Programming with OpenGL Part 3: Three Dimensions

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Objectives

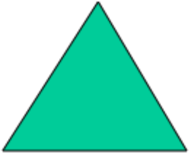
- Develop a more sophisticated three-dimensional example
  - Sierpinski gasket: a fractal
- Introduce hidden-surface removal

Three-dimensional Applications

- In OpenGL, two-dimensional applications are a special case of three-dimensional graphics
- Going to 3D
  - Not much changes
  - Use `glVertex3*( )`
  - Have to worry about the order in which polygons are drawn or use hidden-surface removal
  - Polygons should be simple, convex, flat

Sierpinski Gasket (2D)

- Start with a triangle

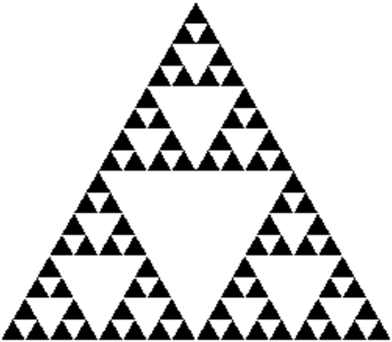


- Connect bisectors of sides and remove central triangle

- Repeat

Example

- Five subdivisions



The gasket as a fractal

- Consider the filled area (black) and the perimeter (the length of all the lines around the filled triangles)
- As we continue subdividing
  - the area goes to zero
  - but the perimeter goes to infinity
- This is not an ordinary geometric object
  - It is neither two- nor three-dimensional
- It is a *fractal* (fractional dimension) object

Gasket Program

```
#include <GL/glut.h>

/* initial triangle */

GLfloat v[3][2]={{-1.0, -0.58},
          {1.0, -0.58}, {0.0, 1.15}};

int n; /* number of recursive steps */
```

Draw one triangle

```
void triangle( GLfloat *a, GLfloat *b,
 GLfloat *c)

/* display one triangle  */
{
      glVertex2fv(a);
      glVertex2fv(b);
      glVertex2fv(c);
}
```

Triangle Subdivision

```
void divide_triangle(GLfloat *a, GLfloat *b, GLfloat *c,
  int m)
{
/* triangle subdivision using vertex numbers */
    point2 v0, v1, v2;
    int j;
    if(m>0)
     {
        for(j=0; j<2; j++) v0[j]=(a[j]+b[j])/2;
        for(j=0; j<2; j++) v1[j]=(a[j]+c[j])/2;
        for(j=0; j<2; j++) v2[j]=(b[j]+c[j])/2;
        divide_triangle(a, v0, v1, m-1);
        divide_triangle(c, v1, v2, m-1);
        divide_triangle(b, v2, v0, m-1);
    }
    else(triangle(a,b,c));
/* draw triangle at end of recursion */
}
```

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display and init Functions

```
void display()
{
    glClear(GL_COLOR_BUFFER_BIT);
    glBegin(GL_TRIANGLES);
       divide_triangle(v[0], v[1], v[2], n);
    glEnd();
    glFlush();
}

void myinit()
{
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
    gluOrtho2D(-2.0, 2.0, -2.0, 2.0);
    glMatrixMode(GL_MODELVIEW);
    glClearColor (1.0, 1.0, 1.0,1.0)
    glColor3f(0.0,0.0,0.0);
}
```

main Function

```
int main(int argc, char **argv)
{
  n=4;
  glutInit(&argc, argv);
  glutInitDisplayMode(GLUT_SINGLE|GLUT_RGB);
  glutInitWindowSize(500, 500);
  glutCreateWindow("2D Gasket");
  glutDisplayFunc(display);
     myinit();
  glutMainLoop();
}
```

Efficiency Note

By having the **glBegin** and **glEnd** in the display callback rather than in the function **triangle** and using **GL_TRIANGLES** rather than **GL_POLYGON** in **glBegin**, we call **glBegin** and **glEnd** only once for the entire gasket rather than once for each triangle

Moving to 3D

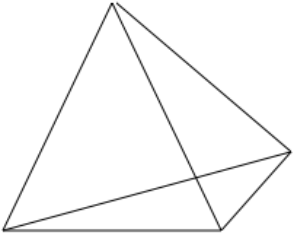
- We can easily make the program three-dimensional by using

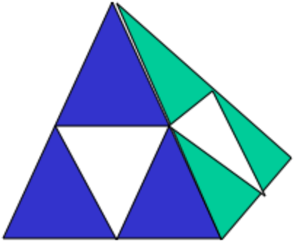
```
GLfloat v[3][3]
glVertex3f
glOrtho
```

- But that would not be very interesting
- Instead, we can start with a tetrahedron

3D Gasket

•We can subdivide each of the four faces

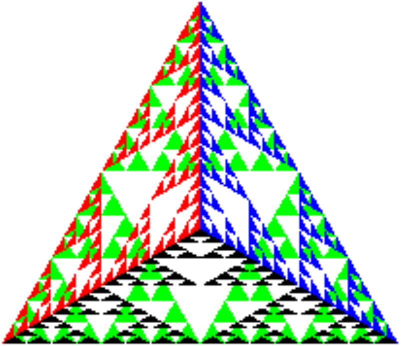




•Appears as if we remove a solid tetrahedron from the center leaving four smaller tetrahedra

Example

after 5 iterations



triangle code

```
void triangle( GLfloat *a, GLfloat *b,
 GLfloat *c)
{
     glVertex3fv(a);
     glVertex3fv(b);
     glVertex3fv(c);
}
```

subdivision code

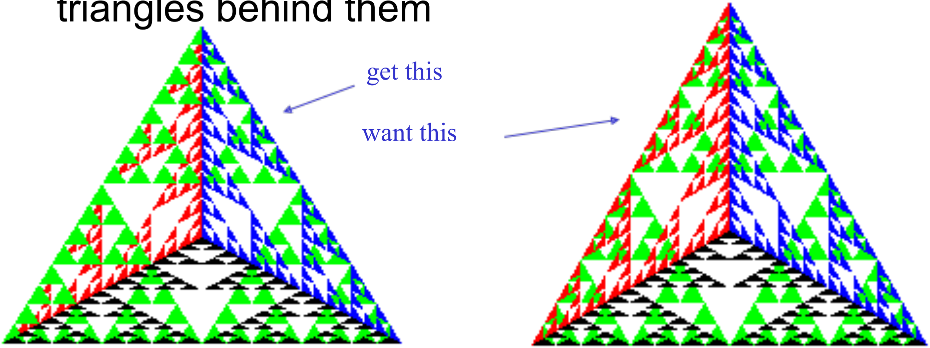
```
void divide_triangle(GLfloat *a, GLfloat *b,
 GLfloat *c, int m)
{
    GLfloat v1[3], v2[3], v3[3];
    int j;
    if(m>0)
    {
        for(j=0; j<3; j++) v1[j]=(a[j]+b[j])/2;
        for(j=0; j<3; j++) v2[j]=(a[j]+c[j])/2;
        for(j=0; j<3; j++) v3[j]=(b[j]+c[j])/2;
        divide_triangle(a, v1, v2, m-1);
        divide_triangle(c, v2, v3, m-1);
        divide_triangle(b, v3, v1, m-1);
    }
    else(triangle(a,b,c));
}
```

tetrahedron code

```
void tetrahedron( int m)
{
    glColor3f(1.0,0.0,0.0);
    divide_triangle(v[0], v[1], v[2], m);
    glColor3f(0.0,1.0,0.0);
    divide_triangle(v[3], v[2], v[1], m);
    glColor3f(0.0,0.0,1.0);
    divide_triangle(v[0], v[3], v[1], m);
    glColor3f(0.0,0.0,0.0);
    divide_triangle(v[0], v[2], v[3], m);
}
```

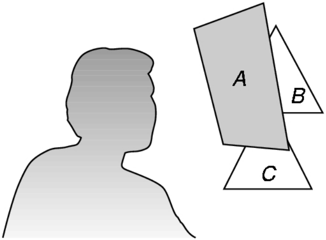
Almost Correct

- Because the triangles are drawn in the order they are defined in the program, the front triangles are not always rendered in front of triangles behind them



Hidden-Surface Removal

- We want to see only those surfaces in front of other surfaces
- OpenGL uses a *hidden-surface* method called the *z*-buffer algorithm that saves depth information as objects are rendered so that only the front objects appear in the image



Using the z-buffer algorithm

- The algorithm uses an extra buffer, the z-buffer, to store depth information as geometry travels down the pipeline
- It must be
  - Requested in **`main.c`**
    - `glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH)`
  - Enabled in **`init.c`**
    - `glEnable(GL_DEPTH_TEST)`
  - Cleared in the display callback
    - `glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)`

Surface vs Volume Subdvision

- In our example, we divided the surface of each face
- We could also divide the volume using the same midpoints
- The midpoints define four smaller tetrahedrons, one for each vertex
- Keeping only these tetrahedrons removes a *volume* in the middle
- See text for code

Volume Subdivision