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

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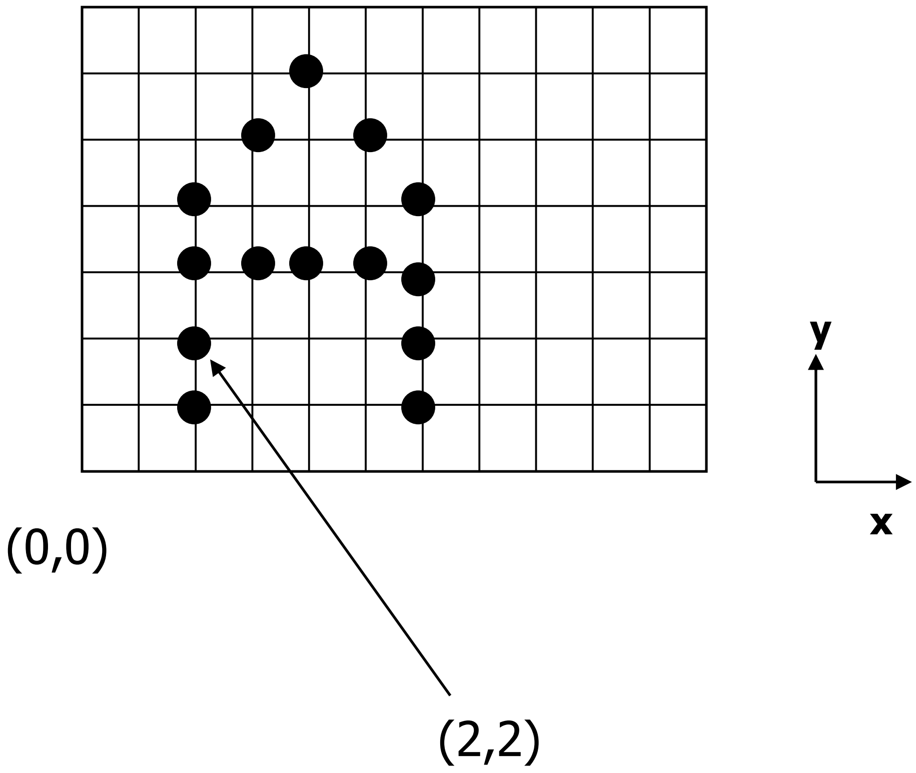
Announcements

- All code from book (working programs) on book website.
  - Quite useful. Take a look
  - https://www.cs.unm.edu/~angel/BOOK/INTERACTIVE_COMPUTER_GRAPHICS/SIXTH_EDITION/CODE/

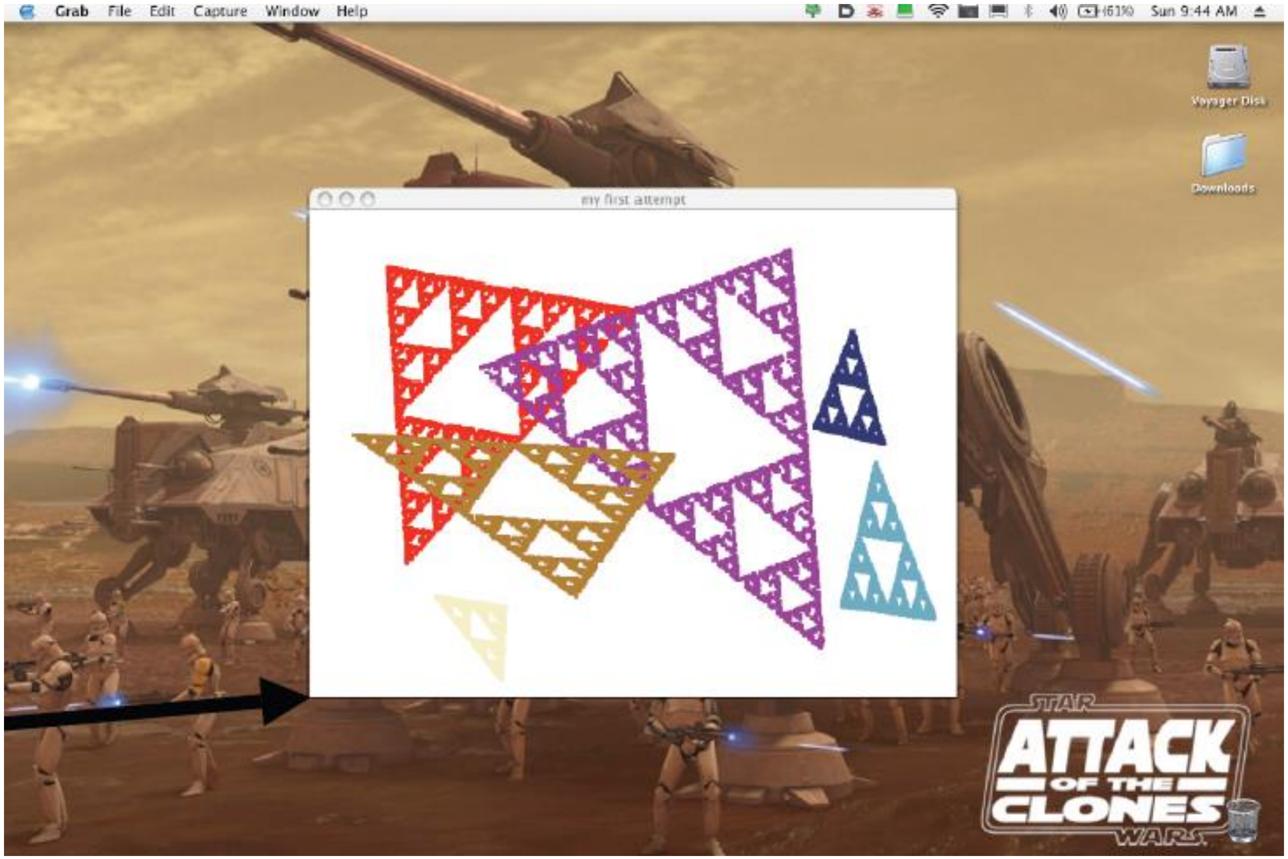
Screen Coordinate System

- 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



Screen Coordinate System

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

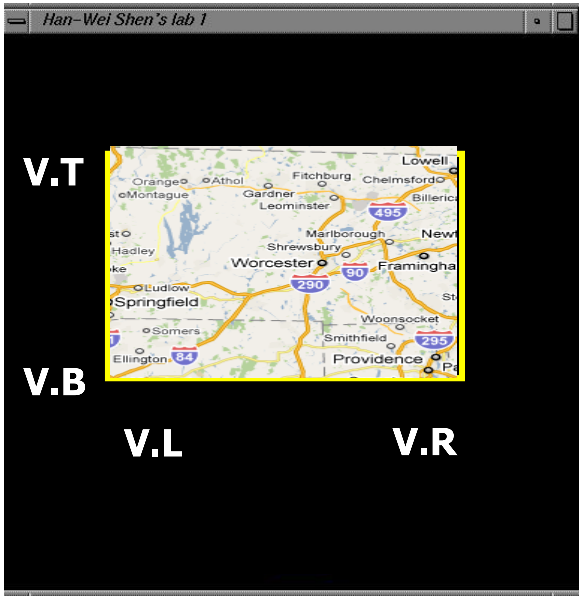


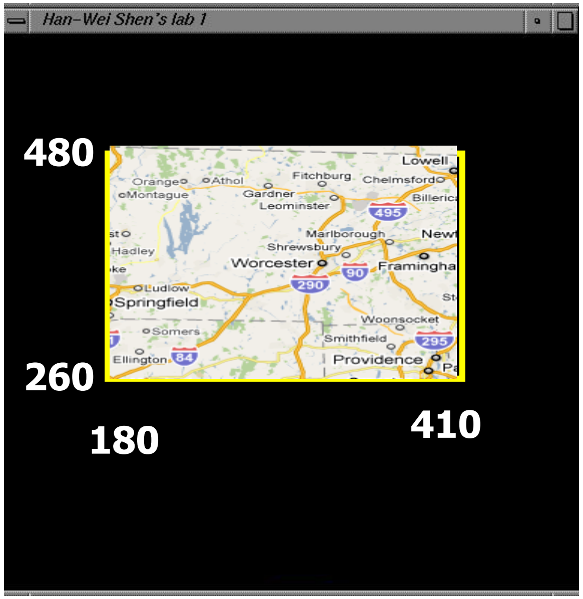
OpenGL's (0,0)

Defining a Viewport

- Can draw to any rectangle (sub-area of screen)
- **Viewport:** Area of screen we want to draw to
- To define viewport

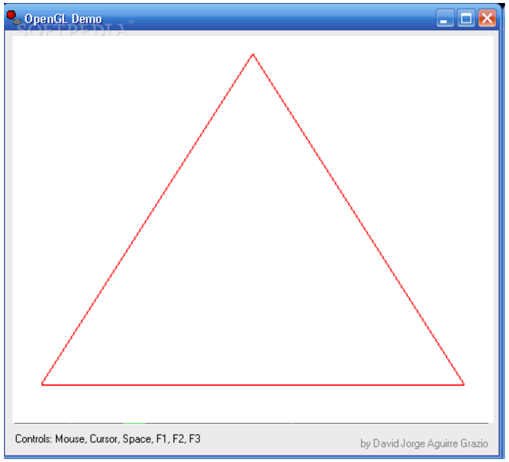
```
glViewport(left, bottom, width, height)
or glViewport(V.L, V.B, V.R – V.L, V.T – V.B)
e.g. glViewport(180, 260, (410 – 180), (480 – 260) )
```





Recall: OpenGL Skeleton

```
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( );
}
```


OpenGL Demo
Controls: Mouse, Cursor, Space, F1, F2, F3
by David Jorge Aguirre Grazio

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

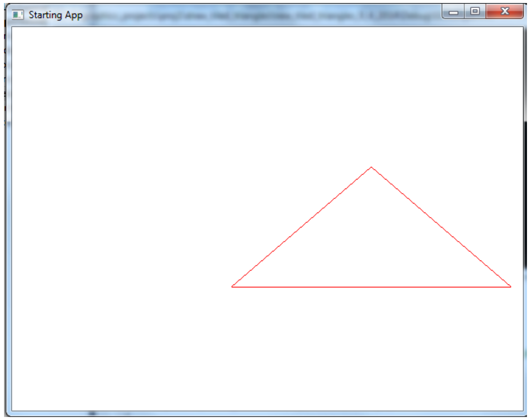
Note: default viewport is entire created window

Example: Changing Viewport

How to change viewport to:

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

```
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( );
}
```

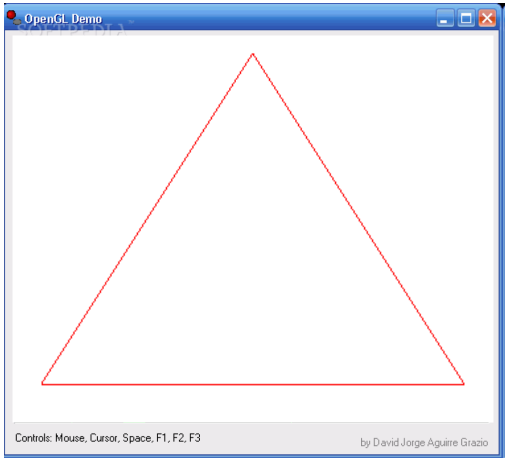


```
void mydisplay(void){
     glClear(GL_COLOR_BUFFER_BIT);
     glViewport(100,80,700,300);
     glDrawArrays(GL_LINE_LOOP, 0, 3);
     glFlush( );
}
```

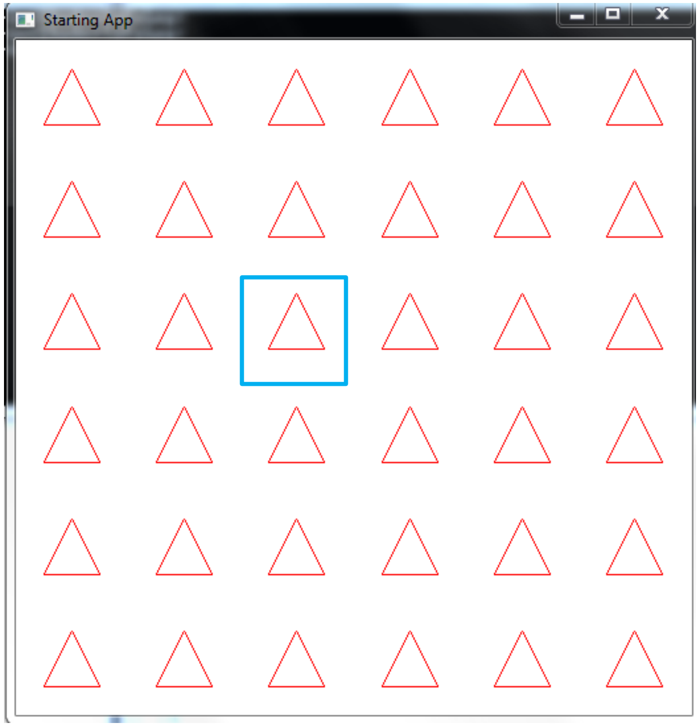
Note: Set desired viewport, then draw

Tiling: Changing Viewport in a Loop

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


OpenGL Demo
Controls: Mouse, Cursor, Space, F1, F2, F3
by David Jorge Aguirre Grazio

One world triangle



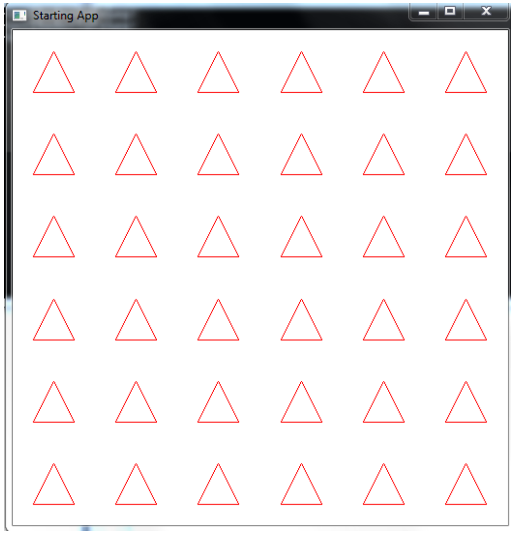
Multiple tiled viewports

Tiling Triangle Code Snippet

- Set viewport, draw into tile in a loop
- Code snippet to draw 6x6 tiles:

```
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);
      }
}
```

Example: Tiling, Changing Viewport

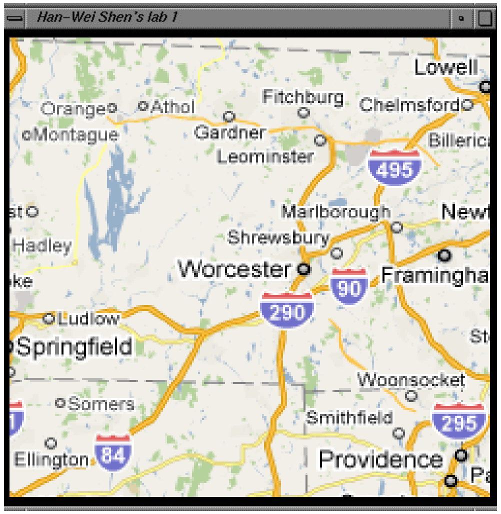


```
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window
    glutInit(&argc, argv);    // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow(“my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

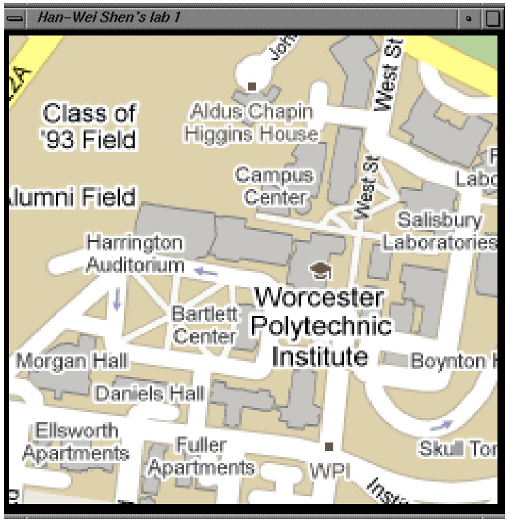
World Coordinate System

- 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

Change World window (mapping)



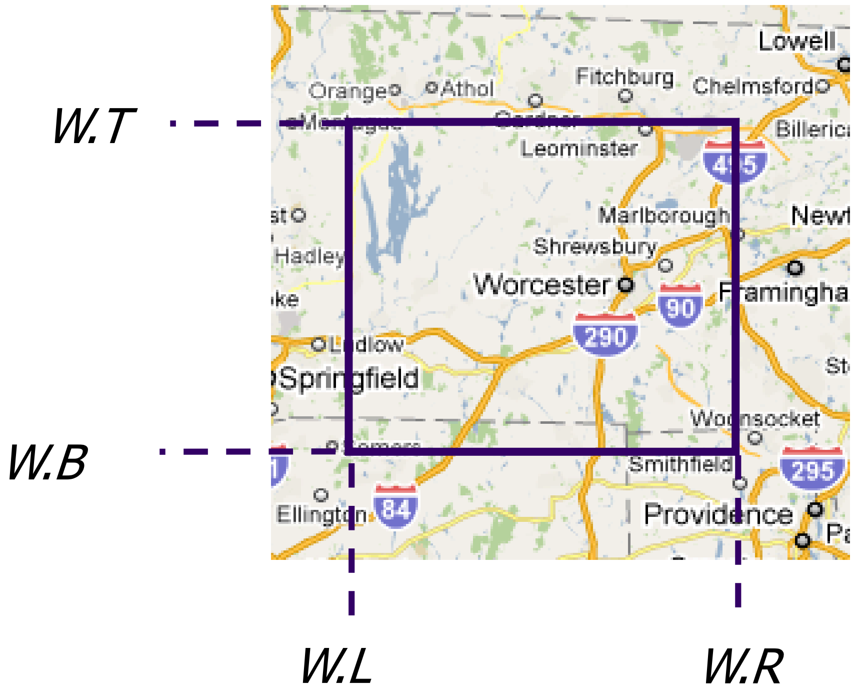
100 pixels = 0.25 miles

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

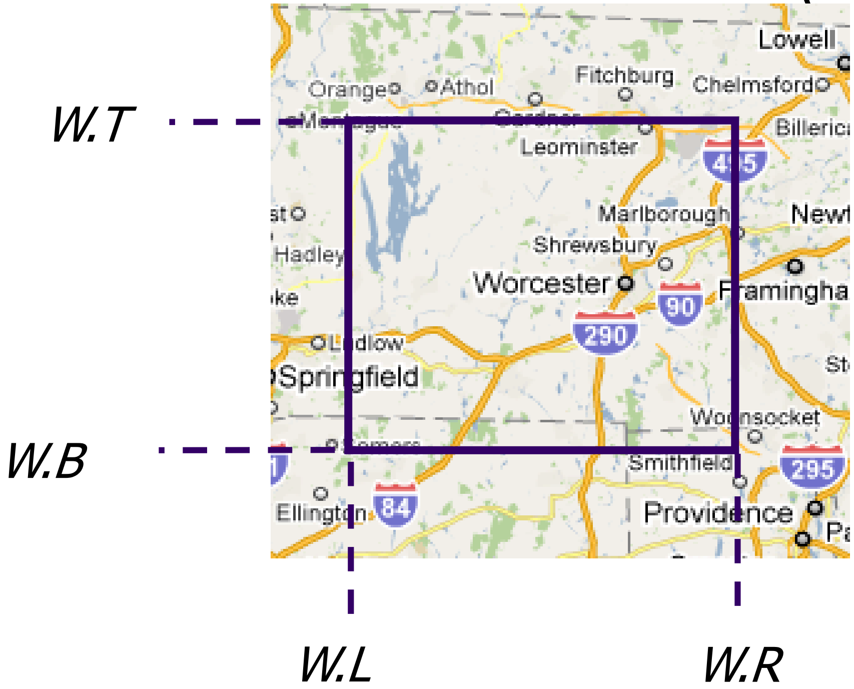
- **World Window:** region of **source** drawing to be rendered
- Rectangle specified by world window is drawn to screen
- Defined by (left, right, bottom, top) or (*W.L, W.R, W.B, W.T)*



Defining World Window

```
mat4 ortho = Ortho2D(left, right, bottom, top)
Or mat4 ortho = Ortho2D(W.L, W.R, W.B, W.T)
```

- **Ortho2D** generates 4x4 matrix that scales input drawing
- **Note:** Need to include **mat.h** (contains **Ortho2D**)

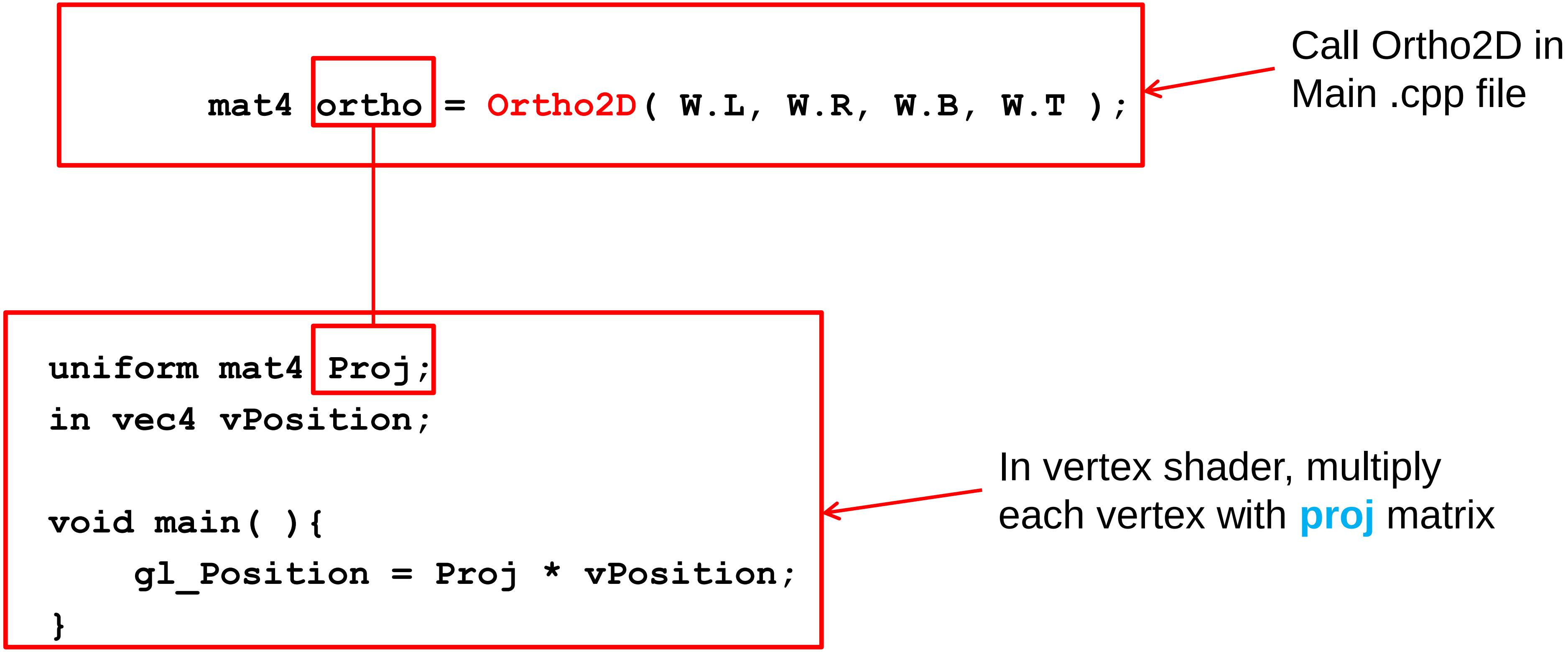


Drawing

- 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



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

Call Ortho2D in Main .cpp file

```
uniform mat4 Proj;
in vec4 vPosition;

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

In vertex shader, multiply each vertex with **proj** matrix

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 );
```

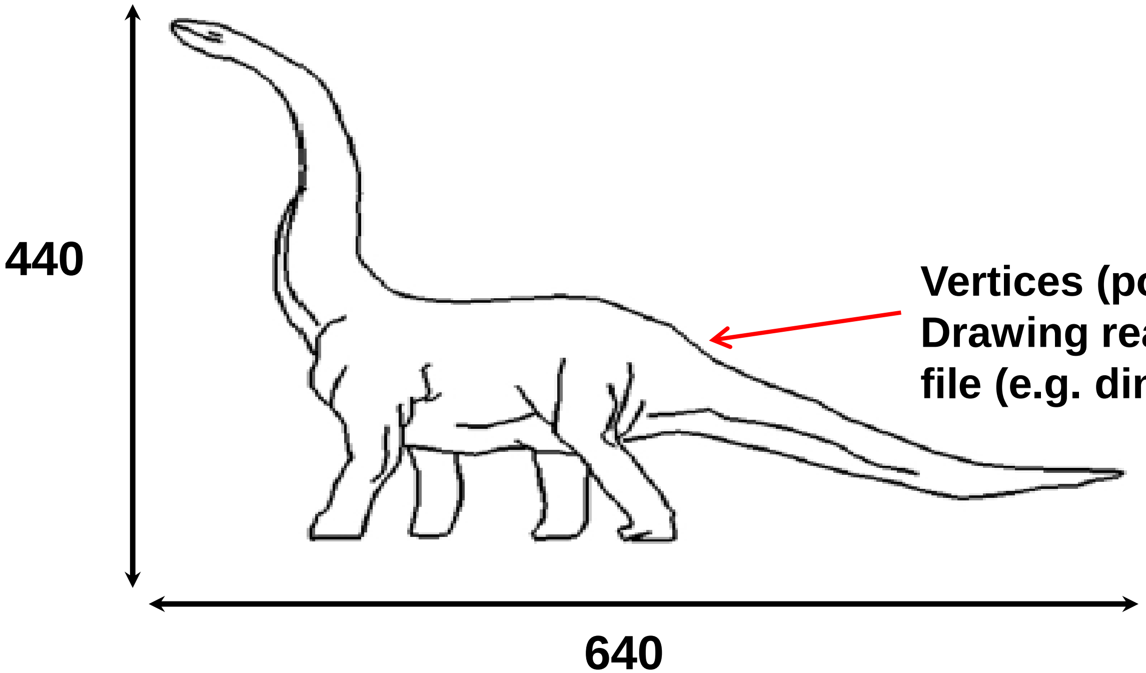
Call Ortho2D in Main .cpp file

```
uniform mat4 Proj;
in vec4 vPosition;

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

In shader, multiply each vertex with **proj** matrix

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



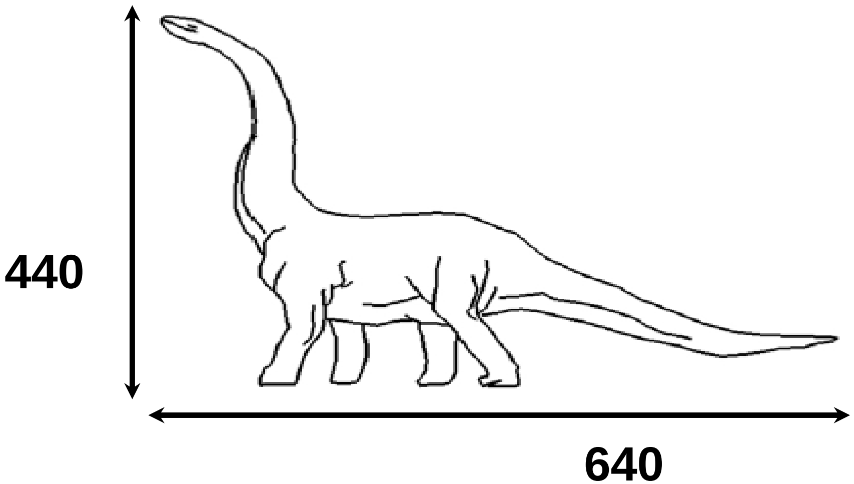
Vertices (points) of Drawing read in from file (e.g. dino.dat)

Drawing Polyline Files

- **Problem:** want to draw single dino.dat on screen
- pseudocode snippet:

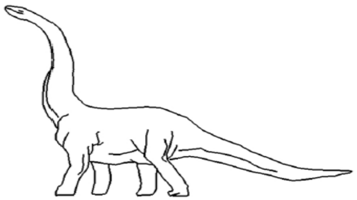
```
// set world window (left, right, bottom, top)
ortho = Ortho2D(0, 640.0, 0, 440.0);

//….. 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?

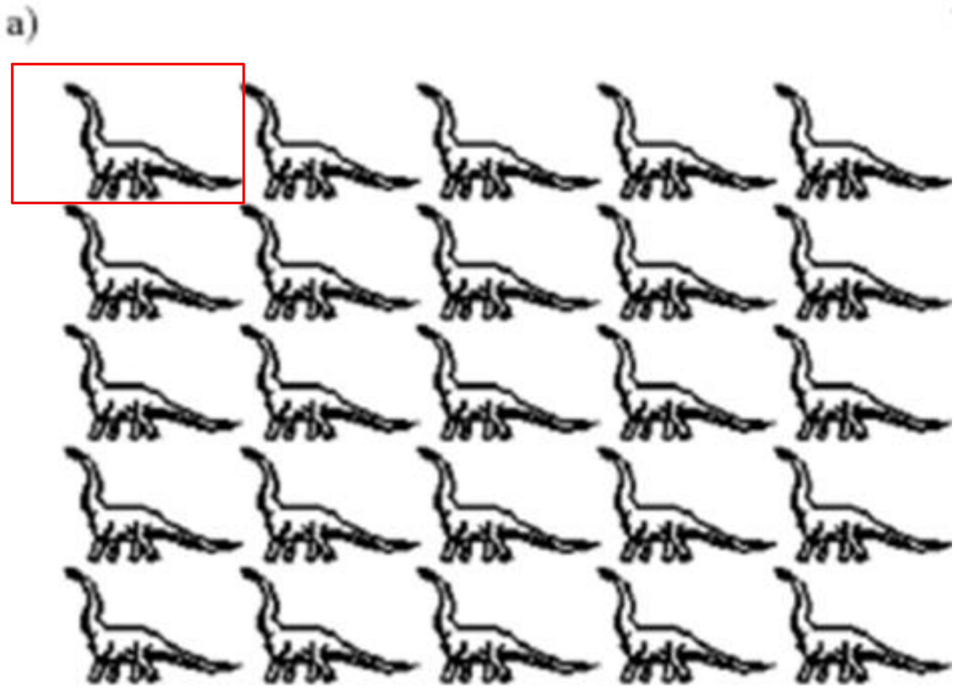


Tiling using W-to-V Mapping

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



One world Window



Multiple tiled viewports

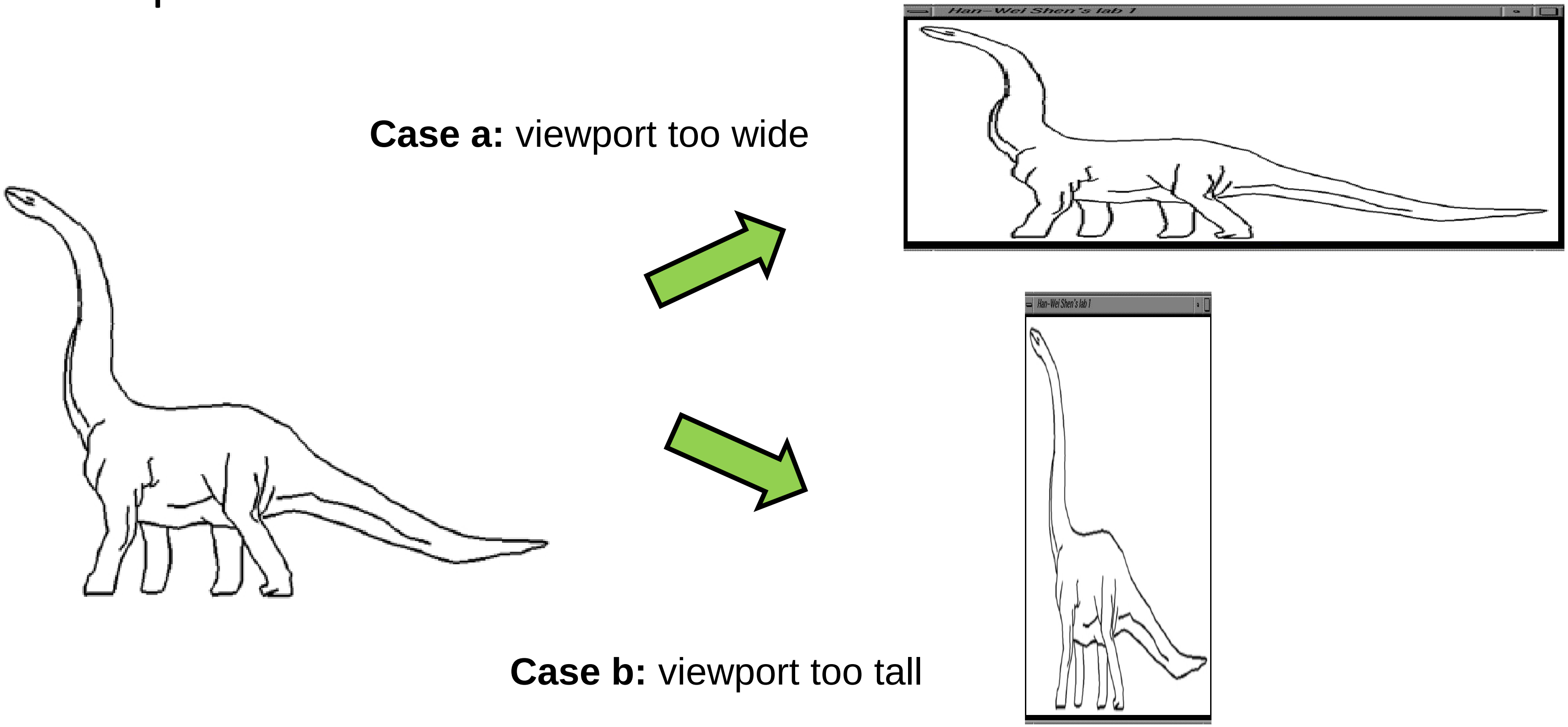
Tiling Polyline Files

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

```
  // 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** = Width/Height
- What if window and viewport have different aspect ratios?
- Two possible cases:

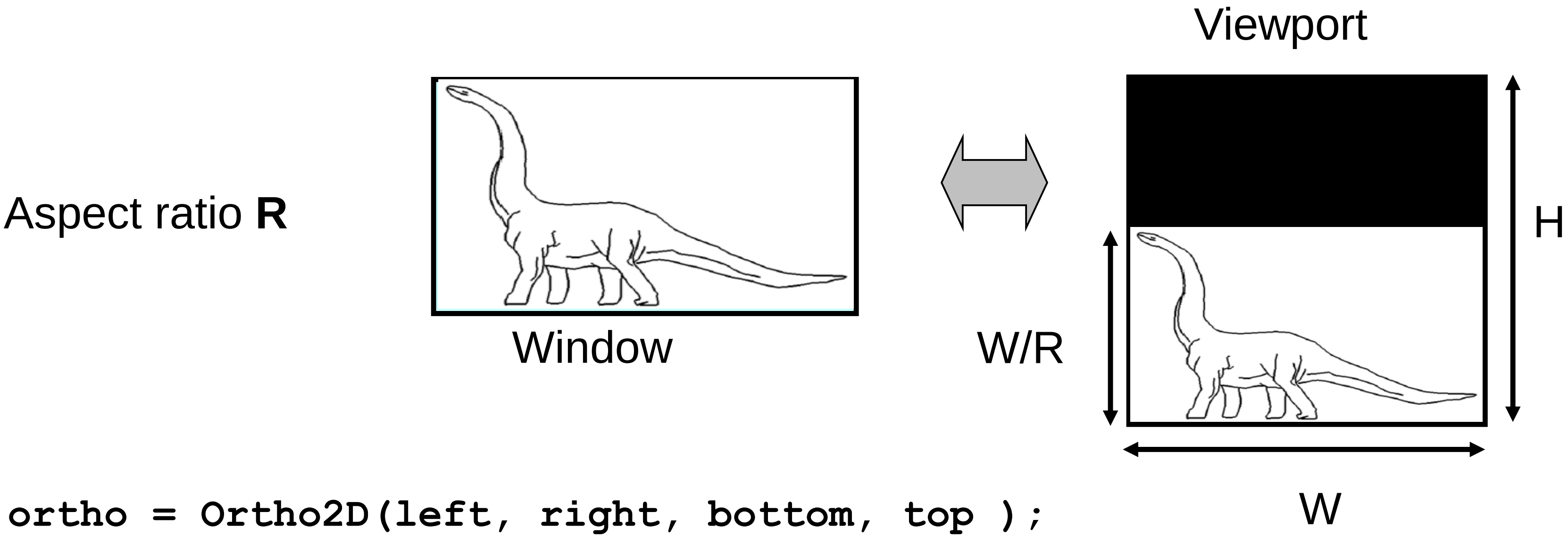


Case a: viewport too wide

Case b: viewport too tall

What if Window and Viewport have different Aspect Ratios?

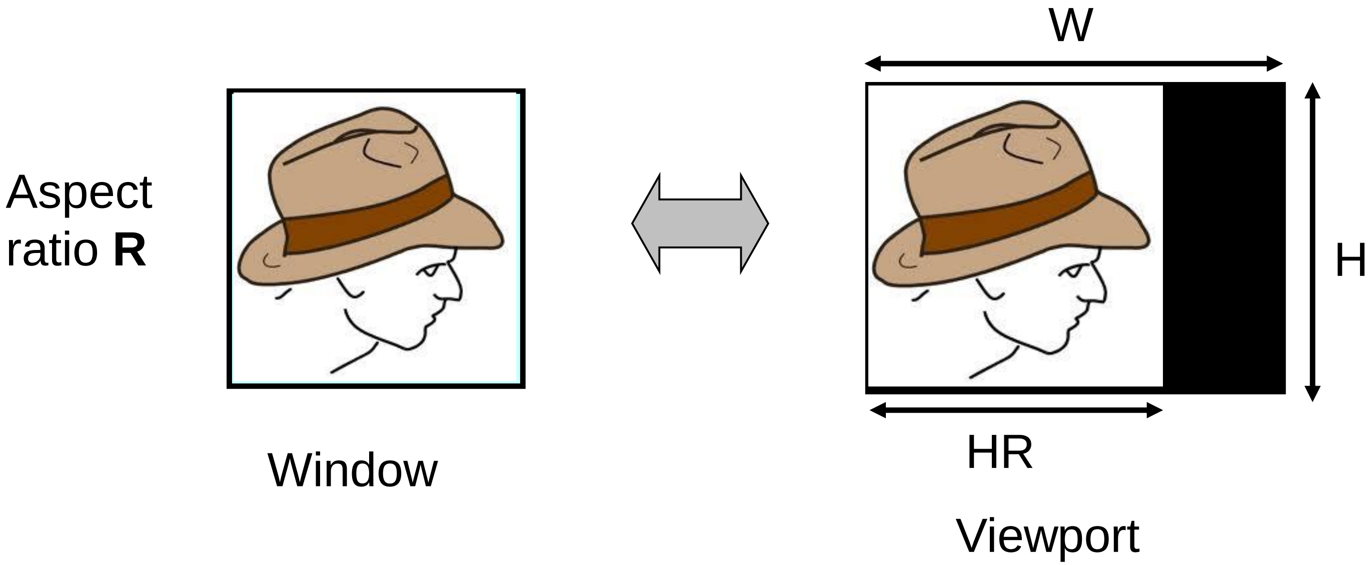
- **R** = window aspect ratio, **W x H** = viewport dimensions
- Two possible cases:
  - **Case A (R > W/H):** map window to tall viewport?



```
ortho = Ortho2D(left, right, bottom, top );
R = (right - left)/(top - bottom);
If(R > W/H)
               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
}
```

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

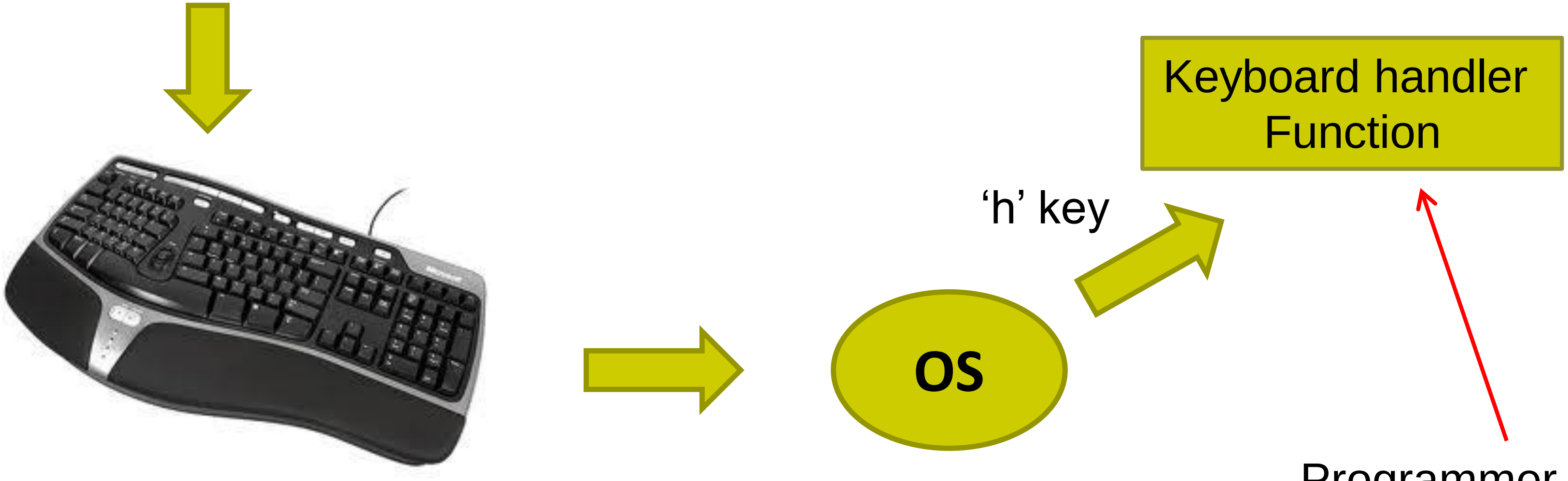
Types of Input Devices

- **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

```
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

ASCII character of pressed key

x,y location of mouse

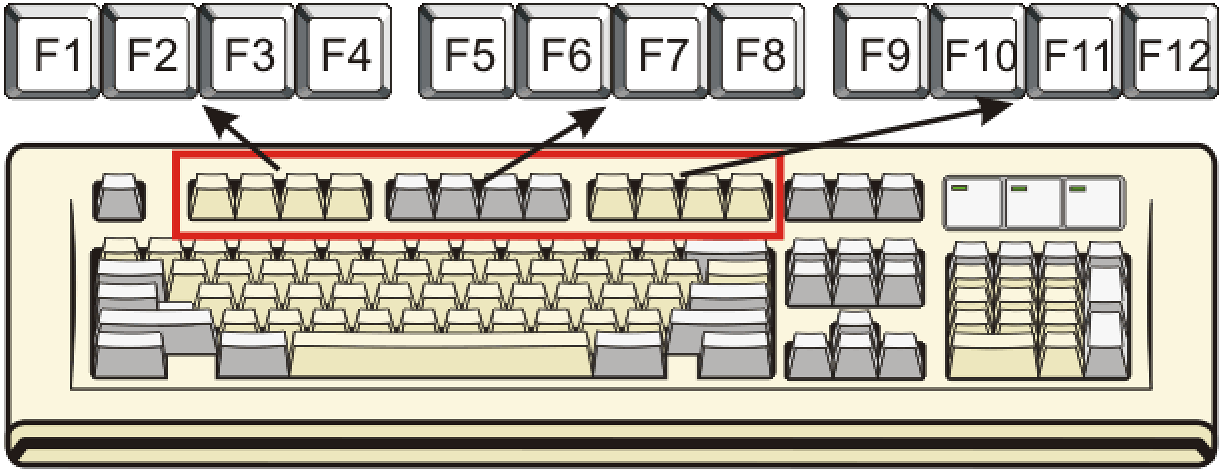
```
void myKeyboard(char key, int x, int y )
{    // put keyboard stuff here
     ……….
        switch(key){    // check which key
           case 'f':
             // do stuff
           break;

           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)
```

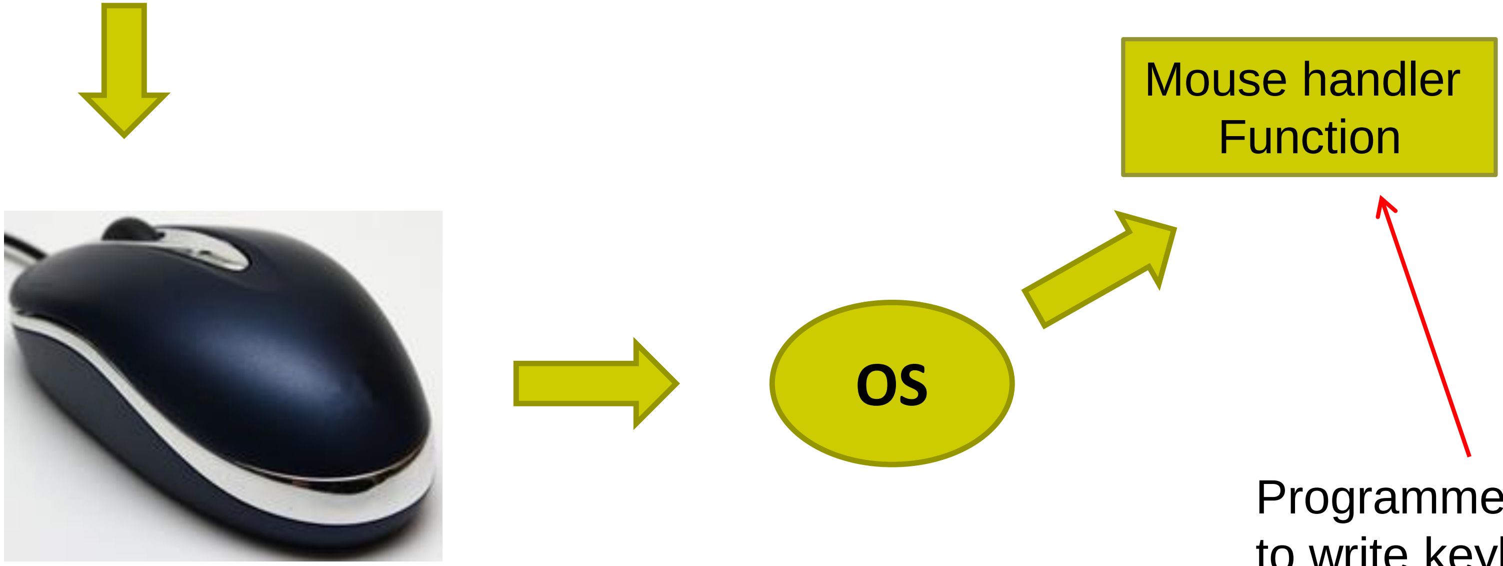
- Example: if (**`specialKey == GLUT_KEY_F1)`** // F1 key pressed
  - **`GLUT_KEY_F1, GLUT_KEY_F12,`** …. for function keys
  - **`GLUT_KEY_UP, GLUT_KEY_RIGHT,`** …. for arrow keys keys
  - **`GLUT_KEY_PAGE_DOWN, GLUT_KEY_HOME,`** …. for page up, home keys
- Complete list of special keys designated in **`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

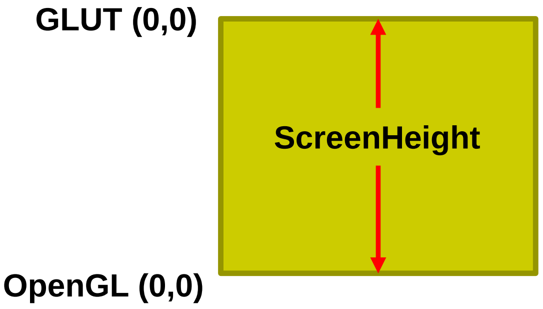
```
void myMouse(int button, int state, int
   x, int y)
{     // put mouse stuff here




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

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



GLUT (0,0)

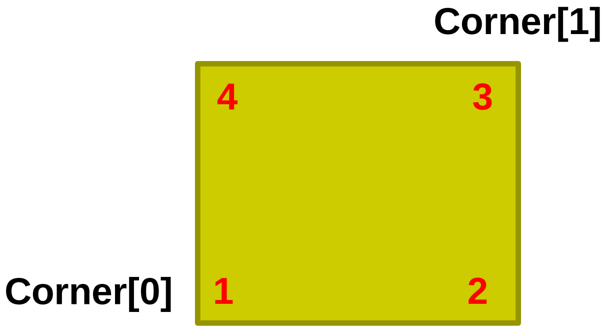
ScreenHeight

OpenGL (0,0)

```
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

Mouse Interaction Example (continued)

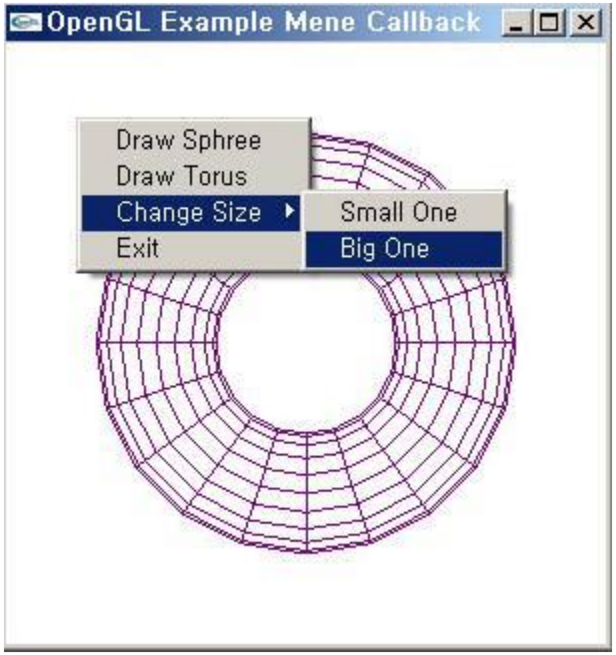


```
if(numCorners == 2)
{
     // draw rectangle or do whatever you planned to do
     Point3 points[4] = corner[0].x, corner[0].y,    //1
                        corner[1].x, corner[0].y,    //2
                        corner[1].x, corner[1].y,    //3
                         corner[0].x, corner[1].y);   //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`**



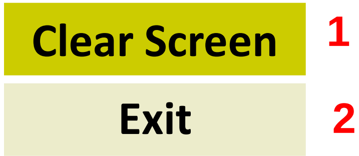
Menus

- Example:

Shows on menu

Checked in mymenu

```
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);
}
```



GLUT Interaction using other input devices

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

```
glutTabletButton (tabletFcn);
…. .
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

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