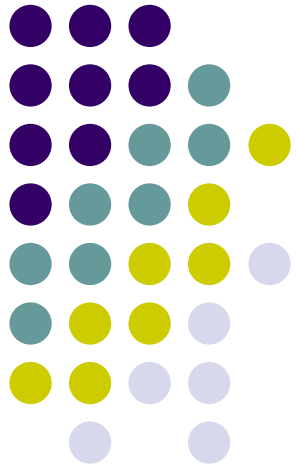
Computer Graphics (CS 4731) Lecture 3: Introduction to OpenGL/GLUT (Part 2)

Prof Emmanuel Agu

Computer Science Dept.

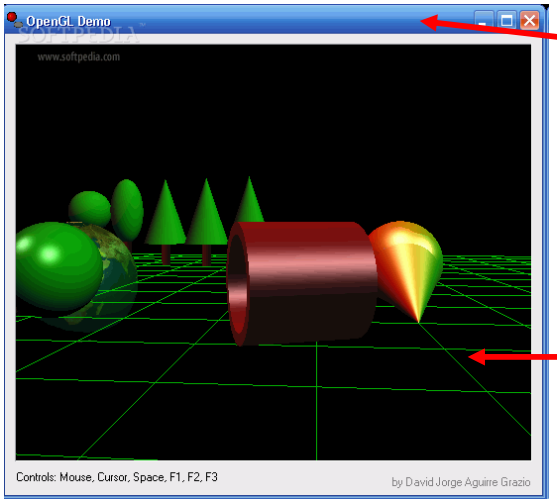
Worcester Polytechnic Institute (WPI)



Recall: OpenGL/GLUT Basics

- **OpenGL:** Specific version (e.g. 4.3)already on your graphics card
  - Just need to check your graphics card, OpenGL version

- **GLUT:** software that needs to be installed
  - already installed in zoolab machines

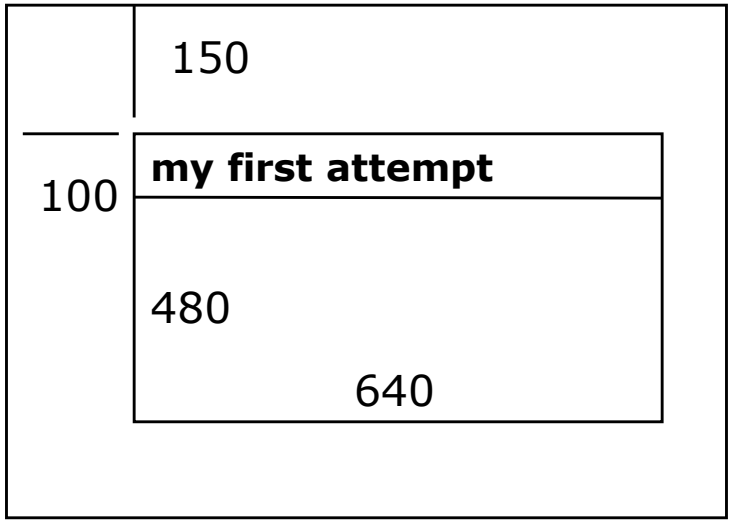


GLUT: install it!

OpenGL: already on graphics card

Recall: OpenGL Skeleton

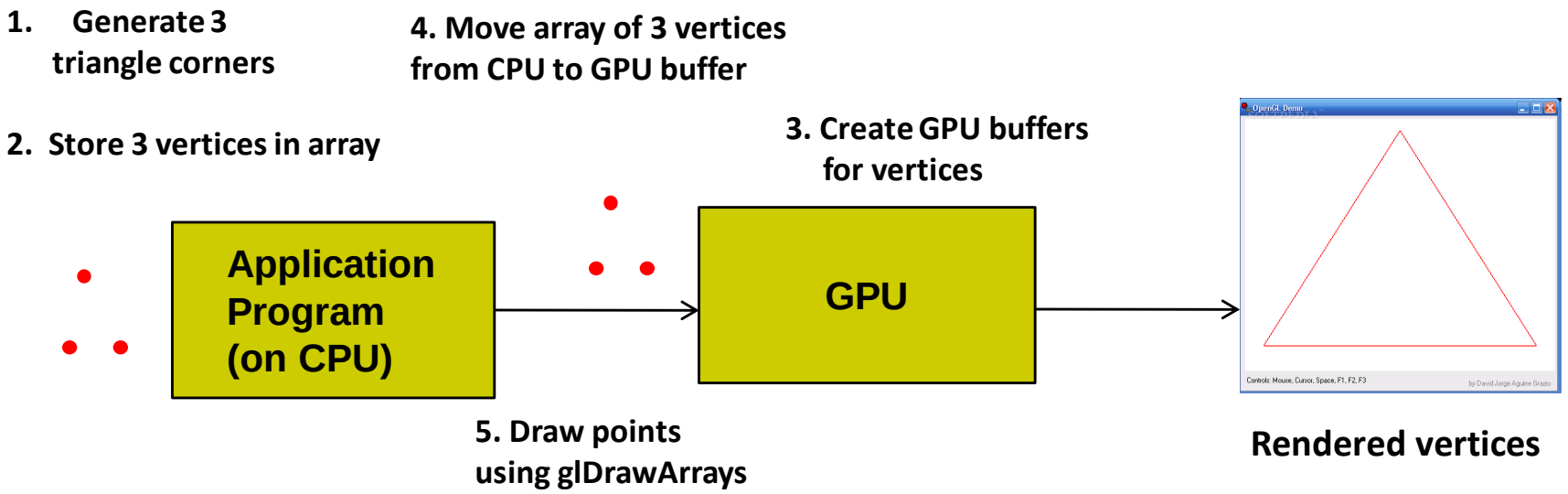
```
void main(int argc, char** argv){
    // First initialize toolkit, set display mode and create window

    glutInit(&argc, argv);    // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

    // … then register callback functions,
    // … do my initialization
    // .. wait in glutMainLoop for events

}
```



Recall: Drawing Red Triangle

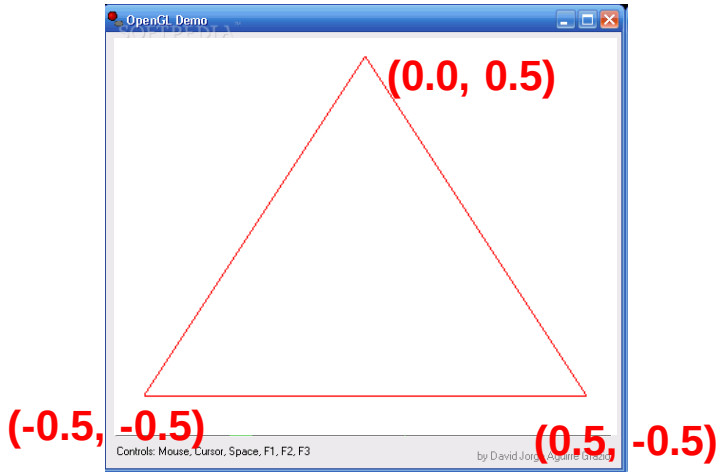
- **Rendering steps:**
  1. Generate triangle corners (3 vertices)
  2. Create GPU buffer for vertices
  3. Move array of 3 vertices from CPU to GPU buffer
  4. Draw 3 points from array on GPU using **`glDrawArray`**

- **Simplified Execution model:**



Recall: OpenGL Skeleton: Where are we?

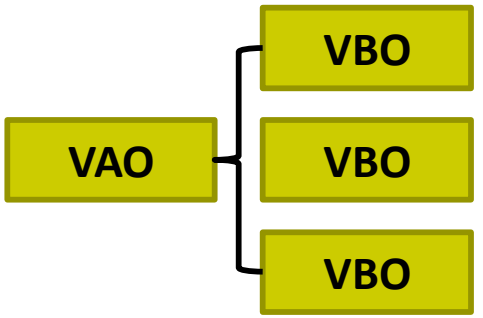
```
void main(int argc, char** argv){
    glutInit(&argc, argv);    // initialize toolkit
    glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize(640, 480);
    glutInitWindowPosition(100, 150);
    glutCreateWindow("my first attempt");
    glewInit( );

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

    glewInit( );
    generateGeometry( );

    glutMainLoop( );
}
```




```
// generate 3 triangle vertices + store in array
void generateGeometry( void ){
        points[0] = point2( -0.5, -0.5 );
        points[1] = point2( 0.0, 0.5 );
        points[2] = point2( 0.5, -0.5 );
}
```

Recall: OpenGL Skeleton: Where are we?

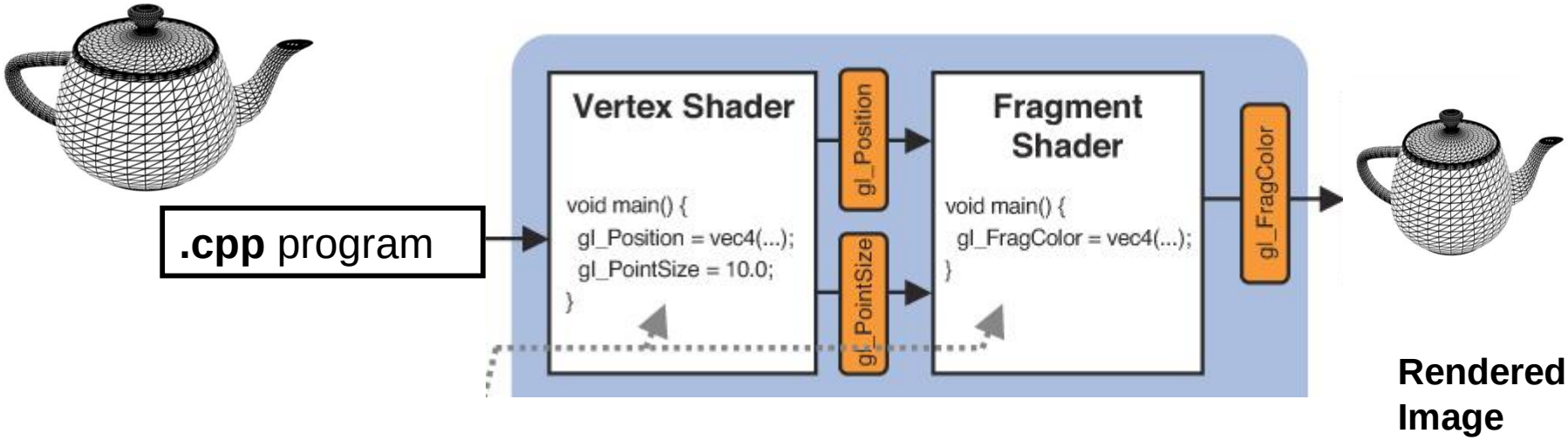
```
void main(int argc, char** argv){
   glutInit(&argc, argv);   // initialize toolkit
   glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
   glutInitWindowSize(640, 480);
   glutInitWindowPosition(100, 150);
   glutCreateWindow("my first attempt");
   glewInit( );

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

   glewInit( );
   generateGeometry( );
   initGPUBuffers( );

   glutMainLoop( );
}
```



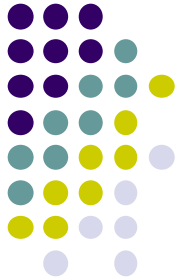

```
void initGPUBuffers( void )
{
   // Create a vertex array object
   GLuint vao;
   glGenVertexArrays( 1, &vao );
   glBindVertexArray( vao );

   // Create and initialize a buffer object
   GLuint buffer;
   glGenBuffers( 1, &buffer );
   glBindBuffer( GL_ARRAY_BUFFER, buffer );
   glBufferData( GL_ARRAY_BUFFER,
          sizeof(points), points, GL_STATIC_DRAW );
}
```

Recall: OpenGL Program?

- Usually has 3 files:
  - **.cpp file:** containing OpenGL code, main( ) function
    - Does initialization, generates/loads geometry to be drawn
  - **Vertex shader:** manipulates vertices (e.g. move vertices)
  - **Fragment shader:** manipulates pixels/fragments (e.g change color)

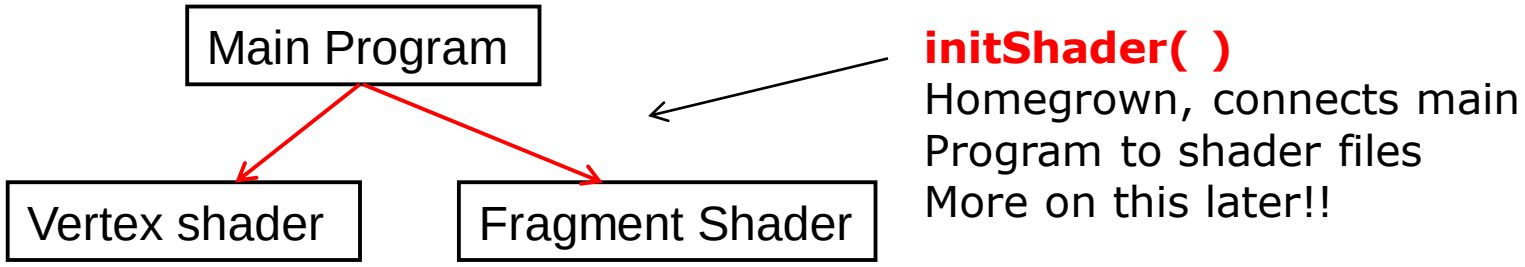


OpenGL Program: Shader Setup

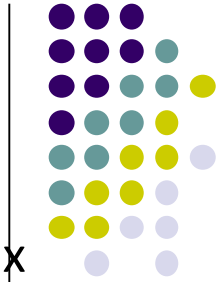


- OpenGL programs now have 3 parts:
  - Main **OpenGL program** (.cpp file), **vertex shader** (e.g. vshader1.glsl), and **fragment shader** (e.g. fshader1.glsl) in same Windows directory
  - In main program, need to link names of vertex, fragment shader
  - **initShader( )** is homegrown shader initialization function. More later

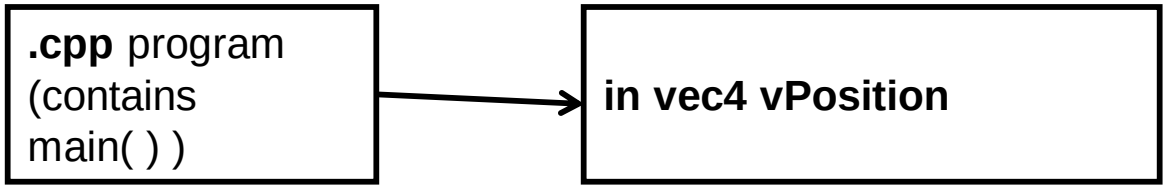
```
GLuint = program;
GLuint program = InitShader( "vshader1.glsl", fshader1.glsl");
glUseProgram(program);
```



Vertex Attributes



- Want to make 3 dots (vertices) accessible as variable **vPosition** in vertex shader
- First declare vPosition in vertex shader, get its address



- Compiler puts all variables declared in shader into a table
- Need to find location of vPosition in table of variables

Location of vPosition

Variable
Variable 1
vPosition
……
Variable N

```
GLuint loc = glGetAttribLocation( program, "vPosition" );
```

Vertex Attributes

Location of vPosition

Variable
Variable 1
vPosition
……
Variable N

Get location of vertex attribute **vPosition**

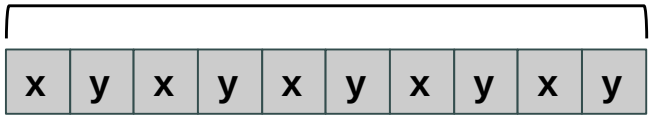
```
GLuint loc = glGetAttribLocation( program, "vPosition" );
glEnableVertexAttribArray( loc );
```

Enable vertex array attribute at location of **vPosition**

glVertexAttribPointer

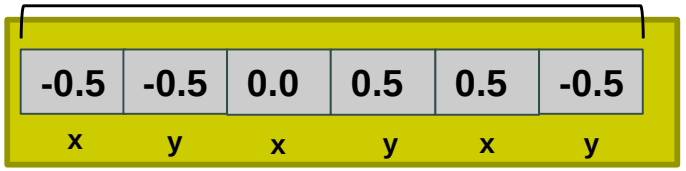
- Data now in VBO on GPU, but need to specify meta format (using **glVertexAttribPointer**)
- Vertices are packed as array of values

Vertices stored in array



vertex 1 vertex 2 .....

E.g. 3 dots stored in array on VBO



dot 1 dot 2 dot 3

Padding between Consecutive vertices

```
glVertexAttribPointer( loc, 2, GL_FLOAT, GL_FALSE, 0,BUFFER_OFFSET(0) );
```

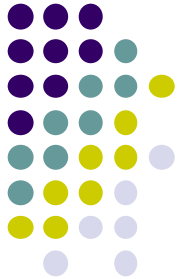
Location of **vPosition** in table of variables

2 (x,y) floats per vertex

Data not normalized to 0-1 range

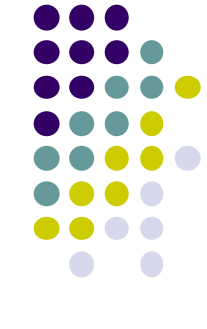
Data starts at offset from start of array

Put it Together: Shader Set up



```
void shaderSetup( void )
{
    // Load shaders and use the resulting shader program
    program = InitShader( "vshader1.glsl", "fshader1.glsl" );
    glUseProgram( program );

    // Initialize vertex position attribute from vertex shader
    GLuint loc = glGetAttribLocation( program, "vPosition" );
    glEnableVertexAttribArray( loc );
    glVertexAttribPointer( loc, 2, GL_FLOAT, GL_FALSE, 0,
                                                BUFFER_OFFSET(0) );

    // sets white as color used to clear screen
    glClearColor( 1.0, 1.0, 1.0, 1.0 );
}
```

OpenGL Skeleton: Where are we?

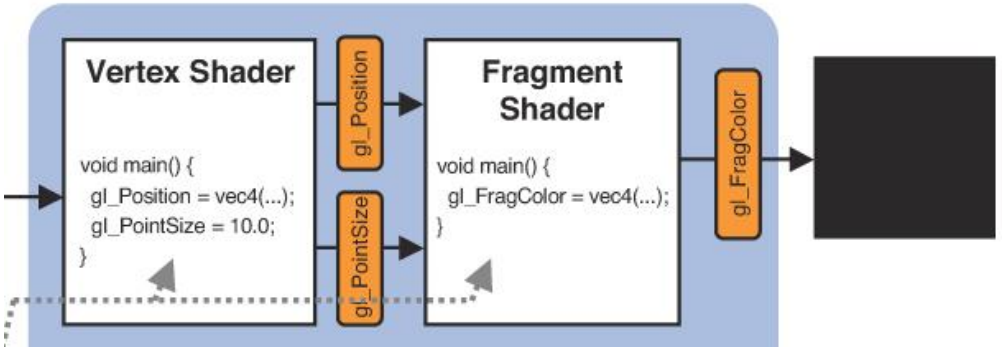


```
void main(int argc, char** argv){
   glutInit(&argc, argv);    // initialize toolkit
   glutInitDisplayMode(GLUT_SINGLE | GLUT_RGB);
   glutInitWindowSize(640, 480);
   glutInitWindowPosition(100, 150);
   glutCreateWindow("my first attempt");
   glewInit( );

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

   glewInit( );
   generateGeometry( );
   initGPUBuffers( );
   void shaderSetup( );

   glutMainLoop( );
}
```

```
void shaderSetup( void )
{
   // Load shaders and use the resulting shader program
   program = InitShader( "vshader1.glsl", "fshader1.glsl" );
   glUseProgram( program );

   // Initialize vertex position attribute from vertex shader
   GLuint loc = glGetAttribLocation( program, "vPosition" );
   glEnableVertexAttribArray( loc );
   glVertexAttribPointer( loc, 2, GL_FLOAT, GL_FALSE, 0,
                                                BUFFER_OFFSET(0) );

   // sets white as color used to clear screen
   glClearColor( 1.0, 1.0, 1.0, 1.0 );
}
```

Vertex Shader

- We write a simple “pass-through” shader
- Simply sets **output vertex position = input position**
- **`gl_Position`** is built in variable (already declared)

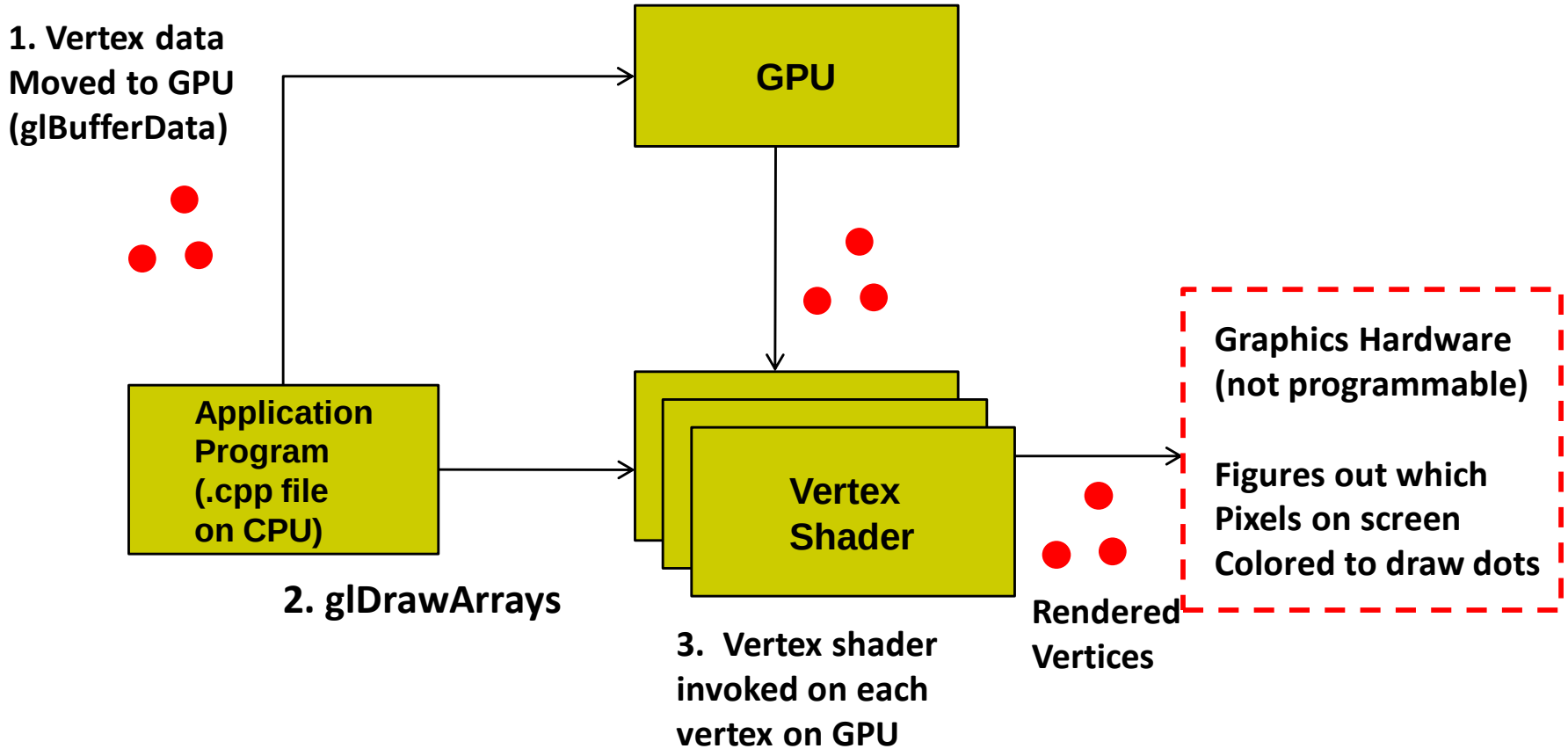



```
in vec4 vPosition

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

output vertex position

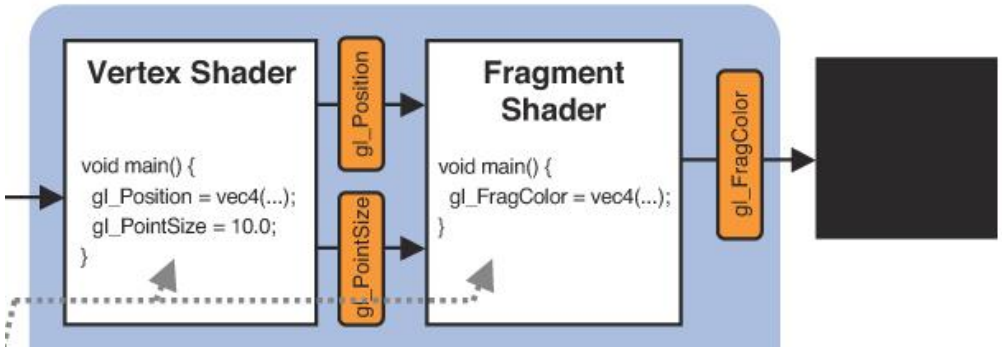
input vertex position (from .cpp file)

Execution Model



Fragment Shader

- We write a simple fragment shader (sets color of dots to red)
- **`gl_FragColor`** is built in variable (already declared)

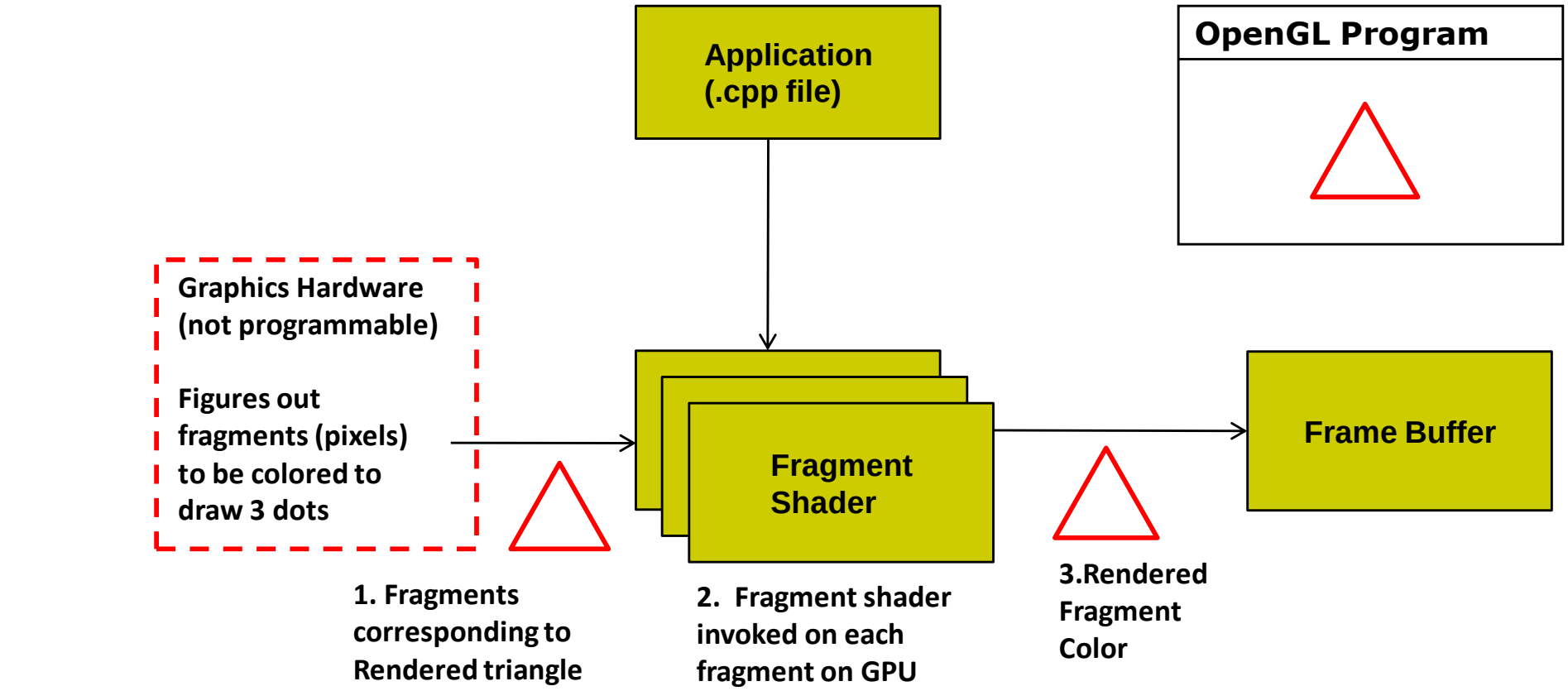


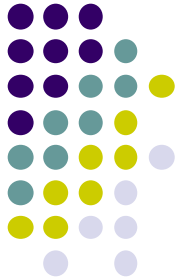

```
void main( )
{
      gl_FragColor = vec(1.0, 0.0, 0.0, 1.0);
}
```

R G B

Set each drawn fragment color to red

Execution Model





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);   <--Next… how to draw in myDisplay
    glutReshapeFunc(myReshape);
    glutMouseFunc(myMouse);
    glutKeyboardFunc(myKeyboard);

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

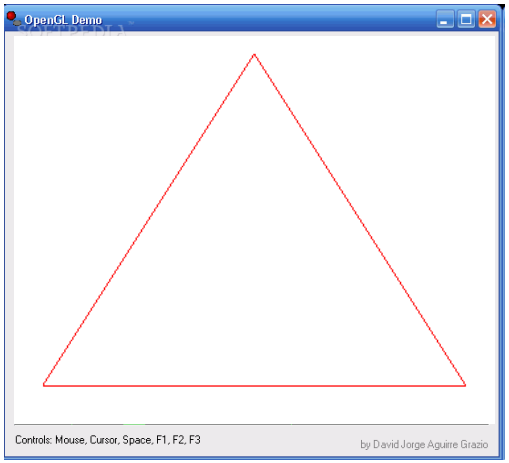
Recall: Draw points (from VBO)

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

Render buffered data as line loop

Starting index

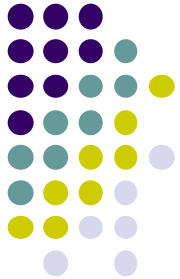
Number of points to be rendered



- Display function using **`glDrawArrays`**:

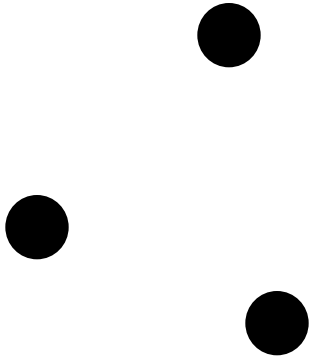
```
void mydisplay(void){
    glClear(GL_COLOR_BUFFER_BIT);        // clear screen
    glDrawArrays(GL_LINE_LOOP, 0, 3);    // draw the points
    glFlush( );                          // force rendering to show
}
```

Other possible arguments to `glDrawArrays` instead of `GL_LINE_LOOP`?



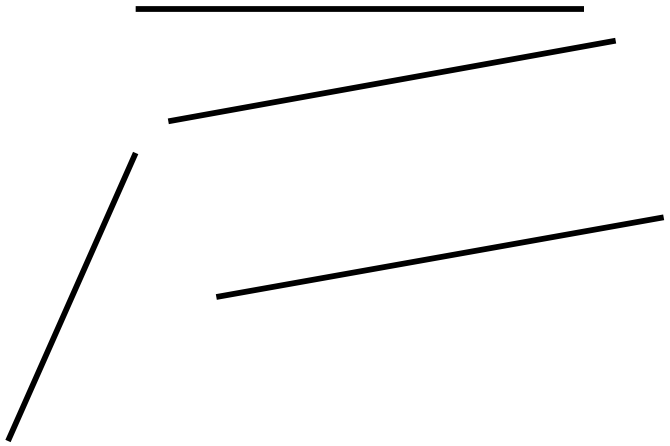
`glDrawArrays`(GL_POINTS, ….)

- draws dots



`glDrawArrays`((GL_LINES, …)

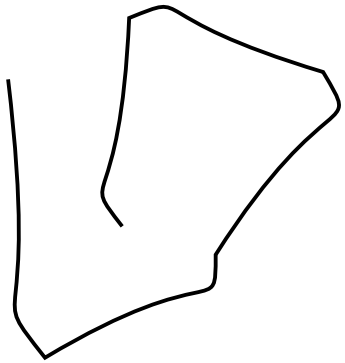
- Connect vertex pairs to draw lines



`glDrawArrays( )` Parameters

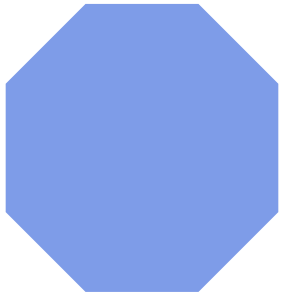
`glDrawArrays`(GL_LINE_STRIP,..)

– polylines



`glDrawArrays`(GL_POLYGON,..)

– convex filled polygon

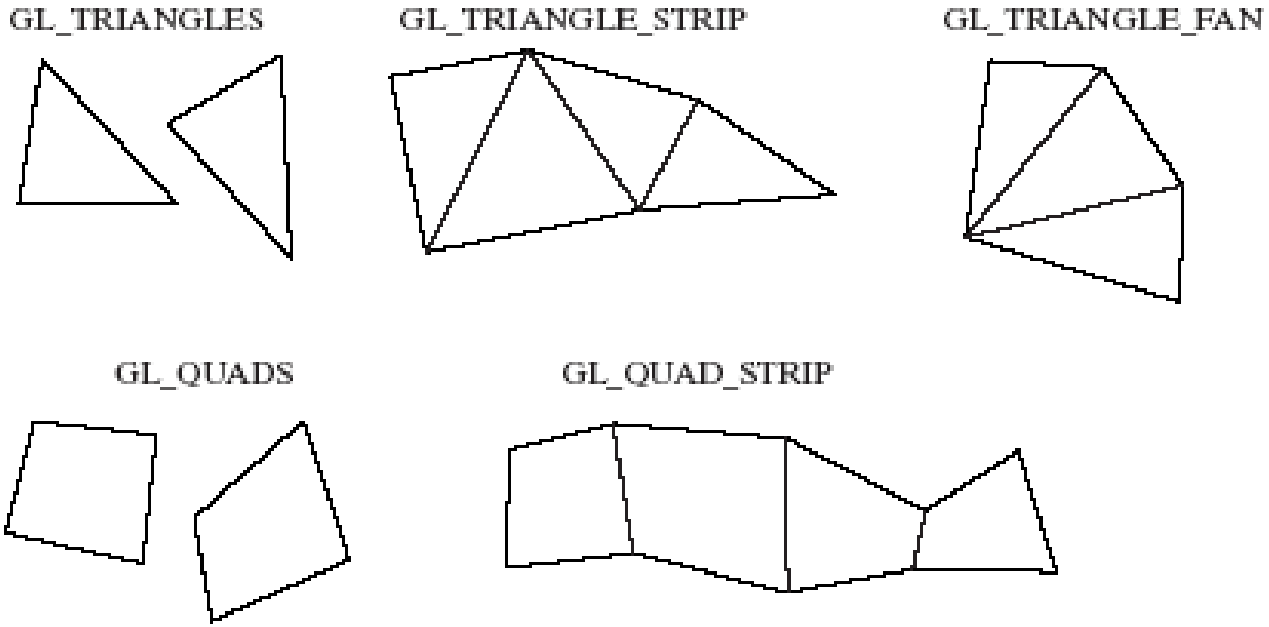


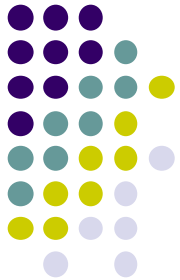
`glDrawArrays`(GL_LINE_LOOP)

– Close loop of polylines
(Like GL_LINE_STRIP but closed)

glDrawArrays( ) Parameters

- Triangles: Connect 3 vertices
  - GL_TRIANGLES, GL_TRIANGLE_STRIP, GL_TRIANGLE_FAN
- Quad: Connect 4 vertices
  - GL_QUADS, GL_QUAD_STRIP

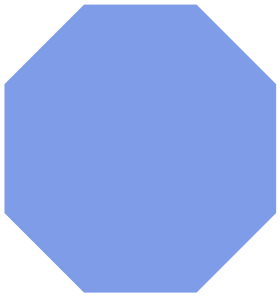


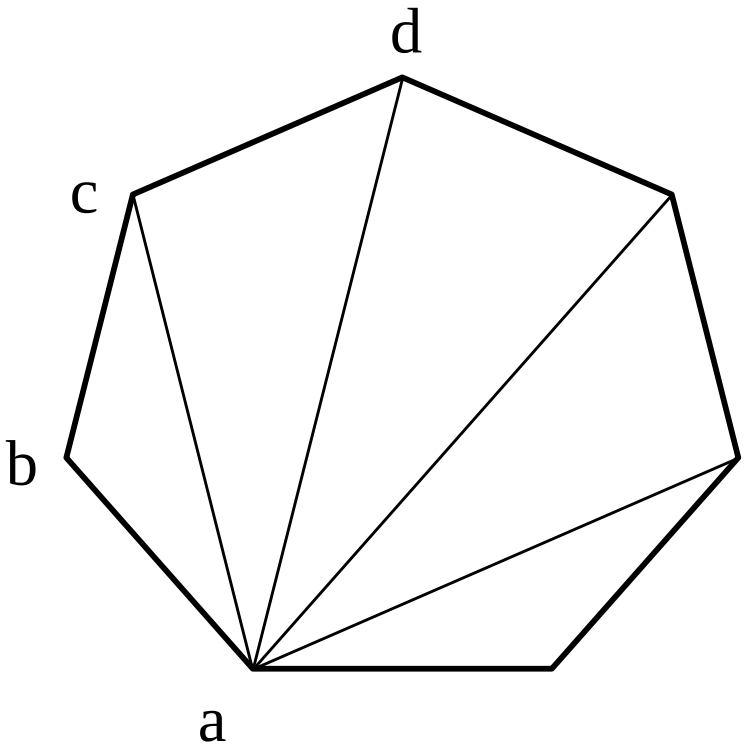


Triangulation

- Generally OpenGL breaks polygons down into triangles which are then rendered. Example

`glDrawArrays`(GL_POLYGON,..)
– convex filled polygon

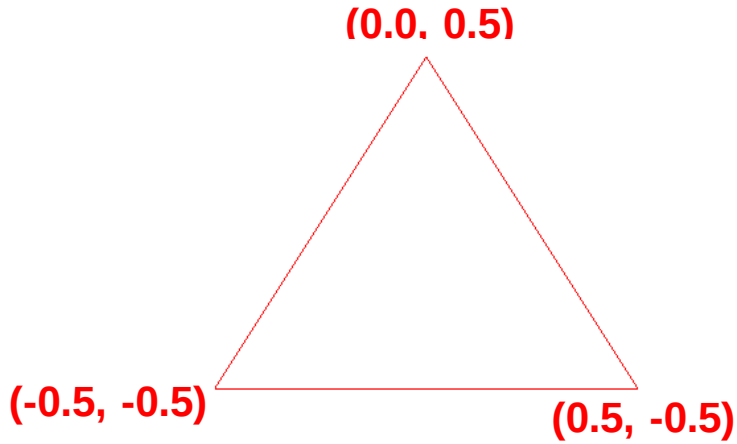




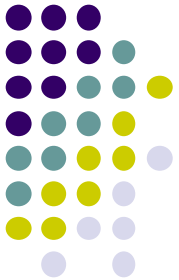
Previously: Generated 3 Points to be Drawn

- Stored points in array **points[**], moved to GPU, draw using **`glDrawArray`**

```
point2 points[NumPoints];

points[0] = point2( -0.5, -0.5 );
points[1] = point2( 0.0, 0.5 );
points[2] = point2( 0.5, -0.5 );
```

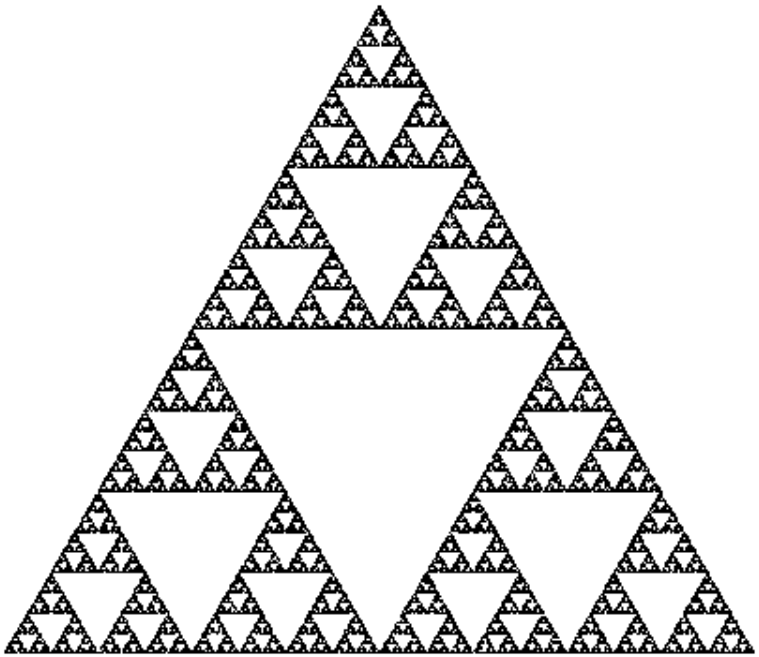


- Once drawing steps are set up, can generate more complex sequence of points algorithmically, drawing steps don't change
- Next: example of more algorithm to generate more complex point sequences

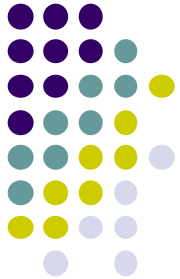


Sierpinski Gasket Program

- Any sequence of points put into array points[ ] will be drawn
- Can generate interesting sequence of points
  - Put in array points[ ], draw!!
- Sierpinski Gasket: Popular fractal



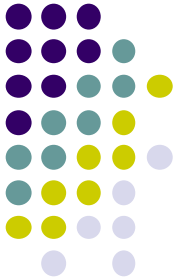
Sierpinski Gasket



Start with initial triangle with corners (*x1, y1, 0*), (*x2, y2, 0*) and (*x3, y3, 0*)

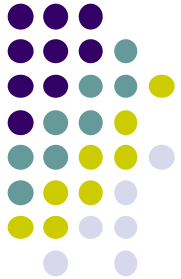
1. Pick initial point **p** = (*x, y, 0*) at random inside a triangle
2. Select on of 3 vertices at random
3. Find **q,** halfway between **p** and randomly selected vertex
4. Draw dot at **q**
5. Replace **p** with **q**
6. Return to step 2

Actual Sierpinski Code

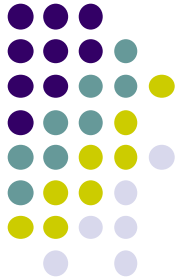


```
#include "vec.h"     // include point types and operations
#include <stdlib.h> // includes random number generator

void Sierpinksi( )
{
    const int NumPoints = 5000;
    vec2 points[NumPoints];

    // Specifiy the vertices for a triangle
    vec2 vertices[3] = {
        vec2( -1.0, -1.0 ), vec2( 0.0, 1.0 ), vec2( 1.0, -1.0 )
    };
```

Actual Sierpinski Code



```
// An arbitrary initial point inside the triangle
points[0] = point2(0.25, 0.50);

// compute and store N-1 new points
for ( int i = 1; i < NumPoints; ++i ) {
    int j = rand() % 3;   // pick a vertex at random

    // Compute the point halfway between the selected vertex
    //   and the previous point
    points[i] = ( points[i - 1] + vertices[j] ) / 2.0;
}
```



References

- Angel and Shreiner, Interactive Computer Graphics, 6th edition, Chapter 2
- Hill and Kelley, Computer Graphics using OpenGL, 3rd edition, Chapter 2