

PhD thesis proposal (2026-2029):

Socially Expressive Pedestrian Agent Modelling for VR-Based Evaluation of Vehicle–Pedestrian Interactions

1. Introduction and Motivation

With the increasing deployment of smart transportation systems and autonomous vehicles (AVs), ensuring the safety of vulnerable road users—particularly pedestrians—has become a central concern in road safety research (Zhang & Berger, 2023). In urban traffic environments, pedestrian–vehicle interactions are not governed solely by physical trajectories, but also by non-verbal communication cues such as gaze direction, head orientation, hand gestures, and posture changes, which convey intent and influence driver decision-making during road-crossing situations (Myers et al., 2022; Camara et al., 2021).

Despite this, most existing pedestrian models used in virtual reality (VR) driving simulators and agent-based traffic simulation tools primarily represent pedestrians using trajectory-based behaviours, even in a 3D environment (Narang et al., 2018). Such representations neglect socially expressive cues and may therefore fail to elicit realistic responses from human drivers in simulation-based experiments (Rock et al., 2022). This limitation reduces the ecological validity of human-in-the-loop driving studies and constrains the applicability of these models to autonomous vehicle evaluation.

This thesis aims to address this gap by developing, validating, and extending a socially expressive pedestrian agent model that integrates kinematic intent communication and social decision-making within VR-based driving simulations.

2. Research Objectives

The main objective is to improve the behavioural realism of pedestrian agents in vehicle–pedestrian interaction scenarios in VR by incorporating expressive motion and socially informed decision-making. The specific objectives are:

- 1) To develop a data-driven pipeline for reconstructing expressive 3D pedestrian motion from real-world datasets;
- 2) To validate the behavioural impact of pedestrian non-verbal cues on human driver decision-making using a VR driving simulator;
- 3) To design a socially cognitive pedestrian agent model capable of automatic decision-making and intent expression.

We also intent to explore transitions of the proposed pedestrian model toward autonomous vehicle and traffic simulation studies.

3. Methodology

3.1 Expressive 3D Pedestrian Motion Modelling

The phase focuses on constructing a 3D skeleton-based pedestrian behaviour modelling pipeline. Pedestrian behaviour data associated with road-crossing intentions (e.g., crossing, waiting, looking, gesturing) will be extracted from annotated datasets such as JAAD (Rasouli et al., 2017) and PIE (Rasouli et al., 2019). Two-dimensional skeletal keypoints will be estimated from video data and lifted to temporally consistent 3D skeletal representations using state-of-the-art pose reconstruction

techniques. The resulting motion sequences will be retargeted to 3D pedestrian avatars and deployed in a VR driving simulation environment.

3.2 Validation via Human-in-the-Loop Driving Simulation

To evaluate the behavioural relevance of the proposed pedestrian model, controlled human-in-the-loop experiments will be conducted using a VR driving simulator. Pedestrian behaviours will be scripted with different combinations of non-verbal cues. Driver responses to these behaviours will be evaluated using quantitative performance indices such as braking and acceleration profiles, yielding behaviour, and manoeuvre smoothness, complemented by subjective measures of perceived realism and predictability.

3.3 Socially Cognitive Pedestrian Agent Model

Beyond scripted behaviours, the third phase aims to develop a socially cognitive pedestrian agent model capable of automatic decision-making in vehicle–pedestrian interaction scenarios. The model will integrate environmental perception (e.g., vehicle distance and speed), decision-making logic for crossing or waiting, and corresponding intent expression through kinematic motion. This enables pedestrians to dynamically adapt their behaviour in response to vehicles (Pekkanen et al., 2022), enhancing interaction realism.

3.4 Transition Toward Autonomous Vehicle and Traffic Simulation Studies

To support broader applicability, the proposed pedestrian agent model will be explored in the context of agent-based autonomous vehicle in traffic simulation. The decision-making logic and expressive motion representation will be integrated into existing agent-based traffic simulation tools, such as Archisim, enabling consistency between VR-based experiments and traffic-level modelling. The expressive pedestrian model may also be used to generate interaction scenarios for evaluating AV decision-making under socially complex pedestrian behaviours.

4. Outlook

By enhancing the realism and social intelligence of pedestrian agents, the proposed framework provides a foundation for future research on socially interactive traffic agents, multi-agent simulation, and human-centred evaluation of autonomous vehicles.

Keywords: 3D pedestrian kinematics; Road-crossing intent; Pedestrian–vehicle interaction; Socially cognitive agents; Virtual reality

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