1 Introduction

The aim of this project was, to build a prototype, showcasing the capabilities a Virtual F1 Attendance application would need and how it could look. The application in mind (Virtual F1 Attendance) would enable a User to watch a virtual F1 race as if he was attending the race at the racetrack, providing the needed immersion into the virtual world for an exhilarating experience.

In order to accomplish this, the choice of a suitable game engine for development needs to be determined. Given the growing popularity of NVIDIA's Omniverse and the increasing adoption of USD (Universal Scene Description) as a standard for 3D development applications, the decision was made to utilize Omniverse in conjunction with Unreal Engine 5. This choice will not only facilitate the creation of the prototype but also allow for testing the collaborative and co-simulation capabilities between Omniverse and Unreal Engine, as Omniverse provides a Connector for Unreal Engine (UE). As a prerequisite we recommend looking at the project "Co-Simulation UE and Omniverse - "SpaceVerse" GTC demo - Return on Experience", as many parts of this project base on it as well as the idea for delving into co-simulation between Omniverse and Unreal Engine was sparked by this project.

1.1 USD and Its Advantages

Universal Scene Description (USD) is a versatile and efficient open-source file format developed by Pixar Animation Studios. It serves as a universal standard for storing and exchanging 3D scene data, fostering collaboration and streamlined workflows in the computer graphics industry. The features of USD, such as scene representation, interoperability, scalability and performance, incremental updates, non-destructive editing, and support for procedural and layered workflows, make it a valuable tool for creating and managing complex 3D content across various applications and pipelines.

To further explore the capabilities and potential applications of USD, it is highly recommended to refer to the "Introduction to USD" document available on the official website.

1.2 Collaboration and Co-simulation in Omniverse and Unreal Engine

One of the remarkable features enabled by USD is the collaboration and co-simulation capabilities between different applications. In this project, the focus was on testing the effectiveness of collaboration between Omniverse and a major game engine like Unreal Engine. The collaboration between Omniverse and Unreal Engine allows for seamless integration of assets and materials from either engine. As both engines are capable of working with USD as the underlying file format, all assets and materials used in either program are saved within the same USD file in a live collaboration setting. For instance, it becomes possible to build a map in Unreal Engine and utilize the Omniverse Physics Engine to create and record a vehicle driving around the Unreal Engine map. The resulting animation can then be used within Unreal Engine itself. This level of collaboration is achievable without the need for data type conversion, as everything is based on USD.

The collaboration and co-simulation feature can prove highly valuable in various stages of the development process, particularly during the prototyping phase and when rapid iterations are required. Co-simulation facilitates rapid prototyping and iterative development by leveraging different engines for different stages of development. Developers can use a high-level engine for quick prototyping and gameplay testing, while employing a specialized engine for optimizing and fine-tuning specific aspects such as physics or AI.

Another significant advantage of Omniverse's collaboration and co-simulation capabilities is evident in cross-platform development. Omniverse provides a connector for both Unreal Engine and Unity, two widely recognized game engines. Co-simulation aids in cross-platform game development by enabling developers to test and optimize their games on multiple platforms simultaneously. Utilizing different engines for different platforms ensures optimal performance and consistent user experiences across various devices.

1.3 USD Property Readout

The ability to read out underlying USD properties offers further versatility, allowing the construction of applications on top of applications built using different engines. For example, in a racing game developed

in one engine, it becomes possible to build an application that enables users to read out engine values in any program or engine as long as it bases on USD. This flexibility allows for extensive scene editing, including adjustments to models, lighting, physics, and more.

2 Prototype: Virtual Attendance of Virtual F1 Race

This section outlines the step-by-step implementation of a prototype showcasing how virtual attendance of virtual sport events, in this case Virtual F1, could be achieved. The objective of such a virtual attendance application is to provide Formula 1 fans with an immersive experience by virtually attending the race as if they were present at the racetrack. The prototype's general idea and technical specifications are as follows:

General Idea:

- Simulation of a racetrack with racecars on it.
- Multiple viewpoints available along the track.
- Users can switch between different viewpoints to watch the race from their preferred perspective.

Technical Specifications / Implementation:

- Cameras positioned at various locations around the racetrack, allowing users to view in all directions (3DOF).
- Enable users to switch between different camera views.
- Construct a simple 3D model of a racetrack and a racecar.
- Animate the racecar to navigate around the track.

2.1 Implementation of the Prototype

2.1.1 Creating a drivable Vehicle

To implement the prototype, the first step is to create the drivable racecar and this is achieved by using the Physics Vehicle Wizard provided by Omniverse. The creation of the drivable vehicle as well as the recording of the animation in a later section bases on this live-stream by $Omniverse3D$, so we strongly recommend watching the live-stream for further insights into the vehicle creation process.

Any 3D car model can be transformed into a drivable vehicle using this tool. In this case, the model chosen is the Red Bull RB6 from the year 2010, which can be downloaded as an FBX file from the provided link. This model was created by $FabianTheFormula1Fan$ and is free to download. The FBX format is compatible with Omniverse, eliminating the need for conversion.

To begin, we open the Omniverse USD Composer and navigate to the Content Browser. We search for and open the downloaded 3D model, which should now appear in the center of the scene. However, the model may include unnecessary lighting and camera components, which we can remove. In the Stage, we delete the $LightPreset$ and $CameraPreset$ Prims included in the RB6 Model. If the scene appears completely black, we select the $Default$ Light Rig from the available lighting options. Additionally, the model may require adjustments in terms of its orientation. For instance, in the case of the RB6 Model, the 3D model was vertically oriented, so a rotation of -90 degrees around the X-axis is needed to correct its placement.

Next you may want to delete unnecessary prims from the model. For example, the RB6 model includes a break-light overlay, which could be used to create a functional break-light, but we will not be utilizing it for this prototype. Thus, we delete the Prim ($object\_250$).
We now focus on preparing the model for the Omniverse Physics Vehicle Wizard. The Physics Vehicle created by the Vehicle Wizard consists of five Prims: one for the chassis and one for each wheel. Therefore, we need to separate the individual objects of the 3D model and combine them into their respective Prims. For example, in the case of the Red Bull RB6 Model, prims $object\_20, object\_38, object\_49$, and $object\_50$

(break disc, rim, tire sidewall and tread) are selected and then grouped together by right-clicking and selecting *GroupSelected*. This action creates a new Prim with the four objects as its children. We rename this Prim to *RearRightWheel*. We repeat this process for all four wheels and afterwards combine the remaining objects to form the *Chassis* Prim. Once the objects are separated into the five Prims, we can save the model as a USD file by selecting *File/SaveAs...*.

With the 3D model now separated into the chassis and four wheels, we can start with the creation of the Vehicle. However, before we create the vehicle, we first need to create the ground plane on which the vehicle will be able to drive. This can be achieved by selecting *Create/Physics/GroundPlane*.
Next we want to create the Vehicle via *Create/Physics/Vehicle*, which opens the Physics Vehicle Wizard. We begin by focusing on the *ChassisBox* section, where we ensure proper weight distribution for the vehicle. Initially, selecting the *Chassis* Prim of the model results in an incorrect weight distribution, as it would make the vehicle top-heavy. To address this, we go to the Stage, Right Click and Create a Cube Mesh, which we then scale to a box, as wide as the car, but only half its height. An example of how the weight distribution cube can look is presented in Figure 1. This configuration provides a low and stable weight distribution suitable for our F1 Car. We then proceed to scan the newly created cube as our Chassis Box within the Vehicle Wizard. By selecting the cube in the Stage and clicking *Scan*, we obtain the dimensions (length, width, and height) of our weight distribution chassis. As we have a F1 Car we want to adjust the Mass to something lightweight, such as 650 kg. Furthermore, we can customize parameters such as horsepower, RPM, and the number of gears. For the F1 Car, we set 750 horsepower, 15000 RPM, and 8 gears. It is essential to align the longitudinal axis with the axis pointing forward in the model (in this case, axis Z).

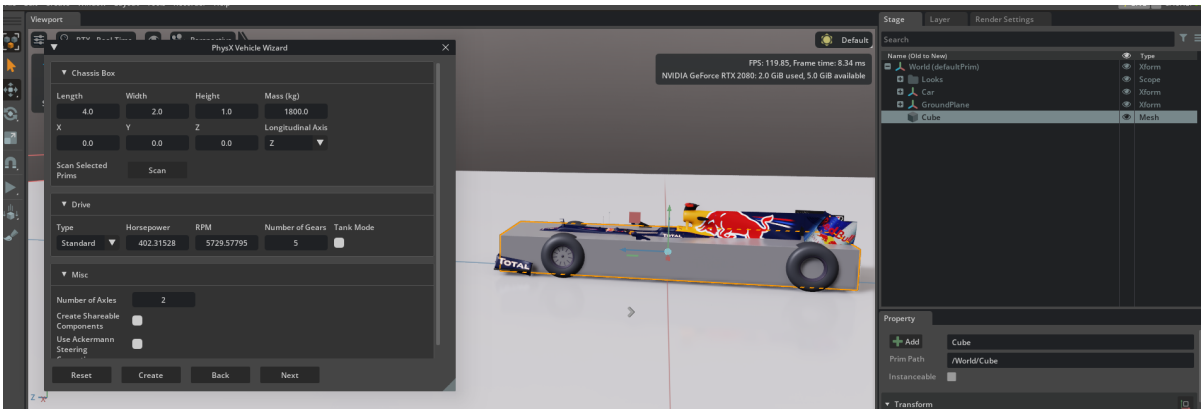


Figure 1: Example of how the weight distribution cube can look.

Moving on to the *Misc* section of the Vehicle Wizard, no additional modifications are required, allowing us to proceed to the next section by clicking *Next*. This section focuses on the axles and wheels of the vehicle. Initially, we set the steering angle to 20 degrees. If desired, four-wheel steering can be enabled by specifying the steering angle for the second axle. In the Vehicle Wizard, *Axle* 1 corresponds to the front axle, while *Axle* 2 represents the rear axle of our vehicle. In this case, the rear axle is designated as the drive axle, by only checking the *Drive* checkbox for *Axle* 2. Weight distribution adjustments can be made, although no changes were made in this prototype. *Suspension Damping* is set to 0 for an extremely stiff F1 car without any suspension. However, for more accurate simulations, some level of damping can be introduced.

Now we focus on the Wheels, where each wheel is scanned individually by selecting the corresponding wheel's prim in the Stage and clicking the corresponding button in the Vehicle Wizard. For example, to scan the rear right wheel, we select the prim of the rear right wheel in the Stage and click the *Right* button in the second row of the Vehicle Wizard. The scanned Wheel now appears in the Wheels Section. This workflow is showcased in Figure 2.

Within the Wheels section, we select the tire type as *Slick* and adjust the mass of each tire to be a bit more lightweight. For a truly accurate simulation these weights should be set more precisely.

With the necessary preparations complete, we can now proceed to create the drivable 3D vehicle model. Upon clicking the *Create* button, we should see the vehicle, which is just a box, equal to our weight dis-

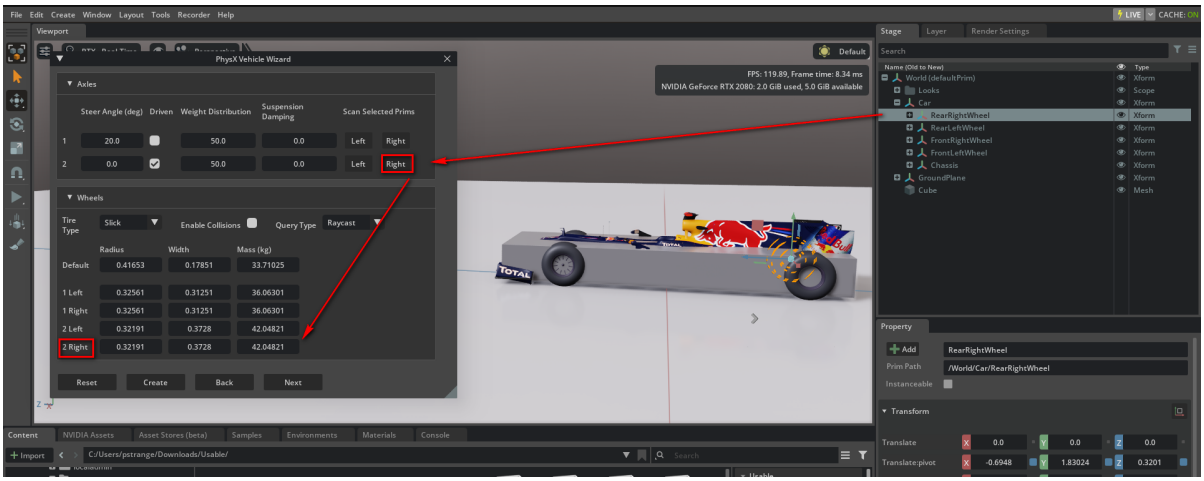


Figure 2: Showcase of the workflow to scan a tire prim in the Vehicle Wizard.

tribution cube, with four cylinders attached as tires. If you press the Play button you can now test drive the vehicle for the first time. However, upon turning left and right, you may observe significant wobbling, which requires correction. To address this issue, we adjust the $SpringStrength$ and $TravelDistance$ of the springs in the Wizard Vehicle.

To begin, we select the $LeftWheel1References$ and the $RightWheel1References$ under $WizardVehicle1/Vehicle$. With these prims selected we scroll down in the Properties Window until we find the $Vehicle\ Suspension$ section. Here, we set the $Spring\ Strength$ to a high value (e.g., 100000) and set the $Travel\ Distance$ to half of the tire radius. The tire radius can be found two sections above in the $Vehicle\ Wheel$ section. For instance, in the case of the RB6 Model, the tire radius is 0.32561, thus the suspensions $Travel\ Distance$ is set to 0.162805. Similarly, we perform the same adjustments for the rear wheels by selecting the $LeftWheel2References$ and $RightWheel2References$ under $WizardVehicle1/Vehicle$, setting the $Spring\ Strength$ to 100000, and configuring the $Travel\ Distance$ as half of the rear tire radius. For the used RB6 model, the rear tire radius is 0.32191, resulting in a suspension $Travel\ Distance$ of 0.16095. After making these adjustments, the vehicle should no longer exhibit wobbling during driving and now we can get to the final step of creating our drivable 3D Vehicle Model.

The final Step is to drag the Prims of the 3D model to the corresponding Prims in the created Vehicle Model. We begin by dragging the Front Left Wheel Prim to the $LeftWheel1References$ of the Wizard Vehicle. Following this, the Front Left Wheel Prim may become displaced, which can be corrected by adjusting the $Translate : pivot$ property, setting all values to 0. This realigns the Left Front Wheel to its correct position. Subsequently, we can either delete or hide the Left Wheel Cylinder (denoted as $Render$) of the Wizard Vehicle. Figure 3 showcases, where the $FrontRightWheel$ prim needs to be dragged to in the Wizard Vehicle.

We repeat this process for all four Wheels and then move the Chassis Prim of our 3D Model into the $Vehicle$ Prim of the Wizard Vehicle. Finally, we hide or remove the $ChassisRender$ prim. Upon ensuring that all Prims of our model are correctly positioned within the Wizard Vehicle and the renders of the original Wizard Vehicle are hidden or removed, we achieve a drivable model based on the original 3D model.

When considering the performance of the vehicle, there are additional configuration options available. We can adjust the $Mass$ of the car or modify the $PeakTorque$ of the Vehicle Engine to fine-tune its performance. Additionally, if the wheels exhibit excessive spinning, we can modify the tire friction in the $SlickTireFrictionTable$ within the $WizardSharedVehicleData$. There you just have to go down to the Raw USD Properties and increase the $Default\ Friction\ Value$.

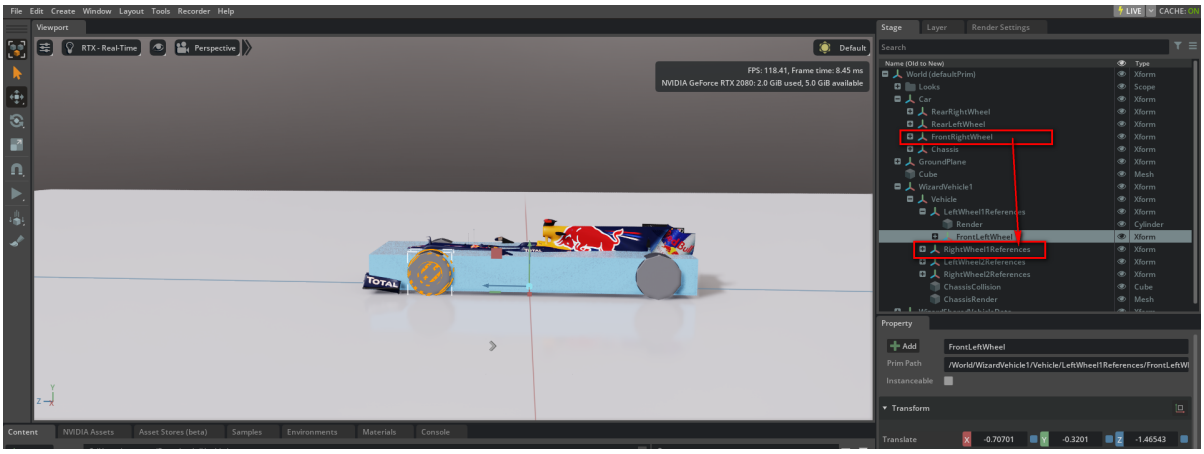


Figure 3: Showcase of where the *FrontRightWheel* prim needs to be dragged to in the Wizard Vehicle.

2.1.2 Creating the Map

After creating the vehicle our focus now shifts to the creation of a Map. In this section, we will not provide a detailed, step-by-step guide on map creation. Instead, we give some pointers on how to design a racetrack suitable for use in Omniverse, along with a brief introduction to the collaboration feature of the Omniverse and Unreal Engine Connector.

The first possibility to create a racetrack is to export the Vehicle Test map from Unreal Engine to Omniverse and then use the Spline Meshes from this Test track to build a custom racetrack. However, this is quite tedious and therefore we can use a quicker approach, by creating the Track in Unreal Engine with the help of Splines and then export the racetrack to Omniverse. An excellent tutorial on road creation using splines in Unreal Engine can be found here.

2.1.3 Live Collaboration

In this section, we will demonstrate the live collaboration feature by utilizing the Vehicle Test map from Unreal Engine, exporting it to Omniverse, and showcasing the addition of assets while working on the map simultaneously in both Omniverse and Unreal Engine. This project has also a very good introduction into the process of creating a live collaboration between Omniverse and Unreal Engine so we highly recommend checking it out.

First, we want to create a new Unreal project, selecting the Vehicle Project from the Games Section as our starting project. After creating the project, we want to add our Nucleus Server to the Unreal Engine Content Browser. We do this by clicking *Add Server* in the Omniverse Menu in the left upper corner of the Unreal Engine Window and then specifying the name of the Server we want to connect to i.e. the name of your Nucleus Server. To set up a Nucleus Server, the Nucleus Workstation must be installed through the Omniverse Application, followed by the configuration of a local server. Further details regarding the Nucleus Workstation installation and setup can be found in the official Omniverse documentation.

After successfully connecting to the Nucleus Server, an Omniverse Folder will be visible in the Unreal Engine Content Browser. Next, we export the Unreal Engine Map to Omniverse by selecting *Export Level to Omniverse*. Within the Omniverse Exporter, the option *Export as* $Y - up\ Axis$ must be chosen, as Omniverse employs a Y-Up Axis, while Unreal Engine uses a Z-Up Axis as default. Save the level to the pre-established Nucleus Server, allowing for easy accessibility within Omniverse, without the need to search for the file within local storage.

Once exported we switch over to Omniverse USD Composer and open the exported UE Level. Here we want to create a .live file, by selecting the Root Layer in the Layer Section and then generating a new Sublayer, which we then save as a .live file, as shown in Figure 4. If prompted to transfer the Root Layer contents to the new sublayer, select *Yes*.

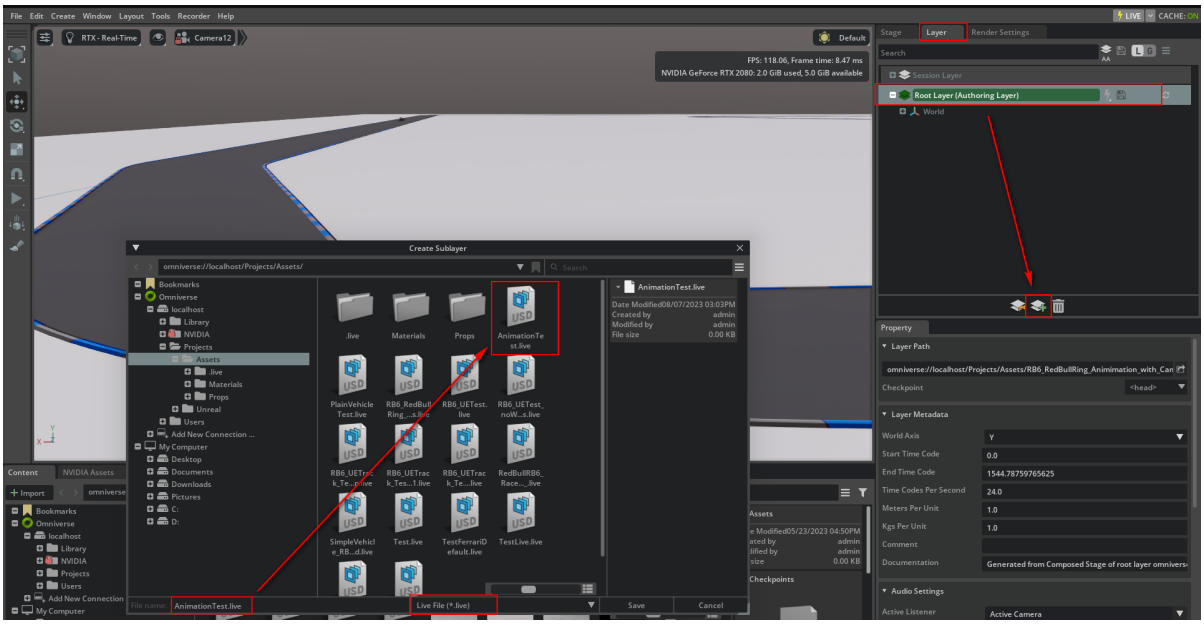


Figure 4: Showcase of how a .live file is created.

After successfully creating the .live file, open it in Omniverse and then switch back to Unreal Engine, where we add an Omniverse Stage Actor to the Scene. In the Details section of the Omniverse Stage Actor, locate the USD Property and drag and drop the previously created .live file onto it. This action loads the .live file, allowing for real-time editing from both applications. It is important to note that when you add materials in Unreal Engine you have to export the Unreal Engine scene to Omniverse after finishing editing the .live file. Similarly, if you add materials and assets in Omniverse you need to save the file in Omniverse.

Once you are finished with editing your map, make sure to save the scene in Omniverse as a .usd file. To add the previously created vehicle, there are two possible approaches. The first approach involves dragging the 3D car model into the scene and utilizing the Vehicle Wizard to create the drivable vehicle. Alternatively, the drivable vehicle created earlier can be dragged into the newly created scene. It is also feasible to reverse the process, where the just-created map is added to the scene containing the vehicle.

2.1.4 Driving and Recording the Car Animation

With a functioning car and racetrack, we can now proceed to drive the car on the track and record it using the *Recorder* to create an animation. The *Recorder* is a native Extension, which can be activated in the Extensions Window (In Omniverse USD Composer you find the Extension Window under *Window/Extensions*). In the Extension Window simply search for *Recorder* and activate it. It should now appear in the Toolbar between *Tools* and *Help*.

Utilizing the *Recorder* is straightforward. In the Stage, simply select the desired Prim(s) to be recorded. For our purposes, we select the *Vehicle* Prim in the Stage and then navigate to the *Recorder*, clicking on *Record Selection*, as is shown in Figure 5. It is important to note that this action only selects the prims to be recorded and does not initiate the recording process. Next, activate the *Timeline* by going to *Window/Animation/Timeline*, which will appear at the bottom of the window. Within the *Timeline*, specify the desired duration for the animation. In this example, a length of 1000 units is chosen. Upon pressing play, the animation recording starts, and it is crucial to ensure that the recording does not exceed the specified animation length. Overstepping this limit may result in the recorder overwriting and potentially crashing the animation. Therefore, closely monitor the recording duration displayed in the timeline. After driving around the racetrack for the set duration stop the scene, which stops the timeline, and click *Stop Recording* in the *Recorder*. Following the stopping of the recording, save the file separately as a .usda file by navigating to *File/SaveAs...*. Here it is important to save the file as a usda (USD ASCII – human readable) file, as we need to edit the file in the next step.

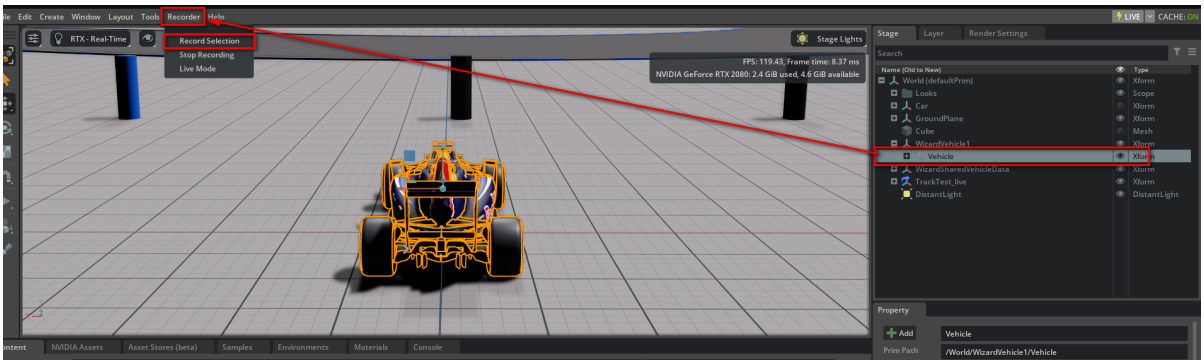


Figure 5: Showcase of how to enable the recording for the $Vehicle$ prim.

2.1.5 Editing the Animation File

Note: This step could change in future versions of Omniverse USD Composer, but at the time of project release, this editing of the animation file is still the required workflow.

After saving the animation, the next step involves editing the .usda file and removing the physics properties from it, as the recorded animation of the car should no longer be drivable. For this process the USDA Editor Extension needs to be enabled. Access the Extensions menu by selecting $Window/Extensions$ and ensure that the USDA Editor extension is enabled. To edit the file, navigate to the Content Browser and right-click on the recently created and saved file, then choose $Edit...$. The file should open in Visual Studio Code, assuming it is installed. It is recommended to use Visual Studio Code, as Omniverse supports VS Code Link, which enables the connection of an Omniverse app to VS Code's Python debugger. This feature proves beneficial when creating custom extensions, a topic that will be explored later on.

In the editor, the objective is to delete all physics references from the USDA file. Consequently, all physics-related variables must be removed from the vehicle prim (referred to as $WizardVehicle1$ in this example) in the .usda file. Each component of the vehicle that has been separated ($Chassis$, $LeftFrontWheel$, ...) will contain certain physics properties that need to be deleted. Meaning all properties containing *physics* or *physx* need to be removed.
For clarity Figure 6 shows the $Vehicle$ prim in the pre-edited state, while Figure 7 shows the $Vehicle$ prim with all physics references removed. Figures 8 and 7 show the same thing for the $LeftWheel1Reference$. Once all physics references are deleted, save the file and return to Omniverse USD Composer. Right-click on the file in the Content Browser and select $Finishediting$ to finalize the changes.

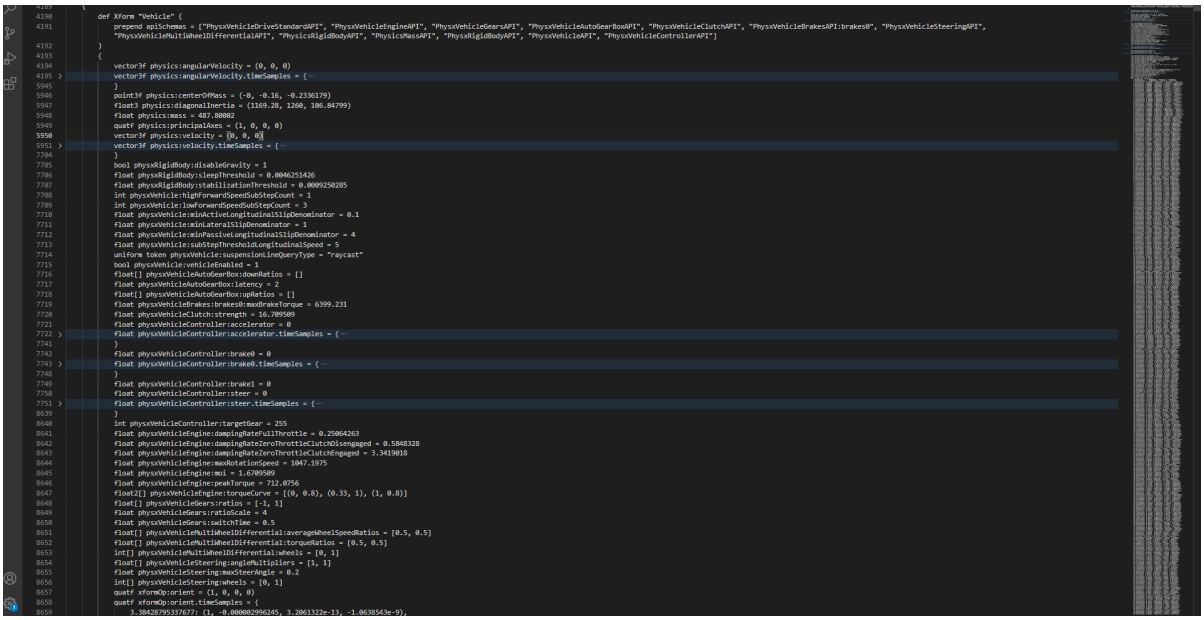


Figure 6: *Vehicle* prim prior to editing.

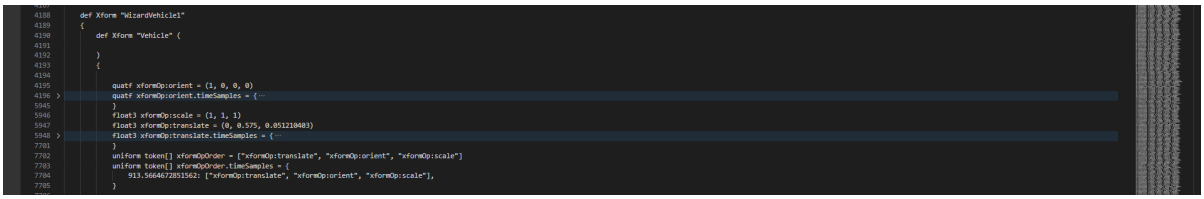


Figure 7: *Vehicle* prim after editing.

Figure 8: *LeftWheel*1 prim prior to editing.

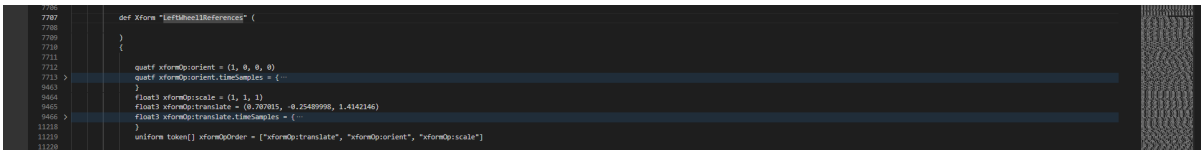


Figure 9: *LeftWheel*1 prim after editing.

2.1.6 Playing the Animation

To view the created .usda file containing your animation, open it in Omniverse USD Composer. Once opened, navigate to the Animation timeline located at the bottom of the screen. If the timeline is not enabled, access it by selecting *Window/Animation/Timeline*. Ensure that the timeline is set to the length of your animation, as the recorder sets the timeline to 0 when it is stopped. By dragging the blue flag along the animation timeline, you can step through the recorded animation. Pressing the *Play* button will play the recorded animation. Furthermore, the animation can be utilized in Unreal Engine

without requiring any modifications. In the Content Browser of Unreal Engine, search for the .usda file containing the animation and open it. In the *Outliner* you should now see a *LevelSequenceActor* holding the Animation. If you now Play the Level you should see your Animation being played. If the animation does not play as expected, access the Level Sequence and adjust the Start and End time in the Playback Options, which should resolve the issue.

2.1.7 Creating Cameras

Next, we focus on the last piece of the Virtual F1 Attendance Prototype, which involves creating cameras positioned around the track to provide different viewpoints for viewing the animation. Further, we will develop an extension to facilitate switching between these cameras.

To create a camera, right-click within the stage and select *Create/Camera*. Place the cameras in the desired locations. For easier placement, switch to the viewpoint of each camera and adjust its position accordingly. With the cameras in place, the extension for the switching between viewpoints can be created. To create a new extension, go to *Window/Extensions* and in the Extension Window click the green Plus icon and select *New Extension Template Project*. Choose a folder location to save the extension project. After selecting a folder, provide a name for the extension project, such as $kit-exts-camera-switcher$, followed by assigning an ID for the extension, which will be displayed in the Extension window. For instance, *company.camera.switcher* can be used as the ID.

Once the extension is created, Visual Studio Code should open with the extension's files displayed. In the root of the extension, locate the *exts* folder, which holds the extension. Inside this folder, find the directory named after the specified extension ID. Navigate further into this folder until you locate the *extension.py* file and open it. In this File you will find an *on_shutdown* and an *on_startup* function. We can ignore the *on_shutdown* function and focus on the *on_startup* function. To begin, retrieve the active viewport window, representing the open scene's viewport, using the *get_active_viewport_window*() function from the viewport utility library, which needs to be imported. Then, obtain the stage of the scene by calling *omni.usd.get_context*().*get_stage*(). This retrieves the currently opened stage.

Once the stage is obtained, traverse the stage to search for all cameras. Utilize the *Traverse* function and examine each Prim to determine if it is a camera. For cameras found, save their names and prim paths. Once all cameras in the scene are gathered, create buttons for each camera and assign a function to execute when a button is clicked. This function will switch the current viewport to the corresponding camera associated with the clicked button.

The complete *on_startup* function as well as all needed imports for this extension are provided below and it should be possible to simply copy and paste the code into the *extension.py* file without any errors. With the completion of this extension, the animation can be played, and users can easily switch between the different cameras placed within the scene. Note that the traversal of the scene also includes the built-in cameras *Perspective*, *Top*, *Front*, and *Right*. With the extension's functionality implemented, the Virtual F1 Viewer Prototype is now complete and Figure 10 presents how the camera switching extension looks.

```
# -------- Imports --------
import omni.ext
import omni.ui as ui
import omni.kit.viewport.utility as vp_utils
import omni.usd
from pxr import UsdGeom


# -------- on_startup --------
    def on_startup(self, ext_id):
        print("[strange.camera.switcher] strange camera switcher startup")

        self._count = 0

        self._window = ui.Window("Camera Switcher", width=300, height=300)
        viewportWindow = vp_utils.get_active_viewport_window()

        with self._window.frame:
            with ui.VStack():
```

```
stage = omni.usd.get_context().get_stage()
if stage is not None:
    # find all cameras in the stage
    cameras = [[x.GetName(), x.GetPrimPath()] for x in stage.Traverse()
               if x.IsA(UsdGeom.Camera)]

    if len(cameras): # If cameras are found -> create button per camera
        with ui.VStack():
            def on_click(camera_name, camera_path):
                viewportWindow.viewport_api.camera_path = camera_path
                print('Switched to camera: ' + camera_name)

            for i in range(len(cameras)):
                var = cameras[i]

                #lambda is needed to make a clickable button - otherwise
                #the click event is triggered on startup
                #further we need to specify the default values of the
                #function and pass them as otherwise only name and path
                #of the last camera are saved
                ui.Button(var[0], clicked_fn=lambda name=var[0],
                    path=var[1]: on_click(name, path))
```

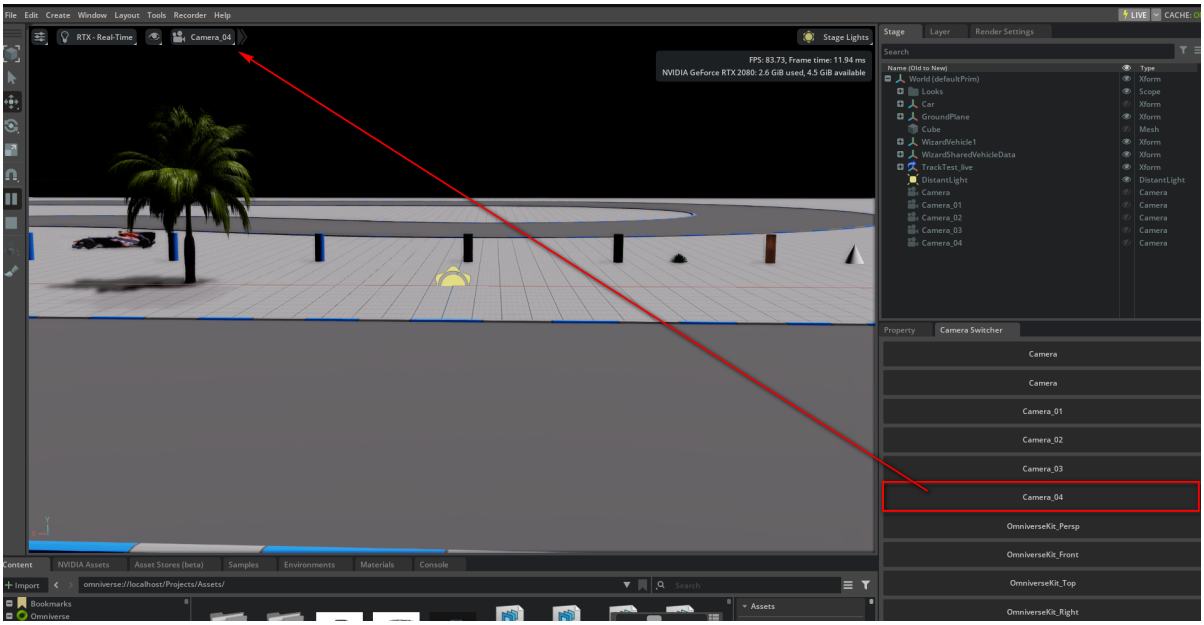


Figure 10: Example of how the camera switching application looks. Clicking its buttons changes the viewport to the clicked camera.

2.2 Co-simulation with Unreal Engine

A goal of this project was to test the co-simulation capabilities between Omniverse and Unreal Engine. Thus, we try to establish a co-simulation that enables concurrent animation playback in both Omniverse and Unreal Engine. To achieve this, we explore the utilization of a Boolean USD Property as a means of controlling the animation start and stop functionalities. However, implementing this approach is not straightforward due to the lack of direct exposure of raw USD Properties within Unreal Engine. Therefore, modifications to the Omniverse Plugin in Unreal Engine are necessary to enable the retrieval and manipulation of USD Properties. Specifically, we focus on expanding the *OmniverseStageActor* Class with additional UFunctions, which can then be utilized in Unreal Engine Blueprints to interact with these properties.

To enable the desired functionalities, it is necessary to have C++ support in our project. If a Blueprint project was created initially, it is necessary to either create a new C++ project or incorporate C++ into the existing project. We opted to create a new *Simulation Blank* C++ project.

Once the new project is created, the first step is to create a Plugins folder in the root directory of the Unreal Engine project. Subsequently, we navigate to the Plugins folder within the Unreal Engine installation directory and copy both the *MDL* and *Omniverse* Plugin folders into our project's local Plugins directory. On the used system, the path to these plugins is *C:\Program Files\Epic Games\UE_5.1\Engine\Plugins\Marketplace\NVIDIA*. The *MDL* Plugin is included alongside the *Omniverse Plugin*, as the latter is dependent on the former.

With the plugins successfully copied to the local Plugins folder, we proceed to modify the *OmniverseStageActor* Class. To accomplish this, we open the *OmniverseStageActor.h* (located at *Omniverse/Source/OmniverseUSD/Public*) and *OmniverseStageActor.cpp* (located at *Omniverse/Source/OmniverseUSD/Private*) files in a suitable editor. Within the *OmniverseStageActor.h* file, we define several UFunction headers for obtaining and setting Boolean, float, and double values (in the examples shown only the Boolean and float functions are necessary), as shown in Figure 11. In the *OmniverseStageActor.cpp* file, we implement the UFunctions specified in the header file. This is shown in Figures 12 and 13. Furthermore, we need to include the *Blueprintable* keyword in the *UCLASS* definition within the *OmniverseStageActor.h* file. This addition is essential as it enables the creation of a Blueprint Class derived from the *OmniverseStageActor* Class. It is important to note, that the UFunctions provided are modified versions of the functions provided in this tutorial.

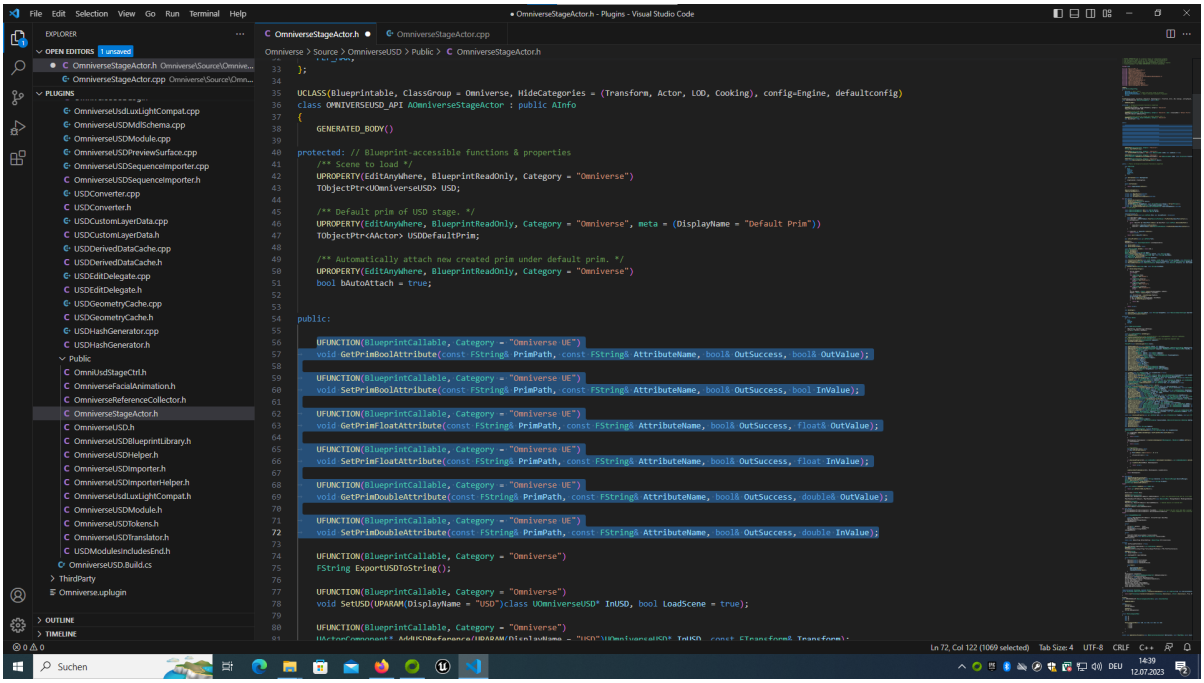


Figure 11: UFunction Headers in *OmniverseStageActor.h*.

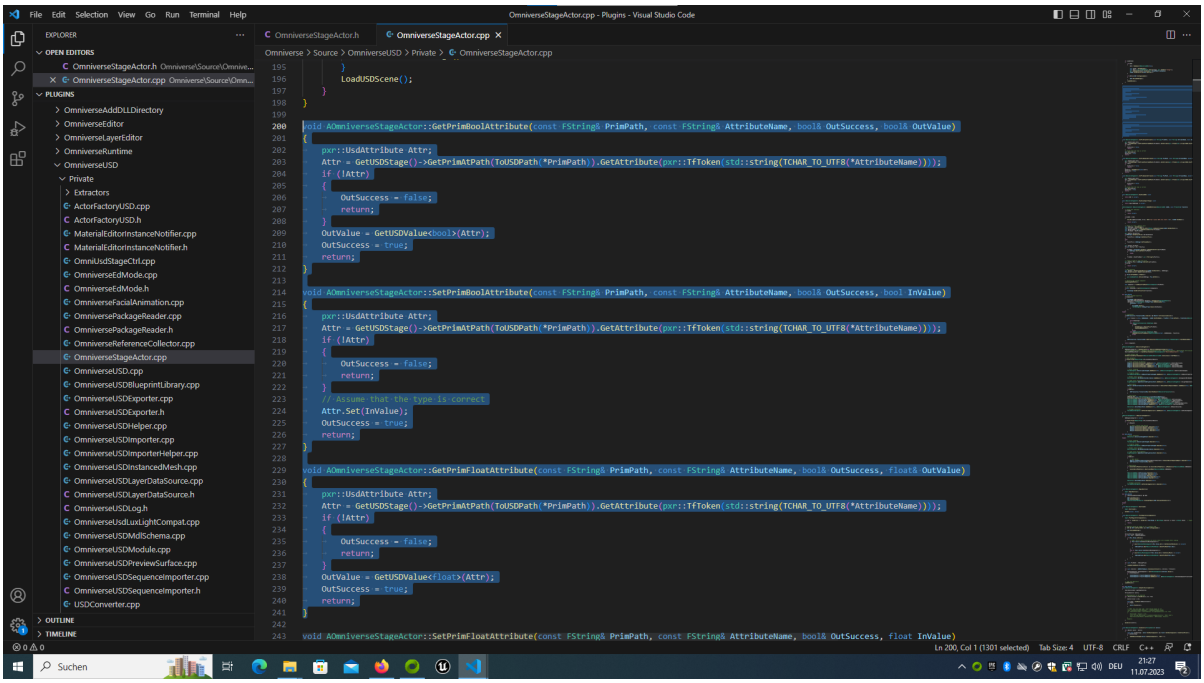


Figure 12: UFunction Definitions in *OmniverseStageActor.h*.

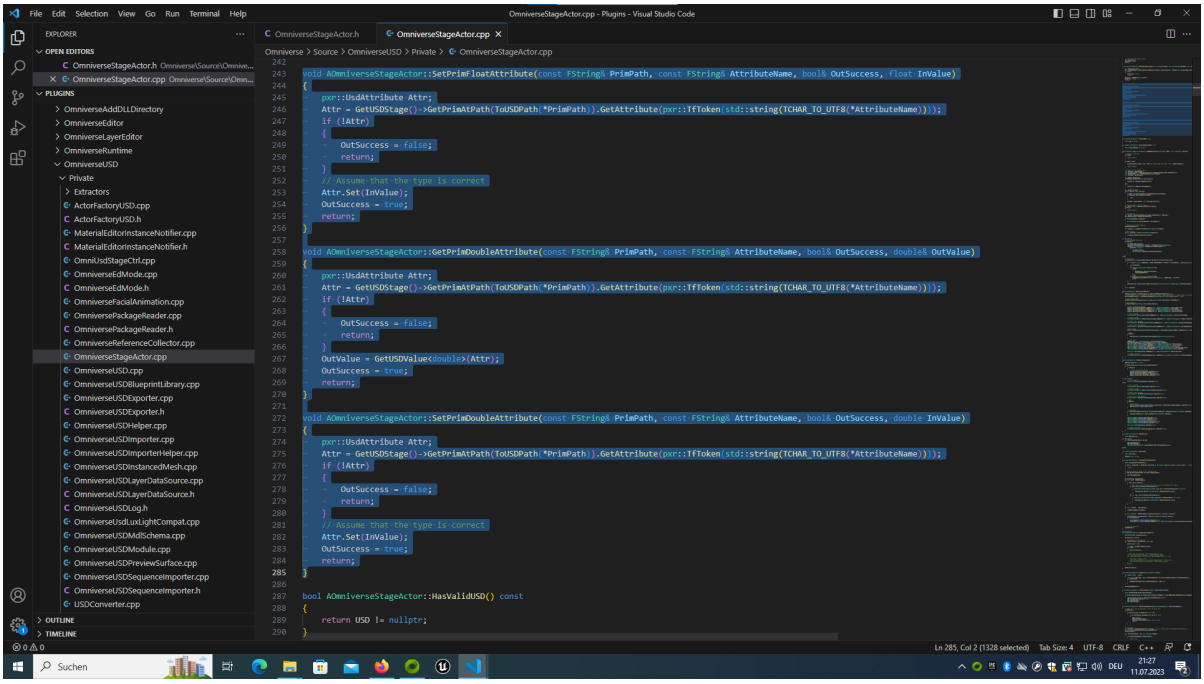


Figure 13: UFunction Definitions in *OmniverseStageActor.h*.

Once the necessary UFunctions for retrieving and setting USD Boolean, float, and double values have been implemented, we proceed to open the Visual Studio Project by double-clicking the .snl file located in the project's root folder. After Visual Studio is opened we simply need to recompile the project. To accomplish this, we select *Development Editor* and *Win64* as the target platform and start the project build (*Build/Build/ProjectName*).

After the project has been rebuilt, we proceed to open it in Unreal Engine and create a Blueprint Class based on the modified *OmniverseStageActor* Class. To do so, make sure the Content Browser displays the Plugins folder since this is where the modified class resides (can be enabled via *Settings* in the Content Browser). Within the Plugins Folder, we find four sub-folders, with two dedicated to the

MDL Plugin and two dedicated to the *Omniverse* Plugin.
Navigating to *NVIDIA Omniverse C++ Classes/OmniverseUSD/Public* within the Plugins Folder, we locate the *OmniverseStageActor* class, which is the class we modified.

Right-click on the *OmniverseStageActor* class and create a Blueprint class based on it. Name the Class as you wish (or leave the default) and click *Create Blueprint Class*, which creates the Blueprint Class within the Content folder and opens it. By right-clicking within its *Event Graph*, we can access the Blueprint functions that we added to the *OmniverseStageActor*. These Blueprint functions enable us to read and modify USD Properties of the underlying USD stage. In the context of our specific objective, we aim to add a Boolean Value to the USD Stage. This Boolean Value will serve as a mechanism to control the concurrent playback and pausing of the animation within Omniverse. Before we get to this specific objective we want to showcase shortly how-to read-out USD Properties in Unreal Engine.

For this we first want to head over to Omniverse USD Composer and look for a USD Property we want to read-out in Unreal Engine. Here, we utilize the previously created map containing the drivable vehicle model, allowing us to explore various vehicle-related USD properties. By selecting the vehicle within the stage and navigating to its Raw USD Properties, we observe an abundance of properties that describe different aspects of the vehicle.

For our real-time read-out demonstration, we choose to focus on the *Steer* USD property. This property represents the current amount of steering applied to the car, ranging from values of up to 1 for left steering, as displayed in Figure 14, and down to -1 for right steering. To enable real-time read-out, we must generate a .live file, as previously outlined. Returning to Unreal Engine, we proceed to implement the functionality required to read the *Steer* property.

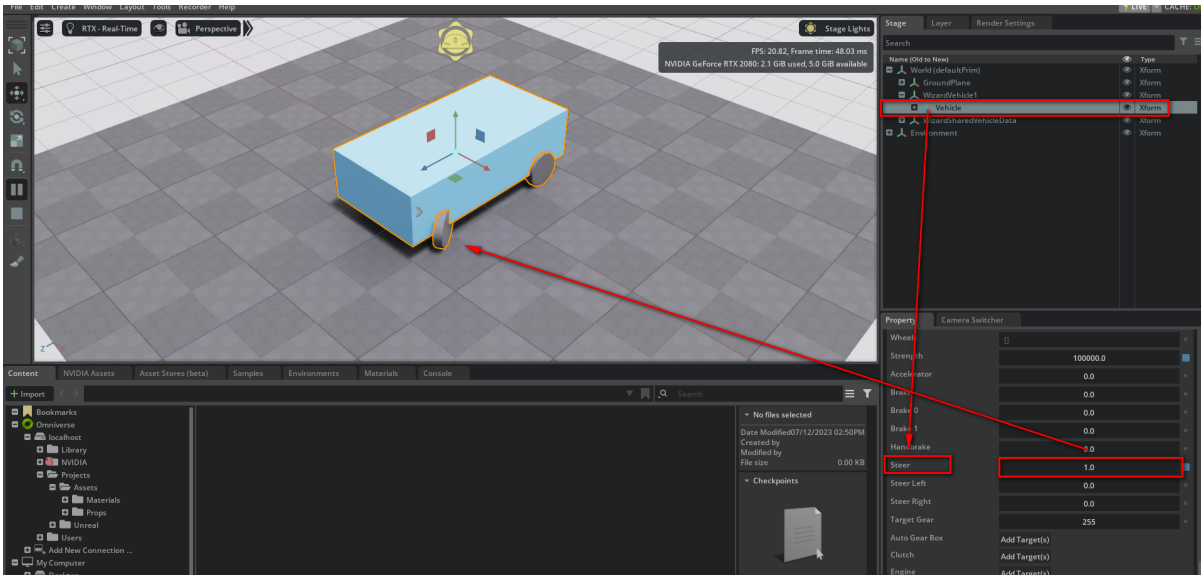


Figure 14: Example showcasing the *Steer* property.

Within the *Event Graph* of the *OmniverseStageActor* Blueprint Class we created, we first drag-out the execution pin from the *Event BeginPlay* node and search for the *Set Timer by Event* node, which allows us to repeatedly call a specific event at a defined interval. Enabling the desired polling behavior, we ensure the *Looping* property is activated. Next, we establish an event that is consecutively triggered within the loop. To achieve this, we drag-away from the *Event* property of the *Set Timer by Event* node and create a *Create Event* node. By selecting the [*Create a matching function*] option within the *Signature* : () drop-down menu, an auto-generated function is created. It is advisable to rename this function to a name reflecting its purpose, such as *PrintFloatValue* in the case of the *Steer* float property.

Within the *PrintFloatValue* function, we drag-away the execution pin and call the previously specified *Get Prim Float Attribute* function. To correctly specify the *Prim Path* and *Attribute Name* parameters, we return to Omniverse and navigate to the *Steer* property. Right-click on the property and select *Copy Property Path*. In Unreal Engine, we paste the path into the *Prim Path* field and remove

everything following the period, which is then pasted into the *Attribute Name* field. It is important to delete the period from the *Prim Path* field.

To help with debugging we add a *Branch* node that allows for differentiation between successful attribute retrieval and cases where the attribute is not found. When the attribute is successfully retrieved, we utilize a *Print String* node to display the corresponding string value. Additionally, an *Append* node is introduced to concatenate the "Steer: " prefix with the float attribute obtained from the USD file. The resulting value is then provided as input to the *Print String* function. To prevent the display of multiple string values on the screen, the *Duration* parameter of the *Print String* nodes is set to 0.1 seconds, aligning with the interval at which the *PrintFloatValue* function will be called. The complete graph of the *PrintFloatValue* function is presented in Figure 15.

Returning to the Event Graph, we configure the *Time* attribute of the *Set Timer by Event* node to 0.11 seconds, ensuring that the *PrintFloatValue* function is called every 0.11 seconds. The slight difference to the *Print String* duration and the *Time* attribute ensures, that only one string is displayed at a time. The Blueprint Class, displayed in Figure 16, is then compiled, saved, and ready for testing.

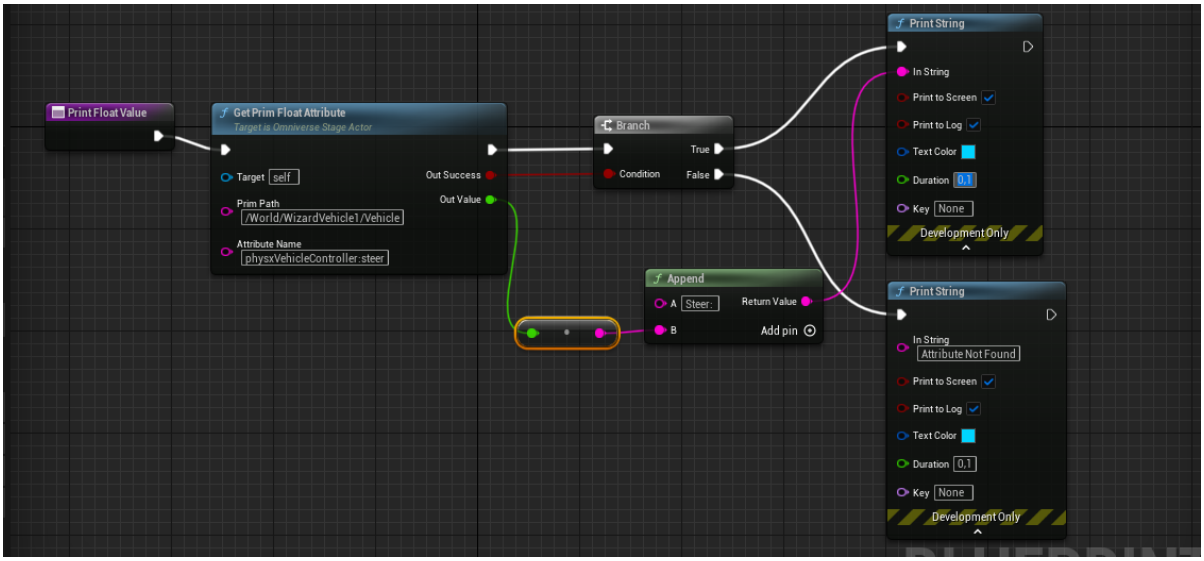


Figure 15: Graph of the *PrintFloatValue* Function.

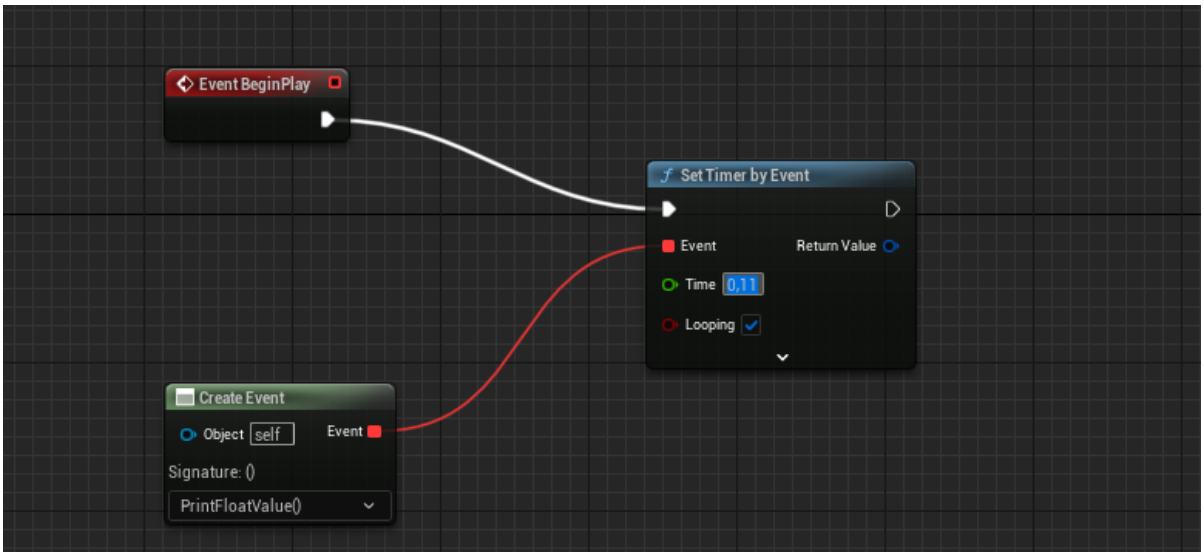


Figure 16: Event Graph of the *OmniverseStageActor* Blueprint Class.

To assess the functionality, we add the *OmniverseStageActor* Blueprint Class to the scene and attach the previously created .live file to the *USD* property. If the scene appears overly bright or white, navigate to the *GlobalPostProcessVolume* and select *Auto Exposure Histogram* within the *Exposure* settings. By playing the Unreal Engine Level, we should observe the output "Steer: 0.0." Playing the Omniverse level and steering the vehicle leads to the steer value being read-out in real-time within Unreal Engine. As can be seen in Figure 17, if we steer left in Omniverse we get an output of "Steer: 1.0" in Unreal Engine, validating, that the read-out of float properties works.

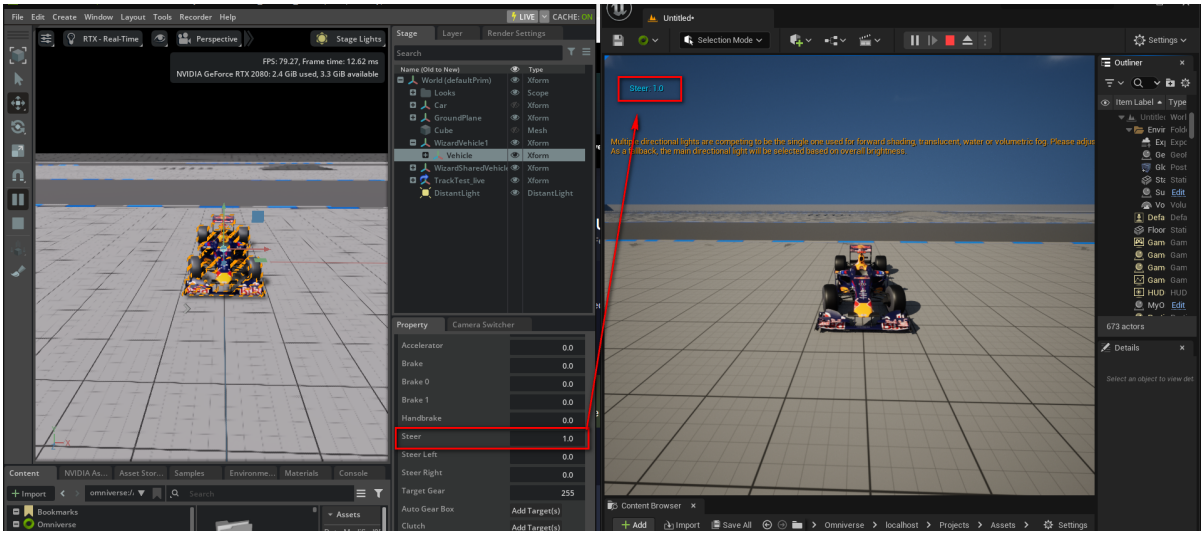


Figure 17: Live read-out of the *Steer* float property in Unreal Engine.

However, it is worth noting that performance issues may arise when the scene contains a large number of vertices, as seemingly Unreal Engine requires updating the entire scene whenever a single value changes. These performance considerations and limitations will be discussed in greater detail in a later section.

2.3 Concurrent Animation Playback in Omniverse and Unreal Engine

Having explored the process of reading USD properties in Unreal Engine, the final objective of this project is to establish concurrent animation control in both Omniverse and Unreal Engine. This will be achieved by introducing a Boolean property to the USD file and utilizing its value to initiate or pause the animation. To enable this functionality, we will develop an extension within Omniverse, which can set this Boolean property in the beginning i.e. start the animation. On the Unreal Engine side, we will implement a polling mechanism to play or pause the animation based on the Boolean value.

The initial step is to add the Boolean property to the USD file. Within the Omniverse Content Browser, the file containing the previously created animation is selected and right-clicked, followed by selecting *Edit...*. In the USD file, find the *World* primitive and add a Boolean variable named *activate* and initialized to 0 to the top of the property list, like shown in Figure 18. The file is then saved, and the editing process is finished by right-clicking on the file and selecting *Finish editing*.

By accessing the Raw USD Properties of the file, while the *World* Prim is selected in the Stage, the newly added Boolean property should be visible, as presented in Figure 19.

```
)

def Xform "World" (
    kind = "component"
)
{

    bool activate = 0

    float3 xformOp:rotateXYZ = (0, 0, 0)
    float3 xformOp:scale = (1, 1, 1)
    double3 xformOp:translate = (0, 0, 0)
    uniform token[] xformOpOrder = ["xformOp:translate", "xformOp:rotateXYZ", "xformOp:scale"]

    def Scope "Looks"
    {
        def Material "info"
```

Figure 18: Addition of the *activate* Boolean property to the *World* prim.

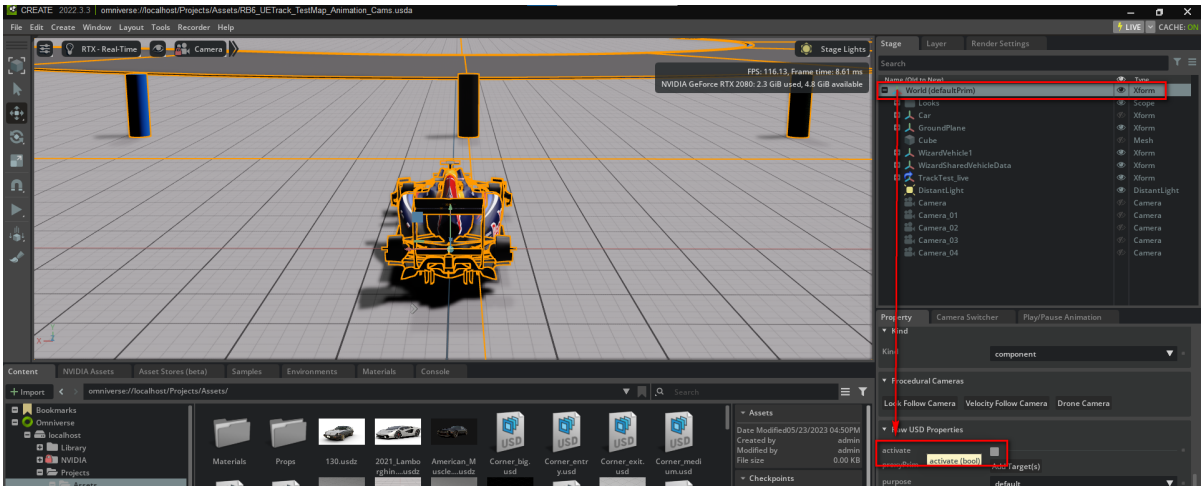


Figure 19: Showcase of the *activate* Boolean property as part of the *World* prim.

Next, an extension is developed to control the animation based on the Boolean property. Within Omniverse open the Extensions window (*Window/Extensions*) and create a new extension template project by clicking the green plus icon. Similar to the previous extension creation process, a folder location and project name, along with an extension ID, are specified. This generates the extension project and opens Visual Studio Code where we open the *extension.py* file. First, the current stage and its associated timeline are retrieved, as the timeline provides control over starting and stopping the animation. The desired play and pause functionality should be achieved by clicking a button, which internally changes the underlying USD Property, while also playing/pausing the animation.

The stage is retrieved using the $omni.usd.get\_context().get\_stage()$ function, and the timeline is accessed through the $get\_timeline\_interface()$ function from the imported *omni.timeline* library. The timeline interface provides functions for playing and pausing the animation. To retrieve the Boolean property, the $GetPrimAtPath('/World').GetAttribute('activate')$ function is used, while utilizing the $Get()$ and $Set()$ functions to access and modify its value, respectively. All the needed imports as well as the complete *on_startup* function is provided below.

After completing the modifications in the *extension.py* file, it is saved, and we go back to Omniverse USD Composer, where the extension with its two buttons should be visible. By clicking the *Play* button, the animation starts, and when inspecting the Raw USD Properties of the World prim, the *activate* Boolean property is now set to true. Pressing the *Pause* button halts the animation, and the *activate* property reverts to false, confirming the successful play and pause functionality of the extension.

```
import omni.ext
import omni.ui as ui
import omni.timeline
```

```
def on_startup(self, ext_id):
    print("[strange.usd.timeline.player] strange usd timeline player startup")

    self._count = 0

    self._window = ui.Window("Play/Pause Animation", width=300, height=300)
    with self._window.frame:
        with ui.VStack():
            # get the stage:
            stage = omni.usd.get_context().get_stage()

            if stage is not None:
                # get a reference to the timeline
                timeline = omni.timeline.get_timeline_interface()

                with ui.VStack():
                    def on_click():
                        # get activate Boolean Attribute reference
                        activate = stage.GetPrimAtPath('/World')
                            .GetAttribute('activate')
                        if activate.Get():
                            print("activate: True")
                        else:
                            print("activate: False")

                        if activate.Get():
                            if timeline.is_playing():
                                timeline.pause()
                                activate.Set(False)
                        else:
                            if not timeline.is_playing():
                                timeline.play()
                                activate.Set(True)

                    ui.Button('Play', clicked_fn=on_click)
                    ui.Button('Pause', clicked_fn=on_click)
```

With the Omniverse extension functioning as intended, we focus on implementing the counterpart functionality within Unreal Engine. Open the project that includes the previously created *OmniverseStageActor* Blueprint Class. Here we want to have a Play/Pause Button to play and pause the animation, by utilizing a UI Widget. To generate the UI Widget, go to the Content Browser, right-click and then under *User Interface* create a *Widget Blueprint* and when prompted to pick the root widget select the *User Widget*. Name the UI widget accordingly (e.g. *BtnPlayPause*). Upon opening the widget, the Play/Pause button is constructed by first dragging a *Button* from the *Common* section into the Designer view. Within the Hierarchy, right-click the button, and wrap the button with a *Size Box*. After this we place a *Text* Block onto the button and change its Text to "Play/Pause". To ensure appropriate button placement and avoid occupying the entire screen, horizontal left alignment and vertical center alignment are selected for the button. Adjustments such as resizing the *Size Box* or applying padding can be made to achieve the desired button position.

After compiling and saving the button, we switch from the *Designer* to the *Graph* and in the *Event* Section we add the *OnClicked* Event to the button by clicking the plus icon. After this, an *EventDispatcher* is created by clicking the small plus icon in the *EVENT DISPATCHER* section, and name it "PlayPause". After creating the *Event Dispatcher*, drag it into the graph and select *Call*, which should create a *Call Play Pause* Node. Connect this node to the *On Clicked* Event, compile and save the Button Widget and close it. For reference the complete graph of the "PlayPause" button is presented in Figure 20.

Within the Event Graph of the *OmniverseStageActor* Blueprint Class, first create a *Set Timer by Event* node by dragging-away the execution pin from the *Event BeginPlay* node. Similarly to the previous implementation for printing the *Steer* property, a *Create Event* node is created by dragging away from the *Event* pin. In the *Create Event* node, we select the option to create a matching function from the "*Select Function...* drop-down. The function is renamed to "TriggerAnimation" to signify its purpose of playing or pausing the animation based on the Boolean property value. Additionally, this function will also print the current value of the Boolean property for debugging purposes. In the "TriggerAnimation"

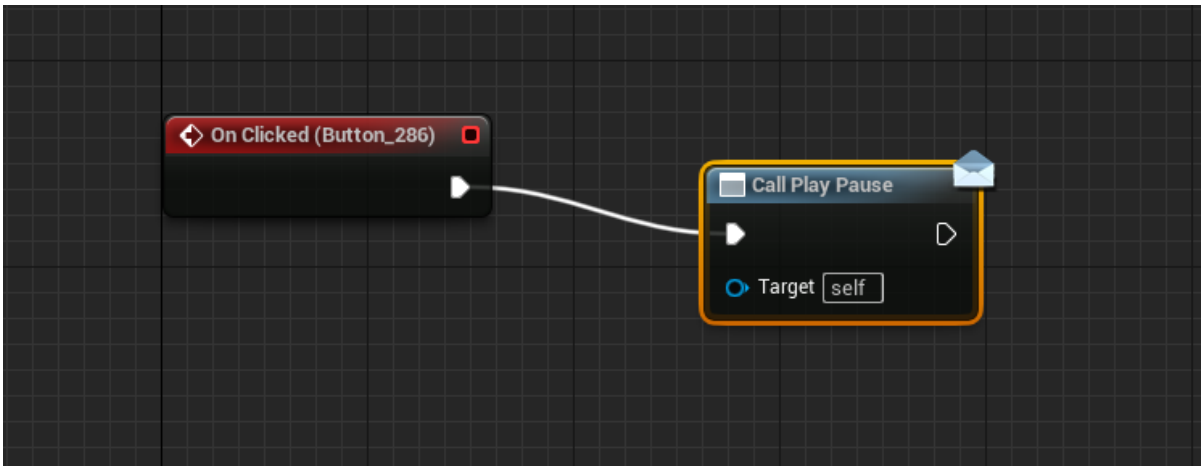


Figure 20: Graph of the "PlayPause" button.

function we first create a *Get Prim Bool Attribute* Node, where we set the *Prim Path* to */World* (the path to our *activate* USD Property) and the *Attribute Name* to *activate*. Then based on the success of the *Get Prim Bool Attribute* Function we either print the value of the Boolean property or we print, that the attribute could not be found.

Next, a *Get Actor of Class* node is created and connected to the *Print String* Node printing the property, where the *Actor Class* is set to *LevelSequenceActor*. The intention is to poll the Boolean property consecutively and either play or pause the animation accordingly. From the *Get Actor Of Class* node, a *Play* (*Sequence Player*) node is created, which also generates a *Sequence Player* node. Similarly, a *Pause* (*Sequence Player*) node is created by dragging away a line from the *Sequence Player* node. To determine the animation state (play or pause), a *Branch* node is connected to the *Get Actor Of Class* node. The True Branch is connected to the *Play* node, while the False Branch is connected to the *Pause* node. The output value of the *Get Prim Bool Attribute* node is used as the condition for the Branch node, determining the play or pause state. For reference, Figure 21 contains the complete graph for the "TriggerAnimation" function.

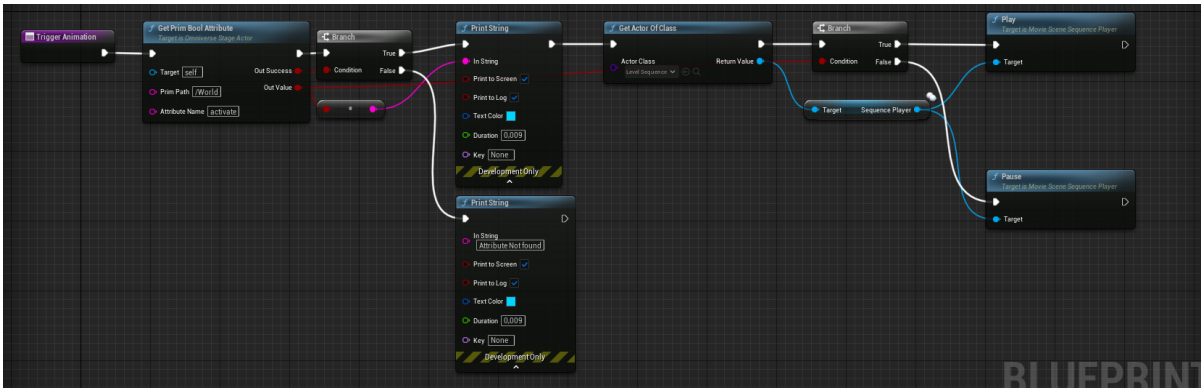


Figure 21: Complete graph for the "TriggerAnimation" function.

Returning to the *Event Graph*, a *Create Widget* node is created and connected to the *Set Timer by Event* node. Within the *Create Widget* node, go to the *Select Class* drop-down and select the previously created Widget Blueprint (*BtnPlayPause*). The Widget is then added to the viewport using an *Add to Viewport* node. The output value of the *Create Widget* node is connected to a *Bind Event to Play Pause* node, which establishes an event for the button click. From the *Event* pin of the *Bind Event to PlayPause* node, a *Create Event* node is created to generate a matching function named "SetBoolProperty". In the "SetBoolProperty" function, first a *Get Prim Bool Attribute* node is initialized with the *Prim Path* set to */World* and the *Attribute Name* set to *activate* to retrieve the *activate* USD property. Then, a *Branch* node is added, using the success output as the condition. The desired logic is to invert the Boolean property value when the button is pressed, toggling between true (playing) and false (paused).

This means we simply have to invert the Boolean properties value whenever the button is pressed. Therefore, a *Set Prim Bool Attribute* node is connected to the True Branch, and the inverted output of the *Get Prim Bool Attribute* node is used as input. The Boolean value inversion is accomplished by using the *NOT Boolean* node. Lastly, the *Prim Path* and *Attribute Name* in the *Set Prim Bool Attribute* node are set to the same values used in the *Get Prim Bool Attribute* node and then the Blueprint Class is compiled and saved. Figures 22 and 23 show the graph for the "SetBoolProperty" function and the Event Graph of the *OmniverseStageActor* Blueprint Class.

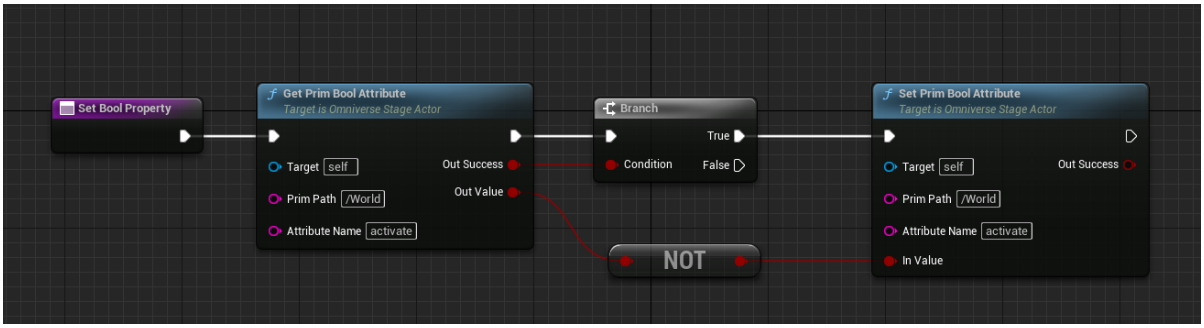


Figure 22: Complete graph for the "SetBoolProperty" function.

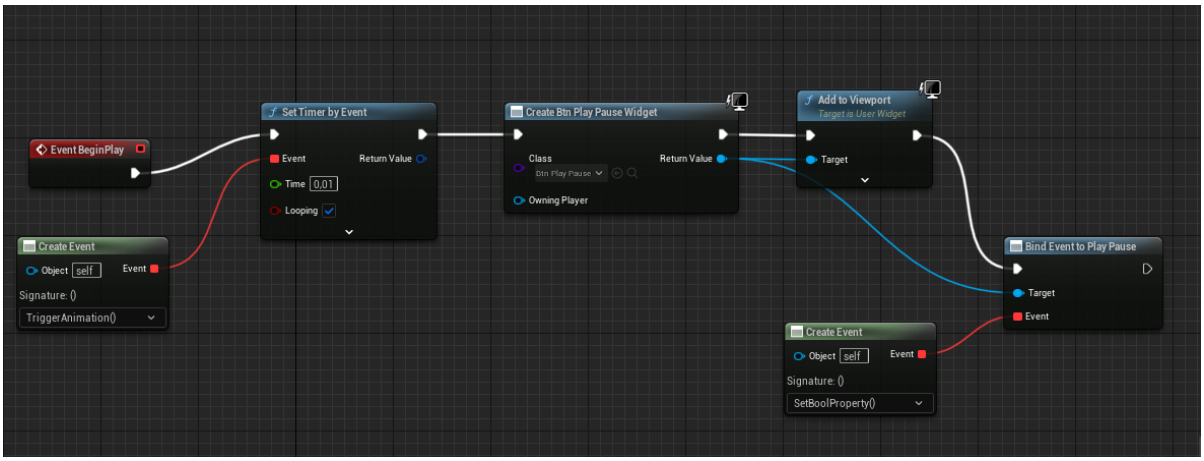


Figure 23: Complete Event Graph of the *OmniverseStageActor* Blueprint Class enabling the playing/-pausing of the animation based on the *activate* Boolean Property.

To test the concurrent animation control, we create a .live file from the USD file containing the animation previously modified to include the *activate* Boolean property in the World Prim. Also make sure your Omniverse Extension for the playing and pausing of the animation is loaded and the timeline is enabled. In case the extension is not loaded or not visible it can be loaded or reloaded from the Extensions menu. The *OmniverseStageActor* Blueprint Class is then added to the Scene in Unreal Engine, and the newly created .live file is dragged onto the USD Property of the *OmniverseStageActor*. If the screen appears overly bright, the *Exposure* in the *GlobalPostProcessVolume*should be set to *Auto Exposure Histogram*. Now click the Play Button in Omniverse and then pause the scene, followed by resetting the animation to 0, by dragging the blue pin in the animation timeline to its beginning. Further make sure the *activate* Property is set to false, as this should be the initial value, to make sure the Unreal Engine animation is paused at the beginning. In Unreal Engine, upon playing the Level, the Play/Pause Button should be displayed, and the animation should be paused (with "false" printed as the value of the *activate* property). To start the concurrent simulation, click the Play Button in the previously created Omniverse extension, which sets the *activate* property to true, resulting in the animation playing concurrently in both applications.

2.4 Development of Standalone Application

In this section, we address the development of a standalone application for our prototype. The objective is to create an executable that allows users to open and view the prototype independently. The application will load the scene with the animated car and provide functionality to switch between cameras and play/pause the animation, enhancing interactivity. Note that Omniverse installation is still required, as the application relies on Omniverse Kit as the core application runtime.

To accomplish the standalone application, we utilize the Omniverse Kit App Template, which can be cloned or downloaded from GitHub. After cloning the template, open it in Visual Studio Code and in the root folder under *source/extensions* you see *my_name.my_app.setup* and *my_name.my_app.window*, which are the Setup and Window Extensions. The Setup Extension is where we can set the layout of the window, configure the menu and most importantly, where we load our USD scene. The Window Extension creates a Window equal to the Window created by the Extensions in Omniverse USD Composer. We aim to recreate the Extension that enables camera switching. First, we focus on loading the USD Scene, thus opening *setup.py*.

In *setup.py*, we want to load the USD scene containing our animation. Before loading the scene, we switch to Omniverse USD Composer and open the scene with the animation. To ensure the scene includes all necessary data, we convert Payloads to References by right-clicking each prim with a blue arrow and selecting *Convert Payloads to References*. The arrow color should change to orange, indicating successful conversion. After converting all payloads to references, we save the file on our disk. After saving the USD file we go back to the *setup.py* and we add the call to open the stage at the bottom of the "on_startup" function. The call to open the stage is as follows:

```
omni.usd.get_context().open_stage('C:\User\user\Documents\USD_file.usd')
```

. If you want to package and distribute the application you should move the USD file into the data folder under *source/extensions/my_name.my_app.setup/data* and open the stage via a relative path. To test if the stage is successfully opened, we open a new terminal and navigate to the root folder. Calling *.\build.bat* compiles the application, which should result in a "Build Success" message. If the build is unsuccessful, rerun the build script or refer to the documentation or Omniverse forum for assistance. Next, we launch the application by executing *._build\windows-x86_64\release\my_name.my_app.viewport.bat* in the terminal. It is important to add *viewport* to indicate that we want to create a viewport app. An editor app can also be created, but for our purposes, we restrict the user from modifying the scene, thus utilizing a viewport app. For more information on the difference between the two visit the documentation.

After launching the application, a window should open with the viewport displaying the loaded USD stage. The Window base app should also be visible on the right side of the application. If this is the case, the application can be closed.
We then open *extension.py* and *window.py* in the Window Extension (*my_name.my_app.window*). In *window.py*, we create an extension that enables camera switching and play/pause functionality for the animation. The code is a refactoring of the two previously created extensions and is provided below. Initially, we retrieve the current stage, timeline, and all cameras in the scene. Then, buttons are created for each camera, and their click events are handled to switch to the corresponding camera (while ensuring that all cameras are hidden in the scene). For play/pause functionality, a simple function is implemented to toggle the timeline state between paused and playing. The full code of the $MyWindow$ application is presented at the end of this section.
In the *extension.py* we only need to make minor changes, as we here only set the initial value of *show_window* to false (last Boolean in line 17 and the Boolean in line 18), as we don't want to display the extension immediately. The cameras in the scene can only be found once the stage is fully loaded, so the user should open the window after the stage is fully loaded to ensure full functionality.

When you open the application now, only the stage with the loaded scene should be visible. To open the extension window, navigate to $Window$ and select $MyWindow$. This should open the extension window and you can drag the window to the side and interact with the scene via the provided buttons.

As you can see the toolbar offers various options like $File$, which allows users to open a different scene. However, this functionality is not required and thus we disable it. In *setup.py*, the *_setup_menu* function can be modified to comment out the lines $self.\_file\_open$ and $self.\_help\_menu$. Additional menus can

also be disabled in the *my_name.my_app.viewport.kit* file under *source/apps*. Below we show, which lines can be commented out, as their functionalities are not needed for this application. Important to note is, that we comment-out the vieport bundle, while un-commenting the viewport window. This removes the different viewport options in the left upper corner of the scene and only provides the window, in which the scene is displayed.

```
# File and Edit Menu -> can be commented out
#"omni.kit.menu.file" = {}
#"omni.kit.menu.edit" = {}

# Comment out the viewport bundle
#"omni.kit.viewport.bundle" = {}

# Uncomment the viewport window
"omni.kit.viewport.window" = {}

# Toolbar and Extensions -> can be commented out
#"omni.kit.window.toolbar" = {}
#"omni.kit.window.extensions" = {}
```

At this point, all necessary adjustments have been made, and the application can be opened to evaluate the final result. As a reference point, Figure 24 displays how the completed application looks.

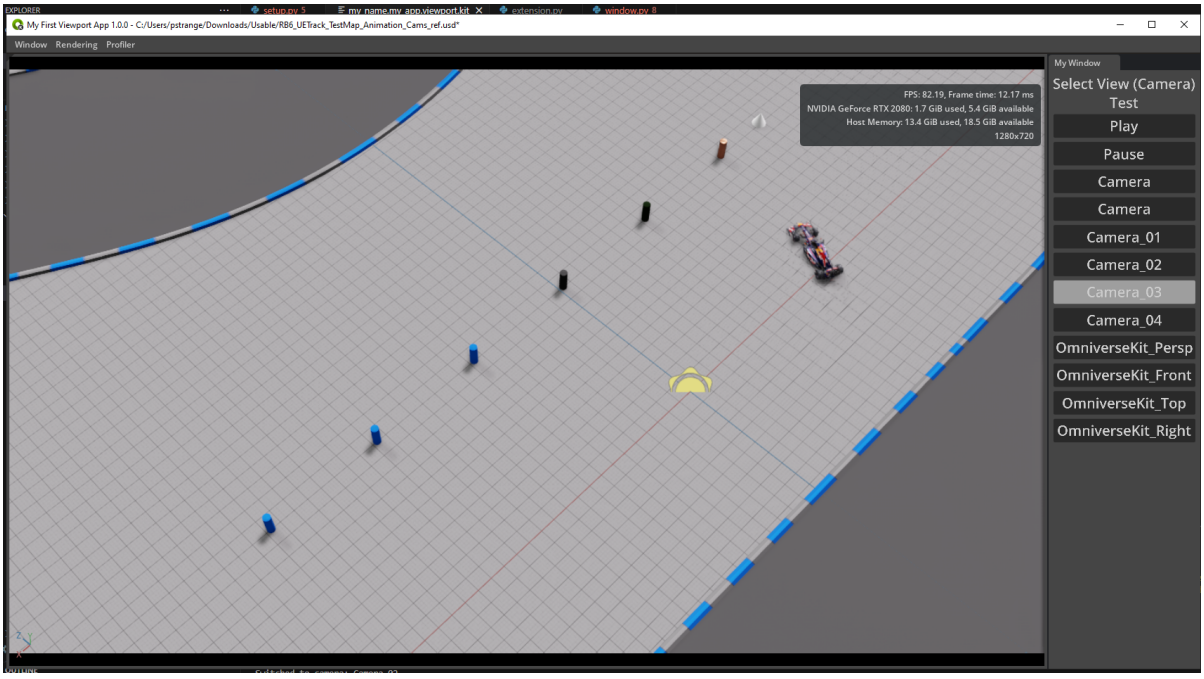


Figure 24: Showcase of the completed application with the *MyWindow* Extension enabled and the animation playing.

To package the application, simply execute the *package.bat* script in the root folder. This creates a zip file in the *_build/packages* directory. The zip file can now be distributed, and users should extract it before running *link_app.bat*. The *link_app.bat* script establishes a link between the application and one of the Omniverse Applications (typically Omniverse USD Composer, formerly Omniverse Create), which is necessary to run the application. After linking, the application can be launched by executing *my_name.my_app.viewport.bat*.

This concludes the development section and we now shift our focus to evaluating the performance of Omniverse and the Connector between Omniverse and Unreal Engine.

```
# Full code for the MyWindow Extension

import omni.usd
from pxr import UsdGeom
import omni.timeline

class MyWindow(ui.Window):
    """My Window"""

    title = "My Window"

    def __init__(self, **kwargs):
        super().__init__(MyWindow.title, **kwargs)

        viewportWindow = vp_utils.get_active_viewport_window()

        with self.frame:
            with ui.VStack():
                ui.Label("Select View (Camera)", height=0,
                    style={"font_size": 24, "alignment": ui.Alignment.CENTER})
                stage = omni.usd.get_context().get_stage()

                if stage is not None:
                    timeline = omni.timeline.get_timeline_interface()
                    # find all cameras in the stage
                    ui.Label("Test", height=0, style={"font_size": 24,
                        "alignment": ui.Alignment.CENTER})
                    cameras = [[x.GetName(), x.GetPrimPath()] for x in stage.Traverse()
                        if x.IsA(UsdGeom.Camera)]
                    if len(cameras): # If cameras are found -> create button per camera
                        with ui.VStack(height=50, style={'font_size':24}):
                            def play_pause():
                                print("Play/Pause pressed")
                                if timeline.is_playing():
                                    print("Pause")
                                    timeline.pause()
                                else:
                                    print("Play")
                                    timeline.play()
                            def on_click(camera_name, camera_path):
                                viewportWindow.viewport_api.camera_path = camera_path
                                print('Switched to camera: ' + camera_name)

                            ui.Button('Play', clicked_fn=play_pause)
                            ui.Button('Pause', clicked_fn=play_pause)

                            for i in range(len(cameras)):
                                var = cameras[i]
                                UsdGeom.Imageable(stage.GetPrimAtPath(var[1]))
                                    .GetVisibilityAttr().Set('invisible')
                                #lambda is needed to make a clickable button -
                                #otherwise the click event is triggered on startup
                                #further we need to specify the default values of the
                                #function and pass them as otherwise only name and path
                                #of the last camera are saved
                                ui.Button(var[0], clicked_fn=lambda name=var[0],
                                    path=var[1]: on_click(name, path))
```

3 Performance and Limitations

In this section, we discuss the performance of Omniverse and the limitations encountered during the development of the prototype. We also explore potential strategies to improve performance.

3.1 General Omniverse Performance and Optimization

During the testing of the animated car prototype, it is observable, that the RTX Renderer in Omniverse is GPU-intensive, resulting in lower FPS counts even with a good GPU. To improve performance, certain render settings can be adjusted. The obtained FPS values were measured while driving along the main straight of a test track, continuously steering the car, and capturing the lowest FPS values within a 2 FPS interval. It is important to note that FPS values are influenced by factors such as window size (resolution), scene complexity (vertices, materials), and the hardware used. Hence, it is recommended to test and customize the performance settings based on individual requirements.

3.1.1 Lighting

Lighting significantly impacts performance, and the default Light Rigs perform worse compared to adding custom lights. Default Light Rigs are combinations of different lights, which contribute to their lower performance. Among the Light Rigs, the *Colored Lights* Light Rig (43-45 FPS) performed the best, followed by the *Default* Light Rig (40-42 FPS), *Sunny Sky* Light Rig (40-42 FPS), and *Grey Studio* Light Rig (38-40 FPS). When considering individually created lights, the *Distant Light* (49-51 FPS) showed the best performance, followed by the *Cylinder Light* (48-50 FPS), *Sphere Light* (46-48 FPS), *Rect Light* (45-47 FPS), *Disk Light* (45-47 FPS), and *Dome Light* (43-45 FPS). Switching from the *Default* Light Rig to a *Distant Light* improved FPS counts by approximately 9 FPS (from 40-42 FPS to 49-51 FPS).

3.1.2 NVIDIA DLSS

The next major performance increase can be achieved by setting the Mode for *NVIDIA DLSS* to *Performance* (the default value here is *Quality*). DLSS stands for Deep Learning Super Sampling and with this the image is rendered in a lower resolution and then upscaled via an AI algorithm. Other DLSS settings did not yield significant performance improvements. Enabling Performance Mode for DLSS increased FPS counts by approximately 10 FPS (from 49 – 51 to 61 – 63).

3.1.3 Reflections, Ambient Occlusion, and Shadows

Further FPS improvements can be achieved by disabling certain rendering features. Disabling reflections resulted in a significant performance boost (+22 FPS), taking FPS from 61-63 FPS to 83-85 FPS. Additionally, turning off ambient occlusion in the *Indirect Diffuse Lighting* section provided a minor improvement (+3 FPS) (83-85 FPS to 86-88 FPS). Finally, disabling shadows in the *Direct Lighting* section increased FPS counts by another 5 FPS, increasing FPS from 86-88 FPS to 91-93 FPS.

For more information on all rendering settings for the RTX Renderer visit the documentation.

3.2 Unreal Engine Lag without Lighting

When working with an empty scene consisting only of a ground plane and the RB6 model placed on top of it, Unreal Engine (UE) experiences significant lag if no light is added to the scene. If the *Default* Light Rig is added to the scene Unreal Engine has no problem rendering the scene, but if the *Default* Light Rig (or any Light) is not added to the scene Unreal Engine struggles heavily. This behavior suggests that UE relies on its own shading calculations, when a light is present in the scene. Without a light, UE might need to retrieve lighting information from Omniverse, as in Omniverse selecting the *Default* Light applies the lighting, but does not add the Lights to the Stage.

To verify this behavior, we can establish a live connection between UE and Omniverse, by loading the USD stage (.live file) in UE. With only the *Default* Light Rig selected in Omniverse, severe lag can be observed when viewing the RB6 model in UE. Tracing the application revealed that a single render frame in the *RenderThread* took approximately 530ms, when looking at the F1 Car Model, with the *DeferredShadingSceneRenderer_Render* function accounting for most of this time (520-530ms). This

is presented in Figure 25, where the period up to 3m 53s correlates with the above described scenario. We can see, that frame times in *RenderThread*0 are somewhere between 530ms and 590ms.
If we keep looking at the RB6 Model in the scene and add a *Directional Light* into the UE scene, frame times decrease to around 10ms and the *DeferredShadingSceneRenderer_Render* takes around 4ms. In Figure 25 the yellow flag at 3m 56s marks the addition of the *Directional Light* into the scene and the difference in frame times is clearly visible. This indicates that when UE can perform lighting calculations based on the *Directional Light* added to the scene, frame times decrease from 530ms to 10ms. To be clear, it does not matter if the Light is added in Omniverse or Unreal Engine, as long as Unreal Engine has a Light, which it can use for lighting calculations.

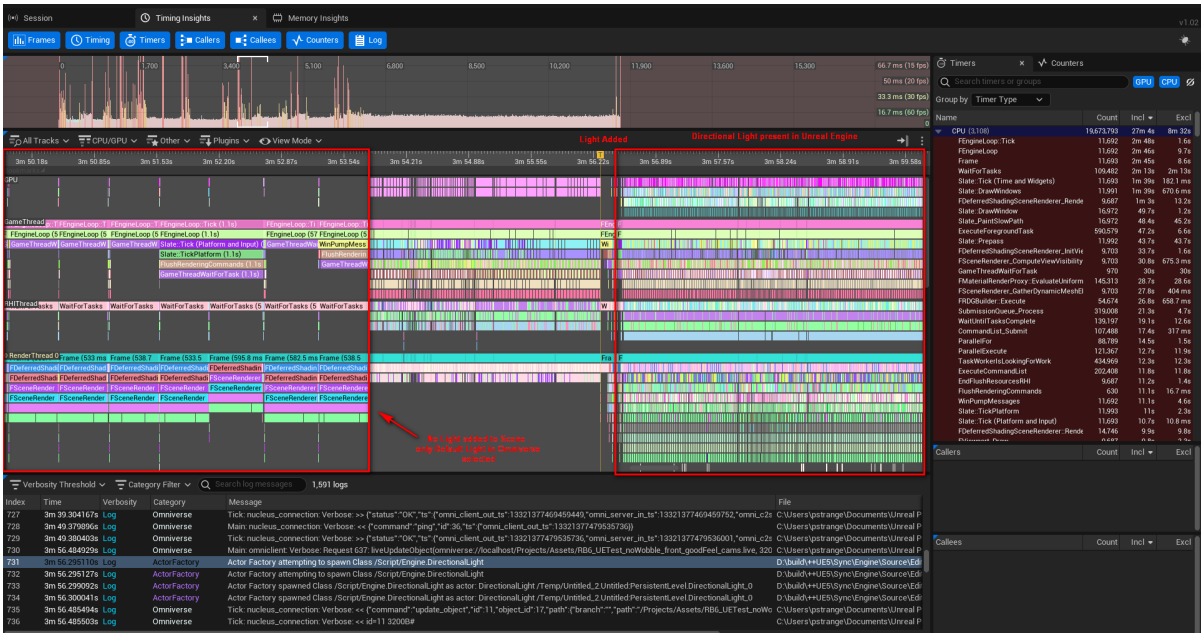
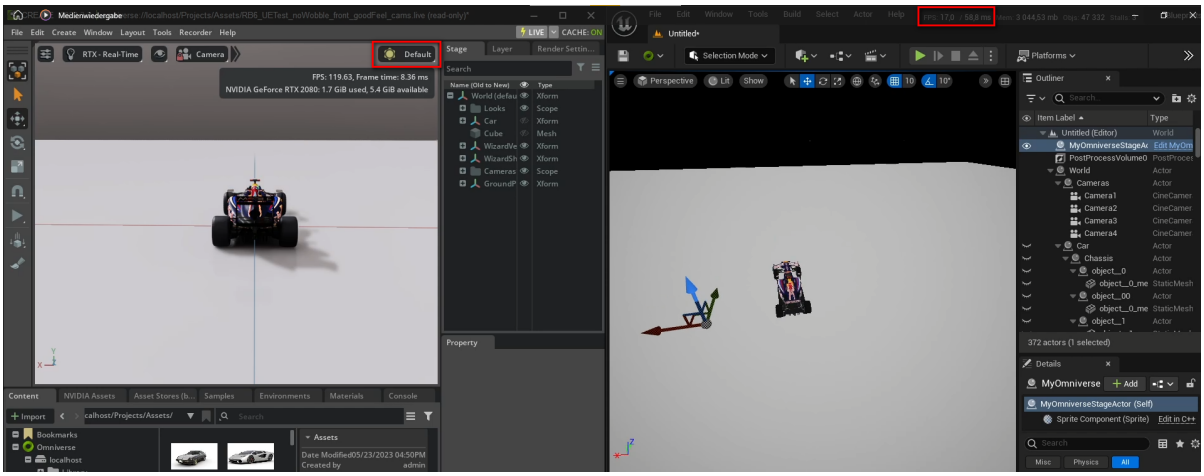
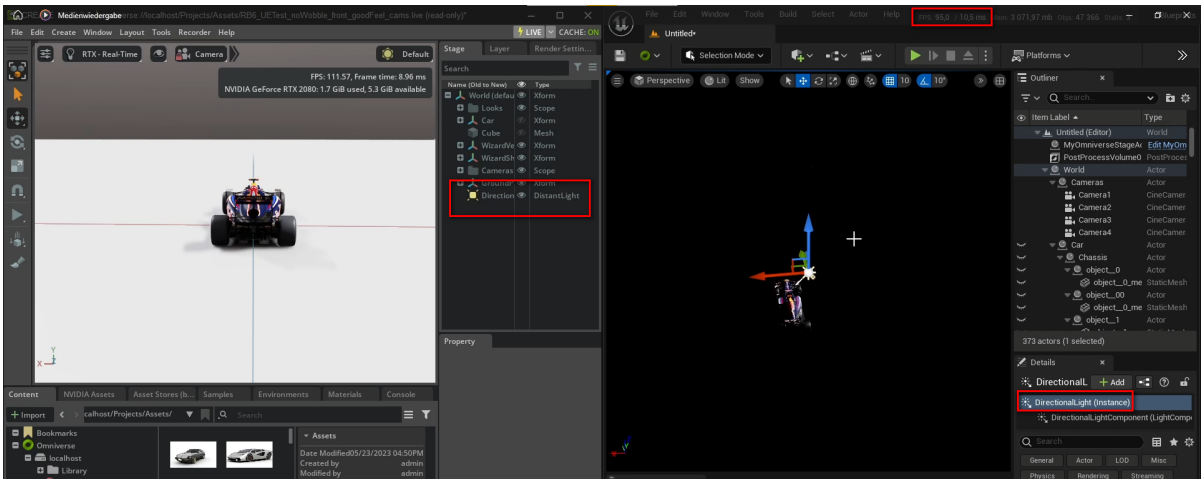


Figure 25: Timing Trace in Unreal Insights, showcasing the impact to the rendering performance, when adding a dedicated light to the scene.

Figure 26 shows such an example, where Figure 26a shows the scene with only the *Default* Light Rig selected in Omiverse, which leads to very laggy performance in Unreal Engine (17 FPS in this example). Figure 26b then shows the scene, after adding a *DirectionalLight* in Unreal Engine and we can see, performance increases substantially.



(a) UE Rendering performance without dedicated Light.



(b) UE Rendering performance with dedicated Light in UE.

Figure 26: Showcase of the performance impact of adding a Light to the Unreal Engine Scene.

3.3 Limitations of Omniverse and Unreal Engine Connector

As touched on in one of the previous sections, the performance of Unreal Engine in the live co-simulation mode depends heavily on the number of vertices in the scene. If we have a scene with a high vertex count and we have a moving prim in this scene (driving a vehicle) Unreal Engine seemingly has to load the whole scene whenever a prim in it changes. As the moving primitive constantly updates (e.g., wheel rotation and position), Unreal Engine must continually load the updated USD file. At a certain vertex count threshold, Unreal Engine struggles to keep up with the USD file updates, resulting in lag. This is our assumption, as it makes no difference if the moving prim has a high or low vertex count i.e. it only depends on the total number of vertices in the scene. This also implies, that UE has to load the whole USD scene again and cannot only update the changed values in the USD file.

This assumption is supported, when we look at a trace in the Unreal Engine Insights, where at first only a simple vehicle (standard Vehicle Wizard vehicle with Wheels from the RB6 Model) was present in the scene. Driving the vehicle leads to no significant lag and allows for a smooth simulation in both Omniverse and Unreal Engine. Then, the RB6 car model (23.4K vertices) was added to the scene, introducing a high vertex count. Now, driving the simple vehicle model in Omniverse leads to significant lag in Unreal Engine. In Figure 27, the point where the RB6 model was added into the scene is marked with the yellow Flag and the time from 26m 45s to 27m 14s is where the simple vehicle was driven in Omniverse, without the RB6 Model being present. As can be seen in Figure 27 neither the Render nor the Game Thread have any performance issues. This changes at around 28m 10s, where again the simple vehicle was driven around in Omniverse, but with also the RB6 Model being present in the scene. It is visible, that the *GameThread* as well as the *RenderThread* are lacking work, while the GPU shows little

to no activity. This indicates that the CPU and GPU are not limiting factors, as they have little to do and are primarily waiting for tasks.

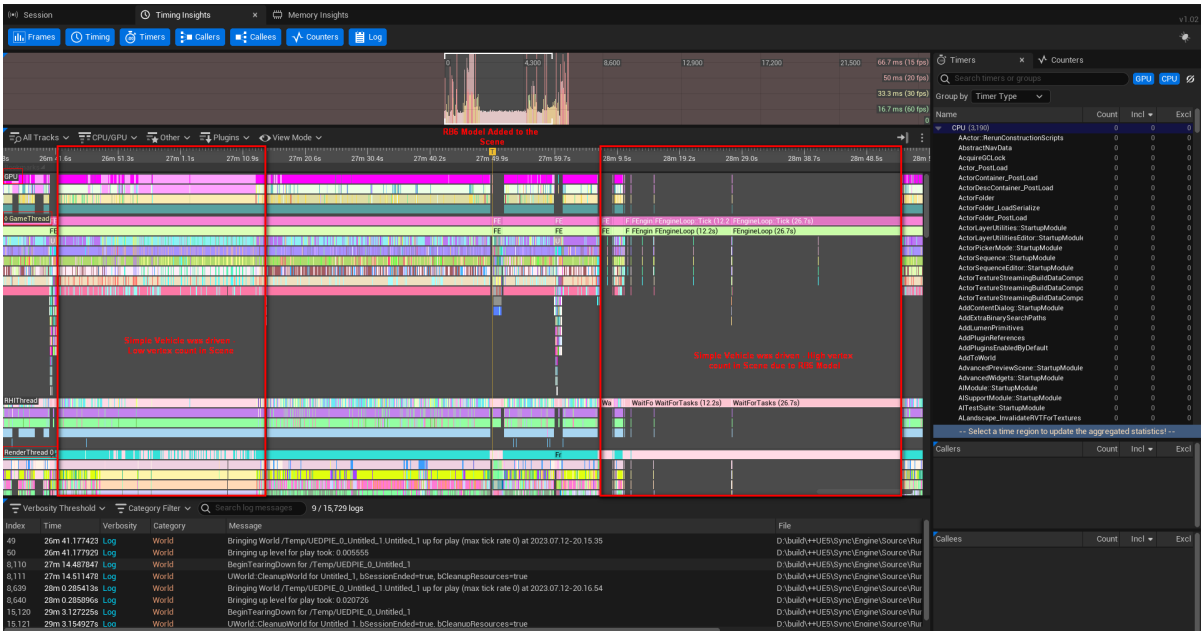


Figure 27: Timing Trace in Unreal Insights, showcasing the performance impact of a high vertex count in the scene.

Looking at the Memory Insights in Figure 28, we see, that at around 28m 0s, when the Level was started (driving of the vehicle started at around 28m 10s) Memory engagement looks similar to when we drove around with the simple vehicle without a high vertex count in the scene (26m 42s – 27m 14s). Thus, Memory engagement is at an equal or higher value (LLM Physics is higher), while GPU and CPU both are waiting for tasks.
Therefore, it is reasonable to assume that the laggy performance in Unreal Engine during live Physics Vehicle co-simulation with a high vertex count in the scene is caused by the way USD scene updates are handled by the connector. As the RB6 model in this example is a stationary non-moving model it is reasonable to assume that the connector updates the whole scene, not just the changed prims or their attributes. Thus, when the vertex count increases, the time required for these updates also increases, resulting in lag.

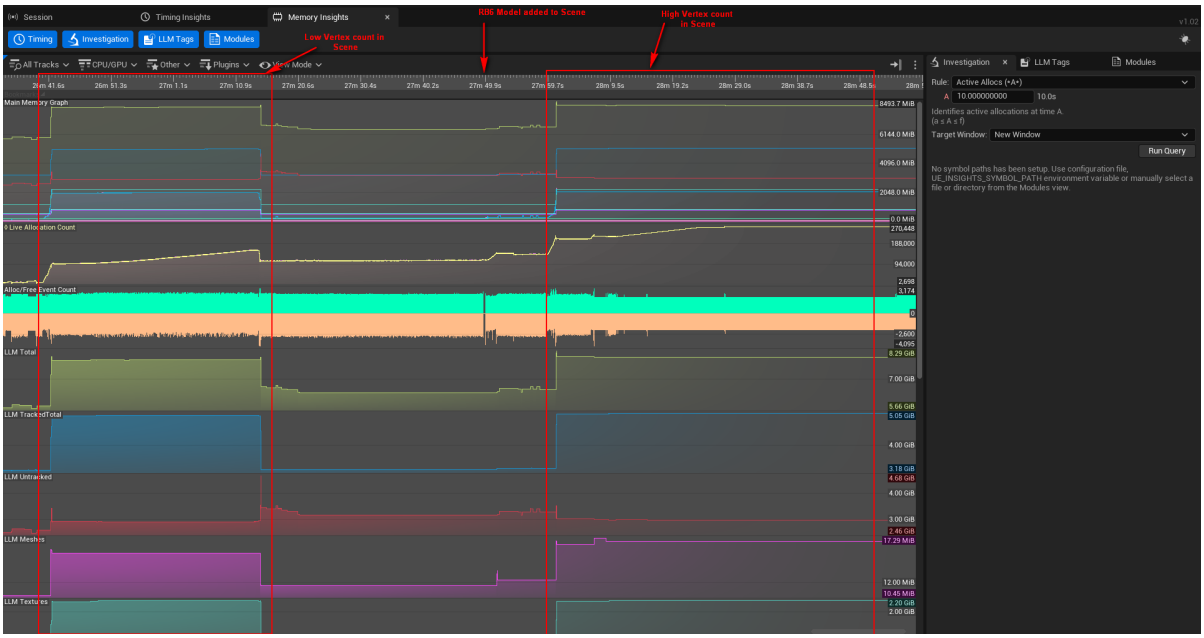


Figure 28: Memory Trace in Unreal Insights, showcasing the impact of a high vertex count to the performance.

There is however a way to circumvent this lag if one locks the stationary prims. This can be achieved by right-clicking the static prim in the Omniverse Stage and selecting *Locks* → *LockSelectedHierarchy*, as presented in Figure 29. In this example, as presented in Figure 29, the RB6 Model Prim is locked, which locks the parent prim, as well as all child primitives with all its properties. This ensures, that the stationary RB6 model does not have to be updated by the Connector, leading to no real lag in Unreal Engine, when reading out the *Steer* property. Thus we recommend locking stationary prims, when doing any live readouts of USD Properties in Unreal Engine.

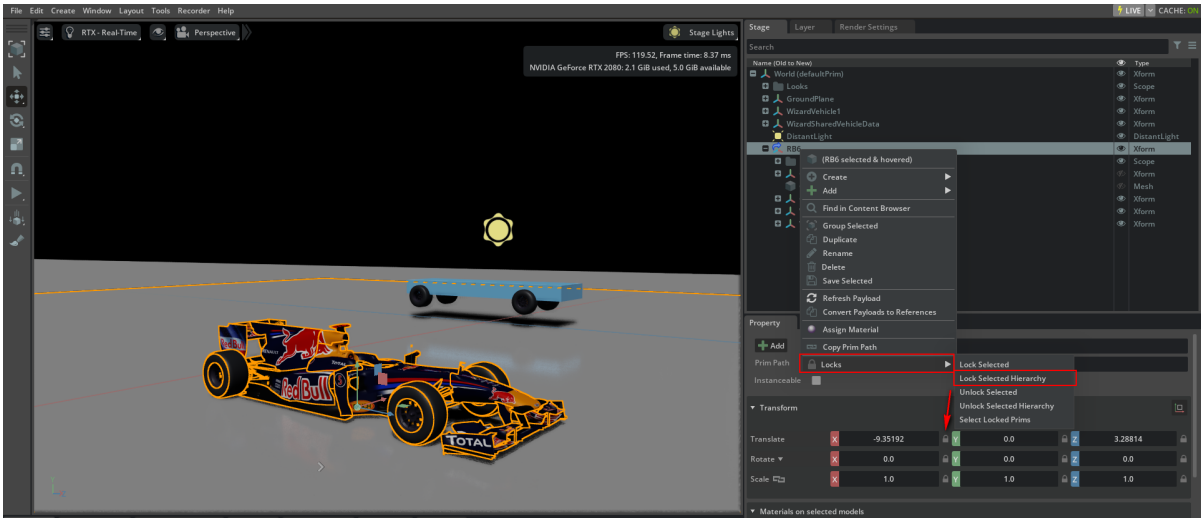


Figure 29: Selecting *Locks* → *LockSelectedHierarchy* locks all properties of a primitive, as well as all properties of its child primitives.

4 Technical Requirements

This section discusses the technical requirements for the project, including the software and hardware specifications necessary to run the implemented prototype. The project was developed using Omniverse USD Composer version 2022.3.3 (formerly known as Omniverse Create) and Unreal Engine 5.1.1. The used version of the Omniverse UE Connector was 201.1.244 and the used Local Nucleus Service version was 2022.4.2.

Omniverse Applications are based on the RTX Renderer, which is optimized for NVIDIA RTX GPUs. Therefore, an RTX GPU is required to run Omniverse Applications with the RTX Renderer. While it is possible to run Omniverse with a non-RTX GPU, it limits the available rendering options to the Pixar Storm Renderer, which seemingly lacks provided shaders. Omniverse provides different modes for the RTX Renderer, namely the RTX - Real-Time mode and the RTX - Interactive (Path Tracing) mode. We used the RTX - Real-Time mode, as the Interactive mode is even more performance hungry.
For the implementation of the prototype using Omniverse USD Composer, it is recommended to have at least an RTX 2080 GPU. The minimum GPU requirement is any RTX GPU with 6GB of VRAM.

In terms of CPU requirements, both the minimum and recommended specifications call for an Intel i7 or AMD Ryzen CPU. The minimum specifications require a minimum of 4 cores, while it is recommended to have 8 cores. Regarding RAM, Omniverse USD Composer requires a minimum of 16GB, with 32GB being recommended for optimal performance.

For our project, the system used was in line with the recommended system requirements. It consisted of an RTX 2080 GPU, an Intel i7 8700 CPU, and 32GB of RAM.

5 Future Work

In future projects, one potential area of exploration is extending the prototype to receive vehicle data through a web service. This enhancement would enable multiple racecars to be present in the same scene, with updates received via a web service. Such functionality could be achieved by developing a custom Python Omniverse Extension.