

Agent-based simulation of cognitive neighbourhoods in large-scale geographical environments

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Biography

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Introduction

A 'sense of place' in an urban environment emerges both from a sense of place as well as a sense of time. It has been shown that behavioural and cognitive studies can provide the basis for a scientific framework within which the formation of a 'sense of place' can be defined (Agarwal 2002). With the research initiatives in geographical information science focussing on incorporating more 'common-sense notions' of geographical phenomenon (Mark, et.al. 1997), several empirical studies have attempted to extract the rules of spatial knowledge acquisition and formulation by individuals while interacting within a city. Theoretical discussions have focussed on human perceptions of both space and time but empirical studies in extracting rules for temporal cognition are still limited because of the complex nature of temporal ordering, and due to lack of appropriate language that can define and describe time associated with space in urban environments. Lack of modelling tools that can handle individual frames of reference present in a cognitive model have also meant that most of the behavioural and cognitive rules extracted through empirical studies can not be tested. Agent-based techniques have been found to be effective in modelling complex human and social systems and micro-scale interactions to test rules applying at a global level (Sullivan 2002). This paper reviews the applicability of agent-based techniques to modelling cognitive frameworks of space and time, and outlines a proposed model that integrates several frames of knowledge, both distinct and overlapping, imparting cognitive capabilities to agents. A set of properties such as internalised semantic rules, personal beliefs and associations are set for the agents that act within the urban environment to adapt, learn and define taxonomies and proximity relations and consequently the extents of individual space at both local and global level of association.

Sense Of Place: Cognitive Framework

Agarwal (2002) has discussed the relevance of notion of 'sense of place (SOP)', within a cognitive science framework, to the extraction of ontologies for neighbourhood considerations in a large-scale geographical environment. Significant work has been done in the last five years on spatial knowledge acquisition; theoretical, empirical and computational (Tuan 1974, Sadalla and Burroughs 1980, Fisher and Orf 1991, Duckham and Worboys 2001, Hirtle 2001), and forms the basis for designing a theoretical and methodological framework in this 'landmark-

neighbourhood' model for SOP. This framework considers proximity relations and the strength of associations for forming spatial knowledge and defining areas of 'closeness' within an egocentric frame of representation and resolution. The notion of 'closeness' in space as resolved on the basis of previously learnt knowledge, memory and beliefs and personal reference points is also indicative of the level of familiarity and the extent of association that emerges from the nature of interaction and movement within the urban environment. Hence, there is an internalised and an externalised framework within which this knowledge and cognitive model of space is formed. Time can not be separated from space in forming a sense of place. However, cognitive and behavioural studies in formulation of temporal knowledge in an urban environment have been few. This model proposes extending spatial metaphors of proximity and using natural language terms such as 'near' and 'far' commonly used to describe spatial relations into a temporal context. Studies have shown that the cognitive ordering of time is not necessarily linear (Prince 1978, Parkes and Thrift 1978) and several parallel time-paths exist within our cognitive models of the urban environment dividing and ordering spatial knowledge. The temporal information, as is spatial information, is structured around a framework of reference points and, hence the landmark-neighbourhood model can be applied to ordering of temporal information. The objects located in space are located in time and are assigned reference status according to their significance and the level of association. Influence zones exist around these 'landmarks' both in time and space. Objects in space and time are compared to the reference points and distance estimates made to assign 'closeness' in space and in time. These proximity relations are made both in an egocentric as well as exo-centric framework defining 'self-object' relations as well as 'object-object' relations. The areas of influence around the landmarks and the clustering of closely lying objects within the cognitive model defines the partitioning of space; space partitioned on the basis of cognitive regions in space as well as in time. Resolving these different multi-dimensional, overlapping regions within the cognitive framework results in neighbourhood definitions. Meanings, association, value and beliefs are all part of this cognitive framework that are difficult to resolve within a traditional modelling environment; the multiple layers of reality and multi-dimensional nature of the cognitive data and relations are too complex to be reduced within the limited dimensionalities available in a GIS.

Background: Urban Simulation And Cognitive Agents

On the other hand, with its capacity to model individual actions and behaviours, agent-based simulation techniques have been found to be more powerful in modelling micro-scale human behaviour and responses to give an insight into rules of human interactions and decision-making in real-world settings. Artificial societies have been developed as computational laboratories and have been applied in simulating social and human systems to study micro-level mechanisms that are indicative of the global level social phenomenon (Epstein and Axtell, 1996). The idea of a 'computational laboratory' as a means to discover ways and develop tools to model people and societies in GIS has been promoted by several research initiatives in GIScience (Dibble, 1996). A detailed discussion of multi-agent based simulation techniques is not possible within the realm of this paper; Zeigler (1976), Drogoul and Ferber (1994), Gilbert and Troitzsch (1999) can be referred to for some introductory reading in agent-based simulation in social contexts.

In the urban context, agent-based applications have been few. Most of the applications of multi-agent systems in urban modelling have emerged out of a need to model multiple interactions that is beyond the capabilities of a cell-based models such as CA (Cellular Automata) commonly used for urban models because of its better integration with the existing algebraic configurations in GIS (Jiang And Gimblett, 2002). Jiang and Gimblett (2002) provide a discussion on the four-feature nature [agents, objects, environment, communications] of MAS and their suitability to modelling space-time dynamics. Latest developments in agent-based models have also been attempting to make the agents more human-like by incorporating more and more behavioural properties.

Ferber in his 'kenetic software' theory has identified two types of agents: reactive and cognitive (Ferber 1999). The availability of cognitive agents, who have inherent capacity to adapt and be influenced by the environment around and have goals and intentions that are largely self-driven is of extreme relevance to modelling complex social and human phenomenon. Franklin and Graesser (1997) have provided a taxonomy for proposed agents from low-level reactive agents to higher-level more deliberative intelligent agents with more adaptive behaviour through learning and communication with other agents, objects and environments, responses through internal emotional and personality traits, and remembrance for decision-making. Agents operate within a system consisting of a set of associated properties for the agent and also for the environment and rules for communication with other agents, objects and environments. The more complex and higher-level an agent becomes, the level of complexity in the framework within which it is operating becomes increasingly difficult to design and set rules for. Many efforts are being made to incorporate higher-level intelligence in autonomous agent systems through developing software that will allow more real-life and effective simulation of the inherent complexities in the real-world. *Swarm* is the most exhaustive object-oriented modelling environment developed and one that is most commonly applied to social and urban simulations. A review of previous work done using agent-based systems in the urban context shows that most of the work is at a regional scale where the cell-based paradigm is still causing some conflict in design of geographically viable, autonomous agents that have extended cognitive capabilities and intelligent behaviour. The complexity of testing these simulated models and the validity of the rules with real-life experiments has meant that the micro-scale behaviour is still a challenge to simulate. Most simulations in urban context have treated the environment as a static entity; some researchers have explored dynamic environments such as Box (2002) who provides an outline of a method using a cell-based GIS integrated with agent-based techniques in SWARM to include the spatio-temporal dynamic nature of the environment. Other specialised software for modelling landscape dynamics have been developed but these are primarily in geomorphology and hence lack the 'people' aspect that social simulation is concerned with. Simulating social systems is complex because the dynamic nature of the environment is coupled with the dynamic, multi-dimensional nature of the agents interacting with it. Early simulation models, having been emerged from biological concepts operated mostly on fixed grids and cells and the inherently spatial nature of the geographical phenomenon or the spatial nature of the real-worlds was not represented. As the environments that agent's actions are simulated and tested in is not indicative of the real-world environments, the inherent complexities of the actions and interactions is difficult to simulate. Research efforts

have proposed including the spatial component in the ABS (agent-based system) through integration with GIS to use the spatial capabilities available within.

In the spatial context, Rodrigues et. al.(1997) provide a good overview of examples of agent-based application in spatial decision support systems, and TRANSIMS (Beckman 1997) and Schelhorn et. al. (1997) with the STREETS model have applied the distributed agent-based technique within a Swarm environment to model navigational behaviour at urban and regional level. Behavioural elements for agents such as visual acuity and fixation have been included to allow for more adaptive agent properties. Portugali and Benenson (1997) and then Benenson (1998) have considered the cognitive and behavioural aspect of the individuals as determinants of the spatio-temporal dynamics in a city. This aspect was included as a uni-dimensional quantitative vector by Portugali et.al (1997) in their agent-based model. The qualitative and multi-dimensional nature of the behavioural factor becomes more defined in Benenson's model who incorporates it into his agent-based urban model as a high-dimensional binary 'cultural code' vector that influences the individuals interactions. The cultural code vector is an advancement on other agent-based models that are purely quantitative but is still limited as the framework of space and time that these agents are acting in is still a static, rigid entity common for all agents. The cognitive properties of the agents have not been extended to include the varying spatio-temporal definitions created by the individuals interacting with the urban environment.

The research, to date, in modelling urban and regional dynamics have used statistical parameters such as Voronoi neighbourhood rules and spatial interaction gravity models for setting spatial properties for agents. The graph-CA model proposed by Sullivan (2000) proposed building in different neighbourhood relations such as Voronoi relations and distance for achieving neighbourhoods simulations as perceived by people in urban environments. This is a simplistic assumption about neighbourhood considerations and one that merges from a purely quantitative view of the world.

Proposed Multi-Agent Model For Sense Of Place

A MAS (multi-agent system) simulation model is designed:

- As a test-bed for testing hypotheses and results emerging from in-vitro experimental studies and empirical psychometric analysis for sense of place.
- As an interface for simulating cognitive decision-making capabilities and behaviour within a large-scale geographical environment.
- With cognitive agents that have an extended set of behavioural and internalised knowledge rules associated with them and act and interact in a spatio-temporal context to determine neighbourhood relations and regionalisations within the urban environments based on linguistic variables and fuzzy rules of beliefs and associations.

This model is designed on the basis of a strong theoretical framework with the rules and variables emerging from an empirical real-life study carried out with an experimental group of subjects. The premise is based on previous work that has emphasised the significance of theory in modelling human-like behaviour through

agent technologies. Theory is critical for modelling complexity and Sullivan (2002) has stressed that it is essential to move between simulation and reality to constantly validate results and observations from both. Gimblett (2002) emphasises on the need to calibrate the agents with behavioural data to have confidence in the results from a model and to ground the model in reality. This paper discusses the outline of a stand-alone prototype that attempts to integrate belief system of the agents and a set of variables forming the internalised knowledge framework that influences the agents' knowledge and reasoning in space and time. The typologies, taxonomies, categories and relations that individuals form in this process of reasoning is an exhaustive list. For the purpose of demonstration and prototype testing, proximity relations and the use of natural language terms such as 'near' and 'far' for partitioning space and time are being modelled. This model takes into considerations some of the ideas of proximal space developed by Takeyama and Couclelis (1997) but argues for more robust reasoning capabilities in agents for proximity than the cell-based model proposed in this study. It proposes a fuzzy-rule based set of neighbourhood operations within an agent-based simulation environment; hence incorporating more human metrics for space and time. Coupling with GIS platform and database is also outlined.

Conclusions

Since behavioural research, both theoretical and empirical, have shown that cognitive spatio-temporal models influence human spatial behaviour and reasoning in urban environments, simulated models can be made more effective by incorporating in agents a reasoning capability and a cognitive framework for geometry, topology and relations in space and time. The simulation of rules and behaviour at local neighbourhood level would have implications on the nature of sense of place formulated at different scales of geographical environments. Besides operationalising behavioural and cognitive matrices within modelling environments and consequently extending the design framework of GIS platforms, this MAS model also provides indicators for making agent-based techniques much more applicable to modelling complexities of human behaviour.

References

- Agarwal, P (2002) Perceptual Places, In D. Mark & M. Egenhofer (Eds.) GIScience 2002 Proceedings, GIScience 2002, 24-26 September, Boulder, USA.
- Benenson, I (1998) Multi-agent simulations of residential dynamics in the city. *Computer, Environment and Urban systems*, Vol. 22, No. 1, pp 25-42.
- Box, P. (2002) Spatial Units as Agents: Making the Landscape an Equal Player in Agent-Based Simulations, In H. R. Gimblett (Ed.) *Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Simulating Social and Ecological Processes*, New York, Oxford University Press.
- Dibble, C. (1996) Representing Individuals and Societies in GIS. In Proceedings of the Third International Conference on Integrating GIS and Environmental Modelling, January 21-25, 1996, National Centre for Geographic Information and Analysis, Santa Barbara, CA.
- Drogoul, A. and J. Ferber. (1994) Multi-agent simulation as a Tool for Studying Emergent Processes in Societies. In N. Gilbert and Doran, J. (Eds.) *Simulating Societies: The Computer Simulation of Social Phenomenon*, London, UCL Press, pp 127-142.

- Duckham, M. & M. Worboys (2001) Computational structures in three-valued nearness relations. COSIT 2001.
- Epstein, J. and R. Axtell (1996) *Growing Artificial Societies: Social Science from the Bottom-Up*. Princeton, Princeton University Press.
- Ferber, J. (1999) *Multi-agent Systems: An Introduction to Distributed Artificial Intelligence*, Rading, MA: Addison-Wesley.
- Fisher, P.F. & T. M. Orf (1991) An investigation of the meaning of near and far on a University Campus. *Computers, Environment and Urban Systems*, 15: 23-35.
- Franklin, S. and A. Graesser (1997) Is it an Agent, or Just a Program? : A Taxonomy for Autonomous Agents. In J. P. Muller, Wooldridge, M. J. and N. R. Jennings (Eds.) *Intelligent Agents III: Agent Theories, Architectures and Languages*, Berlin, Springer, pp 21-35.
- Gilbert, N. and K. G. Troitzsch (1999) *Simulation for the Social Scientist*, Buckingham, UK, Open University Press.
- Gimblett, H. R. (2002) Integrating Geographic Information Systems and Agent-Based Technologies for Modelling and Simulating Social and Ecological Phenomenon. In H. R. Gimblett (Ed.) *Integrating Geographic Information Systems and Agent-Based Technologies for Modelling and Simulating Social and Ecological Phenomenon*, New York, Oxford University Press, pp. 1-20.
- Hirtle, S. (2001) Dividing up space: Creating Cognitive structures from Unstructured Space. Meeting on Fundamental Questions in GIScience, Manchester, UK.
- Jiang, B. & H. R. Gimblett (2002) An agent-based approach to Environmental and Urban systems within Geographic Information Systems. In H. R. Gimblett (Ed.) *Integrating Geographic Information Systems and Agent-Based Technologies for Modelling and Simulating Social and Ecological Phenomenon*, New York, Oxford University Press, pp 171-190.
- Mark D., M. Egenhofer, and K. Hornsby (1997) *Formal Models of Commonsense Geographic Worlds*. National Center for Geographic Information and Analysis, NCGIA Technical Report 97-2.
- Parkes, D. & Thrift, N. (1978) Putting Time in its Place, In T. Calstein, Parkes, D. & Thrift, N., *Making Sense of Time*, Vol. 1, pp 119-129, London, Edward Arnold.
- Portugali, J. & Benenson, I. (1997) Human agents between local and global forces in a self-organising city, In F. Schweitzer (Ed.) *Self-organisation of complex structures: From individual to collective dynamics*, pp 537-546, London, Gordon and Breach.
- Portugali, J., Benenson, I., & Omer, I. (1997) Spatial cognitive dissonance and socio-spatial emergence in a self-organising city. *Environment and Planning B*, 24, 263-285.
- Prince, H. (1978) Time and Historical Geography, In T. Calstein, Parkes, D. & Thrift, N., *Making Sense of Time*, Vol. 1, pp 17-37, London, Edward Arnold.
- Rodrigues, A., C. Grueau, J. Raper, and N. Neves (1996) Environmental Planning using Spatial Agents, In S. Carver (Ed.) *Innovations in GIS 5*, London, Taylor and Francis, pp 108-118.
- Sadalla, E. K. & Burroughs W. J. (1980) Reference Points in Spatial Cognition. *Journal of Environmental Psychology: Human Learning and Memory* 6 (5):516-528.
- Schelhorn, T, O'Sullivan, D, Haklay, M, (1999) STREETS: an agent-based pedestrian model, CASA Working Paper 9, University College London, Centre for Advanced Spatial Analysis, London.
- Sullivan, D. (2000) Exploring the structure of space: towards geo-computational theory, Working Paper Series, Centre for Advanced Spatial Analysis, London.

Takeyama, M. and H. Couclelis (1997) Map Dynamics: Integrating Cellular Automata and GIS through Geo-Algebra, International Journal of Geographic Information Science, 11(1), pp 73-91.

Tuan, Yi-Fu (1974) Topophilia: A study of Environmental Perception, Attitudes and Values, New Jersey, Prentice Hall Inc, Englewood Cliffs.

Zeigler, B. P. (1976) Theory of Modelling and Simulation, New York, John Wiley and Sons.
