Philipps-Universität Marburg

Fachbereich 12 - Mathematik und Informatik

Master Thesis

Dynamic Insertion of 3D Objects from CAD Files into Unreal Engine

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Septermber 2022

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Declaration of Originality

I, Matija Miskovic (Computer Science Student at Philipps-University Marburg, Matrikelnummer 3139015), versichere an Eides statt, dass ich die vorliegende Diplomarbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe. Die hier vorliegende Diplomarbeit wurde weder in ihrer jetzigen noch in einer ähnlichen Form einer Prüfungskommission vorgelegt.

Marburg, 17. Dezember 2009

Max Mustermann

Abstract

Viele der in der Computergrafik verwendeten 3D-Modelle werden mit Hilfe der Dreieck-snetze repräsentiert. ... (max. 1 Seite)

Abstract

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1 Introduction

The topic of this thesis the dynamic insertion of 3D objects, defined in computer assisted design(CAD) Files, into an Unreal Engine program while it is running. Especially important for the project are why this might even a problem and how it can actually be realized. For these purposes an Unreal Engine plug-in was developed which enables such functionality and an additional Unreal Engine program which implements the plug-in and can be used to present and interact with the objects in a multi-user desktop or virtual reality environment.

1.1 Motivation

Virtual reality(VR) is a relatively new field which is constantly seeing a lot of interest and innovation for all the new possibilities in opens up in software development and user interaction. In recent years VR has been used in many companies in various industries such as the engineering, architecture and healthcare and this number keeps on growing. One such company is Inosoft [].
Inosoft is a software development firm in Marburg which was founded in 1993 and has since worked and consulted over two thousand projects for various companies including Viessmann, CSL Behring, Sanofi and many more. They are also very interested in VR and have been working in the field since 2016. Inosoft was also interested in establishing a working relationship with the Phillips University Marburg. As such they reached out with some very interesting projects in the field of VR. Among them was designing and developing a concept to dynamically insert and interact with objects from CAD files in a running Unreal Engine environment.
There are definitely certain scenarios where this could be a very useful tools. As an example, let's take a software Inosoft developed which is used to train workers in a digital production plan while the physical building was being built. This quite a handy tool and has helped quite a bit [**?**]. Slight problems arise when things about the model need to be added or changed. First the changes need to be implemented in Unreal, packaged for standalone use and then redistributed to everyone who needs to use them. It would be a lot simpler if the program could simply open a file and add the new or update objects without ever having to change the version of it.
Another use-case where this could be useful is in collaborative design or presenting 3D models. Instead of having to make the scene and import everything beforehand and distribute this version of the program, simply having a program that can open a file and have the model appear for everyone involved could save a lot of time and effort.
So seeing as there are uses for this technology it makes sense to look into how it could be

done and what the limitations are, as well as looking into why this isn't already officially part of Unreal Engine.

1.2 Goals

The main goal of this work is to develop an efficient and user-friendly plug-in which will make it possible to load 3D objects from the most common CAD formats during the runtime of an Unreal Engine program. Additionally another software will be developed to use the plug-in and allow simple interactions with these objects in a normal desktop window as well as in a virtual reality environment.

Efficiency

The developed plug-in should be capable of handling large amounts of data seeing as the models which can be found in CAD files can be incredibly large, containing thousands or millions of vertices and polygons. If the plug-in were to effect the runtime performance in a significant way, such as causing stutters or freezing the program all together, it would severely worsen the user experience and invalidate the whole point of the program.

Expandability

The field of computer assisted design is very wide and there are countless programs and formats for all the varying use-cases in which it is being used. That is why creating one solution for all of those is incredibly complicated and way out of the scope and possibilities of this project. Instead it is much better to concentrate on creating a simple to use and understand system which can then be further improved upon and adjusted for the concrete cases of clients or projects.

1.3 Thesis Structure

In Chapter 2 the Unreal Engine will be clarified and explained. Seeing as this is both the tool which is being used for development as well as being the software for which the plug-in is being developed, an understanding of how it works and what its limitations are is needed in order to better grasp the project and what problems might arise. It is a rather expansive tool so not everything will be covered, only the more basic aspects and the concrete parts which play a role for this project. Then, in Chapter 3, the plug-in will be analysed, starting of with how the files are parsed and into what sort of form they are transformed in order to be used. After that comes the actual mesh generation mesh, how it is achieved and where extra attention is required. In Chapter 3.3 it will be illustrated in what ways users can interact with the newly created objects, either using mouse and keyboard or a virtual reality headset. In Chapter 4 the developed programs will be presented, evaluated and compared to similar software to see where its strengths and weaknesses are. Lastly in Chapter 5 the reached goals and some possible further projects and improvements will be discussed.

1.4 Related Works

When it comes to this topic there are unfortunately not that many similar works. When it comes generally importing CAD files into Unreal Engine, Datasmith definitely needs to be mentioned.

Datasmith is an official set of tools and plug-ins created by Epic Games, the developers of Unreal Engine, to simplify and streamline the process of importing various CAD formats into the engine []. It is important to note that the main focus of Datasmith is to make the process of transferring a model from a CAD software into the Unreal Engine editor during development smoother and more efficient []. Nonetheless amongst the many features it has it does also contain a plug-in for loading the models in runtime. This plug-in is still in being developed, even upon installation there are clear warnings that the software is still in a beta, so there are some missing features and there also haven't seemingly been many updates to it since the initial research for this project started [].

Outside of Datasmith there are a handful of small plug-ins that can be found which handle this topic, most importantly glTFRuntime [] and Runtime FBX Import []. They were developed by a small team and a single person respectively and are available to be bought in the Unreal Marketplace. The strengths and weaknesses of these tools, as well as Datasmith, will be discussed in further detail later in order better evaluate the programs developed for this project.

2 Unreal Engine

The Unreal Engine is a 3D graphics video game engine, first created for the first person shooter Unreal in 1998 [?]. Originally written mostly by Tim Sweeney, the founder of Epic Games, it has since grown an incredible amount and become one of the most popular game engines on the market, only perhaps beaten by Unity []. It has also had many versions since its initial release, first with Unreal Engine 2 in 2002 and then with version 3 in 2006 []. Up until recently Unreal Engine 4, released in 2014, was the latest version but April of 2022 saw the official release of Unreal Engine 5. All of the versions were written in C++ enabling great performance as well as portability, so that the engine is currently supported on a wide range of desktop, console, mobile and even virtual reality platforms [].

In its more than 25 year history the Unreal Engine has been used to create a vast number of incredibly popular and critically acclaimed games such as Fortnite, Hellblade and the Bioshock series, only to name a few. Even though the main use-case has remained video game development, the engine has seen wide adoption in many other industries as well. In film making it can be used to create virtual sets that can be rendered in real time on large LED screens and lighting systems while also tracking around actors and objects using the camera's movement. Epic Games worked with the Industrial Lights and Magic of division Lucasfilm to develop their StageCraft technology [?], first used in filming the television show The Mandalorian [?]. Outside of these creative fields due to its wast functionalities and ease of use, it has been used to create virtual reality tools to explore building and car designs, as well pharmaceutical drug molecules [?].

For the purposes of this project Unreal Engine 4.27 was used and this is the version that will be described unless specified otherwise. Although this technically isn't the latest version and the development of this project started around the same time as version 5 was officially released, there were multiple reason as to why this decision was made. First of all, pretty much any new software release tends to bring with it a number of bugs and quirks which need to be discovered and fixed first. This doesn't always have to be the case but a lot of developers will wait for the software become more ironed out before using it. That is if they even want to use UE5. There are many programs already written in earlier versions of it and not every one of those might truly require the new features UE5 brings with it so the update might not even occur. Also the initial research for the project, which also included learning how Unreal works and how to use it, was done months before the launch.

On the other hand Unreal Engine 4 is a very mature tool which has been used and improved for years now. There are also many sub-versions of it but the decision was

made to use the latest one, 4.27.2, as it should be UE4 at its best and also due to the excellent compatibility between it and earlier version of UE4.

2.1 Unreal Engine Basics

Developing a video game is quite a complicated process and requires various features in order to create a cohesive experience. As Unreal is primarily a game development engine it also has to support many of these functionalities. In total there are more than dozen editors for levels, materials, meshes,physics and user-interface, to just name a few, but for the purposes of this project only a few are of relevance. These are the level and blueprint editors.

The level editor is the primary editor where the levels are created and modified by placing, transforming and editing properties of objects. This is also the default screen Unreal shows when creating or opening a project and what that looks like is shown in figure 2.1. As can be seen in the figure, in the centre of the screen is the level itself. Above it is a toolbar for managing project settings, code, plug-ins and as well a play button which can be used to launch the game inside of the editor for testing purposes. On the bottom the content browser which display all of the assets which are part of the project can be found. This includes meshes, materials, code as well as project plug-ins. On the left is a toolbar for placing various built in objects and on the right all of the objects in the current world, as well as details about the currently selected object can be seen.
This is also generally the screen where a developer would import any external assets into the engine directly or through one of the engines importer tools.
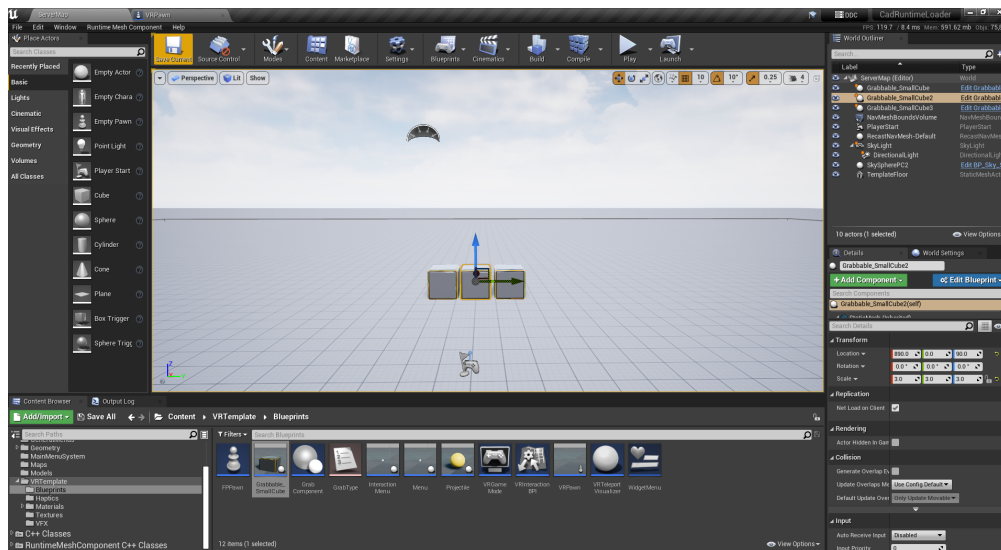

Figure 2.1: Example of what the Level Editor looks like for a project

Actors and Components

In Unreal Engine all of the objects that can be placed inside of a level are called Actors. This includes everything from meshes to particle systems to even the players starting location. This is partially due to Unreal Engines object-oriented nature so having all objects inherit from one base class, in this case Actor, is quite beneficial. Actors can be created and destroyed through code and support 3D transformations like translation, scaling and rotation.

In order to add functionality to an Actor, so called Components are used. Components can offer varying functionalities such as creating sounds, light or movement and once they are added to an Actor, the Actor can access these features and use them for its own purposes. It is important to note that a Component cannot exist on its own and an instance of a Component has to be attached to an instance of an Actor. It doesn't have to be directly attached though, a Component itself can also have several subcomponents. So the Components are what actually makes an Actor what it is supposed to be. One way to think about this is a house. All of the walls, floors, lights and other parts would be the Components, while the house in its entirety is the Actor.

When an Actor is placed inside a level it gets a world transformation which describes the Actors location, scale and rotation in comparison to the world origin. A Component along with that also gets a relative transform, which are again the same values as the world transformation but this time relative to the origin of its parent object. The world transform of a component can be calculating by adding the relative transformation to the parents world transformation. This is very important to keep in mind when components are moved around in a scene.

Pawns and Controllers

Amongst all of the Actor subclasses, there are two which need to be especially highlighted. These are Pawns and Controllers and they form the basis of user-interaction in Unreal Engine.

The Pawn class is the base class for all Actors which can be controlled by a user or through AI. A Pawn determines what a user looks like visually and how they interact with their surroundings either through collision or other physical means. Generally for Pawns that will be controlled by users a further subclass called Character is used. A Character has the additions of a Character Movement, Capsule and Skeletal Mesh Component. The Character Movement Component enables various means of moving like walking, flying, swimming for a character in a scene. It assumes that collision class is vertically-oriented capsule, described in the Capsule Component, and uses this for movement collision. The Skeletal Mesh simply allows for the use of more complex animations which require some sort of skeleton. What this looks like inside the editor can be seen in Figure 2.2. This is the basic template Unreal provides for a third person character. Aside from the already mentioned components, it also has an Arrow Component, which

shows what direction is forwards for the character, and a Camera Component that represents where the view of a user will be in a project.
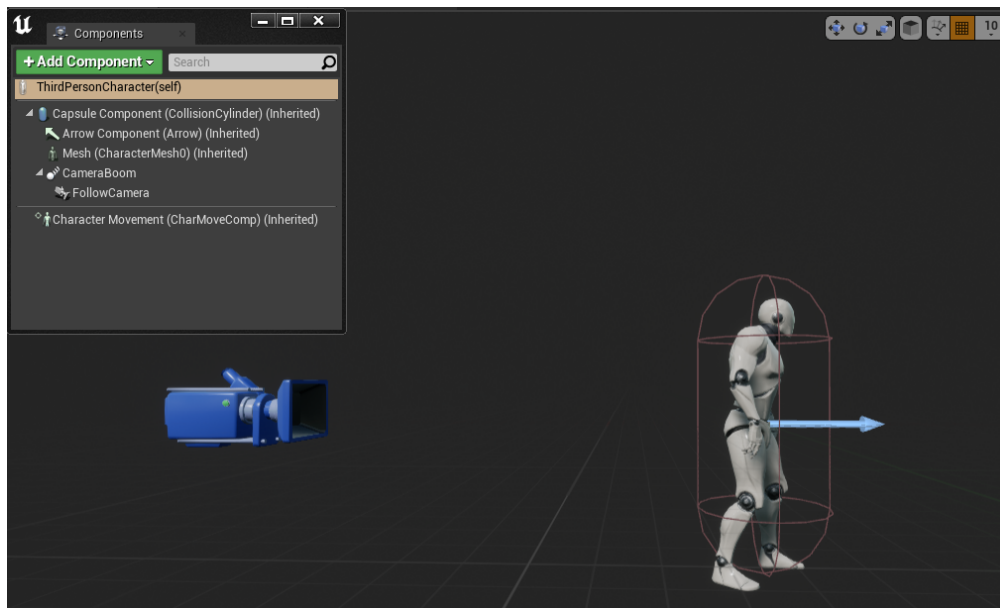

Figure 2.2: Template for third person character

While some functionalities can already be implemented inside of a Pawn, this alone is not enough to get user inputs. For that an additional Actor called a Controller is necessary, specifically a Player Controller. A Player Controller is a non-physical Actor that functions as an interface between a human user and a Pawn. Generally speaking there is a one-to-one relationship between a Player Controller and a Pawn. There are cases where this doesn't have to be the case but for the purposes of this project that is not of interest. This relationship doesn't mean that a Controller can only ever posses one Pawn, just that it can only do one Pawn at a time. The process of gaining controller over a Pawn is called possessing and losing control is called unpossessing. This, alongside slight differences between classes, is why it is important to properly choose whether certain functionalities should be implemented in the Pawn or the Controller.

2.2 C++ and Blueprints

Now that the most important design elements have been explained, the next step is to explain how writing code in Unreal Engine works. When it comes to this regard, Unreal has a rather unique combination of programming tools with C++ and its own Blueprint Visual Scripting system. As already mentioned, Unreal is written in C++ so it makes sense that it would also be used for its programming. What is important to note is the fact that it is not pure C++ that is actually used. Rather, Unreal Engine

has developed its own extensive C++ API, also known as simply Unreal C++, tailored for game development build upon normal C++. This API provides libraries for common game development features as well many built-in classes, functions and utilities. The idea behind this is to have a fully functioning framework that makes the developing process a lot simple and faster than it would've been using standard C++. An excellent example of this is the fact the Unreal C++ support multiplayer and network replication on a core engine level.

The other way to program in Unreal Engine is the Blueprint Visual Scripting system, more commonly referred as simply Blueprints. This system is a relatively new addition to Unreal as it was first released with the launch of Unreal Engine 4. It was meant to be a replacement for the previous Kismet scripting system which was quite complicated and very outdated. Blueprints themself, like many visual scripting languages, use an object-oriented approach for developing. It is a very powerful and flexible tool which is meant to allow designers to create impressive gameplay elements without needing to know how to program. As such it has access to almost all the same frameworks and APIs C++ has. This means that whole games and projects could be made only using blueprints. Likewise the same could also be done with only C++ but such approaches are generally not advised. There is a reason after all why Unreal specifically has both tools and they each have their purposes in development. C++ is advantageous when designing base systems for a project and for writing performance critical features. On the other hand, Blueprints shine when they are used to design the behaviour and incorporate it into the rest of the program. Another great benefit of Blueprints is that, due to their simplicity, allow for rapid prototyping and then these prototypes can easily be translated into C++ if the increased performance is necessary.

Due to this unique mix of tools, a typical workflow for creating features would look as follows. First a C++ programmer would create a new class, add the required features and properties and then make sure that they can properly be accessed in the Blueprints. An example of a header for such a class is shown in Figure 2.3. As can be seen, the code

```
1    #include "MyObject.generated.h"
2
3    UCLASS(Blueprintable)
4    class UMyObject : public UObject{
5        GENERATED_BODY()
6
7        MyUObject();
8
9        UPROPERTY(BlueprintReadWrite, EditAnywhere)
10       float PropertyExample;
11
12       UFUNCTION(BlueprintCallable, Category = "Example")
13       void FunctionExample();
14   };
```

Figure 2.3: Example Unreal C++ Class Header

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does resemble normal C++ header code with a few special lines. Most important are the macros that can be found in the 3rd, 9th and 12th line of code. These special lines of code are used to describe the class, property or function in the line below them. This description is used by the Unreal Editor to determine if and how these objects should be presented in Blueprints. As an example the property is set to "BlueprintReadWrite" so that it can be read and modified in Blueprints. There are many specifiers that can be used depending on what the desired outcome is and it is important that these are used properly to mitigate possible problems.

Once that part of the development is done, the new class can be used in the engine. The class itself, seeing as it is C++ code, can't be directly worked with in the Blueprint editor. Instead a new Blueprint class needs to be made that inherits from the C++ class and then that new class can be opened in the editor.

As already mentioned, Blueprints are a visual scripting system, which means that the code isn't represented through text but rather with nodes which are connected among each other. An example as to how this looks like in the Blueprint editor is shown in Figure 2.4.
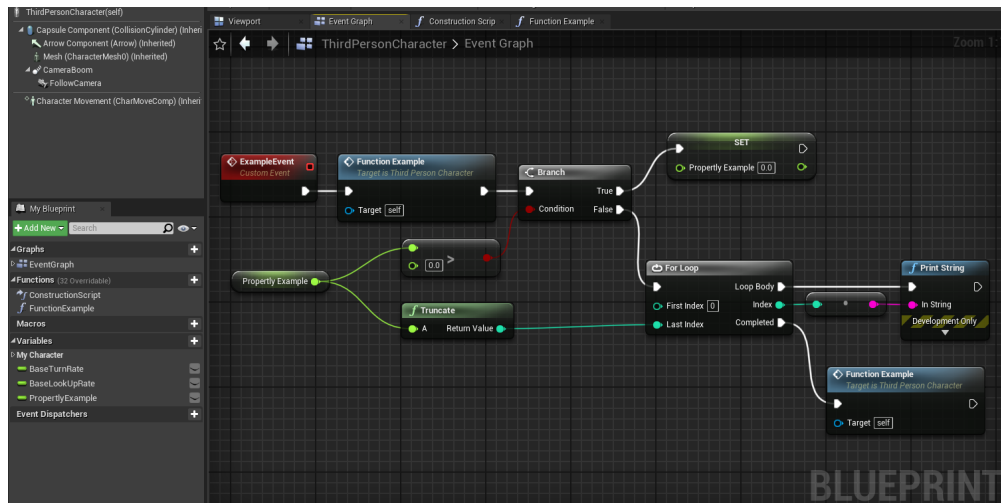

Figure 2.4: Example of Blueprint Code in the Blueprint Editor

In the top left side of the screen the components of the current actor can be seen again. Underneath that is an overview of all the functions, graphs and variables contained in the blueprint. In the centre of the editor is the event graph of the class, this is where all the various events that can happen to it are handled. In the example shown it needs to be noted that the view is heavily zoomed into a single event in order to better see the individual nodes. Typically there will be many events all across the graph and also sub-graphs to keep the code readable.

The execution flow of the code is represented by the white line connecting the nodes. The nodes themselves have varying functions and are accordingly colour coded for better

understanding. Red nodes represent the starting point of an event. This can be triggered by many actions including collision, player inputs or other events. Blue nodes are either functions or event calls and green nodes are usually used for getting values. Lastly grey nodes represent macros or flow control nodes. This is where the typical programming tools such as if conditions, for and while loops can be found. Depending on if they are needed, input and output pins can respectively be found on the left and right side of a node. These are connected using lines that automatically match the colour of the value, which are also colour coded, and can only be connected to other pins of the correct type. All in all, these properties and features make using Blueprints quite simple and almost play-like, which makes them accessible to a wider audience, while staying quite powerful.

2.3 Networking

One trait that is specific to a Player Controller is that only one exists in the world of a user and only that user can access it. All the other users have no idea of any other controllers even existing. For any sort of interaction between them a server is needed, which has access to copies of all of the controllers. That

3 Dynamic 3D Object Insertion

In diesem Kapitel soll das eigene Verfahren beschrieben werden. Es geht dabei nicht nur darum zu beschreiben was gemacht wurde, sondern ebenfalls darum zu begründen, weshalb bestimmte Design-Entscheidungen getroffen wurden. Das Kapitel sollte nicht „Eigenes Verfahren" heißen, sondern etwas mit dem Titel der Arbeit zu tun haben.

3.1 File Formats and Parsing

3.1.1 File Sharing

3.2 Runtime Mesh Generation

3.2.1 Runtime Mesh Component

3.2.2 Material Generation

3.3 Object Interaction

3.3.1 Mouse and Keyboard

3.3.2 Virtual Reality

3.4 Plug-in Installation and Usage

4 Results and Evaluation

In diesem Kapitel sollen die Ergebnisse dieser Diplomarbeit diskutiert werden.

4.1 CAD Runtime Loader

4.2 Comparison to related works

4.3 Shortcomings and possible Improvements

5 Conclusion

In diesem Kapitel sollen zunächst die erreichten Ziele diskutiert und abschließend ein Ausblick auf mögliche, weiterführende Arbeiten gegeben werden.

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List of Abbreviations

ALU Arithmetic Logic Unit
BTF Bidirektionalen Textur Funktion
CPU Central Processing Unit
CU Control Unit
CUDA Compute Unified Device Architecture
FLOPs Floating Point Operations Per Second
FPU Floating Point Unit
GPGPU General Purpose Computation on Graphics Processing Unit
GPU Graphics Processing Unit
HLOD Hierarchische Level of Detail
IFS Indexed-Face-Set
LOD Level of Detail
MIMD Multiple Instruction Multiple Data
OpenCL Open Computing Language
OpenGL Open Graphics Library
PCAM Partitionierung Kommunikation Agglomeration Mapping
PM Progressive Meshes
SFU Spezial Funktion Units
SIMD Single Instruction Multiple Data
SIMT Single Instruction Multiple Threads
SLI Scalable Link Interface
SP Streaming-Prozessoren
SM Streaming-Multiprozessoren
TPC Textur Prozessor Clustern
VBO Vertex Buffer Object

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Listings