Announcements

- All code from book (working programs) on book website.
  - Quite useful. Take a look
Screen Coordinate System

- Screen: 2D coordinate system (WxH)
- 2D Cartesian Grid
- Origin (0,0): lower left corner (OpenGL convention)
- Horizontal axis – x
- Vertical axis – y
- Pixel positions: grid (x,y) intersections  (0,0)
Screen Coordinate System

(0,0) is lower left corner of OpenGL Window. NOT lower left corner of entire desktop.
Defining a Viewport

- Can draw to any rectangle (sub-area of screen)
- **Viewport**: Area of screen we want to draw to
- To define viewport
  
  \[ \text{glViewport}(\text{left}, \text{bottom}, \text{width}, \text{height}) \]
  
  or \[ \text{glViewport}(V.L, V.B, V.R - V.L, V.T - V.B) \]
  
  e.g. \[ \text{glViewport}(180, 260, (410 - 180), (480 - 260)) \]
Recall: OpenGL Skeleton

```c
void main(int argc, char** argv)
{
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);   // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

    // ... now register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

    myInit( );
    glutMainLoop( );
}
```

```c
void mydisplay(void)
{
    glClear(GL_COLOR_BUFFER_BIT);
    glDrawArrays(GL_LINE_LOOP, 0, 3);
    glFlush( );
}
```

Note: default viewport is entire created window
Example: Changing Viewport

How to change viewport to:
Bottom left corner at (100,80)
Width changes to 700, height changes to 300??

```c
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);  // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

    // ... now register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

    myInit( );
    glutMainLoop( );
}

// Example of changing viewport
void mydisplay(void){
    glClear(GL_COLOR_BUFFER_BIT);
    glViewport(100,80,700,300);
    glDrawArrays(GL_LINE_LOOP, 0, 3);
    glFlush( );
}
```

Note: Set desired viewport, then draw
Tiling: Changing Viewport in a Loop

- **Problem:** Want to tile Triangle file on screen
- **Solution:** change viewport in loop, draw tiles
Tiling Triangle Code Snippet

- Set viewport, draw into tile in a loop
- Code snippet to draw 6x6 tiles:
  ```c
  float w, h;

  w = width / 6;
  h = height / 6;

  for (int k=0; k<6; k++) {
    for (int m=0; m<6; m++) {
      glViewport(k * w, m * h, w, h);
      glDrawArrays(GL_LINE_LOOP, 0, NumPoints);
    }
  }
  ```
void main(int argc, char** argv) {
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);    // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit();

    // ... now register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

    myInit( );
    glutMainLoop( );
}

void mydisplay(void) {
    glClear(GL_COLOR_BUFFER_BIT);
    float w, h;

    w = width / 6; h = height / 6;

    for (int k=0; k<6; k++) {
        for (int m=0; m<6; m++) {
            glViewport(k * w, m * h, w, h);
            glDrawArrays(GL_LINE_LOOP, 0, NumPoints);
        }
    }
    glFlush( );
}
World Coordinate System

- Problems with drawing in screen coordinates:
  - \((x,y)\) dimensions in pixels: one mapping, inflexible
  - Not application-specific
- World coordinate: application-specific
- E.g: Same screen area. Change input drawing \((x,y)\) range

100 pixels = 30 miles
100 pixels = 0.25 miles
Using Window Coordinates

- Would like to:
  - Specify **source** boundaries (extents) of original drawing in world coordinates (miles, meters, etc)
  - Display **target region** in screen coordinates (pixels)

- Programming steps:
  1. Define world window (original drawing extents)
  2. Define viewport (drawing extents on screen)
  3. Map drawings within window to viewport

- Mapping called **Window-to-viewport mapping!**
World Coordinate System

- **World Window**: region of source drawing to be rendered
- Rectangle specified by world window is drawn to screen
- Defined by (left, right, bottom, top) or \((W.L, W.R, W.B, W.T)\)
Defining World Window

- \texttt{mat4 \texttt{ortho} = Ortho2D(left, right, bottom, top)}

Or \texttt{mat4 \texttt{ortho} = Ortho2D(W.L, W.R, W.B, W.T)}

- \textbf{Ortho2D} generates 4x4 matrix that scales input drawing

- \textbf{Note:} Need to include \texttt{mat.h} (contains \texttt{Ortho2D})
Drawing

- After setting world window (using ortho2D) and viewport (using glviewport),
  - Draw as usual with `glDrawArrays`
Apply ortho( ) matrix in Vertex Shader

- **One more detail:** Need to pass ortho matrix to shader
- Multiply each vertex by ortho matrix to scale input drawing
- Need to connect **ortho** matrix to **proj** variable in shader

```cpp
mat4 ortho = Ortho2D( W.L, W.R, W.B, W.T );

uniform mat4 Proj;
in vec4 vPosition;

void main( ){
    gl_Position = Proj * vPosition;
}
```
Apply ortho() matrix in Vertex Shader

1. Include mat.h from book website (ortho2D declared in mat.h)

```
#include "mat.h"
```

2. Connect `ortho` matrix to `proj` variable in shader

```
mat4 ortho = Ortho2D( W.L, W.R, W.B, W.T );

ProjLoc = glGetUniformLocation( program, "Proj" );
glUniformMatrix4fv( ProjLoc, 1, GL_TRUE, ortho );
```

```
uniform mat4 Proj;
in vec4 vPosition;

void main( ){
    gl_Position = Proj * vPosition;
}
```
Drawing Polyline Files

- May read in list of vertices defining a drawing
- **Problem:** want to draw single dino.dat on screen
- **Note:** size of input drawing may vary

![Graphical representation of a dinosaur](image)

Vertices (points) of Drawing read in from file (e.g. dino.dat)
**Drawing Polyline Files**

- **Problem:** want to draw single dino.dat on screen
- **pseudocode snippet:**
  ```
  // set world window (left, right, bottom, top)
  ortho = Ortho2D(0, 640.0, 0, 440.0);

  //..... Pass ortho to vertex shader... then...

  // now set viewport (left, bottom, width, height)
  glViewport(0, 0, 64, 44);

  // Draw polyline fine
  drawPolylineFile(dino.dat);
  ```

**Question:** What if I wanted to draw the bottom quadrant of polyline?
Tiling using W-to-V Mapping

- **Problem:** Want to tile polyline file on screen
- **Solution:** W-to-V in loop, adjacent tiled viewports

![Diagram of tiling using W-to-V Mapping]

One world Window

Multiple tiled viewports
Tiling Polyline Files

- Problem: want to tile dino.dat in 5x5 across screen
- Code snippet:

```c
// set world window
ortho = Ortho2D(0, 640.0, 0, 440.0);

//..... Pass ortho to vertex shader... then...

for(int i=0; i < 5; i++)
{
    for(int j = 0; j < 5; j++)
    {
        // .. now set viewport in a loop
        glViewport(i * 64, j * 44; 64, 44);
        drawPolylineFile(dino.dat);
    }
}
```
Maintaining Aspect Ratios

- Aspect ratio $R = \text{Width}/\text{Height}$
- What if window and viewport have different aspect ratios?
- Two possible cases:

  **Case a:** viewport too wide

  **Case b:** viewport too tall
What if Window and Viewport have different Aspect Ratios?

- \( R \) = window aspect ratio, \( W \times H \) = viewport dimensions
- Two possible cases:
  - **Case A** \((R > W/H)\): map window to tall viewport?

\[
\text{ortho} = \text{Ortho2D}(\text{left}, \text{right}, \text{bottom}, \text{top});
\]
\[
R = (\text{right} - \text{left})/(\text{top} - \text{bottom});
\]
\[
\text{If}(R > W/H)
\]
\[
\text{glViewport}(0, 0, W, W/R);
\]
What if Window and Viewport have different Aspect Ratios?

- **Case B (R < W/H):** map window to wide viewport?

```cpp
ortho = Ortho2D(left, right, bottom, top);
R = (right - left)/(top - bottom);
If(R < W/H)
    glViewport(0, 0, H*R, H);
```
reshape( ) function that maintains aspect ratio

// Ortho2D(left, right, bottom, top ) is done previously, // probably in your draw function // function assumes variables left, right, top and bottom // are declared and updated globally

void myReshape(double W, double H ){
    R = (right – left)/(top – bottom);

    if(R > W/H) // tall viewport
        glViewport(0, 0, W, W/R);
    else if(R < W/H) // wide viewport
        glViewport(0, 0, H*R, H);
    else
        glViewport(0, 0, W, H);  // equal aspect ratios
}

Interaction
Adding Interaction

- So far, OpenGL programs just render images
- Can add user interaction
- Examples:
  - User hits ‘h’ on keyboard -> Program draws house
  - User clicks mouse left button -> Program draws table
Types of Input Devices

- **String**: produces string of characters e.g. keyboard
- **Locator**: User points to position on display. E.g. mouse
Types of Input Devices

- **Valuator**: generates number between 0 and 1.0 (proportional to how much it is turned)

- **Pick**: User selects location on screen (e.g. touch screen in restaurant, ATM)
GLUT: How keyboard Interaction Works

- Example: User hits ‘h’ on keyboard -> Program draws house

1. User hits ‘h’ key

OS

‘h’ key

Keyboard handler Function

Programmer needs to write keyboard handler function
Using Keyboard Callback for Interaction

```c
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);     // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

    // … now register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);
    myInit( );
    glutMainLoop( );
}
```

---

1. Register keyboard Function

2. Implement keyboard function

```c
void myKeyboard(char key, int x, int y )
{
    // put keyboard stuff here
    ...........

    switch(key){   // check which key
        case 'f':
            // do stuff
            break;
        case 'k':
            // do other stuff
            break;

        }

    ...........
}
```

Note: Backspace, delete, escape keys checked using their ASCII codes
Special Keys: Function, Arrow, etc

glutSpecialFunc (specialKeyFcn);

Void specialKeyFcn (Glint specialKey, GLint, xMouse, GLint yMouse)

- Example: if (specialKey == GLUT_KEY_F1) // F1 key pressed
- GLUT_KEY_F1, GLUT_KEY_F12, .... for function keys
- GLUT_KEY_UP, GLUT_KEY_RIGHT, .... for arrow keys keys
- GLUT_KEY_PAGE_DOWN, GLUT_KEY_HOME, .... for page up, home keys

- Complete list of special keys designated in glut.h
GLUT: How Mouse Interaction Works

- Example: User clicks on (x,y) location in drawing window -> Program draws a line

1. User clicks on (x,y) location

OS

Mouse handler Function

Programmer needs to write keyboard handler function
Using Mouse Callback for Interaction

void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);   // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

    // ... now register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

    myInit( );
    glutMainLoop( );
}

1. Register keyboard Function

2. Implement mouse function

void myMouse(int button, int state, int x, int y)
{
    // put mouse stuff here
    ..............
}

void myInit(int argc, char** argv){

    // ... register callback functions
    glutDisplayFunc(myDisplay);
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

    myInit( );
    glutMainLoop( );
}
Mouse Interaction

- Declare prototype
  - myMouse(int button, int state, int x, int y)
  - myMovedMouse

- Register callbacks:
  - glutMouseFunc(myMouse): mouse button pressed
  - glutMotionFunc(myMovedMouse): mouse moves with button pressed
  - glutPassiveMotionFunc(myMovedMouse): mouse moves with no buttons pressed

- Button returned values:
  - GLUT_LEFT_BUTTON, GLUT_MIDDLE_BUTTON, GLUT_RIGHT_BUTTON

- State returned values:
  - GLUT_UP, GLUT_DOWN

- X,Y returned values:
  - x,y coordinates of mouse location
Mouse Interaction Example

- **Example:** draw (or select) rectangle on screen
- Each mouse click generates separate events
- Store click points in `global` or `static` variable in mouse function

```c
void myMouse(int button, int state, int x, int y)
{
    static GLintPoint corner[2];
    static int numCorners = 0;   // initial value is 0
    if(button == GLUT_LEFT_BUTTON && state == GLUT_DOWN)
    {
        corner[numCorners].x = x;
        corner[numCorners].y = screenHeight - y;  // flip y coord
        numCorners++;
    }
}
```

*Screenheight is height of drawing window*
if(numCorners == 2)
{
    // draw rectangle or do whatever you planned to do
    Point3 points[4] = corner[0].x, corner[0].y,      //1
                   corner[1].x, corner[0].y,      //2
                   corner[1].x, corner[1].y,      //3
                   corner[0].x, corner[1].y);    //4
    glDrawArrays(GL_QUADS, 0, 4);

    numCorners == 0;
}
else if(button == GLUT_RIGHT_BUTTON && state == GLUT_DOWN)
    glClear(GL_COLOR_BUFFER_BIT); // clear the window
    glFlush();
Menus

- Adding menu that pops up on mouse click

1. Create menu using `glutCreateMenu(myMenu);`

2. Use `glutAddMenuEntry` adds entries to menu

3. Attach menu to mouse button (left, right, middle) using `glutAttachMenu`
Menus

- Example:

  ```c
  glutCreateMenu(mymenu);
  glutAddMenuEntry("Clear Screen", 1);
  glutAddMenuEntry("Exit", 2);
  glutAttachMenu(GLUT_RIGHT_BUTTON);

  ...

  void mymenu(int value){
    if(value == 1){
      glClear(GL_COLOR_BUFFER_BIT);
      glFlush();
    }
    if (value == 2) exit(0);
  }
  ```

  Shows on menu
  Checked in mymenu

- Shows on menu
  Checked in mymenu

- Shows on menu
  Checked in mymenu

- Shows on menu
  Checked in mymenu

- Shows on menu
  Checked in mymenu
GLUT Interaction using other input devices

- Tablet functions (mouse cursor must be in display window)

```c
glutTabletButton (tabletFcn);
```

```c
...,
void tabletFcn(Glint tabletButton, Glint action, Glint xTablet, Glint yTablet)
```

- Spaceball functions
- Dial functions
- Picking functions: use your finger
- Menu functions: minimal pop-up windows within your drawing window

Reference: *Hearn and Baker, 3rd edition (section 20-6)*
References

- Angel and Shreiner, Interactive Computer Graphics, 6\textsuperscript{th} edition, Chapter 2