CS171 Assignment 2: Geometric Modeling

Introduction

In this assignment, you are going to step into the geometric modelling section in computer graphics by generating Bézier surfaces, and other surfaces such as B-Spline/NURBS surfaces if you want. To accomplish the surface restruction, you can reduce this problem into sub-problems in the lower dimension, which is the evaluation of Bézier curve. Once you are able to generate the curve, the surface is then a piece of cake.

In the following, we will give you the specifics about what you need to accomplish, as well as some related guidelines to assist your programming.

Note

Before doing the assignment, please read the materials on curve and surface modeling, and in particular, Bézier curves and surfaces. You can also refer to Delaunay triangulation and subdivision methods for more advanced implementations.

Programming Requirements

- **[must]** You are required to implement the basic iterative de Casteljau Bézier vertex evaluation algorithm. [30%]
- **[must]** You are required to construct Bézier surfaces with the normal evaluation at each mesh vertex. [40%]
- **[must]** You are required to render the Bézier surfaces based on the vertex array. [10%]
- **[must]** You are required to create more complex meshes by stitching multiple Bézier surface patches together. [20%]
- **[optional]** You may construct the B-Spline/NURBS surfaces. [15%]
- **[optional]** You may support the interactive editing (by selection) of control points. [10%]
- **[optional]** You may implement the adaptive mesh construction based on the curvature estimation. [15%]

Demonstration Requirements

In addition to programming, you will also need to demonstrate your code to TAs.

Things you should prepare:

- Explain how you implement the basic iterative de Casteljau Bézier verytex evaluation algorithm, and show the related code fragments.
- Explain how you construct the Bézier surface and evaluate the vertex normal, and show the related code fragments.
- Explain how you render the Bézier surfaces based on the vertex array, show the related code fragments, and demonstrate the result.
- Explain how you stitch multiple Bézier surface patches together, show the related code fragments, and demonstrate the result.
- For the optional part, explain your implementation and show it!

Additional Notification:

- You should try your best to present your ideas as clearly as possible.
- If you do not follow the above requirements, your score will be deduced by 10% of the entire assignment score.

Submission

You are required to submit the following things through the GitHub repository:

- Project scripts and an executable program in the Coding folder.
- A PDF-formatted report which describes what you have done in the Report folder.

Submission deadline: **22:00, Oct 25, 2021**

Grading rules

- You can choose to do the **[optional]** item, and if you choose to do it, you will get additional scores based on the additional work you have done. But the maximum additional score will not exceed 20% of the entire score of this assignment.
- **NO CHEATING**! If found, your score for the assignment is zero. You are required to work **INDEPENDENTLY**. We fully understand that implementations could be similar somewhere, but they cannot be identical. To avoid being evaluated inappropriately, please show your understanding of your code to TAs.
- Late submission of your assignment will be subject to score deduction based on the rule on the course webpage.

Skeleton Project/ Report Template

The skeleton program and report template will be provided once you accept the assignment link of GitHub classroom which will be given below. If you accept the assignment through the link properly, a repository that contains the skeleton project and the report template will be created under your GitHub account. Please follow the template to prepare your report.

You should complete your assignment submission to your repository through GitHub before the deadline.

Implementation Guide

Git Classroom

Accept the assignment in this link or download the zip file to start your assignment.

1. Environment Setup

Just like the warm-up assignment, you will need CMake to build your code. To build the project, firstly you need to download CMake if you do not have one. Then run command

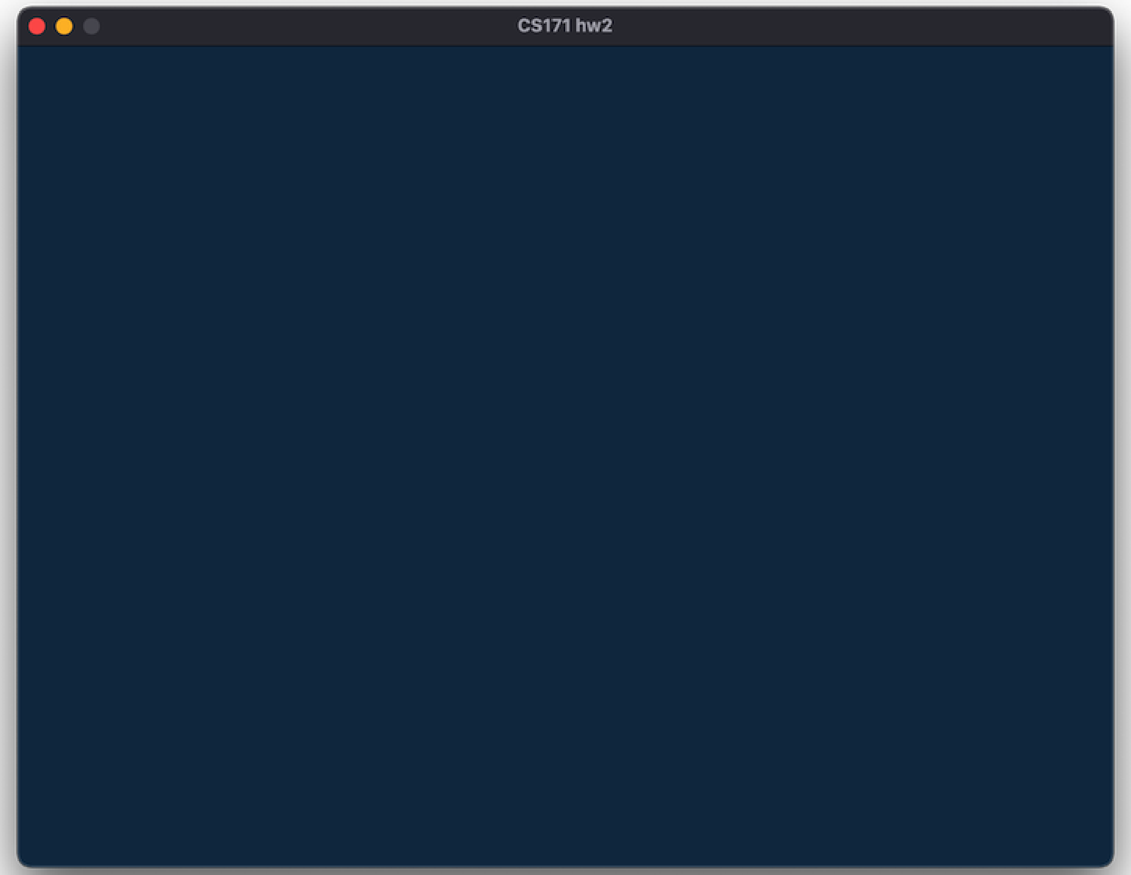
```
mkdir build
cd build
cmake ..
cmake --build
```

These commands first make a directory whose name is "build" and then jump into it. After that, it uses CMake to configure the project and builds the project.

Besides, we recommend using Visual Studio in Windows and Visual Studio Code in Linux. Both of them can build the CMake-based projects automatically (maybe with help of some plugins). If you are an experienced developer, you can choose whatever you like.

2. Creating the window program using GLFW

We have already created a blank window for you to start your drawing. You should expect the following result.



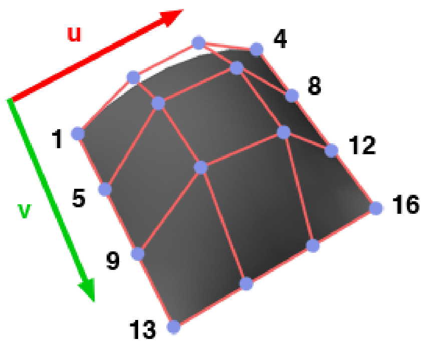
3. Evaluating points in Bézier curve with De Casteljau's Algorithm

Here, you are supposed to implement the function `Vertex BezierCurve::evaluate(std::vector<vec3>& control_points, float t)` in "bezier.cpp", where you need to evaluate two things of each point: the point position and the tangent. For the evaluation of positions, you can follow this site. As for the tangent, it is a by-product of the position evaluation, and thus there is no need to pay extra efforts on the tangent evaluation.

4. Constructing the Bézier surface

Here, you are supposed to implement the function `Vertex BezierSurface::evaluate(std::vector<std::vector<vec3>>& control_points, float u, float v)` in "bezier.cpp" for evaluating the vertices on a Bézier surface.

Since you are already able to evaluate the vertices on a Bézier curve, you can definitely utilize it to make things easier. In short, given $m \times n$ control points to evaluate the point at (u, v), you can first construct m intermediate Bézier curves based on the corresponding n control points and evaluate m points at v, and then, construct another Bézier curve based on the m points and evaluate the point at u, which is shown in the following GIF.



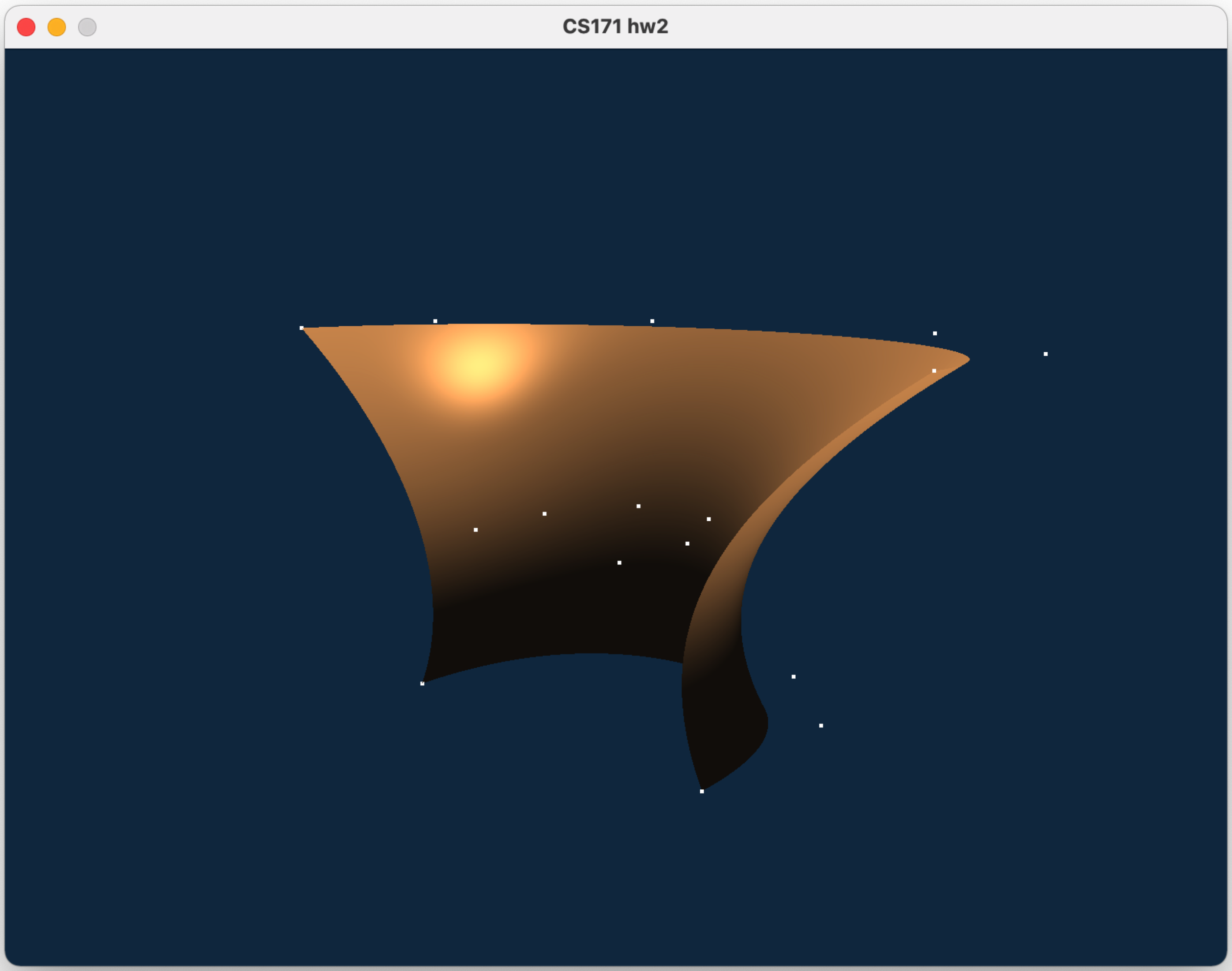
In this process, you can compute the position, and the tangent along one dimension. To compute the normal, you need to apply the cross product of the tangents along two dimensions, which can be obtained along with the above process.

Please refer to this tutorial for this part.

5. Rendering the Bézier surfaces

In this part, you are supposed to firstly implement the function `void Object::init()`, which initializes all the related OpenGL variables like VAO, VBO and EBO, and configure the attributes. After this, you should implement the function `void Object::drawArrays()` or `void Object::drawArrays(const Shader& shader)` to support object drawing with VAO and VBO, and the function `void Object::drawElements()` or `void Object::drawElements(const Shader& shader)` to support object drawing with VAO, VBO and EBO.

After implementing this, you can successfully render all kinds of Bézier surfaces. Here we offer some examples.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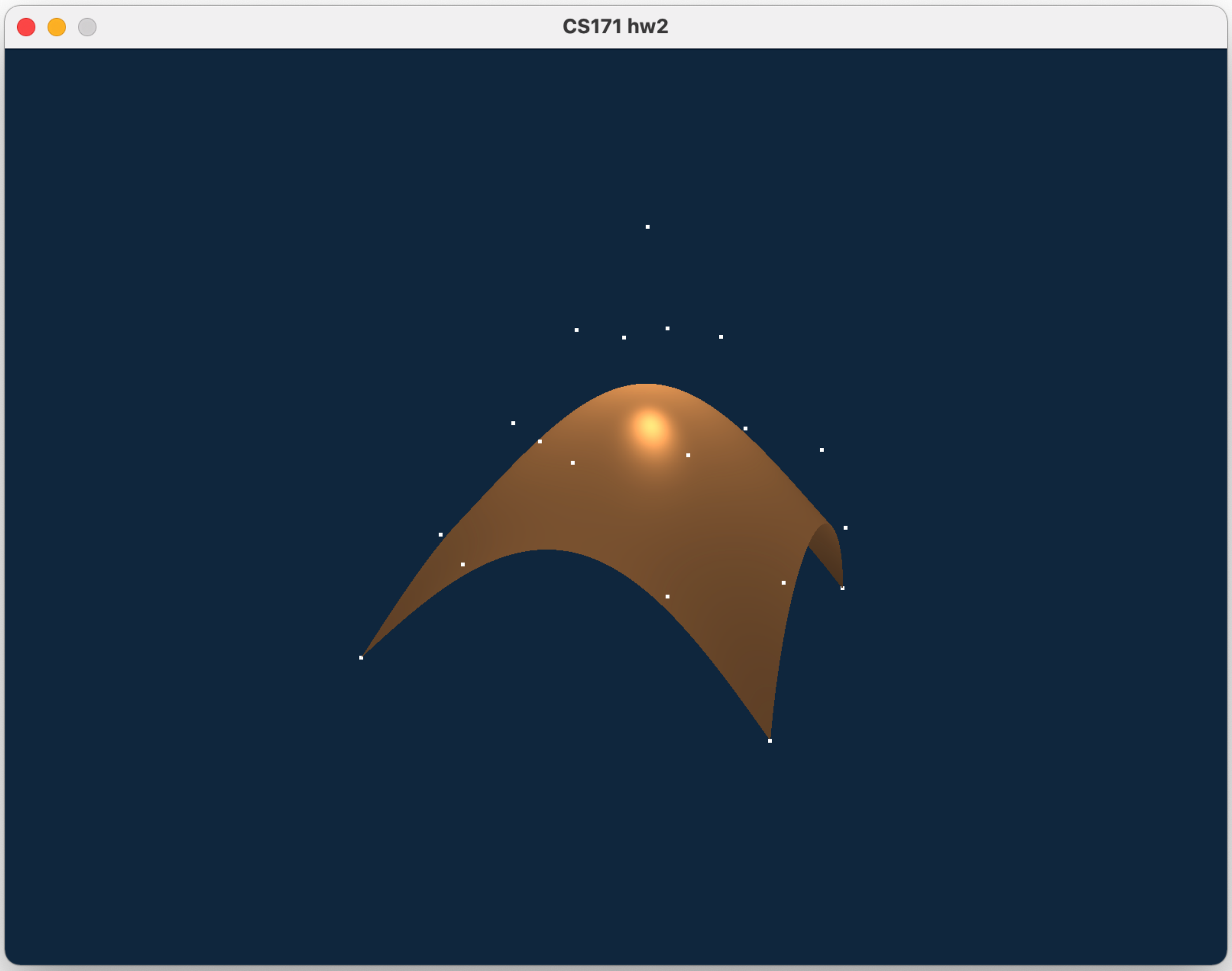
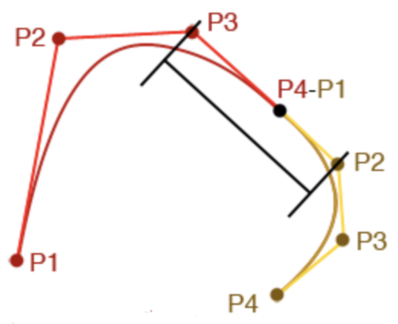
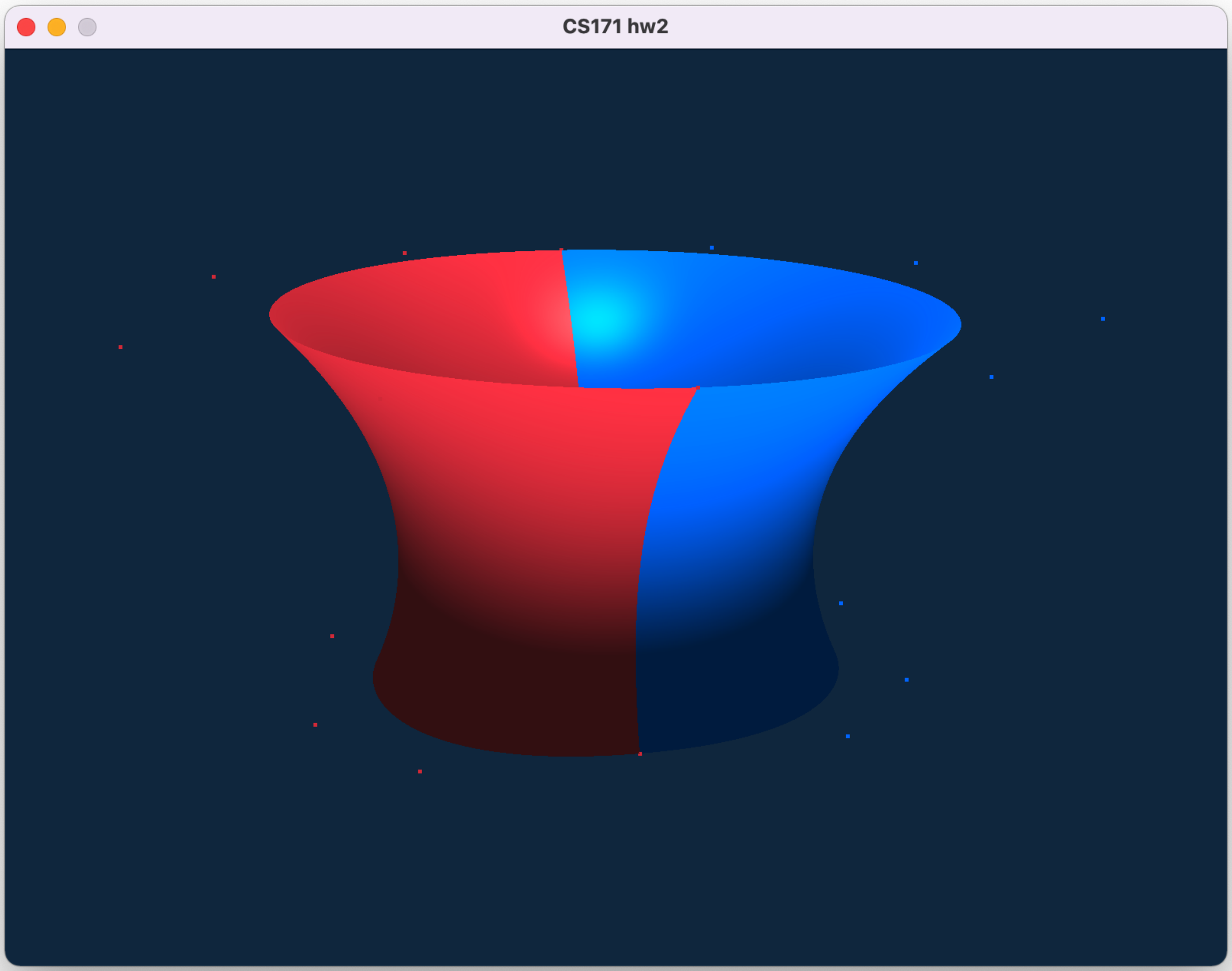


6. Patching together multiple Bézier surfaces

Several Bézier curves/surfaces can be connected to together to form a longer curve/surface. A 0-th order (L0) continuity means that the curves/surfaces are connected only (the last and first control points of the first and second curve/surface are connected), but their tangents are not necessarily continuous. 1st order continuity (L1) means that not only the points are connected, but also their tangents (first derivative) are continuous at the joint. To ensure this, we need to make sure that the control polygon are colinear at the last control point of the first curve/surface and the first control point of the second curve/surface. For example, the following picture shows such a patching of two different Bézier curves, where red P1~P4 form one Bézier curve and yellow Pl~P4 form another curve. To ensure L1 continuity, we need to make sure that the red P3P4 and yellow P1P2 are colinear.



It is similar to patch Bézier surfaces. You can define several surfaces and patch them together to form a more complex shape. For an example, we stitch two surfaces together as below.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