

Manual

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Christophe Riccio

[glm@g-truc.net](mailto:glm@g-truc.net)



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**Table of Contents**

[Introduction 6](#_Toc461310955)

[1. Getting started 7](#_Toc461310956)

[1.1. Setup 7](#_Toc461310957)

[1.2. Faster program compilation 7](#_Toc461310958)

[1.3. Use sample of GLM core 7](#_Toc461310959)

[1.4. Dependencies 8](#_Toc461310960)

[2. Swizzle operators 9](#_Toc461310961)

[2.1. Default C++98 implementation 9](#_Toc461310962)

[2.2. Anonymous union member implementation 9](#_Toc461310963)

[3. Preprocessor options 11](#_Toc461310964)

[3.1. Default precision 11](#_Toc461310965)

[3.2. Compile-time message system 11](#_Toc461310966)

[3.3. C++ language detection 12](#_Toc461310967)

[3.4. SIMD support 12](#_Toc461310968)

[3.5. Force inline 12](#_Toc461310969)

[3.6. Vector and matrix static size 13](#_Toc461310970)

[3.7. Disabling default constructor initialization 13](#_Toc461310971)

[3.8. Require explicit conversions 14](#_Toc461310972)

[3.9. Removing genType restriction 14](#_Toc461310973)

[4. Stable extensions 15](#_Toc461310974)

[4.1. GLM\_GTC\_bitfield 15](#_Toc461310975)

[4.2. GLM\_GTC\_color\_space 15](#_Toc461310976)

[4.3. GLM\_GTC\_constants 15](#_Toc461310977)

[4.4. GLM\_GTC\_epsilon 15](#_Toc461310978)

[4.5. GLM\_GTC\_functions 15](#_Toc461310979)

[4.6. GLM\_GTC\_integer 16](#_Toc461310980)

[4.7. GLM\_GTC\_matrix\_access 16](#_Toc461310981)

[4.8. GLM\_GTC\_matrix\_integer 16](#_Toc461310982)

[4.9. GLM\_GTC\_matrix\_inverse 16](#_Toc461310983)

[4.10. GLM\_GTC\_matrix\_transform 16](#_Toc461310984)

[4.11. GLM\_GTC\_noise 16](#_Toc461310985)

[4.12. GLM\_GTC\_packing 19](#_Toc461310986)

[4.13. GLM\_GTC\_quaternion 20](#_Toc461310987)

[4.14. GLM\_GTC\_random 20](#_Toc461310988)

[4.15. GLM\_GTC\_reciprocal 22](#_Toc461310989)

[4.16. GLM\_GTC\_round 22](#_Toc461310990)

[4.17. GLM\_GTC\_type\_aligned 22](#_Toc461310991)

[4.18. GLM\_GTC\_type\_precision 22](#_Toc461310992)

[4.19. GLM\_GTC\_type\_ptr 23](#_Toc461310993)

[4.20. GLM\_GTC\_ulp 24](#_Toc461310994)

[4.21. GLM\_GTC\_vec1 24](#_Toc461310995)

[5. OpenGL interoperability 25](#_Toc461310996)

[5.1. GLM replacements for deprecated OpenGL functions 25](#_Toc461310997)

[5.2. GLM replacements for GLU functions 26](#_Toc461310998)

[6. Known issues 28](#_Toc461310999)

[6.1. not function 28](#_Toc461311000)

[6.2. Precision qualifiers support 28](#_Toc461311001)

[7. FAQ 29](#_Toc461311002)

[7.1 Why GLM follows GLSL specification and conventions? 29](#_Toc461311003)

[7.2. Does GLM run GLSL program? 29](#_Toc461311004)

[7.3. Does a GLSL compiler build GLM codes? 29](#_Toc461311005)

[7.4. Should I use ‘GTX’ extensions? 29](#_Toc461311006)

[7.5. Where can I ask my questions? 29](#_Toc461311007)

[7.6. Where can I find the documentation of extensions? 29](#_Toc461311008)

[7.7. Should I use ‘using namespace glm;’? 29](#_Toc461311009)

[7.8. Is GLM fast? 29](#_Toc461311010)

[7.9. When I build with Visual C++ with /W4 warning level, I have warnings... 30](#_Toc461311011)

[7.10. Why some GLM functions can crash because of division by zero? 30](#_Toc461311012)

[7.11. What unit for angles is used in GLM? 30](#_Toc461311013)

[8. Code samples 31](#_Toc461311014)

[8.1. Compute a triangle normal 31](#_Toc461311015)

[8.2. Matrix transform 31](#_Toc461311016)

[8.3. Vector types 31](#_Toc461311017)

[8.4. Lighting 32](#_Toc461311018)

[9. References 34](#_Toc461311019)

[9.1. GLM development 34](#_Toc461311020)

[9.2. OpenGL specifications 34](#_Toc461311021)

[9.3. External links 34](#_Toc461311022)

[9.4. Projects using GLM 34](#_Toc461311023)

[9.5. OpenGL tutorials using GLM 35](#_Toc461311024)

[9.6. Equivalent for other languages 36](#_Toc461311025)

[9.7. Alternatives to GLM 36](#_Toc461311026)

[9.8. Acknowledgements 36](#_Toc461311027)

Introduction

OpenGL Mathematics (GLM) is a C++ mathematics library for graphics C++ programs based on the [OpenGL Shading Language](http://www.opengl.org/registry/) (GLSL) specifications.

GLM provides classes and functions designed and implemented with the same naming conventions and functionalities than GLSL so that when a programmer knows GLSL, he knows GLM as well which makes it really easy to use.

This project isn't limited to GLSL features. An extension system, based on the GLSL extension conventions, provides extended capabilities: matrix transformations, quaternions, data packing, random numbers, noise, etc...

This library works perfectly with [OpenGL](http://www.opengl.org) but it also ensures interoperability with other third party libraries and SDK. It is a good candidate for software rendering (raytracing / rasterisation), image processing, physic simulations and any development context that requires a simple and convenient mathematics library.

GLM is written in C++98 but can take advantage of C++11 when supported by the compiler. It is a platform independent library with no dependence and it officially supports the following compilers:

- [Apple Clang](https://developer.apple.com/Library/mac/documentation/CompilerTools/Conceptual/LLVMCompilerOverview/index.html) 4.0 and higher  
- [GCC](http://gcc.gnu.org/) 4.2 and higher

- [Intel C++ Composer](https://software.intel.com/en-us/intel-compilers) XE 2013 and higher  
- [LLVM](http://llvm.org/) 3.0 and higher

- [Visual C++](http://www.visualstudio.com/) 2010 and higher

- [CUDA](https://developer.nvidia.com/about-cuda) 4.0 and higher (experimental)

- Any conform C++98 or C++11 compiler

The source code and the documentation, including this manual, are licensed under [the Happy Bunny License (Modified MIT) and the MIT License](http://glm.g-truc.net/copying.txt).

Thanks for contributing to the project by [submitting reports](https://github.com/g-truc/glm/issues) for bugs and feature requests. Any feedback is welcome at [glm@g-truc.net](mailto:glm@g-truc.net).

1. Getting started

1.1. Setup

GLM is a header only library. Hence, there is nothing to build to use it. To use GLM, a programmer only has to include <glm/glm.hpp> in his program. This include provides all the GLSL features implemented by GLM.

Core GLM features can be included using individual headers to allow faster user program compilations.

<glm/vec2.hpp>: vec2, bvec2, dvec2, ivec2 and uvec2

<glm/vec3.hpp>: vec3, bvec3, dvec3, ivec3 and uvec3

<glm/vec4.hpp>: vec4, bvec4, dvec4, ivec4 and uvec4

<glm/mat2x2.hpp>: mat2, dmat2

<glm/mat2x3.hpp>: mat2x3, dmat2x3

<glm/mat2x4.hpp>: mat2x4, dmat2x4

<glm/mat3x2.hpp>: mat3x2, dmat3x2

<glm/mat3x3.hpp>: mat3, dmat3

<glm/mat3x4.hpp>: mat3x4, dmat2

<glm/mat4x2.hpp>: mat4x2, dmat4x2

<glm/mat4x3.hpp>: mat4x3, dmat4x3

<glm/mat4x4.hpp>: mat4, dmat4

<glm/common.hpp>: all the GLSL common functions

<glm/exponential.hpp>: all the GLSL exponential functions

<glm/geometry.hpp>: all the GLSL geometry functions

<glm/integer.hpp>: all the GLSL integer functions

<glm/matrix.hpp>: all the GLSL matrix functions

<glm/packing.hpp>: all the GLSL packing functions

<glm/trigonometric.hpp>: all the GLSL trigonometric functions

<glm/vector\_relational.hpp>: all the GLSL vector relational functions

1.2. Faster program compilation

GLM is a header only library that makes a heavy usage of C++ templates. This design may significantly increase the compile time for files that use GLM. Hence, it is important to limit GLM inclusion to header and source files that actually use it. Likewise, GLM extensions should be included only in program sources using them.

To further help compilation time, GLM 0.9.5 introduced <glm/fwd.hpp> that provides forward declarations of GLM types.

|  |
| --- |
| // Header file  #include <glm/fwd.hpp>  // Source file  #include <glm/glm.hpp> |

1.3. Use sample of GLM core

|  |
| --- |
| // Include GLM core features  #include <glm/vec3.hpp>  #include <glm/vec4.hpp>  #include <glm/mat4x4.hpp>  #include <glm/trigonometric.hpp>  // Include GLM extensions  #include <glm/gtc/matrix\_transform.hpp>  glm::mat4 transform(  glm::vec2 const& Orientation,  glm::vec3 const& Translate,  glm::vec3 const& Up)  {  glm::mat4 Proj = glm::perspective(glm::radians(45.f), 1.33f, 0.1f, 10.f);  glm::mat4 ViewTranslate = glm::translate(glm::mat4(1.f), Translate);  glm::mat4 ViewRotateX = glm::rotate(ViewTranslate, Orientation.y, Up);  glm::mat4 View = glm::rotate(ViewRotateX, Orientation.x, Up);  glm::mat4 Model = glm::mat4(1.0f);    return Proj \* View \* Model;  } |

1.4. Dependencies

When <glm/glm.hpp> is included, GLM provides all the GLSL features it implements in C++.

There is no dependence with external libraries or external headers such as gl.h, [glcorearb.h](http://www.opengl.org/registry/api/GL/glcorearb.h), gl3.h, glu.h or windows.h. However, if <boost/static\_assert.hpp> is included, [Boost static assert](http://www.boost.org/doc/libs/1_52_0/doc/html/boost_staticassert.html) will be used all over GLM code to provide compiled time errors unless GLM is built with a C++ 11 compiler in which case [static\_assert](http://en.cppreference.com/w/cpp/language/static_assert). If neither are detected, GLM will rely on its own implementation of static assert.

2. Swizzle operators

A common feature of shader languages like GLSL is the swizzle operators. Those allow selecting multiple components of a vector and change their order. For example, “variable.x”, “variable.xzy” and “variable.zxyy” form respectively a scalar, a three components vector and a four components vector. With GLSL, swizzle operators can be both R-values and L-values. Finally, vector components can be accessed using “xyzw”, “rgba” or “stpq”.

|  |
| --- |
| vec4 A;  vec2 B;  ...  B.yx = A.wy;  B = A.xx;  Vec3 C = A.bgr; |

GLM supports a subset of this functionality as described in the following sub-sections. Swizzle operators are disabled by default. To enable them GLM\_SWIZZLE must be defined before any inclusion of <glm/glm.hpp>. Enabling swizzle operators will massively increase the size of compiled files and the compilation time.

2.1. Default C++98 implementation

The C++98 implementation exposes the R-value swizzle operators as member functions of vector types.

|  |
| --- |
| #define GLM\_SWIZZLE  #include <glm/glm.hpp>  void foo()  {  glm::vec4 ColorRGBA(1.0f, 0.5f, 0.0f, 1.0f);  glm::vec3 ColorBGR = ColorRGBA.bgr();  …  glm::vec3 PositionA(1.0f, 0.5f, 0.0f, 1.0f);  glm::vec3 PositionB = PositionXYZ.xyz() \* 2.0f;  …  glm::vec2 TexcoordST(1.0f, 0.5f);  glm::vec4 TexcoordSTPQ = TexcoordST.stst();  …  } |

Swizzle operators return a copy of the component values hence they can’t be used as L-values to change the value of the variables.

|  |
| --- |
| #define GLM\_FORCE\_SWIZZLE  #include <glm/glm.hpp>  void foo()  {  glm::vec3 A(1.0f, 0.5f, 0.0f);  // /!\ No compiler error but A is not affected  // This code modify the components of an anonymous copy.  A.bgr() = glm::vec3(2.0f, 1.5f, 1.0f); // A is not modified!  …  } |

2.2. Anonymous union member implementation

Visual C++ supports anonymous structures in union, which is a non-standard language extension, but it enables a very powerful implementation of swizzle operators on Windows supporting both L-value swizzle operators and a syntax that doesn’t require parentheses in some cases. This implementation is only enabled when the language extension is enabled and GLM\_SWIZZLE is defined.

|  |
| --- |
| #define GLM\_FORCE\_SWIZZLE  #include <glm/glm.hpp>  void foo()  {  glm::vec4 ColorRGBA(1.0f, 0.5f, 0.0f, 1.0f);  // l-value:  glm::vec4 ColorBGRA = ColorRGBA.bgra;  // r-value:  ColorRGBA.bgra = ColorRGBA;  // Both l-value and r-value  ColorRGBA.bgra = ColorRGBA.rgba;  …  } |

Anonymous union member swizzle operators don’t return vector types (glm::vec2, glm::vec3 and glm::vec4) but implementation specific objects that can be automatically interpreted by other swizzle operators and vector constructors. Unfortunately, those can’t be interpreted by GLM functions so that the programmer must convert a swizzle operators to a vector type or call the () operator on a swizzle objects to pass it to another C++ functions.

|  |
| --- |
| #define GLM\_FORCE\_SWIZZLE  #include <glm/glm.hpp>  void foo()  {  glm::vec4 Color(1.0f, 0.5f, 0.0f, 1.0f);  …  // Generates compiler errors. Color.rgba is not a vector type.  glm::vec4 ClampedA = glm::clamp(Color.rgba, 0.f, 1.f); // ERROR  // We need to cast the swizzle operator into glm::vec4  // With by using a constructor  glm::vec4 ClampedB = glm::clamp(glm::vec4(Color.rgba), 0.f, 1.f); // OK  // Or by using the () operator  glm::vec4 ClampedC = glm::clamp(Color.rgba(), 0.f, 1.f); // OK  …  } |

3. Preprocessor options

3.1. Default precision

In C++, it is not possible to implement GLSL default precision (GLSL 4.10 specification section 4.5.3) using GLSL syntax.

|  |
| --- |
| precision mediump int;  precision highp float; |

To use the default precision functionality, GLM provides some defines that need to add before any include of glm.hpp:

|  |
| --- |
| #define GLM\_PRECISION\_MEDIUMP\_INT;  #define GLM\_PRECISION\_HIGHP\_FLOAT;  #include <glm/glm.hpp> |

Available defines for floating point types (glm::vec\*, glm::mat\*):

GLM\_PRECISION\_LOWP\_FLOAT: Low precision  
GLM\_PRECISION\_MEDIUMP\_FLOAT: Medium precision   
GLM\_PRECISION\_HIGHP\_FLOAT: High precision (default)

Available defines for floating point types (glm::dvec\*, glm::dmat\*):

GLM\_PRECISION\_LOWP\_DOUBLE: Low precision  
GLM\_PRECISION\_MEDIUMP\_DOUBLE: Medium precision   
GLM\_PRECISION\_HIGHP\_DOUBLE: High precision (default)

Available defines for signed integer types (glm::ivec\*):

GLM\_PRECISION\_LOWP\_INT: Low precision

GLM\_PRECISION\_MEDIUMP\_INT: Medium precision

GLM\_PRECISION\_HIGHP\_INT: High precision (default)

Available defines for unsigned integer types (glm::uvec\*):

GLM\_PRECISION\_LOWP\_UINT: Low precision

GLM\_PRECISION\_MEDIUMP\_UINT: Medium precision

GLM\_PRECISION\_HIGHP\_UINT: High precision (default)

3.2. Compile-time message system

GLM includes a notification system which can display some information at build time:

- Platform: Windows, Linux, Native Client, QNX, etc.

- Compiler: Visual C++, Clang, GCC, ICC, etc.

- Build model: 32bits or 64 bits

- C++ version : C++98, C++11, MS extensions, etc.

- Architecture: x86, SSE, AVX, etc.

- Included extensions

- etc.

This system is disabled by default. To enable this system, define GLM\_FORCE\_MESSAGES before any inclusion of <glm/glm.hpp>. The messages are generated only by compiler supporting #program message and only once per project build.

|  |
| --- |
| #define GLM\_FORCE\_MESSAGES  #include <glm/glm.hpp> |

3.3. C++ language detection

GLM will automatically take advantage of compilers’ language extensions when enabled. To increase cross platform compatibility and to avoid compiler extensions, a programmer can define GLM\_FORCE\_CXX98 before any inclusion of <glm/glm.hpp> to restrict the language feature set C++98:

|  |
| --- |
| #define GLM\_FORCE\_CXX98  #include <glm/glm.hpp> |

For C++11 and C++14, equivalent defines are available: GLM\_FORCE\_CXX11, GLM\_FORCE\_CXX14.

|  |
| --- |
| #define GLM\_FORCE\_CXX11  #include <glm/glm.hpp> |

GLM\_FORCE\_CXX14 overrides GLM\_FORCE\_CXX11 and GLM\_FORCE\_CXX11 overrides GLM\_FORCE\_CXX98 defines.

3.4. SIMD support

GLM provides some SIMD optimizations based on [compiler intrinsics](https://msdn.microsoft.com/en-us/library/26td21ds.aspx). These optimizations will be automatically thanks to compiler arguments. For example, if a program is compiled with Visual Studio using /arch:AVX, GLM will detect this argument and generate code using AVX instructions automatically when available.

It’s possible to avoid the instruction set detection by forcing the use of a specific instruction set with one of the fallowing define: GLM\_FORCE\_SSE2, GLM\_FORCE\_SSE3, GLM\_FORCE\_SSSE3, GLM\_FORCE\_SSE41, GLM\_FORCE\_SSE42, GLM\_FORCE\_AVX, GLM\_FORCE\_AVX2 or GLM\_FORCE\_AVX512.

The use of intrinsic functions by GLM implementation can be avoided using the define GLM\_FORCE\_PURE before any inclusion of GLM headers.

|  |
| --- |
| #define GLM\_FORCE\_PURE  #include <glm/glm.hpp>  // GLM code will be compiled using pure C++ code |

|  |
| --- |
| #define GLM\_FORCE\_AVX2  #include <glm/glm.hpp>  // If the compiler doesn’t support AVX2 instrinsics,  // compiler errors will happen. |

Additionally, GLM provides a low level SIMD API in glm/simd directory for users who are really interested in writing fast algorithms.

3.5. Force inline

To push further the software performance, a programmer can define GLM\_FORCE\_INLINE before any inclusion of <glm/glm.hpp> to force the compiler to inline GLM code.

|  |
| --- |
| #define GLM\_FORCE\_INLINE  #include <glm/glm.hpp> |

3.6. Vector and matrix static size

GLSL supports the member function .length() for all vector and matrix types.

|  |
| --- |
| #include <glm/glm.hpp>  void foo(vec4 const & v)  {  int Length = v.length();  …  } |

This function returns a int however this function typically interacts with STL size\_t based code. GLM provides GLM\_FORCE\_SIZE\_T\_LENGTH pre-processor option so that member functions length() return a size\_t.

Additionally, GLM defines the type glm::length\_t to identify length() returned type, independently from GLM\_FORCE\_SIZE\_T\_LENGTH.

|  |
| --- |
| #define GLM\_FORCE\_SIZE\_T\_LENGTH  #include <glm/glm.hpp>  void foo(vec4 const & v)  {  glm::size\_t Length = v.length();  …  } |

3.7. Disabling default constructor initialization

By default and following GLSL specifications, vector and matrix default constructors initialize the components to zero. This is a reliable behavior but initialization has a cost and it’s not always necessary. This behavior can be disable at compilation time by define GLM\_FORCE\_NO\_CTOR\_INIT before any inclusion of <glm/glm.hpp> or other GLM include.

GLM default behavior:

|  |
| --- |
| #include <glm/glm.hpp>  void foo()  {  glm::vec4 v; // v is (0.0f, 0.0f, 0.0f, 0.0f)  …  } |

GLM behavior using GLM\_FORCE\_NO\_CTOR\_INIT:

|  |
| --- |
| #define GLM\_FORCE\_NO\_CTOR\_INIT  #include <glm/glm.hpp>  void foo()  {  glm::vec4 v; // v is fill with garbage  …  } |

Alternatively, GLM allows to explicitly not initialize a variable:

|  |
| --- |
| #include <glm/glm.hpp>  void foo()  {  glm::vec4 v(glm::uninitialize);  …  } |

3.8. Require explicit conversions

GLSL supports implicit conversions of vector and matrix types. For example, an ivec4 can be implicitly converted into vec4.

Often, this behaviour is not desirable but following the spirit of the library, this behavior is supported in GLM. However, GLM 0.9.6 introduced the define GLM\_FORCE\_EXPLICIT\_CTOR to require explicit conversion for GLM types.

|  |
| --- |
| #include <glm/glm.hpp>  void foo()  {  glm::ivec4 a; …  glm::vec4 b(a); // Explicit conversion, OK glm::vec4 c = a; // Implicit conversion, OK  …  } |

With GLM\_FORCE\_EXPLICIT\_CTOR define, implicit conversions are not allowed:

|  |
| --- |
| #define GLM\_FORCE\_EXPLICIT\_CTOR  #include <glm/glm.hpp>  void foo()  {  glm::ivec4 a; …  glm::vec4 b(a); // Explicit conversion, OK glm::vec4 c = a; // Implicit conversion, ERROR  …  } |

3.9. Removing genType restriction

By default GLM only supports basic types as genType for vector, matrix and quaternion types:

|  |
| --- |
| #include <glm/glm.hpp>  typedef glm::tvec4<float> my\_fvec4; |

GLM 0.9.8 introduced GLM\_FORCE\_UNRESTRICTED\_GENTYPE define to relax this restriction:

|  |
| --- |
| #define GLM\_FORCE\_UNRESTRICTED\_GENTYPE #include <glm/glm.hpp>  #include "half.hpp" // Define “half” class with equivalent behavior than “float”  typedef glm::tvec4<half> my\_hvec4; |

However, defining GLM\_FORCE\_UNRESTRICTED\_GENTYPE is not compatible with GLM\_FORCE\_SWIZZLE and will generate a compilation error if both are defined at the same time.

4. Stable extensions

GLM extends the core GLSL feature set with extensions. These extensions include: quaternion, transformation, spline, matrix inverse, color spaces, etc.

To include an extension, we only need to include the dedicated header file. Once included, the features are added to the GLM namespace.

|  |
| --- |
| #include <glm/glm.hpp>  #include <glm/gtc/matrix\_transform.hpp>  int foo()  {  glm::vec4 Position = glm::vec4(glm:: vec3(0.0f), 1.0f);  glm::mat4 Model = glm::translate(  glm::mat4(1.0f), glm::vec3(1.0f));  glm::vec4 Transformed = Model \* Position;  …  return 0;  } |

When an extension is included, all the dependent core functionalities and extensions will be included as well.

4.1. GLM\_GTC\_bitfield

Fast bitfield operations on scalar and vector variables.

<glm/gtc/bitfield.hpp> need to be included to use these features.

4.2. GLM\_GTC\_color\_space

Conversion between linear RGB to sRGB and sRGB to linear RGB.

<glm/gtc/color\_space.hpp> need to be included to use these features.

4.3. GLM\_GTC\_constants

Provide a list of built-in constants.

<glm/gtc/constants.hpp> need to be included to use these features.

4.4. GLM\_GTC\_epsilon

Approximate equal and not equal comparisons with selectable epsilon.

<glm/gtc/epsilon.hpp> need to be included to use these features.

4.5. GLM\_GTC\_functions

Useful functions.

<glm/gtc/functions.hpp> need to be included to use these features.

4.6. GLM\_GTC\_integer

Provide integer variants of GLM core functions.

<glm/gtc/integer.hpp> need to be included to use these features.

4.7. GLM\_GTC\_matrix\_access

Define functions to access rows or columns of a matrix easily.

<glm/gtc/matrix\_access.hpp> need to be included to use these features.

4.8. GLM\_GTC\_matrix\_integer

Provide integer matrix types. Inverse and determinant functions are not supported for these types.

<glm/gtc/matrix\_integer.hpp> need to be included to use these features.

4.9. GLM\_GTC\_matrix\_inverse

Define additional matrix inverting functions.

<glm/gtc/matrix\_inverse.hpp> need to be included to use these features.

4.10. GLM\_GTC\_matrix\_transform

Define functions that generate common transformation matrices.

The matrices generated by this extension use standard OpenGL fixed-function conventions. For example, the lookAt function generates a transform from world space into the specific eye space that the projective matrix functions (perspective, ortho, etc) are designed to expect. The OpenGL compatibility specifications define the particular layout of this eye space.

<glm/gtc/matrix\_transform.hpp> need to be included to use these features.

4.11. GLM\_GTC\_noise

Define 2D, 3D and 4D procedural noise functions.

<glm/gtc/noise.hpp> need to be included to use these features.



Figure 4.11.1: glm::simplex(glm::vec2(x / 16.f, y / 16.f));



Figure 4.11.2: glm::simplex(glm::vec3(x / 16.f, y / 16.f, 0.5f));



Figure 4.11.3: glm::simplex(glm::vec4(x / 16.f, y / 16.f, 0.5f, 0.5f));



Figure 4.11.4: glm::perlin(glm::vec2(x / 16.f, y / 16.f));



Figure 4.11.5: glm::perlin(glm::vec3(x / 16.f, y / 16.f, 0.5f));



Figure 4.11.6: glm::perlin(glm::vec4(x / 16.f, y / 16.f, 0.5f, 0.5f)));



Figure 4.11.7: glm::perlin(glm::vec2(x / 16.f, y / 16.f), glm::vec2(2.0f));



Figure 4.11.8: glm::perlin(glm::vec3(x / 16.f, y / 16.f, 0.5f), glm::vec3(2.0f));



Figure 4.11.9: glm::perlin(glm::vec4(x / 16.f, y / 16.f, glm::vec2(0.5f)), glm::vec4(2.0f));

4.12. GLM\_GTC\_packing

Convert scalar and vector types to packed formats. This extension can also unpack packed data to the original format. The use of packing functions will results in precision lost. However, the extension guarantee that packing a value previously unpacked from the same format will be perform loselessly.

<glm/gtc/packing.hpp> need to be included to use these features.

4.13. GLM\_GTC\_quaternion

Define a quaternion type and several quaternion operations.

<glm/gtc/quaternion.hpp> need to be included to use these features.

4.14. GLM\_GTC\_random

Generate random number from various distribution methods.

<glm/gtc/random.hpp> need to be included to use these features.



Figure 4.14.1: glm::vec4(glm::linearRand(glm::vec2(-1), glm::vec2(1)), 0, 1);



Figure 4.14.2: glm::vec4(glm::circularRand(1.0f), 0, 1);

  
Figure 4.14.3: glm::vec4(glm::sphericalRand(1.0f), 1);



Figure 4.14.4: glm::vec4(glm::diskRand(1.0f), 0, 1);



Figure 4.14.5: glm::vec4(glm::ballRand(1.0f), 1);



Figure 4.14.6: glm::vec4(glm::gaussRand(glm::vec3(0), glm::vec3(1)), 1);

4.15. GLM\_GTC\_reciprocal

Provide hyperbolic functions: secant, cosecant, cotangent, etc.

<glm/gtc/reciprocal.hpp> need to be included to use these functionalities.

4.16. GLM\_GTC\_round

Rounding operation on power of two and multiple values.

<glm/gtc/round.hpp> need to be included to use these functionalities.

4.17. GLM\_GTC\_type\_aligned

Aligned vector types.

<glm/gtc/type\_aligned.hpp> need to be included to use these functionalities.

4.18. GLM\_GTC\_type\_precision

Add vector and matrix types with defined precisions. Eg, i8vec4: vector of 4 signed integer of 8 bits.

This extension adds defines to set the default precision of each class of types added:

Available defines for signed 8-bit integer types (glm::i8vec\*):

GLM\_PRECISION\_LOWP\_INT8: Low precision

GLM\_PRECISION\_MEDIUMP\_INT8: Medium precision

GLM\_PRECISION\_HIGHP\_INT8: High precision (default)

Available defines for unsigned 8-bit integer types (glm::u8vec\*):

GLM\_PRECISION\_LOWP\_UINT8: Low precision

GLM\_PRECISION\_MEDIUMP\_UINT8: Medium precision

GLM\_PRECISION\_HIGHP\_UINT8: High precision (default)

Available defines for signed 16-bit integer types (glm::i16vec\*):

GLM\_PRECISION\_LOWP\_INT16: Low precision

GLM\_PRECISION\_MEDIUMP\_INT16: Medium precision

GLM\_PRECISION\_HIGHP\_INT16: High precision (default)

Available defines for unsigned 16-bit integer types (glm::u16vec\*):

GLM\_PRECISION\_LOWP\_UINT16: Low precision

GLM\_PRECISION\_MEDIUMP\_UINT16: Medium precision

GLM\_PRECISION\_HIGHP\_UINT16: High precision (default)

Available defines for signed 32-bit integer types (glm::i32vec\*):

GLM\_PRECISION\_LOWP\_INT32: Low precision

GLM\_PRECISION\_MEDIUMP\_INT32: Medium precision

GLM\_PRECISION\_HIGHP\_INT32: High precision (default)

Available defines for unsigned 32-bit integer types (glm::u32vec\*):

GLM\_PRECISION\_LOWP\_UINT32: Low precision

GLM\_PRECISION\_MEDIUMP\_UINT32: Medium precision

GLM\_PRECISION\_HIGHP\_UINT32: High precision (default)

Available defines for signed 64-bit integer types (glm::i64vec\*):

GLM\_PRECISION\_LOWP\_INT64: Low precision

GLM\_PRECISION\_MEDIUMP\_INT64: Medium precision

GLM\_PRECISION\_HIGHP\_INT64: High precision (default)

Available defines for unsigned 64-bit integer types (glm::u64vec\*):

GLM\_PRECISION\_LOWP\_UINT64: Low precision

GLM\_PRECISION\_MEDIUMP\_UINT64: Medium precision

GLM\_PRECISION\_HIGHP\_UINT64: High precision (default)

Available defines for 32-bit floating-point types (glm::f32vec\*, glm::f32mat\*, glm::f32quat):

GLM\_PRECISION\_LOWP\_FLOAT32: Low precision

GLM\_PRECISION\_MEDIUMP\_FLOAT32: Medium precision

GLM\_PRECISION\_HIGHP\_FLOAT32: High precision (default)

Available defines for 64-bit floating-point types (glm::f64vec\*, glm::f64mat\*, glm::f64quat):

GLM\_PRECISION\_LOWP\_FLOAT64: Low precision

GLM\_PRECISION\_MEDIUMP\_FLOAT64: Medium precision

GLM\_PRECISION\_HIGHP\_FLOAT64: High precision (default)

<glm/gtc/type\_precision.hpp> need to be included to use these functionalities.

4.19. GLM\_GTC\_type\_ptr

Handle the interaction between pointers and vector, matrix types.

This extension defines an overloaded function, glm::value\_ptr, which takes any of the core template types (vec3, mat4, etc.). It returns a pointer to the memory layout of the object. Matrix types store their values in column-major order.

This is useful for uploading data to matrices or copying data to buffer objects.

|  |
| --- |
| // GLM\_GTC\_type\_ptr extension provides a safe solution: #include <glm/glm.hpp>  #include <glm/gtc/type\_ptr.hpp>  void foo()  {  glm::vec4 v(0.0f);  glm::mat4 m(1.0f);  ...  glVertex3fv(glm::value\_ptr(v))  glLoadMatrixfv(glm::value\_ptr(m));  }  // Another solution inspired by STL:  #include <glm/glm.hpp>  void foo()  {  glm::vec4 v(0.0f);  glm::mat4 m(1.0f);  ...  glVertex3fv(&v[0]);  glLoadMatrixfv(&m[0][0]);  } |

*Note: It would be possible to implement* [*glVertex3fv*](http://www.opengl.org/sdk/docs/man2/xhtml/glVertex.xml)*(glm::vec3(0)) in C++ with the appropriate cast operator that would result as an implicit cast in this example. However cast operators may produce programs running with unexpected behaviours without build error or any form of notification.*

<glm/gtc/type\_ptr.hpp> need to be included to use these features.

4.20. GLM\_GTC\_ulp

Allow the measurement of the accuracy of a function against a reference implementation. This extension works on floating-point data and provides results in [ULP](http://ljk.imag.fr/membres/Carine.Lucas/TPScilab/JMMuller/ulp-toms.pdf).

<glm/gtc/ulp.hpp> need to be included to use these features.

4.21. GLM\_GTC\_vec1

Add \*vec1 types.

<glm/gtc/vec1.hpp> need to be included to use these features.

5. OpenGL interoperability

5.1. GLM replacements for deprecated OpenGL functions

OpenGL 3.1 specification has deprecated some features that have been removed from OpenGL 3.2 core profile specification. GLM provides some replacement functions.

**glRotate{f, d}:**

|  |
| --- |
| glm::mat4 glm::rotate(  glm::mat4 const & m,  float angle,  glm::vec3 const & axis);  glm::dmat4 glm::rotate(  glm::dmat4 const & m,  double angle,  glm::dvec3 const & axis); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

[**glScale{f, d}:**](http://www.opengl.org/sdk/docs/man2/xhtml/glScale.xml)

|  |
| --- |
| glm::mat4 glm::scale(  glm::mat4 const & m,  glm::vec3 const & factors);  glm::dmat4 glm::scale(  glm::dmat4 const & m,  glm::dvec3 const & factors); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

**glTranslate{f, d}:**

|  |
| --- |
| glm::mat4 glm::translate(  glm::mat4 const & m,  glm::vec3 const & translation);  glm::dmat4 glm::translate(  glm::dmat4 const & m,  glm::dvec3 const & translation); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

**glLoadIdentity:**

|  |
| --- |
| glm::mat4(1.0) or glm::mat4();  glm::dmat4(1.0) or glm::dmat4(); |

From GLM core library: <glm/glm.hpp>

**glMultMatrix{f, d}:**

|  |
| --- |
| glm::mat4() \* glm::mat4();  glm::dmat4() \* glm::dmat4(); |

From GLM core library: <glm/glm.hpp>

**glLoadTransposeMatrix{f, d}:**

|  |
| --- |
| glm::transpose(glm::mat4());  glm::transpose(glm::dmat4()); |

From GLM core library: <glm/glm.hpp>

**glMultTransposeMatrix{f, d}:**

|  |
| --- |
| glm::mat4() \* glm::transpose(glm::mat4());  glm::dmat4() \* glm::transpose(glm::dmat4()); |

From GLM core library: <glm/glm.hpp>

[**glFrustum:**](http://www.opengl.org/sdk/docs/man2/xhtml/glFrustum.xml)

|  |
| --- |
| glm::mat4 glm::frustum(  float left, float right,  float bottom, float top,  float zNear, float zFar);  glm::dmat4 glm::frustum(  double left, double right,  double bottom, double top,  double zNear, double zFar); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

**glOrtho:**

|  |
| --- |
| glm::mat4 glm::ortho(  float left, float right,  float bottom, float top,  float zNear, float zFar);  glm::dmat4 glm::ortho(  double left, double right,  double bottom, double top,  double zNear, double zFar); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

5.2. GLM replacements for GLU functions

**gluLookAt:**

|  |
| --- |
| glm::mat4 glm::lookAt(  glm::vec3 const & eye,  glm::vec3 const & center,  glm::vec3 const & up);  glm::dmat4 glm::lookAt(  glm::dvec3 const & eye,  glm::dvec3 const & center,  glm::dvec3 const & up); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

**gluOrtho2D:**

|  |
| --- |
| glm::mat4 glm::ortho(  float left, float right, float bottom, float top);    glm::dmat4 glm::ortho(  double left, double right, double bottom, double top); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

**gluPerspective:**

|  |
| --- |
| glm::mat4 perspective(  float fovy, float aspect, float zNear, float zFar);  glm::dmat4 perspective(  double fovy, double aspect, double zNear, double zFar); |

One difference between GLM and GLU is that fovy is expressed in radians in GLM instead of degrees.

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

**gluPickMatrix:**

|  |
| --- |
| glm::mat4 pickMatrix(  glm::vec2 const & center,  glm::vec2 const & delta,  glm::ivec4 const & viewport);  glm::dmat4 pickMatrix(  glm::dvec2 const & center,  glm::dvec2 const & delta,  glm::ivec4 const & viewport); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

[**gluProject:**](http://www.opengl.org/sdk/docs/man2/xhtml/gluProject.xml)

|  |
| --- |
| glm::vec3 project(  glm::vec3 const & obj,  glm::mat4 const & model,  glm::mat4 const & proj,  glm::{i, ' '}vec4 const & viewport);  glm::dvec3 project(  glm::dvec3 const & obj,  glm::dmat4 const & model,  glm::dmat4 const & proj,  glm::{i, ' ', d}vec4 const & viewport); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

**gluUnProject:**

|  |
| --- |
| glm::vec3 unProject(  glm::vec3 const & win,  glm::mat4 const & model,  glm::mat4 const & proj,  glm::{i, ' '}vec4 const & viewport);  glm::dvec3 unProject(  glm::dvec3 const & win,  glm::dmat4 const & model,  glm::dmat4 const & proj,  glm::{i, ' ', d}vec4 const & viewport); |

From GLM\_GTC\_matrix\_transform extension: <glm/gtc/matrix\_transform.hpp>

6. Known issues

This section reports the divergences of GLM with GLSL.

6.1. not function

The GLSL keyword not is also a keyword in C++. To prevent name collisions, ensure cross compiler support and a high API consistency, the GLSL not function has been implemented with the name not\_.

6.2. Precision qualifiers support

GLM supports GLSL precision qualifiers through prefixes instead of qualifiers. For example, additionally to vec4, GLM exposes lowp\_vec4, mediump\_vec4 and highp\_vec4 types.

Similarly to GLSL, GLM precision qualifiers are used to handle trade-off between performances and precisions of operations in term of [ULPs](http://en.wikipedia.org/wiki/Unit_in_the_last_place).

By default, all the types use high precision.

|  |
| --- |
| // Using precision qualifier in GLSL:  ivec3 foo(in vec4 v)  {  highp vec4 a = v;  mediump vec4 b = a;  lowp ivec3 c = ivec3(b);  return c;  }  // Using precision qualifier in GLM:  #include <glm/glm.hpp>  ivec3 foo(const vec4 & v)  {  highp\_vec4 a = v;  medium\_vec4 b = a;  lowp\_ivec3 c = glm::ivec3(b);  return c;  } |

7. FAQ

7.1 Why GLM follows GLSL specification and conventions?

Following GLSL conventions is a really strict policy of GLM. It has been designed following the idea that everyone does its own math library with his own conventions. The idea is that brilliant developers (the OpenGL ARB) worked together and agreed to make GLSL. Following GLSL conventions is a way to find consensus. Moreover, basically when a developer knows GLSL, he knows GLM.

7.2. Does GLM run GLSL program?

No, GLM is a C++ implementation of a subset of GLSL.

7.3. Does a GLSL compiler build GLM codes?

No, this is not what GLM attends to do.

7.4. Should I use ‘GTX’ extensions?

GTX extensions are qualified to be experimental extensions. In GLM this means that these extensions might change from version to version without any restriction. In practice, it doesn’t really change except time to time. GTC extensions are stabled, tested and perfectly reliable in time. Many GTX extensions extend GTC extensions and provide a way to explore features and implementations and APIs and then are promoted to GTC extensions. This is fairly the way OpenGL features are developed; through extensions.

7.5. Where can I ask my questions?

A good place is the [OpenGL Toolkits](http://www.opengl.org/discussion_boards/ubbthreads.php?ubb=postlist&Board=10&page=1) forum on [OpenGL.org](http://www.opengl.org/).

7.6. Where can I find the documentation of extensions?

The Doxygen generated documentation includes a complete list of all extensions available. Explore this [API documentation](http://glm.g-truc.net/html/index.html) to get a complete view of all GLM capabilities!

7.7. Should I use ‘using namespace glm;’?

NO! Chances are that if using namespace glm; is called, especially in a header file, name collisions will happen as GLM is based on GLSL which uses common tokens for types and functions. Avoiding using namespace glm; will a higher compatibility with third party library and SDKs.

7.8. Is GLM fast?

GLM is mainly designed to be convenient and that's why it is written against the GLSL specification.

Following the Pareto principle where 20% of the code consumes 80% of the execution time, GLM operates perfectly on the 80% of the code that consumes 20% of the performances. Furthermore, thanks to the lowp, mediump and highp qualifiers, GLM provides approximations which trade precision for performance. Finally, GLM can automatically produce SIMD optimized code for functions of its implementation.

However, on performance critical code paths, we should expect that dedicated algorithms should be written to reach peak performance.

7.9. When I build with Visual C++ with /W4 warning level, I have warnings...

You should not have any warnings even in /W4 mode. However, if you expect such level for your code, then you should ask for the same level to the compiler by at least disabling the Visual C++ language extensions (/Za) which generates warnings when used. If these extensions are enabled, then GLM will take advantage of them and the compiler will generate warnings.

7.10. Why some GLM functions can crash because of division by zero?

GLM functions crashing is the result of a domain error that follows the precedent given by C and C++ libraries. For example, it’s a domain error to pass a null vector to glm::normalize function.

7.11. What unit for angles is used in GLM?

GLSL is using radians but GLU is using degrees to express angles. This has caused GLM to use inconsistent units for angles. Starting with GLM 0.9.6, all GLM functions are using radians. For more information, follow the [link](http://www.g-truc.net/post-0693.html#menu).

8. Code samples

This series of samples only shows various GLM features without consideration of any sort.

8.1. Compute a triangle normal

|  |
| --- |
| #include <glm/glm.hpp> // vec3 normalize cross  glm::vec3 computeNormal  (  glm::vec3 const & a,  glm::vec3 const & b,  glm::vec3 const & c  )  {  return glm::normalize(glm::cross(c - a, b - a));  }  // A much faster but less accurate alternative:  #include <glm/glm.hpp> // vec3 cross  #include <glm/gtx/fast\_square\_root.hpp> // fastNormalize  glm::vec3 computeNormal  (  glm::vec3 const & a,  glm::vec3 const & b,  glm::vec3 const & c  )  {  return glm::fastNormalize(glm::cross(c - a, b - a));  } |

8.2. Matrix transform

|  |
| --- |
| // vec3, vec4, ivec4, mat4  #include <glm/glm.hpp>  // translate, rotate, scale, perspective  #include <glm/gtc/matrix\_transform.hpp>  // value\_ptr  #include <glm/gtc/type\_ptr.hpp>  void setUniformMVP  (  GLuint Location,  glm::vec3 const & Translate,  glm::vec3 const & Rotate  )  {  glm::mat4 Projection =  glm::perspective(45.0f, 4.0f / 3.0f, 0.1f, 100.f);  glm::mat4 ViewTranslate = glm::translate(  glm::mat4(1.0f),  Translate);  glm::mat4 ViewRotateX = glm::rotate(  ViewTranslate,  Rotate.y, glm::vec3(-1.0f, 0.0f, 0.0f));  glm::mat4 View = glm::rotate(  ViewRotateX,  Rotate.x, glm::vec3(0.0f, 1.0f, 0.0f));  glm::mat4 Model = glm::scale(  glm::mat4(1.0f),  glm::vec3(0.5f));  glm::mat4 MVP = Projection \* View \* Model;  glUniformMatrix4fv(Location, 1, GL\_FALSE, glm::value\_ptr(MVP));  } |

8.3. Vector types

|  |
| --- |
| #include <glm/glm.hpp> //vec2  #include <glm/gtc/type\_precision.hpp> //hvec2, i8vec2, i32vec2  std::size\_t const VertexCount = 4;  // Float quad geometry  std::size\_t const PositionSizeF32 = VertexCount \* sizeof(glm::vec2);  glm::vec2 const PositionDataF32[VertexCount] =  {  glm::vec2(-1.0f,-1.0f),  glm::vec2( 1.0f,-1.0f),  glm::vec2( 1.0f, 1.0f),  glm::vec2(-1.0f, 1.0f)  };  // Half-float quad geometry  std::size\_t const PositionSizeF16 = VertexCount \* sizeof(glm::hvec2);  glm::hvec2 const PositionDataF16[VertexCount] =  {  glm::hvec2(-1.0f, -1.0f),  glm::hvec2( 1.0f, -1.0f),  glm::hvec2( 1.0f, 1.0f),  glm::hvec2(-1.0f, 1.0f)  };  // 8 bits signed integer quad geometry  std::size\_t const PositionSizeI8 = VertexCount \* sizeof(glm::i8vec2);  glm::i8vec2 const PositionDataI8[VertexCount] =  {  glm::i8vec2(-1,-1),  glm::i8vec2( 1,-1),  glm::i8vec2( 1, 1),  glm::i8vec2(-1, 1)  };  // 32 bits signed integer quad geometry  std::size\_t const PositionSizeI32 = VertexCount \* sizeof(glm::i32vec2);  glm::i32vec2 const PositionDataI32[VertexCount] =  {  glm::i32vec2(-1,-1),  glm::i32vec2( 1,-1),  glm::i32vec2( 1, 1),  glm::i32vec2(-1, 1)  }; |

8.4. Lighting

|  |
| --- |
| #include <glm/glm.hpp> // vec3 normalize reflect dot pow  #include <glm/gtx/random.hpp> // vecRand3  // vecRand3, generate a random and equiprobable normalized vec3  glm::vec3 lighting  (  intersection const & Intersection,  material const & Material,  light const & Light,  glm::vec3 const & View  )  {  glm::vec3 Color = glm::vec3(0.0f);  glm::vec3 LightVertor = glm::normalize(  Light.position() - Intersection.globalPosition() +  glm::vecRand3(0.0f, Light.inaccuracy());  if(!shadow(  Intersection.globalPosition(),  Light.position(),  LightVertor))  {  float Diffuse = glm::dot(Intersection.normal(), LightVector);  if(Diffuse <= 0.0f)  return Color;  if(Material.isDiffuse())  Color += Light.color() \* Material.diffuse() \* Diffuse;  if(Material.isSpecular())  {  glm::vec3 Reflect = glm::reflect(  -LightVector,  Intersection.normal());  float Dot = glm::dot(Reflect, View);  float Base = Dot > 0.0f ? Dot : 0.0f;  float Specular = glm::pow(Base, Material.exponent());  Color += Material.specular() \* Specular;  }  }  return Color;  } |

9. References

9.1. GLM development

- [GLM website](http://glm.g-truc.net)

- [GLM HEAD snapshot](https://github.com/g-truc/glm/archive/master.zip)

- [GLM bug report and feature request](https://github.com/g-truc/glm/issues)

- [G-Truc Creation’s page](http://www.g-truc.net/project-0016.html)

9.2. OpenGL specifications

- [OpenGL 4.3 core specification](http://www.opengl.org/registry/doc/glspec43.core.20120806.withchanges.pdf)

- [GLSL 4.30 specification](http://www.opengl.org/registry/doc/GLSLangSpec.4.30.7.diff.pdf)

- [GLU 1.3 specification](http://www.opengl.org/documentation/specs/glu/glu1_3.pdf)

9.3. External links

- [The OpenGL Toolkits forum to ask questions about GLM](http://www.opengl.org/discussion_boards/ubbthreads.php?ubb=postlist&Board=10&page=1)

- [GLM on stackoverflow](http://stackoverflow.com/search?q=GLM)

****9.4. Projects using GLM

[**Leo’s Forture**](http://www.leosfortune.com/)

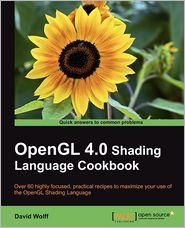
Leo’s Fortune is a platform adventure game where you hunt down the cunning and mysterious thief that stole your gold. Available on PS4, Xbox One, PC, Mac, iOS and Android.

Beautifully hand-crafted levels bring the story of Leo to life in this epic adventure.

“I just returned home to find all my gold has been stolen! For some devious purpose, the thief has dropped pieces of my gold like breadcrumbs through the woods.”

“Despite this pickle of a trap, I am left with no choice but to follow the trail.”

“Whatever lies ahead, I must recover my fortune.” -Leopold

[**OpenGL 4.0 Shading Language Cookbook**](http://www.packtpub.com/opengl-4-0-shading-language-cookbook/book?tag=rk/opengl4-abr1/0811)

A full set of recipes demonstrating simple and advanced techniques for producing high-quality, real-time 3D graphics using GLSL 4.0.

How to use the OpenGL Shading Language to implement lighting and shading techniques.

Use the new features of GLSL 4.0 including tessellation and geometry shaders.

How to use textures in GLSL as part of a wide variety of techniques from basic texture mapping to deferred shading.

[**Outerra**](http://outerra.com/)

3D planetary engine for seamless planet rendering from space down to the surface. Can use arbitrary resolution of elevation data, refining it to centimetre resolution using fractal algorithms.

**Falcor**

Real-time rendering research framework by NVIDIA.

**Cinder**

Cinder is a free and open source library for professional-quality creative coding in C++.

Cinder is a C++ library for programming with aesthetic intent - the sort of development often called creative coding. This includes domains like graphics, audio, video, and computational geometry. Cinder is cross-platform, with official support for OS X, Windows, iOS, and WinRT.

Cinder is production-proven, powerful enough to be the primary tool for professionals, but still suitable for learning and experimentation. Cinder is released under the [2-Clause BSD License](http://opensource.org/licenses/BSD-2-Clause).

[**opencloth**](http://code.google.com/p/opencloth/)

A collection of source codes implementing cloth simulation algorithms in OpenGL.

Simple, easy-to-follow examples with GLSL source code, as well as a basic description of the theory behind each technique.

[**Are you using GLM in a project?**](mailto:glm@g-truc.net)

9.5. OpenGL tutorials using GLM

- [The OpenGL Samples Pack](http://www.g-truc.net/project-0026.html#menu), samples that show how to set up all the different new features

- [Learning Modern 3D Graphics rogramming](http://www.arcsynthesis.org/gltut/), a great OpenGL tutorial using GLM by Jason L. McKesson

- [Morten Nobel-Jørgensen’s](http://blog.nobel-joergensen.com/2011/04/02/glm-brilliant-math-library-for-opengl/) review and use an [OpenGL renderer](https://github.com/mortennobel/RenderE)

- [Swiftless’ OpenGL tutorial](http://www.swiftless.com/opengltuts.html) using GLM by Donald Urquhart

- [Rastergrid](http://rastergrid.com/blog/), many technical articles with companion programs using GLM by Daniel Rákos  
- [OpenGL Tutorial](http://www.opengl-tutorial.org), tutorials for OpenGL 3.1 and later

- [OpenGL Programming on Wikibooks](http://en.wikibooks.org/wiki/OpenGL_Programming): For beginners who are discovering OpenGL.

- [3D Game Engine Programming](http://3dgep.com/): Learning the latest 3D Game Engine Programming techniques.

- [Game Tutorials](mailto:http://www.gametutorials.com/opengl-4-matrices-and-glm/), graphics and game programming.

- [open.gl](mailto:https://open.gl/), OpenGL tutorial

- [c-jump](mailto:http://www.c-jump.com/bcc/common/Talk3/Math/GLM/GLM.html), GLM tutorial

- [Learn OpenGL](mailto:http://learnopengl.com/), OpenGL tutorial

- [Are you using GLM in a tutorial?](mailto:glm@g-truc.net)

9.6. Equivalent for other languages

- [GlmSharp](https://github.com/Philip-Trettner/GlmSharp): Open-source semi-generated GLM-flavored math library for .NET/C#.

- [glm-js](https://github.com/humbletim/glm-js): JavaScript adaptation of the OpenGL Mathematics (GLM) C++ library interfaces

- [Java OpenGL Mathematics (GLM)](https://github.com/java-graphics/glm)

- [JGLM](https://github.com/jroyalty/jglm) - Java OpenGL Mathematics Library

- [SwiftGL Math Library](https://github.com/SwiftGL/Math/blob/master/Sources/glm.swift)

- [glm-go](https://github.com/jbowtie/glm-go): Simple linear algebra library similar in spirit to GLM

- [openll](https://github.com/Polkm/openll): Lua bindings for OpenGL, GLM, GLFW, OpenAL, SOIL and PhysicsFS

- [glm-rs](https://github.com/dche/glm-rs): GLSL mathematics for Rust programming language

9.7. Alternatives to GLM

- [CML](http://cmldev.net/): The CML (Configurable Math Library) is a free C++ math library for games and graphics.

- [Eigen](http://eigen.tuxfamily.org/): A more heavy weight math library for general linear algebra in C++.

- [glhlib](http://glhlib.sourceforge.net/): A much more than glu C library.

- [Are you using or working on an alternative library to GLM?](mailto:glm@g-truc.net)

9.8. Acknowledgements

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