Announcement

Homework 1 has been posted in dropbox and course website

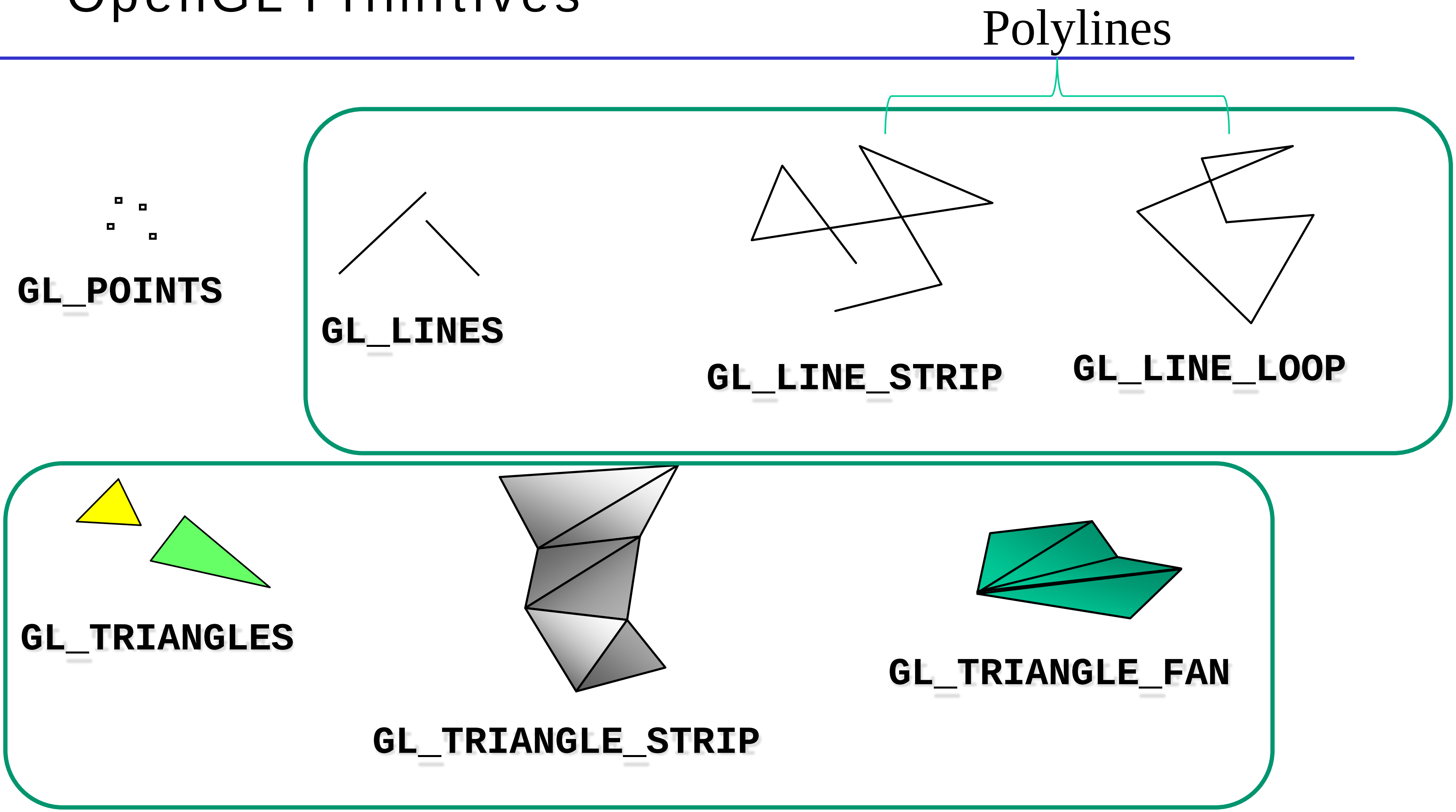
Due: 1:15 pm, Monday, September 12

Today’s Agenda

Primitives

Programming with OpenGL

OpenGL Primitives



OpenGL Primitives

Primitive	Description
GL_POINTS	Each vertex is a single point on the screen.
GL_LINES	Each pair of vertices defines a line segment.
GL_LINE_STRIP	A line segment is drawn from the first vertex to each successive vertex.
GL_LINE_LOOP	Same as GL_LINE_STRIP, but the last and first vertex are connected.
GL_TRIANGLES	Every three vertices define a new triangle.
GL_TRIANGLE_STRIP	Triangles share vertices along a strip.
GL_TRIANGLE_FAN	Triangles fan out from an origin, sharing adjacent vertices.

Wright et al: OpenGL SuperBible 5^{th} Ed

Primitive #1: Points

Points are either 2- or 3-dimensional

- by convention, represent them as column vectors

$$\mathbf{v} = \begin{bmatrix} x \\ y \end{bmatrix} \qquad \text{or} \qquad \mathbf{v} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

A 2D point, a special case of a 3D point, can be represented as

- A 2D vector (e.g, vec2(0,1)),
- A 3D vector (e.g., vec3(0,1,0)),
- and more general a 4D vector (e.g., vec4(0,1,0,1)),

```
glDrawArrays(GL_POINTS, 0, N);
```

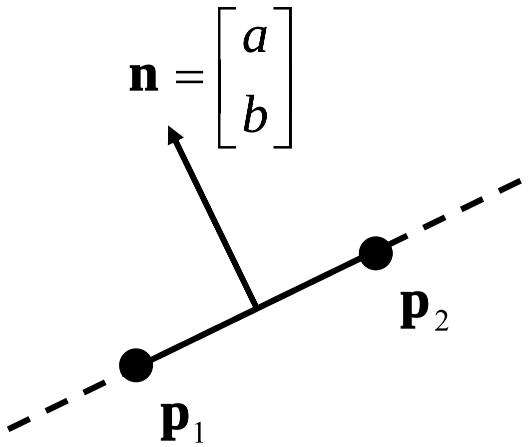
Primitive #2: Line Segments

2-D lines are the set of all points satisfying

$$ax + by + c = 0 \qquad \text{or} \qquad \mathbf{n} \cdot \mathbf{p} + c = 0$$

- vector $[a\ b]$ is perpendicular to segment
- it is a normal vector of the segment
- (almost) always want unit normals!

$$\mathbf{n} \cdot \mathbf{n} = a^2 + b^2 = 1$$



Can also use a vector-valued function:

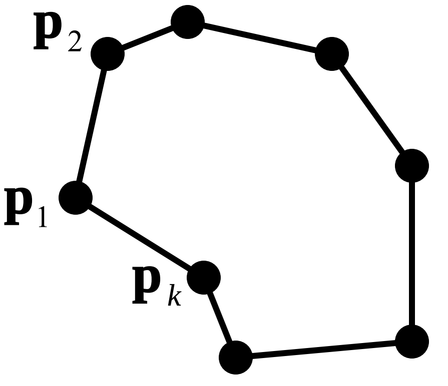
$$\mathbf{p}(t) = \mathbf{p}_1 + t(\mathbf{p}_2 - \mathbf{p}_1) \qquad \text{for } 0 \le t \le 1$$

Drawing Piecewise-Linear 2-D Curves

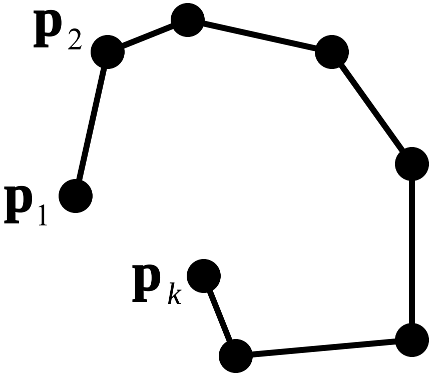
The 3 types of polyline objects:

- GL_LINE_STRIP — open curve
- GL_LINE_LOOP — closed curve
- GL_LINES — separate segments

GL_LINE_LOOP



GL_LINE_STRIP



Triangle

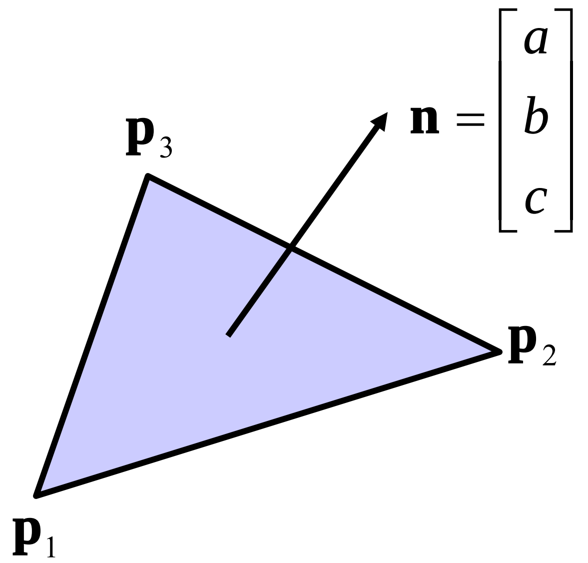
Triangles define a unique plane in 3-D

- set of all points satisfying equation

$$ax + by + cz + d = 0$$

- vector [a b c] is the plane normal
- hence perpendicular to the triangle
- typically use unit normal vector

$$a^2 + b^2 + c^2 = 1$$



Normals will show up again and again

- especially in rendering

Polygons

OpenGL will only display triangles

- Simple: edges cannot cross, i.e., only meet at the end points
- Convex: All points on line segment between two points in a polygon are also in the polygon
- Flat: all vertices are in the same plane

Display triangles in three ways:

- Points (GL_POINT)
- Edges (GL_LINE)
- Filled (GL_FILL)

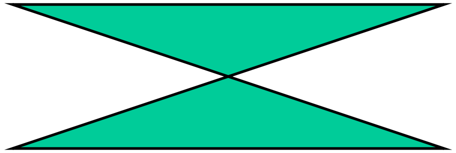
Determined by glPolygonMode

Polygon Issues

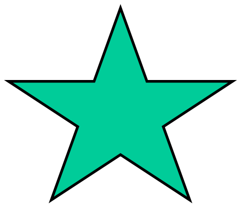
OpenGL will only display triangles

- Simple: edges cannot cross, i.e., only meet at the end points
- Convex: All points on line segment between two points in a polygon are also in the polygon
- Flat: all vertices are in the same plane

Application program must tessellate a polygon into triangles (triangulation)



nonsimple polygon



nonconvex polygon

Polygon Testing

Conceptually simple to test for simplicity and convexity

Time consuming

Earlier versions left testing to the application

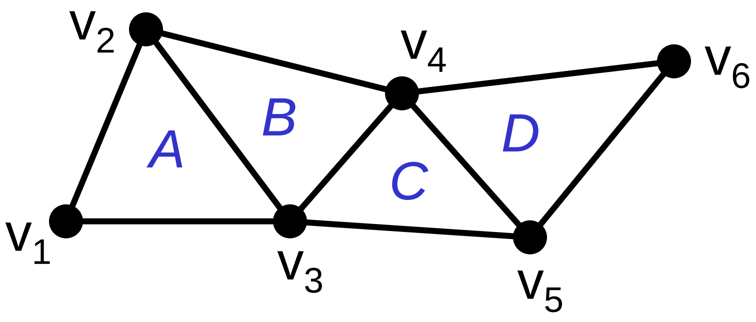
Present version only renders triangles

Need algorithm to triangulate an arbitrary polygon

- trivial if polygon is convex: connect all vertices to a point of interior
- requires more sophisticated algorithms for general polygons

Optimizing Drawing: Triangle Strips

```
glBegin(GL_TRIANGLE_STRIP);
  glVertex3fv(v1);
  glVertex3fv(v2);
  glVertex3fv(v3); // Triangle A
  glVertex3fv(v4); // Triangle B
  glVertex3fv(v5); // Triangle C
  glVertex3fv(v6); // Triangle D
glEnd();
```



Emitting vertices costs something

- each must be transformed fewer vertices = faster drawing

Take advantage of prior vertices

- first 3 specify triangle
- for each subsequent vertex
  - take previous 2 vertices
  - this will define the next triangle

Up to a factor of 3 improvement

- for sufficiently long strips
- requires only 1 vertex/triangle

Triangle Fans

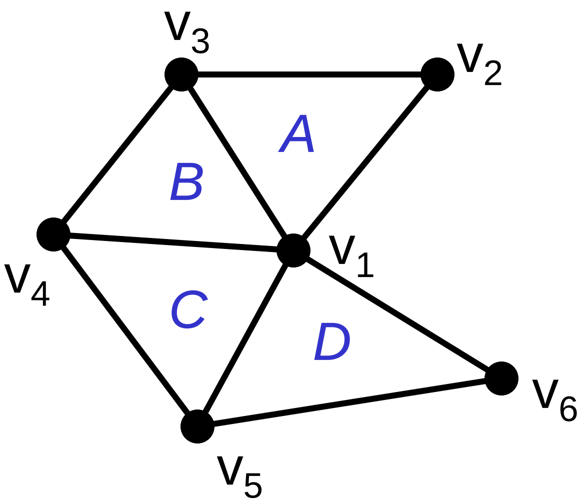
```
glBegin(GL_TRIANGLE_FAN);
  glVertex3fv(v1);
  glVertex3fv(v2);
  glVertex3fv(v3);  // Triangle A
  glVertex3fv(v4);  // Triangle B
  glVertex3fv(v5);  // Triangle C
  glVertex3fv(v6);  // Triangle D
glEnd();
```

start with a central point

build triangles around it

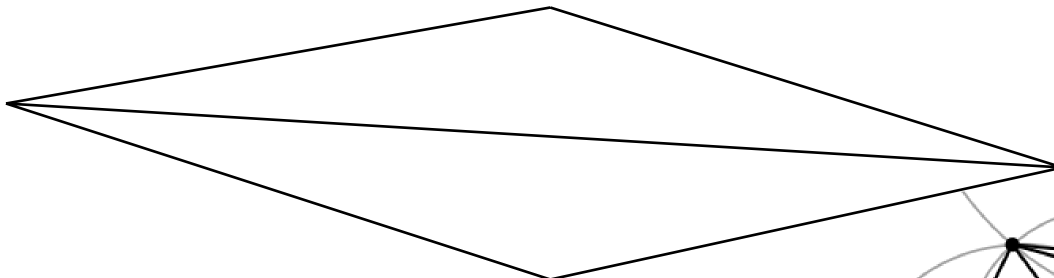
Also 1 vertex per triangle

- if the loop is sufficiently large
- but it usually won't be



Good and Bad Triangles

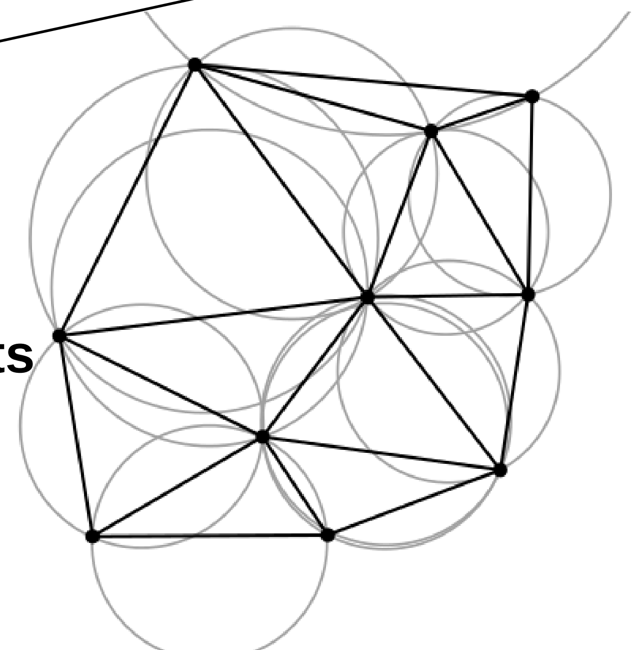
Long thin triangles render badly



Equilateral triangles render well

Maximize minimum angle

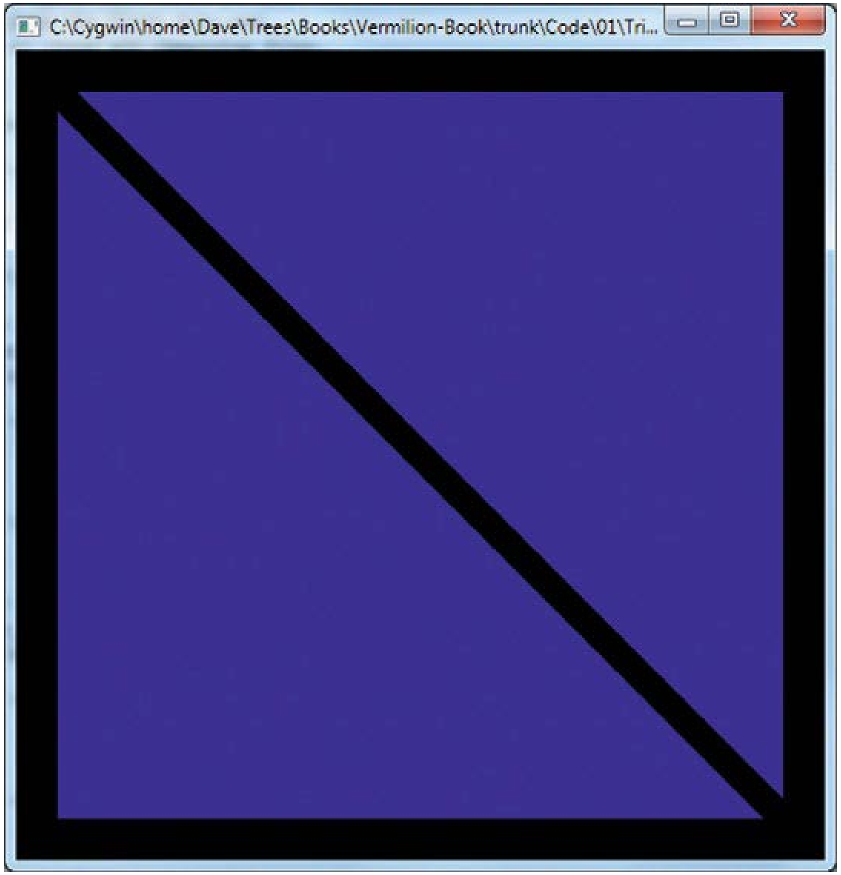
Delaunay triangulation for unstructured points



https://en.wikipedia.org/wiki/Delaunay_triangulation

A Simple Program (?)

Generate two triangles on a solid background



Shreiner et al, OpenGL Programming Guide, the Official Guide to Learning OpenGL, Version 4.3, the 8th Ed,

OpenGL Camera

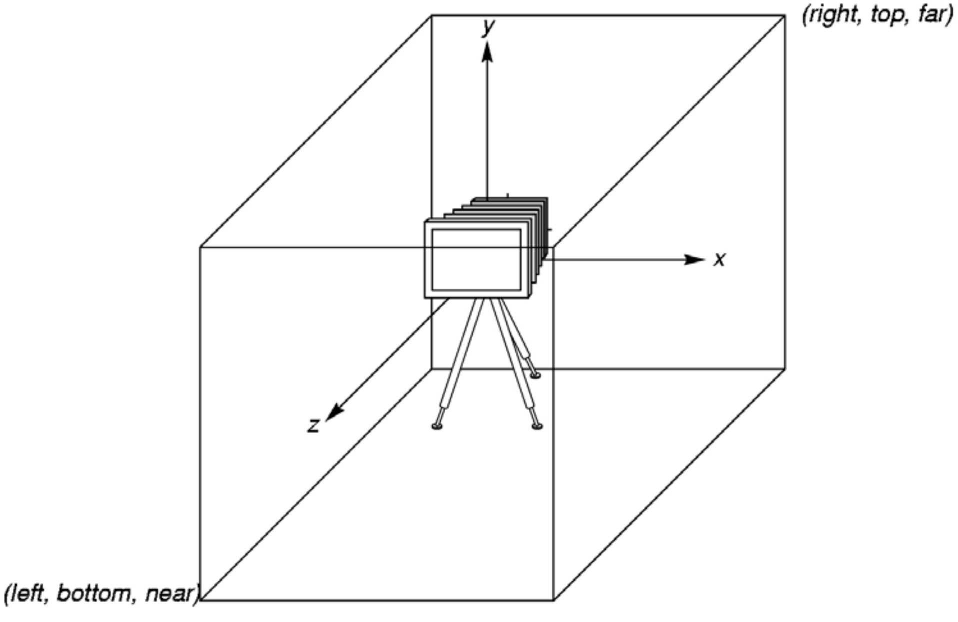
OpenGL places a camera at the origin in object space pointing in the negative z direction

The default viewing volume

is a box centered at the

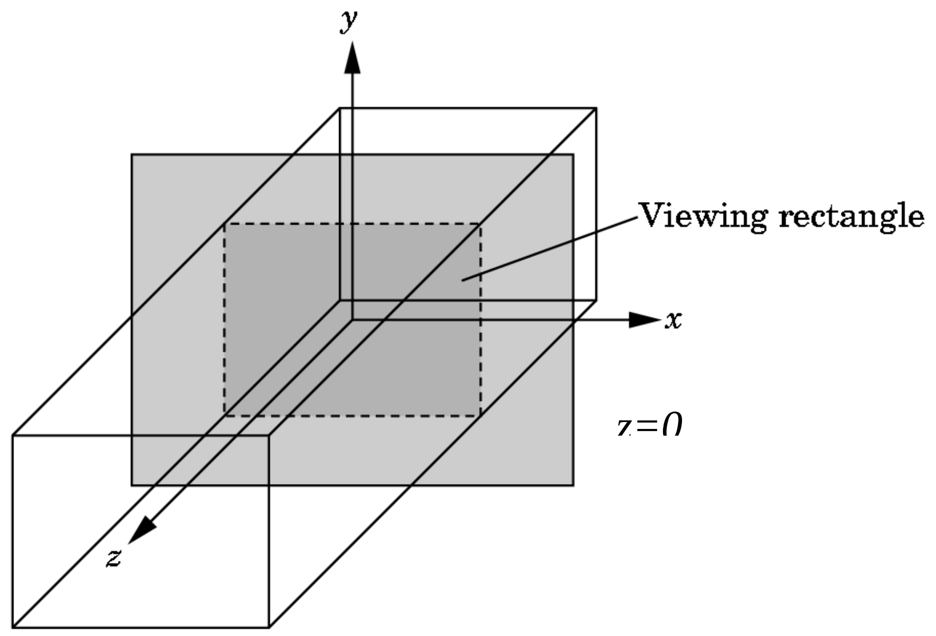
origin with sides of

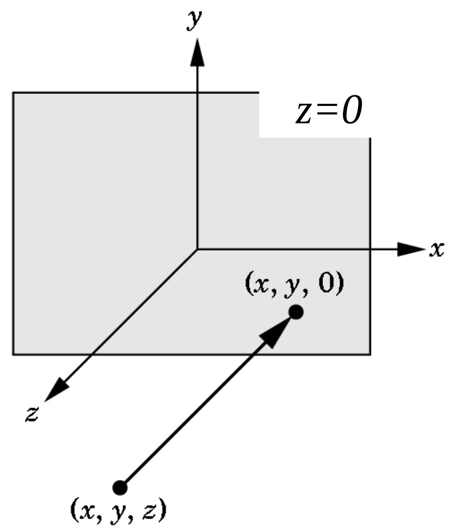
length 2



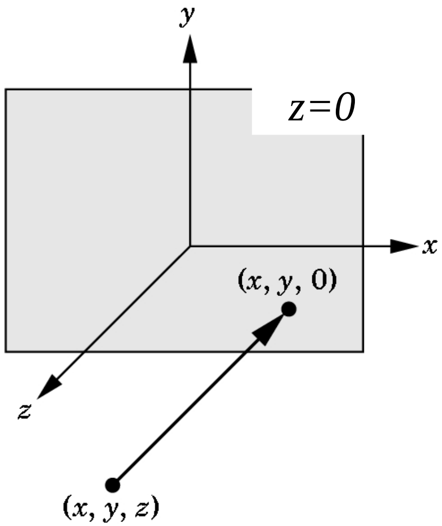
Orthographic Viewing

In the default orthographic view, points are projected forward along the z axis onto the plane $z=0$



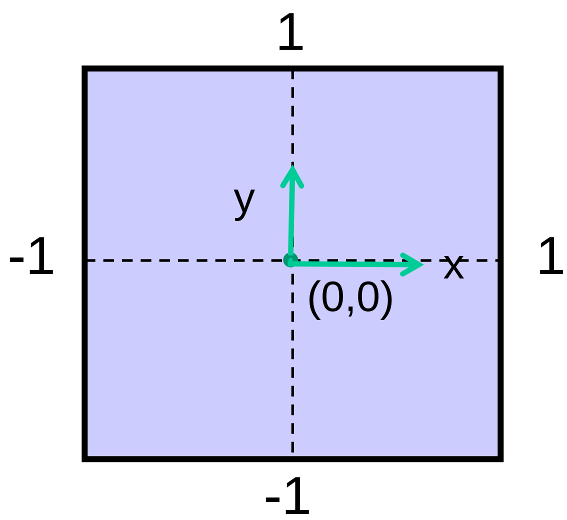


Orthographic Viewing



E. Angel and D. Shreiner: Interactive Computer Graphics 6E © Addison-Wesley 2012

OpenGL coordinates



Clipping

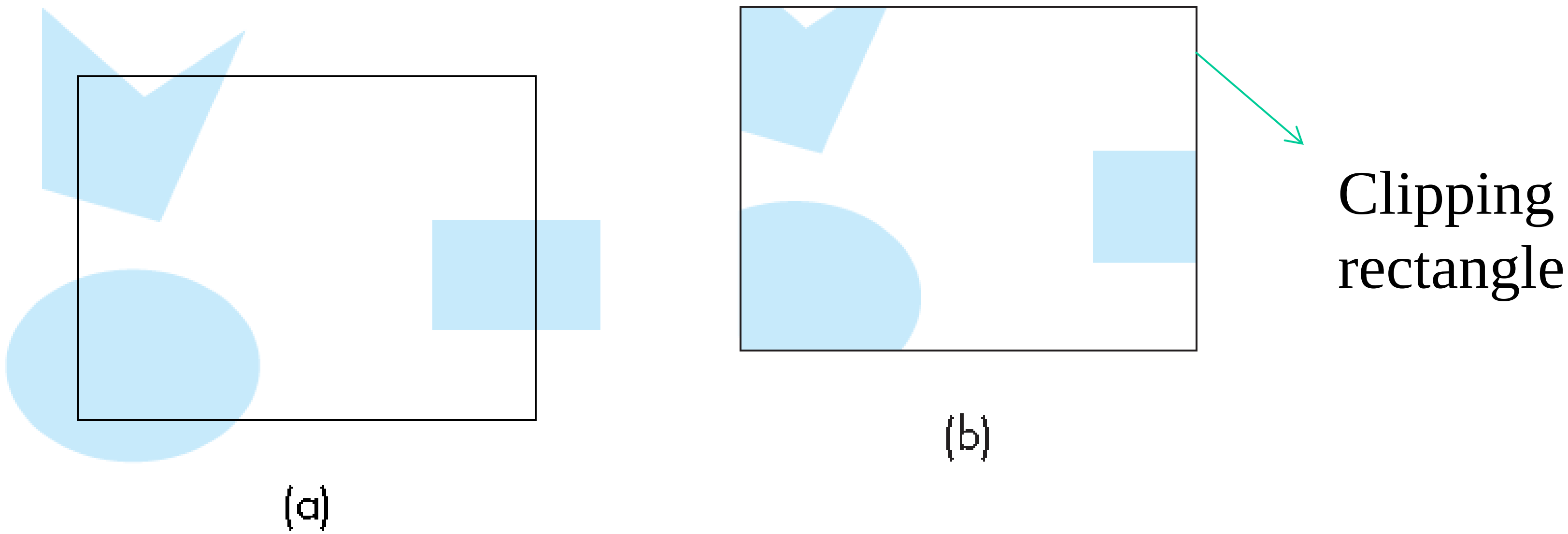
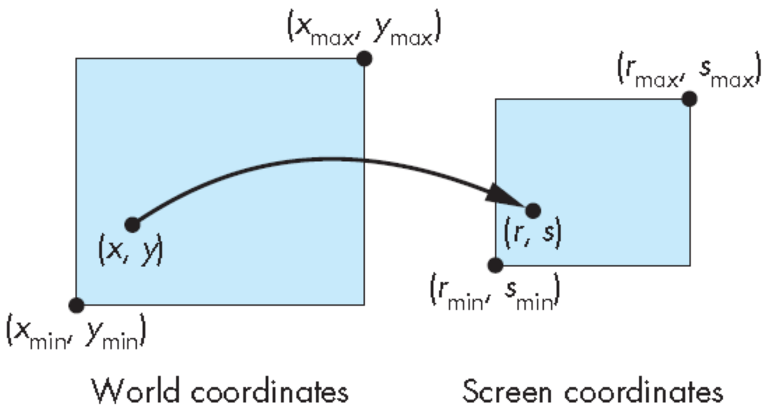


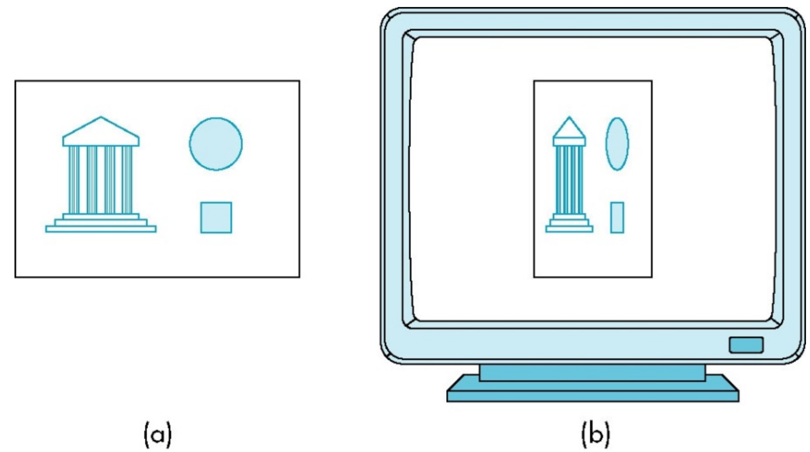
FIGURE 2.35 Two-dimensional viewing. (a) Objects before clipping. (b) Image after clipping.

From Vertex to Screen

Mapping from vertex coordinates to screen coordinates

Aspect ratio mismatched



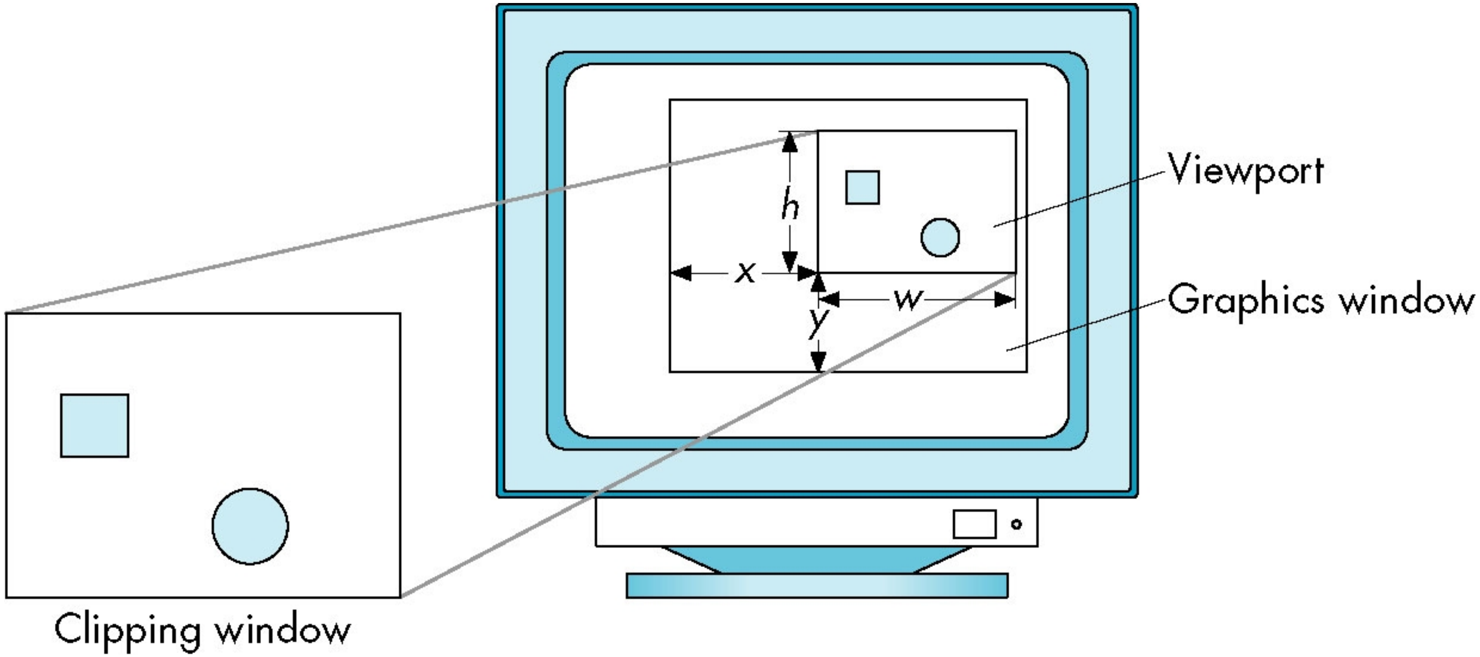


Flexible Way to Treat it

Solution: Do not have use the entire window for the image

void glViewport (GLint x, GLint y, GLsizei w, GLsizei h)

- (x,y): Lower-left corner of the view port in pixels
- (w,h): width and height in pixels



Now, Let’s Start the First Program

Build a complete first program

- Introduce shaders
- Introduce a standard program structure

Initialization steps and program structure

Program Structure

Most OpenGL programs have a similar structure that consists of the following functions

- **`main`**:
  - specifies the callback functions
  - opens one or more windows with the required properties
  - enters event loop (last executable statement)
- **`init()`**: sets the state variables
  - Viewing
  - Attributes
- **`initShader:`** read, compile and link shaders
- callbacks
  - Display function
  - Input and window functions

triangle.c

```
enum VAO_IDs { Triangles, NumVAOs };
enum Buffer_IDs { ArrayBuffer, NumBuffers };
enum Attrib_IDs { vPosition = 0 };

GLuint  VAOs[NumVAOs];
GLuint  Buffers[NumBuffers];

const GLuint  NumVertices = 6;
```

Shreiner et al, OpenGL Programming Guide, the Official Guide to Learning OpenGL, Version 4.3, the 8th Ed,

triangle.c

```
#include <GL/glew.h>
#include <GL/freeglut.h>
```

includes **`gl.h`**

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_RGBA);
    glutInitWindowSize(512, 512);
    glutInitContextVersion(4, 3);
    glutInitContextProfile(GLUT_CORE_PROFILE);
    glutCreateWindow(argv[0]);
    if (glewInit()) {
        cerr << "Unable to initialize GLEW ... exiting" << endl;
        exit(EXIT_FAILURE);
    }
    init();
    glutDisplayFunc(display);
    glutMainLoop();
}
```

GLUT functions

- **`glutInit` initializes GLUT library, processes command line arguments and setups data structures**
- **`glutInitDisplayMode` requests properties for the window (the *rendering context*),**
  - RGB color
  - Single buffering
  - Other options such as depth buffers, or animation
- **`glutInitWindowSize` specifies the size of windows in pixels**
- **`glutInitContextVersion` and `glutInitContextProfile` specify the type of OpenGL context, i.e., the internal data structure**

GLUT functions

`glutCreateWindow` **creates window with title as arg[0]**

`glewInit` **initializes the GLEW library**

`Init` **initializes OpenGL states and initializes the shader**

`glutDisplayFunc` **sets up display callback**

`glutMainLoop` **enter infinite event loop to process user input**

Initialization

Initialize the vertex array

Vertex array objects and buffer objects can be set up on init()

Also set up shaders as part of initialization

- Read
- Compile
- Link

init()

```
void init(void)
{
    glGenVertexArrays(NumVAOs, VAOs);


    glBindVertexArray(VAOs[Triangles]);

    GLfloat  vertices[NumVertices][2] = {
        { -0.90, -0.90 },  // Triangle 1
        {  0.85, -0.90 },
        { -0.90,  0.85 },
        {  0.90, -0.85 },  // Triangle 2
        {  0.90,  0.90 },
        { -0.85,  0.90 }
    };
…
```

GLuint VAOs[NumVAOs];
Vertex-Array object: Bundles all vertex data (positions, colors, ..,)
Initialize the VAO and get name for buffer

Create a new VAO with the assigned name or activate a VAO if binding to an existing VAO

A vertex array can hold many attributes of vertices, such as position, color, texture, coordinates, etc.

init()

…

```
glGenBuffers(NumBuffers, Buffers);
```

GLuint Buffers[NumBuffers];
Buffer objects store data to be used
Create a BO and return a name

Specify the type of BO

```
glBindBuffer(GL_ARRAY_BUFFER, Buffers[ArrayBuffer]);
```

Transfer the vertex data to a BO

```
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices,GL_STATIC_DRAW);
```

Target, e.g., vertex attribute data, index data, pixel data, etc

Usage, how the data will be read and written, e.g., GL_STREAM_DRAW

…

init()

```
ShaderInfo  shaders[] = {
        { GL_VERTEX_SHADER, "triangles.vert" },
        { GL_FRAGMENT_SHADER, "triangles.frag" },
        { GL_NONE, NULL }
    };

    GLuint program = LoadShaders(shaders);
    glUseProgram(program);

    glVertexAttribPointer(vPosition, 2, GL_FLOAT,
                          GL_FALSE, 0, BUFFER_OFFSET(0));
    glEnableVertexAttribArray(vPosition);
}
```

Initialize the vertex and fragment shaders

Load, compile and link shaders

Location of shader attributes

Connect shader “in” to a vertex-attribute array

Display Callback

```
void display(void)
{
    glClear(GL_COLOR_BUFFER_BIT);

    glClearColor(r,g,b, α=0);


    glBindVertexArray(VAOs[Triangles]);
    glDrawArrays(GL_TRIANGLES, 0, NumVertices);

    glFlush();
}
```

Clear buffer, e.g., color buffer and depth buffer

An optional operation to clear canvas with desired background color

Select the VAO to draw

Send the data to OpenGL pipeline