

# Towards DEVS-Based Simulations of GeoAgent-Based Models with Decentralised Dynamic Properties

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## Abstract

This paper is based on work in progress for integrating simulations of agent-based models with geographic information systems using a DEVS-based approach. Work on multi-agent systems (agents-centric view) and geographic information systems (resource-centric view) reveals that actual platforms do not provide truly integrative modelling and simulation of both views. We argue that actual DEVS-based simulators facilitates that integration, providing a process of composing behaviours depending of time passage, however other mechanisms are needed to enable decentralised dynamic interactions of agents in spatio-temporal contexts.

## INTRODUCTION

Modelling systems behaviour with explicit dependency of the geographic space, such as spread phenomena, and interactions with humans (agents) in a spatial context, requires a geographic modelling task. In work based on geographic representations, it is widely accepted that this task is usually accomplished within Geographic Information Systems (GIS) while modelling agents behaviour and their interactions is nowadays accomplished by Agent-Based Models (ABM) [Ferber, 1999; Gimblett, 2002; Luck, et al., 2005].

GIS are a special case of information systems enabling the manipulation of database models of real world objects (e.g. streets, rivers, administrative divisions, land use, etc.) within a 3D coordinate system. GIS also provide complex operators for spatial visualisation and spatial analysis. Thus, modern GIS provide process and data models. GIS data models can have two computational representations: i) vector model where the basic element is the point, defined by coordinates specified in the GIS reference system, from which lines and polygons are constructed to represent spatial objects with different geometric

attributes (i.e. area); ii) cellular model where the basic element is the cell and the geographic space is divided into a homogenised grid. Regardless of the data model, spatial representations within GIS are organised in layers. Real world objects are thus modelled by a stack of those data model layers.

On the other hand, ABM simulation, also called multi-agent simulation, concerns modelling and simulation (M&S) of individuals, i.e. M&S of their behaviour and interactions, within dynamic domains such as societies, physical and biological environments.

In the context of this work, the authors are interested in agent interactions situations framed by spatio-temporal dynamic constraints such as those emerged, for instance, in rescue and emergency management, fire and flood fighter, etc. In this context, GIS-based frameworks for ABM simulations are key tools for studying the behaviour of multi-agent systems with spatial awareness and given that GIS and multi-agent systems integration is truly needed [Gimblett, 2002; Parker and Maguire, 2005] the obvious question is: how to integrate them? In general, this issue has been tackled at two levels: at the lower level, i.e. using a software engineering view point; and, at the high level, i.e. through GIS modellers and GIS practitioners.

An overview about integrative M&S of ABM and GIS, identifying weaknesses of the current approaches is given. Afterwards, the GeoAgent architecture is presented. Its concepts are actually based on integrative Discrete Event Systems Specifications (DEVS) building blocks as a facility for GIS-ABM integration, by composing time dependent behaviours, but not enough for the simulation of decentralised dynamic properties of agents. Finally, considerations about future developments are presented.

## MULTI-AGENT SIMULATION AND GIS

Integration of ABM simulation and GIS is an interdisciplinary field; therefore it has been regarded from two perspectives:

- GIS users (end-users and research users [Parker and Maguire, 2005]) are more concerned with modelling entities behaviour in a spatial context and less with the architectural concepts of the tools, platforms or frameworks. Examples of this perspective are the works by Paul Box, James Westervelt or Duck-Sylvester as described by Gimblett [Gimblett, 2002] and Michael Batty and Itami and Gimblett, about pedestrians behaviour within urban/park areas [Itami and Gimblett, 2000].
- Multi-agent systems researchers, where the integration of ABM and GIS is done by using a general ABM framework plus some mechanisms to import spatial data models. This approach can be found in platforms such as Repast, Swarm, Kenge, Cormas (<http://cormas.cirad.fr/>), etc. where a module to import GIS spatial data is added to the simulator, usually in a loosely coupled way [Westervelt, 2002], i.e. through the use of files.

In the work outside the geography field, ABM simulation is usually nonspatial [Benenson and Torrens, 2004] leading to general multi-agent frameworks where functions/operators already available within GIS platforms need to be implemented with high costs [Brown, et al., 2005]. Thus, those frameworks are full of functionality for modelling agents, their interactions and actions, but do not rely on GIS functions which need to be written, debugged and tested. In this way, integration by adding import modules to ABM tools reveals to be some how naïve.

Brown et al. [2005] characterise very well the approaches underplayed by those two perspectives calling them GIS-Centric (the resource-centric view) and ABM-Centric (the agents-centric view). Without excluding the advantages of ABM-Centric, we are interested in GIS-centric in order to:

1. Increase complexity as we want to use real-world spatial contexts instead of simplified cellular-based worlds of ABM-centric tools such as Repast, Ascape, Swarm, Cormas, James, StarLogo, etc.;
2. Re-use GIS spatial operators already available from GIS packages;
3. Develop architectures of elementary behaviours (in particular the ones exhibiting spatial awareness) through hierarchical composition.

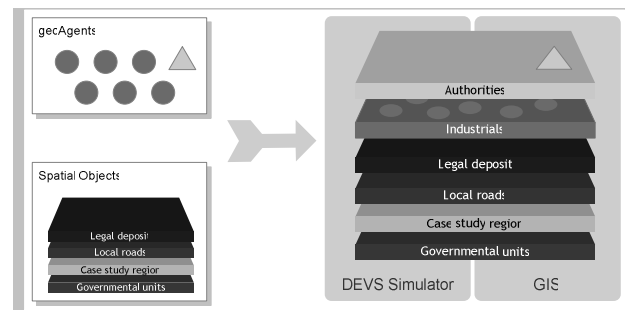
From work done in this field it is clear that agent models should be based on the spatial object model (regardless of it being vector or cellular based [Benenson and Torrens,

2004; Brown, et al., 2005]). Also important is that the ABM and GIS integration enables agents behaviour based on available GIS complex functions (spatial awareness of agents is achieved only if agents can access GIS operators and thus become capable of spatial reasoning [Rodrigues, 1999]). Benenson and Torrens proposed the Geographic Automata System concept to associate a geographic feature with a behaviour specified by an automaton within their framework OBEUS. However, this work is specific for urban modelling, and it does not use such concepts as hierarchical system decomposition and model structure and uses constant time steps.

## THE GEOAGENT CONCEPT

Basically, we are interested in obtaining a framework for M&S multi-agent system interactions where conflicts and coordination needs are raised by dynamic spatial-temporal restrictions and where either perspective, resource-centric or agent-centric, can be equally modelled. Also, this framework should be possible to compose complex behaviours based on elementary ones specified by DEVS, X-machine ([www.x-machines.net](http://www.x-machines.net)), Petri Nets, Timed Automata, Reactive Machines (see SugarCubes (<http://www.inria.fr/meije/rc>), etc. , which facilitates analysis and model-checking.

In order to enable the modelling of both views, as described above, the authors proposed the GeoAgents conceptual architecture where agents are organized in geographic layers [Gonçalves, et al., 2004], see Figure 1.

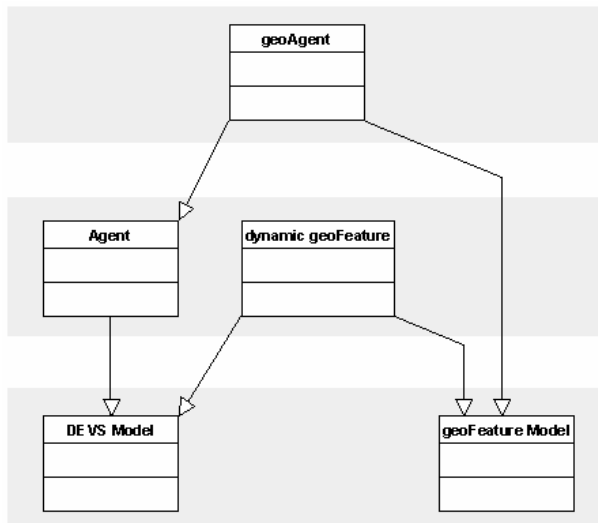


**Figure 1:** GeoAgents conceptual architecture

This conceptual architecture constitutes a preliminary approach to developing GIS-centric simulation tools for agent-based models of systems with spatial awareness (i.e. GeoAgent-based models simulation tools) in opposition to the existing ABM-centric tools. The interaction mechanisms behind GeoAgents are supported by a simulator that schedules and executes the generated discrete events of each geoAgent. This is accomplished by a classic DEVS simulator [Zeigler, et al., 2000] but, in practical terms other simulators could be used, which would imply changing the way agents are specified. As it was a preliminary approach, the GeoAgent-based

architecture needs to be more detailed and formalized in order to enable dynamic properties which are not presented on the current implementations of this architecture [Lucas, et al., 2006] realised under the project MAGIC (see acknowledgments).

In this work, a *geoAgent* is a spatially positioned agent, embedded in a GIS Layer and agents can have either vector or cellular representations. Agents are, thus, organized in layers like GIS spatial objects.



**Figure 2:** Concepts and relations on *geoAgents*

In Figure 2, there are 3 levels of concepts which are represented as classes, with properties and methods, and where relationships are represented by arrows meaning inheritance/specialization as it is usual in UML. At the bottom level are placed the basic constructs, i.e. the DEVS model and geographic features (spatial models). At the centre level, an internal clock is part of the objects of these classes; an agent inherits the properties of DEVS atomic models or the coupled model; a dynamic geographic feature is a model of a spatial object with a specified behaviour given by a DEVS model – a dynamic geographic feature is not an agent because it is supposed not to be proactive. For instance, in a Lotka-Volterra model of preys and predators, preys and predators are modelled by *geoAgents* and the grass eaten by preys is modelled by dynamic *geoFeatures*. In this sense, the *geoFeatures* are the base constructs of semantic environments in the *GeoAgents* world. Finally, at the top level we have the *geoAgent* class inheriting Agent models properties and *geoFeatures* properties.

It is important to keep in mind that *geoAgent*-based model simulations take place within a platform coupling a GIS and a DEVS simulator where those classes co-exist. One of the advantages of using DEVS concepts to integrate GIS and Agent-based models is that the DEVS formalism

enables defining asynchronous interactions with explicit local time delays. Using DEVS, the mechanism to define constraints based on time is already available. This is not the case in the X-machine specifications, for instance.

Thus, the construction of an M&S environment with the *geoAgent* concept facilitates the work of modellers/scientists who are already familiar with the GIS paradigm. They define the spatial agent simply by constructing a geographic layer and by specifying its class behaviour. Then, by using a DEVS simulation environment, the relationships between the agents are defined through DEVS coupled models and the simulation can begin. This type of interface or interaction can not be achieved on platforms, also DEVS-based but not GIS-based, e.g. GALACTEA and JAMES frameworks.

## GEOAGENT'S DYNAMIC PROPERTIES

The classic DEVS coupled models enable pre-establish links between atomic models. In the context of the *GeoAgents* conceptual architecture, these links (at the lower level) are mapped to *geoAgents* channels of communication. However, in an ABM where thousands of agents interact with each other, the computational (mainly memory) complexity associated with pre-links between agents is not supported in low-end computational systems. Also, conceptually, relationships between agents can not be always pre-defined. This issue is more obvious if only temporary links are needed to support dynamic interactions between agents such as re-grouping (i.e. dynamic organization of groups), local and temporary relationships (i.e. dynamic relations).

For instance, suppose that we need to set up a model of warning systems where an agent informs other agents with geographic mobility (*geoAgent*) and only the agents within a certain area should be warned. At DEVS level, a pre-established coupling between all agents (i.e. a DEVS coupled model specification) could be used. However, this may involve exponential complexity as it is not possible to guess when and who will be within that area. A broadcast or multicast communication model should be used and adapted for the effect.

Thus, the mechanisms to dynamically set up interactions channels need to be similar to yellow pages (a higher level to be inserted in the structure in Figure 2). In this way any agent can determine, through a GIS operator, the ID of agents within the problematic area and use yellow pages to send a warning multicast message to their input ports (lower level). However, using this mechanism, the coordinator simulator for DEVS coupled model [Zeigler, et al., 2000] needs to be changed and, conceptually, it is a centralized approach.

The most recent work on this field, in the context of DEVS formalism specification, is called dynamic structure [Barros, 1997; Uhrmacher, 2001] or variable

structure modelling [Hu, et al., 2005]. Barros presents a centralised conceptualisation where a network executive centralises the structure changes (i.e. structure changes are the result of state changes of the *network executive codified in their state variables and within transition functions*). Also in the work of Uhrmacher it is centralized on a *model transition function* and in the work of Hu et. al. it is given examples of centralization, e.g. in dynamic team formation of a distributed robotic system, connections between robots are centralized in a third entity – the manager.

These works are now being analysed in order to determine, whether or not, their approaches are appropriate to incorporate in the concepts of Figure 2.

## FUTURE WORK

Using DEVS specification formalism will have a theoretical foundation and consistence to accommodate, in the future, other model specifications languages, since it was already demonstrated that formalisms ranging from Petri-nets to UML can be mapped to DEVS. However, the DEVS approach for specification and implementation of systems with decentralised dynamic properties needs to be formalised, compared and tested against other approaches. This work is being carried out in the context of the Ph.D. programme of the first author

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## REFERENCES

- Barros, Fernando J. "Modeling Formalisms for Dynamic Structure Systems." *ACM Transactions on Modeling and Computer Simulation* 7, no. 4 (1997): 501-515.
- Benenson, Itzhak, and Paul M. Torrens. *Geosimulation: Automata-Based Modeling of Urban Phenomena*. John Wiley and Sons, 2004.
- Brown, Daniel G., Rick Riolo, Derek T. Robinson, Michael North, and William Rand. "Spatial Process and Data Models: Toward Integration of Agent-Based Models and Gis." *Journal of Geographical Systems* 7, no. 1 (2005): 25.
- Ferber, J. *Multi-Agent Systems - an Introduction to Distributed Artificial Intelligence*. Great Britain: Addison-Wesley, 1999.

Gimblett, H. R. *Integrating Geographic Information Systems and Agent-Based Modelling Techniques*. New York: Oxford University Press, 2002.

Gonçalves, António, Armanda Rodrigues, and Luís Correia. "Multi-Agent Simulation within Geographic Information Systems." Paper presented at the Proceedings of the 5th International Workshop on Agent-Based Simulation (ABS-2004), Lisbon, Portugal, May 3-5, 2004.

Hu, Xiaolin, Bernard P. Zeigler, and Saurabh Mittal. "Variable Structure in DEVS Component-Based Modeling and Simulation." *SIMULATION: Transactions of the Society of Modeling and Simulation International* 81, no. 2 (2005): 91-102.

Itami, R. M., and H. R. Gimblett. "Intelligent Recreation Agents in a Virtual Gis World." Paper presented at the Proceedings of Complex Systems 2000 Conference, University of Otago, Dunedin, New Zealand., November 19-22, 2000.

Lucas, Bruno, Armanda Rodrigues, Cedric Grueau, and António Gonçalves. "Geoagents: A Framework for Multi-Agent Simulation within Geographical Information Systems." Paper presented at the International Workshop on Agent Based Modeling and Simulation (to appear), Vienna, April 18 - 21, 2006.

Luck, Michael, Peter McBurney, Onn Shehory, and Steve Willmott. "Agent Technology Roadmap - a Roadmap for Agent Based Computing." *Agent Link III*, 2005.

Parker, D. C. 2005. D. J., and M. F. Goodchild Maguire, and M. Batty, eds. "Integration of Geographic Information Systems and Agent-Based Models of Land Use: Challenges and Prospects." In *Gis, Spatial Analysis and Modeling*, edited by D. J. Maguire, M. F. Goodchild and M. Batty. Redlands, CA: ESRI Press, 2005.

Rodrigues, Armanda. "The Development of Spatial Intelligent Agents with Geographic Information Systems." PhD Thesis, City University, 1999.

Uhrmacher, Adelinde M. "Dynamic Structures in Modeling and Simulation: A Reflective Approach." *ACM Transactions on Modeling and Computer Simulation* 11, no. 2 (2001): 206-232.

Westervelt, James D. "Geographic Information Systems and Agent-Based Modeling." In *Integrating Geographic Information Systems and Agent-Based Modelling Techniques*, edited by H. R. Gimblett. New York: Oxford University Press, 2002.

Zeigler, B. P., H. Praehofer, and T. G. Kim. *Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems*. San Diego: Academic Press, 2000.