Computer Graphics (CS 543)
Lecture 2 (Part 1): 2D Graphics Systems
(Drawing Polylines, tiling, & Aspect Ratio)

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Announcements

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

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

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

OpenGL’s (0,0)
Defining a Viewport

- Can draw to any rectangle (sub-area of screen)
- **Viewport**: Area of screen we want to draw to
- To define viewport
  
  ```
  glViewport(left, bottom, width, height)
  
  or glViewport(V.L, V.B, V.R - V.L, V.T - V.B)
  
  e.g. 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();
}

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( );
}
```

```c
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:
  ```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
- \textbf{World coordinate:} application-specific
- E.g: Same screen area. Change input drawing \((x,y)\) range

\begin{itemize}
  \item 100 pixels = 30 miles
  \item 100 pixels = 0.25 miles
\end{itemize}

Change World window (mapping)
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 \text{ortho} = Ortho2D(left, right, bottom, top)}
- \texttt{Or mat4 \text{ortho} = Ortho2D(W.L, W.R, W.B, W.T)}

- **Ortho2D** generates 4x4 matrix that scales input drawing
- **Note:** Need to include \texttt{mat.h} (contains 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;
}
```

In vertex shader, multiply each vertex with proj matrix

Call Ortho2D in Main .cpp file
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

Vertices (points) of Drawing read in from file (e.g. dino.dat)
Problem: want to draw single dino.dat on screen

Code snippet:

```cpp
// set world window (left, right, bottom, top)
ortho = Ortho2D(0, 640.0, 0, 440.0);

// 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

One world Window

Multiple tiled viewports
Tiling Polyline Files

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

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

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 a: viewport too wide](image)

  **Case b:** viewport too tall

  ![Case b: viewport too tall](image)
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?

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

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

```
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
}

References