Agent-Based Services for Validating Multi-Agent Models

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1. Introduction

Agent-based modelling has been increasingly applied to the simulation of spatial phenomena *in silico*. In an agent-based spatial simulation, agents have tended to be defined as spatial objects to computationally represent the behaviour of individuals in order to study emergent patterns arising from micro-level interactions. More recently, agents have been used to represent spatial processes as the modelling primitives in order to focus on process information in dynamic models. However, a recurrent problem in agent-based modelling is the validation of outcomes. Thus a third approach investigated here, is to harness the mobility and intelligence of agents to create tools that offer agent-based services for the validation of agent-based modelling. A typical agent-based service for spatial simulation might be quality analyses of both data and models. In this paper we specifically investigate agent-based services for sensitivity analysis and calibration of multi-agent models. In order to develop an interoperable and distributed system, remote multi-agent technology is deployed. A collection of collaborating agents can then be shared as services across a network.

2. Agent-based modelling

The initial development of remote multi-agent systems comes out of classical artificial intelligence and object-oriented programming (Adler and Cottman 1989). Remote agents are those which can be accessed across a network as distributed components. Key features of agents are their ability to sense and respond to their environment (reactivity) and to communicate with other agents. Other features that provide agents with added intelligence include: autonomisity, pro-activity, adaptivity, social ability, collaboration, cloning, mobility and ontology (Woolridge and Jennings 1995).

Within geosimulation (Benenson and Torrens 2004, Albrecht 2005), the most common implementation of multi-agent models is for the agents behave as objects within a spatial framework. Agents are used represent collectives of spatial individuals such as households, roads and land parcels. Simulation models could then be developed as an attempt to understand the aggregate behaviour or emergent patterns from the behaviour of individuals which can communicate, sense their environment and interact (Ferber 2005). When spatial dynamics are embedded in the rules of the agents or in the dynamic extensions of agents, the processes can be simulated, stored and queried. Thus, for example in pedestrian modelling (Batty et al. 2003), agents can simulate the behaviours of individual persons to link uncoordinated actions at the local level with emergence of more global structures. In integrating with GIS software, object agents can represent points, lines or polygons. These agents may be dynamic in their state (i.e. changing attributes) or space (i.e. moving in position), and may change the state or location of other objects (Brown et al. 2005). More recently, agents have been used to represent processes in a model to gain new insights into how spatial phenomena operate (Reitsma and Albrecht 2005).

3. Agent-based services

For spatial data and modelling, agents have been employed to provide services such as web search and models management. Purvis et al. (2003) used a multi-agent system to query and integrate distributed environmental information over a network. Sengupta et al. (2003) designed an agent-based framework to utilize online data and models for spatial decision support. In these applications, agents behave as online or offline tools.

In line with other numerical modelling, agent-based modelling requires validation. However, when dealing with complexity and emergent behaviour, the validation of outcomes can be problematic (Batty & Torrens 2005) and is indeed seen as a recurring problem in multi-agent modelling (Amblard et al. 2005). Two key elements of validation are testing robustness of outcomes through sensitivity analysis and calibration of models against empirical data, though Batty and Torrens (2005) would argue for a more qualitative evaluation of a model's plausibility. One solution is to develop agent-based services specifically for the validation of multi-agent models that harness the intelligence, interoperability and mobility of agent-based technologies. The efficacy of such a solution has already been demonstrated for data quality analysis where GIS are loosely coupled with numerical simulation models (Li Y 2006). The agent-based services could reside on the Internet and collaborate with each other to offer services autonomously. As a proof of concept, two agent-based services (as collaborative sets of agents) have been developed to perform a range of tasks for sensitivity analysis and for model calibration.

4. Case study

The case study to be presented models wayfinding behaviour in the context of location-based services, that is, with the delivery of requested spatial information to a mobile device. The agent behaviours are derived from empirical studies of wayfinding behaviour for which important aspects of emergent patterns are known for a test locality (see Li C 2006). To use such agents to study emergent behaviours in other localities requires that they first be validated. The multi-agent model and the agent-based services have been implemented using JACK (www.agent-software.com), an agent development environment supporting distributed applications.

In the multi-agent model, each individual is an object that is assigned wayfinding tasks and has programmed behaviours regarding requests for information, information preferences, spatial learning and walking speed. Their mobile device (e.g. mobile phone) is also a programmed agent with rules for the release of information depending on what is requested. The individuals interact both with their environment (road network) and their mobile device. As they travel, each individual maintains a record of its track, states and activities for later analysis.

The agent-based services are designed to fulfil two mains validation tasks: to test robustness of the emergent patterns through sensitivity analysis, and to carry out calibration. The former concerns internal validity, the latter concerns external validity. Each agent-based service comprises a set of sub-agents that perform specific tasks with some sub-agents shared between the two services. In the sensitivity analysis, parameters influencing object agent behaviours are perturbed and the multi-agent model repeatedly re-run in order to analyse the stability of the emergent patterns and if necessary to establish bounds. Done manually this is laborious work but is efficiently managed by an agent-based service. For the calibration, the emergent pattern from the multi-agent model is matched against the empirical data. Parameters are incrementally changed until an optimal fit is achieved. The multi-agent model can then be reliably deployed, for example, to study comparative emergent patterns of behaviour across a range of urban morphologies.

5. Conclusion

Validation is a recurrent problem in multi-agent modelling used for geosimulation. In this paper, the concept of using agent-based technologies to create services has been developed. These agent-based services are collaborative sets of agents that perform key tasks in model validation. The case study shows how agent-based services can be deployed for testing the robustness of emergent patterns through sensitivity analysis and in model calibration.

7. References

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