Introduction to Computer Graphics with WebGL

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Programming with WebGL Part 3: Shaders

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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

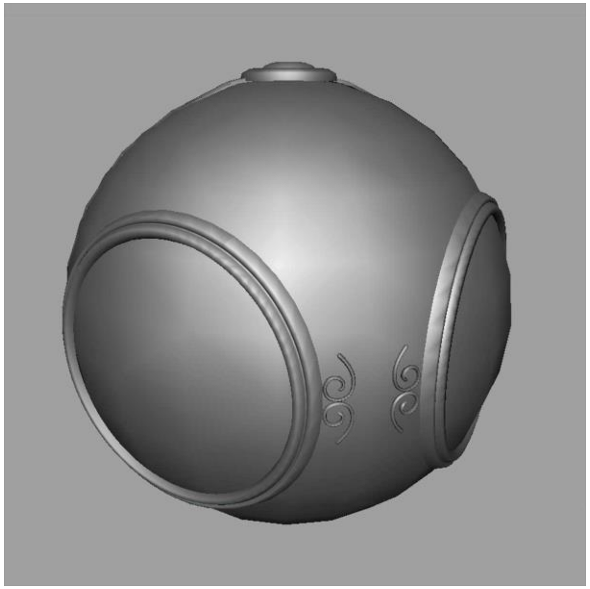
Per fragment lighting calculations

per vertex lighting

per fragment lighting

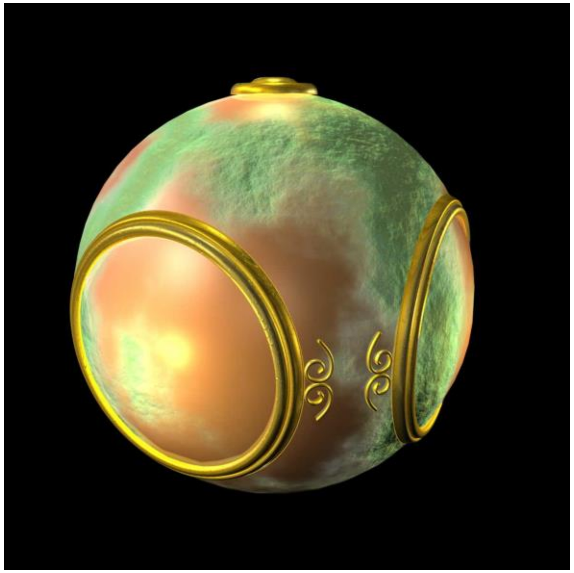
Fragment Shader Applications

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

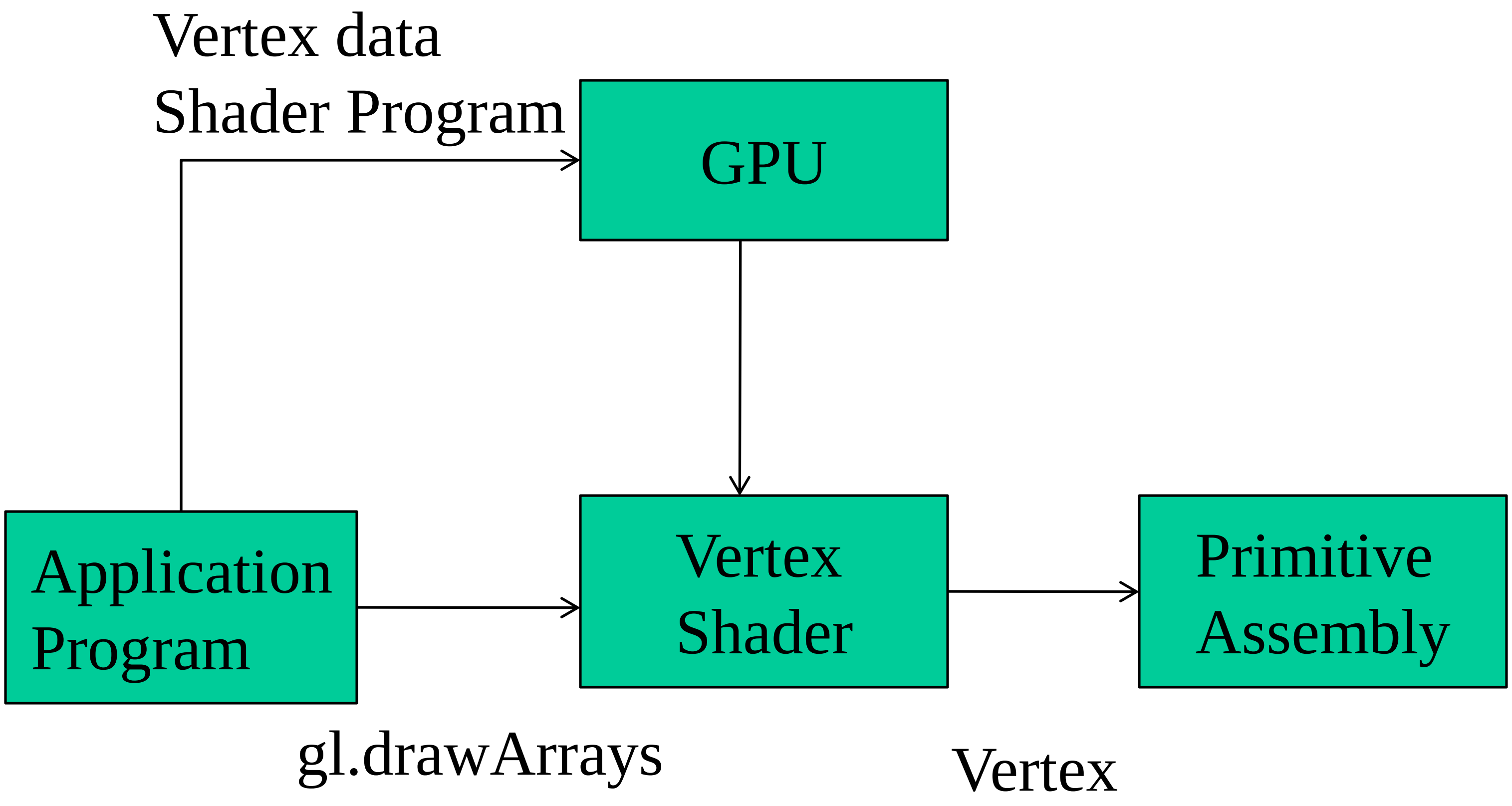
input from application

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

must link to variable in application

built in variable

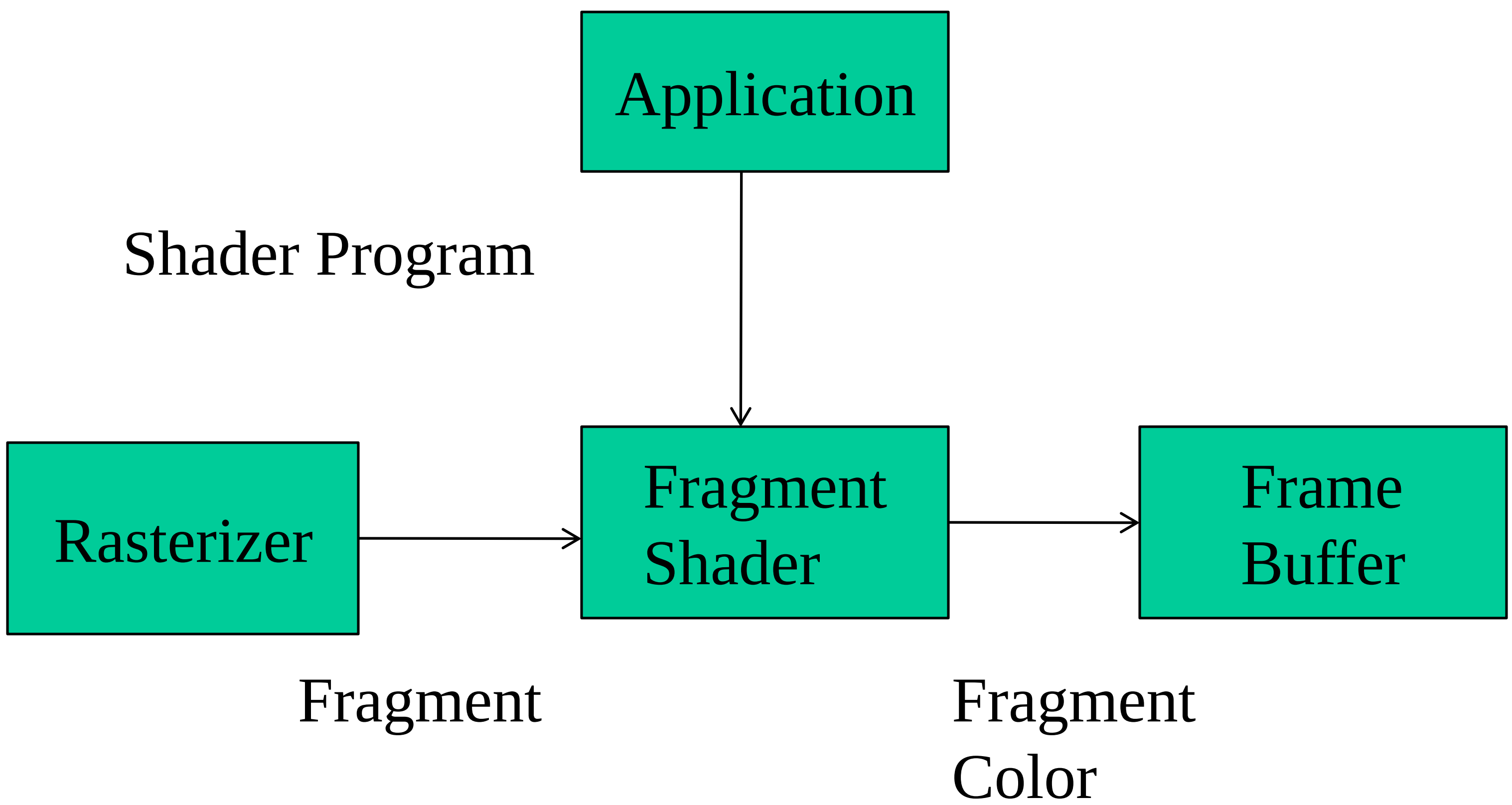
Execution Model



Simple Fragment Program

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

Execution Model



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Part 3: Shaders

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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 Qualified

- 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 Qualified

- 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 (vPosition, vColor) in both the application and the shader
  - Note that these are different entities with the same name
- Varying 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;  //out vec4 fColor;
void main()
{
  gl_Position = vPosition;
  fColor = vColor;
}
```

Corresponding Fragment Shader

```
precision mediump float;


varying vec4 fColor;   //in vec4 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;
```

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Programming with WebGL
Part 4: Color and Attributes

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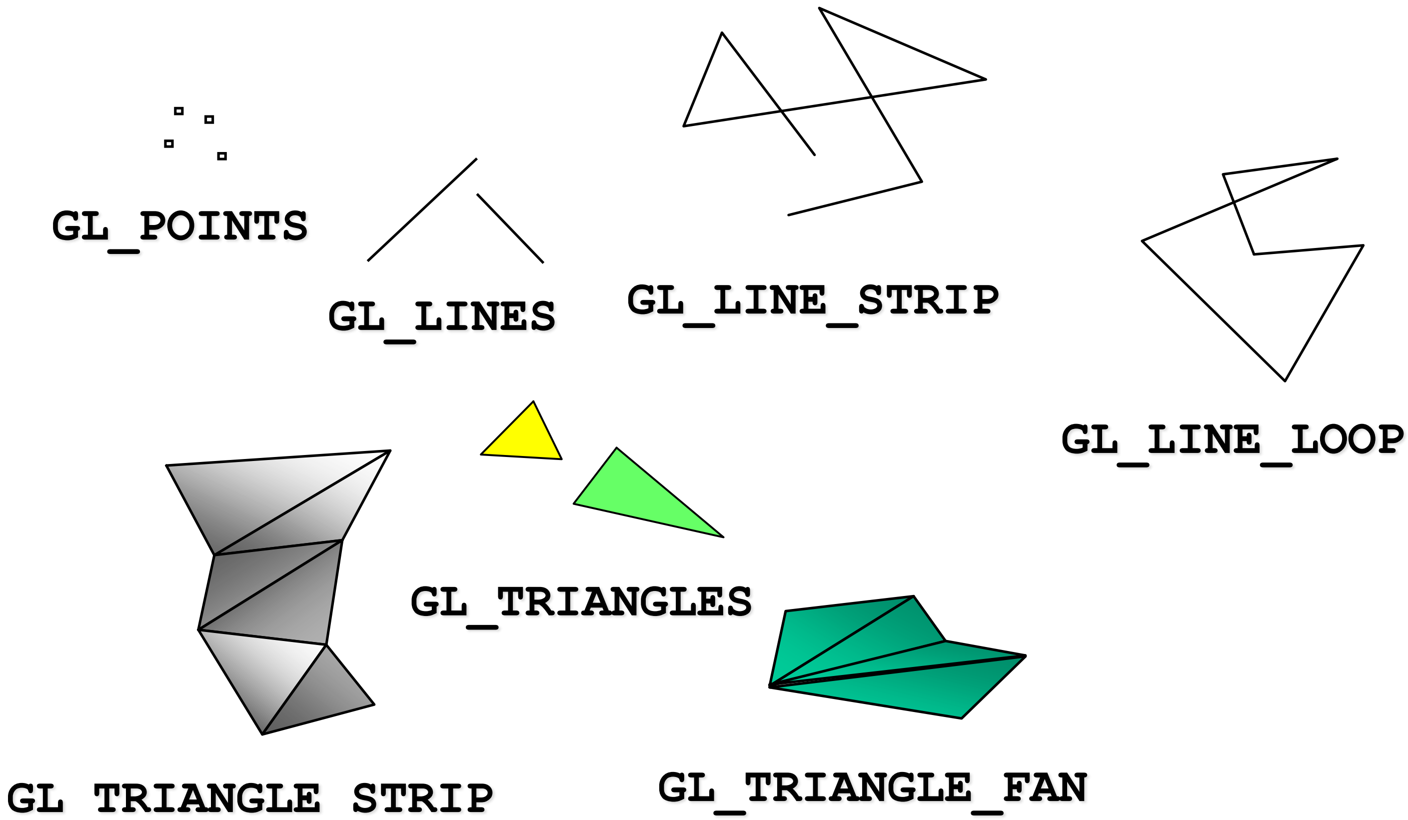
Objectives

- Expanding primitive set
- Adding color
- Vertex attributes

WebGLPrimitives



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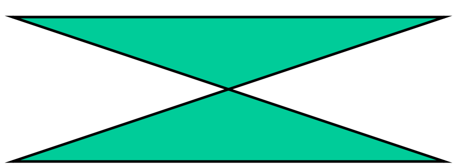
Polygon Issues

- 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

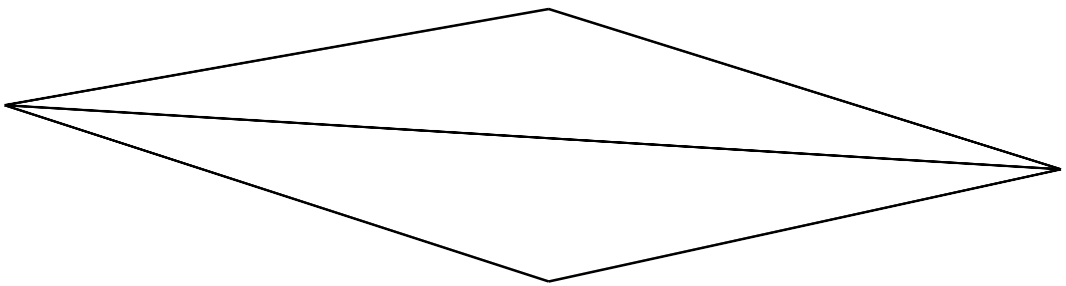
nonconvex polygon

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

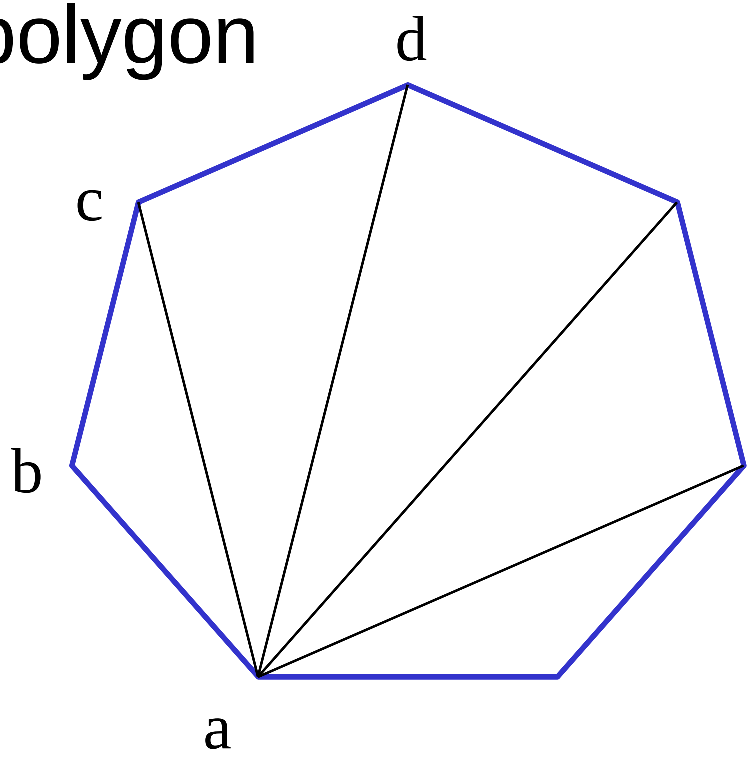
- Long thin triangles render badly



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

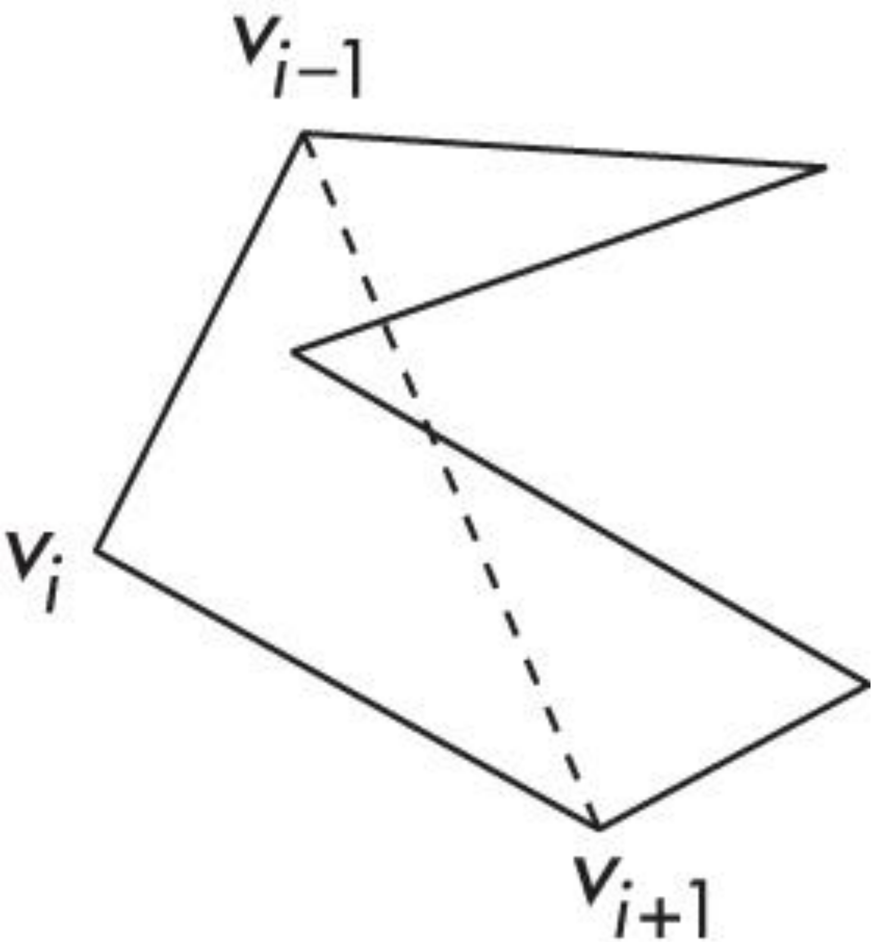
Triangularization

- Convex polygon



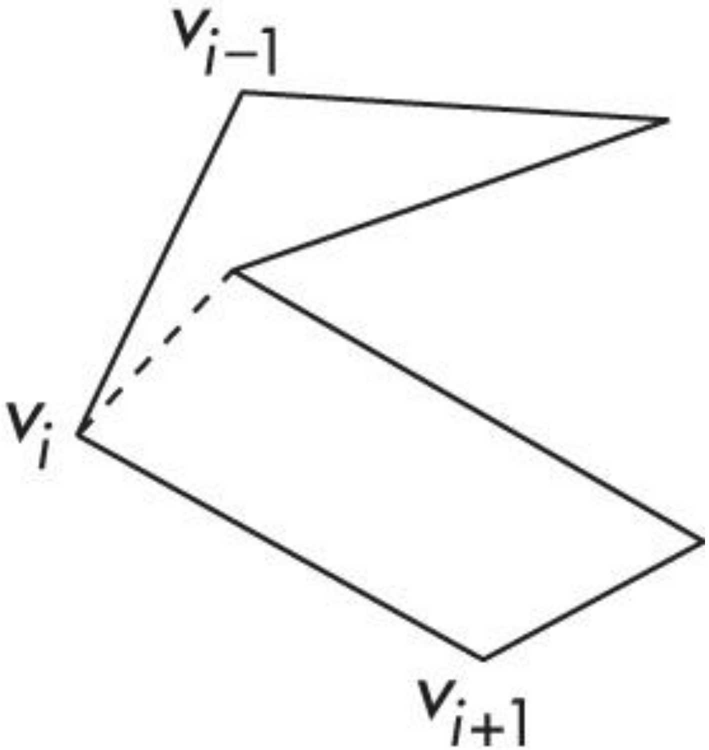
- Start with abc, remove b, then acd, ….

Non-convex (concave)



Recursive Division

- Find leftmost vertex and split

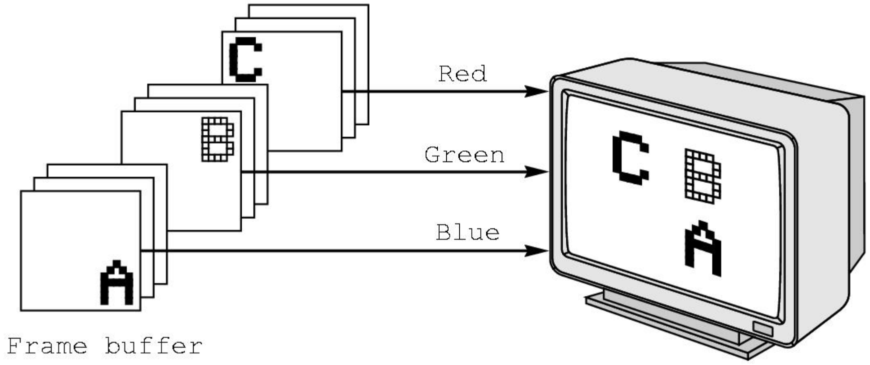


Attributes

- 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

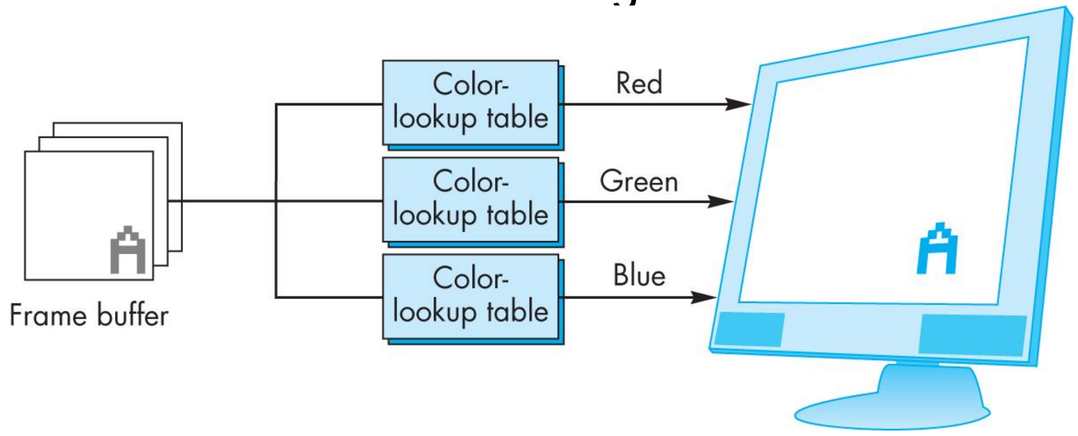
RGB color

- 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



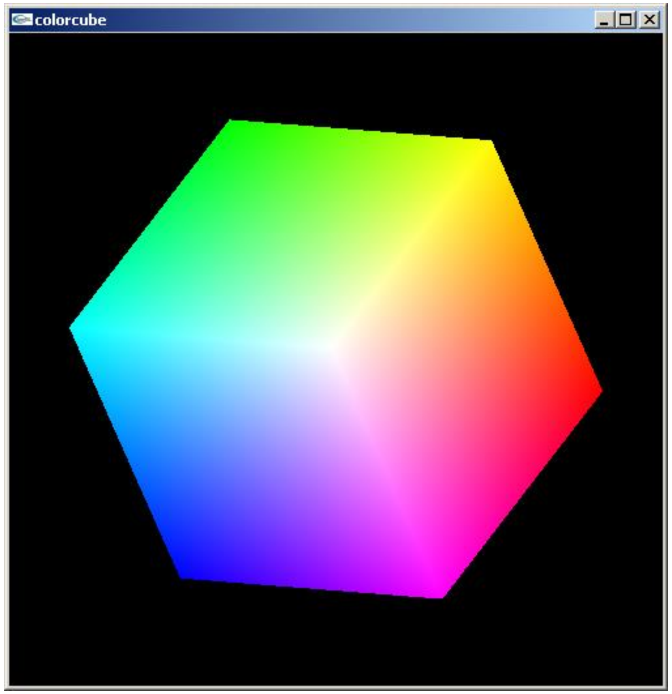
Indexed Color

- 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