APPLICATION FOR THE SPECIALIST WORKSHOP ON AGENT-BASED MODELING OF COMPLEX SPATIAL SYSTEMS

Stephan Winter
Department of Geomatics, The University of Melbourne, VIC 3010, Australia
winter@unimelb.edu.au

1. PERSONAL PERSPECTIVE ON THE TOPIC OF THE WORKSHOP

Over the past few years I recognized in my research that the community of agent-based modelers of spatial systems on the one hand, and the community interested in complex dynamic systems on the other developed more or less independently from each other. And I became interested in studying potential relationships between the realms of the communities for mutual benefits and discovery of new knowledge. The complex dynamic systems I am working on are forms of social networks, more particularly ad-hoc social networks—agents that are near to each other and hence can interact. The latter brings in a geographic perspective, which can become more relevant if the matter of interaction is solving spatial problems, e.g., wayfinding, or spatiotemporal problems, e.g., transportation planning.

1.1 An Example

Research on geosensor networks is typically concerned with the efficient extraction of information of sensor observations, hence, looking into hardware, protocols, routing of messages, and data aggregation, acknowledging that geosensor network nodes are mobile and always aware of their location. My research focus is different in three respects.

- First of all, its focus is on movement of the nodes, not of information. The investigated geosensor network consists of nodes that have individual travel intentions. If two nodes meet, one of them can ride piggy-back on the other one for reasons such as saving fuel or traveling faster, depending on the abilities of the two nodes. We call this behavior ride sharing, and are interested in all forms of travel optimization.
- Secondly, this geosensor network allows for different types of nodes. In applications, one will distinguish transportation clients—nodes that can travel piggy-back—from transportation hosts—nodes that offer piggy-back traveling. Some clients may be able to move only with a host—think of parcels in a freight application—, while other clients may be able to move independently, for example pedestrians in an urban transport application. There may also be hosts that offer piggy-back traveling not only to clients, but also to other hosts, as for example a ferry to vehicles. Even immobile nodes can be thought of as part of the geosensor network, participating in the peer-to-peer communication—think of bus stops in a public transportation application, mediating between buses and pedestrians. With all their individuality, nodes can be conceptualized as agents.
- Thirdly, special challenges arise from the typical communication constraints of geosensor networks: scarce resources in terms of battery and bandwidth, and of a fragile communication network topology due to node mobility. Nodes have to communicate with each other to gather current transportation network knowledge for trip planning. Being restricted to local communication means that nodes can only gather local transportation network knowledge, and hence, find sub-optimal trips.

The interesting research questions in this context are on the nodes' communication strategies, on their (optimal) trip planning strategies, on competition, on trust and reputation in peer-to-peer systems, on the general behavior of large transportation geosensor networks considering the autonomy and intentionality of the nodes, or on the potential for heterogeneous network architectures (wired/wireless), to name just a few. While these questions give a hint of the challenges, I will illuminate the questions by a concrete realization: a shared ride system for persons traveling by multiple modes in the city.

The envisioned peer-to-peer shared ride system enables pedestrians to negotiate in an ad-hoc manner for ride sharing with diverse vehicles in urban traffic, such as private cars, buses, trains, or taxi cabs. In such a system pedestrians are the clients, and vehicles are the hosts. Finding rides in an ad-hoc manner is accomplished by local negotiation between these agents via radio-based communication. For this purpose, clients collect local real-time transportation network information. Based on this information and their preferences for various optimization criteria, such as travel fees or travel time, they are able to select hosts that offer optimal trips with respect to their limited information. The selected hosts are booked then, and the ride can take place. Since the selection was made based on local knowledge, and other opportunities could come along, the client revises its travel plans regularly.

In previous research we have investigated the clients' ability to make trip plans from local transportation network knowledge. Optimizing for travel time in this case, the results show that local communication is both efficient and effective. It is efficient because it leads to less communication messages than for complete current transportation network knowledge, and it is effective because it leads to travel times comparable to the travel times of trips computed from complete current knowledge. This investigation was realized by simulation of a peer-to-peer shared ride system, with an immobile and inflexible client agent and homogeneous host agents. We were concerned whether the simulation design was elaborate enough to reflect sufficiently the behavior of a system deployed in the real world. For this reason, the simulation was extended, introducing diverse types of client and host agents with different behavior and capabilities, including deterministic mobility models. It turned out that with every step to more complexity, local communication is always both efficient and effective compared to other communication strategies, even if the trips themselves may change significantly. For details on this work see the references in Section 2.2.

1.2 Some Observations from the Example

Current multi-agent systems, such as Swarm, Repast, or Ptolemy, are lacking spatial awareness. Developing ad-hoc alternative systems seems not a viable solution.

- On the agenda: engage in public domain projects and contribute spatial abilities to multi-agent systems, such as spatial data and knowledge representation, route planning and following, or a spatial communication layer.

Multi-agent systems are perfect tools to simulate mobile sensor networks. Simulations with multi-agent systems, in particular in the area of mobile sensor networks, use frequently simple mobility models such as random walking models.

- On the agenda: engage in the development of mobility models better reflecting goal-oriented behavior of typically repetitive patterns.

Multi-agent systems that have other mobility models (micro-simulation models) are designed for realistic traffic modeling (Nagel 2001; Torrens 2004) or modeling of dynamic urban processes (Batty et al. 2003; Benenson and Torrens 2004).

- On the agenda: engage in models of cooperation and communication, since real-world agents will more and more being ubiquitously connected by some communication technology and do interact.

2. RESUME

I am Senior Lecturer at the Department of Geomatics, The University of Melbourne, Australia. Previously I held positions at the University of Bonn, Germany (1990-97, PhD in 1997), and the Technical University Vienna, Austria (1997-2003, habilitation in 2001).

My current research focuses on spatial information theory with a specific interest in spatial cognition, wayfinding and navigation. I also look into conceptual route planning, network analysis, and, recently, mobile ad-hoc geosensor networks and their application in real-time and dynamic route planning. My preferred research approach is simulating complex dynamic systems by modeling autonomous agents, and analyzing the decision strategies of the agents with respect to optimality or efficiency. I am also member of the virtual sensor network laboratory of the University of Melbourne, providing a testbed environment for ideas.

Currently I am leading a CRCSI project on adapting route information for different user groups, and recently I have won an ARC Linkage project on cognitive ergonomic wayfinding directions. Another project, on peer-to-peer shared ride systems, runs without major external funding. Two years ago I started a collaboration with Silvia Nittel, head of the Geosensor Network Lab at the University of Maine, and looked into peer-to-peer shared ride trip planning with mobile location-aware sensor networks (Winter and Nittel, 2006). These papers explore whether this novel approach to improve urban mobility is feasible, which communication strategies and protocols are required and efficient, and what the next research questions are. In the next paper, with Martin Raubal, at that time University of Muenster, I proposed algorithms from time geography to identify relevant data for shared ride planning, by this way reducing peer-to-peer communication to a minimum (Winter and Raubal, 2006).

Previous research concerned topological relations in presence of location uncertainty. Working in this area I applied a model of raster-vector-unification for topological analysis, and reused it later for formal specifications for interoperability. Parts of these research results were included in the OpenGIS specifications. During this time I participated in several research projects on interoperability, before I won European and national research projects in the area of navigation and tourist information.

My publication record notes more than 100 publications over the last 10 years, 42 of them full paper reviewed. Among these papers is the most cited GIScience paper (according to Google Scholar, September 2005), written together with Martin Raubal. Courses I am teaching deal with spatial data management and analysis, webmapping and interoperability, and navigation services.

In 2007 I will chair the Eighth International Conference on Spatial Information Theory (COSIT’07), together with Benjamin Kuipers, Texas. In conjunction with COSIT’07, I will also chair the first international workshop on social space and geographic space, looking into social networks and their geographic conditions. This workshop will be sponsored by the ARC Network of Spatially Integrated Social Sciences (ARCNSISS), of which I am founding member. I chaired already an ARCNSISS workshop on trust and reputation in ad-hoc local communities. In 2000, I chaired the EuroConference on Ontology and Epistemology for Spatial Data Standards in France, 2000. I am co-chair of the ISPRS WG II/6: Geo-spatiotemporal semantics and interoperability, and chaired the *Working Group in Interoperability* in the Association of GI Laboratories in Europe until 2003.

2.1 My ten career-best publications

Claramunt, C.; **Winter**, S., forthcoming: Structural Salience of Elements of the City. Environment and Planning B, accepted for publication in October 2006.

Raubal, M.; **Winter**, S.; Tessmann, S.; Gaisbauer, C., forthcoming: Time Geography for Intelligent Ad-Hoc Shared-Ride Trip Planning. International Journal of Photogrammetry and Remote Sensing (Special Issue on From Sensors to Systems: Advances in Distributed Geoinformatics), accepted for publication in December 2006.

Winter, S.; Nittel, S., 2006: Ad-Hoc Shared-Ride Trip Planning by Mobile Geosensor Networks. International Journal of Geographical Information Science, 20 (8): 899-916.

Klippel, A.; **Winter**, S., 2005: Structural Salience of Landmarks for Route Directions. In: Cohn, A.G.; Mark, D.M. (Eds.), Spatial Information Theory. Lecture Notes in Computer Science, Vol. 3693. Springer, Berlin, pp. 347-362.

Nothegger, C.; **Winter**, S.; Raubal, M., 2004: Computation of the Salience of Features. Spatial Cognition and Computation, 4 (2): 113-136.

Winter, S.; Nittel, S., 2003: Formal Information Modeling for Standardisation in the Spatial Domain. International Journal of Geographical Information Science, 17(8):721-741.

Raubal, M.; **Winter**, S., 2002: Enriching Wayfinding Instructions with Local Landmarks. In: Egenhofer, Max J.; Mark, David M. (Eds.), Geographic Information Science. Lecture Notes in Computer Science, Vol. 2478. Springer, Berlin, pp. 243-259.

Winter, S., 2002: Modeling Costs of Turns in Route Planning. GeoInformatica, 6(4): 345-360.

Winter, S., 2000: Uncertain Topological Relations between Imprecise Regions. International Journal of Geographical Information Science, 14(5): 411-430.

Winter, S.; Frank, A.U., 2000: Topology in Raster and Vector Representation. GeoInformatica, 4(1): 35-65.

2.2 Any papers already published by me in the area of the workshop contribution

Winter, S.; Nittel, S., 2006: Ad-Hoc Shared-Ride Trip Planning by Mobile Geosensor Networks. International Journal of Geographical Information Science, 20 (8): 899-916.

Winter, S.; Raubal, M., 2006: Time Geography for Ad-Hoc Shared-Ride Trip Planning. In: Aberer, K.; Hara, T.; Joshi, A. (Eds.), 7th International Conference on Mobile Data Management (MDM'06). IEEE Computer Society, Nara, Japan, Paper 6.

Extended version accepted as:

Raubal, M.; Winter, S.; Tessmann, S.; Gaisbauer, C.: Time Geography for Intelligent Ad-Hoc Shared-Ride Trip Planning. International Journal of Photogrammetry and Remote Sensing (Special Issue on From Sensors to Systems: Advances in Distributed Geoinformatics), forthcoming.

Wu, Y.-H.; Guan, L.-J.; Winter, S., 2007: Peer-to-Peer Shared Ride Systems. In: Nittel, S.; Stefanidis, A.; Labrinidis, A. (Eds.), 2nd International Conference on GeoSensor Networks. University of Maine, Boston, MA, pp. 27-38.

Revised version accepted for:

Nittel, S.; Labrinidis, A.; Stefanidis, A. (Eds.), GeoSensor Networks 2006. Lecture Notes in Computer Science, Springer, Berlin, forthcoming.

3. REFERENCES

Batty, M.; Desyllas, J.; Duxbury, E., 2003: The Discrete Dynamics of Small-Scale Spatial Events: Agent-Based Models of Mobility in Carnivals and Street Parades. International Journal of Geographical Information Science, 17 (7): 673-697.

Benenson, I.; Torrens, P.M., 2004: Geosimulation: Automata-based Modeling of Urban Phenomena. John Wiley & Sons, Chichester, UK, 336 pp.

Nagel, K., 2001: Multi-modal traffic in TRANSIMS. In: Schreckenberg, M.; Sharma, S.D. (Eds.), Pedestrian and Evacuation Dynamics, Springer, Berlin, pp. 161-172.

Torrens, P.M., 2004: Geosimulation, Automata, and Traffic Modelling. In: Hensher, D.A. et al. (Eds.), Handbook of Transport Geography and Spatial Systems. Handbooks in Transport, 5. Elsevier, Amsterdam, pp. 549-564.