

# Project: 3D Pipeline in Software

## Topics covered

- 3D transforms
- Frustum plane equations
- Spherical bounding volume construction and transformation
- Culling models using spherical bounding volume
- Clipping triangles against frustum plane equations
- Depthbuffer algorithm
- Back-face removal
- Rasterization of triangle and line primitives

## Final Project Sandbox Script

Create a new directory, say [csd2101-project](#) and download the project sandbox batch file [csd2101-project.bat](#) from the tutorial web page into it. Use File Explorer to open directory [csd2101-project](#). Open the command-line shell by typing [cmd](#) [and pressing Enter in the Address Bar]. Execute script [csd2101-project.bat](#) [by typing the script's name in the shell and then pressing Enter]. Select option S to setup project environment. This option also creates a Visual Studio 2022 solution called [csd2101+proj.sln](#) in directory [csd2101-project\build](#). Select option 0 to create a nested directory [csd2101+proj](#) in the [projects](#) directory and pull starter-code source code. Open the [csd2101+proj.sln](#) in visual studio, compile and execution final project. Below is the folder layout:-

```

1  └ csd2101-project/   # 📁 Sandbox directory for final project submission
2  |   └ build/         # All build files for your platform exist here
3  |   └ content/       # Texture and mesh resource files for project
4  |   └ lib/            # Contain glm and GfxLib
5  |   └ projects/
6  |   |   └ csd2101+proj  # 💾 stater code folder for project
7  |   |   |   └ GfxDriver    # 📂 Contain engine implementation source folder
8  |   |   |   |   └ src        # 📂 Source and Header files
9  |   |   |   |   |   └ main.cpp      # ⚡ main entry point
10 |   |   |   |   |   └ YourBoundingBoxSphere.cpp # ⚡ Bounding Sphere algo
11 |   |   |   |   |   └ YourCamera.cpp      # ⚡ FPS camera implementation
12 |   |   |   |   |   └ YourCamera.h        # 📄 FPS camera header
13 |   |   |   |   |   └ YourCullerClipper.cpp # ⚡ Culling and cliping impl.
14 |   |   |   |   |   └ YourCullerClipper.h  # 📄 Culling and cliping header
15 |   |   |   |   |   └ YourRasterizer.cpp  # ⚡ Rasterizer implementation
16 |   |   |   |   |   └ YourRasterizer.h    # 📄 Rasterizer header
17 |   |   |   └ GfxLib          # ⚡ Source files - *.cpp and .c files
18 |   |   |   |   └ gfx            # 📂 Contain many GfxLib header files
19 |   |   └ CMakeLists.txt     # 🛠 CMake configuration file
20 |   └ csd2101-project.bat  # 📄 Automation Script

```

# Software Framework

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- A codebase that abstracts a software-based graphics pipe is provided for this assignment. The tasks described in the project specs below are completely implemented by the framework. You can implement the project specs in any order. Thus, while completing a certain task, you can use the framework's implementations for other unfinished tasks to test your current task.
- The software implementation of the graphics pipe renderer is included as library file **GfxLib.lib** [in directory `csd2101-project\lib\gfx\lib\[Debug|Release]`]. The project will create an executable program by linking the software emulator library to the object code generated by your contribution in project **csd2101+proj**.
- The framework is completely based on the OpenGL based graphics pipeline discussed in lectures. Just as with GLFW, **GfxLib** will create color buffers, depthbuffer, and the store for texture images. All coordinate systems described in lectures will work as is – there are no surprises except for one [see below].
- OpenGL has always used a different coordinate system than computer hardware, display devices, and Windows to reference and index two-dimensional entities such as windows, viewports, color and depth buffers, and textures. Windows uses the upper-left corner as origin with  $x$ -axis oriented right and  $y$ -axis oriented *down*. Recall that OpenGL describes its viewport and texture coordinates using the lower-left corner as origin with  $x$ -axis oriented right and  $y$ -axis oriented *up*. This means that a pixel [or a texel]  $(x, y)$  generated by OpenGL [and the framework] cannot be rendered as is. Instead, the pixel's  $y$  coordinate must be mapped to the coordinate system used by Windows. You **must** implement this mapping to correctly access the color buffer, depth buffer, and texture images.
- Since this framework was written before GLM was invented, it uses homegrown classes `Vector3`, `Vector4`, and `Matrix4` to implement the mathematical elements of a graphics rendering pipeline. GLM has now been integrated into the project - you can use GLM functionality in your code simply by including the appropriate headers in source files without modifying the project's properties.

## What is to be implemented?

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- *Triangle rasterizer* with the following features: back-face culling, depth buffering, color, and texture coordinate interpolation. Assume *repeat* wrap mode for texture coordinates along both  $s$  and  $t$  axes. Assume vertex color coordinates  $(r, g, b, a)$  are in range  $[0, 1]$ . You will have to implement one interpolation technique: *linear* barycentric interpolation [equivalent to GLSL `noperspective` interpolation qualifier and equivalent to your previous assignments].
- *Wireframe rasterizer* that uses Bresenham algorithm to render edges of triangles.
- *Spherical bounding volume construction and transform*. Use Ritter's method to compute model bounding spheres. Once a bounding sphere is constructed, it must be transformed into the destination frame in which the object is culled. Assume affine transforms on objects are always applied in the following order: scale, followed by rotation, followed by translation.
- *Six frustum plane equations* of the frustum in view frame are computed using only the matrix manifestation of perspective (or, orthographic) transformation.
- *View-frustum object culling* using spherical bounding volumes in view frame.
- *Convex polygon clipping* using Sutherland-Hodgeman algorithm.
- *First person camera*.

- A correct implementation of the specs is provided. The sample also implements picking and planar perspective shadows [you're not required to implement these features].
- For a complete list of user controls, see the definition of functions `MyMouseHandler()` and `MyKeyHandler()` in `csd2101-project\projects\csd2101+proj\GfxDriver\src\main.cpp`.

## Step-by-step implementation

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The first two steps must be implemented while the remaining steps can be implemented in any order you choose.

- The VS 2022 solution `csd2101+proj.sln` contains a single project labeled `csd2101+proj`. The project's properties [in both Debug and Release configurations] are setup to include a simplistic software implementation of OpenGL [in `csd2101-project\lib\gfx\lib\[Debug|Release]\GfxLib.lib`] for both Debug and Release configurations; setup of geometric models and textures; Windowing and I/O facilities; and GLM. The software emulator's header files are accessible from the project and are located in `csd2101-project\projects\csd2101+proj\GfxLib\gfx`. Open the solution, and then compile, link, and execute the project. You should see the scene displayed [although with a reduced framerate]. Unlike the sample, the default implementation will not be able to pick objects. To improve framerate and to get picking to work, you'll have to implement auxiliary functions `gfxModel::ComputeModelBVSphere()` and `gfxSphere::Transform()` [in the next step].

*The software pipe requires spherical bounding volumes to implement view frustum culling, clipping, and picking. Therefore, you must first implement both auxiliary functions `gfxModel::ComputeModelBVSphere()` and `gfxSphere::Transform()` [described below] before proceeding to implement other functionalities required by the spec.*

- *Bounding spheres:* Complete the following steps in file `\csd2101-project\projects\csd2101+proj\GfxDriver\src\YourBoundingSphere.cpp`:
  - `gfxModel::ComputeModelBVSphere()`: This function is called once for each model at program startup to enclose the model's position coordinates in a bounding sphere constructed using Ritter's method. Note: Computing the bounding sphere using a trivial method involving AABBs will result in significant deductions.
  - `gfxSphere::Transform()`: This function transforms the model's bounding sphere with the corresponding object's geometric transform [recall that an object is an instance of a model] into a reference destination frame. Assume the sequence of affine transforms that may be applied to the model's instance will always consist of scale [if any], followed by rotation [if any], followed by translation [if any].
- *Culling:* Before transferring an object's geometry and render data to the graphics pipe, the bounding volume must be checked for trivial acceptance or trivial rejection with respect to the frustum. Trivially rejected objects are discarded while trivially accepted objects are not clipped. Objects that are neither trivially accepted nor rejected will intersect with the frustum and must therefore be clipped. To facilitate trivial acceptance or rejection tests, implement the following functions in file `\csd2101-project\projects\csd2101+proj\GfxDriver\src\YourCullerClipper.cpp`:

- `ComputeFrustum()` : This function computes the six plane equations of the frustum in view frame.
- `cull()` : Using an object's bounding sphere and the graphics pipe's frustum, this function first computes the bounding sphere's *outcode*. Using this *outcode*, the function will determine an object's status with respect to clipping: *trivial acceptance*, or *trivial rejection*, or *intersection*.
- *Triangle clipping*: If an object is neither trivially accepted nor rejected [as reported by previous function `cull()`], the object's triangles must be clipped. Implement the following functions in file

`\csd2101-project\projects\csd2101+proj\GfxDriver\src\YourCullerClipper.cpp:`

- `clip()` : Clips object triangles using Sutherland-Hodgeman algorithm.
- To test your culling and clipping implementation and for correct submission, uncomment the following line in  
`\csd2101-project\projects\csd2101+proj\GfxDriver\src\main.cpp:`

```
1 | //#define YOUR_CULLER_CLIPPER
```

- *Triangle and wireframe rasterizer*: Implement a triangle and wireframe rasterizer in file  
`\csd2101-project\projects\csd2101+proj\GfxDriver\src\YourRasterizer.cpp` with the following features:

- Back-face culling, depth buffering, texture coordinate interpolation, vertex color interpolation, and texture wrapping.
- Vertex color and texture coordinates must be interpolated using linear barycentric interpolation method.
- Some objects in the scene are texture mapped while others are lit. There are no objects that are both lit and texture mapped. The stub function `drawFilled()` provides details on how to determine if the triangle is texture mapped or lit.
- In wireframe mode, use Bresenham algorithm to complete definition of stub function `DrawLine()`. The function must be implemented using integer-only arithmetic and should render pixels using black color.
- To test your rasterizer, uncomment the following line in  
`\csd2101-project\projects\csd2101+proj\GfxDriver\src\main.cpp:`

```
1 | //#define YOUR_RASTERIZER
```

- *First person camera*: The camera described in class lectures is suitable for applications such as flight simulators. For this project, you will instead implement a slightly different camera. This camera should allow a character to walk on a planar floor even if the character is looking up into the sky. This behavior is different than a flight simulator where the aircraft is displaced in the direction in which it looks.

- Read declaration of base camera class, `gfxcamera`, in  
`csd2101-project\lib\gfx\Camera.h`.
- Read declaration of derived camera class, `YourCamera`, in  
`\csd2101-project\projects\csd2101+proj\GfxDriver\src\YourCamera.h`.
- Implement the derived camera class, `YourCamera`, in  
`\csd2101-project\projects\csd2101+proj\GfxDriver\src\YourCamera.cpp`.

- To test your implementation [as opposed to the framework implementation], uncomment the following line in  
`\csd2101-project\projects\csd2101+proj\GfxDriver\src\main.cpp:`

```
1 | //">#define YOUR_CAMERA
```

## Submission

1. The source and header files for `csd2101+proj` must be placed in a directory labeled as: `<student-login-name>-<course>-<proj>`. If your DIT student login is foo, then the directory would be labeled as `foo-csd2100-proj` and would have the following structure and layout:

```
1 | ┌─ foo-csd2100-proj   # 🖊 You're submitting final project with your login
  |   name
  2 |   └─ GfxDriver
  3 |     └─ src
  4 |       └─ ┌─ main.cpp
  5 |       └─ ┌─ YourBoundingSphere.cpp
  6 |       └─ ┌─ YourCamera.cpp
  7 |       └─ ┌─ YourCamera.h
  8 |       └─ ┌─ YourCullerClipper.cpp
  9 |       └─ ┌─ YourCullerClipper.h
 10 |       └─ ┌─ YourRasterizer.cpp
 11 |       └─ ┌─ YourRasterizer.h
 12 |   └─ GfxLib
 13 |     └─ gfx           # ⚠ [NO CHANGES EXPECTED HERE!]
```

2. Zip the directory and upload the resultant file `foo-csd2100-proj.zip` to the submission page on the course web page.

## Grading Rubrics

The core competencies assessed for this assessment are:

- **[core1]** Submitted code must build an executable file with **zero** warnings. This rubric is not satisfied if the generated executable crashes or displays nothing. In other words, if your source code doesn't compile nor link nor execute, there is nothing to grade.
- **[core2]** This competency indicates whether you're striving to be a professional software engineer, that is, are you implementing software that satisfies project requirements [are you submitting the required files? are they properly named? are they properly archived? are you submitting unnecessary files?], that is maintainable and easy to debug by you and others [are file and function headers properly annotated?]. Submitted source code must satisfy **all** requirements listed below. Any missing requirement will decrease your grade by one letter grade.
  - Source code must compile with **zero** warnings. Pay attention to all warnings generated by the compiler and fix them.
  - Source code files submitted is correctly named.
  - Source code files are *reasonably* structured into functions and *reasonably* commented. See next two points for more details.

- If you've created a new source code file, it must have file and function header comments.
- If you've edited a source code file provided by the instructor or from a previous tutorial, the file header must be annotated to indicate your co-authorship and the changes made to the original or previous document. Similarly, if you're amending a previously defined function, you must annotate the function header to document your amendments. You must add a function header to every new function that you've defined.
- [core3] Bounding spheres are correctly computed using Ritter's algorithm. ***Implementation using a trivial algorithm involving AABB or similar scheme will not be accepted.***
- [core4] Wireframe images must be rendered using integer-only Bresenham algorithm with pixels rendered in black color.
- [core5] Triangle rasterization [with depth buffering, back-face removal, vertex color and texture coordinates interpolated using barycentric interpolation method, and repeat texture wrap mode] is correctly implemented. Rasterization artifacts such as holes and dropouts will be significantly penalized.
- [core6] Object culling is correctly implemented. Frustum plane equations should be computed as described in class lectures. Computing plane equations using naïve methods will result in significant deductions. Bounding spheres must be correctly transformed into a destination reference frame. Incorrect transforms of bounding spheres will result in significant deductions.
- [core7] Triangle clipping is correctly implemented using Sutherland-Hodgeman algorithm. Clipping artifacts such as tears and holes will be significantly penalized.
- [core8] First-person camera is correctly implemented. This camera should allow a character to walk on a planar floor even if the character is looking up into the sky.

## Mapping of Grading Rubrics to Letter Grades

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The following table illustrates the mapping of core competencies listed in the grading rubrics to letter grades:

Grading Rubric Assessment	Letter Grade
There is no submission.	F
core1 rubric is not satisfied. Submitted property page and/or source code doesn't build. Or, executable generated by build crashes or displays nothing.	F
If core2 rubrics are not satisfied, final letter grade will be decreased by one. This means that if you had received a grade A and core2 is not satisfied, your grade will be recorded as B, an A– would be recorded as B–, and so on.	
If core3 is not implemented, then the main learning outcomes of this assignment cannot be assessed.	F
If none of six rubrics [core3 thro' core8] are correctly implemented.	F
One of six rubrics [core3 thro' core8] is correctly implemented.	D
Two of six rubrics [core3 thro' core8] are correctly implemented.	D+

Grading Rubric Assessment	Letter Grade
Three of six rubrics [ <b>core3</b> thro' <b>core8</b> ] are correctly implemented.	<i>C</i>
Four of six rubrics [ <b>core3</b> thro' <b>core8</b> ] are correctly implemented.	<i>C+</i>
Five of six rubrics [ <b>core3</b> thro' <b>core8</b> ] are correctly implemented.	<i>B+</i>
All six rubrics [ <b>core3</b> thro' <b>core8</b> ] are correctly implemented.	<i>A+</i>
<p>Note that your implementation will be tested with different scenes. You can modify the scene [by adding additional objects for instance] by amending the code in <code>InitScene()</code> defined in  <code>csd2101-project\projects\csd2101+proj\GfxDriver\src\main.cpp</code>.</p>	