TRUSTWORTHY MULTI-AGENT SYSTEMS

LÁSZLÓ Z. VARGA



PROGRAM FINANCED FROM THE NRDI FUND

Trustworthy Algorithmic Routing of Autonomous Vehicles

• development of the intention-aware online routing game model for trustworthy routing



• development of the routing model evaluator software to evaluate the routing model in a simulation environment



• multi-agent paradigm in software engineering and trustworthiness: comparison of the online routing model and other routing models





Dynamics – Why?

- the agent behaviour goes in cycles:
 - the agents perceive their environment (possibly communicating with other agents),
 - decide what action to perform, and then
 - perform the action
- Will the multi-agent system go to the equilibrium through these feedback cycles and stay in the equilibrium?



Intention-Aware Online Routing Games

• intention-aware online routing games are online routing games where

- the decision making agents of the flows are the vehicle agents
- the delegate MAS predicts the travel times for each path of the trip
- the decision is to select the path with the shortest predicted travel time
- several properties are proved, but now we want to know how it works in the real world

László Z. Varga. On Intention-Propagation-Based Prediction in Autonomously Self-adapting Navigation. Scalable Computing: Practice and Experience, 16(3):221–232, 2015. <u>link</u>



System Developed by Four BSc Students on their Laptops



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Routing Model Evaluation: Achieving Dynamic Equilibrium



Fig. 5. Travel durations in the experiments.

Fig. 6. Relative deviations of the travel durations in the experiments.

SUMO Duaiterate: 30 minutes Predictive Model: faster than real-time



Models of Trustworthy Routing

Artificial Intelligence Review SCI JOURNAL Artificial Intelligence Review Impact Factor Impact Facto Artificial 5.747 9.329 78 Intelligence Artificia best quartile Intelligence SIR 2020 Review 1.2 powered by scimagojr.com

Springer

• L. Z. Varga,

"Solutions to the Routing Problem - Towards Trustworthy Autonomous Vehicles," Artificial Intelligence Review, Open Access, Published: 08 January 2022, <u>https://doi.org/10.1007/s10462-021-10131-y</u>

- trustworthy multi-agent systems
- route selection of autonomous vehicles
- comparison of the online routing model and other routing models



Evaluation of machine learning prediction

- HERE Technologies: mapping, location data and related automotive services (Zürich research centre)
- tensor data: for each city a grid of approximately 100m x 100m cells, 5 min time intervals, high-resolution GPS trajectories mapped to spatiotemporal cells
- forecasting tensor data for 6 periods: 5min, 10min, 15min, 30min, 45min és 60min
- our evaluation goal:
 - using these forecasts in our intention aware online routing game model
 - evaluation results: 5 min period prediction is too large





Damping in dynamic multi-agent systems

- introducing damping into SUMO ("Simulation of Urban MObility") simulator
- software technology issues and performance problems
- periodic updates to eliminate performance problems, but is spoils the routing algorithm
- the intention aware online routing game model is still the best !!!



Results

- Publications
 - Laszlo Z. Varga. "Prediction capabilities for cyber physical vehicles". International Journal of Cyber-Physical Systems, 1(1):45-70, 2019
 - Antal, V.; Farkas, T. G.; Kiss, A.; Miskolczi, M. & Varga, L. Z.: "Routing Model Evaluator" Advances in Practical Applications of Agents, Multi-Agent Systems, and Trustworthiness. The PAAMS Collection, Springer International Publishing, 2020, 30-41
 - Antal, V.; Farkas, T. G.; Kiss, A.; Miskolczi, M. & Varga, L. Z.: "A Demonstration of the Routing Model Evaluator" Advances in Practical Applications of Agents, Multi-Agent Systems, and Trustworthiness. The PAAMS Collection, Springer International Publishing, 2020, 384-387
 - Antal, V.; Farkas, T. G.; Kiss, A.; Miskolczi, M. & Varga, L. Z.: "Intention-Aware Model to Support Agent Deliberation in a Large-Scale Dynamic Multi-Agent Application" Artificial Intelligence XXXVII, Springer International Publishing, 2020
 - László Z. Varga "The autonomous agent and multi-agent paradigm in software engineering" Annales Universitatis Scientiarum Budapestinensis De Rolando Eotvos Nominatae Sectio Computatorica 52 pp. 349-368. , 20 p. (2021)
 - L. Z. Varga, "Solutions to the Routing Problem Towards Trustworthy Autonomous Vehicles," Artificial Intelligence Review, Open Access, Published: 08 January 2022, <u>https://doi.org/10.1007/s10462-021-10131-y</u>
- Software
 - Routing Model Evaluator (EFOP +TKP)
- Resources
 - 1 investigator (TKP)
 - 4 BSc students (EFOP)
 - 1 laptop (ELTE) 4 laptops (students)



Multi-agent Optimizations to Increase Trustworthiness (with TTK)

• agents in a grid world, simulation software for a warehouse



• enhancement of multi-agent algorithms to improve warehouse operation



• development of agent architecture for a grid world multi-agent system



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Simulation program for a traditional warehouse

- implementation of the Conflict-Based Search (CBS) algorithm
- extending CBS with waiting at shelves
- CBS for life-long operation
- CBS lookahead only for x steps
- task assignment optimization





Simulation results: considerable reduction of "irritation"





Results

- Publications
 - Ács, Botond ; Dóra, László ; Jakab, Olivér ; Varga, László Z. "Multi-agent Techniques to Solve a Real-World Warehouse Problem" 2021 Dignum, Frank ; Corchado, Juan Manuel ; De La Prieta, Fernando (Eds.) Advances in Practical Applications of Agents, Multi-Agent Systems, and Social Good. The PAAMS Collection Lecture Notes in Computer Science Springer International Publishing: Cham p. 1-13
 - Ács, Botond ; Dóra, László ; Jakab, Olivér ; Jüttner, Alpár ; Madarasi, Péter ; Varga, László Z. "Optimizations of a Multi-Agent System for a Real-World Warehouse Problem" 2022 SN Computer Science p. 19 Comment: submitted on 31st January 2022
- Software
 - Warehouse simulator (EFOP +TKP)
- Resources
 - 1 investigator (TKP)
 - 3 BSc students (EFOP)
 - 3 researchers from TTK (parttime)
 - 1 laptop (ELTE) 3 laptops (students)



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