Office Hours: Week 7

• Monday: 1-2 (Roscoe)
• **Tuesday: 1230-115 (Hank)**
• Tuesday: 1-2 (Roscoe)
• Wednesday: 1-3 (Roscoe)
• Thursday: 1130-1230 (Hank)
• Friday: 1130-1230 (Hank)
Timeline (1/2)

- **1F**: assigned Feb 7\(^{th}\), due Feb 19\(^{th}\)
  - → not as tough as 1E
- **2A**: posted now, due Feb 21\(^{st}\)-Feb 23rd
- → you need to work on both 1F and 2A during Week 6 (Feb 11-15)
- **2B**: posted now, due Feb 27\(^{th}\)
- YouTube lectures for Feb 12\(^{th}\) and 14\(^{th}\)
## Timeline (2/2)

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<tr>
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<td><img src="super_bowl_liii.png" alt="Super Bowl LIII" /></td>
<td>Feb 4</td>
<td>Feb 5 Lec 8</td>
<td>Feb 6 1E due</td>
<td>Feb 7 Begin 1F, begin 2A</td>
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<td>Feb 19 1F due</td>
<td>Feb 20</td>
<td>Feb 21 2A due, begin 2B</td>
<td>Feb 22</td>
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Midterm

• Date: Tues Feb 26th
• Considering different plan: 25 & 5
  — Still no feedback received
• Midterm worth 30 points, no quiz on Week 10
• Details:
  — No notes.
  — Not expected to memorize Phong shading equation.
  — Will be derived directly from 1A-1F, 2A. Not 2B.
Midterm

• Questions will mostly derive from Project 1A, 1B, 1C, 1D, 1E, 1F, 2A

• Example: here’s a triangle, what pixels does it contribute to?
  – Example: write GL program to do something
    • errors in syntax will receive minor deductions

• No notes, closed book, no calculators, internet, etc.
Questions on 2A?
We will replace these and write our own GL calls.

Cone.py Pipeline Diagram (type "python Cone.py" to run)

- **Source**
  - Data

- **Mapper**

- **Actor**

- **Renderer**

- **Window**

- **Interactor**

Either reads the data from a file or creates the data from scratch.

Moves the data from VTK into OpenGL.

For setting colors, surface properties, and the position of the object.

The rectangle of the computer screen that VTK draws into.

The window, including title bar and decorations.

Allows the mouse to be used to interact with the data.

```
from vtkpython import *
cone = vtkConeSource()
cone.SetResolution(10)
coneMapper = vtkPolyDataMapper()
coneMapper.SetInput(cone.GetOutput())
coneActor = vtkActor()
coneActor.SetMapper(coneMapper)
ren = vtkRenderer()
ren.AddActor(coneActor)
renWin = vtkRenderWindow()
renWin.SetWindowName("Cone")
renWin.SetSize(300,300)
renWin.AddRenderer(ren)
iren = vtkRenderWindowInteractor()
iren.SetRenderWindow(renWin)
iren.Initialize()
iren.Start()
```
Project #2A (8%), Due Feb. 23rd

- Goal: OpenGL program that does regular colors and textures
- New VTK-based project2A.cxx
- New CMakeLists.txt (but same as old ones)
Hints

- I recommend you “walk before you run” & “take small bites”. OpenGL can be very punishing. Get a picture up and then improve on it. Make sure you know how to retreat to your previously working version at every step.

- OpenGL “state thrashing” is common and tricky to debug.
  - Get one window working perfectly.
  - Then make the second one work perfectly.
  - Then try to get them to work together.
    - Things often go wrong, when one program leaves the OpenGL state in a way that doesn’t suit another renderer.
Hints

- MAKE MANY BACKUPS OF YOUR PROGRAM
- USE VTK 6
- If you are having issues on your laptop with a GL program, then use Room 100
  - (There’s only 2 of these projects)
The Triangle class now has a “fieldValue” data member, which ranges between 0 and 1.

You will map this to a color using the GetColorMap function.

- GetColorMap returns 256 colors.

Mappings

- A fieldValue value of 0 should be mapped to the first color.
- A fieldValue value of 1 should be mapped to the 255th color.
- Each fieldValue in between should be mapped to the closest color of the 256, but interpolation of colors is not required.
How to do colors (texture)...

- Same idea, but use texture infrastructure
- (easier)
Final Projects

- 541: everyone should do a self-defined project
- 441: your choice
  - Do a self-defined project
  - Do a pre-defined project
Pre-defined projects

- Hoping to have prompts up by Thursday Feb 28th
- Likely topics:
  - 2 WebGL projects
  - 3 shader programs
  - GPU programming
  - Blender
- Possible topics:
  - Vulcan
  - Computer vision (?)
Self-defined projects

- Write a screen saver
- Write a SIMPLE video game
- Make a movie
- Model something
- Advanced computer graphics effects
  - Example: collision detection
  - Example: ray tracing
  - Example: volume rendering
  - Example: physics-based rendering
Process

☐ Send me a proposal by Saturday March 2\textsuperscript{nd}

☐ The proposal should be for \(\sim\) 24 hours of work

☐ I will send feedback (too much, too little)

☐ If you don’t send a proposal, then it is assumed that you are doing the pre-defined projects
Transforms in GL
ModelView and Projection Matrices

- **ModelView idea:** two purposes … model and view
  - **Model:** extra matrix, just for rotating, scaling, and translating geometry.
    - How could this be useful?
  - **View:** Cartesian to Camera transform

- (We will focus on the model part of the modelview matrix now & come back to others later)
SLIDE REPEAT: Our goal

Add additional transforms here....

World space:
- Triangles in native Cartesian coordinates
- Camera located anywhere

Camera space:
- Camera located at origin, looking down -Z
- Triangle coordinates relative to camera frame

Image space:
- All viewable objects within -1 <= x, y, z <= +1

Screen space:
- All viewable objects within -1 <= x, y <= +1

Device space:
- All viewable objects within 0 <= x <= width, 0 <= y <= height
ModelView and Projection Matrices

- ModelView idea: two purposes ... model and view
  - Model: extra matrix, just for rotating, scaling, and translating geometry.
    - How could this be useful?
  - View: Cartesian to Camera transform
- (We will focus on the model part of the modelview matrix now & come back to others later)
Common commands for modifying model part of ModelView matrix

- glTranslate
- glRotate
- glScale
NAME

`glTranslated, glTranslatef` - multiply the current matrix by a translation matrix

C SPECIFICATION

```c
void glTranslated(GLdouble x,
                 GLdouble y,
                 GLdouble z )
void glTranslatef(GLfloat x,
                 GLfloat y,
                 GLfloat z )
```

PARAMETERS

- `x, y, z`

  Specify the `x`, `y`, and `z` coordinates of a translation vector.

DESCRIPTION

`glTranslated` produces a translation by `(x,y,z)`. The current matrix (see `glMatrixMode`) is multiplied by this translation matrix, with the product replacing the current matrix, as if `glMultMatrix` were called with the following matrix for its argument:

```
1 0 0 x
0 1 0 y
0 0 1 z
0 0 0 1
```

Note: this matrix transposed from what we did earlier
NAME

`glRotated`, `glRotatef` - multiply the current matrix by a rotation matrix

C SPECIFICATION

```c
void glRotated(GLdouble angle,
               GLdouble x,
               GLdouble y,
               GLdouble z )

void glRotatef(GLfloat angle,
               GLfloat x,
               GLfloat y,
               GLfloat z )
```

PARAMETERS

- `angle` Specifies the angle of rotation, in degrees.
- `x`, `y`, `z`
  Specify the `x`, `y`, and `z` coordinates of a vector, respectively.

DESCRIPTION

`glRotate` produces a rotation of `angle` degrees around the vector `(x, y, z)`. The current matrix (see `glMatrixMode`) is multiplied by a rotation matrix with the product replacing the current matrix, as if `glMultMatrix` were called with the following matrix as its argument:

```
\begin{bmatrix}
x^2(1-c)+c & xy(1-c)-zs & xz(1-c)+ys & 0 \\
yx(1-c)+zs & y^2(1-c)+c & yz(1-c)-xs & 0 \\
xz(1-c)-ys & yz(1-c)+xs & z^2(1-c)+c & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
```

Where `c = cos(angle)`, `s = sin(angle)`, and `\| (x, y, z) \| = 1` (if not, the GL will normalize this vector).
NAME

`glScale`, `glScalef` - multiply the current matrix by a general scaling matrix

C SPECIFICATION

```c
void glScale( GLdouble x,
             GLdouble y,
             GLdouble z )

void glScalef( GLfloat x,
               GLfloat y,
               GLfloat z )
```

PARAMETERS

`x`, `y`, `z`

Specify scale factors along the `x`, `y`, and `z` axes, respectively.

DESCRIPTION

`glScale` produces a nonuniform scaling along the `x`, `y`, and `z` axes. The three parameters indicate the desired scale factor along each of the three axes.

The current matrix (see `glMatrixMode`) is multiplied by this scale matrix, and the product replaces the current matrix as if `glScale` were called with the following matrix as its argument:

```
  x 0 0 0
  0 y 0 0
  0 0 z 0
  0 0 0 1
```
How do transformations combine?

```glScale(2, 2, 2)
glTranslate(1, 0, 0)
glRotate(45, 0, 1, 0)```

→ Rotate by 45 degrees around (0,1,0), then translate in X by 1, then scale by 2 in all dimensions.

→ (the last transformation is applied first)
Which of two of these three are the same?

- **Choice A:**
  - `glScalef(2, 2, 2);`
  - `glTranslate(1, 0, 0);`

- **Choice B:**
  - `glTranslate(1, 0, 0);`
  - `glScalef(2, 2, 2);`

- **Choice C:**
  - `glTranslate(2, 0, 0);`
  - `glScalef(2, 2, 2);`
dl = GenerateTireGeometry();
glCallList(dl);  // place tire at (0, 0, 0)
glTranslatef(10, 0, 0);

Each glTranslatef call updates the state of the ModelView matrix.

glCallList(dl);  // place tire at (10, 0, 0)

glTranslatef(0, 0, 10);

glCallList(dl);  // place tire at (10, 0, 10)

glTranslatef(-10, 0, 0);

glCallList(dl);  // place tire at (0, 0, 10)
glPushMatrix, glPopMatrix

NAME

glPushMatrix, glPopMatrix - push and pop the current matrix stack

C SPECIFICATION

void glPushMatrix( void )

C SPECIFICATION

void glPopMatrix( void )

DESCRIPTION

There is a stack of matrices for each of the matrix modes. In GL_MODELVIEW mode, the stack depth is at least 32. In the other two modes, GL_PROJECTION and GL_TEXTURE, the depth is at least 2. The current matrix in any mode is the matrix on the top of the stack for that mode.

glPushMatrix pushes the current matrix stack down by one, duplicating the current matrix. That is, after a glPushMatrix call, the matrix on top of the stack is identical to the one below it.

glPopMatrix pops the current matrix stack, replacing the current matrix with the one below it on the stack.

Initially, each of the stacks contains one matrix, an identity matrix.
dl = GenerateTireGeometry();
glCallList(dl); // place tire at (0, 0, 0)
glPushMatrix();
glTranslatef(10, 0, 0);
glCallList(dl); // place tire at (10, 0, 0)
glPopMatrix();
glPushMatrix();
glTranslatef(0, 0, 10);
glCallList(dl); // place tire at (10, 0, 10) (0, 0, 10)
glPopMatrix();

Why is this useful?
Matrices in OpenGL

- OpenGL maintains matrices for you and provides functions for setting matrices.

- There are four different modes you can use:
  - Modelview
  - Projection
  - Texture
  - Color (rarely used, often not supported)

- You control the mode using glMatrixMode.
- The matrices are the identity matrix by default and you can modify them by:
  - 1) setting the matrix explicitly
  - 2) using OpenGL commands for appending to the matrix
- You can have \( \geq 32 \) matrices for modelview, \( \geq 2 \) for others
8.010 How does the camera work in OpenGL?

As far as OpenGL is concerned, there is no camera. More specifically, the camera is always located at the eye space coordinate (0., 0., 0.). To give the appearance of moving the camera, your OpenGL application must move the scene with the inverse of the camera transformation.

8.020 How can I move my eye, or camera, in my scene?

OpenGL doesn't provide an interface to do this using a camera model. However, the GLU library provides the gluLookAt() function, which takes an eye position, a position to look at, and an up vector, all in object space coordinates. This function computes the inverse camera transform according to its parameters and multiplies it onto the current matrix stack.
8.030 Where should my camera go, the ModelView or Projection matrix?

The GL_PROJECTION matrix should contain only the projection transformation calls it needs to transform eye space coordinates into clip coordinates.

The GL_MODELVIEW matrix, as its name implies, should contain modeling and viewing transformations, which transform object space coordinates into eye space coordinates. Remember to place the camera transformations on the GL_MODELVIEW matrix and never on the GL_PROJECTION matrix.

Think of the projection matrix as describing the attributes of your camera, such as field of view, focal length, fish eye lens, etc. Think of the ModelView matrix as where you stand with the camera and the direction you point it.

Source: www.opengl.org/archives/resources/faq/technical/viewing.htm
How do you put the Camera Transform in the ModelView matrix?

- No single GL call.
- Options are:
  - (1) you do it yourself (i.e., calculate matrix and load it into OpenGL)
  - (2) you use somebody’s code, i.e., gluLookAt
  - (3) you use a combination of glRotatef, glScalef, and glTranslatef commands.
NAME

`glMatrixMode` - specify which matrix is the current matrix

C SPECIFICATION

```c
void glMatrixMode( GLenum mode )
```

PARAMETERS

- `-mode` Specifies which matrix stack is the target for subsequent matrix operations. Three values are accepted: `GL_MODELVIEW`, `GL_PROJECTION`, and `GL_TEXTURE`. The initial value is `GL_MODELVIEW`.

Additionally, if the `GL_ARB_imaging` extension is supported, `GL_COLOR` is also accepted.

DESCRIPTION

`glMatrixMode` sets the current matrix mode. `-mode` can assume one of four values:

- `GL_MODELVIEW` Applies subsequent matrix operations to the modelview matrix stack.
- `GL_PROJECTION` Applies subsequent matrix operations to the projection matrix stack.
- `GL_TEXTURE` Applies subsequent matrix operations to the texture matrix stack.
- `GL_COLOR` Applies subsequent matrix operations to the color matrix stack.

To find out which matrix stack is currently the target of all matrix operations, call `glGet` with argument `GL_MATRIX_MODE`. The initial value is `GL_MODELVIEW`. 
How do you put the projection transformation in GL_PROJECTION?

- Two options:
  - `glFrustum()` (perspective projection)
  - `glOrtho()` (orthographic projection)
glFrustum

NAME

glFrustum - multiply the current matrix by a perspective matrix

C SPECIFICATION

```c
void glFrustum( Gldouble left,
               Gldouble right,
               Gldouble bottom,
               Gldouble top,
               Gldouble zNear,
               Gldouble zFar )
```

PARAMETERS

- **left, right** Specify the coordinates for the left and right vertical clipping planes.
- **bottom, top** Specify the coordinates for the bottom and top horizontal clipping planes.
- **zNear, zFar** Specify the distances to the near and far depth clipping planes. Both distances must be positive.

DESCRIPTION

glFrustum describes a perspective matrix that produces a perspective projection. The current matrix (see glMatrixMode) is multiplied by this matrix and the result replaces the current matrix, as if glPushMatrix were called with the following matrix as its argument:

\[
\begin{bmatrix}
    2 & zNear & 0 & A \\
    0 & 2 & zNear & 0 \\
    0 & 0 & 1 & C \\
    0 & 0 & 0 & -1 \\
\end{bmatrix}
\]

Typically, the matrix mode is GL_PROJECTION, and (left, bottom, -zNear) and (right, top, -zNear) specify the points on the near clipping plane that are mapped to the lower left and upper right corners of the window, assuming that the eye is located at (0, 0, 0). zFar specifies the location of the far clipping plane. Both zNear and zFar must be positive.

Use glPushMatrix and glPopMatrix to save and restore the current matrix stack.
NAME

`glOrtho` - multiply the current matrix with an orthographic matrix

C SPECIFICATION

```c
void glOrtho( Gdoule left,
             Gdoule right,
             Gdoule bottom,
             Gdoule top,
             Gdoule zNear,
             Gdoule zFar )
```

PARAMETERS

- `left`, `right` Specify the coordinates for the left and right vertical clipping planes.
- `bottom`, `top` Specify the coordinates for the bottom and top horizontal clipping planes.
- `zNear`, `zFar` Specify the distances to the nearer and farther depth clipping planes. These values are negative if the plane is to be behind the viewer.

DESCRIPTION

`glOrtho` describes a transformation that produces a parallel projection. The current matrix (see `glMatrixMode`) is multiplied by this matrix and the result replaces the current matrix, as if `glMultMatrix` were called with the following matrix as its argument:

```
2
---
right - left
```

```
0
---
tx
```

```
0
---
0
ty
```

```
0
---
2
tz
```

```
0
---
0
```

```
0
---
zFar-zNear
```

```
0
---
1
```

where

- `tx` = - (right + left) / (right - left)
- `ty` = - (top + bottom) / (top - bottom)
- `tz` = - (zFar + zNear) / (zFar - zNear)

Typically, the matrix mode is `GL_PROJECTION`, and `(left, bottom, -zNear)` and `(right, top, -zNear)` specify the points on the near clipping plane that are mapped to the lower left and upper right corners of the window, respectively, assuming that the eye is located at `(0, 0, 0)`. `zFar` specifies the location of the far clipping plane. Both `zNear` and `zFar` can be either positive or negative.

Use `glPushMatrix` and `glPopMatrix` to save and restore the current matrix stack.
virtual void RenderPiece(vtkRenderer *ren, vtkActor *actor) {
    RemoveVTKOpenGLStateSideEffects();
    SetupLight();
    glMatrixMode(GL_TEXTURE);
    glPushMatrix();
    glScalef(3, 2.5, 1);
    glEnable(GL_TEXTURE_2D);
    glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, p[0], p[0], 0, GL_RGB, GL_UNSIGNED_BYTE, p);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glBegin(GL_QUADS);
    glVertex2f(0, 0);
    glVertex2f(0, 0);
    glVertex2f(1, 0);
    glVertex2f(1, 0);
    glEnd();
    glPopMatrix();
}
Goal: modify ModelView matrix to create dog out of spheres and cylinders

New code skeleton: “project2B.cxx”

No geometry file needed.

You will be able to do this w/ glPush/PopMatrix, glRotatef, glTranslatef, and glScalef.
Goal: modify ModelView matrix to create dog out of spheres and cylinders

New code skeleton: "project2B.cxx"

No geometry file needed.

You will be able to do this with glPush/PopMatrix, glRotatef, glTranslatef, and glScalef.
Contents of project2B.cxx

- Routine for generating spheres
- Routine for generating cylinders
- Routine for generating head, eyes, and pupils
What is the correct answer?

- The correct answer is:
  - Something that looks like a dog
    - No obvious problems with output geometry.
  - Something that uses the sphere and cylinder classes.
    - If you use something else, please clear it with me first.
      - I may fail your project if I think you are using outside resources that make the project too easy.
  - Something that uses rotation for the neck and tail.

- Aside from that, feel free to be as creative as you want ... color, breed, etc.
For your reference: my dog
Transparent Geometry
COMPOSING AND BLENDING

Ed Angel
Professor of Computer Science, Electrical and Computer Engineering, and Media Arts
University of New Mexico
Opaque surfaces permit no light to pass through

Transparent surfaces permit all light to pass

Translucent surfaces pass some light

translucency = 1 – opacity (\(\alpha\))
Transparency

- If you have an opaque red square in front of a blue square, what color would you see?
  - Red

- If you have a 50% transparent red square in front of a blue square, what color would you see?
  - Purple

- If you have a 100% transparent red square in front of a blue square, what color would you see?
  - Blue
(One) Formula For Transparency

- **Front** = \((F_r,F_g,F_b,F_a)\)
  - \(a = \text{alpha, transparency factor}\)
    - Sometimes percent
    - Typically 0-255, with 255 = 100%, 0 = 0%

- **Back** = \((B_r,B_g,B_b,B_a)\)

- **Equation** = 
  \[
  \begin{align*}
  &F_a \cdot F_r + (1 - F_a) \cdot B_r, \\
  &F_a \cdot F_g + (1 - F_a) \cdot B_g, \\
  &F_a \cdot F_b + (1 - F_a) \cdot B_b, \\
  &F_a + (1 - F_a) \cdot B_a
  \end{align*}
  \]
Transparency

- If you have an 25% transparent red square (255,0,0) in front of a blue square (0,0,255), what color would you see (in RGB)?
  - (192,0,64)

- If you have an 25% transparent blue square (0,0,255) in front of a red square (255,0,0), what color would you see (in RGB)?
  - (64,0,192)
Implementation

- Per pixel storage:
  - RGBA: 3 bytes
  - Alpha: 1 byte
  - Z: 4 bytes

- Alpha used to control blending of current color and new colors
Vocab term reminder: fragment

- Fragment is the contribution of a triangle to a single pixel

**Scanline algorithm**

- Determine rows of pixels triangles can possibly intersect
  - Call them rowMin to rowMax
    - rowMin: ceiling of smallest Y value
    - rowMax: floor of biggest Y value
- For r in [rowMin \(\rightarrow\) rowMax] ; do
  - Find end points of r intersected with triangle
    - Call them leftEnd and rightEnd
  - For c in [ceiling(leftEnd) \(\rightarrow\) floor(rightEnd)] ; do
    - ImageColor(r, c) ← triangle color
Examples

- Imagine pixel \((i, j)\) has:
  - \(\text{RGB} = 255/255/255\)
  - \(\text{Alpha} = 255\)
  - \(\text{Depth} = -0.5\)

- And we contribute fragment:
  - \(\text{RGB} = 0/0/0\)
  - \(\text{Alpha} = 128\)
  - \(\text{Depth} = -0.25\)

- What do we get?
- Answer: \(128/128/128, Z = -0.25\)
- What’s the alpha?
Examples

- Imagine pixel \((i, j)\) has:
  - \(RGB = 255/255/255\)
  - \(Alpha = 128\)
  - \(Depth = -0.25\)

- And we contribute fragment:
  - \(RGB=0/0/0\)
  - \(Alpha=255\)
  - \(Depth = -0.5\)

- What do we get?
  - Answer: (probably) 128/128/128, \(Z = -0.25\)

- What’s the alpha?
System doesn’t work well for transparency

- Contribute fragments in this order:
  - $Z=-0.1$
  - $Z=-0.9$
  - $Z=-0.5$
  - $Z=-0.4$
  - $Z=-0.6$

- Model is too simple. Not enough info to resolve!
Is this image correct?
- Probably not
- Polygons are rendered in the order they pass down the pipeline
- Blending functions are order dependent
How do you sort?

- 1) Calculate depth of each triangle center.
- 2) Sort based on depth
  - Not perfect, but good

- In practice: sort along X, Y, and Z and use “dominant axis” and only do “perfect sort” when rotation stops
But there is a problem…
**Depth Peeling**

- a multi-pass technique that renders transparent polygonal geometry without sorting
- **Pass #1:**
  - render as opaque, but note opacity of pixels placed on top
  - treat this as “top layer”
  - save Z-buffer and treat this as “max”
- **Pass #2:**
  - render as opaque, but ignore fragments beyond “max”
- repeat, repeat…