DEMONSTRATION

GrokWalks: A Portable Virtual Reality Platform to Facilitate Studying Driver-Pedestrian Interactions

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Figure 1: GrokWalks is a portable, multi-participant simulator platform that facilitates studying naturalistic driver-pedestrian interaction in a virtual environment: the images above show real-life and virtual representation of interacting participants.

Abstract

Driving simulators are vital for human-centered automotive research, offering safe, replicable environments for studying human interaction with transportation technology interfaces and behaviors. However, traditional driving simulators are not well-suited to studying traffic interactions with various degrees of freedom in a way that allows for the capture of nuances in implicit and explicit interactions, e.g. gestures, body language, and movement. We developed a multi-participant virtual reality (VR) driving simulation platform to study these interactions. This portable system supports cross-cultural experiments by modeling diverse scenarios, generating analyzable data, and capturing human behaviors in traffic. Our interactive demo allows participants to experience roles as drivers or pedestrians in a shared virtual environment, with the goal of providing a hands-on experience with this open-source VR simulator and demonstrating its affordability and scalability for traffic interaction studies to researchers and practitioners.

CCS Concepts

• **Human-centered computing** → **User studies**; **Virtual reality**.

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Keywords

Driving simulation, Virtual reality, Automotive, Vehicle, Pedestrian, User studies, Multi-participant

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1 Introduction & Related Work

To facilitate the adaptation of autonomous vehicles to local driving norms, it is essential to understand how driver-pedestrian interactions vary across different geographical regions. Ethnographic studies have qualitatively described these regional differences through real-life observations, yet such methods are costly, resource-intensive, and impractical for experimental replication in controlled settings [6, 23]. In contrast, data-driven statistical and computational models offer a promising alternative, enabling autonomous vehicles to emulate local driving behaviors and recognize signals from pedestrians and other drivers through their movements [7, 26]. To support this approach, we have developed an experimental platform utilizing a multi-participant virtual reality (VR) driving simulation environment. This system is portable and designed to facilitate cross-cultural research by modeling diverse scenarios, generating data suitable for analysis, and capturing human traffic behaviors in real-time. The primary aim of this platform is to simplify the modeling of various traffic scenarios and produce analysis-ready data to observe and understand interactions between multiple participants. In an interactive demo of this open-source system, participants can experience the roles of both driver and pedestrian, interacting within a shared virtual environment. This demonstration highlights the GrokWalks simulator's potential as an affordable and scalable tool for conducting traffic interaction studies, providing a practical solution for researchers.

Driving Simulators

Driving simulators range from low-cost systems like City Car Driving and GTA-based OpenIV to high-fidelity setups like the National Advanced Driving Simulator[1] at the University of Iowa and Ford's VIRTTEX simulator [11]. These tools vary in their immersion and scientific replicability, with each type serving specific research needs. Immersion is essential for ecological validity, combining visual, auditory, and motion stimuli to create realistic driving experiences. Studies show that immersion can influence responses significantly [12, 16, 25]. Immersive simulators enable the study of naturalistic responses by combining various stimuli to create realistic experiences. This approach is essential for understanding human behavior in traffic interactions [14]. However, immersiveness cannot come at the expense of replicability, since it is critical for reproducible science, ensuring other researchers can replicate and extend findings [5]. This involves accessible tools and materials for building on previous work. Based on replicability, driving simulators can be broadly categorized under four groups:

- **Bespoke Simulators:** Closed-source, hardware-specific, and difficult to replicate [8, 29].
- **Partially Open-Source Simulators:** Some components are open-source, but hardware dependency limits replication [1].
- **Open-Source and Hardware Agnostic Simulators:** Use standard hardware and software interfaces, making them more accessible [3, 18].
- **Research Platforms:** Fully open-source, modular, and scalable, supporting a wide range of applications [2].

Simulators must record detailed interactions to analyze participant responses accurately. Traditional driving performance measures like steering wheel reversals and time-to-line crossing remain relevant but need to adapt to modern vehicle technologies and AV interactions (SAE J2944) [13]. Besides, driving behavior models categorize driving tasks into strategic, tactical, and operational levels, each requiring different information processing [17, 21]. Simulators must provide data streams for discovery-based research to capture nuanced interactions [22]. Qualitative measures capture naturalistic responses and offer insights into human-technology interactions that quantitative data might miss. Open, discovery-focused methods uncover new interaction patterns and inform the design of future automotive systems [19, 20]. Existing simulators are often high-fidelity but expensive and complex, limiting replicability and accessibility. Integrating real-world scenarios into simulated environments can uncover new insights into AV interactions and human behavior [24, 27].

Recently, the concept of distributed, multi-participant simulators has gained traction as researchers seek to conduct multi-agent studies to understand interaction behaviors in traffic [4, 15, 28]. However, these simulators often lack the capability to express the full range of movement in multiple degrees of freedom as experienced in the real world, thereby limiting the scope of naturalistic interaction studies. An open-source simulation setup that addresses this limitation is the Strangeland platform [10], which focuses on multi-driver interactions and enables rich data exploration through animated data playback. This is facilitated by the ReRun tool [9], designed for recording and replaying virtual scenarios, and specifically tailored for behavioral coding. We have extended the Strangeland platform to accommodate driver-pedestrian interactions and creating the GrokWalks simulator, thereby enhancing its applicability for comprehensive traffic interaction studies.

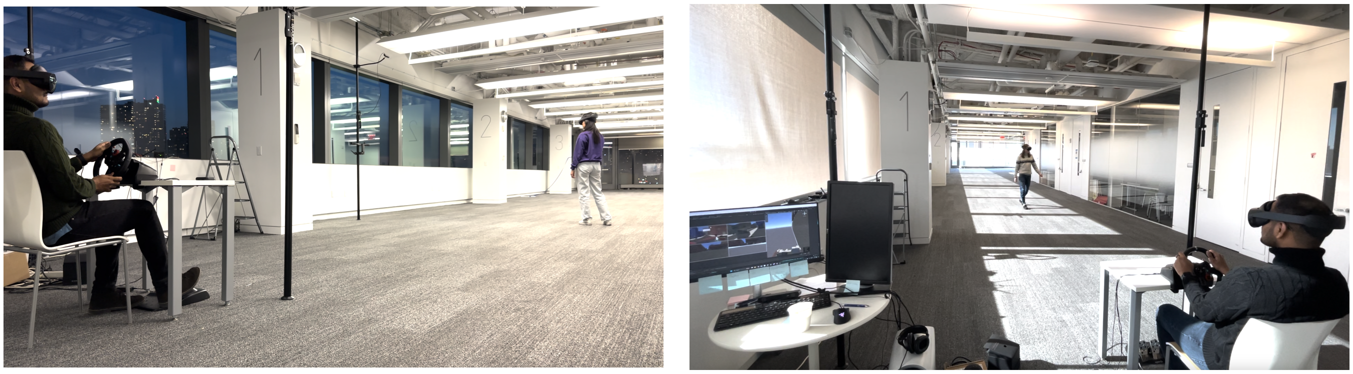
[1]https://dsri.uiowa.edu/nads-1, last accessed: July 10, 2024

2 Technical Setup

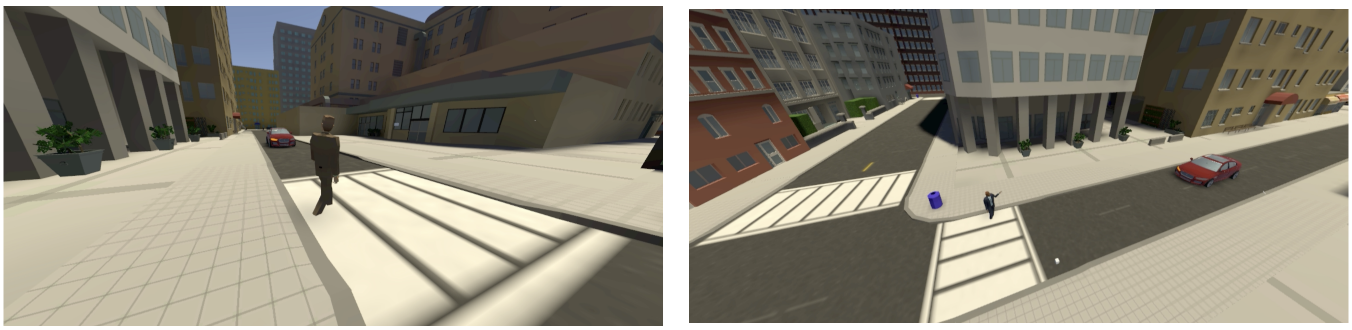
The demo setup features a Unity-based distributed driving simulator, allowing participants to immerse themselves in the roles of either a driver in a passenger vehicle or a pedestrian within a shared virtual urban environment. This portable system utilizes a computer (desktop or laptop) as a server to run the entire simulation. Two commercial VR headsets, specifically Meta Quest Pros[2] (one for the driver, one for the pedestrian), connect to the server. The driver participant wears a VR headset and uses a portable steering wheel (a Logitech gaming steering wheel connected to the server PC). The pedestrian participant is equipped with a portable motion capture device, a Sony mocopi[3], which includes six inertial motion units (IMUs) attached to the head, hip, wrists, and ankles. This setup allows the system to track the participant's movements within the large physical space in which the setup is deployed (Figure 2a) and transmit skeleton data to the server in real-time. Unity renders this data as an avatar that reflects the pedestrian's movements in the virtual environment (Figure 2b). Both the driver and pedestrian participants can see each other's avatars and interact with one another (Figure 2c).

During the demo, participants can walk or drive in the virtual environment through pre-formulated traffic scenarios, allowing them to move freely and naturally. This setup captures realistic interactions, including gestures, body language, and movement nuances that express implicit cues like hesitation. The 3D model of the environment is developed at a 1:1 scale, with objects and scenery created using Blender and based on existing open-source third-party 3D assets. These models are imported and scripted into a 3D virtual reality scene using Unity 3D, to run on the Meta Quest Pro VR headsets. The scenarios represent realistic intersections with regulatory lane markings. The driver-pedestrian dyad is introduced into the virtual environment and receives navigation directions via audio cues for the pedestrian or instructions in the In-Vehicle Information System (IVIS) for the driver. They interact within the virtual environment and then complete an in-VR questionnaire about their interaction. This demonstrates the platform's capability to ask in-situ questions about situation awareness without breaking immersion.

[2]https://forwork.meta.com/quest/quest-pro/, last accessed: July 10, 2024
[3]https://electronics.sony.com/more/mocopi/all-mocopi/p/qmss1-uscx, last accessed: July 10, 2024



(a) The physical setup of the platform..



(b) View of the virtual environment.

(c) Driver and pedestrian views.

Figure 2: Setup and example of the GrokWalks simulator.

3 Use Cases

Scenarios are essential for describing the various traffic contexts that influence pedestrians' behavior when interacting with drivers. Signalized crossings with traffic lights are highly effective for controlling traffic, as they separate traffic movements and indicate when pedestrians can cross. Conversely, unsignalized crossings require pedestrians and drivers to self-regulate without explicit control mechanisms. To investigate the extent of negotiations and interactions that arise in ambiguous situations, we selected unsignalized intersections and removed crosswalks. This setup ensures that pedestrians do not expect the right of way, and all crossings occur through communication, negotiation, and interaction to resolve ambiguity. We developed a set of 12 traffic scenarios illustrating different contexts where these interactions might unfold. These scenarios include intersections (without signals or crosswalks), parking lots, midblock crossings (with and without occlusions from parked cars), and shared road situations where cars and pedestrians must navigate around each other without clear right of way. These scenarios were modeled within the Unity environment, and additional scenarios can be easily created by modifying these existing ones to cover a wide variety of interaction situations.

4 Conclusion & Future Work

With this simulator setup, we provide a robust platform for researchers to examine near-naturalistic interactions between drivers and pedestrians within a controlled environment, providing a level of replicability that is challenging to achieve in real-world settings. The system's portability and cost-effectiveness significantly contribute to its replicability, facilitating the rapid and straightforward deployment of the setup across diverse geographical locations. This capability is particularly advantageous for conducting cross-cultural research on traffic interactions, allowing for the exploration of regional variations with relative ease. Furthermore, ongoing developments aim to extend the simulator's functionality by integrating Non-Player Characters (NPCs) representing pedestrians and other traffic participants. These NPCs can be programmed to exhibit varying densities and behaviors reflective of different geographical contexts. This enhancement will not only increase the immersiveness of the simulation experience but also potentially improve the ecological validity of the studies conducted using this platform. By incorporating these dynamic elements, the simulator can more accurately represent real-world traffic scenarios, thereby providing more reliable data for research in human-vehicle interactions.

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References

[1] Ignacio Alvarez, Laura Rumbel, and Robert Adams. 2015. Skyline: a rapid prototyping driving simulator for user experience. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.* ACM, 101–108.

[2] Sonia Baltodano, Jesus Garcia-Mancilla, and Wendy Ju. 2018. Eliciting Driver Stress Using Naturalistic Driving Scenarios on Real Roads. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.* ACM, 298–309.

[3] Sonia Baltodano, Srinath Sibi, Nikolas Martelaro, Nikhil Gowda, and Wendy Ju. 2015. The RRADS Platform: A Real Road Autonomous Driving Simulator. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Nottingham, United Kingdom) *(AutomotiveUI '15).* Association for Computing Machinery, New York, NY, USA, 281–288. https://doi.org/10.1145/2799250.2799288

[4] Pavlo Bazilinskyy, Lars Kooijman, Dimitra Dodou, Kirsten P.T. Mallant, Victor E.R. Roosens, Marloes D.L.M. Middelweerd, Lucas D. Overbeek, and Joost C.F. De Winter. 2022. Get Out of The Way! Examining eHMIs in Critical Driver-Pedestrian Encounters in a Coupled Simulator. In *Main Proceedings - 14th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2022.* Association for Computing Machinery, Inc, 360–371. https://doi.org/10.1145/3543174.3546849

[5] Philip Cash. 2020. Where next for design research? Understanding research impact and theory building. *Design Studies* 68 (2020), 113–141. https://doi.org/10.1016/j.destud.2020.03.001

[6] Joshua Domeyer, Azadeh Dinparastdjadid, John D. Lee, Grace Douglas, Areen Alsaid, and Morgan Price. 2019. Proxemics and Kinesics in Automated Vehicle–Pedestrian Communication: Representing Ethnographic Observations. *Transportation Research Record* 2673, 10 (2019), 70–81. https://doi.org/10.1177/0361198119848413

[7] Joshua E. Domeyer, John D. Lee, and Heishiro Toyoda. 2020. Vehicle automation-other road user communication and coordination: Theory and mechanisms. *IEEE Access* 8 (2020), 19860–19872. https://doi.org/10.1109/ACCESS.2020.2969233

[8] Florin-Timotei Ghiurău, Mehmet Aydın Baytaş, and Casper Wickman. 2020. ARCAR: On-Road Driving in Mixed Reality by Volvo Cars. In *Adjunct Publication of the 33rd Annual ACM Symposium on User Interface Software and Technology* (Virtual Event, USA) *(UIST '20 Adjunct).* Association for Computing Machinery, New York, NY, USA, 62–64. https://doi.org/10.1145/3379350.3416186

[9] David Goedicke, Harald Haraldsson, Navit Klein, Lunshi Zhou, Avi Parush, and Wendy Ju. 2022. Rerun: Enabling Multi-Perspective Analysis of Driving Interaction in VR. In *Adjunct Proceedings of the 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.* ACM, Seoul Republic of Korea, 204–205. https://doi.org/10.1145/3544999.3550155

[10] David Goedicke, Carmel Zolkov, Natalie Friedman, Talia Wise, Avi Parush, and Wendy Ju. 2022. Strangers in a Strange Land: New Experimental System for Understanding Driving Culture Using VR. *IEEE Transactions on Vehicular Technology* 71, 4 (2022), 3399–3413. https://doi.org/10.1109/TVT.2022.3152611

[11] Peter Grant, Bruce Artz, Jeff Greenberg, and Larry Cathey. 2001. Motion Characteristics of the VIRTTEX Motion System.

[12] Arne Helland, Gunnar D Jenssen, Lone-Eirin Lervåg, Andreas Austgulen Westin, Terje Moen, Kristian Sakshaug, Stian Lydersen, Jørg Mørland, and Lars Slørdal. 2013. Comparison of driving simulator performance with real driving after alcohol intake: A randomised, single blind, placebo-controlled, cross-over trial. *Accident Analysis & Prevention* 53 (2013), 9–16.

[13] SAE International. 2023. J2944 202302: Operational Definitions of Driving Performance Measures and Statistics. Retrieved July 21, 2023 from https://www.sae.org/standards/content/j2944_202302/

[14] Wendy Ju. 2022. *The design of implicit interactions.* Springer Nature.

[15] Amir Hossein Kalantari, Yue Yang, Jorge Garcia de Pedro, Yee Mun Lee, Anthony Horrobin, Albert Solernou, Christopher Holmes, Natasha Merat, and Gustav Markkula. 2023. Who goes first? a distributed simulator study of vehicle–pedestrian interaction. *Accident Analysis and Prevention* 186, April (2023), 107050. https://doi.org/10.1016/j.aap.2023.107050

[16] Nico Kaptein, Jan Theeuwes, and Richard Van Der Horst. 1996. Driving simulator validity: Some considerations. *Transportation Research Record: Journal of the Transportation Research Board* 1550 (1996), 30–36.

[17] Esko Keskinen, Mika Hatakka, Sirkku Laapotti, Ari Katila, and M Peräaho. 2004. Driver behaviour as a hierarchical system. *Traffic and Transport Psychology* (2004), 9–29.

[18] Christopher Knauf. 2022. 6DOF Rotary Stewart Motion Simulator Platform. Retrieved July 21, 2023 from https://github.com/knaufinator/6DOF-Rotary-Stewart-Motion-Simulator

[19] Nikolas Martelaro and Wendy Ju. 2017. WoZ Way: Enabling Real-time Remote Interaction Prototyping & Observation in On-road Vehicles. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW '17).* ACM, New York, NY, USA, 169–182. https://doi.org/10.1145/2998181.2998293

[20] Nikolas Martelaro and Wendy Ju. 2017. WoZ Way: Enabling Real-time Remote Interaction Prototyping & Observation in On-road Vehicles. In *Companion of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing.* ACM, 21–24.

[21] John A. Michon. 1985. *A Critical View of Driver Behavior Models: What Do We Know, What Should We Do?* Springer US, Boston, MA, 485–524. https://doi.org/10.1007/978-1-4613-2173-6_19

[22] J. Rasmussen. 1983. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics* SMC-13, 3 (1983), 257–266.

[23] MARKUS ROTHMÜLLER, PERNILLE HOLM RASMUSSEN, and SIGNE ALEXANDRA VENDELBO-LARSEN. 2018. Designing for Interactions with Automated Vehicles: Ethnography at the Boundary of Quantitative-Data-Driven Disciplines. *Ethnographic Praxis in Industry Conference Proceedings* 2018, 1 (2018), 482–517. https://doi.org/10.1111/1559-8918.2018.01219 arXiv:https://anthrosource.onlinelibrary.wiley.com/doi/pdf/10.1111/1559-8918.2018.01219

[24] G Schmidt, M Kiss, E Babbel, and A Galla. 2008. The Wizard on Wheels: Rapid Prototyping and User Testing of Future Driver Assistance Using Wizard of Oz

Technique in a Vehicle. In *Proceedings of the FISITA 2008 World Automotive Congress, Munich*.

[25] Jonathan Stevens, Peter Kincaid, and Robert Sottilare. 2015. Visual modality research in virtual and mixed reality simulation. *The Journal of Defense Modeling and Simulation* 12, 4 (2015), 519–537.

[26] Kai Tian, Gustav Markkula, Chongfeng Wei, and Richard Romano. 2020. Creating Kinematics-dependent Pedestrian Crossing Willingness Model When Interacting with Approaching Vehicle. *2020 IEEE 23rd International Conference on Intelligent Transportation Systems, ITSC 2020* (2020). https://doi.org/10.1109/ITSC45102.2020.9294430

[27] Peter Wang, Srinath Sibi, Brian Mok, and Wendy Ju. 2017. Marionette: Enabling On-Road Wizard-of-Oz Autonomous Driving Studies. In *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 234–243.

[28] Yue Yang, Amir Hossein Kalantari, Yee Mun Lee, Albert Solernou, Gustav Markkula, and Natasha Merat. 2023. A Distributed Simulation Study to Examine Vehicle - Pedestrian Interactions. In *ACM International Conference Proceeding Series*. Association for Computing Machinery, 327–329. https://doi.org/10.1145/3581961.3609852

[29] Dohyeon Yeo, Gwangbin Kim, and Seungjun Kim. 2020. Toward Immersive Self-Driving Simulations: Reports from a User Study across Six Platforms. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376787