CompSci 373 Tutorial

OpenGL

What is OpenGL?

- What is OpenGL?
  - A cross-platform API (library) to produce 2D and 3D computer graphics application
- How can we use it?
  - It provides a set of primitive but powerful high-level rendering command. All drawing must be done through these.

Structure of an OpenGL Program

```
#include <windows.h>
#include <cmath>
#include "gl/glut.h"

const int windowWidth = 400;
const int windowHeight = 400;

void display(void)
{
    //Drawings are done here
}

void init(void)
{
    //setup properties of the scene such as background color,
    //width, height of the scene, etc.
}

int main(int argc, char** argv)
{
    glutInit(&argc, argv);

    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);

    glutInitWindowSize(windowWidth, windowHeight);
    glutInitWindowPosition(100, 100);

    glutCreateWindow("Simple OpenGL Program");

    init();
    glutDisplayFunc(display);

    glutMainLoop();
    return 0;
}
```

Structure of an OpenGL Program

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}
```

File Headers to be included

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}
```

Main(): Program's entry point

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}
```

Setup the display window

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    init();
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    return 0;
}
```

Tell OpenGL that the display() is where we do our drawing

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}
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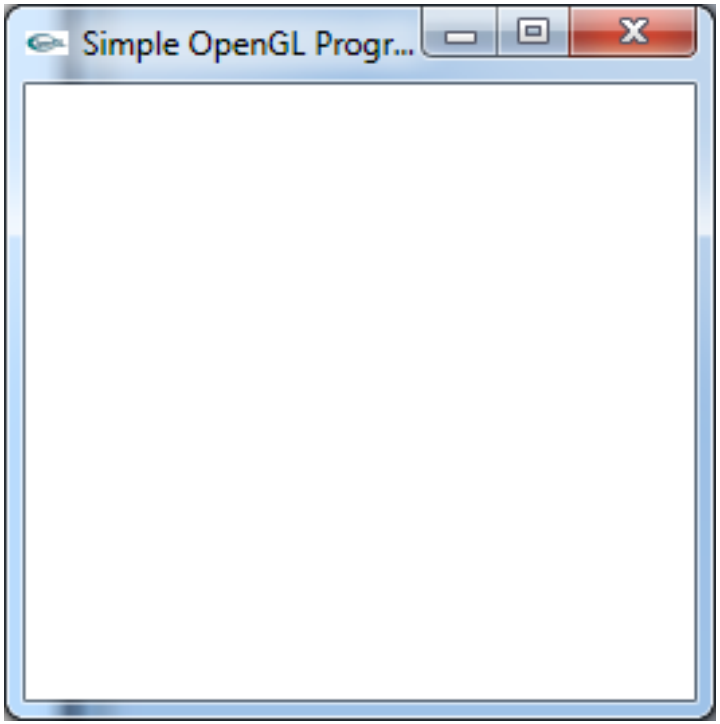

A Simple OpenGL Program

```
void display(void)
{
    // Clear The Screen Buffer And The Depth Buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    //draw something here
    glBegin(GL_TRIANGLES);                          // Drawing Using Triangles
        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top Vertex
        glVertex3f(-100.0f,-100.0f, 0.0f);              // Bottom Left Vertex
        glVertex3f( 100.0f,-100.0f, 0.0f);              // Bottom Right Vertex
    glEnd();

    // start processing buffered OpenGL routines
    glFlush();
}

void init(void)
{
    glClearColor(0.0, 0.0, 0.0, 0.0);

    //simple orthographic projection
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
    GLdouble halfWidth=(GLdouble) windowWidth/2.0;
    GLdouble halfHeight=(GLdouble) windowHeight/2.0;
    gluOrtho2D(-halfWidth, halfWidth,-halfHeight, halfHeight);
}

int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(windowWidth, windowHeight);
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A Simple OpenGL Program

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}
```

Setup necessary properties

A Simple OpenGL Program

```
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{
    // Clear The Screen Buffer And The Depth Buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    //draw something here
    glBegin(GL_TRIANGLES);                          // Drawing Using Triangles
        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top Vertex
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void init(void)
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    gluOrtho2D(-halfWidth, halfWidth,-halfHeight, halfHeight);
}

int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(windowWidth, windowHeight);
    glutInitWindowPosition(100, 100);
    glutCreateWindow("Simple OpenGL Program");

    init();
    glutDisplayFunc(display);

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    return 0;
}
```

Specify the background color (RGBA)

A Simple OpenGL Program

```
void display(void)
{
    // Clear The Screen Buffer And The Depth Buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    //draw something here
    glBegin(GL_TRIANGLES);                          // Drawing Using Triangles
        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top Vertex
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    init();
    glutDisplayFunc(display);

    glutMainLoop();
    return 0;
}
```

Specify a simple orthographic projection

A Simple OpenGL Program

```
void display(void)
{
    // Clear The Screen Buffer And The Depth Buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    //draw something here
    glBegin(GL_TRIANGLES);                          // Drawing Using Triangles
        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top Vertex
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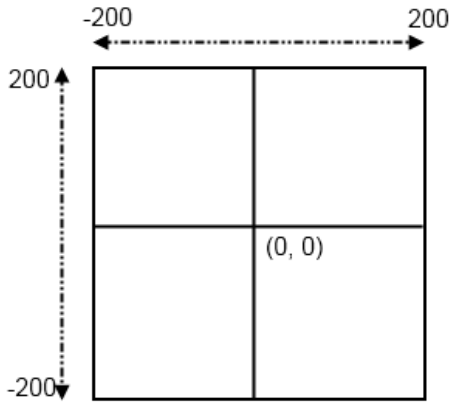
    gluOrtho2D(-halfWidth, halfWidth,-halfHeight, halfHeight);
}

int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(windowWidth, windowHeight);
    glutInitWindowPosition(100, 100);
    glutCreateWindow("Simple OpenGL Program");

    init();
    glutDisplayFunc(display);

    glutMainLoop();
    return 0;
}
```

Specify the screen coordinates



A Simple OpenGL Program

```
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{
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    init();
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}
```

The actual drawings in here

A Simple OpenGL Program

```
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    // Clear The Screen Buffer And The Depth Buffer
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    init();
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    glutMainLoop();
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}
```

Clear all the buffers.

A Simple OpenGL Program

```
void display(void)
{
    // Clear The Screen Buffer And The Depth Buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    //draw something here
    glBegin(GL_TRIANGLES);                          // Drawing Using Triangles
        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top Vertex
        glVertex3f(-100.0f,-100.0f, 0.0f);              // Bottom Left Vertex
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    glEnd();

    // start processing buffered OpenGL routines
    glFlush();
}

void init(void)
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}
```

Draw a triangle

A Simple OpenGL Program

```
void display(void)
{
    // Clear The Screen Buffer And The Depth Buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    //draw something here
    glBegin(GL_TRIANGLES);                          // Drawing Using Triangles
        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top Vertex
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    glEnd();

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}

int main(int argc, char** argv)
{
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    glutMainLoop();
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}
```

Process the buffers and display onto the screen

A Simple OpenGL Program

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    // Clear The Screen Buffer And The Depth Buffer
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    //draw something here
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        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top Vertex
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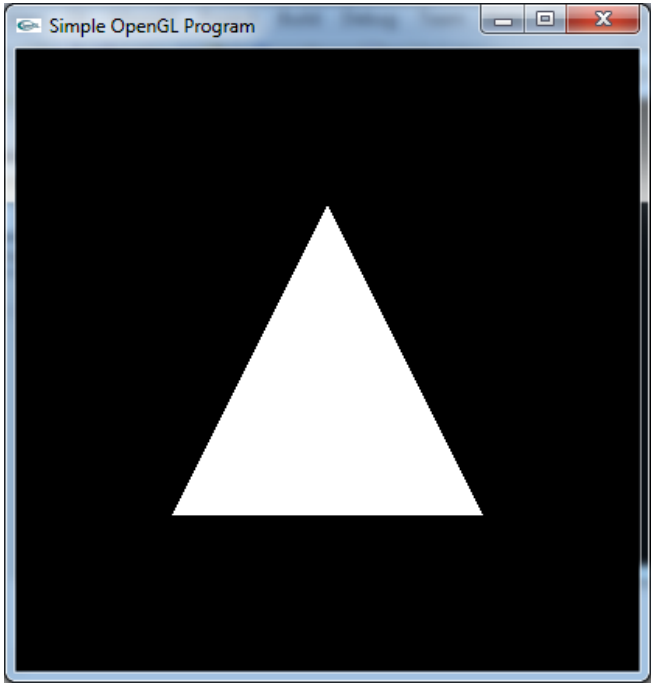


A Simple OpenGL Program

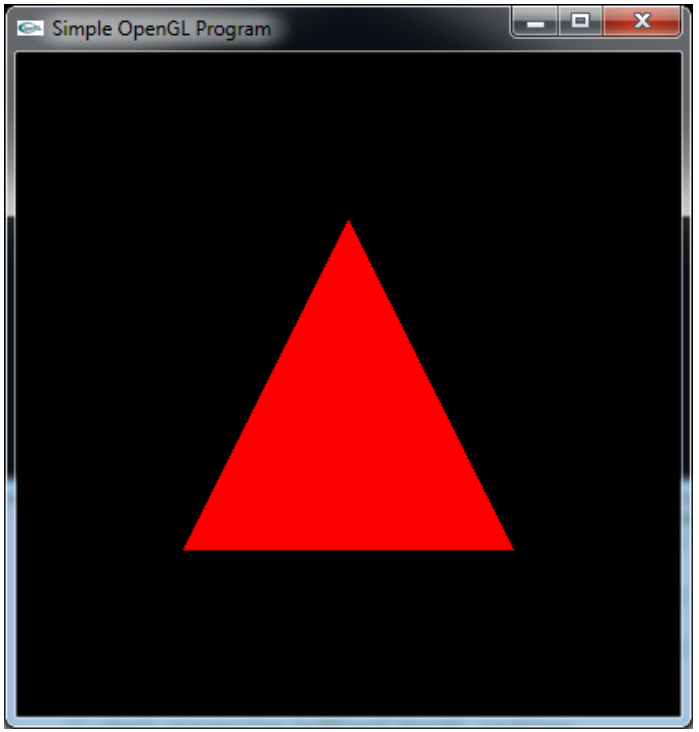
```
void display(void)
{
    // Clear The Screen Buffer And The Depth Buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    //draw something here
    glColor3f(1.0f, 0.0f, 0.0f);
    glBegin(GL_TRIANGLES);                          // Dra
        glVertex3f( 0.0f, 100.0f, 0.0f);              //

        glVertex3f(-100.0f,-100.0f, 0.0f);            //

        glVertex3f( 100.0f,-100.0f, 0.0f);            //
    glEnd();

    // start processing buffered OpenGL routines
    glFlush();
}
```



A Simple OpenGL Program

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{
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    //draw something here
    glBegin(GL_TRIANGLES);                          // Drawing
        glColor3f(1.0f, 0.0f, 0.0f);
        glVertex3f( 0.0f, 100.0f, 0.0f);                // Top

        glColor3f(0.0f, 1.0f, 0.0f);
        glVertex3f(-100.0f,-100.0f, 0.0f);              // Bott

        glColor3f(0.0f, 0.0f, 1.0f);
        glVertex3f( 100.0f,-100.0f, 0.0f);              // Bott
    glEnd();

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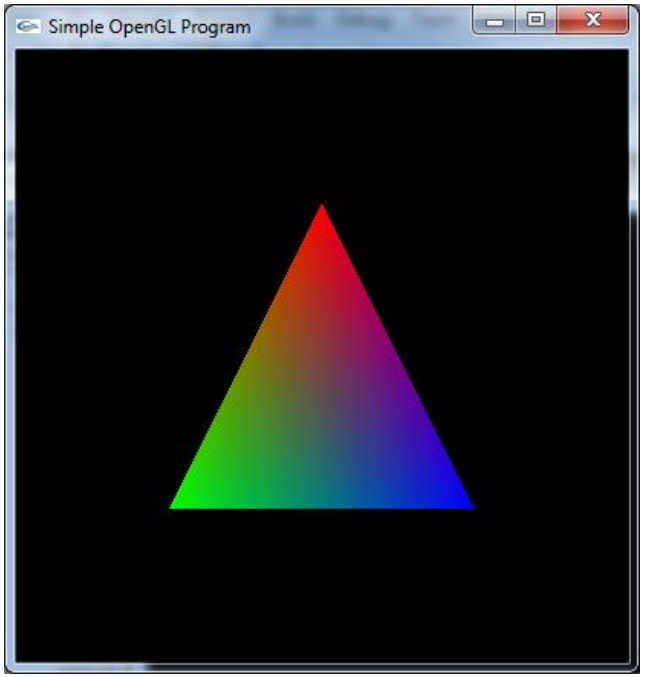
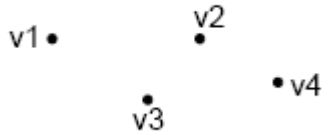
    glFlush();
}
```



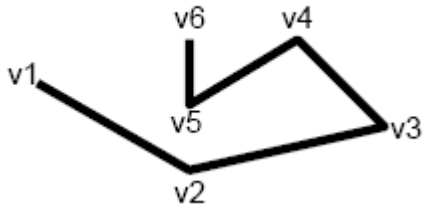
glBegin(…)

- GL_POINTS

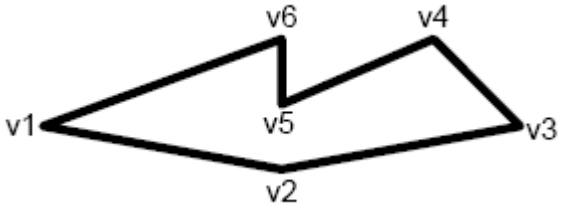


- GL_LINES

- GL_LINE_STRIP



- GL_LINE_LOOP



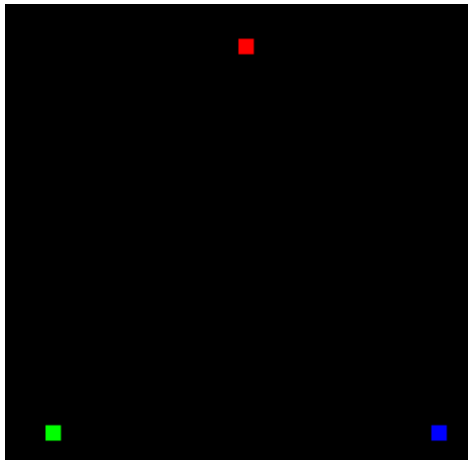
glBegin(…)

- GL_POINTS

```
glBegin(GL_POINTS);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( 0.0f, 100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f(-100.0f,-100.0f, 0.0f);

    glColor3f(0.0f, 0.0f, 1.0f);
    glVertex3f( 100.0f,-100.0f, 0.0f);
glEnd();
```



glBegin(…)

- GL_POINTS

```
glBegin(GL_POINTS);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( 0.0f, 100.0f, 0.0f);

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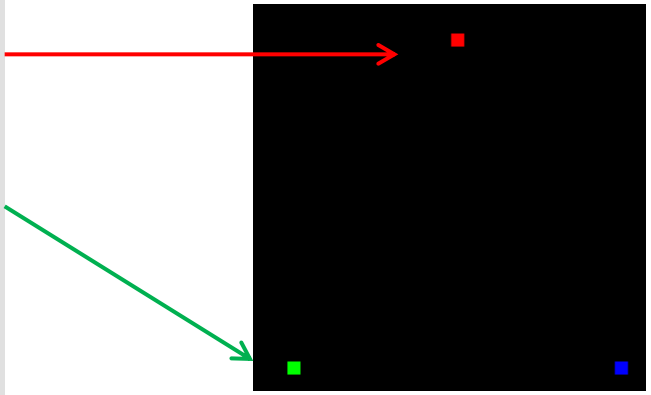
    glVertex3f(-100.0f,-100.0f, 0.0f);

    glColor3f(0.0f, 0.0f, 1.0f);
    glVertex3f( 100.0f,-100.0f, 0.0f);
glEnd();
```



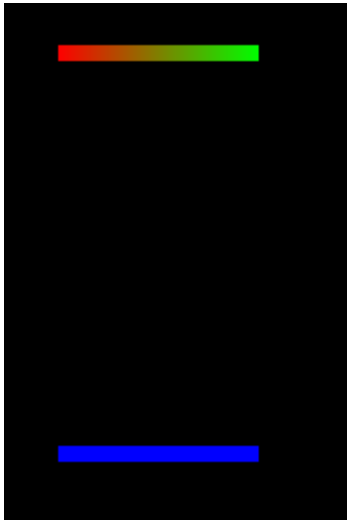
glBegin(…)

- GL_LINES

```
glBegin(GL_LINES);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( 0.0f, 100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f(100.0f,100.0f, 0.0f);

    glColor3f(0.0f, 0.0f, 1.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);
    glVertex3f( 100.0f,-100.0f, 0.0f);
glEnd();
```



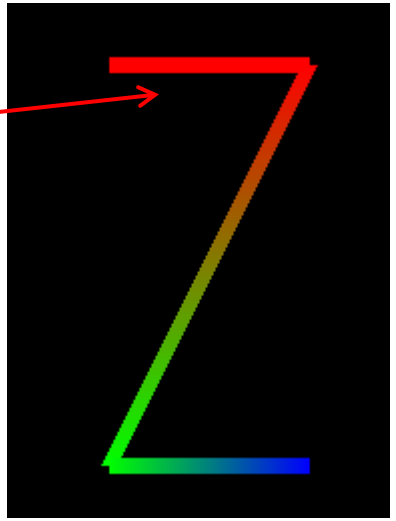
glBegin(…)

- GL_LINE_STRIP

```
glBegin(GL_LINE_STRIP);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( 0.0f, 100.0f, 0.0f);
    glVertex3f(100.0f,100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 0.0f, 1.0f);
    glVertex3f( 100.0f,-100.0f, 0.0f);
glEnd();
```



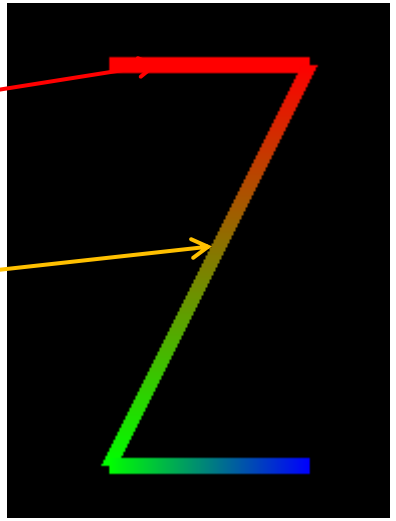
glBegin(…)

- GL_LINE_STRIP

```
glBegin(GL_LINE_STRIP);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( 0.0f, 100.0f, 0.0f);
    glVertex3f(100.0f,100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 0.0f, 1.0f);
    glVertex3f( 100.0f,-100.0f, 0.0f);
glEnd();
```



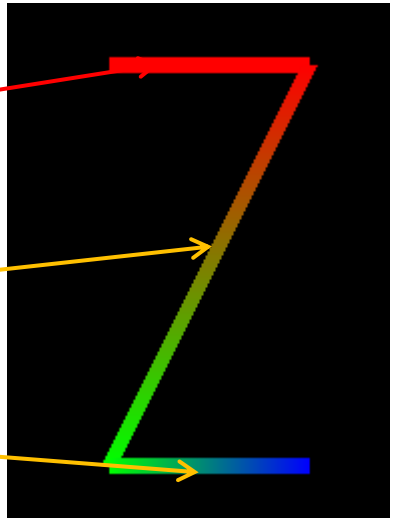
glBegin(…)

- GL_LINE_STRIP

```
glBegin(GL_LINE_STRIP);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( 0.0f, 100.0f, 0.0f);
    glVertex3f(100.0f,100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 0.0f, 1.0f);
    glVertex3f( 100.0f,-100.0f, 0.0f);
glEnd();
```



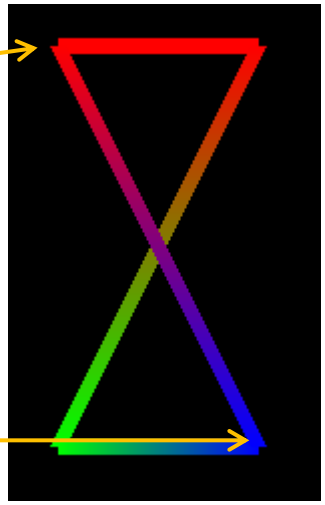
glBegin(…)

- GL_LINE_LOOP

```
glBegin(GL_LINE_LOOP);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( 0.0f, 100.0f, 0.0f);
    glVertex3f(100.0f,100.0f, 0.0f);

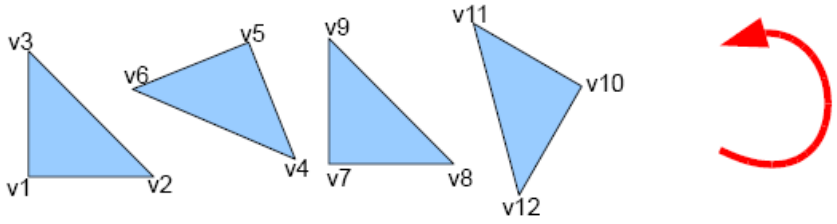
    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 0.0f, 1.0f);
    glVertex3f( 100.0f,-100.0f, 0.0f);
glEnd();
```

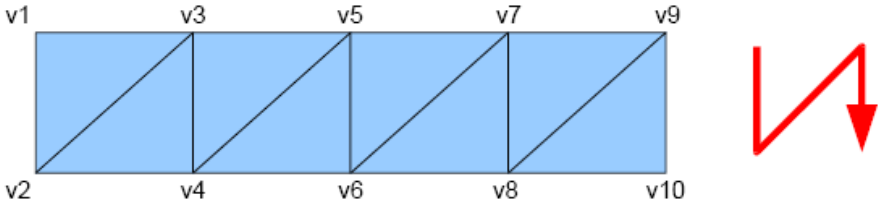


glBegin(…)

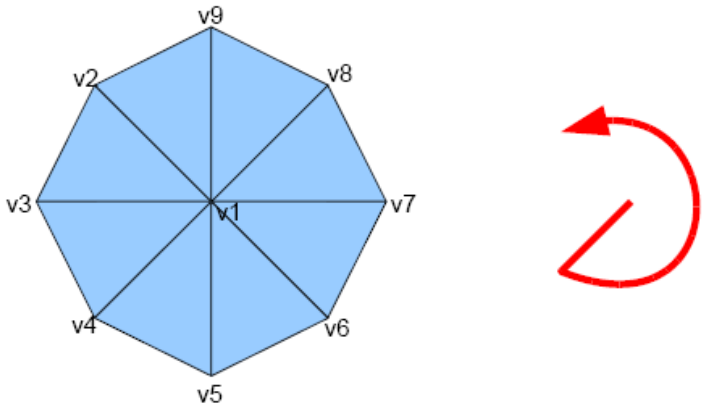
- GL_TRIANGLES



- GL_TRIANGLE_STRIP



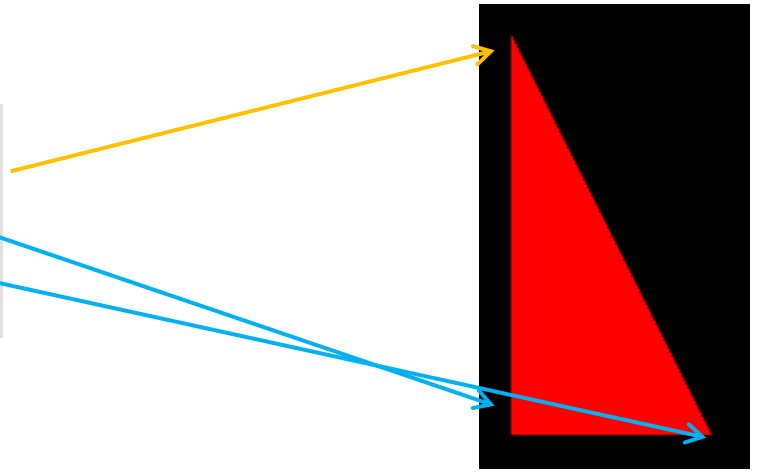
- GL_TRIANGLE_FAN



glBegin(…)

- GL_TRIANGLES

```
glBegin(GL_TRIANGLES);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( -100.0f, 100.0f, 0.0f);
    glVertex3f(-100.0f, -100.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);
glEnd();
```

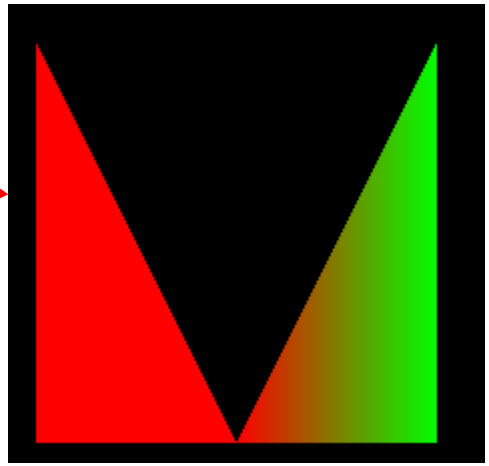


glBegin(…)

- GL_TRIANGLE_STRIP

```
glBegin(GL_TRIANGLE_STRIP);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( -100.0f, 100.0f, 0.0f);
    glVertex3f(-100.0f, -100.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 100.0,-100.0f, 0.0f);
    glVertex3f( 100.0, 100.0f, 0.0f);
glEnd();
```

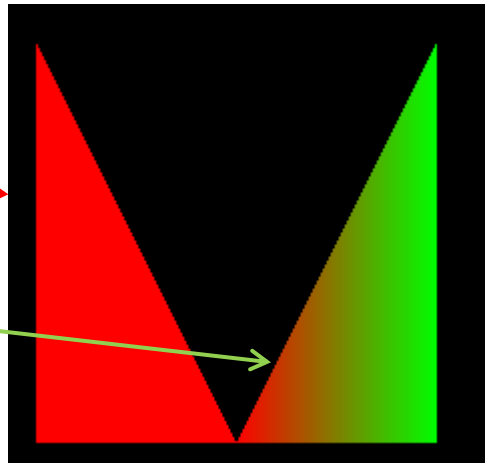


glBegin(…)

- GL_TRIANGLE_STRIP

```
glBegin(GL_TRIANGLE_STRIP);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( -100.0f, 100.0f, 0.0f);
    glVertex3f(-100.0f, -100.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 100.0,-100.0f, 0.0f);
    glVertex3f( 100.0, 100.0f, 0.0f);
glEnd();
```

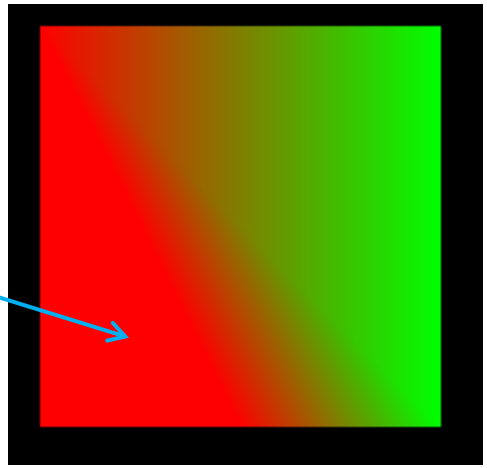


glBegin(…)

- GL_TRIANGLE_FAN

```
glBegin(GL_TRIANGLE_FAN);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( -100.0f, 100.0f, 0.0f);
    glVertex3f(-100.0f, -100.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 100.0,-100.0f, 0.0f);
    glVertex3f( 100.0, 100.0f, 0.0f);
glEnd();
```

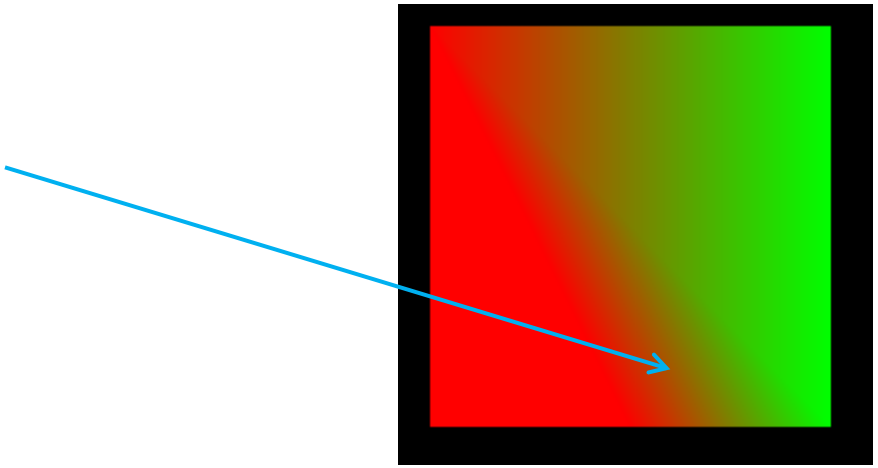


glBegin(…)

- GL_TRIANGLE_FAN

```
glBegin(GL_TRIANGLE_FAN);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( -100.0f, 100.0f, 0.0f);
    glVertex3f(-100.0f, -100.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 100.0,-100.0f, 0.0f);
    glVertex3f( 100.0, 100.0f, 0.0f);
glEnd();
```

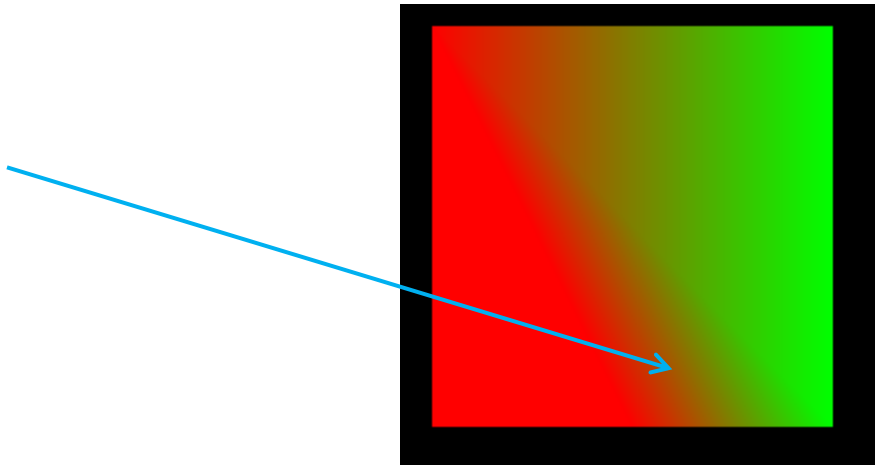


glBegin(…)

- GL_TRIANGLE_FAN

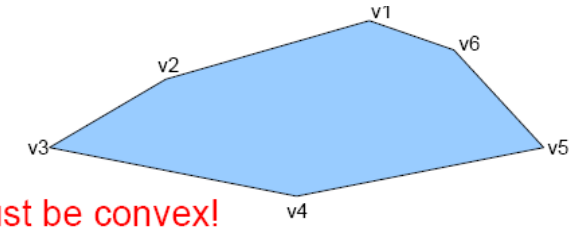
```
glBegin(GL_TRIANGLE_FAN);
    glColor3f(1.0f, 0.0f, 0.0f);
    glVertex3f( -100.0f, 100.0f, 0.0f);
    glVertex3f(-100.0f, -100.0f, 0.0f);
    glVertex3f( 0.0,-100.0f, 0.0f);

    glColor3f(0.0f, 1.0f, 0.0f);
    glVertex3f( 100.0,-100.0f, 0.0f);
    glVertex3f( 100.0, 100.0f, 0.0f);
glEnd();
```



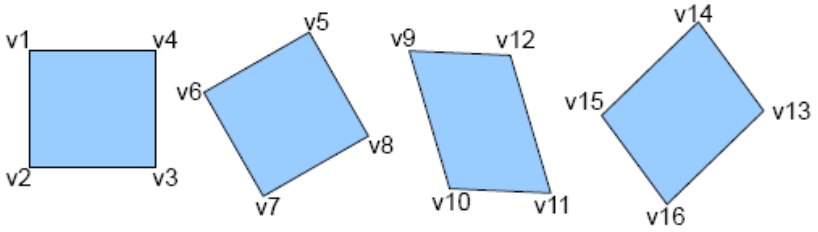
glBegin(…)

- GL_POLYGON

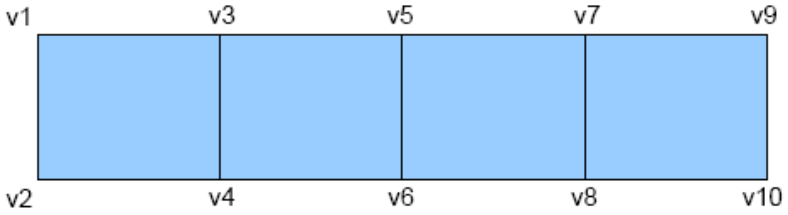


Polygon must be convex!
If not, the result is undefined.

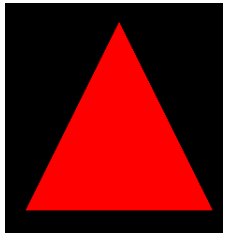
- GL_QUADS



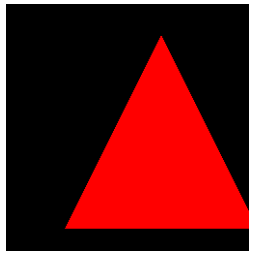
- GL_QUAD_STRIP



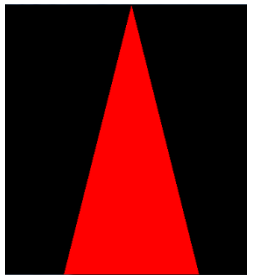
Transformations



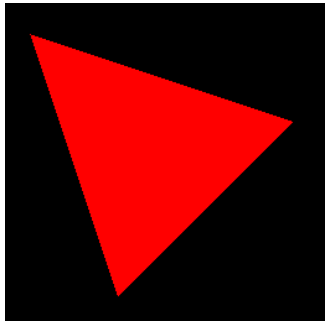
- **Translation**
  - glTranslatef(xUnits, yUnits, zUnits);
  - Ex: glTranslatef(100.0f, 0.0f, 0.0f);



- **Scaling**
  - glScalef(xUnits, yUnits, zUnits);
  - Ex: glScalef(1, 2, 1);



- **Rotation**
  - glRotatef(degree, xAxis, yAxis, zAxis);
  - Ex: glRotatef(45, 0.0f, 0.0f, 1.0f);



Transformations

OpenGL's transformations are done with *right multiply* of matrices, which is the opposite order of the operation applied:

```
glRotatef(...);
glTranslatef(...);

= R * T
⇒First Translate THEN Rotate
```

Parametric Curves and Surfaces

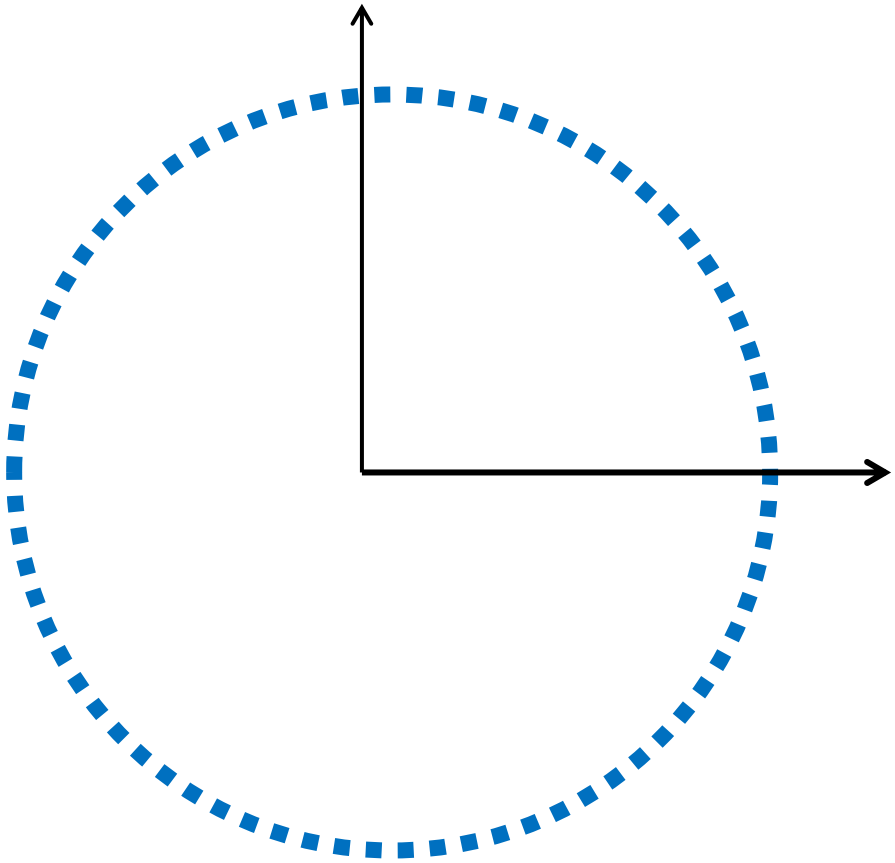
Describe the x, y, z coordinates by other parameters:

2D curve: $$p(t) = \begin{pmatrix} x(t) \\ y(t) \end{pmatrix}$$

where x(t) and y(t) are simple functions t goes from 0 to 1

Parametric Curves and Surfaces

Ex: Circle

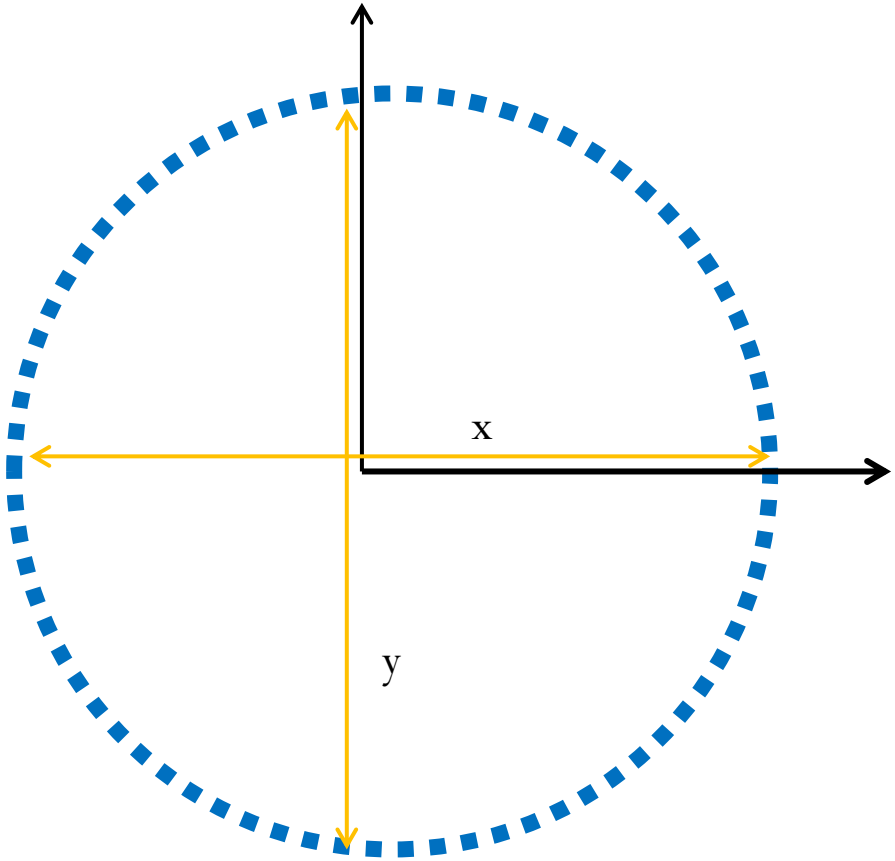


$$p(t) = \begin{pmatrix} f_x(t) \\ f_y(t) \end{pmatrix}$$

$$0 \le t \le 1$$

Parametric Curves and Surfaces

Ex: Circle

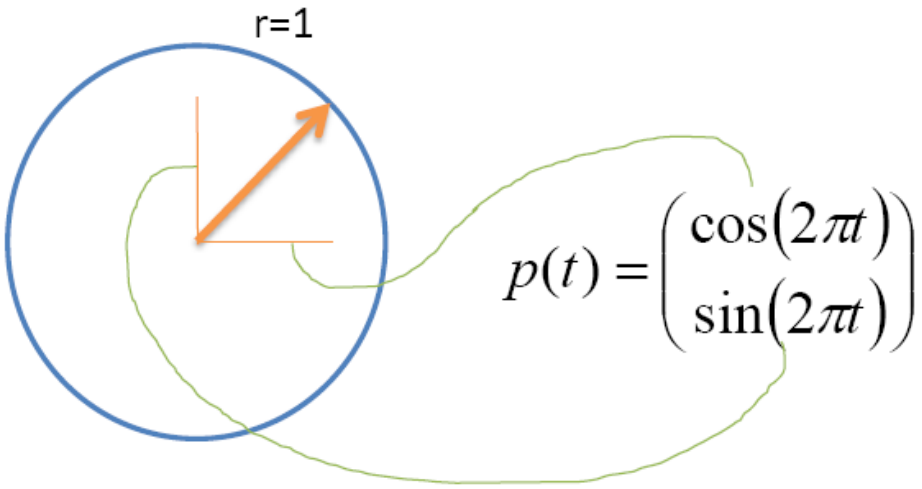


$$p(t) = \begin{pmatrix} f_x(t) \\ f_y(t) \end{pmatrix}$$

$$0 \le t \le 1$$

Parametric Curves and Surfaces

Ex: Circle



$$p(t) = \begin{pmatrix} \cos(2\pi t) \\ \sin(2\pi t) \end{pmatrix}$$

We can compute the tangent and normal at any point

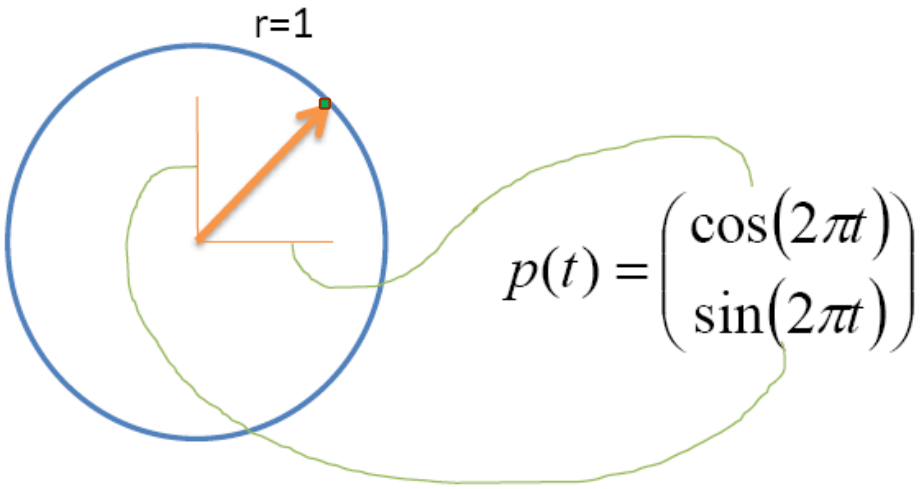
- Tangent:

$$p'(t) = \begin{pmatrix} \left(\frac{\partial x}{\partial t}\right) \\ \left(\frac{\partial y}{\partial t}\right) \end{pmatrix} = \begin{pmatrix} -2\pi \sin(2\pi t) \\ 2\pi \cos(2\pi t) \end{pmatrix}$$

- Normal is perpendicular to tangent

Parametric Curves and Surfaces

Ex: Circle



$$p(t) = \begin{pmatrix} \cos(2\pi t) \\ \sin(2\pi t) \end{pmatrix}$$

We can compute the tangent and normal at any point

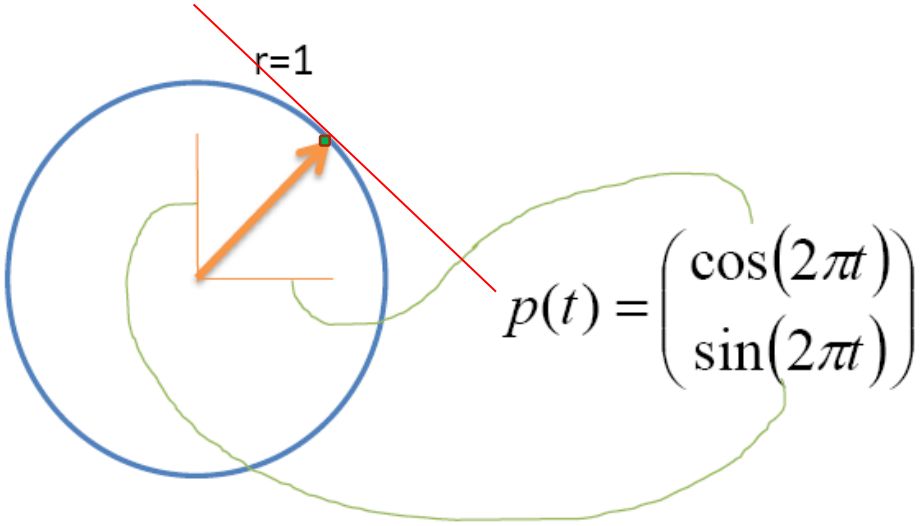
- Tangent:

$$p'(t) = \begin{pmatrix} \left(\frac{\partial x}{\partial t}\right) \\ \left(\frac{\partial y}{\partial t}\right) \end{pmatrix} = \begin{pmatrix} -2\pi \sin(2\pi t) \\ 2\pi \cos(2\pi t) \end{pmatrix}$$

- Normal is perpendicular to tangent

Parametric Curves and Surfaces

Ex: Circle



$$p(t) = \begin{pmatrix} \cos(2\pi t) \\ \sin(2\pi t) \end{pmatrix}$$

We can compute the tangent and normal at any point

- Tangent:

$$p'(t) = \begin{pmatrix} \left(\frac{\partial x}{\partial t}\right) \\ \left(\frac{\partial y}{\partial t}\right) \end{pmatrix} = \begin{pmatrix} -2\pi \sin(2\pi t) \\ 2\pi \cos(2\pi t) \end{pmatrix}$$

- Normal is perpendicular to tangent

Parametric Curves and Surfaces

Ex: Circle

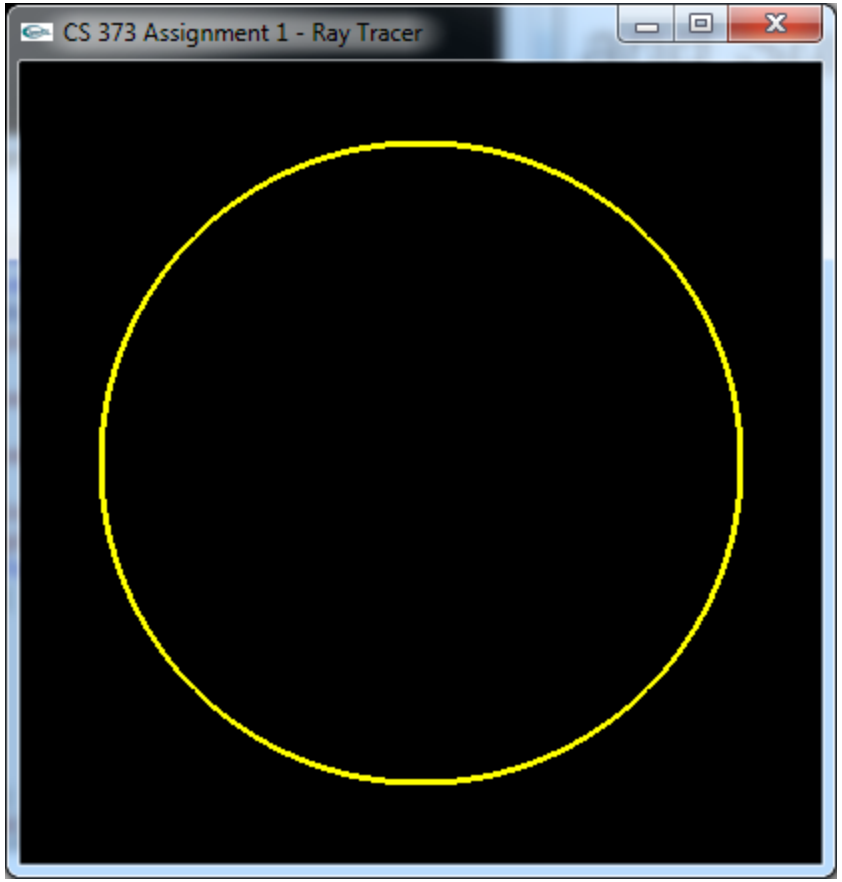
```
const float MAX_T = 360;
const float PI = 3.14159265;
float radius = 8;
void display(void)
{
    glClear(GL_COLOR_BUFFER_BIT);

    glLineWidth(3.0);

    glColor3f(1.0, 1.0, 0.0);
    glBegin(GL_LINE_LOOP);
        for(int i = 0; i < MAX_T; i++)
        {
            float t = (float) i  / MAX_T;

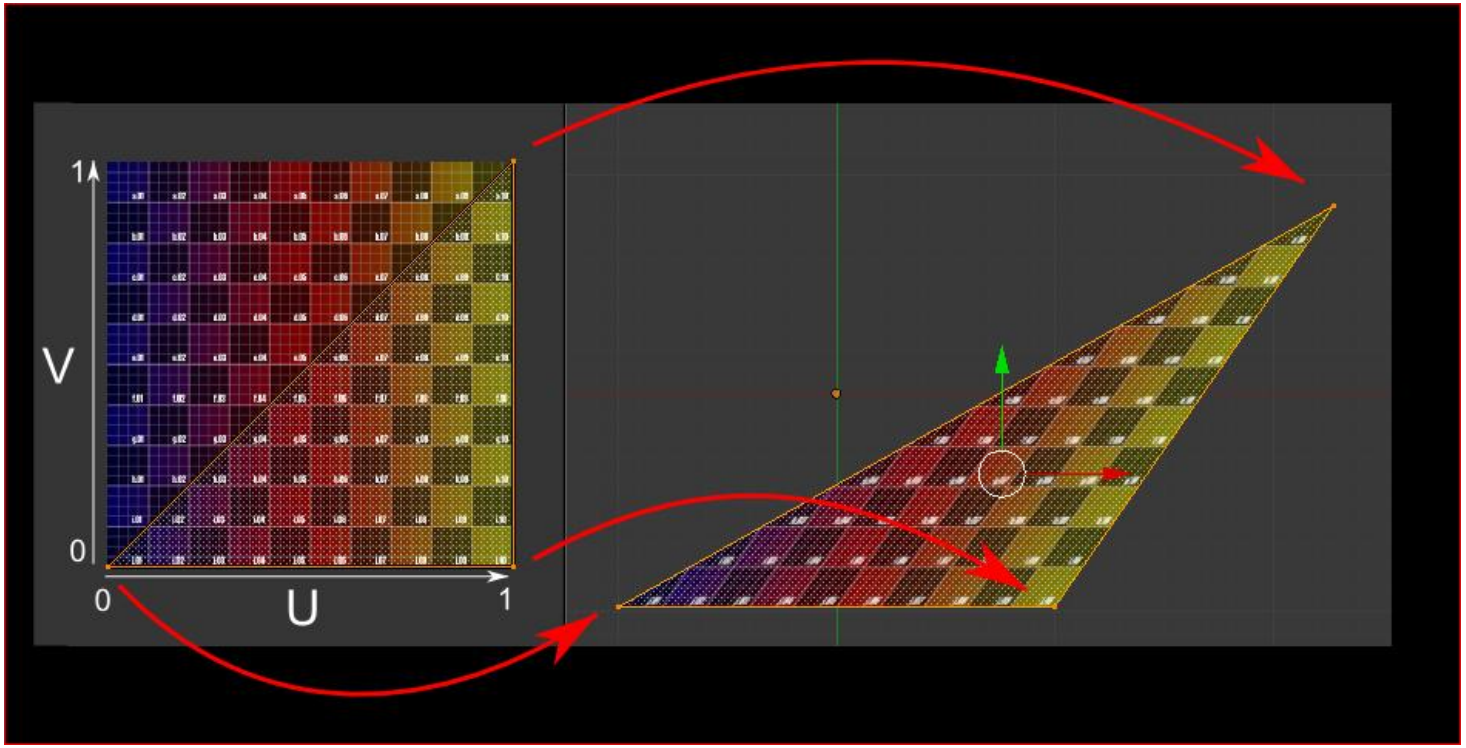
            float x = radius * cos(2 * PI * t);
            float y = radius * sin(2 * PI * t);

            glVertex2f(x, y);
        }
    glEnd();
```



Texture Mapping

When texturing a mesh, you need a way to tell to OpenGL which part of the image has to be used for each triangle. This is done with UV coordinates



Texture Mapping

Must Setup Texture Before You can use it

```
GLuint textureID;

void init(void)
{
    ......

    glGenTextures(1, &textureID);

    // "Bind" the newly created texture
    glBindTexture(GL_TEXTURE_2D, textureID);

    // Give the image to OpenGL
    glTexImage2D(GL_TEXTURE_2D, 0,GL_RGB, width, height, 0, GL_BGR, GL_UNSIGNED_BYTE, data);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

}
```

Tells OpenGL we want to generate one texture name

Texture Mapping

Must Setup Texture Before You can use it

```
GLuint textureID;

void init(void)
{
    ......

    glGenTextures(1, &textureID);

    // "Bind" the newly created texture
    glBindTexture(GL_TEXTURE_2D, textureID);

    // Give the image to OpenGL
    glTexImage2D(GL_TEXTURE_2D, 0,GL_RGB, width, height, 0, GL_BGR, GL_UNSIGNED_BYTE, data);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

}
```

Tells OpenGL we are going to use texture with the given ID

Texture Mapping

Must Setup Texture Before You can use it

```
GLuint textureID;

void init(void)
{
    ......

    glGenTextures(1, &textureID);

    // "Bind" the newly created texture
    glBindTexture(GL_TEXTURE_2D, textureID);

    // Give the image to OpenGL
    glTexImage2D(GL_TEXTURE_2D, 0,GL_RGB, width, height, 0, GL_BGR, GL_UNSIGNED_BYTE, data);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

}
```

Create the actual texture

Texture Mapping

Must Setup Texture Before You can use it

```
GLuint textureID;

void init(void)
{
    ......

    glGenTextures(1, &textureID);

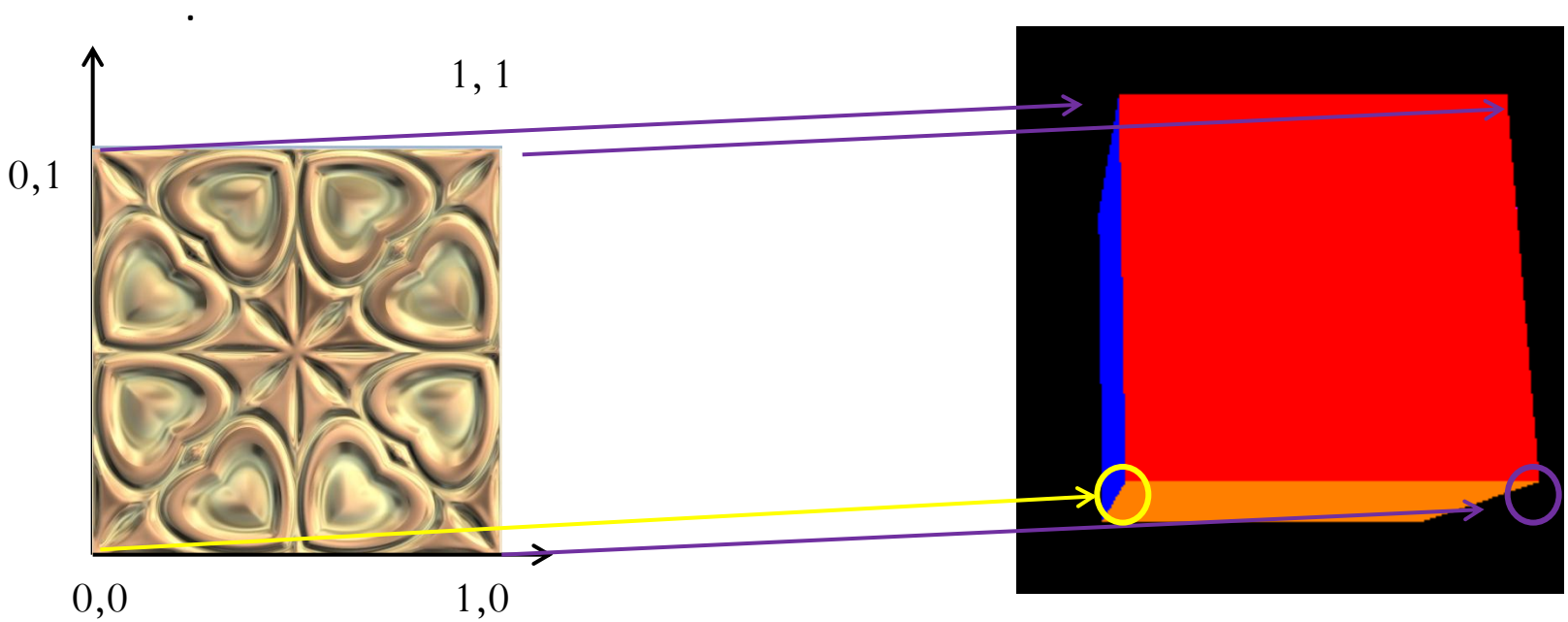
    // "Bind" the newly created texture
    glBindTexture(GL_TEXTURE_2D, textureID);

    // Give the image to OpenGL
    glTexImage2D(GL_TEXTURE_2D, 0,GL_RGB, width, height, 0, GL_BGR, GL_UNSIGNED_BYTE, data);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

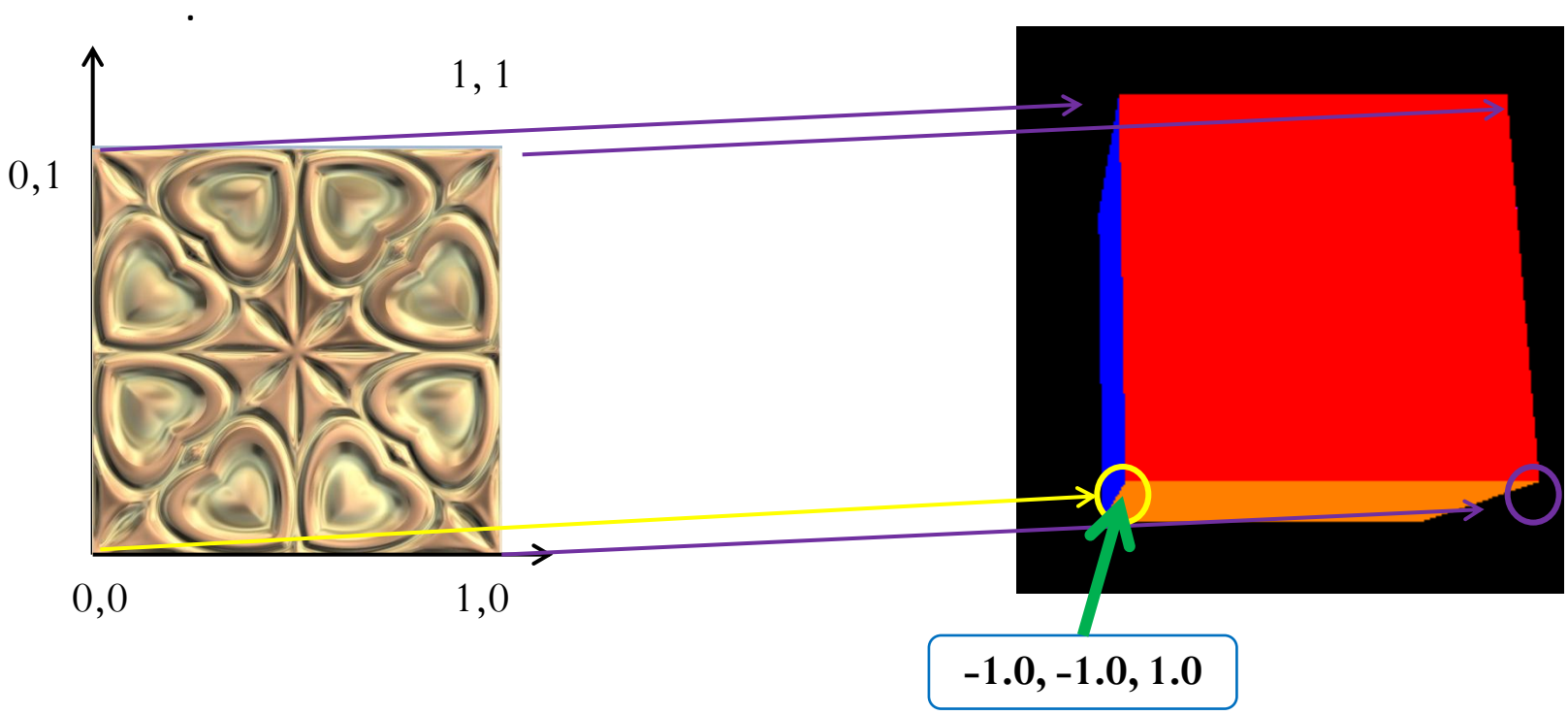
}
```

How we want OpenGL handle the texture when the object is bigger or smaller than the texture

Texture Mapping



Texture Mapping



Texture Mapping

The coordinate of the texture to be mapped with this vertex

```
glBegin(GL_QUADS);
    // Front Face
    glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);  // Bottom Left Of The Texture and Quad
    glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);  // Bottom Right Of The Texture and Quad
    glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f,  1.0f);  // Top Right Of The Texture and Quad
    glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);  // Top Left Of The Texture and Quad
    // Back Face
    glTexCoord2f(1.0f, 0.0f); glVertex3f(-1.0f, -1.0f, -1.0f);  // Bottom Right Of The Texture and Quad
    glTexCoord2f(1.0f, 1.0f); glVertex3f(-1.0f,  1.0f, -1.0f);  // Top Right Of The Texture and Quad
    glTexCoord2f(0.0f, 1.0f); glVertex3f( 1.0f,  1.0f, -1.0f);  // Top Left Of The Texture and Quad
    glTexCoord2f(0.0f, 0.0f); glVertex3f( 1.0f, -1.0f, -1.0f);  // Bottom Left Of The Texture and Quad
    // Top Face
    glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f, -1.0f);  // Top Left Of The Texture and Quad
    glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f,  1.0f,  1.0f);  // Bottom Left Of The Texture and Quad
    glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f,  1.0f,  1.0f);  // Bottom Right Of The Texture and Quad
    glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f, -1.0f);  // Top Right Of The Texture and Quad
    // Bottom Face
    glTexCoord2f(1.0f, 1.0f); glVertex3f(-1.0f, -1.0f, -1.0f);  // Top Right Of The Texture and Quad
    glTexCoord2f(0.0f, 1.0f); glVertex3f( 1.0f, -1.0f, -1.0f);  // Top Left Of The Texture and Quad
    glTexCoord2f(0.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);  // Bottom Left Of The Texture and Quad
    glTexCoord2f(1.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);  // Bottom Right Of The Texture and Quad
    // Right face
    glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f, -1.0f);  // Bottom Right Of The Texture and Quad
    glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f,  1.0f, -1.0f);  // Top Right Of The Texture and Quad
    glTexCoord2f(0.0f, 1.0f); glVertex3f( 1.0f,  1.0f,  1.0f);  // Top Left Of The Texture and Quad
    glTexCoord2f(0.0f, 0.0f); glVertex3f( 1.0f, -1.0f,  1.0f);  // Bottom Left Of The Texture and Quad
    // Left Face
    glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f, -1.0f);  // Bottom Left Of The Texture and Quad
    glTexCoord2f(1.0f, 0.0f); glVertex3f(-1.0f, -1.0f,  1.0f);  // Bottom Right Of The Texture and Quad
    glTexCoord2f(1.0f, 1.0f); glVertex3f(-1.0f,  1.0f,  1.0f);  // Top Right Of The Texture and Quad
    glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f,  1.0f, -1.0f);  // Top Left Of The Texture and Quad
glEnd();
```

Texture Mapping

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