Introduction to Computer Graphics with WebGL

Week3

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Objectives

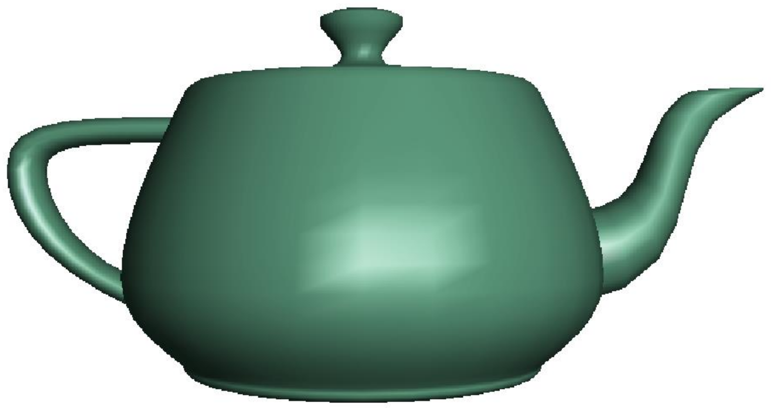
- Simple Shaders
  - Vertex shader
  - Fragment shaders
- Programming shaders with GLSL
- Finish first program

Vertex Shader Applications

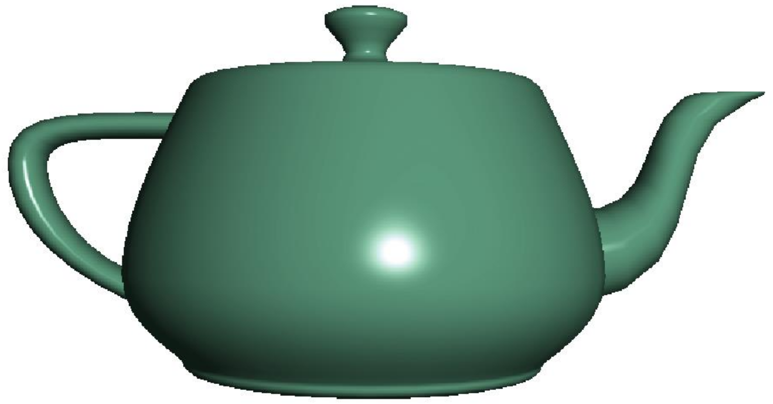
- Moving vertices
    - Morphing
    - Wave motion
    - Fractals
- Lighting
    - More realistic models
    - Cartoon shaders

Fragment Shader Applications

Per fragment lighting calculations



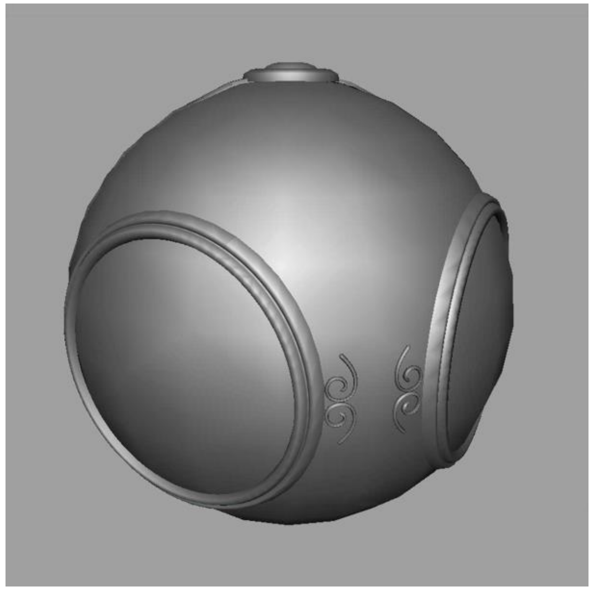
per vertex lighting

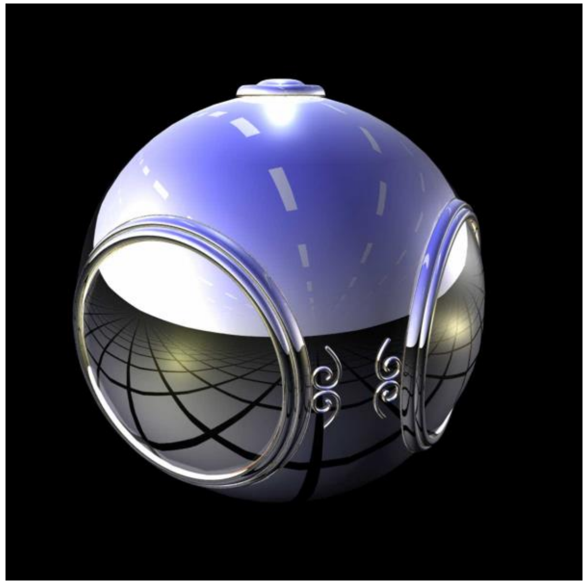


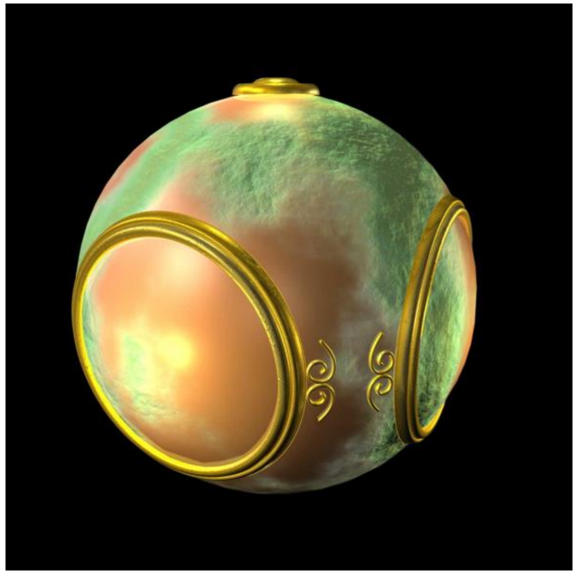
per fragment lighting

Fragment Shader Applications

Texture mapping


smooth shading


environment mapping


bump mapping

Writing Shaders

- First programmable shaders were programmed in an assembly-like manner
- OpenGL extensions added functions for vertex and fragment shaders
- Cg (C for graphics) C-like language for programming shaders
  - Works with both OpenGL and DirectX
  - Interface to OpenGL complex
- OpenGL Shading Language (GLSL)

GLSL

- OpenGL Shading Language
- Part of OpenGL 2.0 and up
- High level C-like language
- New data types
  - Matrices
  - Vectors
  - Samplers
- As of OpenGL 3.1, application must provide shaders

Simple Vertex Shader

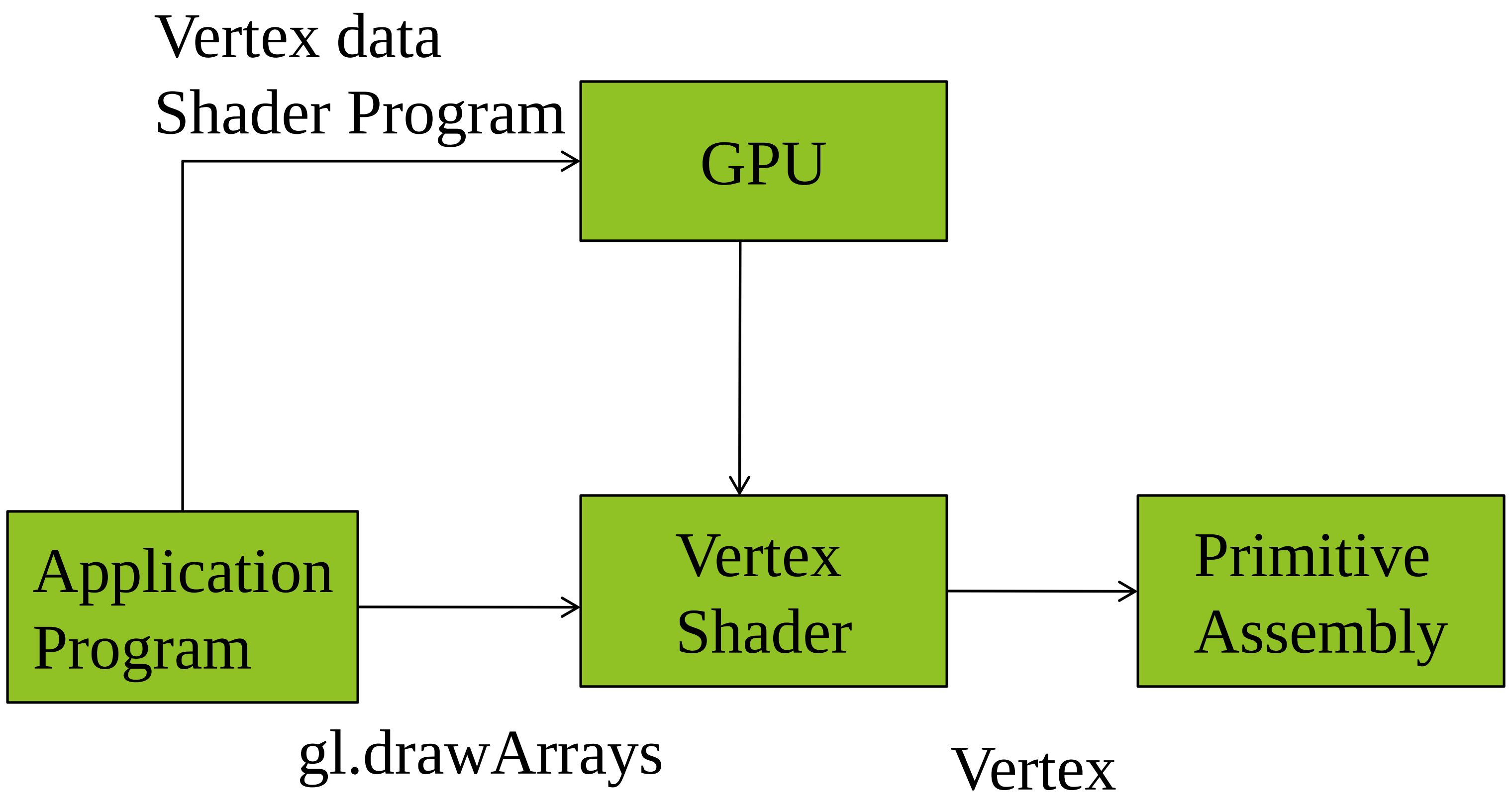
input from application

```
attribute vec4 vPosition;
void main(void)
{
    gl_Position = vPosition;
}
```

must link to variable in application

built in variable

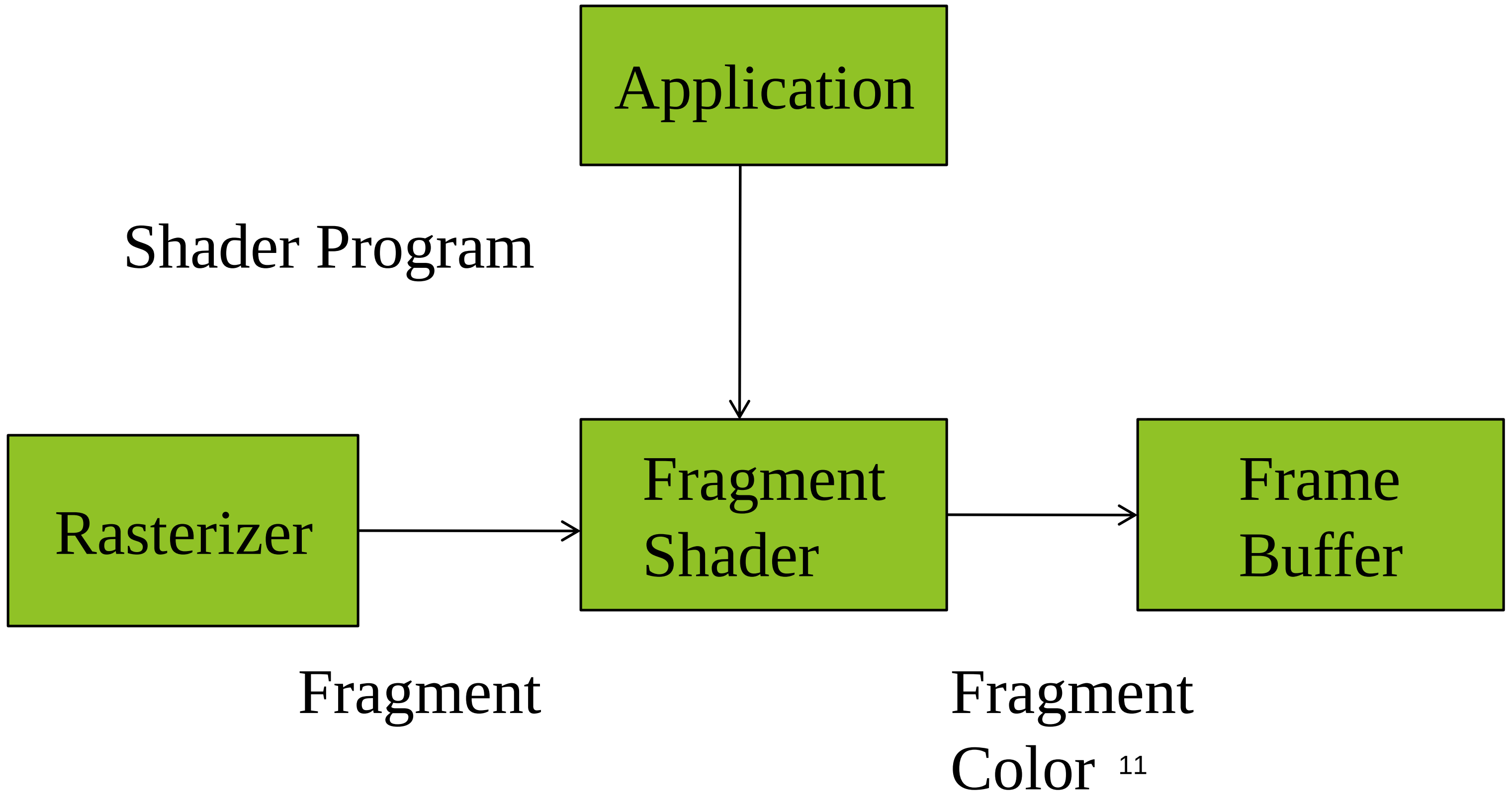
Execution Model



Simple Fragment Program

```
precision mediump float;
void main(void)
{
   gl_FragColor = vec4(1.0, 0.0, 0.0, 1.0);
}
```

Execution Model



Data Types

- C types: int, float, bool
- Vectors:
  - float vec2, vec3, vec4
  - Also int (ivec) and boolean (bvec)
- Matrices: mat2, mat3, mat4
  - Stored by columns
  - Standard referencing m[row][column]
- C++ style constructors
  - vec3 a =vec3(1.0, 2.0, 3.0)
  - vec2 b = vec2(a)

No Pointers

- There are no pointers in GLSL
- We can use C structs which

 can be copied back from functions

- Because matrices and vectors are basic types they can be passed into and output from GLSL functions, e.g.

  mat3 func(mat3 a)
- variables passed by copying

Qualifiers

- GLSL has many of the same qualifiers such as **`const`** as C/C++
- Need others due to the nature of the execution model
- Variables can change
  - Once per primitive
  - Once per vertex
  - Once per fragment
  - At any time in the application
- Vertex attributes are interpolated by the rasterizer into fragment attributes

Attribute Qualifier

- Attribute-qualified variables can change at most once per vertex
- There are a few built in variables such as gl_Position but most have been deprecated
- User defined (in application program)
  - **`attribute float temperature`**
  - **`attribute vec3 velocity`**
  - recent versions of GLSL use **`in`** and **`out`** qualifiers to get to and from shaders

Uniform Qualifier

- Variables that are constant for an entire primitive
- Can be changed in application and sent to shaders
- Cannot be changed in shader
- Used to pass information to shader such as the time or a bounding box of a primitive or transformation matrices

Varying Qualifier

- Variables that are passed from vertex shader to fragment shader
- Automatically interpolated by the rasterizer
- With WebGL, GLSL uses the varying qualifier in both shaders

```
varying vec4 color;
```

- More recent versions of WebGL use **out** in vertex shader and **in** in the fragment shader

```
out vec4 color; //vertex shader
in vec4 color;  // fragment shader
```

Our Naming Convention

- attributes passed to vertex shader have names beginning with v (v Position, vColor) in both the application and the shader
  - Note that these are different entities with the same name
- Variable variables begin with f (fColor) in both shaders
  - must have same name
- Uniform variables are unadorned and can have the same name in application and shaders

Example: Vertex Shader

```
attribute vec4 vColor;
varying vec4 fColor;
void main()
{
  gl_Position = vPosition;
  fColor = vColor;
}
```

Corresponding Fragment Shader

```
precision mediump float;


varying vec3 fColor;
void main()
{
  gl_FragColor = fColor;
}
```

Sending Colors from Application

```
var cBuffer = gl.createBuffer();
gl.bindBuffer( gl.ARRAY_BUFFER, cBuffer );
gl.bufferData( gl.ARRAY_BUFFER, flatten(colors),
                                        gl.STATIC_DRAW );

var vColor = gl.getAttribLocation( program, "vColor" );
gl.vertexAttribPointer( vColor, 3, gl.FLOAT, false, 0, 0 );
gl.enableVertexAttribArray( vColor );
```

Sending a Uniform Variable

```
 // in application

vec4 color = vec4(1.0, 0.0, 0.0, 1.0);
colorLoc = gl.getUniformLocation( program, ”color" );
gl.uniform4f( colorLoc, color);

// in fragment shader (similar in vertex shader)

uniform vec4 color;

void main()
{
    gl_FragColor = color;
}
```

Operators and Functions

- Standard C functions
  - Trigonometric
  - Arithmetic
  - Normalize, reflect, length
- Overloading of vector and matrix types

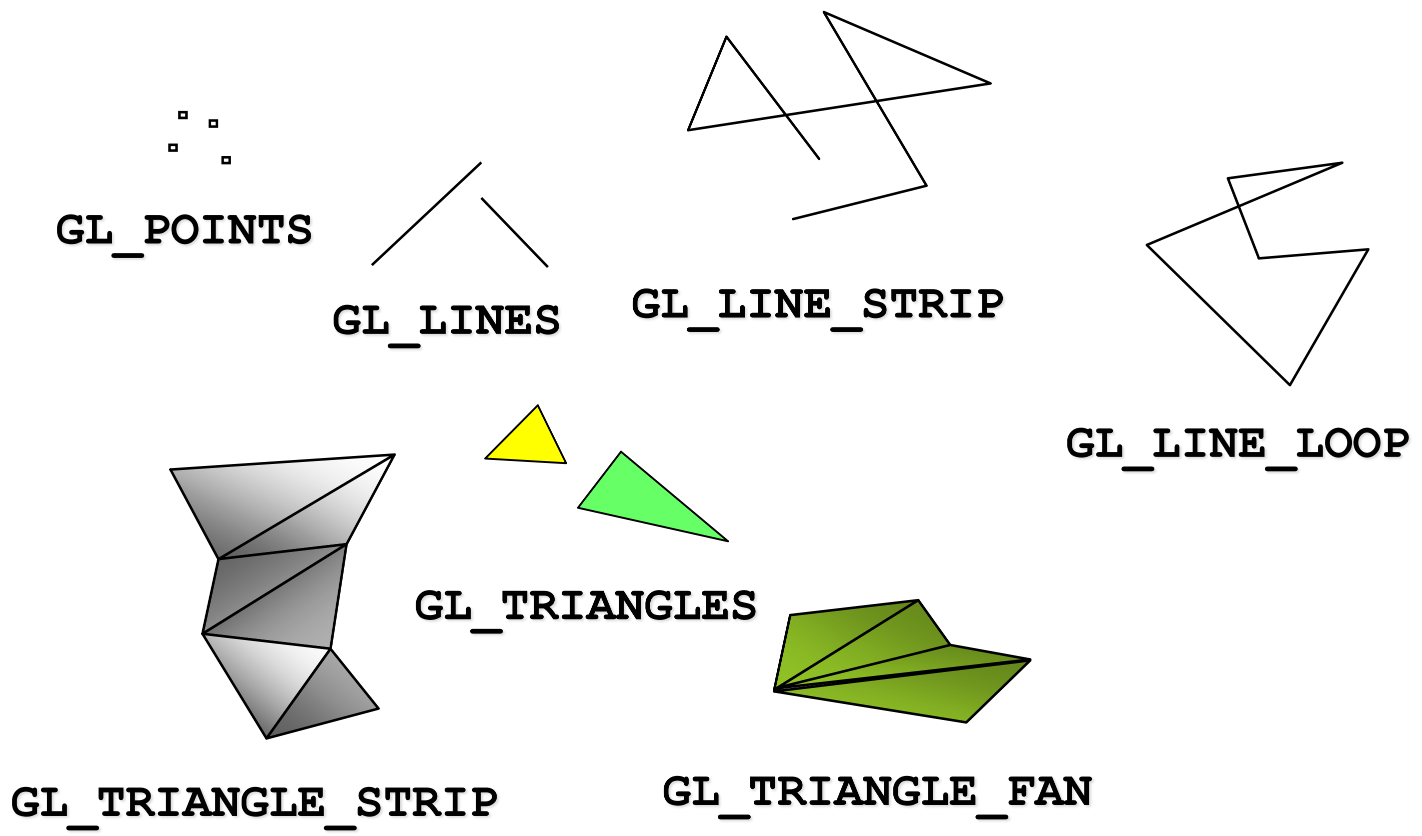
```
mat4 a;
vec4 b, c, d;
c = b*a; // a column vector stored as a 1d array
d = a*b; // a row vector stored as a 1d array
```

Swizzling and Selection

- Can refer to array elements by element using [] or selection (.) operator with
  - x, y, z, w
  - r, g, b, a
  - s, t, p, q
  - **`a[2], a.b, a.z, a.p`** are the same
- **Swizzling** operator lets us manipulate components

```
vec4 a, b;
a.yz = vec2(1.0, 2.0, 3.0, 4.0);
b = a.yxzw;
```

WebGLPrimitives



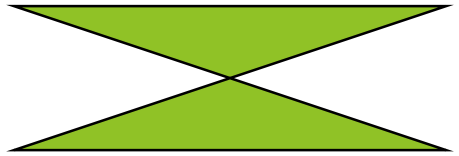
Point Sprites and Lines

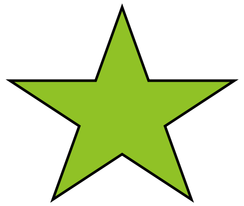
- gl.GL_LINES independent lines: two vertices will be used for each line and therefore number of lines = number of vertices / 2
- gl.GL_LINE_STRIPS line strips draw connected lines so one line starts at the same point as another line ended. Number of drawn lines = number of vertices – 1
- gl.GL_LINE_LOOP: It works very similar to a line strip. The only difference is that for a line loop there is one drawn from last to the first vertex specified. Number of drawn lines = number of vertices
- gl.POINTS when you render point sprites, one point sprite is rendered for each coordinate that you specify in the vertex shader. When you use a point sprite, you should also set the size of the point by setting the gl_PointSize

```
<script id="vertex-shader" type="x-shader/x-vertex">
    attribute vec4 vPosition;
    void main() {
    gl_Position = vPosition;
     gl_PointSize=5.0 }
  </script>
```

Polygon Issues

- WebGL will only display triangles
  - Simple: edges cannot cross
  - 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)
- OpenGL 4.1 contains a tessellator but not WebGL


nonsimple polygon

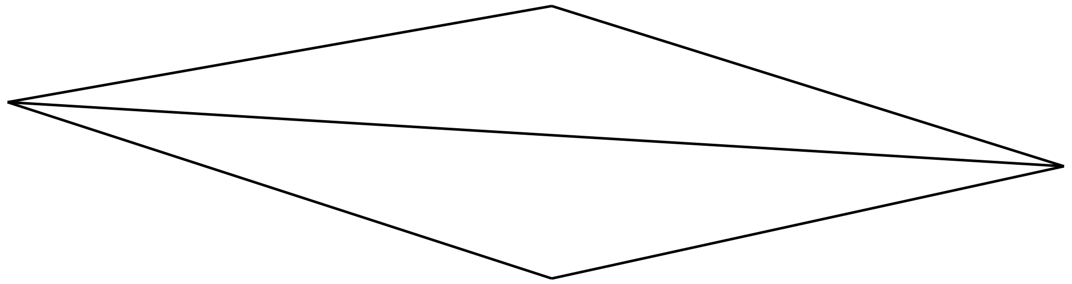

nonconvex polygon

Polygon Testing

- Conceptually simple to test for simplicity and convexity
- Time consuming
- Earlier versions assumed both and left testing to the application
- Present version only renders triangles
- Need algorithm to triangulate an arbitrary polygon

Good and Bad Triangles

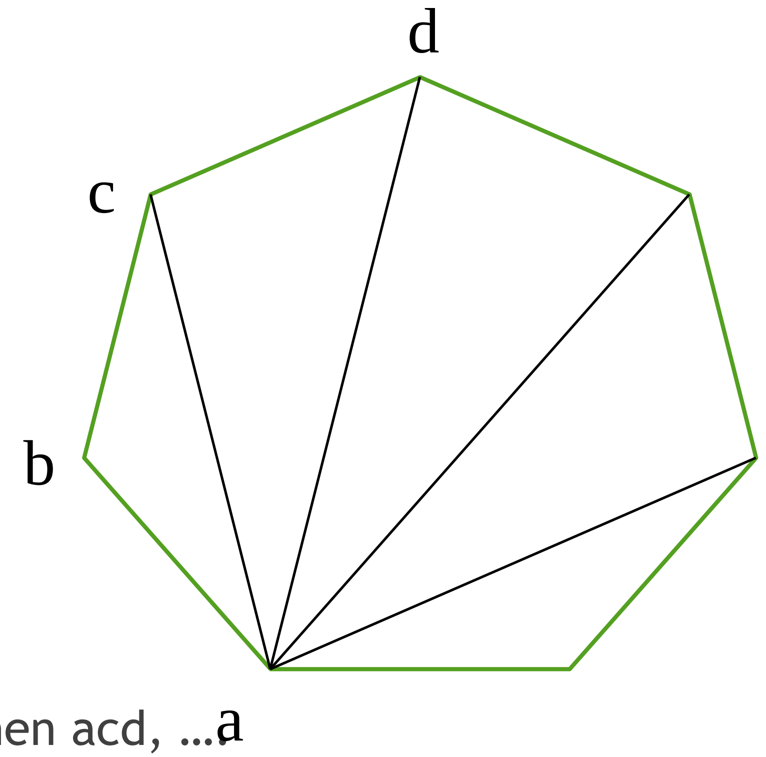
- Long thin triangles render badly



- Equilateral triangles render well
- Maximize minimum angle
- Delaunay triangulation for unstructured points

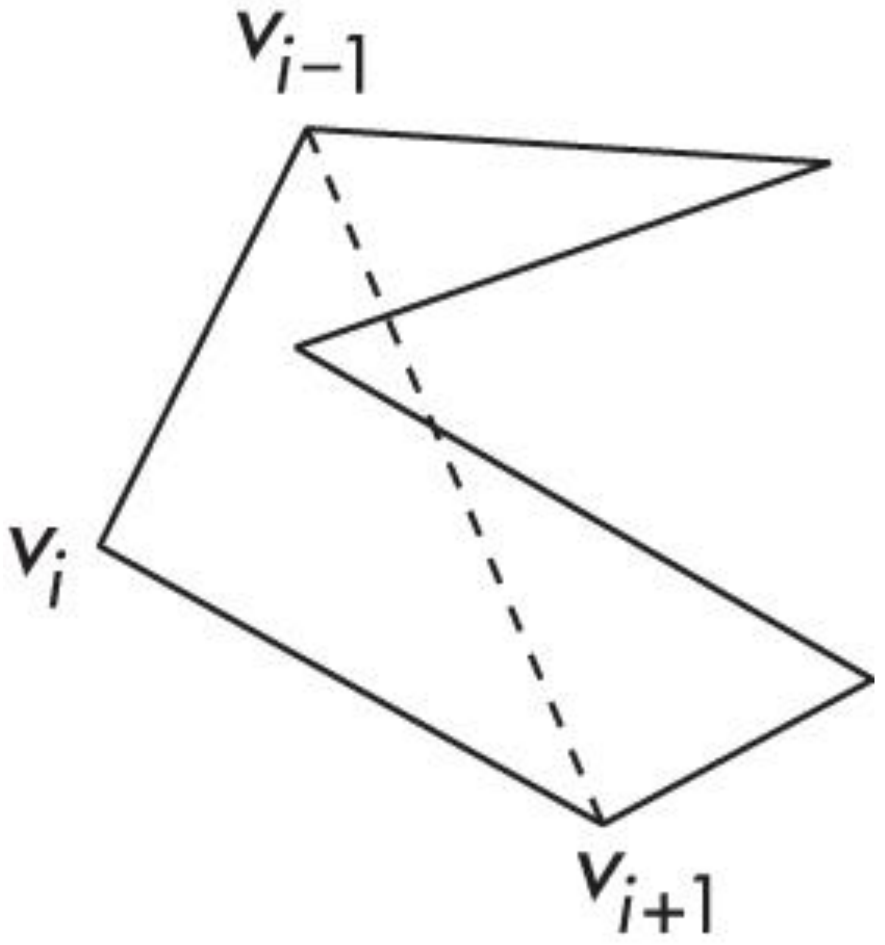
Triangularization

- Convex polygon



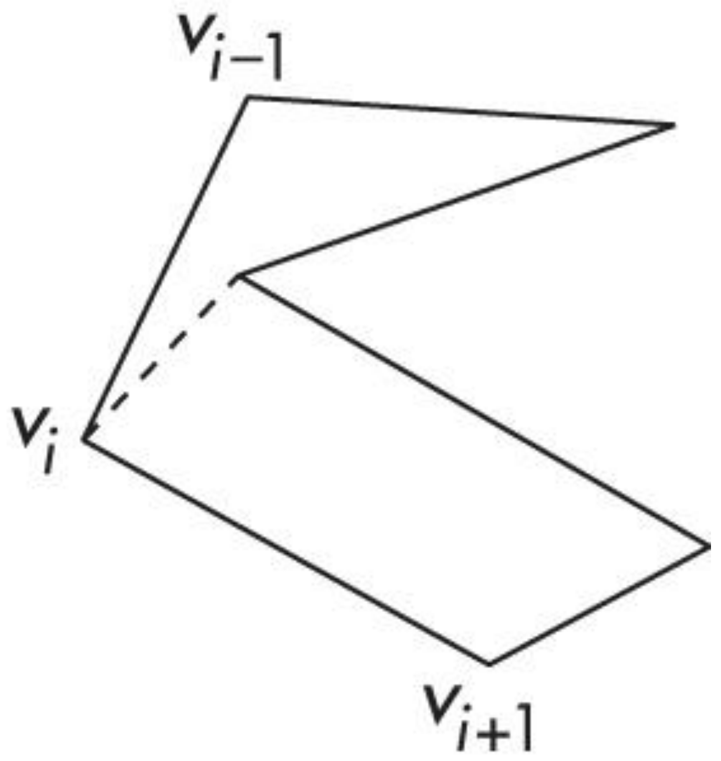
- Start with abc, remove b, then acd, ….

Non-convex (concave)



Recursive Division

- Find leftmost vertex and split

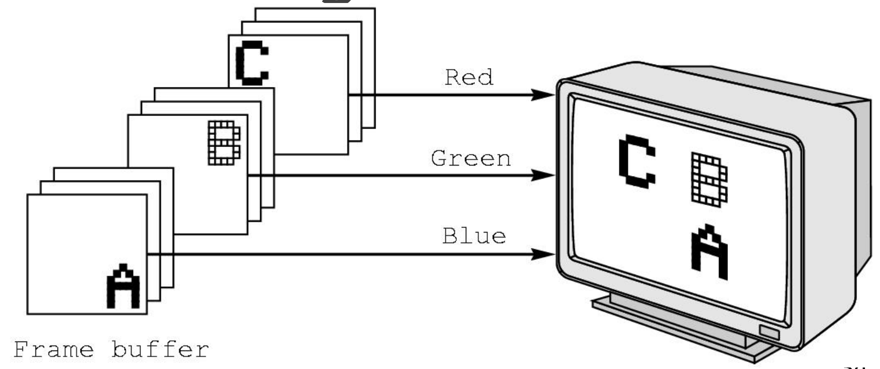


Attributes

- Attributes determine the appearance of objects
    - Color (points, lines, polygons)
    - Size and width (points, lines)
    - Stipple pattern (lines, polygons)
    - Polygon mode
        - Display as filled: solid color or stipple pattern
        - Display edges
        - Display vertices
- Only a few (gl_PointSize) are supported by WebGL functions

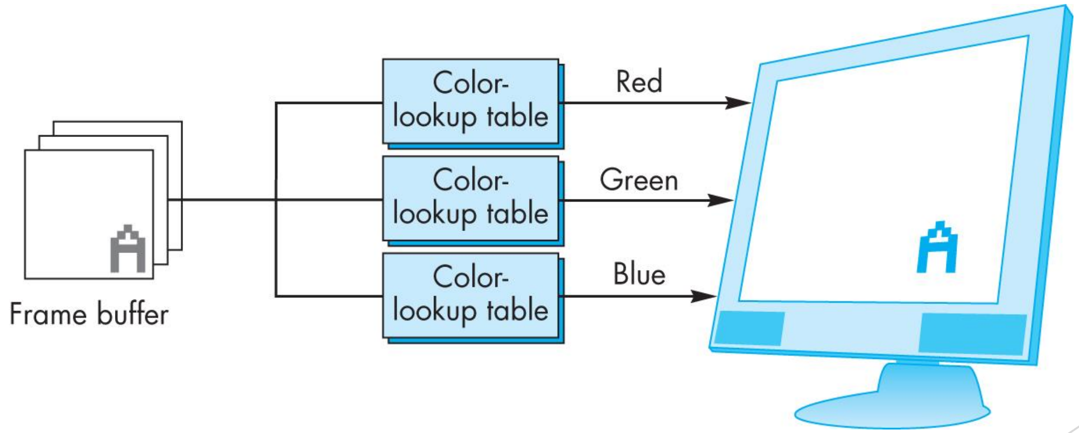
RGB color

- Each color component is stored separately in the frame buffer
- Usually 8 bits per component in buffer
- Color values can range from 0.0 (none) to 1.0 (all) using floats or over the range from 0 to 255 using unsigned bytes



Indexed Color

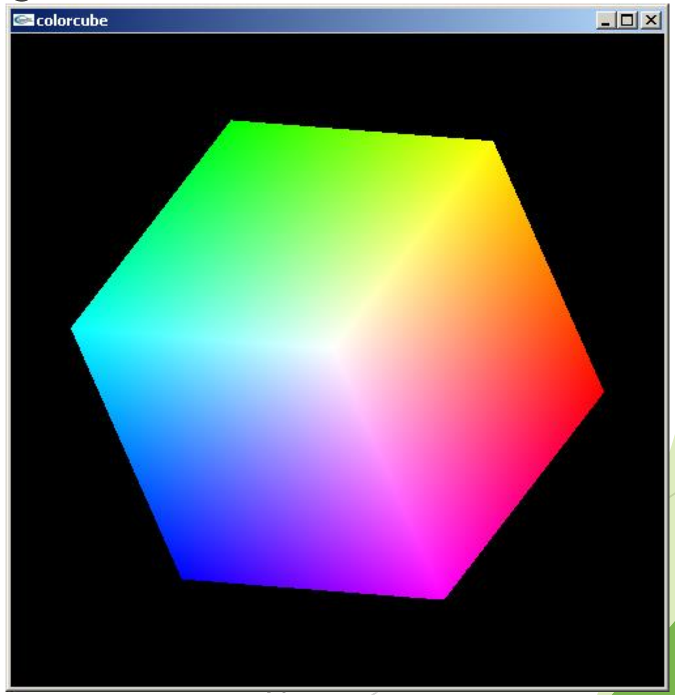
- Colors are indices into tables of RGB values
- Requires less memory
  - indices usually 8 bits
  - not as important now
    - Memory inexpensive
    - Need more colors for shading



Smooth Color

- Default is *smooth* shading
  - Rasterizer interpolates vertex colors across visible polygons
- Alternative is *flat shading*
  - Color of first vertex

  determines fill color
  - Handle in shader



Setting Colors

- Colors are ultimately set in the fragment shader but can be determined in either shader or in the application
- Application color: pass to vertex shader as a uniform variable or as a vertex attribute
- Vertex shader color: pass to fragment shader as varying variable
- Fragment color: can alter via shader code

Linking Shaders with Application

- Read shaders
- Compile shaders
- Create a program object
- Link everything together
- Link variables in application with variables in shaders
  - Vertex attributes
  - Uniform variables

Program Object

- Container for shaders
  - Can contain multiple shaders
  - Other GLSL functions

```
var program = gl.createProgram();

gl.attachShader( program, vertShdr );
gl.attachShader( program, fragShdr );
gl.linkProgram( program );
```

Reading a Shader

- Shaders are added to the program object and compiled
- Usual method of passing a shader is as a null-terminated string using the function
- gl.shaderSource(fragShdr, fragElem.text);
- If shader is in HTML file, we can get it into application by getElementById method
- If the shader is in a file, we can write a reader to convert the file to a string

Adding a Vertex Shader

```
var vertShdr;
var vertElem =
    document.getElementById( vertexShaderId );

vertShdr = gl.createShader( gl.VERTEX_SHADER );

gl.shaderSource( vertShdr, vertElem.text );
gl.compileShader( vertShdr );

// after program object created
gl.attachShader( program, vertShdr );
```

Shader Reader

- Following code may be a security issue with some browsers if you try to run it locally
  - Cross Origin Request

```
function getShader(gl, shaderName, type) {
        var shader = gl.createShader(type);
        shaderScript = loadFileAJAX(shaderName);
        if (!shaderScript) {
            alert("Could not find shader source:
                    "+shaderName);
        }
}
```

Precision Declaration

- In GLSL for WebGL we must specify desired precision in fragment shaders
  - artifact inherited from OpenGL ES
  - ES must run on very simple embedded devices that may not support 32-bit floating point
  - All implementations must support mediump
  - No default for float in fragment shader
- Can use preprocessor directives (#ifdef) to check if highp supported and, if not, default to mediump

Pass Through Fragment Shader

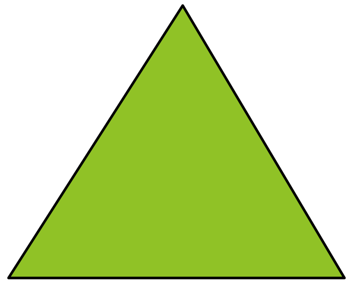
```
#ifdef GL_FRAGMENT_SHADER_PRECISION_HIGH
  precision highp float;
#else
  precision mediump float;
#endif

varying vec4 fcolor;
void main(void)
{
     gl_FragColor = fcolor;
}
```

Three-dimensional Applications

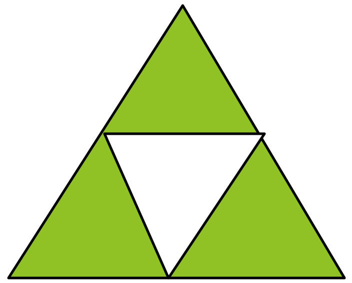
- In WebGL, two-dimensional applications are a special case of three-dimensional graphics
- Going to 3D
  - Not much changes
  - Use **`vec3, gl.uniform3f`**
  - Have to worry about the order in which primitives are rendered or use hidden-surface removal

Sierpinski Gasket (2D)

- Start with a triangle



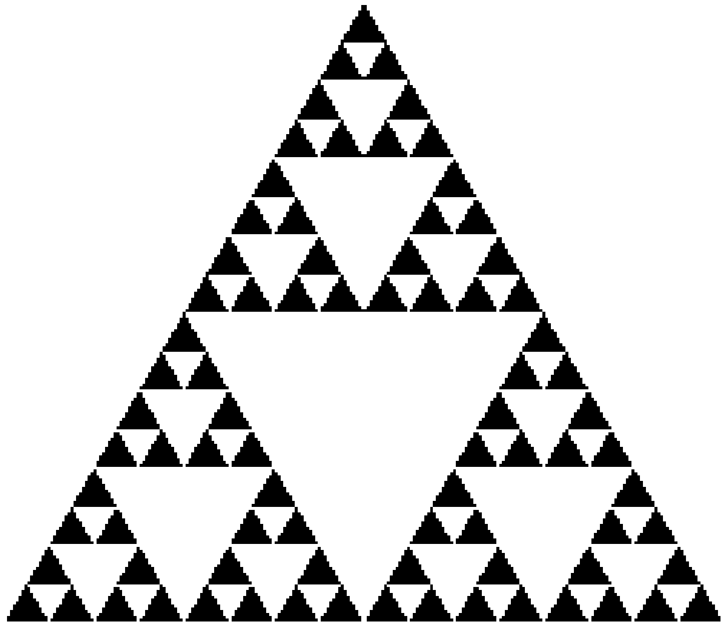
- Connect bisectors of sides and remove central triangle



- 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

- HTML file
  - Same as in other examples
  - Pass through vertex shader
  - Fragment shader sets color
  - Read in JS file

Gasket Program

```
var points = [];
var NumTimesToSubdivide = 5;

/* initial triangle */

 var vertices = [
        vec2( -1, -1 ),
        vec2(  0,  1 ),
        vec2(  1, -1 )
    ];

divideTriangle( vertices[0],vertices[1],
     vertices[2], NumTimesToSubdivide);
```

Draw one triangle

```
/* display one triangle  */

function triangle( a, b, c ){
    points.push( a, b, c );
}
```

Triangle Subdivision

```
function divideTriangle( a, b, c, count ){
 // check for end of recursion
    if ( count === 0 ) {
    triangle( a, b, c );
    }
    else {
//bisect the sides
    var ab = mix( a, b, 0.5 );
    var ac = mix( a, c, 0.5 );
    var bc = mix( b, c, 0.5 );
    --count;
// three new triangles
    divideTriangle( a, ab, ac, count-1 );
    divideTriangle( c, ac, bc, count-1 );
    divideTriangle( b, bc, ab, count-1 );
    }
}
```

init()

```
var program = initShaders( gl, "vertex-
  shader", "fragment-shader" );
    gl.useProgram( program );
    var bufferId = gl.createBuffer();
  gl.bindBuffer( gl.ARRAY_BUFFER, bufferId )
  gl.bufferData( gl.ARRAY_BUFFER,
  flatten(points), gl.STATIC_DRAW );
var vPosition = gl.getAttribLocation(
  program, "vPosition" );
    gl.vertexAttribPointer( vPosition, 2,
  gl.FLOAT, false, 0, 0 );
    gl.enableVertexAttribArray( vPosition );
    render();
```

Render Function

```
function render(){
    gl.clear( gl.COLOR_BUFFER_BIT );
    gl.drawArrays( gl.TRIANGLES, 0, points.length );
}
```

Moving to 3D

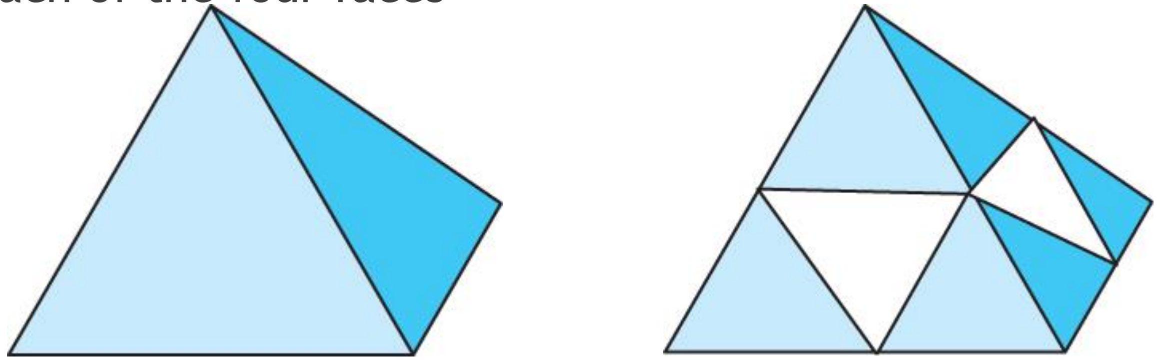
- We can easily make the program three-dimensional by using three dimensional points and starting with a tetrahedron

```
var vertices = [
  vec3(  0.0000,  0.0000, -1.0000 ),        vec3(
   0.0000,  0.9428,  0.3333 ),        vec3( -0.8165, -
   0.4714,  0.3333 ),        vec3(  0.8165, -0.4714,
   0.3333 )
];
```

subdivide each face

3D Gasket

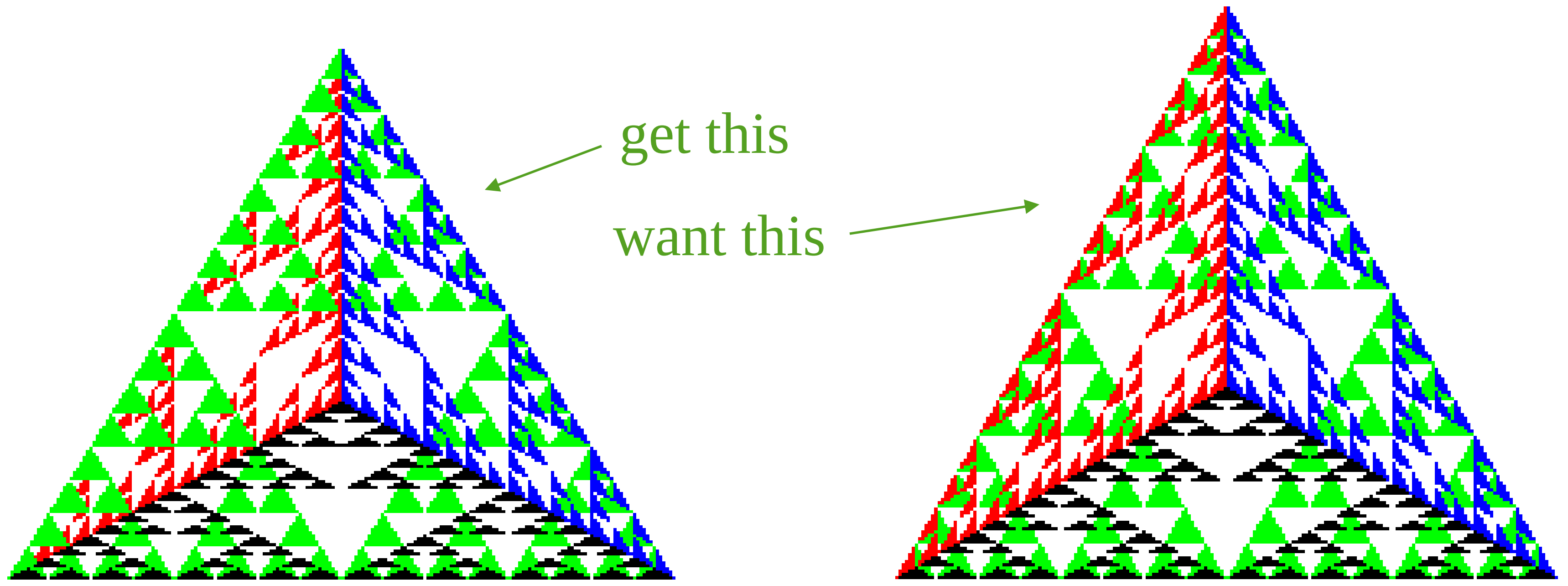
- We can subdivide each of the four faces



- Appears as if we remove a solid tetrahedron from the center leaving four smaller tetrahedra
- Code almost identical to 2D example

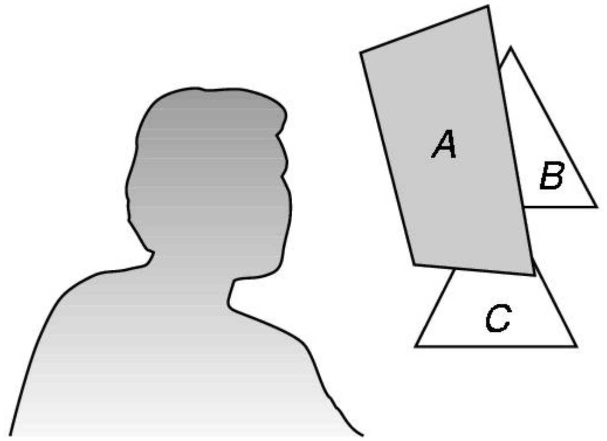
Almost Correct

- Because the triangles are drawn in the order they are specified 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



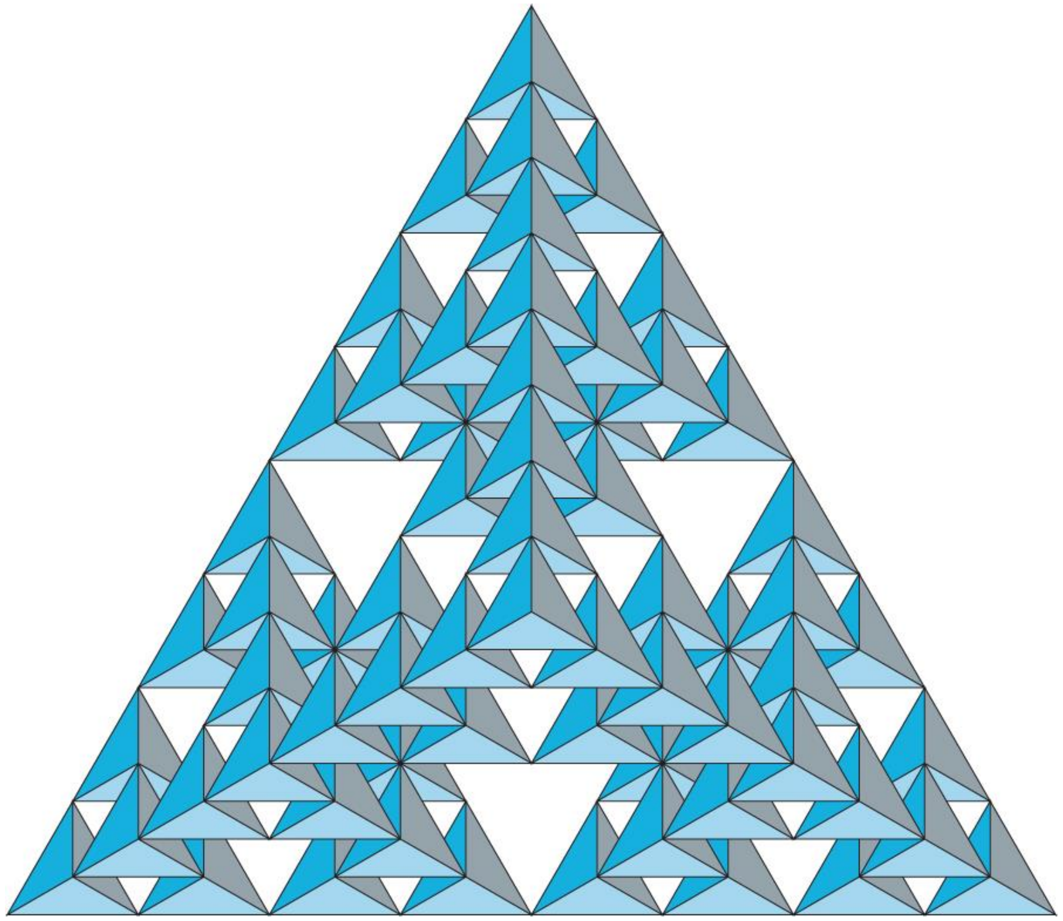
Using the z-buffer algorithm

- The algorithm uses an extra buffer, the z-buffer, to store depth information as geometry travels down the pipeline
- Depth buffer is required to be available in WebGL
- It must be
  - Enabled
    - `gl.enable(gl.DEPTH_TEST)`
  - Cleared in for each render
    - `gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT)`

Surface vs Volume Subdvision

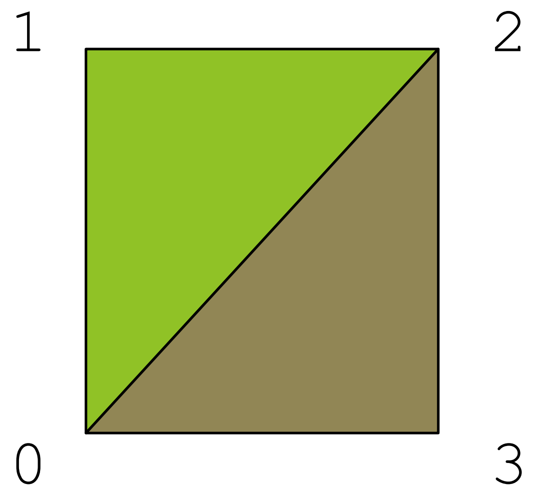
- In our example, we divided the surface of each face
- We could also divide the volume using the same midpoints
- The midpoints define four smaller tetrahedrons, one for each vertex
- Keeping only these tetrahedrons removes a *volume* in the middle
- See text for code

Volume Subdivision



gl.drawElements() method

- Sometimes referred to as index drawing
- Uses the array buffers that contain the vertex data, but in addition, it uses an “element” array buffer that contains the indices into the array buffer with vertex data.
- Vertex data can be in any order in the array buffer.
- Array buffer [V0, V1, V2, V3] Element Array Buffer [1,0,2,2,0,3]



gl.drawElements() method

- The prototype: void drawElements(Glenum mode, Glsizei count, Glenum type, Glintptr offset)
- mode specifies the primitive you want to render (gl.POINTS, gl.LINES, gl.LINE_LOOP, gl.LINE_STRIP, gl.TRIANGLES, gl.TRIANGLE_STRIP, gl.TRIANGLE_FAN
- count specifies how many indices you have in the buffer bound to the gl.ELEMENT_ARRAY_BUFFER target.
- type specifies the type for element indices that are stored in the buffer bound to gl.ELEMENT_ARRAY_BUFFER. The types you can specify are either gl.UNSIGNED_BYTE or gl.UNSIGNED_SHORT
- offset specifies the offsets into the buffer bound to gl.ELEMENT_ARRAY_BUFFER where the indices start.

gl.drawElements()

- Before you can call gl.drawElements(), you must do the following:

1. Create a WebGL Buffer object with gl.createBuffer().
2. Bind WebGLBuffer object to the target gl.ELEMENT_ARRAY_BUFFER using gl.bindBuffer()
3. Load indices thatdecide the order in which the vertex data is used into the buffer using gl.bufferData()

- You should always try to have as few calls as possible to gl.drawArrays or gl.drawElements().
- It's more efficient to have one call to gl.drawArrays or gl.drawElements() with an array that contains 200 triangles that to have 100 draw calls that each draws two triangles.

Degenerate Triangles

- If you are using gl.TRIANGLE_STRIP, you can combine different strips when there is a discontinuity.
- How? A degenerate triangle has at least two indices(or vertices) that are the same, and therefore the triangle has zero area.
- The degenerate triangles are detected by the GPU and destroyed.
- Assuming that you want to keep the same winding order:
  - The first strip consists of an even number of triangles. To connect the second strip, you need to add two extra indices.
  - The first strip consists of an odd number of triangles. To connect the second strip, you need to add three extra indices if you want to keep the winding order.

Degenerate Triangles

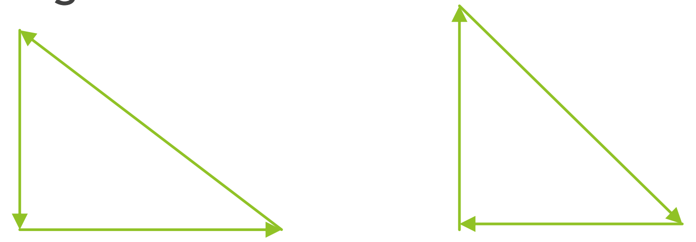
- To connect [0,1,2,3] to [4,5,6,7] in the element array buffer
- The result is [0,1,2,3,3,4,4,5,6,7]
- Generated triangles
  - [0,1,2]
  - [2,1,3]
  - [2,3,3] ➔ degenerate
  - [3,3,4] ➔ degenerate
  - [3,4,4] ➔ degenerate
  - [4,4,5] ➔ degenerate
  - [4,5,6]
  - [6,5,7]

Degenerate triangles

- To connect [0,1,2,3,4] to [5,6,7,8] in the element array buffer
- The result is [0,1,2,3,4,4,4,5,5,6,7,8]
- Generated triangles
  - [0,1,2]
  - [2,1,3]
  - [2,3,4]
  - [4,3,4] → degenerate
  - [4,4,4] → degenerate
  - [4,4,5] → degenerate
  - [4,5,5] → degenerate
  - [5,5,6] → degenerate
  - [5,6,7]
  - [7,6,8]

Winding Order

- An important property for a triangle in WebGL is called the winding order.
- CCW(Counter clockwise) winding order occurs when vertices build up the triangle in CCW order. Clockwise (CW) winding order occurs when the vertices buildup the triangle in clockwise.
- The winding order decides whether or not triangles face the viewer.
- Triangles face the viewer are called front-facing and triangles that are not facing the viewer called back-facing.



Culling

- In many cases, there is no need for WebGL to rasterize triangles that are back-facing.
- You can tell WebGL to cull the faces that cannot be seen.
  - gl.frontFace(gl.CCW) tells WebGL that triangles with CCW winding are front facing
  - gl.enable(gl.CULL_FACE) enables the culling for faces
  - gl.cullFace(gl.BACK) cull the back-facing triangles
- gl.frontFace(gl.CW) tells WebGL that triangles with CW are front-facing
- gl.cullFace(gl.Front) cull the front-facing triangles
- If you have a scene that consists of objects whose back side the users cannot see, it’s a good idea to enable back-facing culling. This can increase performance since the GPU will not need to rasterize triangles that are not visible.