GLM

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What is GLM?

GLM is a set of C++ classes and functions to fill in the programming gaps in writing the basic vector and matrix mathematics for OpenGL applications. However, even though it was written for OpenGL, it works fine with Vulkan.

Even though GLM looks like a library, it actually isn't – it is all specified in ***.hpp** header files so that it gets compiled in with your source code.

You can find it at:

http://glm.g-truc.net/0.9.8.5/

You invoke GLM like this:

```
#define    GLM_FORCE_RADIANS

#include <glm/glm.hpp>
#include  <glm/gtc/matrix_transform.hpp>
#include  <glm/gtc/matrix_inverse.hpp>
```

OpenGL treats all angles as given in *degrees*. This line forces GLM to treat all angles as given in *radians*. I recommend this so that *all* angles you create in *all* programming will be in radians.

If GLM is not installed in a system place, put it somewhere you can get access to. Later on, these notes will show you how to use it from there.

Why are we even talking about this?

All of the things that we have talked about being ***deprecated*** in OpenGL are *really* **deprecated** in Vulkan -- built-in pipeline transformations, begin-end, fixed-function, etc. So, where you might have said in OpenGL:

```
glMatrixMode( GL_MODELVIEW );
glLoadIdentity( );
gluLookAt( 0., 0., 3.,     0., 0., 0.,     0., 1., 0. );
glRotatef( (GLfloat)Yrot, 0., 1., 0. );
glRotatef( (GLfloat)Xrot, 1., 0., 0. );
glScalef( (GLfloat)Scale, (GLfloat)Scale, (GLfloat)Scale );
```

you would now say:

```
glm::mat4 modelview = glm::mat4( 1. );      // identity
glm::vec3 eye(0.,0.,3.);
glm::vec3 look(0.,0.,0.);
glm::vec3   up(0.,1.,0.);
modelview = glm::lookAt( eye, look, up );                              // {x',y',z'} = [v]*{x,y,z}
modelview = glm::rotate( modelview, D2R*Yrot, glm::vec3(0.,1.,0.) );   // {x',y',z'} = [v]*[yr]*{x,y,z}
modelview = glm::rotate( modelview, D2R*Xrot, glm::vec3(1.,0.,0.) );   // {x',y',z'} = [v]*[yr]*[xr]*{x,y,z}
modelview = glm::scale( modelview, glm::vec3(Scale,Scale,Scale) );     // {x',y',z'} = [v]*[yr]*[xr]*[s]*{x,y,z}
```

This is exactly the same concept as OpenGL, but a different expression of it. Read on for details …

The Most Useful GLM Variables, Operations, and Functions

// constructor:

```
glm::mat4( 1. );            // identity matrix
glm::vec4( );
glm::vec3( );
```

GLM recommends that you use the **“glm::”** syntax and avoid **“using namespace”** syntax because they have not made any effort to create unique function names

// multiplications:

```
glm::mat4  *  glm::mat4
glm::mat4  *  glm::vec4
glm::mat4  *  glm::vec4(  glm::vec3,  1.  )        // promote a vec3 to a vec4 via a constructor
```

// emulating OpenGL transformations *with concatenation*:

glm::mat4 **glm::rotate**(glm::mat4 const & m, float angle, glm::vec3 const & axis);

glm::mat4 **glm::scale**(glm::mat4 const & m, glm::vec3 const & factors);

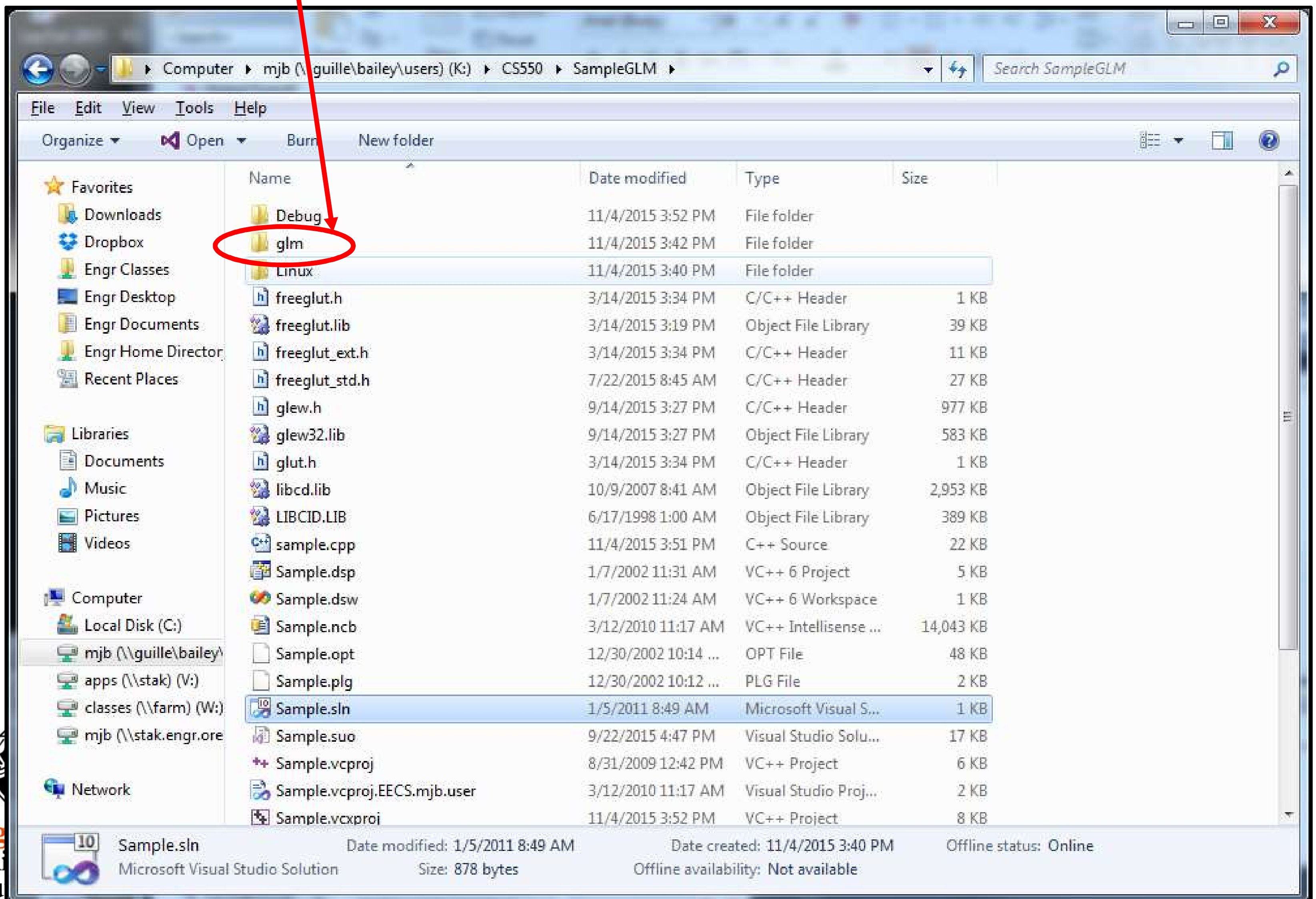
glm::mat4 **glm::translate**(glm::mat4 const & m, glm::vec3 const & translation);

The Most Useful GLM Variables, Operations, and Functions

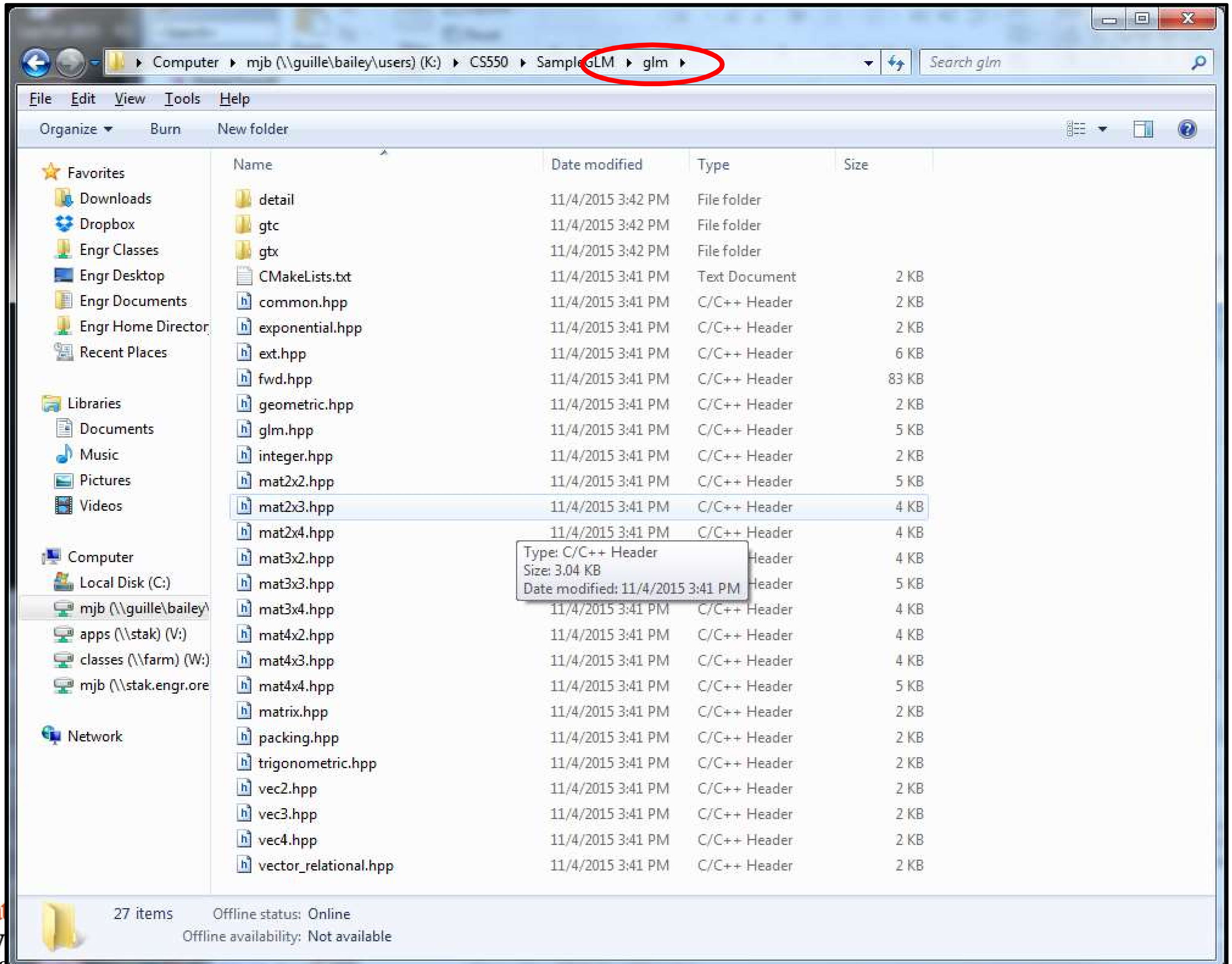
```
// viewing volume  (assign, not concatenate):

glm::mat4  glm::ortho(  float left,  float right,  float bottom,  float top,  float near,  float far );
glm::mat4  glm::ortho(  float left,  float right,  float bottom,  float top );

glm::mat4  glm::frustum(  float left,  float right,  float bottom,  float top,  float near,  float far );
glm::mat4  glm::perspective(  float fovy,  float aspect,  float near,  float far);


// viewing  (assign, not concatenate):

glm::mat4  glm::lookAt(  glm::vec3 const & eye,  glm::vec3 const & look,  glm::vec3 const & up );
```

Installing GLM into your own space

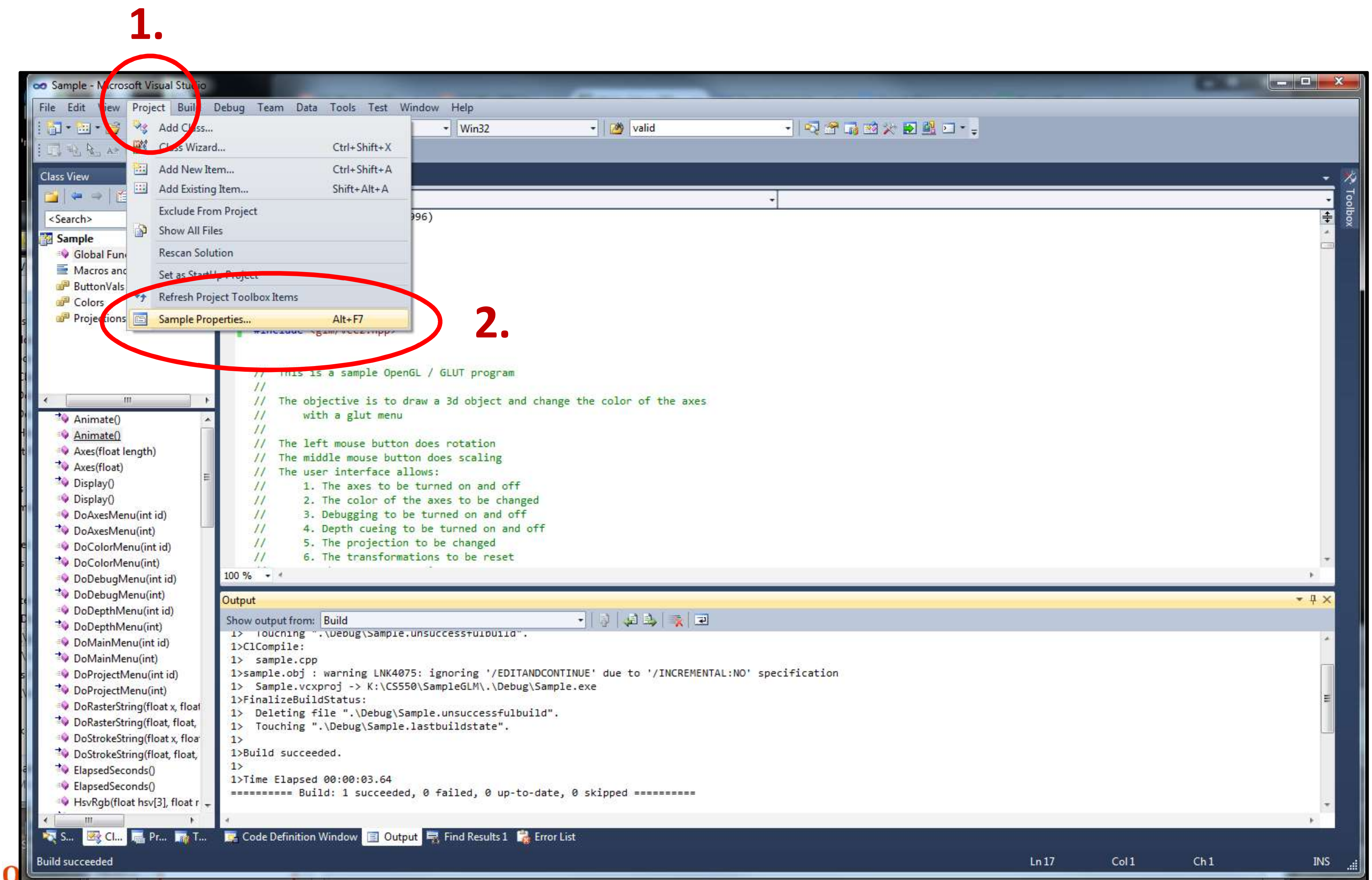
I like to just put the whole thing under my Visual Studio project folder so I can zip up a complete project and give it to someone else.



Here's what that GLM folder looks like



Telling Visual Studio about where the GLM folder is

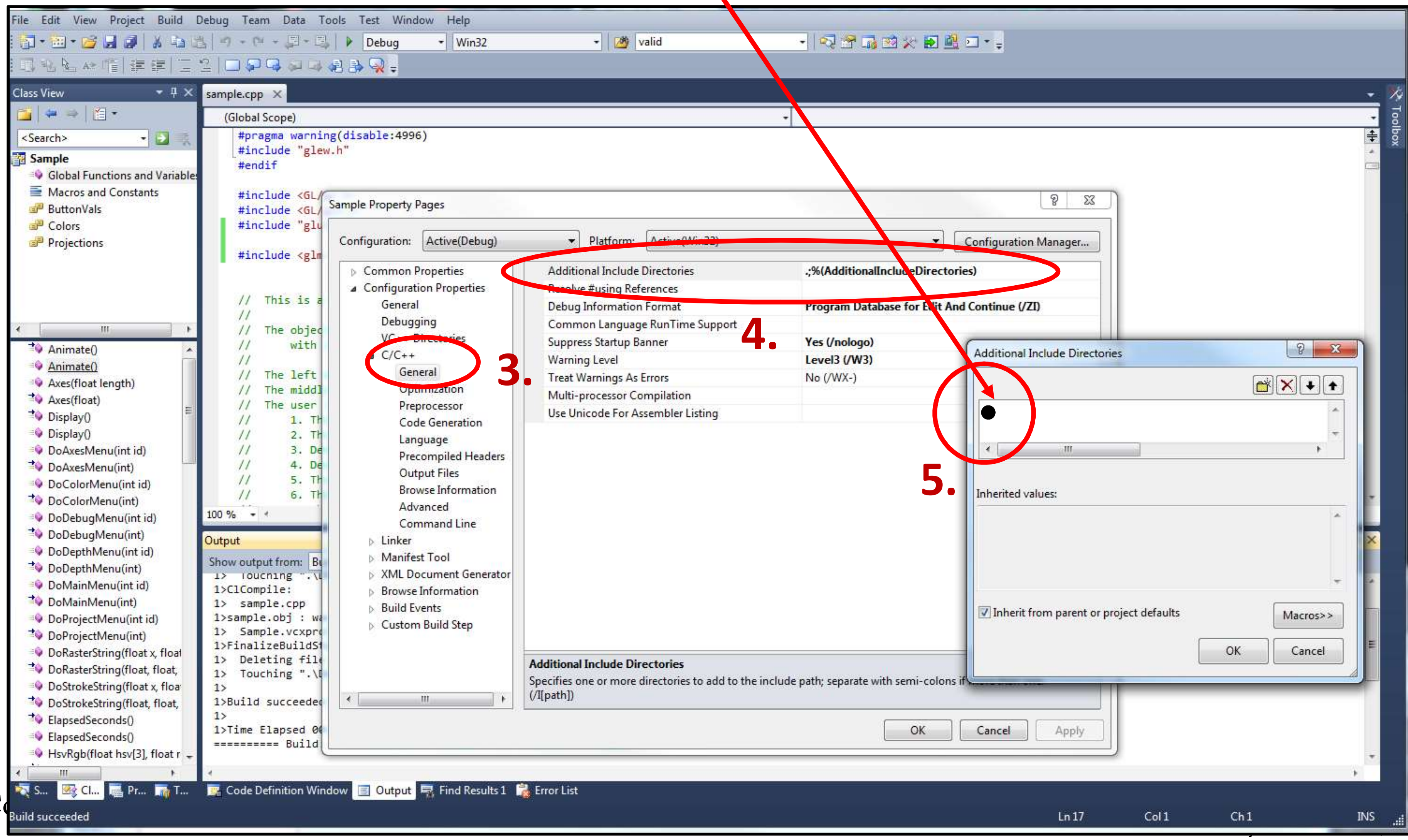


Telling Visual Studio about where the GLM folder is

A ***period***, indicating that the **project folder** should also be searched when a

#include <xxx>

is encountered. If you put it somewhere else, enter that full or relative path instead.



GLM in the Vulkan sample.cpp Program


```
if( UseMouse )
{
        if( Scale < MINSCALE )
           Scale = MINSCALE;
        Matrices.uModelMatrix = glm::mat4( 1. );        // identity
        Matrices.uModelMatrix = glm::rotate( Matrices.uModelMatrix, Yrot, glm::vec3( 0.,1.,0.) );
        Matrices.uModelMatrix = glm::rotate( Matrices.uModelMatrix, Xrot, glm::vec3( 1.,0.,0.) );
        Matrices.uModelMatrix = glm::scale(  Matrices.uModelMatrix, glm::vec3(Scale,Scale,Scale) );
                            // done this way, the Scale is applied first, then the Xrot, then the Yrot
}
else
{
      if( ! Paused )
      {
           const glm::vec3 axis = glm::vec3( 0., 1., 0. );
           Matrices.uModelMatrix      = glm::rotate( glm::mat4( 1. ),  (float)glm::radians( 360.f*Time/SECONDS_PER_CYCLE ),   axis );
      }
}

glm::vec3 eye(0.,0.,EYEDIST );
glm::vec3 look(0.,0.,0.);
glm::vec3   up(0.,1.,0.);
Matrices.uVewMatrix = glm::lookAt( eye, look, up );

Matrices.uProjectionMatrix = glm::perspective( FOV, (double)Width/(double)Height, 0.1f, 1000.f );
Matrices.uProjectionMatrix[1][1] *= -1.;             // Vulkan's projected Y is inverted from OpenGL

Matrices.uNormalMatrix = glm::inverseTranspose(  glm::mat3( Matrices.uModelMatrix );   // note: inverseTransform !

Fill05DataBuffer( MyMatrixUniformBuffer, (void *) &Matrices );

Misc.uTime = (float)Time;
Misc.uMode = Mode;
Fill05DataBuffer( MyMiscUniformBuffer, (void *) &Misc );
```

How Does this Matrix Stuff Really Work?

$$
\begin{aligned}
x' &= Ax + By + Cz + D \\
y' &= Ex + Fy + Gz + H \\
z' &= Ix + Jy + Kz + L
\end{aligned}
$$

This is called a "Linear Transformation" because all of the coordinates are raised to the 1st power, that is, there are no x^2, x^3, etc. terms.

Or, in matrix form:

$$
\begin{array}{l}
\\
\text{x' producing row} \\
\text{y' producing row} \\
\text{z' producing row} \\
\\
\end{array}
\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix}
=
\begin{array}{cccc}
\text{x consuming column} & \text{y consuming column} & \text{z consuming column} & \text{constant column} \\
\end{array}
\begin{bmatrix} A & B & C & D \\ E & F & G & H \\ I & J & K & L \\ 0 & 0 & 0 & 1 \end{bmatrix}
\cdot
\begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}
$$

Transformation Matrices

Translation

$$\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 & T_x \\ 0 & 1 & 0 & T_y \\ 0 & 0 & 1 & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

Scaling

$$\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

Rotation about X

$$\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

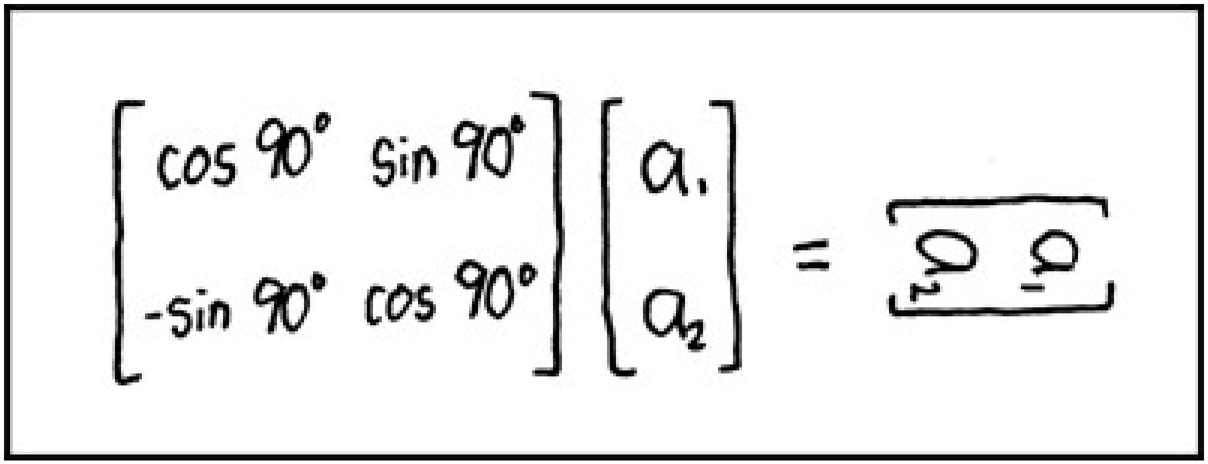
Rotation about Y

$$\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

Rotation about Z

$$\begin{Bmatrix} x' \\ y' \\ z' \\ 1 \end{Bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

How it Really Works :-)



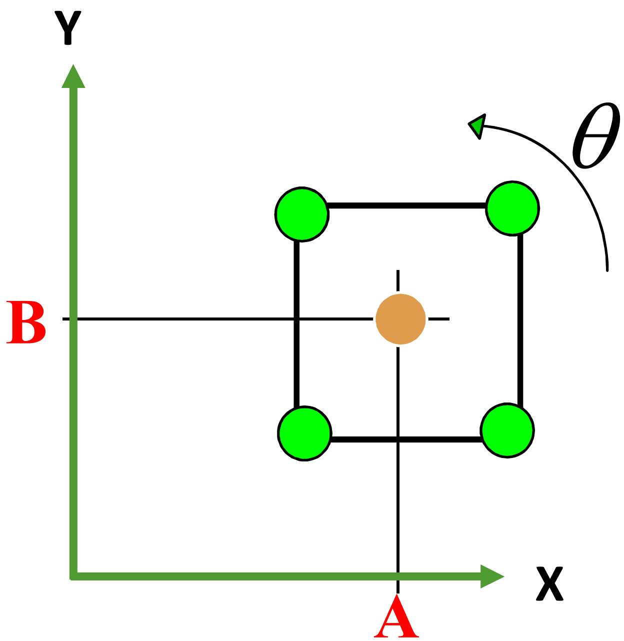
http://xkcd.com

The Rotation Matrix for an Angle (θ) about an Arbitrary Axis (Ax, Ay, Az)

$$[M]=\begin{bmatrix} A_xA_x+\cos\theta(1-A_xA_x) & A_xA_y-\cos\theta(A_xA_y)-\sin\theta A_z & A_xA_z-\cos\theta(A_xA_z)+\sin\theta A_y \\ A_yA_x-\cos\theta(A_yA_x)+\sin\theta A_z & A_yA_y+\cos\theta(1-A_yA_y) & A_yA_z-\cos\theta(A_yA_z)-\sin\theta A_x \\ A_zA_x-\cos\theta(A_zA_x)-\sin\theta A_y & A_zA_y-\cos\theta(A_zA_y)+\sin\theta A_x & A_zA_z+\cos\theta(1-A_zA_z) \end{bmatrix}$$

For this to be correct, A must be a unit vector

Compound Transformations



Q: Our rotation matrices only work around the origin? What if we want to rotate about an arbitrary point (A,B)?

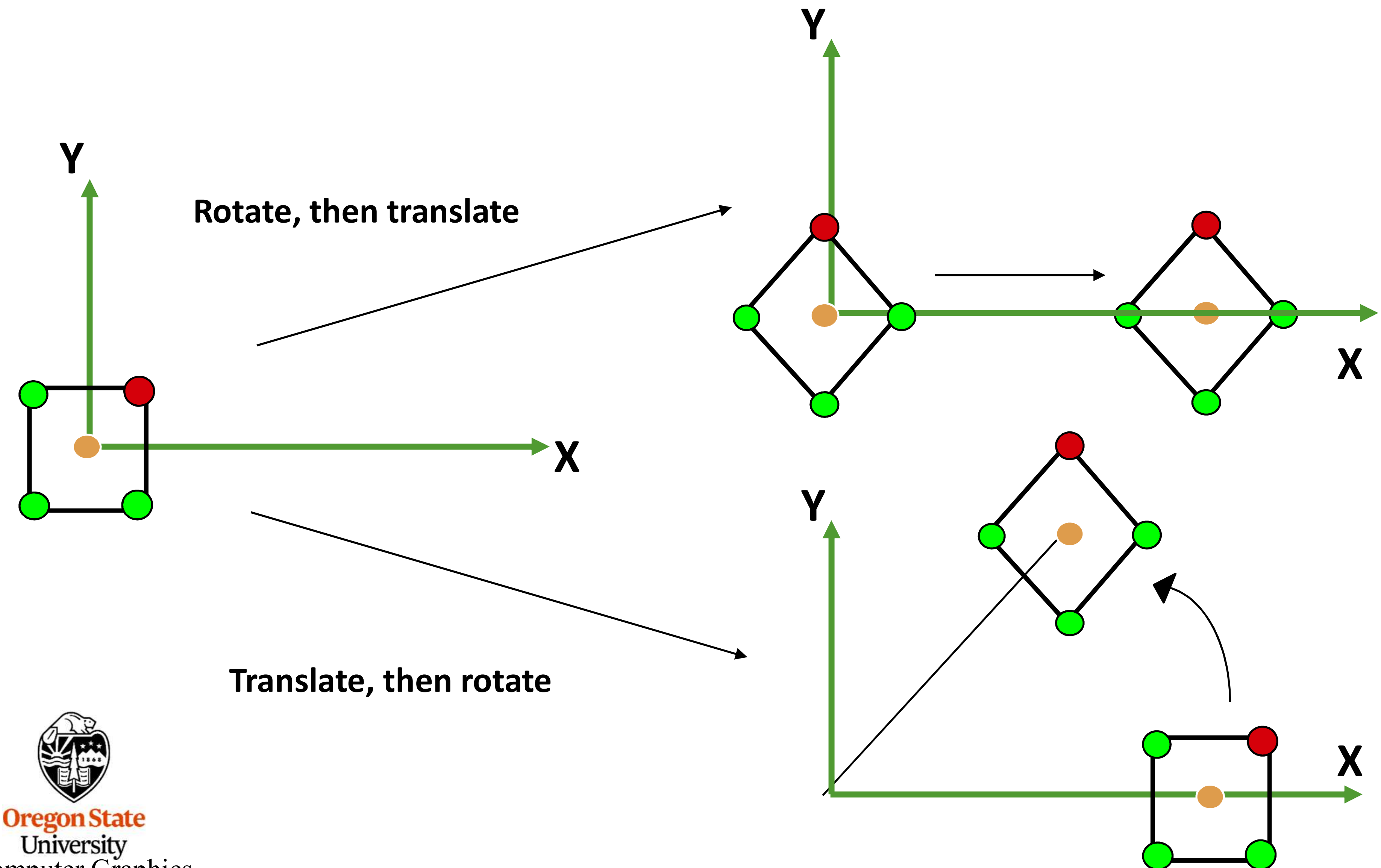
A: We create more than one matrix.

Write it

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \left(\overset{\boxed{3}}{\left[T_{+A,+B} \right]} \cdot \left(\overset{\boxed{2}}{\left[R_\theta \right]} \cdot \left(\overset{\boxed{1}}{\left[T_{-A,-B} \right]} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} \right) \right) \right)$$

Say it

Matrix Multiplication *is not* Commutative



Matrix Multiplication *is* Associative

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \left(\left[T_{+A,+B} \right] \cdot \left(\left[R_\theta \right] \cdot \left(\left[T_{-A,-B} \right] \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} \right) \right) \right)$$

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \underbrace{\left(\left[T_{+A,+B} \right] \cdot \left[R_\theta \right] \cdot \left[T_{-A,-B} \right] \right)} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$

One matrix to rule them all –
the Current Transformation Matrix, or **CTM**

From the Data Buffer Noteset

Here's the vertex shader shader code to use the matrices:

```
layout( std140, set = 0, binding = 0 ) uniform sceneMatBuf
{
        mat4 uProjectionMatrix;
        mat4 uViewMatrix;
        mat4 uSceneMatrix;
} SceneMatrices;

layout( std140, set = 1, binding = 0 ) uniform objectMatBuf
{
        mat4 uModelMatrix;
        mat4 uNormalMatrix;
} ObjectMatrices;
```

```
vNormal = uNormalMatrix * aNormal;

gl_Position = uProjectMatrix * uViewMatrix * uSceneMatrix * uModelMatrix * aVertex;
```

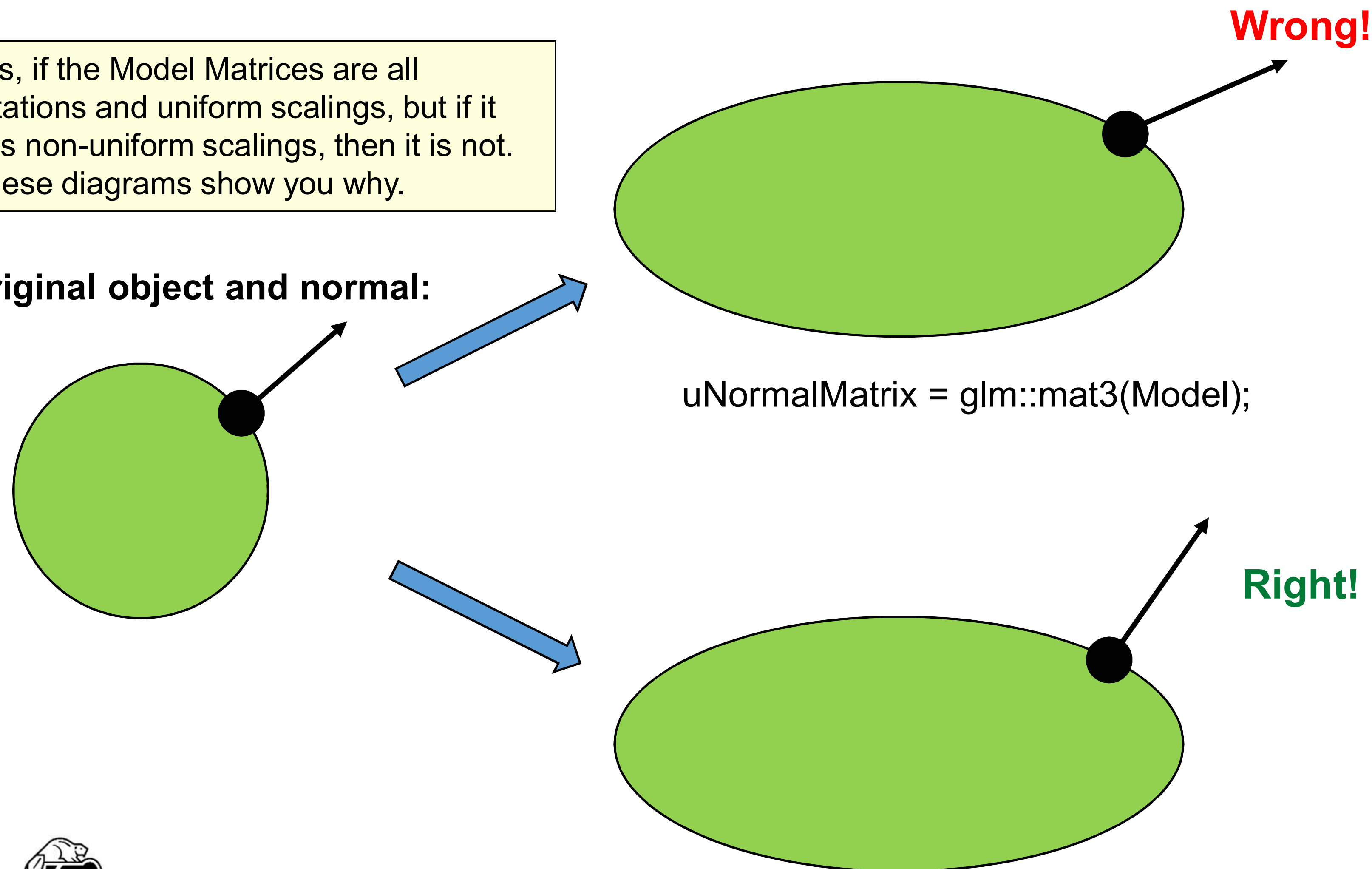
"CTM"

Why Isn't The Normal Matrix exactly the same as the Model Matrix?

```
glm::mat4  Model = uViewMatrix*uSceneMatrix*uModelMatrix;
uNormalMatrix     = glm::inverseTranspose(  glm::mat3(Model)  );
```

It is, if the Model Matrices are all rotations and uniform scalings, but if it has non-uniform scalings, then it is not. These diagrams show you why.

Original object and normal:



uNormalMatrix = glm::**inverseTranspose**(glm::mat3(Model));