Manual

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Introduction

OpenGL Mathematics (GLM) is a C++ mathematics library for graphics C++ programs based on the OpenGL Shading Language (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 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 4.0 and higher
- GCC 4.2 and higher
- Intel C++ Composer XE 2013 and higher
- LLVM 3.0 and higher
- Visual C++ 2010 and higher
- 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.

Thanks for contributing to the project by submitting reports for bugs and feature requests. Any feedback is welcome at 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>
```

```cpp
// 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`, `gl3.h`, `glu.h` or `windows.h`. However, if `<boost/static_assert.hpp>` is included, Boost static assert 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`. 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. 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_integer

Provide integer variants of GLM core functions.

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

4.6. 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.

4.7. 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.

4.8. GLM_GTC_matrix_inverse

Define additional matrix inverting functions.

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

4.9. 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.

4.10. GLM_GTC_noise

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

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

Figure 4.10.1: glm::simplex(glm::vec2(x / 16.f, y / 16.f));

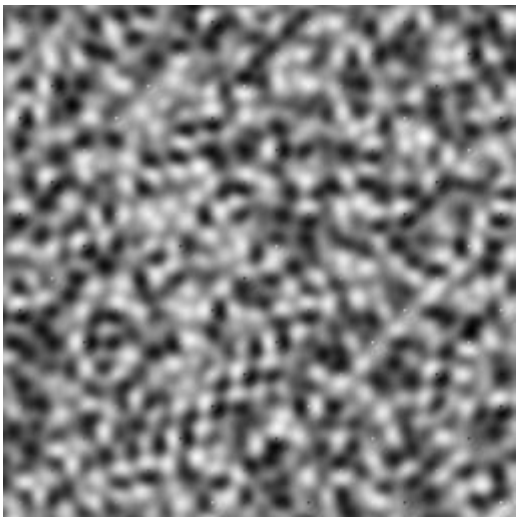


Figure 4.10.2: glm::simplex(glm::vec3(x / 16.f, y / 16.f, 0.5f));

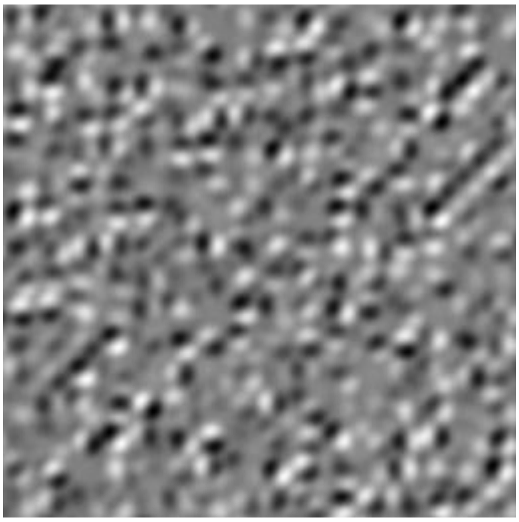


Figure 4.10.3: glm::simplex(glm::vec4(x / 16.f, y / 16.f, 0.5f, 0.5f));

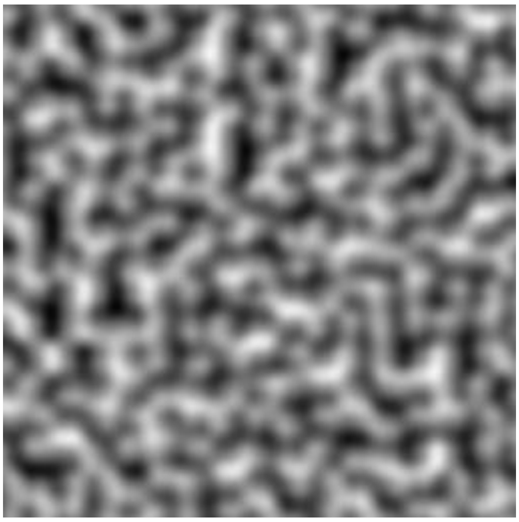


Figure 4.10.4: glm::perlin(glm::vec2(x / 16.f, y / 16.f));

Figure 4.10.5: `glm::perlin(glm::vec3(x / 16.f, y / 16.f, 0.5f));`

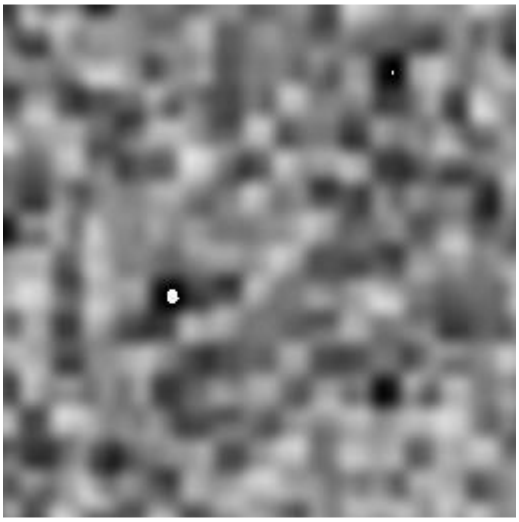


Figure 4.10.6: `glm::perlin(glm::vec4(x / 16.f, y / 16.f, 0.5f, 0.5f)));`

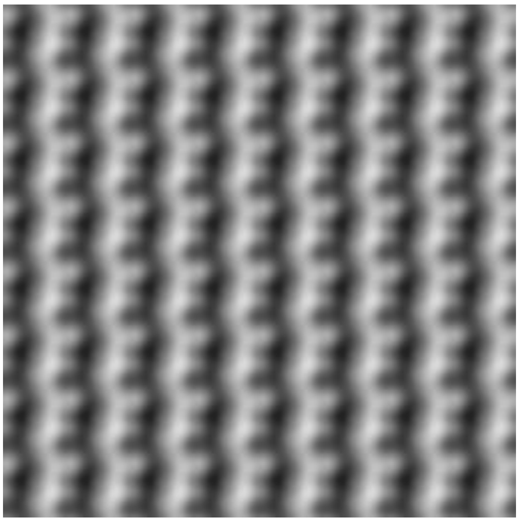


Figure 4.10.7: `glm::perlin(glm::vec2(x / 16.f, y / 16.f), glm::vec2(2.0f));`

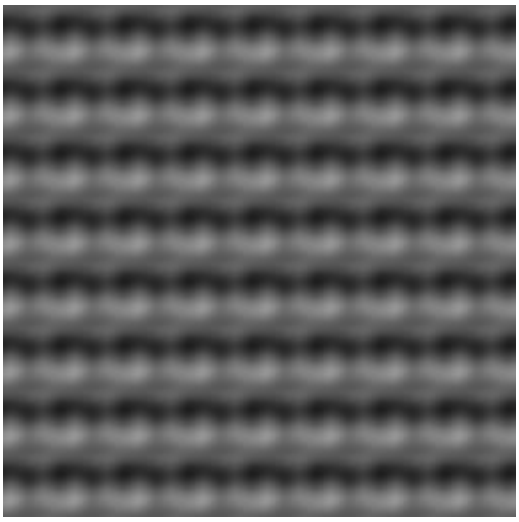


Figure 4.10.8: `glm::perlin(glm::vec3(x / 16.f, y / 16.f, 0.5f), glm::vec3(2.0f));`

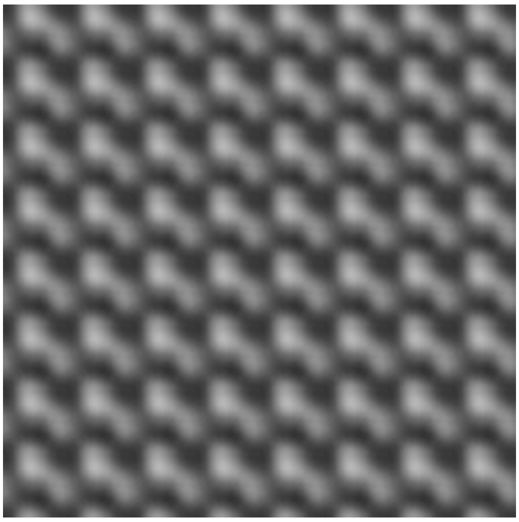


Figure 4.10.9: `glm::perlin(glm::vec4(x / 16.f, y / 16.f, glm::vec2(0.5f)), glm::vec4(2.0f));`

4.11. 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.

4.12. GLM_GTC_quaternion

Define a quaternion type and several quaternion operations.

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

4.13. GLM_GTC_random

Generate random number from various distribution methods.

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

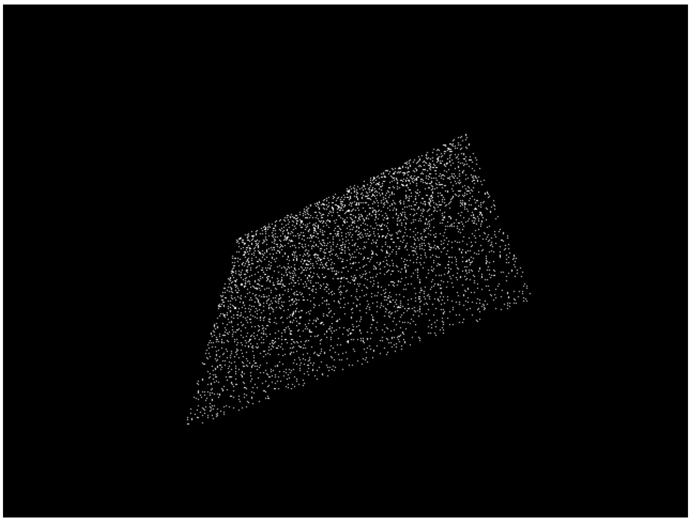


Figure 4.13.1: `glm::vec4(glm::linearRand(glm::vec2(-1), glm::vec2(1)), 0, 1);`

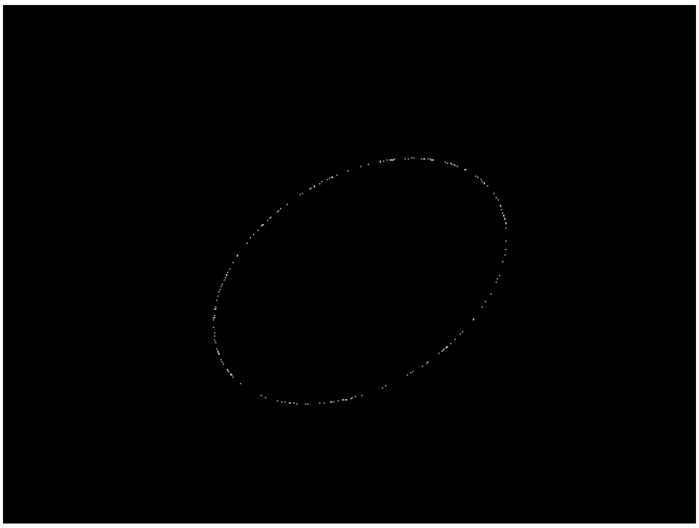


Figure 4.13.2: `glm::vec4(glm::circularRand(1.0f), 0, 1);`

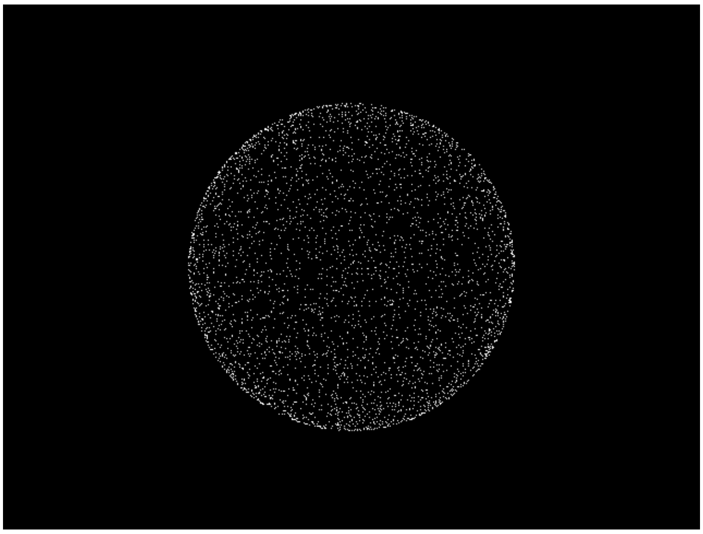


Figure 4.13.3: `glm::vec4(glm::sphericalRand(1.0f), 1);`

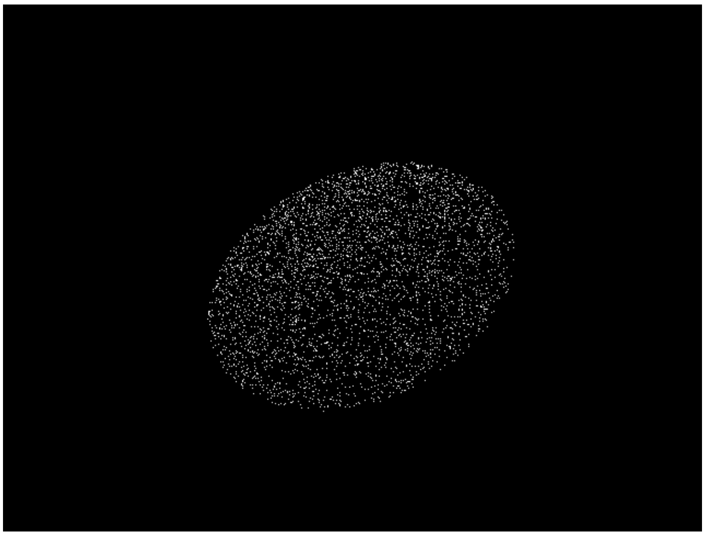


Figure 4.13.4: `glm::vec4(glm::diskRand(1.0f), 0, 1);`

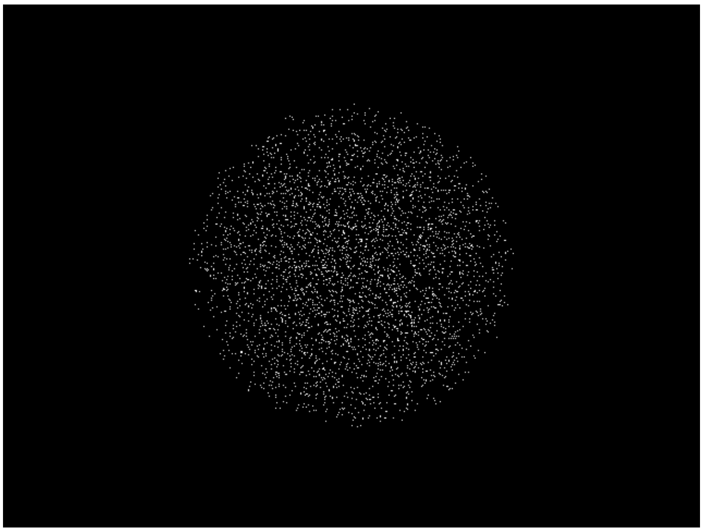


Figure 4.13.5: `glm::vec4(glm::ballRand(1.0f), 1);`

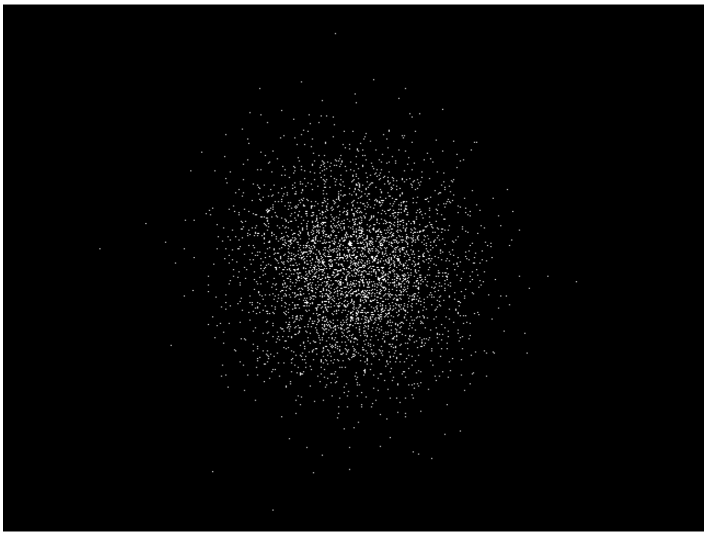


Figure 4.13.6: `glm::vec4(glm::gaussRand(glm::vec3(0), glm::vec3(1)), 1);`

4.14. GLM_GTC_reciprocal

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

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

4.15. GLM_GTC_round

Rounding operation on power of two and multiple values.

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

4.16. 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.

4.17. 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(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.

4.18. 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.

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

4.19. 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}:

```
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:
```
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:

```
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.

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 forum on 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 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.

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
- GLM HEAD snapshot
- GLM bug report and feature request
- G-Truc Creation's page

9.2. OpenGL specifications

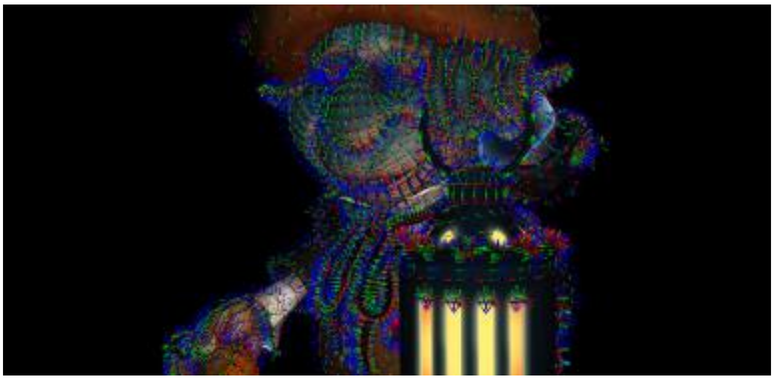
- OpenGL 4.3 core specification
- GLSL 4.30 specification
- GLU 1.3 specification

9.3. External links

- The OpenGL Toolkits forum to ask questions about GLM
- GLM on stackoverflow

9.4. Projects using GLM

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.

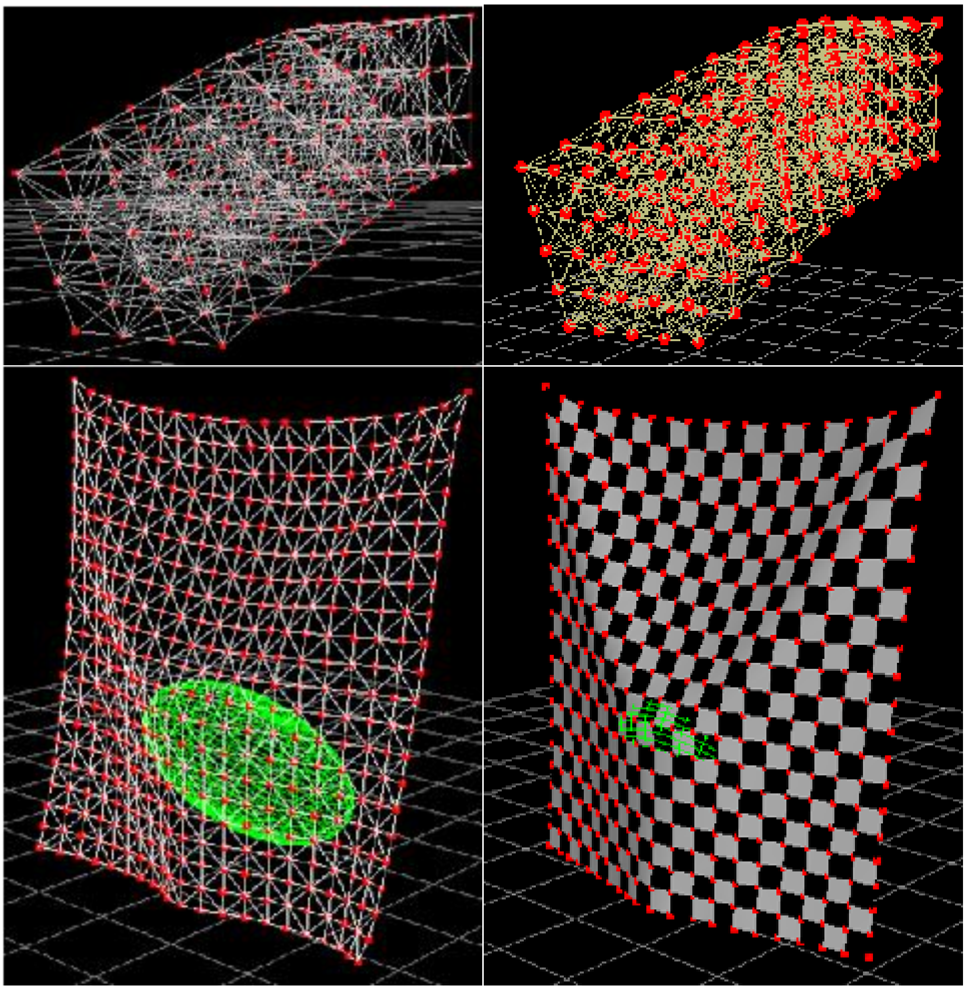
Cinder is production-proven, powerful enough to be the primary tool for professionals, but still suitable for learning and experimentation. Cinder is released under the 2-Clause BSD License.

Outerra

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.

opencloth

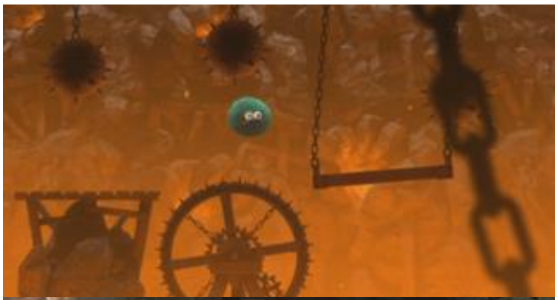
A collection of source codes implementing cloth simulation algorithms in OpenGL.

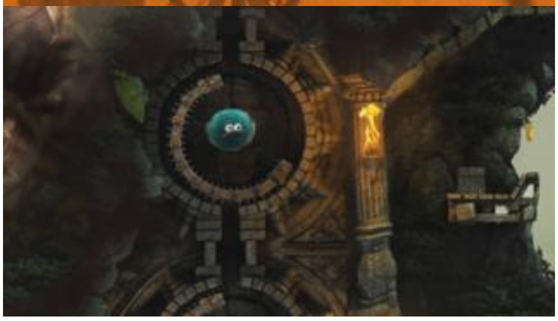


Falcor

Real-time rendering research framework by NVIDIA.

Leo’s Fortune





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

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.

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?

9.5. OpenGL tutorials using GLM

- The OpenGL Samples Pack, samples that show how to set up all the different new features
- Learning Modern 3D Graphics rogramming, a great OpenGL tutorial using GLM by Jason L. McKesson
- Morten Nobel-Jørgensen's review and use an OpenGL renderer
- Swiftless' OpenGL tutorial using GLM by Donald Urquhart
- Rastergrid, many technical articles with companion programs using GLM by Daniel Rákos
- OpenGL Tutorial, tutorials for OpenGL 3.1 and later
- OpenGL Programming on Wikibooks: For beginners who are discovering OpenGL.
- 3D Game Engine Programming: Learning the latest 3D Game Engine Programming techniques.
- Game Tutorials, graphics and game programming.
- open.gl, OpenGL tutorial
- c-jump, GLM tutorial
- Learn OpenGL, OpenGL tutorial

- Are you using GLM in a tutorial?

9.6. Equivalent for other languages

- GlmSharp: Open-source semi-generated GLM-flavored math library for .NET/C#.
- glm-js: JavaScript adaptation of the OpenGL Mathematics (GLM) C++ library interfaces
- Java OpenGL Mathematics (GLM)
- JGLM - Java OpenGL Mathematics Library
- SwiftGL Math Library
- glm-go: Simple linear algebra library similar in spirit to GLM
- openll: Lua bindings for OpenGL, GLM, GLFW, OpenAL, SOIL and PhysicsFS
- glm-rs: GLSL mathematics for Rust programming language

9.7. Alternatives to GLM

- CML: The CML (Configurable Math Library) is a free C++ math library for games and graphics.
- Eigen: A more heavy weight math library for general linear algebra in C++.
- glhlib: A much more than glu C library.

- Are you using or working on an alternative library to GLM?

9.8. Acknowledgements

GLM is developed and maintained by Christophe Riccio but many contributors have made this project what it is.

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