A 3D Multi-Agent Simulation Architecture for Passenger Flow Optimisation in Mobility Hubs

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Motivation

- **Problem:** Large mobilty hubs suffer from congestions, safety issues and are difficult to test in real life.
- **Gap:** Existing tools rarely combine: (i) cognitively plausible agents, (ii) integration with real-time external data and (iii) modular extensibility.
- **Contribution:** A modular simulator with agent cognition, 3D environments and data-driven scenarios.
- **Case Study:** Hamburg-Harburg train station as a representative mobilty hub.

Architecture & Formalisation

- **Platform:** Built in Godot [1], physics-based agents, 3D environment with collision and weighted navigation meshes.
- **Modules:** Data Lake, POI Management, Journey Creator, Cognition, Prediction, Flow Management, Data Export & Analysis.
- **Formalisation:** Agent spawning via probabilistic equations, incorporating external data sources such as schedules, events, weather.
- **Key Strengths:** Real-time adaptability, scenario customisation & reproducability, integration with live external data.
- **Focus:** Individuality, dynamic environment, decision-making via cognition.

Agent Modelling

- **Personas:** 11 types (commuters, tourists, students, reduced mobility, ...) [2]
- **Spawning:** Agent generation is weighted by (regularly updated) train schedules, date-related factors and context.
- **Attributes:** Speed, avoidance behaviour, luggage-based mobility constraints.
- **Cognition:** (i) Knowledge base updates by signage, POIs, peer agents. (ii) Decision-making based on knowledge, needs and environmental observations. (iii) Includes re-planning routes, switching goals and agent-to-agent interaction.
- **Needs:** Food, drink, toilet, rest, nicotine, information.
- **Interactions:** Agent-to-agent and environment-to-agent influence decision-making.

Evaluation & Results

- **Setup:** Hamburg-Harburg station, 1h simulation (14–15h, Oct 2024); Realism test with live schedule data.
- **Metrics:** Agent density per segment, travel distance per agent, rerouting frequency, POI visit rates, persona dynamics.
- **Findings:** (i) Density peaks at train arrivals. (ii) Realistic rerouting and waiting behaviour. (iii) Persona distributions evolve plausibly.
- **Outcome:** Validated realism and intervention testing capability.
- **Potential:** World creation seeds as well as cofigurable spawning and flexible navigation layers allow for a wide range of scenario testing.

Sources

[1] Godot Engine Contributors. Godot engine. `https://godotengine.org`, 2024. Version 4.2, accessed 2025-05-06.

[2] Bernhard Preim and Raimund Dachselt. *Interaktive Systeme: Band 2: User Interface Engineering, 3D-Interaktion, Natural User Interfaces*. eXamen.press. Springer, Berlin, Heidelberg, 2015.

System Architecture Overview

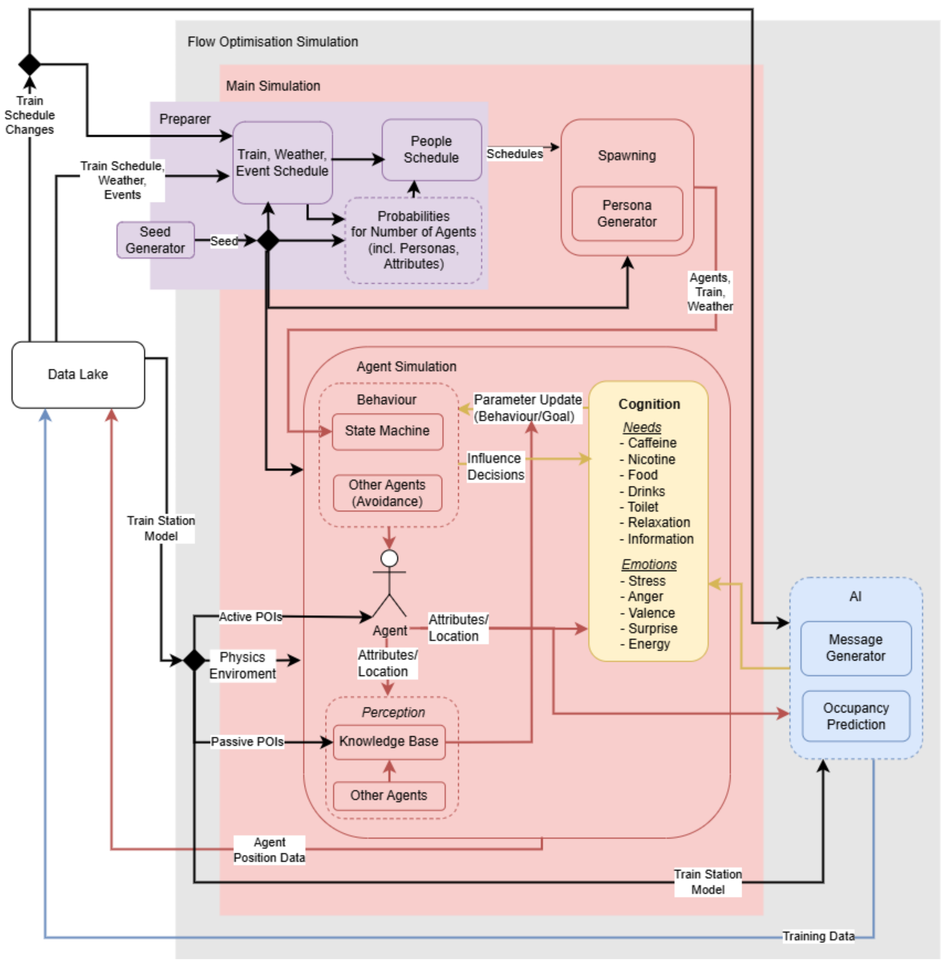

Fig. 1: Architecture with core modules and data flow.

Agent State Machine

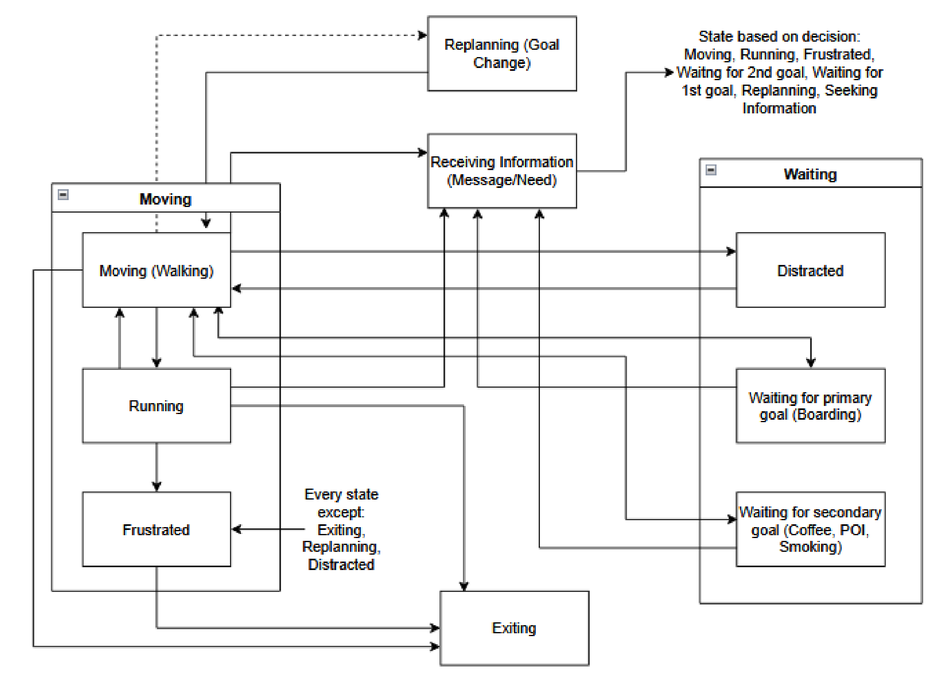

Fig. 2: State machine with goals, cognition and interactions.

Evaluation Metrics

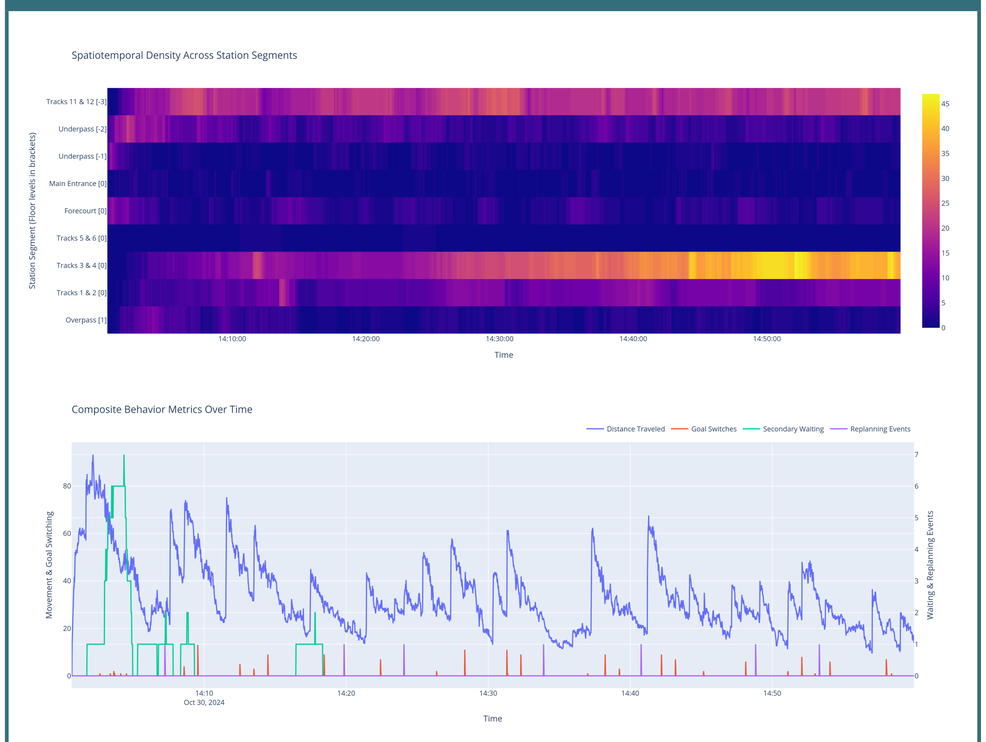

Fig. 3a: Spatiotemporal density heatmap by station segment.
Fig. 3b: Composite behaviour metrics. Primary axis: distance travelled and goal switches. Secondary axis: secondary waiting and replanning events.