Poster: A case for heterogenous co-simulation of cooperative and autonomous driving

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***Abstract*—Many exciting future research topics in the field of Cooperative Autonomous Vehicles (CAVs) require the simulation of both connectivity and automation components. However, existing simulation tools focus on only one of these two aspects while making idealistic assumptions about the other. In this work, we motivate the use of established libraries such as gRPC to couple existing independent simulation tools tailored to either connectivity or automation, and demonstrate the feasibility of such an approach. We also describe an Open Source reference implementation coupling CARLA and Veins.**

I. Introduction

For many years, the Cooperative Autonomous Vehicle (CAV) research community has relied on simulations that really only focus on one of the two aspects – cooperation or autonomy – and model the other as an idealized process. Thus, in the context of autonomous driving research, networking and communication have often been considered a solved problem, leading to assumptions such as unit disk coverage and channels with infinite capacity, uninterrupted availability, and perfect robustness. Conversely, in the context of cooperative driving research, sensing has often been considered as an abstract process generating opaque chunks of data to be shared.

For a large number of problems in either domain, this has been sufficient, but more recently, cooperative driving research has begun to address problems where sensor data cannot be treated as opaque. Such problems include cooperative perception, cooperative localization, mobile edge-enabled cooperative sensor data fusion, and federated learning based on sensor data. In each of these cases, it is clear that the exact contents of the sensor data to be exchanged may dictate the relative performance of the potential algorithms under study and the quality of the results.

It could be argued that a potential solution to unifying the two domains is to augment existing simulation frameworks for cooperative driving with increasingly complex simulation components modeling autonomous driving – or vice versa. However, such an approach would no longer lend itself to the use of existing simulation tools that have developed in isolation over the years. Instead, we therefore propose to couple existing simulation frameworks for cooperative and autonomous driving, and to use them in a co-simulation setup, allowing the respective components to keep evolving independently – each driven by the needs of its own research community. This is in line with the successful approaches taken in the past for similar cross-cutting problems, leading to co-simulation frameworks using independent simulators for road traffic and wireless communication [1], independent simulators for pedestrian and vehicular mobility [2]–[4], and independent simulators for road traffic and autonomous driving [5]–[9]. However, of the latter, though relevant to the problem at hand, approaches are either not concerned with sensing [5], not concerned with wireless communication simulation [6]–[8], or assume a perfect wireless channel [9], e.g., with unlimited capacity and no interference.

In this paper, we thus advocate for a co-simulation setup integrating simulators for both communication and sensing, show how such a system can be designed, and demonstrate how it can be used to study cooperative perception algorithms in a realistic setting. We also discuss an Open Source reference implementation showing how the CARLA simulator [10] can be coupled with the OMNeT++ ecosystem.[1]

II. carla_adapter Concept

CARLA [10] is an open-source simulator for autonomous driving research, mainly focused on urban areas. One core concept is that arbitrary types of sensors (the simulator already includes GNSS, cameras, LiDAR, and many more) can be attached to vehicles to provide the basis for autonomous driving. However, CARLA does not provide models for wireless communication, which would be necessary for the realistic simulation of CAVs.

Therefore, we propose a generic bidirectional coupling approach using OMNeT++ as an example to combine the sensing capabilities of CARLA with the wireless communication models provided by the OMNeT++ Veins framework [1].

Instead of designing the "traditional" use case specific language, serialization, and command protocol for simulator interlinking – an approach that many works in the literature have followed in the past – which would require custom libraries adapted to different domains and their tools, we propose the use of a much simpler generic coupling approach:

[1] http://www.cms-labs.org/research/software/veins_carla/

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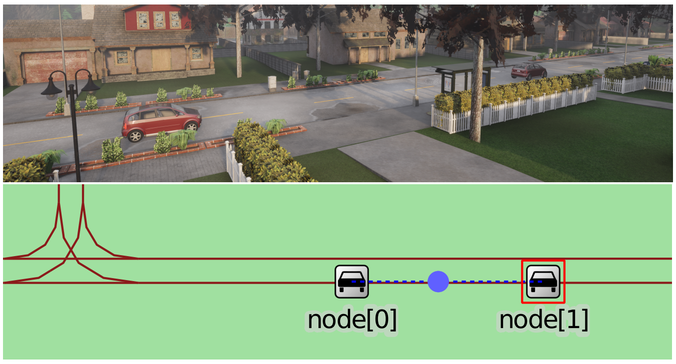

Figure 1. Sample screenshots of CARLA (top) and Veins (bottom) running in tandem to simulate two cars driving autonomously through a suburban area with buildings, hedges, and trees while exchanging information wirelessly.

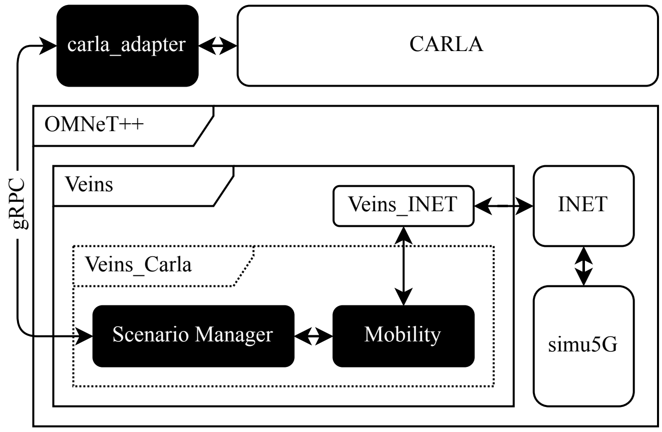

Figure 2. Architecture of the proposed co-simulation approach; here: coupling the CARLA and OMNeT++ ecosystems (new code with black background).

the use of widely-available RPC libraries. In our reference implementation, we choose Google Protobuf and gRPC to bidirectionally couple CARLA with any other simulator that can incorporate generic gRPC interfaces (e.g., ns-3, OMNeT++, and others). Since gRPC is available in various programming languages such as C++, Python, and others, a wide range of potential use cases are possible.

As CARLA provides a Python API, we created a new proxy application written in Python which we call carla_adapter. It creates a gRPC server that can be used by any other simulator and calls CARLA methods to control the simulation. To guarantee the synchronicity of both simulators, we configure CARLA to run in synchronous mode, allowing us to trigger single simulation steps with a predefined time step length.

To use the carla_adapter, the appropriate gRPC interfaces only need to be implemented in the second simulator. For our reference implementation we couple CARLA and Veins. We call this implementation Veins_Carla. For this, we created a new module called *CarlaScenarioManager* for the Veins framework. It implements the gRPC interfaces and establishes the gRPC connection to carla_adapter. At the beginning of the simulation, we synchronize the simulators via code in Veins_Carla. The vehicles in CARLA (actors) are generated in OMNeT++ (as modules) and vice versa. We also created a mobility module for Veins that receives the vehicle positions from carla_adapter and updates the Veins mobility model accordingly. We can thus use Veins_Carla to simulate aspects of autonomous driving and sensing in CARLA and aspects of cooperation and wireless communication in Veins. Further libraries can be added to either simulator to extend the simulation capabilities, e.g., models specific to backbone networks or the 5G New Radio user plane.

A sample co-simulation is shown in Figure 1. The architecture of the proposed co-simulation approach as it applies to the reference implementation is illustrated in Figure 2.

III. CONCLUSION AND FUTURE WORK

In this paper, we presented a co-simulation approach that couples two existing tools, each designed to simulate one of the key components of Cooperative Autonomous Vehicles (CAVs) – connectivity and automation – using a generic RPC interface with widely available libraries. We also described its Open Source reference implementation for CARLA (autonomous driving) and Veins (wireless communication). This approach allows heterogeneous simulations of autonomous and cooperative driving without the need to substantially extend existing simulators.

In the future, we plan to use the proposed co-simulation approach to study cooperative perception and localization algorithms, as well as cooperative sensor data fusion techniques, in realistic cooperative and autonomous driving environments.

REFERENCES

[1] C. Sommer, R. German, and F. Dressler, "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis," *IEEE Transactions on Mobile Computing (TMC)*, vol. 10, no. 1, 2011.
[2] S. Schuhbäck, N. Daßler, L. Wischhof, and G. Köster, "Towards a bidirectional coupling of pedestrian dynamics and mobile communication simulation," *EPiC Series in Computing*, vol. 66, pp. 60–67, 2019.
[3] D. Garrido, J. Jacob, D. Castro Silva, and R. J. F. Rossetti, "Pedestrian Simulation In SUMO Through Externally Modelled Agents," in *35th ECMS International Conference on Modelling and Simulation (ECMS 2021)*, May 2021, pp. 111–118.
[4] P. Lawrence, V. Pellacini, D. Blackshields, and L. Filippidis, "The Development of Pedestrian Gap Acceptance and Midblock Pedestrian Road Crossing Behavior Utilizing SUMO," in *SUMO Conference Proceedings*, vol. 2, TIB Open Publishing, Jun. 2022, pp. 33–51.
[5] M. Klischat, O. Dragoi, M. Eissa, and M. Althoff, "Coupling SUMO with a Motion Planning Framework for Automated Vehicles," *EPiC Series in Computing*, vol. 62, 2019.
[6] R. Xu, Y. Guo, X. Han, X. Xia, H. Xiang, and J. Ma, "OpenCDA: an open cooperative driving automation framework integrated with co-simulation," in *2021 IEEE International Intelligent Transportation Systems Conference (ITSC)*, IEEE, Sep. 2021, pp. 1155–1162.
[7] D. Cui et al., "Extensible Co-Simulation Framework for Supporting Cooperative Driving Automation Research," *Transportation Research Record*, Sep. 2022.
[8] Y. Shi, Z. Liu, Z. Wang, J. Ye, W. Tong, and Z. Liu, "An integrated traffic and vehicle co-simulation testing framework for connected and autonomous vehicles," *IEEE Intelligent Transportation Systems Magazine*, vol. 14, no. 6, pp. 26–40, Nov. 2022.
[9] J. Cui, H. Qiu, D. Chen, P. Stone, and Y. Zhu, "Coopernaut: End-to-End Driving with Cooperative Perception for Networked Vehicles," in *IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, IEEE, Jun. 2022.
[10] A. Dosovitskiy, G. Ros, F. Codevilla, A. Lopez, and V. Koltun, "CARLA: An Open Urban Driving Simulator," in *Proceedings of the 1st Annual Conference on Robot Learning*, 2017.