COMP220: Graphics & Simulation

3: Vertices, Transforms & Projections

Learning outcomes

By the end of this week, you should be able to:

- **Recall** alternative ways to represent mesh vertices in memory.
- **Apply** basic transforms using the GLM library.
- **Explain** the constituents of the model-view-projection matrix and how it can be used to create a first-person camera controller.

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- Lecture (async):
  - **Compare** different ways to store vertex data in memory.
  - **Review** the transforms required to display 3D objects on a 2D screen.

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  - **Compare** different ways to store vertex data in memory.
  - **Review** the transforms required to display 3D objects on a 2D screen.
- Workshop (sync):
  - **Adapt** our basic triangle implementation to draw meshes with multiple triangles efficiently.
  - **Experiment** with creating transforms using GLM and using them to move objects and the camera.

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Vertices and Elements

Vertex Data

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```
struct Vertex { float x,y,z; };
Vertex v[]={{-0.5f,-0.5f,0.0f},
            {0.5f,-0.5f,0.0f},
            {0.0f,0.5f,0.0f}};

struct Colour { float r,g,b,a; };
Colour c[]={{1.0f,0.0f,0.0f,1.0f},
            {0.0f,1.0f,0.0f,1.0f},
            {0.0f,0.0f,1.0f,1.0f}};
```

Using Separate Vertex Buffers

```
GLuint vertexbuffers[2];
glGenBuffers(2, vertexbuffers);

// Set up vertex position buffer
glBindBuffer(GL_ARRAY_BUFFER, vertexbuffers[0]);
glBufferData(GL_ARRAY_BUFFER, sizeof(v), v, GL_STATIC_DRAW);
glEnableVertexAttribArray(0);
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE,
        3 * sizeof(GL_FLOAT), (void*)0);

// Set up vertex colour buffer
glBindBuffer(GL_ARRAY_BUFFER, vertexbuffers[1]);
glBufferData(GL_ARRAY_BUFFER, sizeof(c), c, GL_STATIC_DRAW);
glEnableVertexAttribArray(1);
glVertexAttribPointer(1, 4, GL_FLOAT, GL_FALSE,
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```

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struct Vertex
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Vertex v[]={{-0.5f,-0.5f,0.0f, 1.0f,0.0f,0.0f,1.0f},
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            {0.0f,0.5f,0.0f,   0.0f,0.0f,1.0f,1.0f}};
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```
GLuint vertexbuffer;
glGenBuffers(1, &vertexbuffer);
glBindBuffer(GL_ARRAY_BUFFER, vertexbuffer);
glBufferData(GL_ARRAY_BUFFER, sizeof(v), v, GL_STATIC_DRAW);

glEnableVertexAttribArray(0);    // Position attribute
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE,
        sizeof(Vertex), (void*)0);

glEnableVertexAttribArray(1);    // Colour attribute
glVertexAttribPointer(1, 4, GL_FLOAT, GL_FALSE,
        sizeof(Vertex), (void*)(3 * sizeof(GL_FLOAT)));
```

Vertices in Memory

	X	Y	Z	R	G	B	A
V_0	-0.5	-0.5	0.0	1.0	0.0	0.0	1.0
V_1	0.5	-0.5	0.0	0.0	1.1	0.0	1.0
V_2	0.0	0.2	0.0	0.0	0.0	1.0	1.0

Vertices in Memory: Stride

V_0	-0.5	-0.5	0.0	1.0	0.0	0.0	1.0
V_1	0.5	-0.5	0.0	0.0	1.1	0.0	1.0
V_2	0.0	0.2	0.0	0.0	0.0	1.0	1.0

Vertices in Memory: Offset

V_0	-0.5	-0.5	0.0	1.0	0.0	0.0	1.0
V_1	0.5	-0.5	0.0	0.0	1.1	0.0	1.0
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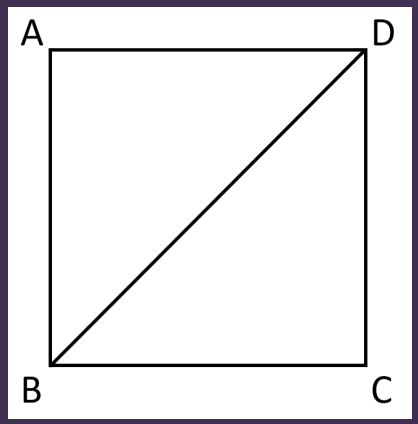

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2 triangles: 6 vertices

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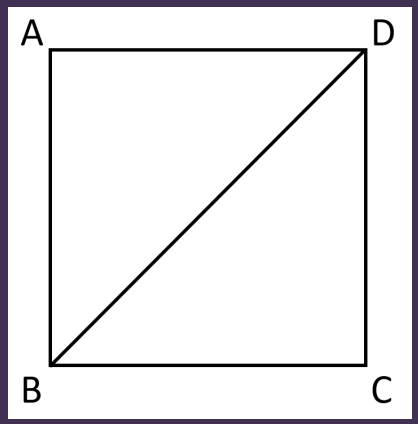

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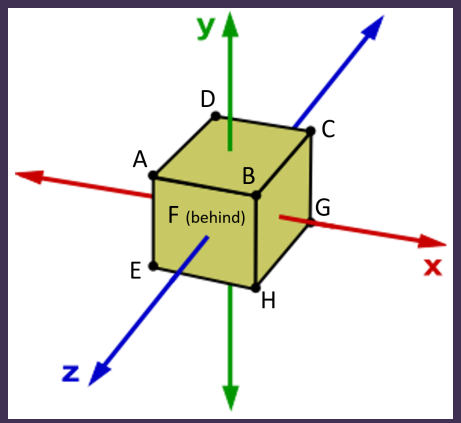

Cube: 8 vertices
12 triangles: 36 vertices
(6 square faces)

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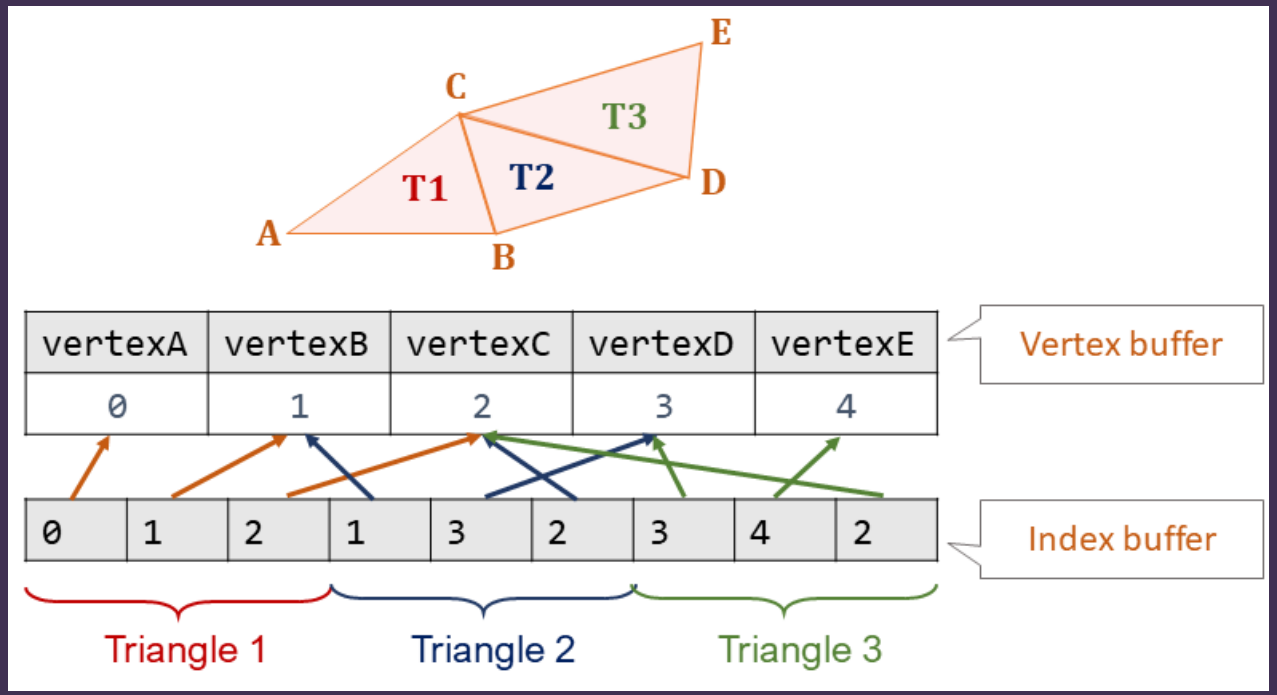

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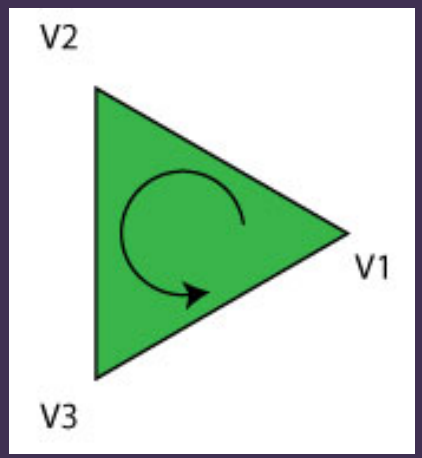

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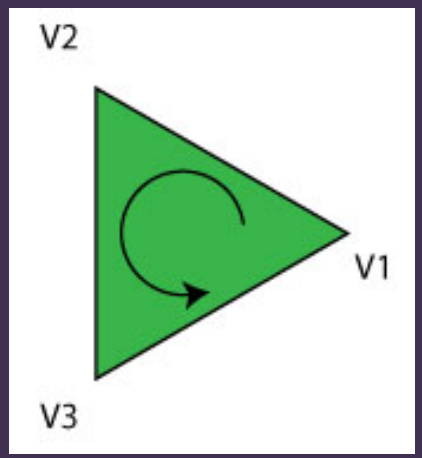

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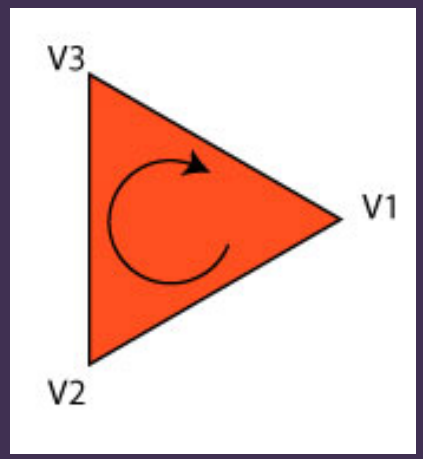

If the vertices go **clockwise**, you are looking at the **back**

Backface culling

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- Triangles whose front face is not visible will be **culled**
- Culled faces are not passed through the rasteriser or fragment shader
- Saves time, and should make no difference to appearance — as long as all meshes are closed and have correct winding

When backface culling goes bad?

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Transforms & Projections

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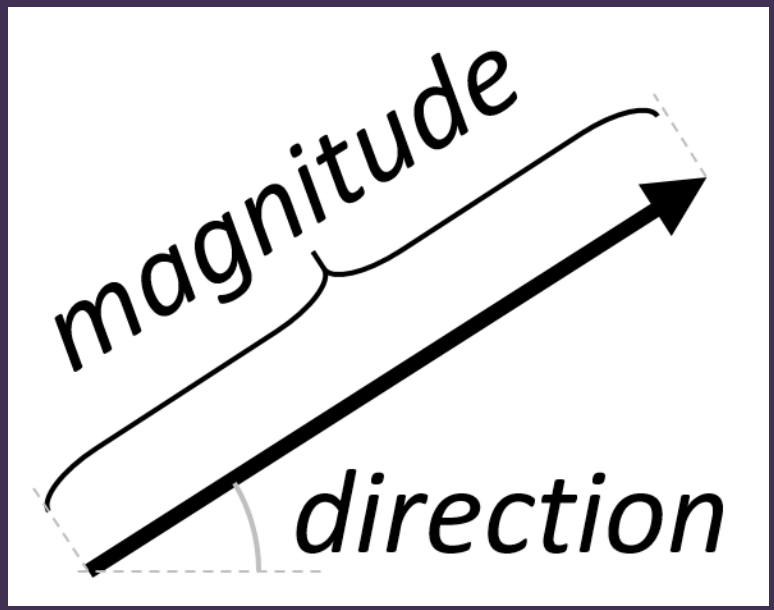

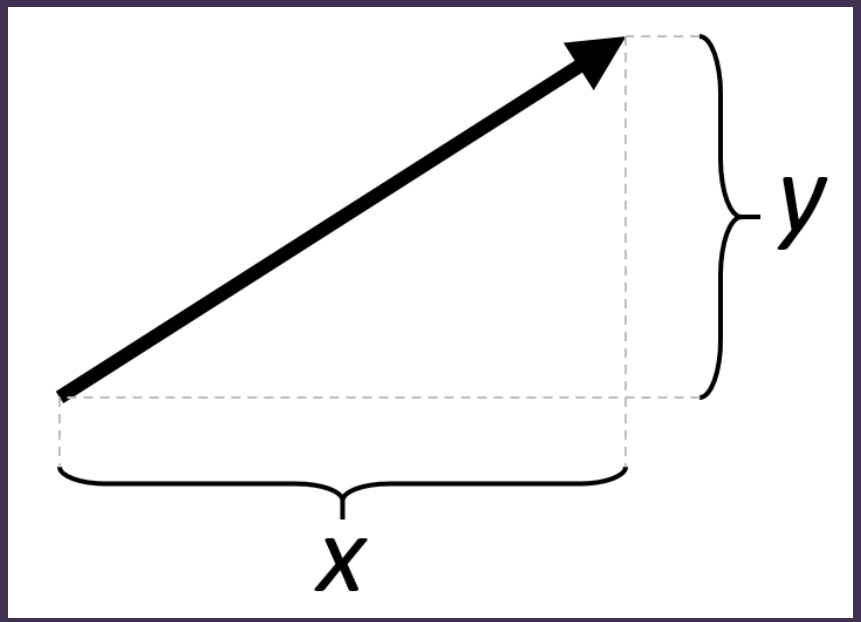

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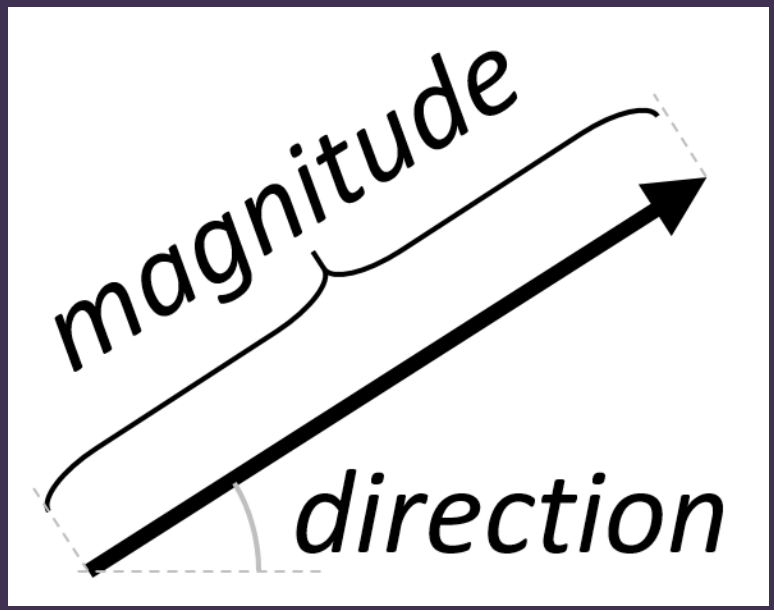

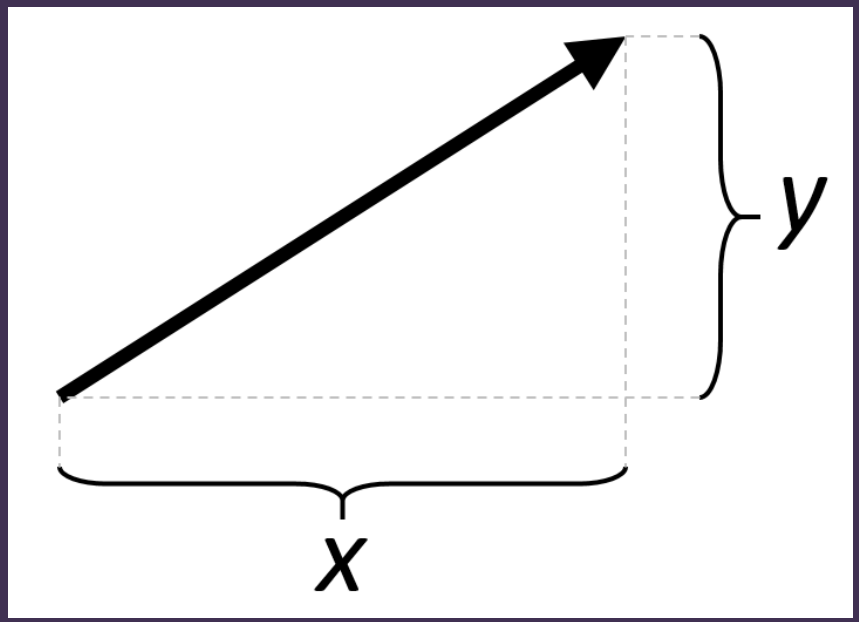

- A vector can represent a position in space as an offset from the origin.

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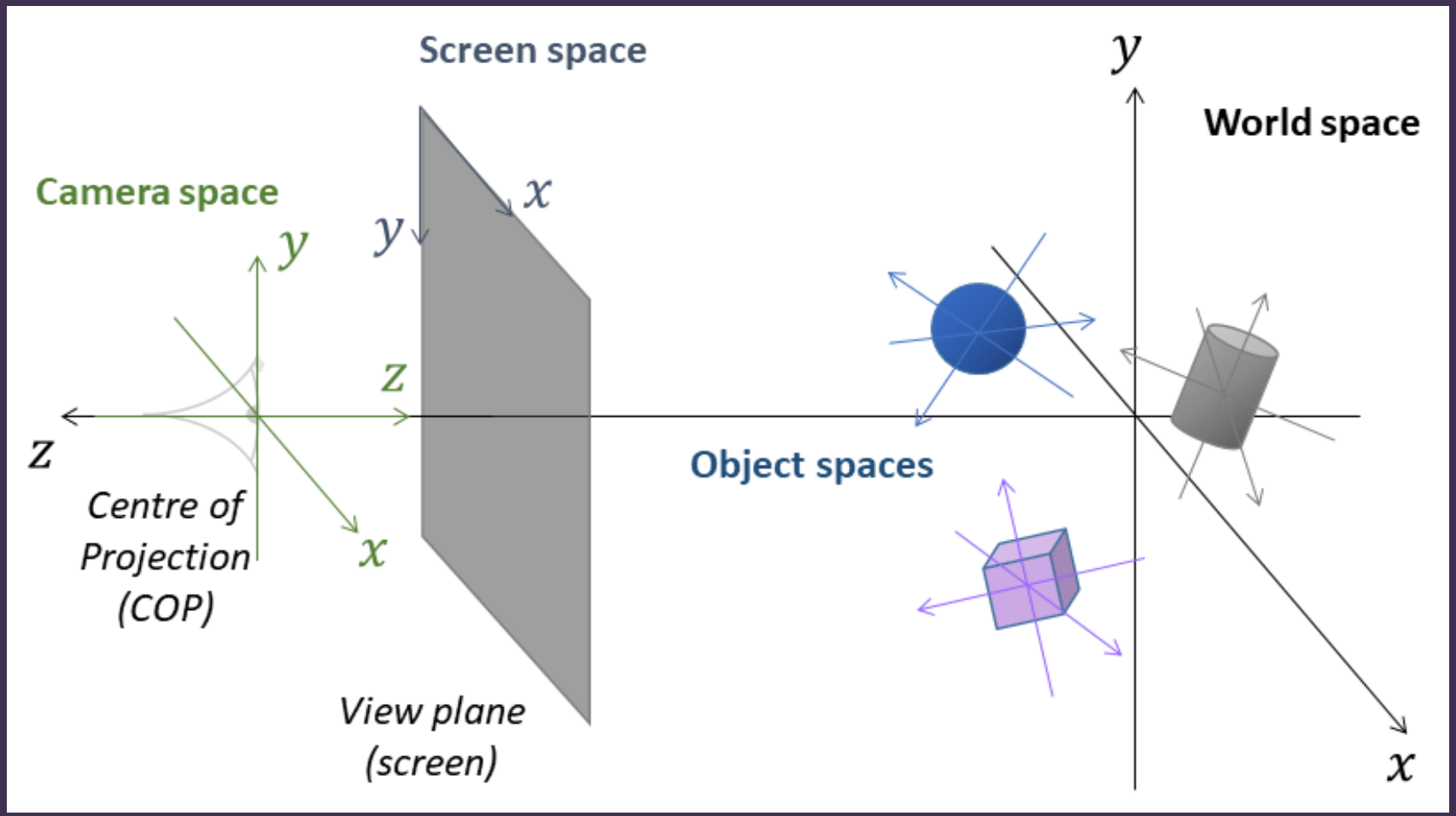
  - Matrix multiplication is **NOT commutative**: the order matters.
  - Standard order is **right to left**.
  - It's generally best to apply scale first, then rotation, then finally translation - otherwise results can be unexpected...

Recap: Coordinate Spaces



Model, View, Projection

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- **Model**: translate, rotate and scale the object into its place in the scene
- **View**: translate and rotate the scene to put the observer at the origin
- **Projection**: convert points in 3D space to points on the 2D screen

The **model-view-projection (MVP) matrix**:

$$M_{MVP} = M_{\text{projection}} \times M_{\text{view}} \times M_{\text{model}}$$

The view frustum

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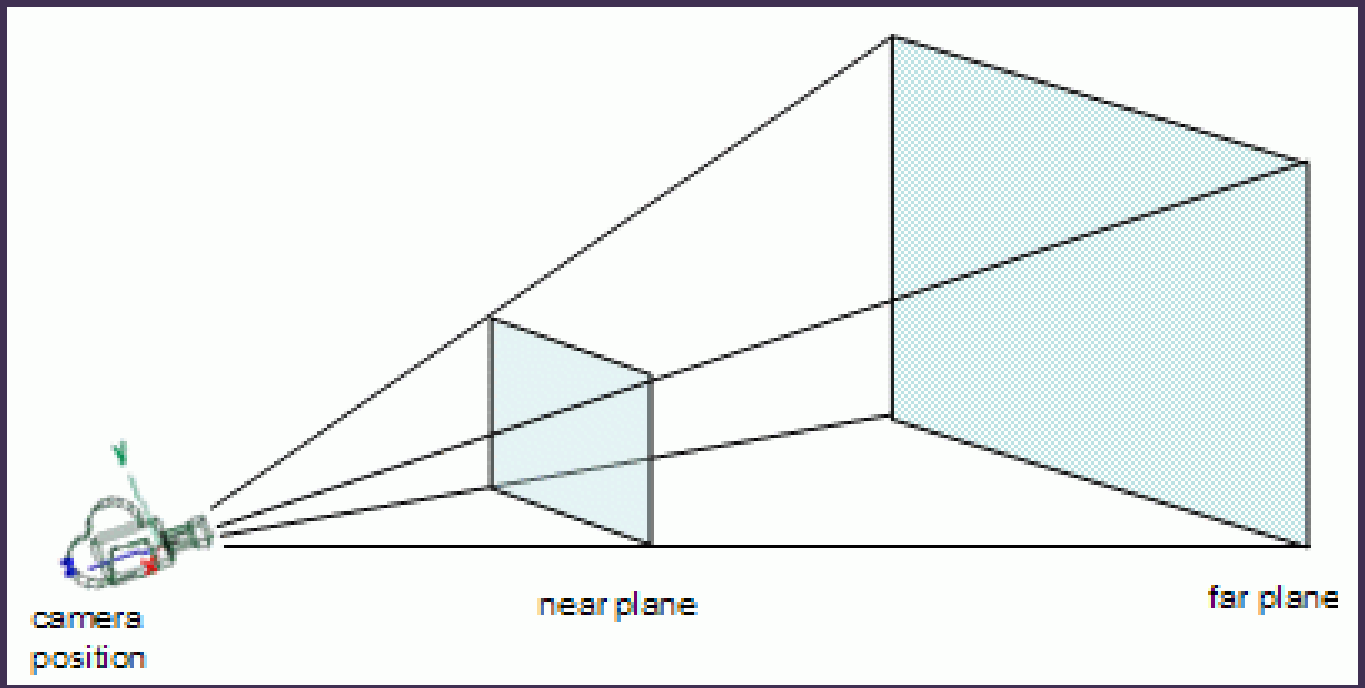

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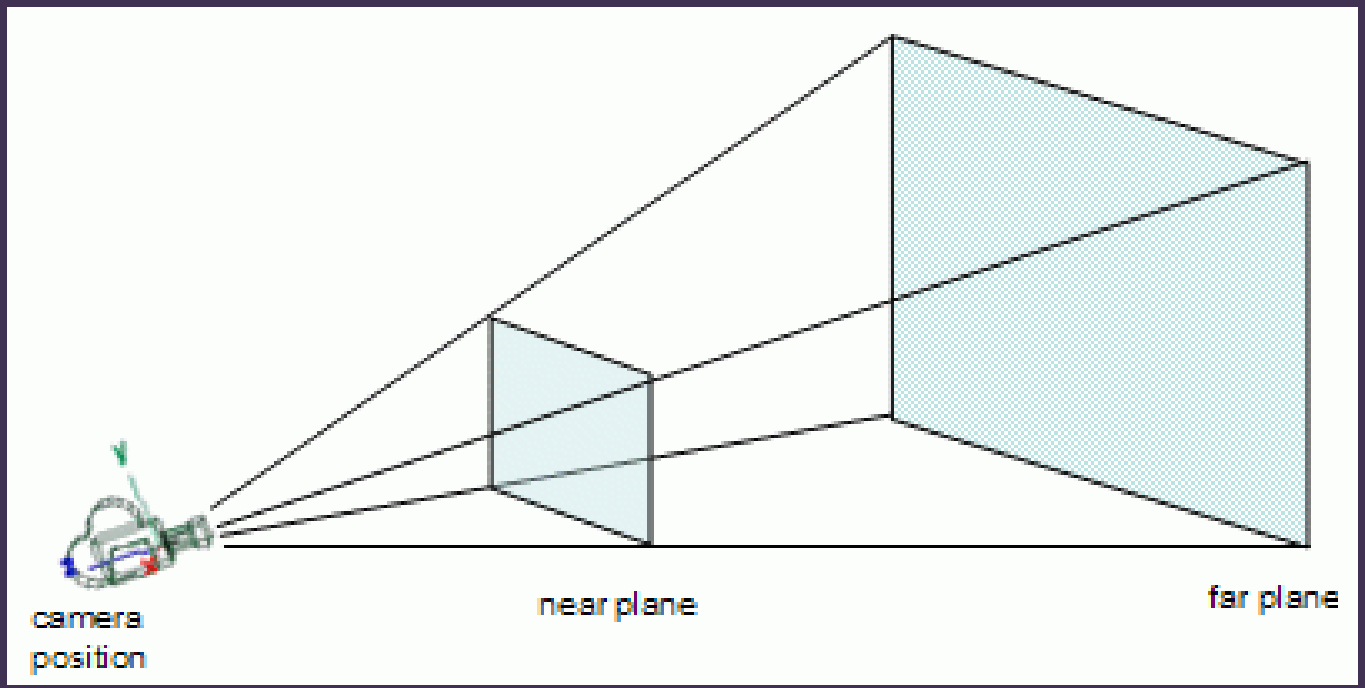

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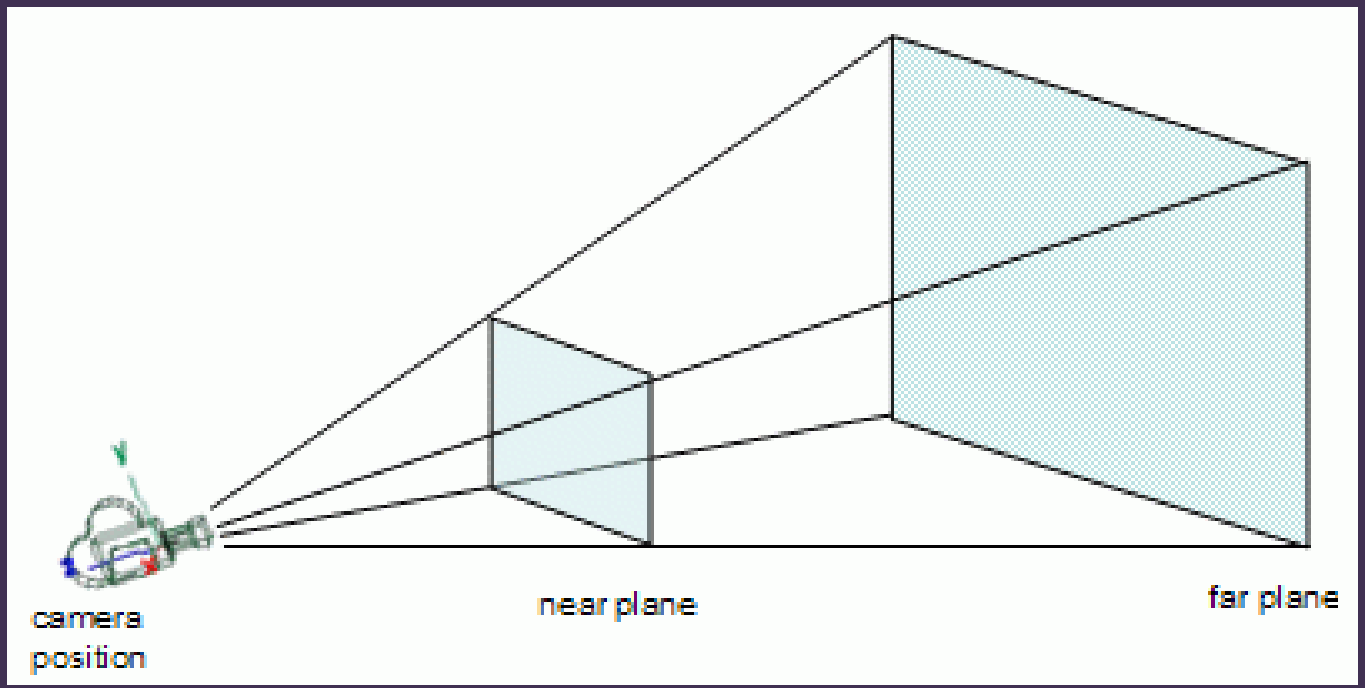

- Defined by the **near and far clipping planes** and the **edges of the screen**
- **Nothing outside** the view frustum is visible

Types of projection

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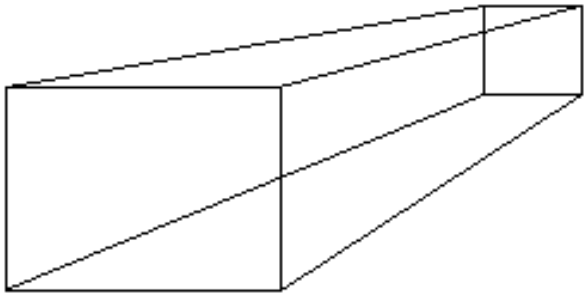
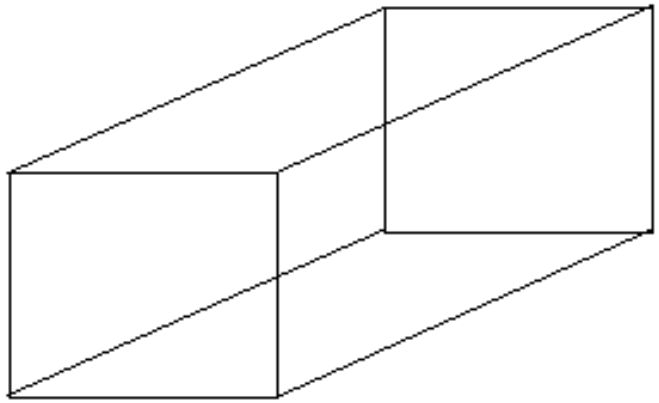
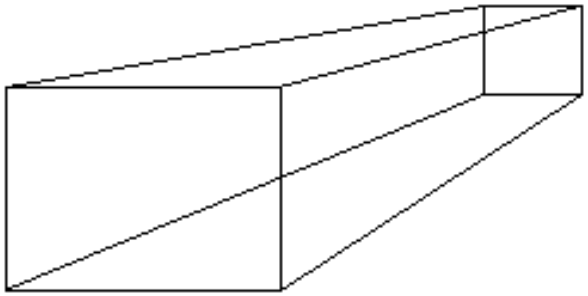


Perspective projection



Orthographic projection

Types of projection



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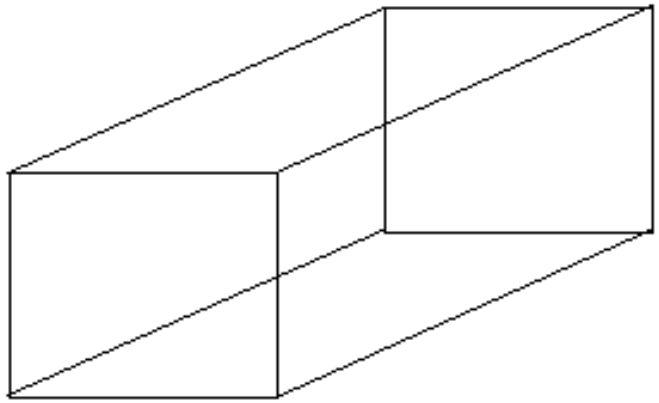

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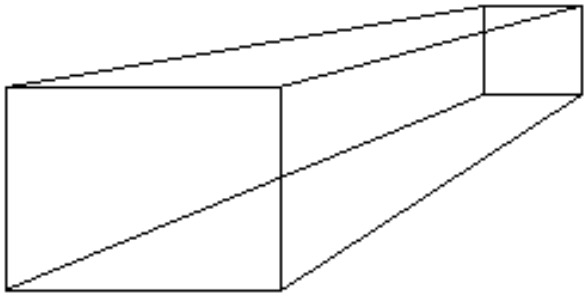

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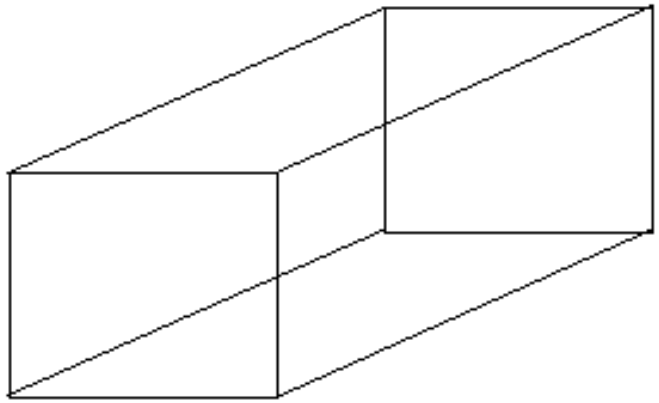

Orthographic projection

- Generally use **perspective** for 3D graphics
- **Orthographic** is useful for 2D or pseudo-2D graphics (e.g. isometric projection for engineering or technical drawings)

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First person camera control

The plan

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- Represent the player's **position** by a 3D vector

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- Represent the player's **orientation** by Euler angles

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- Represent the player's **position** by a 3D vector
- Represent the player's **orientation** by Euler angles
- Mouse events change these angles
- View matrix is calculated using position and orientation
- To move forwards, use the Euler angles to find the "forward" vector, and offset the position by this vector

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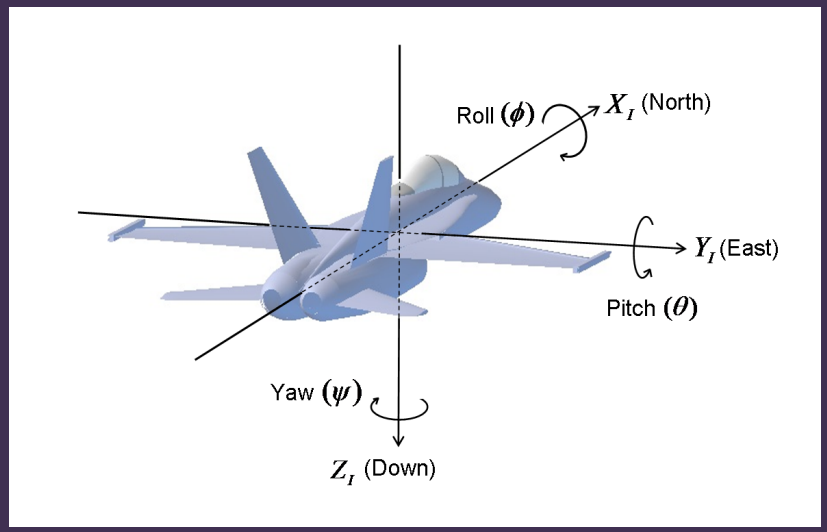
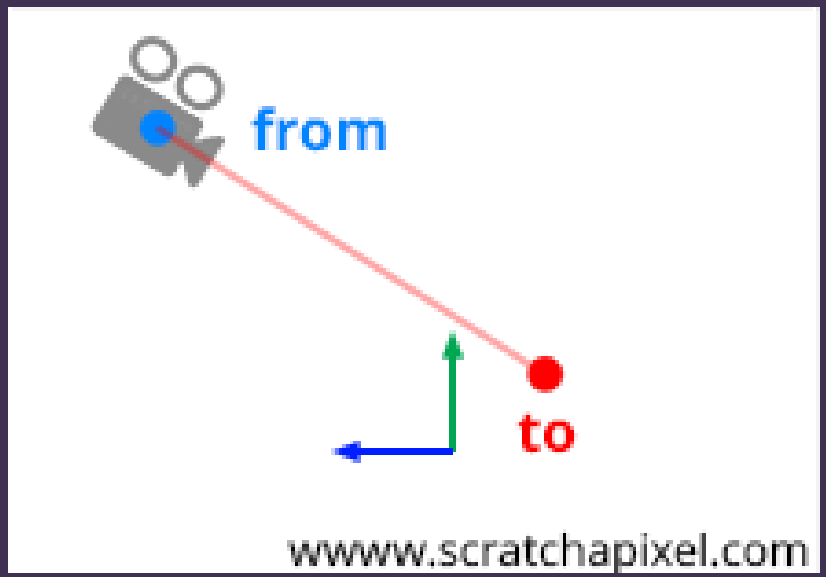
- Any orientation of an object in 3D space can be described by **three** rotations around:
  - The x-axis $(1, 0, 0)$
  - The y-axis $(0, 1, 0)$
  - The z-axis $(0, 0, 1)$
- These angles are sometimes called **roll**, **pitch** and **yaw**



Representing look direction

Representing look direction



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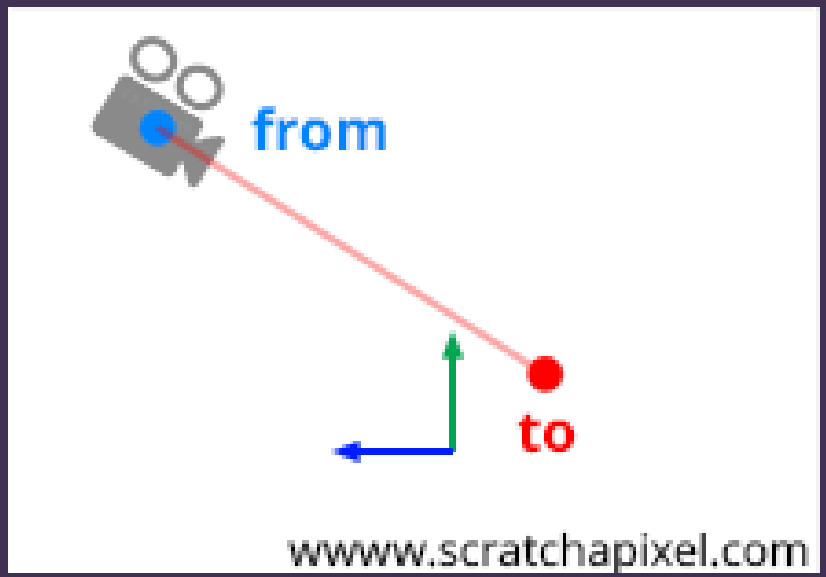

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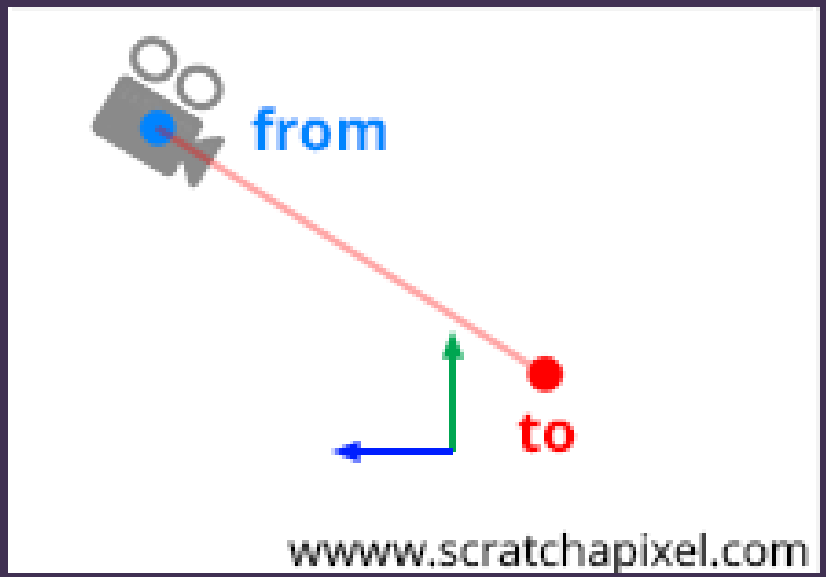

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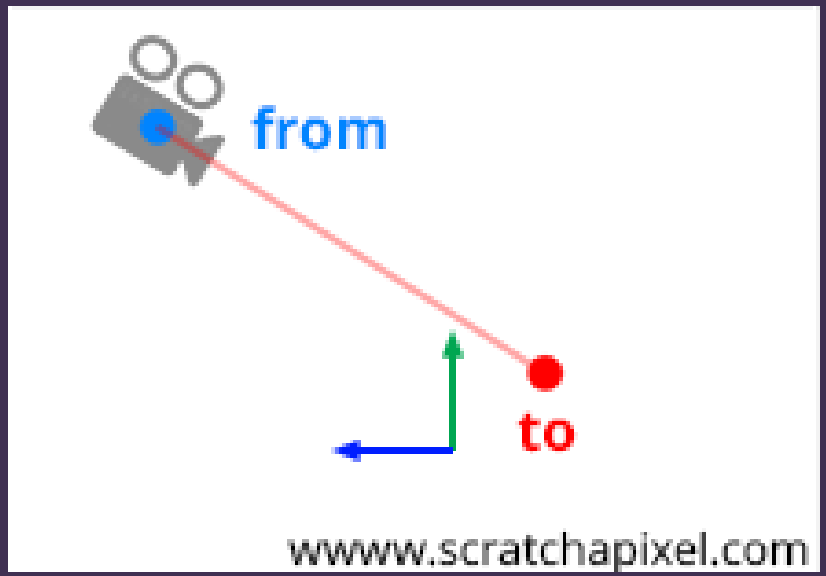

- Don't need roll, just pitch and yaw to look up/down and left/right.
- Eliminates the gimbal lock problem! :D
- **Forward vector** / **look vector** can be obtained by appropriate rotation of a **unit vector**.

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- So multiplying a unit vector by b gives a vector of length b, parallel to the unit vector

Moving forwards

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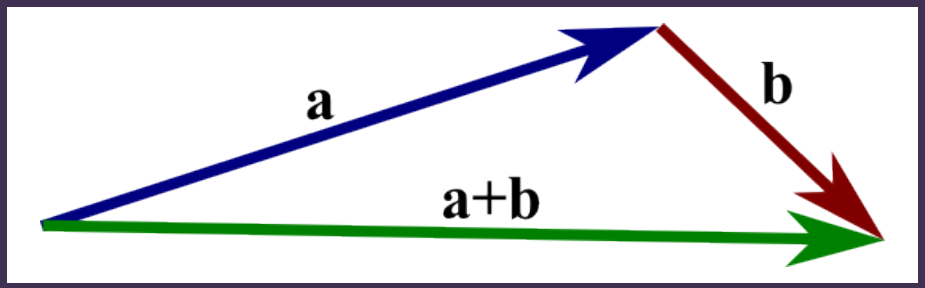

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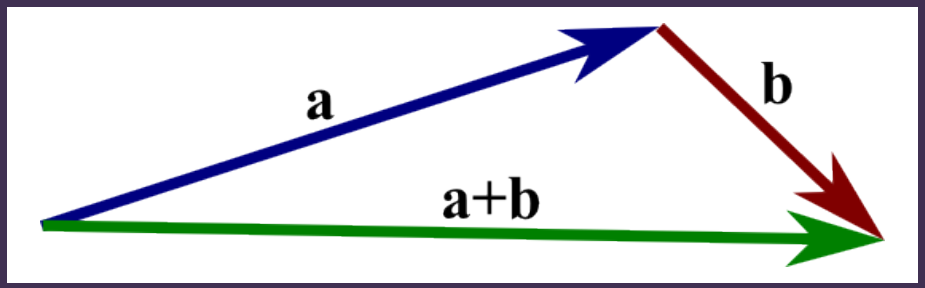

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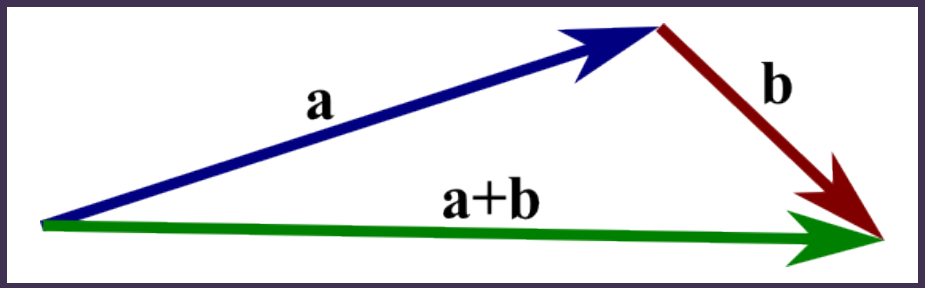

- E.g. if *a* is current position, and
- *b* is the distance and direction we want to move, then

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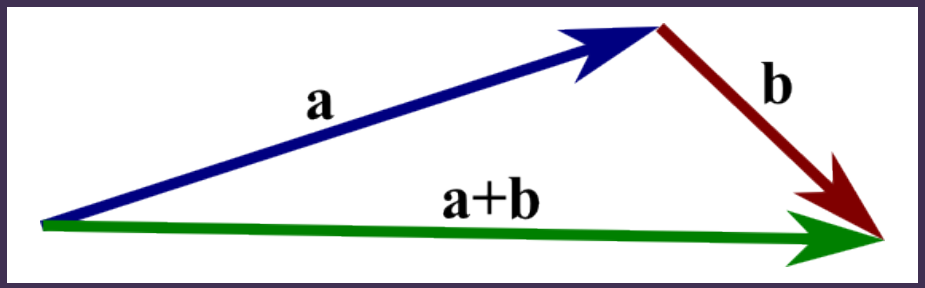

- E.g. if a is current position, and
- b is the distance and direction we want to move, then
- $a + b$ is the new position

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offset	+	offset	=	offset	$w = 0 + 0 = 0$
position	+	offset	=	position	$w = 1 + 0 = 1$
position	+	position	=	???	$w = 1 + 1 = 2$

Next steps

- **Review** the additional asynchronous material for more background on representing mesh vertices and calculating the model, view and projection matrices.
- **Attend** the workshop to see how to implement an Element Buffer in OpenGL and use GLM to create and apply transforms.