Introduction to OpenGL

CS 4620

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Introduction

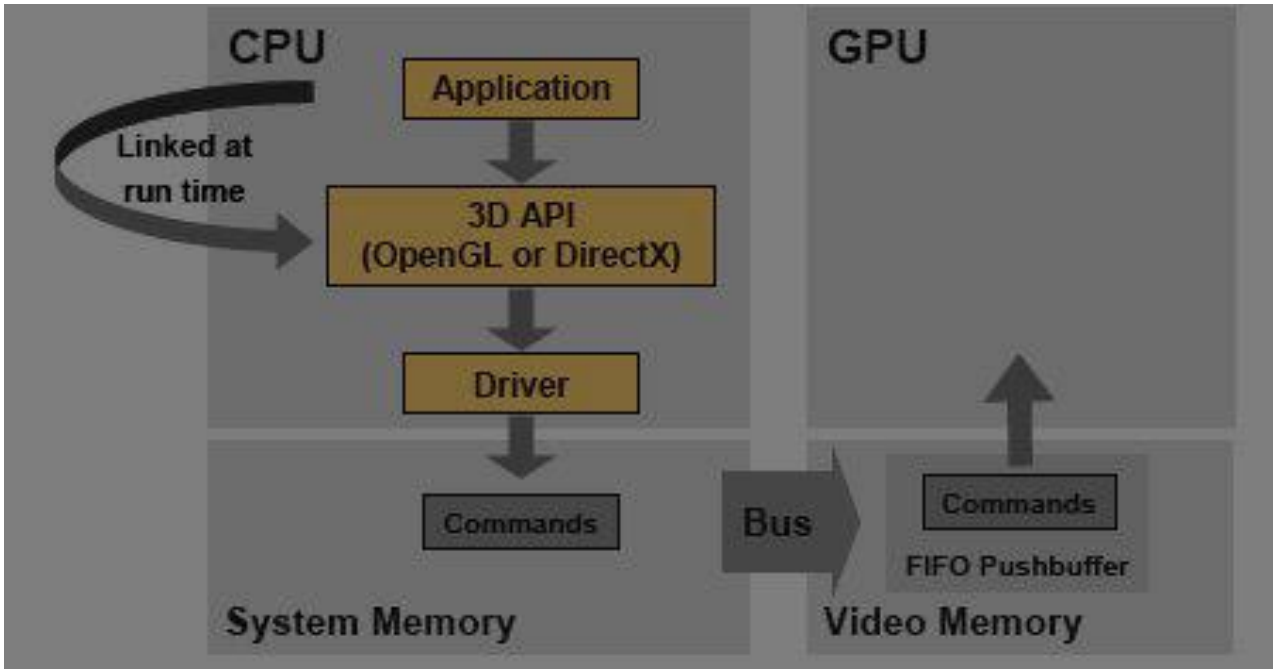
- Show how to produce graphics using OpenGL
- Introduce our framework for OpenGL programming

OpenGL

- Open Graphics Library
- API for GPU-accelerated 2D / 3D rendering
- Cross-platform (Windows, OS X, Linux, iOS, Android, ...)
- Developed by SGI in 1992
  - 2009: OpenGL 3.2
  - 2010: OpenGL 4.0
  - 2011: OpenGL 4.2
- Main alternative: Direct3D (Windows / XBox)

Why Use OpenGL?

- Tap massive power of GPU hardware to render images
- Use GPU without worrying about exact details of hardware



What OpenGL Does For Us

- Controls GPU
- Lets user specify resources...:
  - Geometry (vertices and primitives)
  - Textures
  - Shaders (programs that run in the graphics pipeline)
  - Etc.
- ...and use them:
  - Rasterize and draw geometry

How We'll Use OpenGL

- OpenGL version
  - We use 2.1, plus extensions
  - Some features in 2.1 are no longer commonly used
  - Code uses subset of features used in 3.x and 4.x
- LWJGL
  - Lightweight Java Game Library
  - Java bindings for OpenGL API
- CS 4620 Framework
  - Simplifies creating and using OpenGL resources

Creating an OpenGL Program

MainGame

- A window which can display GameScreens
- Initializes OpenGL context
- Forwards keyboard and mouse events to the event dispatcher

- Usage
  - Inherit from MainGame and implement methods
  - Create instance and call run method

MainGame

```
@Override
protected void buildScreenList() {
	// Create objects inherited from GameScreen and
	// initialize screenList attribute
}

@Override
protected void fullInitialize() {
	// Code Executed Before Window Is Created
}

@Override
protected void fullLoad() {
	// Code Executed With An Active OpenGL Context
}
```

GameScreen

- Can display images created by OpenGL
- OpenGL “context”
  - Stores OpenGL state (geometry, buffers, etc.)

- Usage
  - Inherit from class and implement methods
  - Create instance in MainGame.buildScreenList

GameScreen

```
@Override
public void update(GameTime gameTime) {
	// Animation: Update position of scene objects, camera
}

@Override
public void draw(GameTime gameTime) {
	// Drawing: Use LWJGL to draw to the screen
}

@Override
public void onEntry(GameTime gameTime) {
	// Initialization code
}

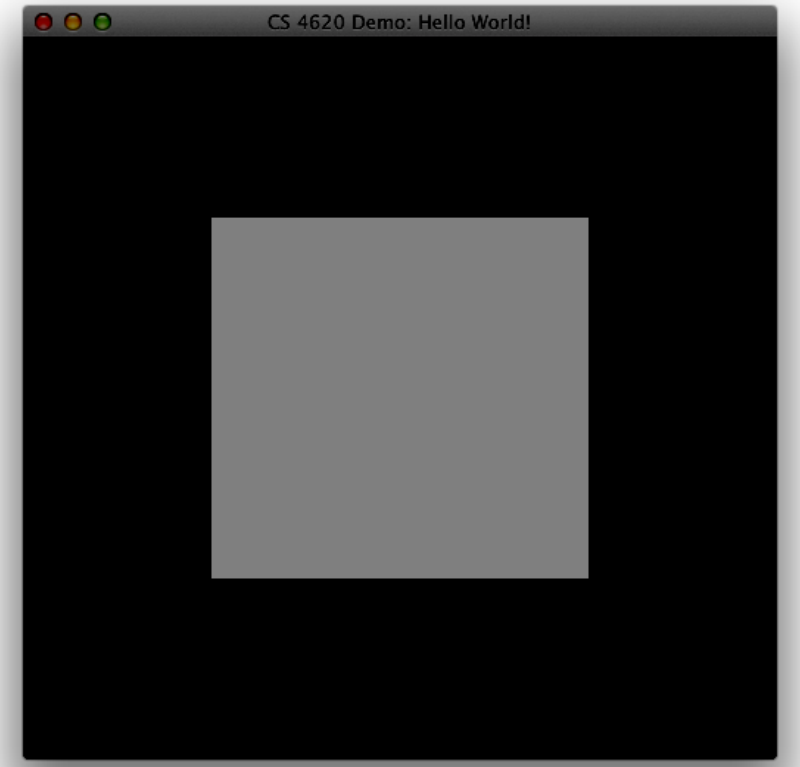
@Override
public void onExit(GameTime gameTime) {
	// Destruction, free allocated resources here
}
```

Events

- MainGame can trigger certain events
  - Something happens (e.g. user resizes window)
  - MainGame forwards event to the event dispatcher
    - KeyboardEventDispatcher
    - MouseEventDispatcher
  - Objects interested in the event can sign up as listeners
    - E.g. KeyboardEventDispatcher.OnKeyPressed.add(…)

- These events let us interact with OpenGL

Demo: Hello World!



OpenGL Commands and Resources

Example: Hello World's draw()

```
@Override
public void draw(GameTime gameTime) {
        GL11.glClearColor(0.0f, 0.0f, 0.0f, 1.0f);
        GL11.glClear(GL11.GL_COLOR_BUFFER_BIT);

        program.use();

        GLUniform.setST(program.getUniform("VP"),
        new Matrix4(), false);
        GLUniform.set(program.getUniform("uGridColor"),
        new Vector4(1, 1, 1, 1));

        vb.useAsAttrib(program.getAttribute("vPos"));
        ib.bind();
        GL11.glDrawElements(GL11.GL_TRIANGLES, indexCount,
        GLType.UnsignedInt, 0);
        ib.unbind();

        GLProgram.unuse();
}
```

OpenGL Commands

- Get OpenGL context is already initialized
- API calls: glxx.glSomeCommandName
- GL11.glClearColor(0.0f, 0.0f, 0.0f, 1.0f)
  - Set black as the color to use when clearing the screen
- GL11.glClear(GL11.GL_COLOR_BUFFER_BIT)
  - Clear the display buffer using the color given by glClearColor
- GL11.glDrawElements(…)
  - Draw primitives (now triangles)

Framework Commands

- program.use()
  - Set which shader program the pipeline will use to draw geometry
  - We talked about this during the GLSL lecture
- GLUniform.*setST(program.getUniform("VP"), …)*
  - Tell shader program to use the specified transformation as “VP”
- GLUniform.*set(program.getUniform("uGridColor"), …)*
  - Tell shader program to use the specified color as “uGridColor”
- GLProgram.unuse()
  - Tell OpenGL we are done drawing for now
- **Each of these has OpenGL commands under the hood**

Framework Commands

- vb.useAsAttrib(program.getAttribute("vPos"))
  - Tell shader program to use “vb” as vertex buffer and access vertex position using “vPos”
- ib.bind(), ib.unbind()
  - Bind (and unbind) the index buffer to tell OpenGL about how we use the vertices in the vertex buffer

Why Have a Framework?

- You write:

  vb.useAsAttrib(program.getAttribute("vPos"));

- Framework does:

```
GL15.glBindBuffer(GL11.GL_ARRAY_BUFFER, vb.id);
GL15.glEnableVertexAttribArray(program.getAttribute("vPos"));
GL15.glVertexAttribPointer(program.getAttribute("vPos"), componentCount,
componentFormat, norm, elementByteSize, offset * elementByteSize);
```

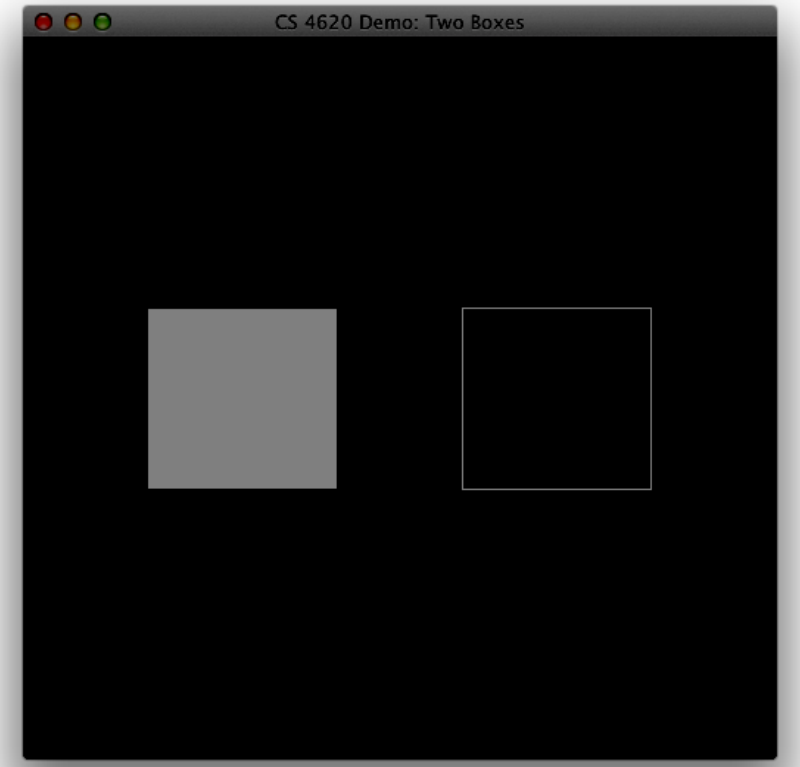
- Annoying to retype full sequence of commands for every draw

Framework and GL Resources

- OpenGL API has “objects” that hold rendering resources
  - Geometry, textures, shader programs, etc.
- Framework represents these with Java classes
  - GLProgram (shader programs)
  - GLBuffer (used to specify geometry)
- Constructing an object creates OpenGL resource
  - Object's data lives in GPU memory
  - Allows faster access while rendering

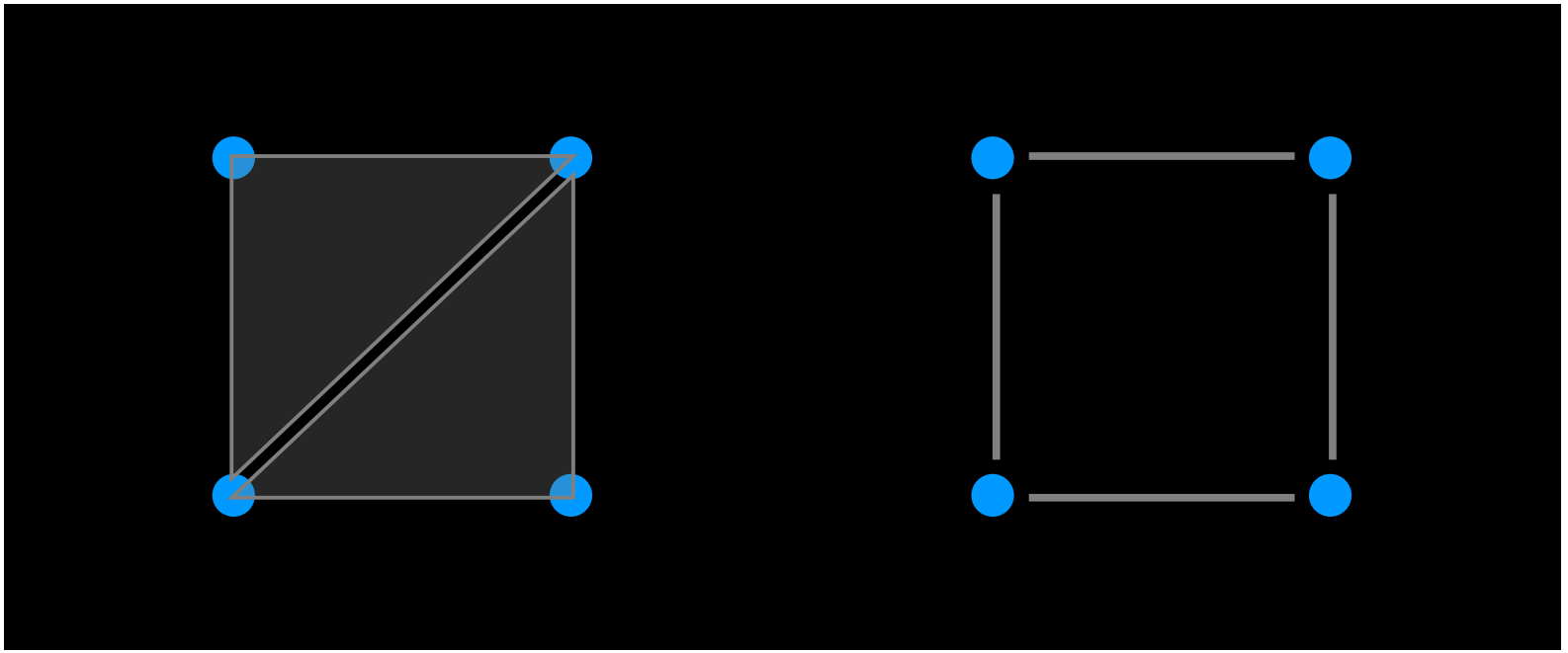
OpenGL Resources:
Geometry

Demo: Two Boxes



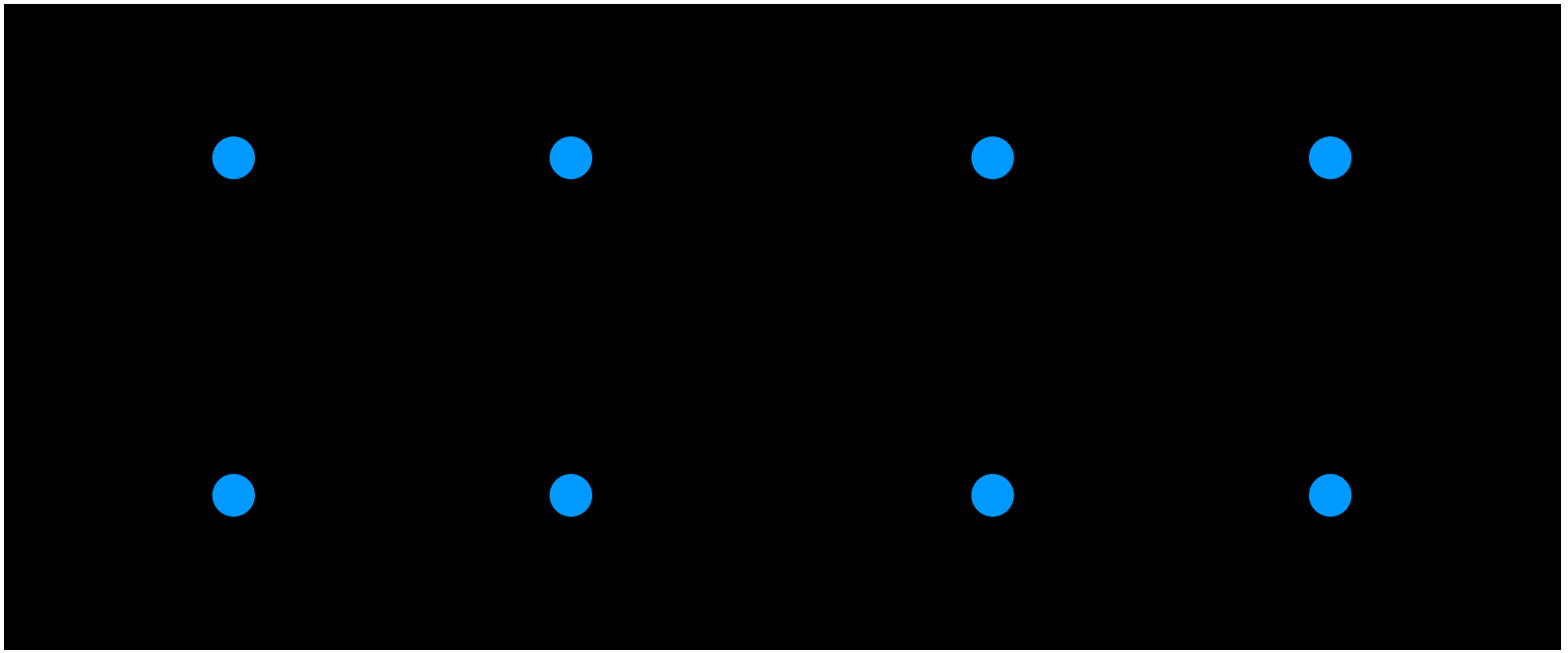
What We're Seeing

- Box on left: two triangles
- Box on right: four lines



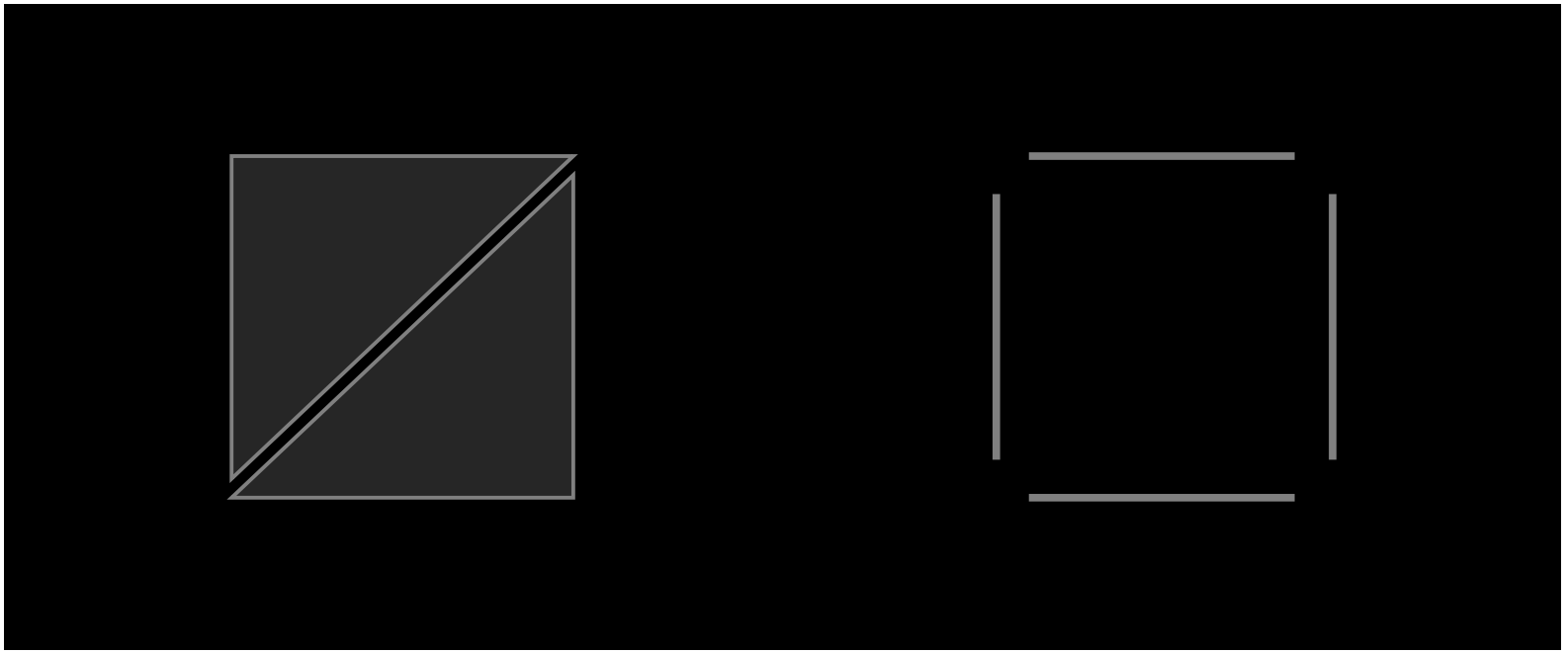
Vertices

- Foundation for all geometry
- OpenGL: specify with GLBuffer



Primitives

- Basic shapes built from vertices; e.g. triangles, lines
  - Assemble to build more complicated shapes
- OpenGL: specify both with GLBuffer

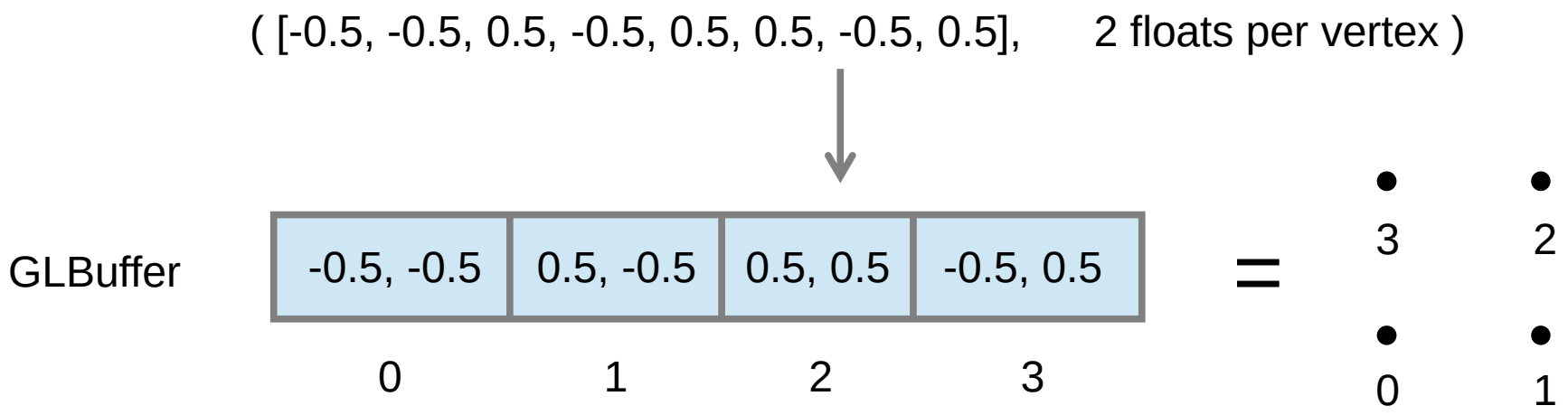


GLBuffer

- OpenGL object to store arrays like vertex positions, vertex colors, indices
- We have to specify
  - How many component per element
    - Color: 3D vector
    - Position: 2D/3D vector
    - Index: 1D
  - Type of stored element components (int, float, double, …)
  - Array of element components
    - The stored data itself

Specifying Vertices

- GLBuffer: store sequence of vertex positions
- Info needed:
  - Array of floats representing vertices
  - How many dimensions per vertex (2D? 3D?)



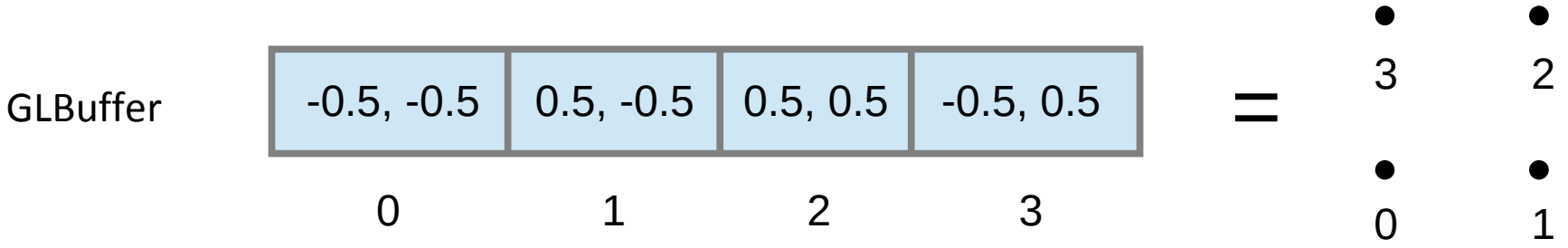
Specifying Vertices: TwoBoxes' init()

```
@Override
public void onEntry(GameTime gameTime) {
        // define vertex positions
        float [] vertexPositions = {
                        -0.5f, -0.5f,       // vertex 0
                         0.5f, -0.5f,       // vertex 1
                         0.5f,  0.5f,       // vertex 2
                        -0.5f,  0.5f        // vertex 3
        };

        GLBuffer vertexBuffer = GLBuffer.createAsVertex(
        vertexPositions, 2, BufferUsageHint.StaticDraw);
        ...
```

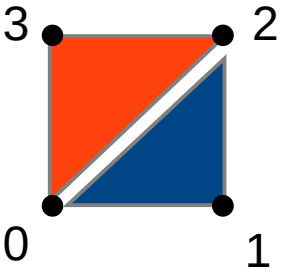
Grouping Vertices into Primitives

- GLBuffer gives vertices in some order



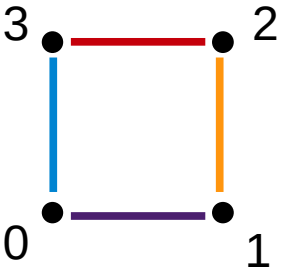
- Can re-order vertices to form primitives, so that:
  - Every three vertices form a triangle

[0, 1, 2, 0, 2, 3]



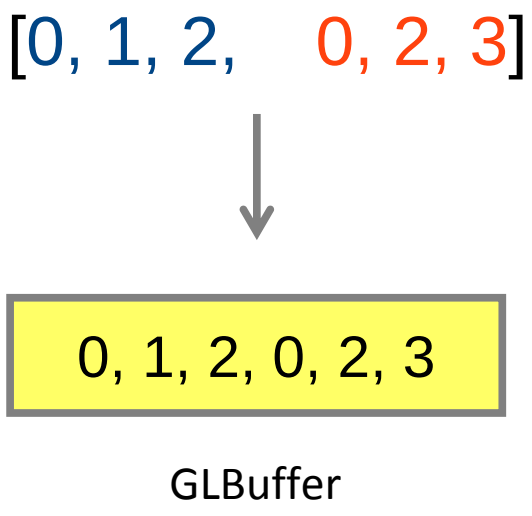
  - Every two vertices form a line

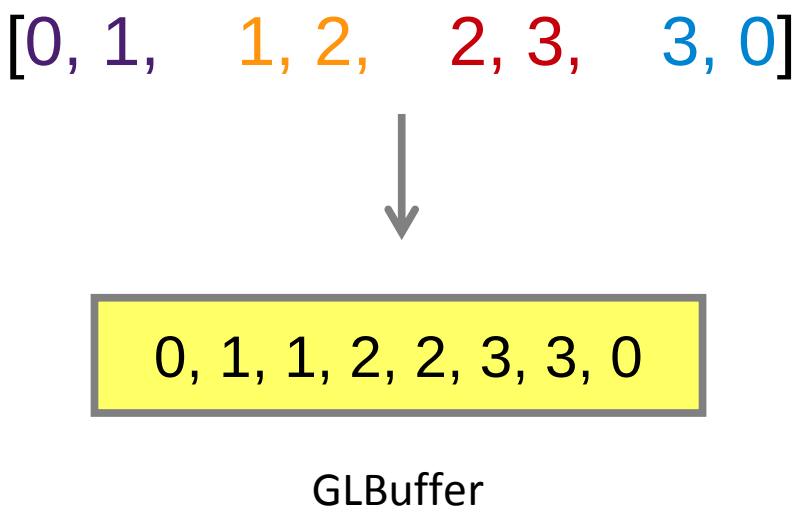
[0, 1, 1, 2, 2, 3, 3, 0]



Grouping Vertices

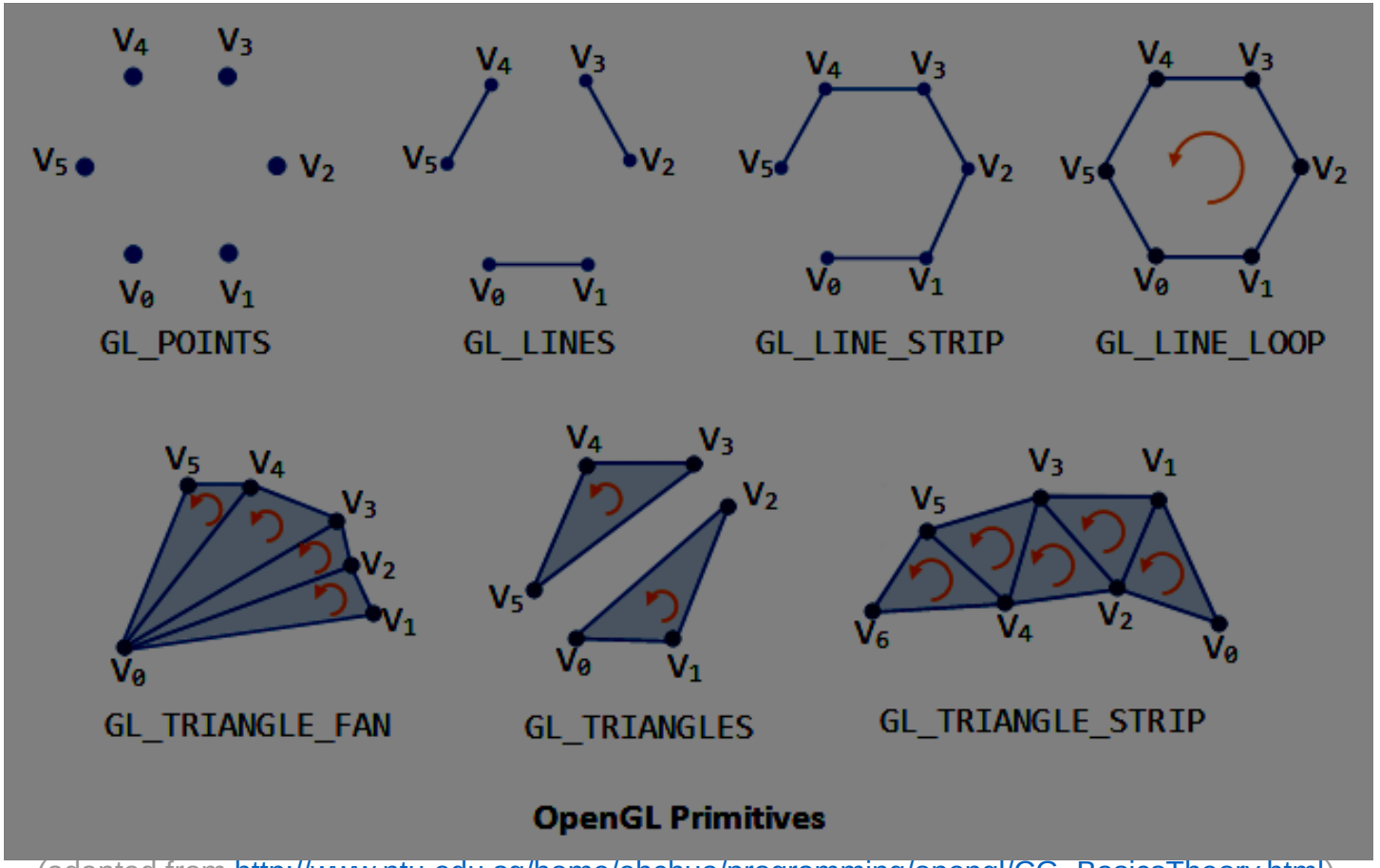
- GLBuffer: store sequence of vertex indices
- Info needed:
  - List of integer indices





Ways to Group: GL Primitives

- OpenGL declares several primitive types
- Determine how to group a sequence of verts into primitives



(adapted from http://www.ntu.edu.sg/home/ehchua/programming/opengl/CG_BasicsTheory.html)

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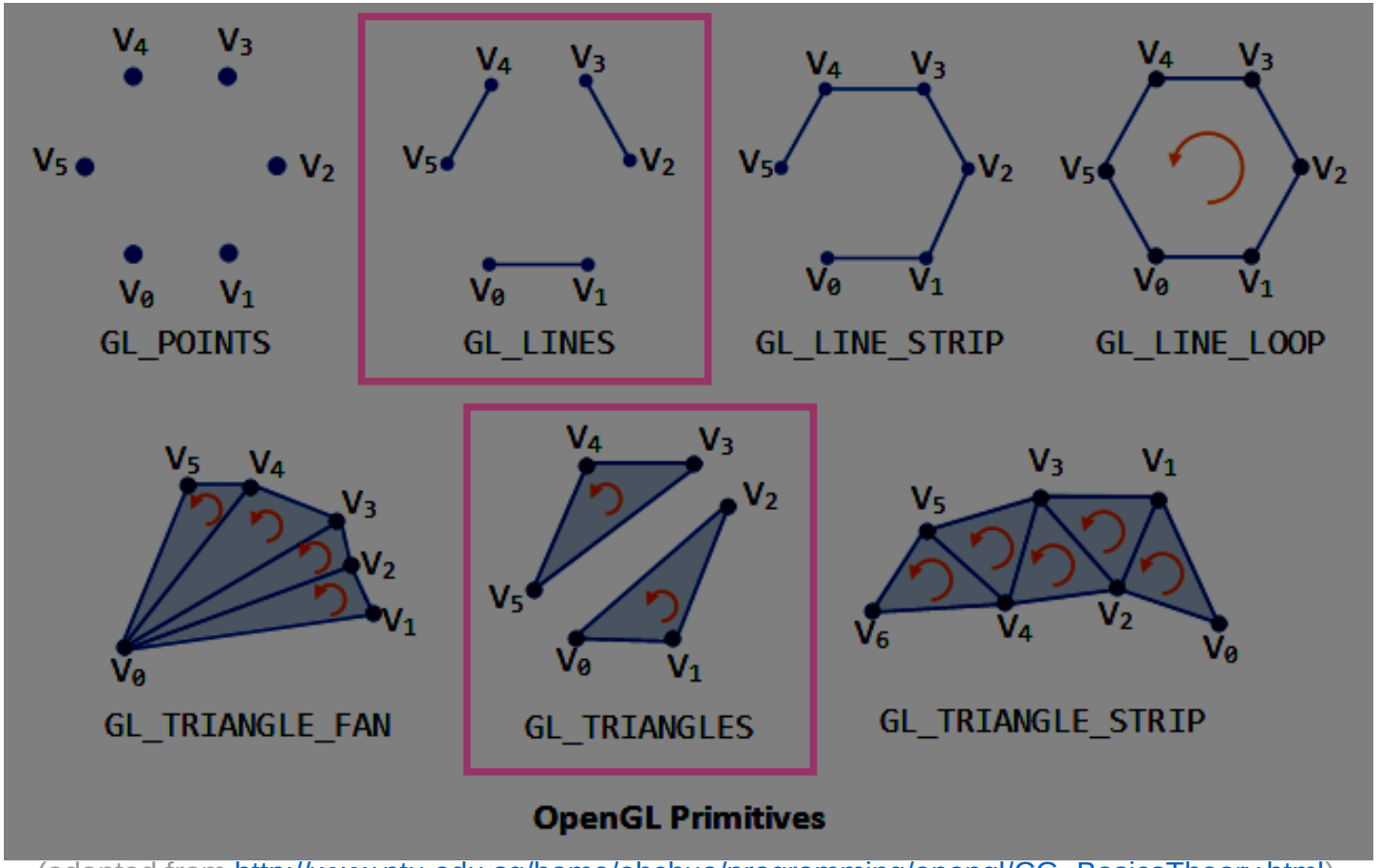
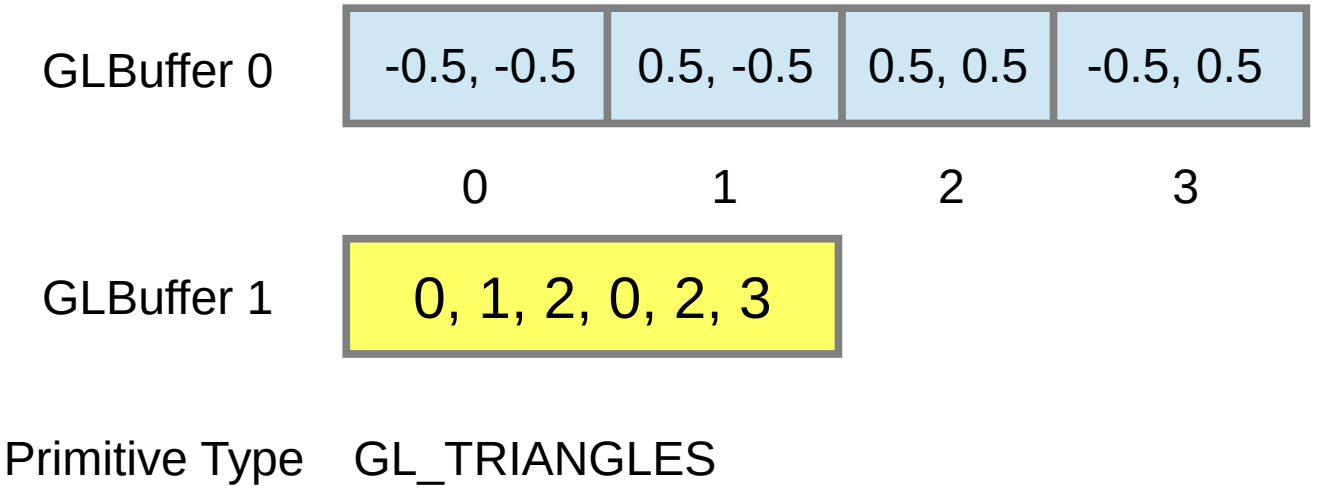


(adapted from http://www.ntu.edu.sg/home/ehchua/programming/opengl/CG_BasicsTheory.html)

Putting it Together

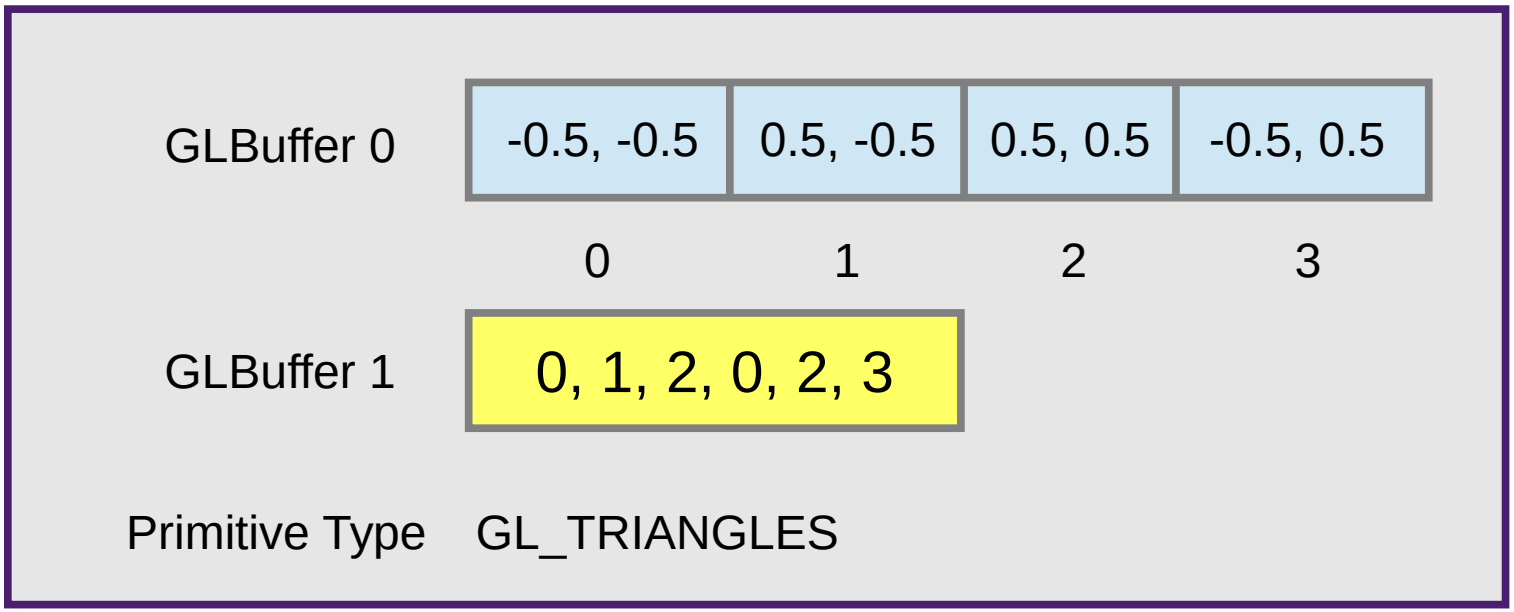
- GLBuffer 0: what the vertices are
- GLBuffer 1 (index array): in what order to put them
- Primitive Type: how to group ordered vertices into primitives

- Together, fully describes geometry



Putting it Together: Bindings

- Bind buffer elements to vertex attributes
- Bind indices to buffer in OpenGL
- Draw using OpenGL
- Info needed:
  - GLBuffer with vertice attributes, GLBuffer with indices, primitive type



Index arrays in TwoBoxes' onEntry()

```
... // earlier, filled GLBuffer vertexPositions

int [] linesIndices = {
        0, 1,
        1, 2,
        2, 3,
        3, 0
};
int [] trianglesIndices = {
        0, 1, 2,
        0, 2, 3
};
// make index buffers
ibLines = GLBuffer.createAsIndex(linesIndices,
BufferUsageHint.StaticDraw);
indexCountLines = linesIndices.length;
ibTriangles = GLBuffer.createAsIndex(trianglesIndices,
BufferUsageHint.StaticDraw);
indexCountTriangles = trianglesIndices.length;
...
```

TwoBoxes' draw()

```
...
// Use box vertices we defined before
vb.useAsAttrib(program.getAttribute("vPos"));
// Setup transformations
...
// Binding indices and drawing
ibTriangles.bind();
GL11.glDrawElements(GL11.GL_TRIANGLES, indexCountTriangles,
GLType.UnsignedInt, 0);
ibTriangles.unbind();
// Setup transformations
...
// Binding indices and drawing
ibLines.bind();
GL11.glDrawElements(GL11.GL_LINES, indexCountLines,
GLType.UnsignedInt, 0);
ibLines.unbind();
```

TwoBoxes' draw()

```
...
// Use box vertices we defined before
vb.useAsAttrib(program.getAttribute("vPos"));

// Setup transformations
...
// Binding indices and drawing
ibTriangles.bind();
GL11.glDrawElements(GL11.GL_TRIANGLES, indexCountTriangles,
GLType.UnsignedInt, 0);
ibTriangles.unbind();
// Setup transformations
...
// Binding indices and drawing
ibLines.bind();
GL11.glDrawElements(GL11.GL_LINES, indexCountLines,
GLType.UnsignedInt, 0);
ibLines.unbind();
```

- Bind index array and say what primitives we will build
- One will make triangles, the other lines

TwoBoxes' draw()

```
...
// Use box vertices we defined before
vb.useAsAttrib(program.getAttribute("vPos"));

// Setup transformations
...
// Binding indices and drawing
ibTriangles.bind();
GL11.glDrawElements(GL11.GL_TRIANGLES, indexCountTriangles,
GLType.UnsignedInt, 0);
ibTriangles.unbind();
// Setup transformations
...
// Binding indices and drawing
ibLines.bind();
GL11.glDrawElements(GL11.GL_LINES, indexCountLines,
GLType.UnsignedInt, 0);
ibLines.unbind();
```

- Tell OpenGL how to order the vertices when building primitives
- Triangles and lines will need different vertex orders

TwoBoxes' draw()

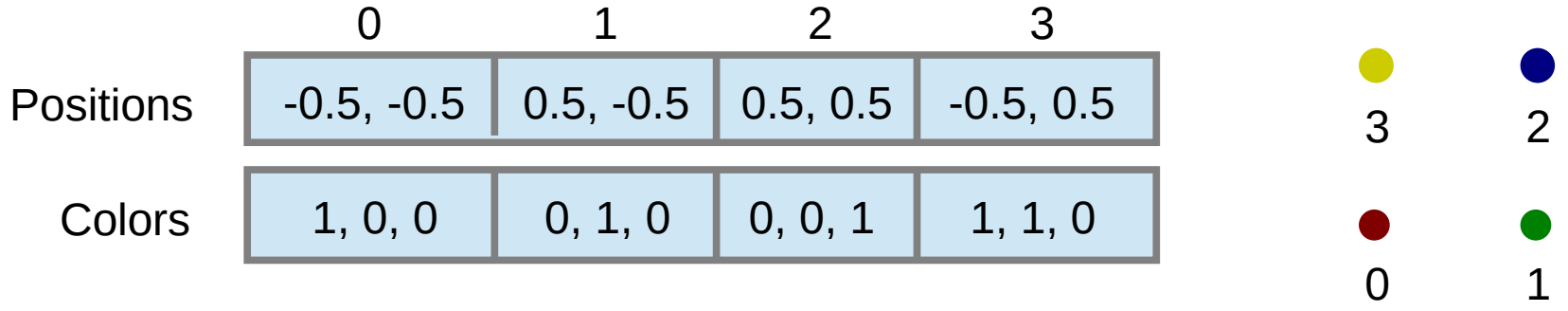
```
...
// Use box vertices we defined before
vb.useAsAttrib(program.getAttribute("vPos"));

// Setup transformations
...
// Binding indices and drawing
ibTriangles.bind();
GL11.glDrawElements(GL11.GL_TRIANGLES, indexCountTriangles,
GLType.UnsignedInt, 0);
ibTriangles.unbind();
// Setup transformations
...
// Binding indices and drawing
ibLines.bind();
GL11.glDrawElements(GL11.GL_LINES, indexCountLines,
GLType.UnsignedInt, 0);
ibLines.unbind();
```

- Both boxes use the same buffer of four vertices

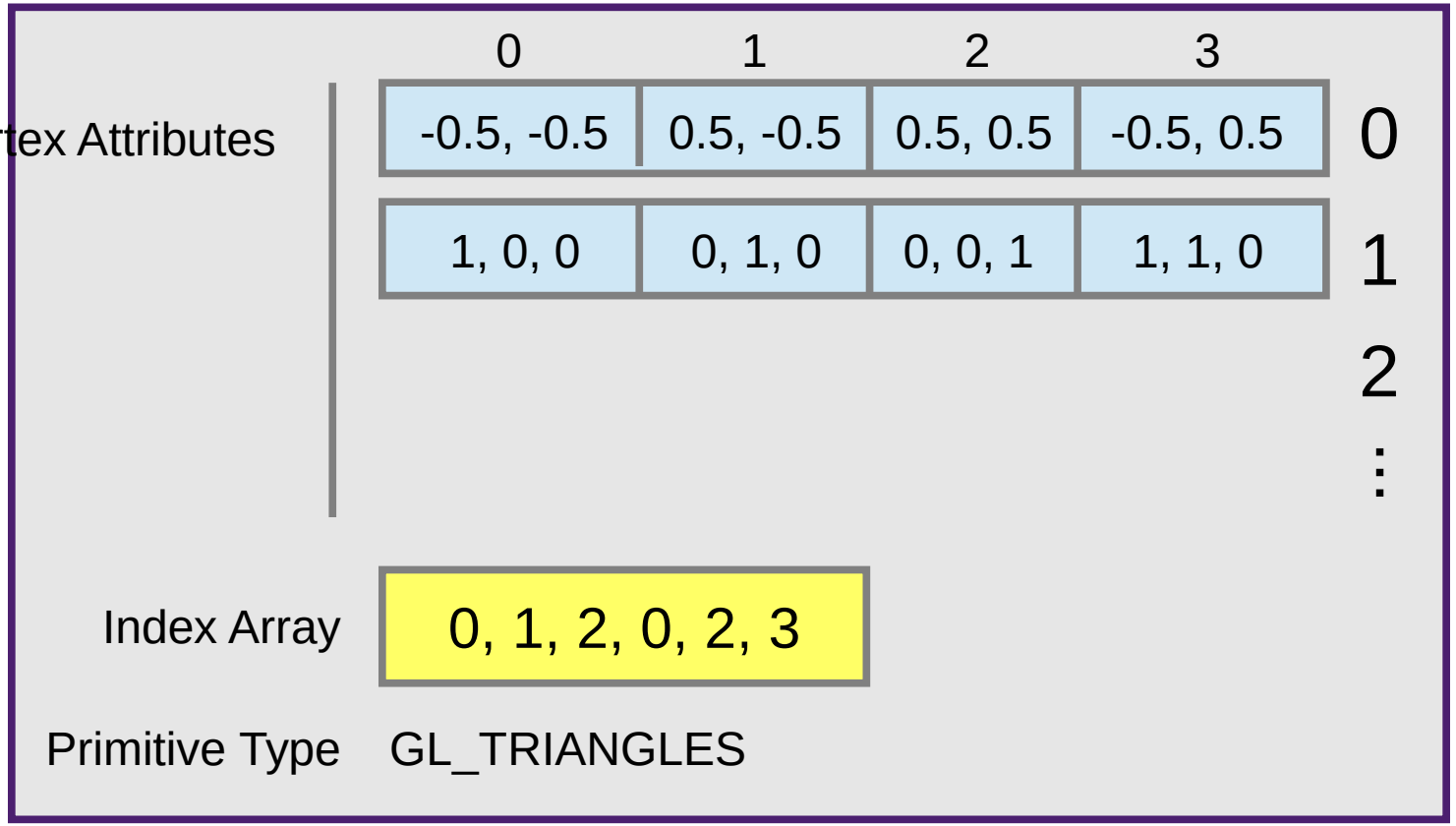
Vertices are More than Positions

- A vertex has a position
- But it can also have other attributes:
  - Normal vector
  - Color
  - Texture coordinate
  - etc.
- Use multiple GLBuffers to store this info



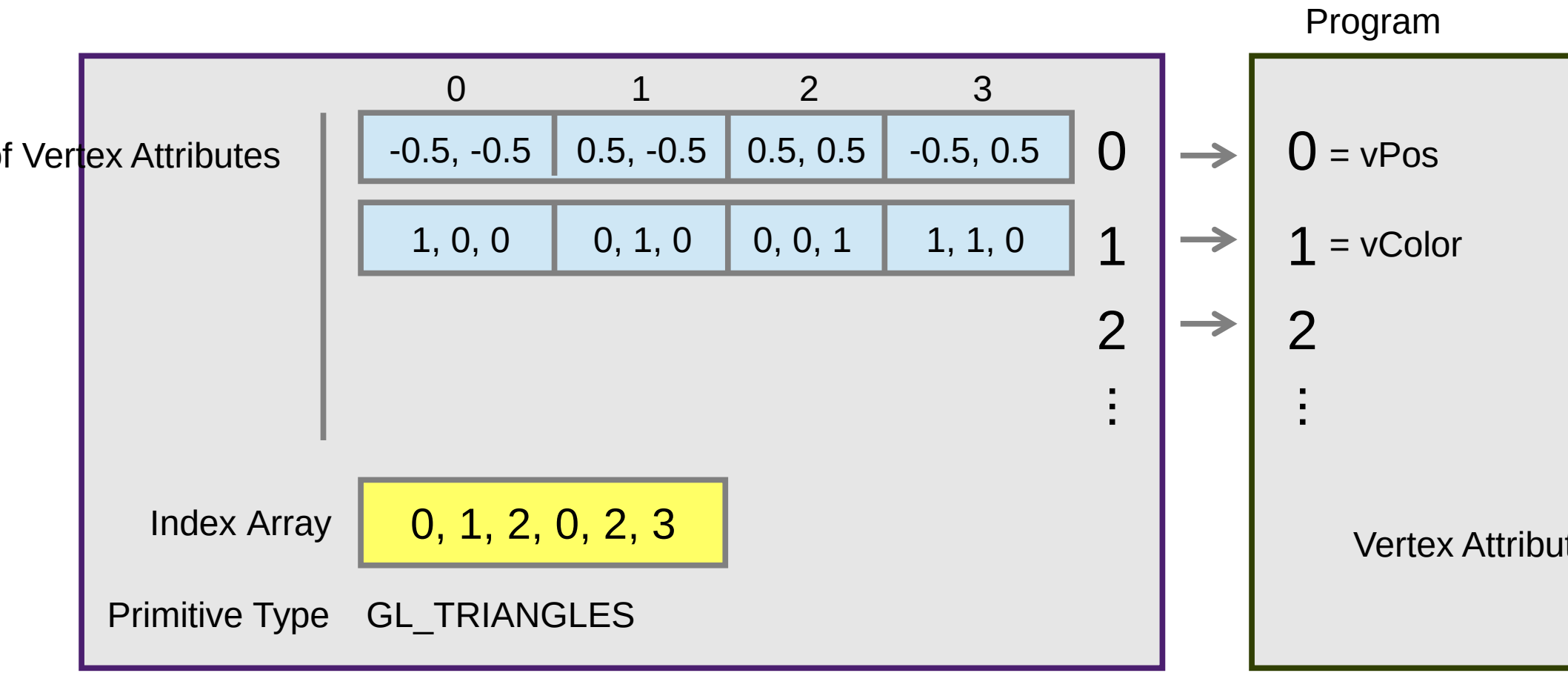
Multiple Vertex Attributes

- We can bind a GLBuffer to a vertex attribute
- We can use multiple attributes per vertex

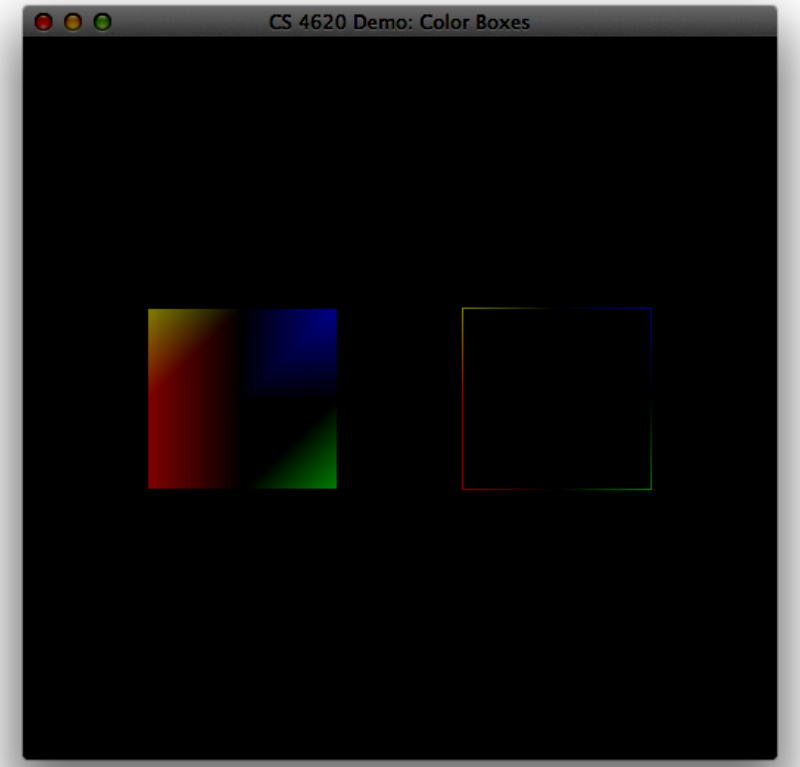


Attribute Bindings

- Shader program draws vertices using array of attributes
- Program declares a variable (vPos, vColor) for each attribute



Demo: Color Boxes



ColorBoxes' onEntry()

```
@Override
public void onEntry(GameTime gameTime) {

        ... // fill vertexBuffer as before

        float [] vertexColors = {
                        1.0f, 0.0f, 0.0f,  // vertex 0
                        0.0f, 1.0f, 0.0f,  // vertex 1
                        0.0f, 0.0f, 1.0f,  // vertex 2
                        1.0f, 1.0f, 0.0f   // vertex 3
        };

        vbColor = GLBuffer.createAsVertex(vertexColors, 3,
        BufferUsageHint.StaticDraw);
        ...
```

ColorBoxes' draw()

```
...
// Use box vertex positions and colors as we defined before
// Bind attribute array values to a variable in the shader
vb.useAsAttrib(program.getAttribute("vPos"));
vbColor.useAsAttrib(program.getAttribute("vColor"));

// Draw the two boxes as we did before
...
```

Transformations

Representing Transformations

- We will use Matrix3, Matrix4 classes
  - Set matrix contents:

```
Matrix3 translate = new Matrix3(1.0f, 0.0f, 3.0f,
                                0.0f, 1.0f, -4.0f,
                                0.0f, 0.0f, 1.0f);
```

  - Copy matrices:

```
Matrix3 translateAgain = new Matrix3(translate);
```

  - Multiply matrices:

```
translate.mulBefore(translateAgain);
// translate = translate * translateAgain
```

  - Transform points:

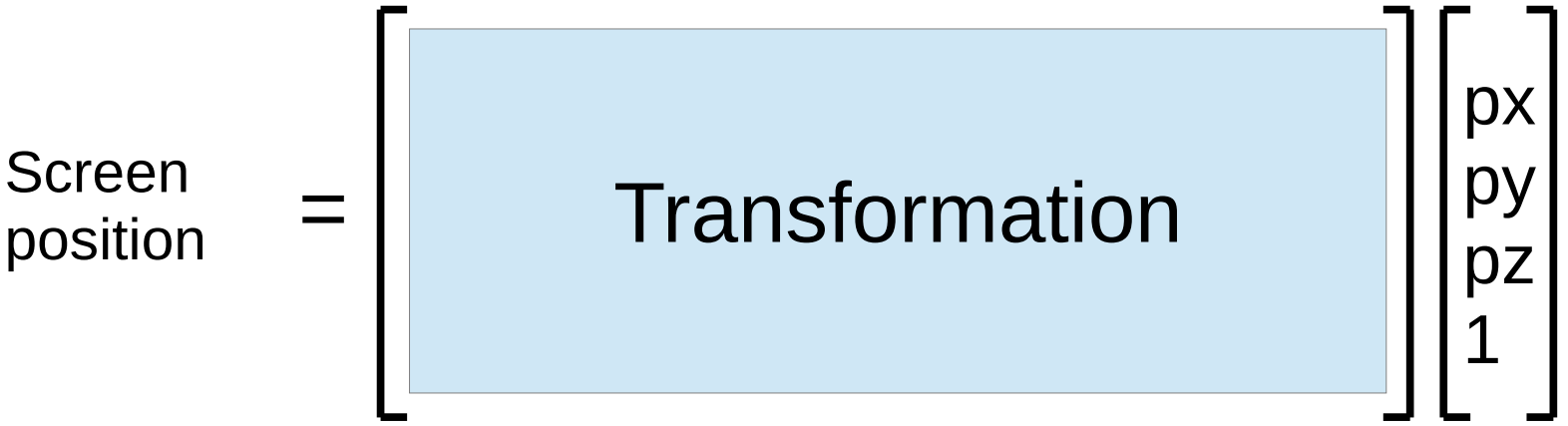
```
Vector3 vert = new Vector3(2.0f, 0.0f, 1.0f);
translate.mulPos(vert);  // vert = translate * vert
```

Matrix3/4 Class

- Static functions provide various useful transformation matrices
  - Identity matrices
  - Translations, scales, rotations
  - Projection matrices

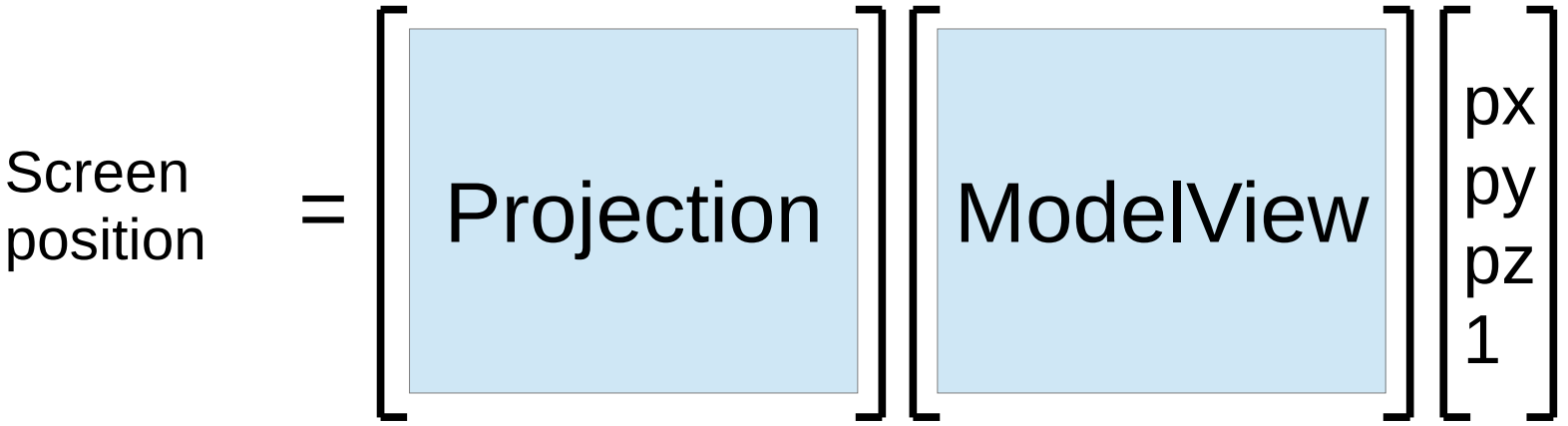
Transforming a Vertex

- GLBuffer gives vertices to shader program
- Program transforms them onto screen before drawing



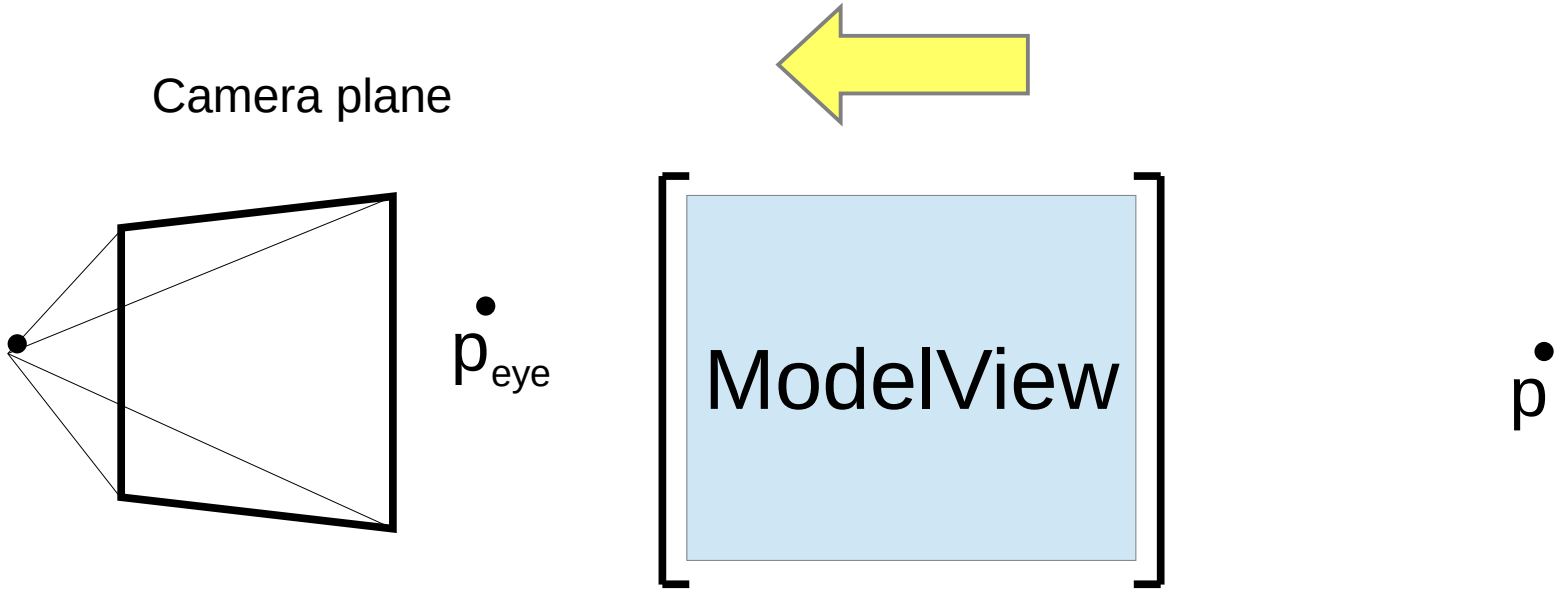
Transforming a Vertex

- Applies two transforms: Projection and ModelView
- Very basic description now; we have discussed this topic already



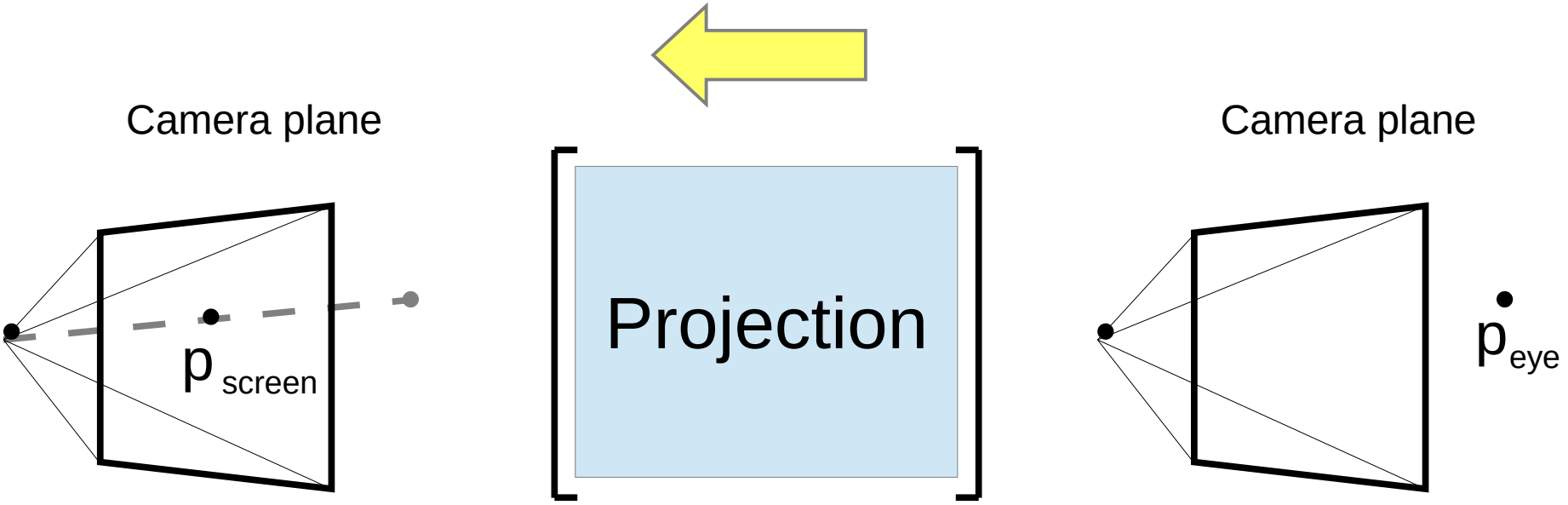
ModelView matrix

- Transforms vertex into coordinates of the viewer
- Modify matrix to transform objects to different places



Projection matrix

- Projects point down onto camera plane
- Usually set matrix once at beginning of draw()

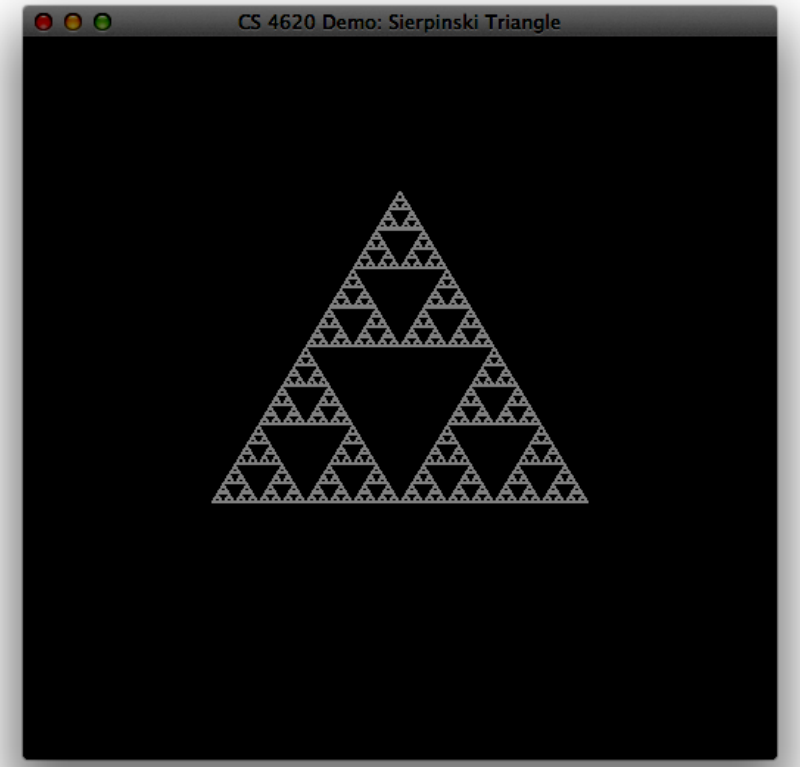


Setting Matrices

- You tell the shader program what matrices to use
  - GLUniform.*setST(program.getUniform("VP"), tr, false);*
  - You can bind a matrix to a variable in the shader, similarly to vertex attributes

- **Program keeps drawing with the same matrices until you change them**
- Common use pattern:
  - GLUniform.*setST(program.getUniform(“tr"),* transformForThisObject*, false);*
  - GL11.glDrawElements(…)
  - Define other transformation
  - Draw something else

Demo: Sierpinski Triangle



Sierpinski's draw()

```
@Override
public void draw(GameTime gameTime) {
    GL11.glClearColor(0.0f, 0.0f, 0.0f, 1.0f);
    GL11.glClear(GL11.GL_COLOR_BUFFER_BIT);

    program.use();

    GLUniform.set(program.getUniform("uGridColor"),
    new Vector4(1, 1, 1, 1));

    // Use box vertices
    vb.useAsAttrib(program.getAttribute("vPos"));

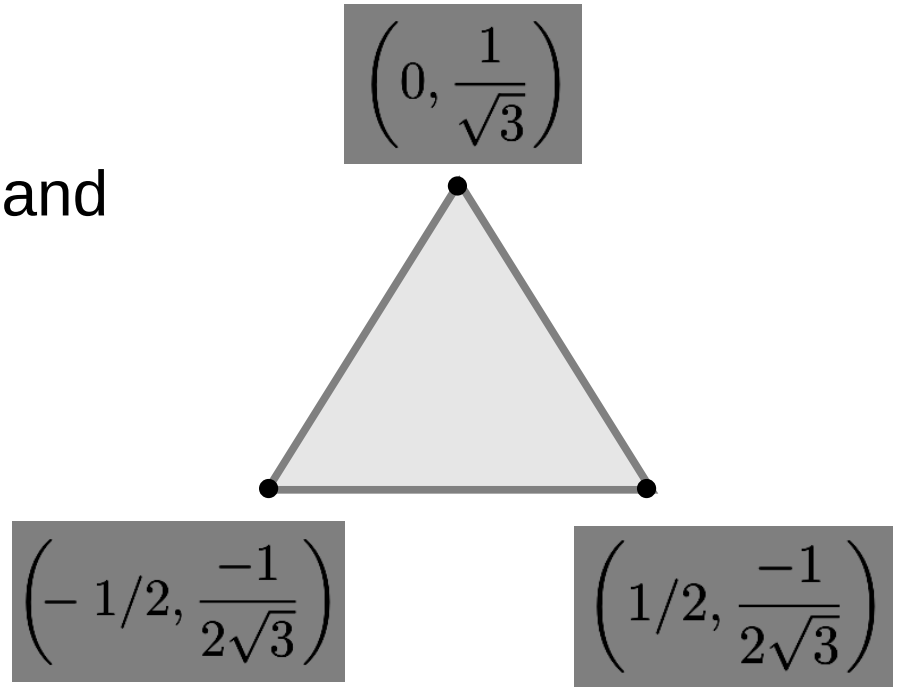
    // Transformation
    Matrix4 tr = new Matrix4();
    tr.mulAfter(Matrix4.createTranslation(
    new Vector3(0.0f, -(float)Math.sqrt(3)/6, 0.0f)));

    sierpinski(ibLines, tr, 10);

    GLProgram.unuse();
}
```

Recursively Drawing Fractal

- sierpinski(gl, tr, k):
  - Draw a level-k Sierpinski triangle, and
  - transform by tr
  - k = 0: draw triangle to the right



- Recursively: at level k, draw three k-1 Sierpinski triangles, transforming them to the three corners of the triangle

sierpinski()

```
public void sierpinski(GLBuffer lines, Matrix4 tr, int k) {
      if (k == 0) {
            GLUniform.setST(program.getUniform("VP"), tr, false);

            // Draw the triangle
            ibLines.bind();
            GL11.glDrawElements(GL11.GL_LINES, indexCountLines, GLType.UnsignedInt, 0);
            ibLines.unbind();
      } else {
            Matrix4 next;

            //draw the up triangle
            next = new Matrix4(tr);
            next.mulAfter(Matrix4.createScale(new Vector3(0.5f, 0.5f, 0.5f)));
            next.mulAfter(Matrix4.createTranslation(new Vector3(0.0f, 0.5f / (float)Math.sqrt(3.0f), 0.0f)));
            sierpinski(lines, next, k-1);

            //draw the right triangle
            next = new Matrix4(tr);
            next.mulAfter(Matrix4.createScale(new Vector3(0.5f, 0.5f, 0.5f)));
            next.mulAfter(Matrix4.createTranslation(new Vector3(0.25f, -0.25f / (float)Math.sqrt(3.0f), 0.0f)));
            sierpinski(lines, next, k-1);

            //draw the left triangle
            next = new Matrix4(tr);
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            sierpinski(lines, next, k-1);
      }
}
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sierpinski()

```
public void sierpinski(GLBuffer lines, Matrix4 tr, int k) {
     if (k == 0) {
          GLUniform.setST(program.getUniform("VP"), tr, false);

          // Draw the triangle
          ibLines.bind();
          GL11.glDrawElements(GL11.GL_LINES, indexCountLines, GLType.UnsignedInt, 0);
          ibLines.unbind();
     } else {









          [...]

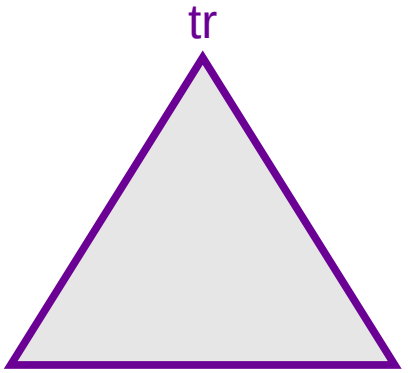








     }
}
```



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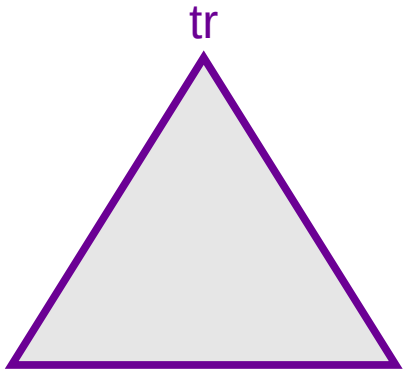

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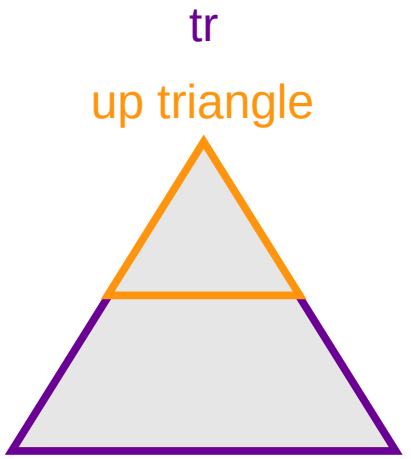

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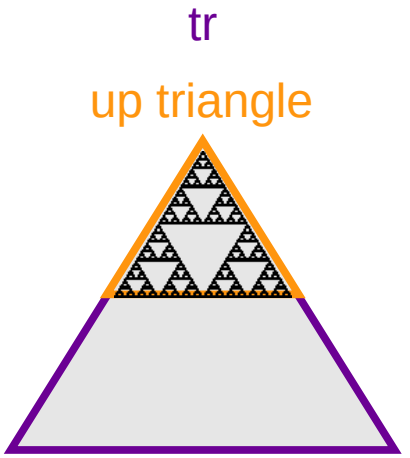

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