - Configure stencil test with:

```
glStencilFuncSeparate(GLenum face, GLenum func,
    GLint ref, GLuint mask);
```

  - The names are different, but this is conceptually identical to the depth test

Stencil Test

```
glStencilFuncSeparate(GLenum face, GLenum func,
    GLint ref, GLuint mask);
```

- `face` specifies whether front, back, or both front and back face state is set
- `func` specifies the test function: `GL_NEVER`, `GL_LESS`, `GL_LEQUAL`, `GL_GREATER`, `GL_GEQUAL`, `GL_EQUAL`, `GL_NOTEQUAL`, and `GL_ALWAYS`
- `ref` specifies the reference value for the stencil test
- `mask` specifies a mask that is ANDed with both the reference value and the stored stencil value when the test is done

Stencil Test

- Occurs per-fragment, just like the depth test
  - Stencil test occurs *before* the depth test
  - Per-fragment operation is:

    `(ref & mask) op (stencil & mask)`

  - Remember: `ref`, `op`, and `mask` all depend on the polygon's facing!

Stencil Operation

- Stencil buffer values are modified per-fragment depending on the state of the fragment:
  - Fragment failed the stencil test
  - Fragment passed the stencil test but failed the depth test
  - Fragment passed the stencil test and passed the depth test

Stencil Operation

- Eight possible operations:
  - `GL_KEEP` – Keep existing value
  - `GL_ZERO` – Set value to zero
  - `GL_REPLACE` – Replace value with a reference value
  - `GL_INCR` – Increment value, clamp to max
    - `GL_INCR_WRAP` – Increment value, wrap to zero
  - `GL_DECR` – Decrement value, clamp to zero
    - `GL_DECR_WRAP` – Decrement value, wrap to max
  - `GL_INVERT` – Bitwise inversion of value
- Result is always masked with the stencil mask

Stencil Operation

- All three operations set using:

```
void glStencilOpSeparate(GLenum face,
    GLenum sfail, GLenum dpfail,
    GLenum dppass);
```

  - `face` specifies whether front, back, or both front and back face state is set
  - `sfail` specifies the operation for fragments that fail the stencil test
  - `dpfail` specifies the operation for fragments that fail the depth test
  - `dppass` specifies the operation for fragments that pass the stencil and depth tests

Stencil Buffer

- Clear the stencil buffer with the `GL_STENCIL_BUFFER_BIT` to `glClear`:

  ```
  glClear(GL_STENCIL_BUFFER_BIT);
  ```

  - If you're going to also clear the depth buffer, ***always*** do it at the same time as the stencil buffer!
    - Hardware is optimized for clearing depth and stencil together
    - Clearing them separately is often much, *much* slower
- Clear value is specified with `glStencilClear`

Stencil Buffer

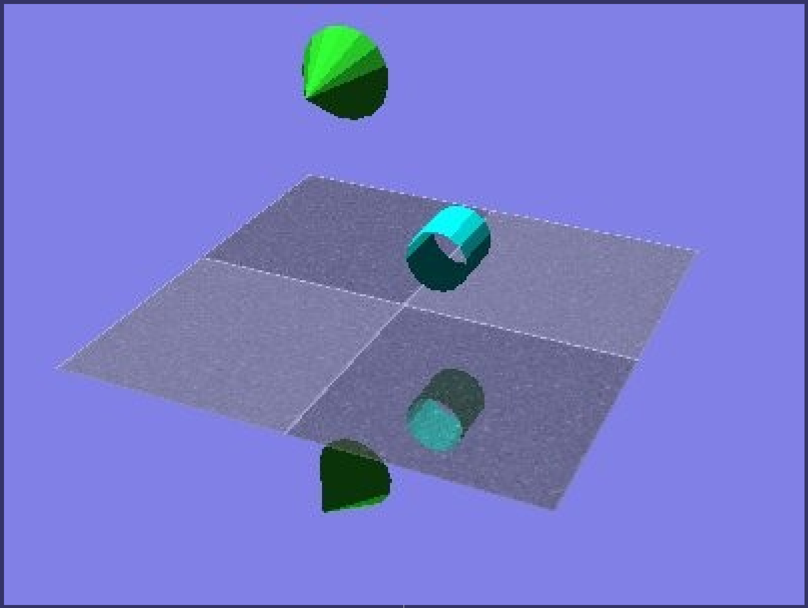
- Writing to bits of the stencil buffer is controlled by *another* write mask

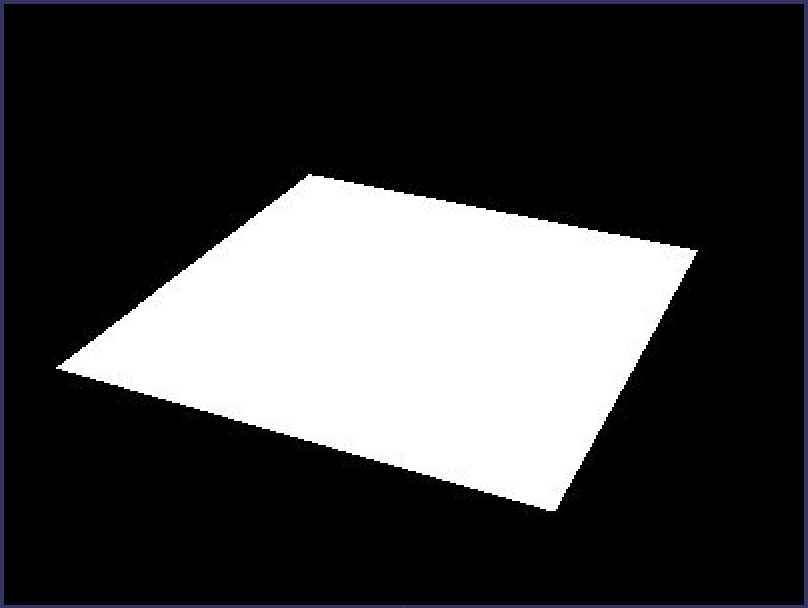
```
void glStencilMask(GLuint mask);
```

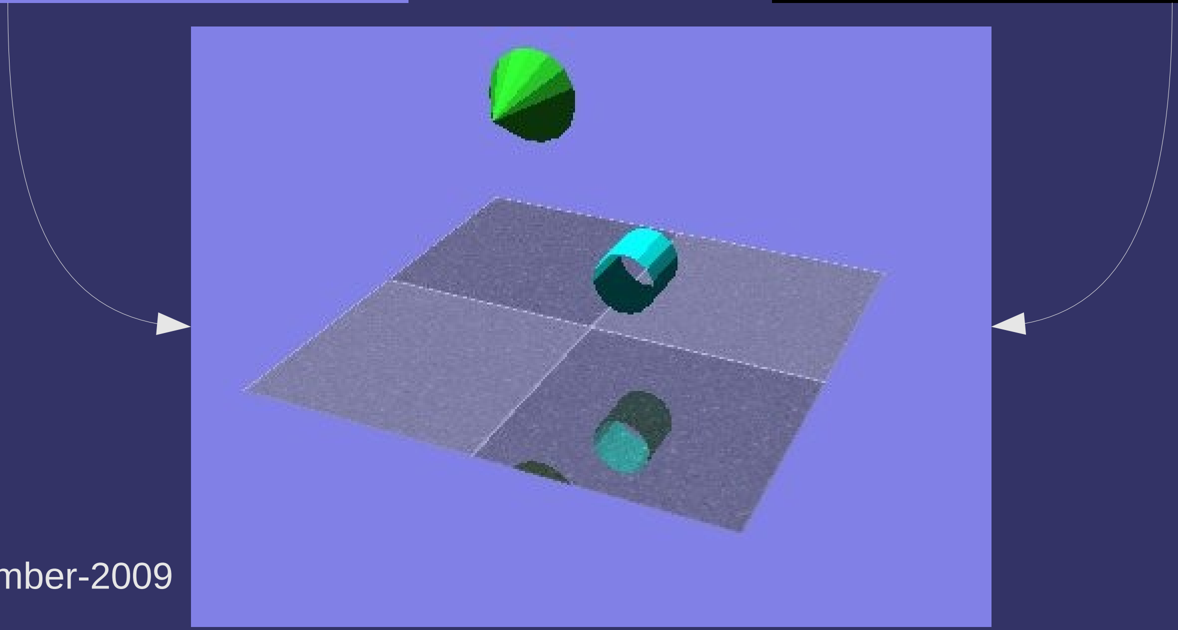
Stencil Buffer

```
glClearStencil(0);
glClear(GL_STENCIL_BUFFER_BIT | GL_DEPTH_BUFFER_BIT
        | GL_COLOR_BUFFER_BIT);
glEnable(GL_STENCIL_TEST);

/* Write 1 to stencil where polygon is drawn.
 */
glStencilFuncSeparate(GL_FRONT_AND_BACK,
                      GL_ALWAYS, 1, ~0);
glStencilOpSeparate(GL_FRONT_AND_BACK,
                    GL_KEEP, GL_KEEP, GL_REPLACE);
draw_some_polygon();

/* Draw scene only where stencil buffer is 1.
 */
glClear(GL_DEPTH_BUFFER_BIT | GL_COLOR_BUFFER_BIT);
glStencilFuncSeparate(GL_FRONT_AND_BACK,
                      GL_EQUAL, 1, ~0);
glStencilOpSeparate(GL_FRONT_AND_BACK,
                    GL_KEEP, GL_KEEP, GL_KEEP);
draw_scene();
```

Stencil Buffer







Stencil Buffer

Image from Quake 3, © Copyright 1999 id Software, Inc.

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Fog

- Typical fog... objects father away from the camera are more fog colored
  - Eventually objects disappear into the fog
  - Objects closer than some minimum distance may have no fog coloring applied

Fog

- Can be used for other, related effects:
  - In dark environments, distant objects are darker
    - Analogous to distance attenuation for lights
  - Underwater objects fade to the water color
    - The *only* difference is the *color* used for the fog!

Fog

- Simple fog usually works in one of three modes:
  - Linear fog:

$$\frac{f_{end} - p}{f_{end} - f_{start}}$$

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Fog

- Simple fog usually works in one of three modes:
  - Linear fog:

$$\frac{f_{end} - p}{\underbrace{f_{end}}_{\text{Distance where fog ends}} - \underbrace{f_{start}}_{\text{Distance where fog starts}}}$$

Fog

- Simple fog usually works in one of three modes:
  - Linear fog:

$$\frac{f_{end} - p}{f_{end} - f_{start}}$$

  - Exponential fog:

$$e^{(-d \times p)}$$

Fog

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  - Linear fog:

$$\frac{f_{end}-p}{f_{end}-f_{start}}$$

  - Exponential fog:

$$e^{(-d \times p)}$$

Fog density

Fog

- Simple fog usually works in one of three modes:
  - Linear fog:

$$\frac{f_{end}-p}{f_{end}-f_{start}}$$

  - Exponential fog:

$$e^{(-d\times p)}$$

  - Exponential-squared fog:

$$e^{(-d\times p)^2}$$

Fog

- Once the fog factor is calculated, use it to linearly blend between the fragment color and the fog color

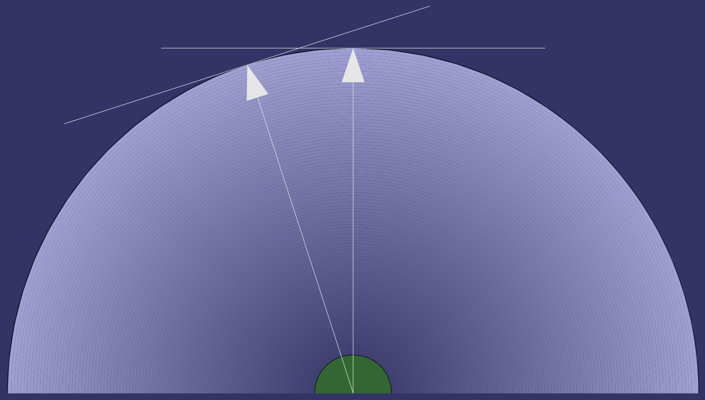
$$C = F \cdot C_{fragment} + (1 - F) \cdot C_{fog}$$

Fog

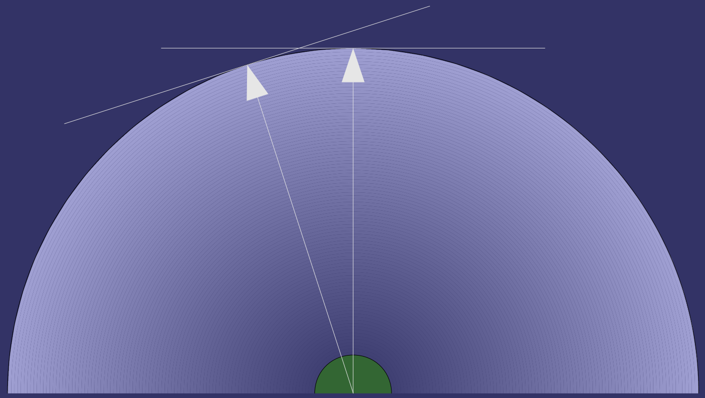
- Where does p come from?

Fog

- Where does p come from?
  - Easy answer: eye-space Z
    - “Off center” points receive less fog than they should



Fog



- Where does p come from?
  - Easy answer: eye-space Z
    - “Off center” points receive less fog than they should
  - Better answer: use eye-space distance
    - More expensive to calculate
    - Still has artifacts when calculated per-vertex

Height-based Fog

- Fog factor given by:

$$e^{-\int_A^B \alpha(t)\,dt}$$

Where:

α is the fog density function

A and B are points in space

  - This integral gives the “optical depth”
  - One simplifying assumption: α depends only on height

Height-based Fog

- Two components to the optical distance between the eye and the fogged point:
  - Change in altitude: $\Delta y = \mathbf{p}_y - \mathbf{e}_y$
  - Distance in the plane: $\Delta d = \sqrt{((\mathbf{p}_x - \mathbf{e}_x)^2 + (\mathbf{p}_z - \mathbf{e}_z)^2)}$
- Two important cases:

$$f = \begin{cases} \Delta d \times \alpha(\mathbf{p}_y) & \Delta y = 0 \\ \sqrt{1 + \left(\frac{\Delta d}{\Delta y}\right)^2} \times \int_{\mathbf{e}_y}^{\mathbf{p}_y} \alpha(\mathrm{y})\,\mathrm{dy} & \Delta y \neq 0 \end{cases}$$

Height-based Fog

- Two components to the optical distance between the eye and the fogged point:
  - Change in altitude: $\Delta y = \mathbf{p}_y - \mathbf{e}_y$
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- Two important cases:

$$f = \begin{cases} \Delta d \times \alpha(\mathbf{p}_y) & \Delta y = 0 \\ \sqrt{1 + \left(\frac{\Delta d}{\Delta y}\right)^2} \times \int_{\mathbf{e}_y}^{\mathbf{p}_y} \alpha(\mathrm{y})\,\mathrm{dy} & \Delta y \neq 0 \end{cases}$$

This is the “standard” fog case!

Height-based Fog

- At each index n of a look-up table, store the value:

$$\int_{-\infty}^{n} \alpha(y)\, dy$$

- To calculate the integral over $\mathbf{e}_y$ to $\mathbf{p}_y$, simply calculate `table[p.y]` – `table[e.y]`
  - This kind of table is called a *summed-area table*, and they are incredibly useful!

References

http://developer.nvidia.com/object/shadows_transparency_fog.html

- Older, but has some useful information and image

http://mrl.nyu.edu/~perlin/experiments/ball/

http://mrl.nyu.edu/~perlin/experiments/gabor/

- Very cool example of what can be done with explicitly calculated fog coordinates. Second link has the theory behind the Java applet.

Legakis, J. Fast multi-layer fog. In *ACM SIGGRAPH 98 Conference Abstracts and Applications* (Orlando, Florida, United States, July 19 - 24, 1998). SIGGRAPH '98. ACM, New York, NY.

Nuebel, M. "Introduction to Different Fog Effects," In ShaderX^2: Introductions and Tutorials with DirectX 9. Ed. Wolfgang Engel. Wordware, pp. 151-179, 2003.
http://www.gamedev.net/reference/programming/features/shaderx2/Introductions_and_Tutorials_with_DirectX_9.pdf

Next week...

- More anti-aliasing
  - AA during primitive rasterization
  - FSAA
    - Supersampling
    - Multisampling
  - Temporal AA

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