

# JOAN: a framework for human-automated vehicle interaction experiments in a virtual reality driving simulator

Niek Beckers<sup>\*1</sup>, Olger Siebinga<sup>†1</sup>, Joris Giltay<sup>1</sup>, and André van der Kraan<sup>1</sup>

<sup>1</sup> Human-Robot Interaction group, Department of Cognitive Robotics, Faculty 3mE, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands

DOI: [10.21105/joss.04162](https://doi.org/10.21105/joss.04162)

## Software

- [Review](#) ↗
- [Repository](#) ↗
- [Archive](#) ↗

Editor: [Pending Editor](#) ↗

Submitted: 14 February 2022

Published: 15 February 2022

## License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)).

## Summary

With the rapid development of automated driving systems, human drivers will soon have to share the road, and interact with, autonomous vehicles (AVs). To design AVs that can be safely introduced in our mixed traffic, research into human-AV interaction is needed. Driving simulators are invaluable tools, however, existing driving simulators are expensive, implementing new functionalities (e.g., AV control algorithms) can be difficult, and setting up new experiments can be tedious. To address these issues, we present JOAN, a framework for human-AV interaction experiments. JOAN connects to the open-source AV-simulation program Carla and enables quick and easy implementation of simple driving experiments. It supports experiments in VR, a variety of human input devices, and haptic feedback. JOAN is easy to use, flexible, and enables researchers to design, store, and perform human-factors experiments without writing a single line of code.

## Statement of need

Real-world traffic is rapidly changing: automated vehicles, even autonomous vehicles, are rapidly being introduced on the roads interacting with other road users. It is likely that traffic will be mixed for the coming decades, with manually driven vehicles, vehicles of various levels of automation, and vulnerable road users (e.g., pedestrians and cyclists) sharing the same road ([Di & Shi, 2021](#)). Therefore, investigating the interaction between AVs and other road users is critical for the development of safe and acceptable AV behavior. Driving simulators are invaluable tools to study such human-AV interactions.

State-of-the-art driving simulators use motion platforms, immersive graphics ([WIVW, n.d.](#)), and/or high-fidelity haptic feedback ([Mulder et al., 2012](#)) to create simulations with high levels of realism ([Slob, 2008](#)). However, such simulators require dedicated and often expensive hardware, limiting their availability for algorithm development and evaluation. Furthermore, they require a steep programming learning curve and lack the flexibility to quickly implement customized experiments.

Alternatively, virtual-reality-based driving simulators offer reasonable levels of realism, require relatively low-cost hardware, and are generally more flexible in terms of rapid algorithm development or experiment evaluation. Traffic simulators based on the Unity game engine have

<sup>\*</sup>co-first author

<sup>†</sup>co-first author

37 been developed for studying human-human interaction in mixed traffic (Bazilinskyy et al.,  
38 2020; Kearney & Noyce, 2018). However, both lack the framework to implement AV driving  
39 models, which is necessary to simulate mixed-traffic scenarios.

40 Several game engine-based simulators exist that only specifically focus on AV algorithm de-  
41 velopment (e.g., (Dosovitskiy, 2017; LG Electronics America R&D Center, n.d.; Shah et al.,  
42 2018)). While such simulators provide possibilities for implementing, training, and evaluating  
43 fully automated driving algorithm, they do not support human-in-the-loop experiments. A  
44 popular open-source simulators is CARLA (based on the Unreal-Engine); it provides a flexible  
45 and well-documented API, pre-trained automated driving models, common roadmap standards  
46 (OpenDrive), and is actively maintained.

47 Silvera et al. extended Carla to support human-in-the-loop experiments (Silvera et al., 2022).  
48 They created an affordable driving simulator primarily implemented in C++ and python that  
49 can be used for human-AV interaction experiments which leverages the benefits of CARLA for  
50 AV development. However, because their software is not set up with a more general experiment  
51 framework that allows customizability, their software is restricted to specific hardware (both for  
52 human input and VR headsets) and requires extensive programming to implement customized  
53 experiments.

54 To address these issues, we created JOAN, an open-source framework for conducting human-  
55 in-the-loop driving experiments. JOAN interfaces with Carla, is written in Python, is fully  
56 customizable through code and graphical user interfaces (GUI). JOAN can be used with a  
57 variety of human input devices, including game console controllers (e.g., Xbox or PlaySta-  
58 tion), generic USB controllers (e.g., Logitech G920), or a SensoDrive high-fidelity steering  
59 wheel (SensoDrive, n.d.) (for including haptic feedback). JOAN includes a framework for  
60 experiment design to create and execute experiments, and provides reliable data acquisition.  
61 These features can be accessed through a user-friendly interface, which means no extensive  
62 (knowledge of) programming nor a lot of time is required to set up new experiments.

63 For detailed instructions on how to install and use JOAN, see our online documentation<sup>1</sup>.  
64 JOAN can be found in a GitLab repository<sup>2</sup>, a video with more information can be found on  
65 YouTube<sup>3</sup>.

## 66 Software functionality

67 We set the following requirements for JOAN based on the needs of a typical human-in-the-loop  
68 driving experiment. JOAN should:

- 69 ■ provide reliable data acquisition,
- 70 ■ enable researchers to connect multiple types of user input devices,
- 71 ■ facilitate the design and execution of experiment protocols; create repeatable traffic  
72 scenarios involving multiple agents,
- 73 ■ provide an easy way to design experiments by providing access to most functionality  
74 from a GUI,
- 75 ■ be flexible and extensible by design, and
- 76 ■ include support for haptic feedback.

77 JOAN consists of modules, each with a functionality, to address the flexibility and extensibility  
78 requirements. These modules can be enabled or disabled based on the needs of a researcher,  
79 if needed they can easily be adapted, and researchers can create new modules to implement  
80 new functionality. The standard modules included with JOAN:

<sup>1</sup><https://joan.readthedocs.io>

<sup>2</sup><https://gitlab.tudelft.nl/tud-cor-hri/joan-framework/joan>

<sup>3</sup><https://www.youtube.com/watch?v=TLLw48isYJU>

- 81     ▪ log and plot experiment data,
- 82     ▪ handle hardware inputs,
- 83     ▪ design and execute experiments with multiple conditions,
- 84     ▪ implement traffic scenarios with dynamic triggers for events,
- 85     ▪ provide a human with haptic feedback.

86     Each module has its own GUI which appears if the module is enabled. These interfaces  
 87     provide access to all standard functionality of the module. A researcher can design and  
 88     perform a simple human-in-the-loop experiment without writing a single line of code. The  
 89     documentation provides more information for researchers who want to adapt existing modules  
 90     (e.g. to implement new hardware), or who want to write a new module (e.g. to implement  
 91     specific controllers).

## 92     Usage in Science and Education

93     JOAN was used to quickly develop and perform several human-in-the-loop experiments (in-  
 94     cluding various MSc students, for a published example, see ([Melman et al., 2021](#))), illustrating  
 95     that JOAN provides a framework that is flexible and quick to implement (most projects are  
 96     completed in 6 months). Furthermore, a core research focus of our department is the haptic  
 97     interaction between human drivers and their vehicles (e.g., ([Abbink et al., 2018](#); [Mulder et al., 2012](#))),  
 98     for which we implemented a module to control a haptic force-feedback steering wheel.  
 99     The `SteeringWheelController` module enables implementation of control algorithms for  
 100     force feedback and comes with two example implementations: a standard PD controller ([Mul-  
 101     der et al., 2012](#)) and a Four Design Choice Architecture controller (FDCA) ([van Paassen et  
 102     al., 2017](#)).

## 103    Acknowledgements

104    We thank Timo, Cedric, Sam, Peter, Mark, and Tarbiya for their support in the initial stages  
 105    of software development.

## 106    References

- 107    Abbink, D. A., Carlson, T., Mulder, M., de Winter, J. C. F., Aminravan, F., Gibo, T. L.,  
 108    & Boer, E. R. (2018). A Topology of Shared Control Systems Finding Common Ground  
 109    in Diversity. *IEEE Transactions on Human-Machine Systems*, 48(5), 509–525. <https://doi.org/10.1109/THMS.2018.2791570>  
 110
- 111    Bazilinsky, P., Kooijman, L., Dodou, D., & de Winter, J. C. F. (2020). Coupled simulator for  
 112    research on the interaction between pedestrians and (automated) vehicles. *19th Driving  
 113    Simulation Conference (DSC)*, 7.
- 114    Di, X., & Shi, R. (2021). A survey on autonomous vehicle control in the era of mixed-  
 115    autonomy: From physics-based to AI-guided driving policy learning. *Transportation Re-  
 116    search Part C: Emerging Technologies*, 125(July 2020), 103008. [https://doi.org/10.1016/  
 117    j.trc.2021.103008](https://doi.org/10.1016/j.trc.2021.103008)
- 118    Dosovitskiy, A. (2017). CARLA: An Open Urban Driving Simulator. *Proceedings of the  
 119    1st Annual Conference on Robot Learning*, 1–16. [http://proceedings.mlr.press/v78/  
 120    dosovitskiy17a/dosovitskiy17a.pdf](http://proceedings.mlr.press/v78/dosovitskiy17a/dosovitskiy17a.pdf)

- 121 Kearney, J. K., & Noyce, D. A. (2018). *Multi-Modal Distributed Simulation Combining Cars,*  
122 *Bicyclists, and Pedestrians* (p. 31).
- 123 LG Electronics America R&D Center, A. P. L. at the. (n.d.). *LGSVL simulator*. <https://www.lgsvlsimulator.com/>  
124
- 125 Melman, T., Visser, P., Mouton, X., & Winter, J. de. (2021). Creating the Illusion of  
126 Sportiness: Evaluating Modified Throttle Mapping and Artificial Engine Sound for Electric  
127 Vehicles. *Journal of Advanced Transportation*, 2021, 1–15. [https://doi.org/10.1155/](https://doi.org/10.1155/2021/4396401)  
128 [2021/4396401](https://doi.org/10.1155/2021/4396401)
- 129 Mulder, M., Abbink, D. A., & Boer, E. R. (2012). Sharing Control With Haptics: Seamless  
130 Driver Support From Manual to Automatic Control. *Human Factors: The Journal of*  
131 *the Human Factors and Ergonomics Society*, 54(5), 786–798. [https://doi.org/10.1177/](https://doi.org/10.1177/0018720812443984)  
132 [0018720812443984](https://doi.org/10.1177/0018720812443984)
- 133 SensoDrive. (n.d.). *SensoDrive force feedback*. [https://www.sensodrive.de/products/](https://www.sensodrive.de/products/force-feedback-products.php)  
134 [force-feedback-products.php](https://www.sensodrive.de/products/force-feedback-products.php)
- 135 Shah, S., Dey, D., Lovett, C., & Kapoor, A. (2018). *AirSim: High-Fidelity Visual and*  
136 *Physical Simulation for Autonomous Vehicles* (pp. 621–635). [https://doi.org/10.1007/](https://doi.org/10.1007/978-3-319-67361-5_40)  
137 [978-3-319-67361-5\\_40](https://doi.org/10.1007/978-3-319-67361-5_40)
- 138 Silvera, G., Biswas, A., & Admoni, H. (2022). *DReyeVR: Democratizing Virtual Reality*  
139 *Driving Simulation for Behavioural & Interaction Research*. [http://arxiv.org/abs/2201.](http://arxiv.org/abs/2201.01931)  
140 [01931](http://arxiv.org/abs/2201.01931)
- 141 Slob, J. (2008). *State-of-the-art driving simulators, a literature survey* (DCT No. 107).
- 142 van Paassen, M. M., Boink, R., Abbink, D. A., Mulder, M., & Mulder, M. (2017). Four  
143 Design Choices for Haptic Shared Control. In M. A. Vidulich, P. S. Tsang, & J. Flach  
144 (Eds.), *Advances in Aviation Psychology, Volume 2: Using Scientific Methods to Address*  
145 *Practical Human Factors Needs* (First, pp. 237–254). Routledge. [https://doi.org/10.](https://doi.org/10.4324/9781315565712)  
146 [4324/9781315565712](https://doi.org/10.4324/9781315565712)
- 147 WIVW. (n.d.). *Driving simulation and SILAB*. <https://wivw.de/en/silab>