11

Multi-Agent Geosimulation in Support to Qualitative Spatio-Temporal Reasoning: COAs' "What if" Analysis as an Example

Hedi Haddad and Bernard Moulin
Laval University
Canada

1. Introduction

Multi-Agent Geosimulation (MAGS) is a relatively novel approach to model-building and application in the geographic sciences and geocomputing (Torrens, 2008). It is mainly characterized by the use of Agent-Based Models – particularly Multi-Agent Systems (MAS) - and Geographic Information Systems (GIS) in order to model, simulate and study complex phenomena taking place in geographical environments (Benenson and Torrens, 2004; Moulin et al., 2003). Recent research works in MAGS focused on two main trends. The first trend consists in improving different conceptual and computational aspects of MAGS models such as development methodologies (Ali, 2008), 2D and 3D virtual geographic environments models (Silva et al., 2008; Paris et al., 2009), agents perception and navigation models (Silva et al., 2008), generic MAGS platforms (Blecic et al., 2008) and models calibration and validation (Hagen-Zanker and Martens, 2008). The second trend consists in applying MAGS techniques to solve new problems such as parking policies evaluation (Benenson et al., 2007), prediction of house prices evolution (Bossomaier et al., 2007) and public health risk management (Bouden et al., 2008), to mention a few. Although these works allow modeling and simulating several geospatial phenomena, they do not guarantee that the simulation results will be well understood by a human user. In fact, results of geosimulations are usually presented using statistical, mathematical and / or graphical techniques (Ali et al., 2007). The complexity of the simulated phenomena and the huge volume of generated data make these techniques difficult to be interpreted by users. Indeed, human reasoning is mainly qualitative and not quantitative. Therefore, we believe in the importance of linking MAGS models with qualitative reasoning techniques, and we think that this link will allow the development of new systems which support qualitative reasoning in spatial contexts. While some recent works have been interested in this issue (Furtao and Vasconcelos, 2007), to our knowledge there is a lack of works that address its theoretical and computational aspects. Our contribution in this chapter aims at proposing an approach that uses MAGS techniques to support qualitative spatio-temporal reasoning. Particularly, we are interested in supporting a specific kind of qualitative reasoning called "What-if" reasoning and its particular application to the planning of courses of actions

(COAs). In this chapter we present a general overview of the proposed approach from its theoretical foundations to its computational implementation. More specifically, we highlight how this approach requires integrating several disciplines in addition to MAGS techniques.
The structure of the chapter is as following. In Section 2 we present the "What-if" thinking process and its application to the COAs' analysis problem. In Section 3 we present our MAGS-based approach. We explain its principle and present its main steps. We also list the main requirements that must be dealt with in order to implement it. These requirements are respectively presented in sections 4, 5, and 6. In Section 7 we present MAGS-COA, a tool that we developed as a proof of concept of the proposed approach. We also present how we used MAGS-COA to implement and evaluate scenarios in the search and rescue domain. Finally, in Section 8 we discuss the limits of the proposed approach and we conclude with future work.

2. "What-if" Thinking Process and the COAs' Analysis Problem

We aim to propose a MAGS-based approach to support a kind of qualitative spatio-temporal reasoning called *COAs' "What-if" analysis*. *"What-if" reasoning* is a kind of counterfactual thinking used by humans to deal with uncertainty when it is either impossible or impractical to conduct physical experiments (Lebow, 2007). Practically, "What-if" reasoning allows a human being to explore the consequences of different alternatives by asking questions of the form "WHAT will the situation be IF …". From a cognitive perspective, "What-if" reasoning is a qualitative mental simulation-based process consisting of three steps: 1) elaborating an analogical mental model of a situation (mental visualization); 2) mentally carrying out one or several operations on it; and 3) seeing what occurs. During the third phase qualitative *causal reasoning* is used to interpret the results of the manipulation(s) carried out during the second phase (Trickett and Trafton, 2007).
In practice, "What-if" counterfactual thinking is usually applied to explore the consequences of several alternatives in order to either plan future activities or explain historical events (Ferrario, 2001; Gaglio, 2004). As an example, we are interested in the application of "What-if" reasoning to the problem of courses of action (COAs) planning. A *COA* is an outline of a plan specifying the tasks to be performed by a set of resources (i.e. people, planes, teams) as well as the spatio-temporal and coordination constraints that must be satisfied in order to achieve a desired objective. Consequently, the success of the COA widely depends upon the performance of the resources when carrying out their tasks. Considering the context of planning COAs in a geographical environment, this performance is constrained by several factors, two among them being characterized by an inherent uncertainty: 1) On the one hand, there are several unpredictable natural phenomena that may occur in the geographic environment; 2) On the other hand, there are other entities acting in the environment and reacting to the COA resources' activities. In order to deal with such an uncertainty, human planners usually apply "What-if" reasoning in order to think about the implications of different assumptions by playing out different alternatives, and then by evaluating the plausibility of their consequences. However, human beings have some limits when reasoning in the context of changing geographic spaces. In fact, it has been proved that trying to mentally encompass changes (mental simulation) is a difficult task for humans (Forbus, 1981; Kahneman and Tversky, 1982). It is even more difficult in a large scale space because of the complexity and the diversity of phenomena which take place in it. In

addition, the human mental representation of space presents some limits, such as difficulties to judge distances and to estimate the three-dimensional aspects of the geographic space (Rothkegel et al., 1998; Tversky, 2005). Moreover, human planning is often carried out under stressful conditions such as time pressure and tiredness which affect human attention and memory, hence influencing the quality of decisions. For these reasons, the use of decision support systems that somewhat alleviate the mental charge of human decision makers is considered to be helpful during the COAs' "What-if" analysis process.

3. A MAGS-Based Approach to Support COAs' "What-if" Analysis

Multi-Agent Geosimulation (MAGS) inherits from two research fields: multi-agent systems (MAS) and geographic information systems (GIS) (Fournier, 2005). On the one hand, some AI research works have been interested in agent and multi-agent simulations in a spatial context, and the concept of spatial multi-agent systems has emerged (Rodrigues and Raper 1999; Batty and Jiang 2000; Frank et al., 2001). More recently, GIS have attracted a growing interest within the MAS research community as an explicit representation of spatial environments in multi-agent simulations (Gimblett, 2002; Brown and Xie, 2006; Phan and Amblard, 2007). On the other hand, geographers have been interested in MAS in order to introduce a temporal (dynamic) dimension in GIS which are typically static. By combining advanced characteristics of artificial agents and explicit and faithful representations of the geographic space, MAGS has been recognized as an effective technique for simulating complex systems composed of interacting agents in a simulated geographic environment. It has been recognized that such an approach is of great potential for verifying and evaluating hypotheses about how real spatial complex systems operate (Albrecht, 2005).
Therefore, we think that a MAGS-based approach is suitable for the COAs' "What-if" analysis problem. In the remainder of this section we present a general view of our approach; we discuss its principle, we present its main steps and finally we identify the main requirements that must be satisfied in order to implement it.

3.1 Principle

In Section 2 we presented the COAs' "What-if" thinking process as a kind of qualitative spatio-temporal reasoning based on a mental simulation. The key idea we are defending here is that combining MAGS techniques with qualitative modelling and reasoning techniques is suitable to support such a reasoning process. Consequently, we propose an approach that enriches MAGS techniques with spatio-temporal qualitative reasoning techniques (Figure 1). The approach mainly consists in: 1) using MAGS techniques to simulate the execution of COAs in a *Virtual Geographic Environment* (*VGE*) which can change during the simulation; 2) then allowing the user to explore various assumptions through different simulations and to analyze their outcomes. Results of the simulation are then transformed into a qualitative representation and therefore can be analyzed using qualitative reasoning techniques.

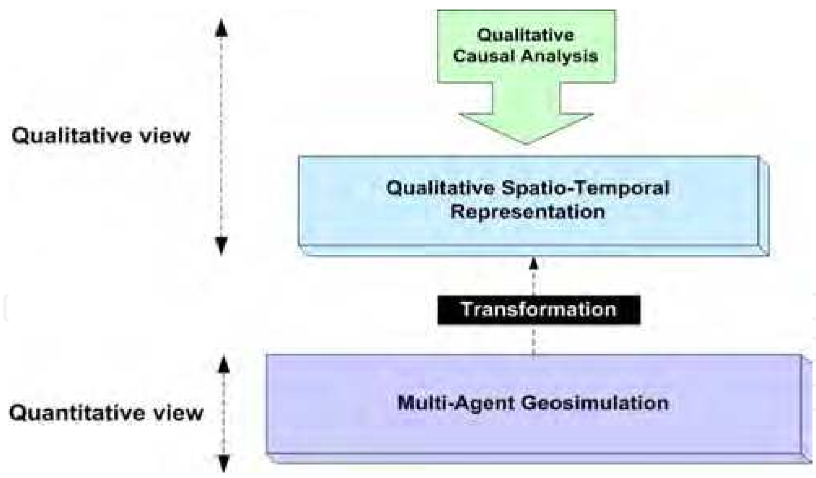


Fig. 1. Linking MAGS models with qualitative spatio-temporal reasoning

Our approach can be thought of as a new form of knowledge representation and reasoning about dynamic geographical phenomena which relies on integrating both quantitative and qualitative representation approaches. Indeed, multi-agent geosimulations – taking advantage of technological advances in autonomous agents, GIS data and natural phenomena modeling – provide a somewhat faithful analog representation of the geographic reality and of its dynamism. It can be a good support to the "what-if" mental simulation and a good way to represent the dynamism corresponding to the behaviours of the resources involved in the COA and their interactions. However, spatial reasoning, in our every day interaction with the physical world, is often driven by qualitative abstractions rather than complete quantitative knowledge (Cohn and Hazarika, 2001), and, as we mentioned in Section 2, human beings have cognitive difficulties when reasoning about various quantitative aspects of the geographic space. Therefore, it becomes interesting to exploit the geosimulation results in a qualitative manner by transforming them into models of dynamic situations which can be used to carry out different kinds of qualitative reasoning.

We think that such a combination of quantitative and qualitative representations allows us to take advantage of both of them. On the one hand, geosimulation is a good way to support a human being during her mental simulation and guaranties that our qualitative models are based on more realistic sources. On the other hand, qualitative representations take the user away from non-relevant details, by capturing only relevant information. The integration of quantitative and qualitative approaches is not a new idea: it has been widely supported by the GIS community (Winchester, 2000). However, to our knowledge it is still not fully implemented in current spatial decision support systems.

3.2 Steps

Considering the characteristics of the COAs' "What-if" analysis process presented in Section 2, we propose an approach composed of three steps: scenarios specification, MAGS and data causal analysis (Figure 2).

During the first step, the user specifies the *scenario* to be analyzed. We call a scenario the description of both a COA and the set of related assumptions specified by the user. The description of a COA indicates the initial positions of the involved resources in the *VGE* and shows *how* (which tasks or goals need to be carried out), *when* (temporal constraints) and *where* (spatial positions) they must achieve a given mission. Assumptions mainly correspond to the different "happenings" or events that may occur in the *VGE* and that are not caused by the resources' intentional actions, as for example rain falls and movements of fog patches[1].

The second step consists in using a multi-agent-based geosimulation system to simulate the specified scenario in a *VGE*. The resources of the COA are represented by software agents that are inserted in the *VGE* and that autonomously carry out their activities. They react to the actions of other agents, they are constrained by the characteristics of the *VGE* and they are influenced by the effects of the different "happenings" that occur in it.

The third step consists in analyzing the results generated by the simulation. Since we aim to support a "what-if" analysis, we are particularly interested in causal reasoning and in identifying the causal relationships between the user's assumptions and the geosimulation results.

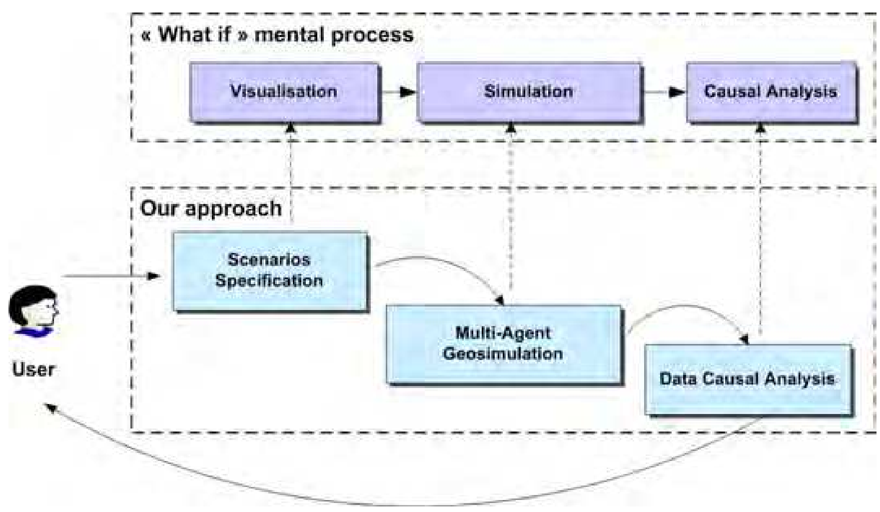


Fig. 2. Steps of the proposed approach

3.3 Requirements for MAGS Applied to "What-if" Analysis

Once the steps of the proposed approach are identified, the important question that must be dealt with is the following: what does the implementation of such an approach means in terms of conceptual and computational requirements? To answer this question, let us start from the end. Indeed, the goal is to establish cause / effect relationships between certain "elements". Let us call the "concepts of interest" these elements. However, we must first be able to express the results of geosimulations in terms of these concepts of interest, and therefore we have a new requirement of data transformation. Of course, we must have a MAGS platform allowing the simulation of the considered scenarios. Since we already have such a platform (which will be presented in Section 7) we do not consider it as a requirement in this chapter. Finally, we have a requirement of defining and modeling the concepts of interest that will be used to express the results of the MAGS and to apply causal reasoning on them.

[1] In historical "What-if" reasoning, assumptions can be related to the decisions or actions that may have been taken by a resource of the COA. An example will be presented in Section 7.2.

The fundamental question is thus the following: what are these concepts of interest? In the literature, situations describing changes in a spatial context are usually called *spatio-temporal phenomena* (or dynamic geographical phenomena). Therefore, the scenarios which we are interested in (simulation of COAs and happenings) are considered as spatio-temporal phenomena. Consequently, our first requirement consists in proposing a conceptual model of such spatio-temporal phenomena, i.e. COAs and happenings occurring in a virtual geographic environment. Our second and third requirements respectively consist in expressing the results of our geosimulations using the concepts of the proposed model, and in applying causal reasoning techniques on these concepts (Figure 3). In the following sections we detail the solution that we propose to deal with the three above-mentioned requirements. Section 4 introduces the concept of *spatio-temporal situations* that we use to model dynamic geographical phenomena. Section 5 presents data transformations required to express the results of the simulated scenarios in terms of spatio-temporal situations. Section 6 presents our model of causal reasoning about spatio-temporal situations and how it is used to analyze the results of the MAGS.

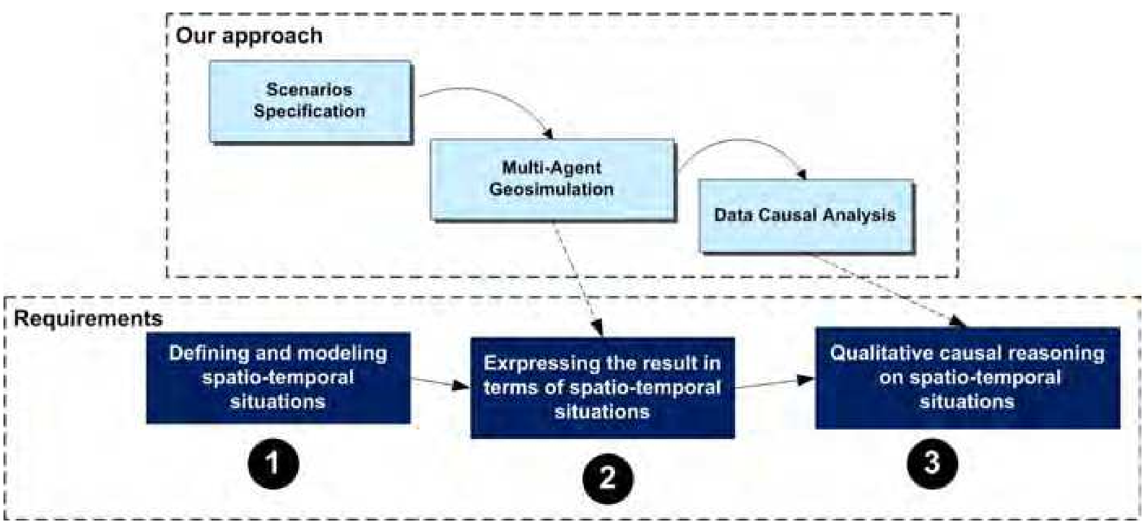


Fig. 3. Requirements to implement the proposed approach

4. A Model of Spatio-Temporal Situations

We aim to model dynamic phenomena in a geographic environment in which there are different kinds of complex spatial entities (such as rivers and buildings). There are also different kinds of objects (such as people and cars) which may move in this geographic environment and modify its state (for example, “block a road”). In addition, different “happenings” may occur in the environment (for example, explosions or floods) and may influence it (for example, “destroying a bridge may block a road and disrupt a river”).

The study of dynamic phenomena consists of studying properties of the world that change over *time*. Spatial dynamic phenomena describe changes over both *time* and *space*, and are therefore called *spatio-temporal* phenomena. Several models have been proposed in the literature in order to model spatio-temporal phenomena. A review of these models and their limits with respect to the COAs’ “What-if” problem is beyond the scope of this chapter and will be presented in a subsequent paper (see (Haddad, 2009) for further details). However, our model differs from existing models with respect to two main aspects: its theoretical foundations and its knowledge representation formalism.

In contrast to the majority of existing approaches, the theoretical roots of our spatio-temporal model derive from natural language research community. This community assumes that we use language to describe *situations* of the world (Helbig, 2006): "states of affairs and courses of events in which objects have properties and stand in relations to each other at various space-time locations" (Lindström, 1991). A situation is a finite configuration of some aspect of the world in a limited region of space and time and is characterized by various properties or relations that hold among the various objects in that situation (Sowa, 1984). As the world evolves through time, it changes from one state to another. Such changes of state are brought about by the occurrences of events (Georgeff et al., 1993). Consequently, a situation "may be a static configuration that remains unchanged for a period of time, or it may include processes and events that are causing changes" and "it may include people and things with their actions and attributes" (Sowa, 1984). Several conceptual models of static and dynamic situations expressed by natural language have been proposed by linguists. In our project, we push further works of the French linguist Desclés (Desclés, 1990; 2005) in order to define the concept of *spatio-temporal situations* which we use to model our spatio-temporal phenomena (Section 4.2).

With respect to knowledge representation language, we formalize our spatio-temporal situations using the conceptual graphs (CGs) formalism. Sowa (Sowa, 1984) introduced CGs as a system of logic based on Peirce's existential graphs and semantic networks proposed in artificial intelligence. We decided to use CGs because they are known to express meaning in a form that is logically precise and computationally tractable. In fact, there is a well-defined mapping between conceptual graphs and corresponding first-order logical formulae, although CGs also allow for representing temporal and non-monotonic logics, thus exceeding the expressive power of first-order logic (Hensman and Dunnion, 2004). In addition, they provide extensible means to capture and represent real-world knowledge and have been used in a variety of projects for information retrieval, database design, expert systems, qualitative simulations and natural language processing. However, their application to model dynamic phenomena in geographic spaces and to reason about them is an innovative issue (Haddad and Moulin, 2007). More details about CGs and their theoretical foundations can be found in (Sowa, 1984), among others.

Figure 4 illustrates the concepts of our model for spatio-temporal phenomena in a geographic space. Besides the work of the linguist Desclés which we used to define the concept of *spatio-temporal situations* and to capture a qualitative view of dynamic phenomena, we take advantage of ontological works on geographic space and geographic objects to define the structure of space in our model. Indeed, according to Grenon and Smith (Grenon and Smith, 2004) we may distinguish two *modes of existence* for entities populating the world. The first mode corresponds to an *'endurant' view* according to which there are entities "that have continuous existence and a capacity to endure through time even while undergoing different sorts of changes". The second mode corresponds to an *occurrent view* that describes 'occurrent entities' that "occur in time and unfold themselves through a period of time" (Grenon and Smith, 2004). Similarly to this classification, we define two views in our model: the *endurant* view and the *dynamic* view (Figure 4). Our *endurant view* is composed of the geographic space and the objects located in it. A geographic space is composed of geographic objects (*Geo-Object*) such as rivers, mountains and cities. For spatial referencing purposes, each geo-object is projected onto a spatial zone. Other endurant entities of the world (such as people, cars and animals) are represented using the *Actor* concept. Actors are located in the geo-objects composing the geographic environment and may navigate between them. Different relationships (as for example spatial relationships) may hold between geo-objects. Our *dynamic view* is composed of spatio-temporal situations. A spatio-temporal situation may be static (a state) or dynamic (an event or a process). A situation may involve[2] actors and geo-objects, and is characterized by various properties or relations that hold between them. Dynamic situations introduce changes in static situations. We say that they modify states. In addition, a process is characterized by an event that marks its beginning and an event corresponding to its end. These concepts are detailed in the following sub-sections.

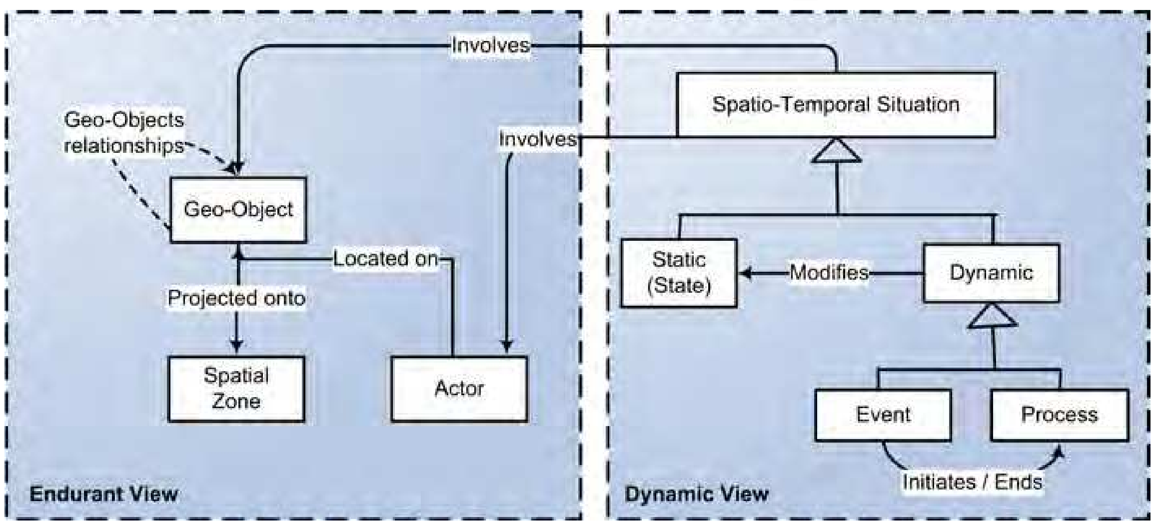


Fig. 4. Our model for spatio-temporal situations

4.1 Endurant View

This view describes the structure of the geographic space and the actors that may be located in it. We define and use the following concepts:

- ***Space*** **and** ***Spatial zone***: We adopt the definition of *Space* and *spatial zone* proposed in (Grenon and Smith, 2004). *Space* is the entire spatial universe (the maximal spatial region) and all spatial zones are parts of it. However, we use a different partition of *Space*. At a first elementary level, the *Space* is partitioned into a set of regular cells called pixels. Then, *spatial zones* are incrementally constructed in *Space*. A spatial zone is thus associated with a set of pixels. At a second level, *Space* is completely partitioned by a set of adjacent *spatial zones* in a manner that *Space* is totally covered. Let n be the number of spatial zones of *Space*, we have: *Space* = m Mereological[3] sum (z_i), i = 1 .. n. Spatial zones are used as a reference framework to localize geographic objects in *Space*.

[2] The term involvement is used by (Grenon and Smith, 2004) to refer to the relations that objects may have with events and processes (objects participate in situations and situations involve objects).

[3] Mereology (also called Part/Whole) formalizes the relation between a complex object and its parts. More details can be found, among others, in (Casati et al., 1998).

- Geographic object: According to (Mark et al., 1999), the domain of geographic objects "comprehends regions, parcels of land and water-bodies, topographic features such as bays, promontories, mountains and canyons, hills and valleys, roads, buildings, bridges, as well as the parts and aggregates of all of these". "Geographic objects are thus in every case spatial objects on or near the surface of the earth. They are objects of a certain minimal scale; they are typically complex, and they have parts". A geographic object has borders that distinguish it from other geographic objects in the environment. These borders can be concrete (*bona fide*) such as mountains and rivers or abstract (*fiat*) such as cities and municipalities (borders which exist only in virtue of the different sorts of demarcations effected cognitively by human beings) (Smith, 1994). We use the concept of *Geo-Object* to designate a geographic object (Fonseca et al., 2002). A geo-object has several descriptive attributes, a geometrical representation and is associated – by projection – to a spatial zone which represents its position in *Space*. The form and the size of the spatial zone are thus identical to the form and the size of its equivalent geo-object.

- Geo-Objects relationships: These are spatial relationships which describe the relative spatial positions of geo-objects. In the spatial literature we may distinguish the following conceptual categories of spatial relationships:

- *Topological relationships*: In the area of qualitative spatial reasoning, topology "is intended to describe properties of and relationships between spatial entities such as regions of points of a certain space, for instance, of two- or three-dimensional Euclidean space" (Renz, 2002). Several topological relations are proposed in the literature depending on the structure of the spatial objects (for example, simple or composite objects) and on computational models used to implement them (for example, *raster* or *vector* GIS data models).
- *Superposition relationship*: Superposition is an important relationship when reasoning about geographic space. Providing a formal definition of the superposition relationship is not an easy task (Desclés, 1990). A simple solution proposed by (Grenon and Smith, 2004) consists of adding another dimension in the projection function to specify that a geo-portion is located *over*, *under* or *on* a spatial zone.
- *Proximity relationships*: There are several models proposed in the literature to determine proximity relationships between spatial objects. An example of a generic model is proposed by (Kettani and Moulin, 1999) based on objects' *influence areas* to define a set of proximity relationships between spatial objects. This model can be used to compute proximity relationships such as *Close to* (*near*) and *Distant* (*far from*).

- Actor: Actors are used to specify endurant entities other than geo-objects. In the context of our project, actors represent the resources participating in the COA. Therefore, and depending on the application domain, actors may correspond to several entities such as people and cars. An actor has several descriptive attributes and can be stationary or mobile. In our model, at a given instant of time, an Actor is located in one and only one geo-object.

4.2 Dynamic View

We adopt Desclés' definitions of static and dynamic situations (Desclés, 1990). According to Desclés, a static situation represents the absence of change, while a dynamic situation introduces change and is abstracted as a transition of the world from an initial situation Sit_1 to another posterior situation Sit_2. The transition comprises three temporal zones: *before* *transition* (Sit_1), *during transition* from Sit_1 to Sit_2, and *after transition* (Sit_2). In addition to the model of Desclés, we extend the model of *temporal situations* proposed by Moulin (Moulin, 1997). A temporal situation is associated with a time interval which characterizes its temporal location on a time axis. An elementary time interval is specified by a list of parameters, essentially the begin-time *BT*, the end-time *ET*, the time scale *TS* and the time interval duration *DU*. We extend the concept of temporal situation to define the concept of *spatio-temporal situation*. A spatio-temporal situation is a temporal situation associated with a set of *spatio-temporal positions*.

Formally, a spatio-temporal situation is a quadruple <*SD, SPC, STI, SSTP*> where:

-The situation description *SD* is a pair [situation-type, situation-descriptor] used to identify the spatio-temporal situation. The situation type is used to semantically distinguish different kinds of spatio-temporal situations: states, events and processes. The situation descriptor identifies an instance of a situation and is used for referential purposes.

-The situation propositional content *SPC* is a non-temporal knowledge structure described by a conceptual graph. It makes a situation's semantic characteristics explicit.

-The situation time interval *STI* is a structure which aggregates the temporal information associated with the spatio-temporal situation.

-The situation's spatio-temporal position *SSTP* is a knowledge structure which describes positions of a spatio-temporal situation in space and time. The *SSTP* is formalized as a set of triples <$time_1$, $time_2$, *geo-obj*> indicating that during the interval time [$time_1$, $time_2$], the spatio-temporal situation is localized in a certain geo-object *geo-obj*.

Spatio-temporal situations are related by *temporal relations*. Based on Allen's temporal relations (Allen, 1983) we consider three basic relations called "*BEFORE*", "*DURING*" and "*AFTER*". Given two time intervals *X* and *Y*, the relation *BEFORE*(*X, Y, Lap*) holds if we have the following constraints between the begin- and end-times of X and Y compared on a time scale with the operators {>, <, =}: $BT(X) < ET(X); BT(Y) < ET(Y); BT(X) < BT(Y); ET(X) < ET(Y); BT(Y) – ET(X) = Lap, Lap => 0$. The *Lap* parameter is a real number that measures the distance between the beginning of interval *Y* and the end of interval *X* on their time scale. *DURING* and *AFTER* relations are defined in the same way (Moulin, 1997).

Graphically, we represent a spatio-temporal situation by a rectangle composed of three parts, top, middle and bottom respectively representing knowledge associated with the SD & STI, the SPC and the SSTP (examples are presented later).
Using this notation we formalize three kinds of spatio-temporal situations: state, event, and process.

- State: A state corresponds to a static situation (i.e. a finite configuration of some aspect of the world in a limited region of space that remains unchanged for a period of time). We have already mentioned that a situation is characterized by various properties or relations that hold among the various objects in that situation (Sowa, 1984). Desclés (1990) distinguished between localization states (spatial and temporal) and attribution states (assign a property to an object). Figure 5 illustrates a simple example of an attribution state identified by *st1*. Note that in conceptual graphs formalizm, each conceptual graph is associated with a propositional content, which is set to *true* by default. If the negation symbol "¬" is associated with a conceptual graph, the propositional content is set to *false*. In

Figure 5, the SPC of *st1* specifies that the person Dany is sick[4]. The STI specifies that Dany was sick during the time interval [September 23 2004, January 20 2005]. The SSTP specifies that during his state of illness, Dany was in Québec till December 11 2004 then in Paris from December 12 2004. Note that STI and SSTP's information is optional because, depending on the context, it can be unavailable or partially available. In this case, the temporal and spatio-temporal parameters are not specified.

Attribution_State: st1 BT: September 23 2004; ET: January 20 2005; TS: Date
[PERSON: Dany]->(ATT)->[Sick]
{<23-09-2004, 11-12-2004, Québec>, <12-12-2004, 20-01-2005, Paris>}

Fig. 5. An example of state

- Event: We adopt Desclés' definition (Desclés, 1990). An event expresses a temporal occurrence that appears in a static background, which may or may not change the world. It marks a break between the "before-event" and the "after-event". However, in our model we consider that events are punctual, i.e. their duration corresponds to a single time unit. Using the temporal relations *BEFORE* and *AFTER*, we define two relationships *BEFORE-SITUATION* and *AFTER-SITUATION* respectively corresponding to the initial situation (before the event) and the final situation (at the end of the event). Figure 6 illustrates an example of a simple event of type *Spatial_Zone_Entry_Event* identified by *ev1*. Its propositional content makes explicit the agent and the destination of the movement. Its time interval parameters are: BT: 10:00:00; ET: 10:00:00; TS: Time; DU: 1 (Duration = ET – BT + 1) and DS. In addition, its SSTP specifies that the event occurred at Laval University's campus at time 10:00:00. The event triggers a change from a "before event situation" to an "after event situation". The first situation is a localization state identified by *st1*. It has only two time parameters: ET: 09:59:59 and TS: time. Its propositional content describes the fact that the person Hedi is located outside Laval University's campus. This state is related to the event *ev1* by the *Before-Situation* relationship. The second situation is a localization state identified by *st2*. It also has only two time parameters: BT: 10:00:00 and TS: time. Its propositional content describes the fact that Hedi is located inside Laval University's campus. This state is related to the event *ev1* by the After-Situation relationship.

[4] Syntactically, a conceptual graph is a network of concept nodes linked by relation nodes. Concept nodes are represented by the notation [Concept Type: Concept instance] and relation nodes by (Relationship-Name). The concept instance can either be a value, a set of values or a CG. The formalism can be represented in either graphical or character-based notations. In the graphical notation, concepts are represented by rectangles, relations by circles and the links between concept and relation nodes by arrows. The character-based notation (or linear form) is more compact than the graphical one and uses square brackets instead of boxes and parentheses instead of circles.

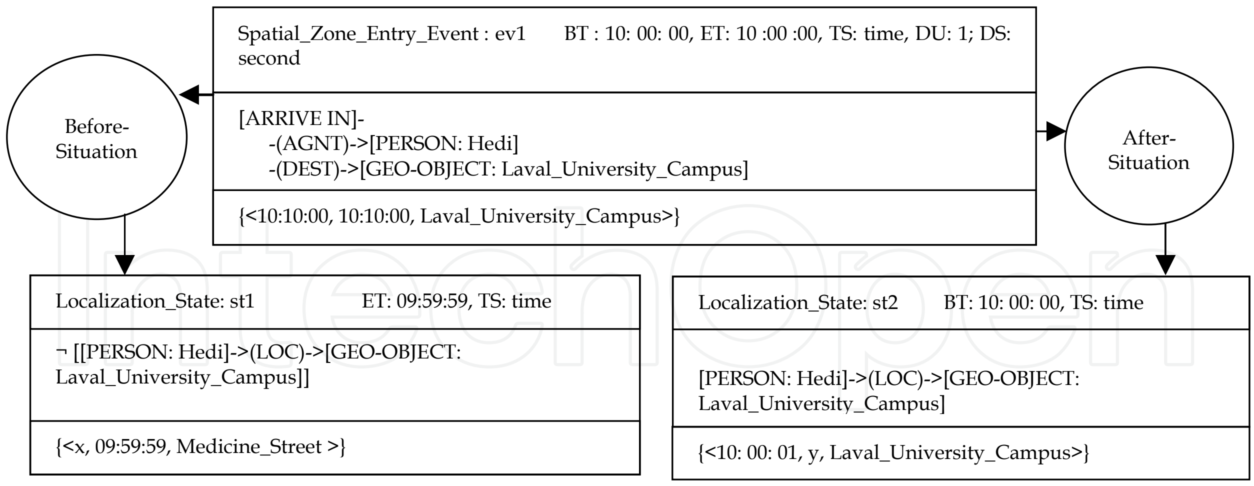


Fig. 6. An example of event

-Process: We adopt Desclés' definition of a process (Desclés, 1990). A process expresses a change initiated by an event that marks the beginning of the process, and may have an end-event and a resulting state. A process makes the universe transit from an initial situation corresponding to the "before-process" to a final situation describing the "after-process". In contrast to an event, a process has a significant duration, and we can talk about "a situation holding during the process". Using the temporal relation *DURING*, we define the relationship *DURING-SITUATION* corresponding to the intermediate situation which holds during the process. Figure 7 illustrates a process corresponding to the fact that "Hedi takes 10 minutes to go from home to Laval University Campus using his bicycle". The situation is a movement process, identified by *cp1*. It has an initial and a final situation specified similarly to those that we presented for the event. In addition, a process may be associated with a situation describing the state that holds during its progress. In the case of *cp1*, the 'during situation' is a localization state identified by *st3*. It has the same temporal parameters as the process *cp1*. Its propositional content describes the fact that the person Hedi is located neither at home nor in Laval University Campus (we don't know where exactly, that is why the SSTP of *st3* and *cp1* are empty). It is related to the process *cp1* by the During-Situation relationship.

Different relationships can be defined between states, events and processes. In Figure 4 we presented only some of these relationships (an event initiates or ends a process, and a process modifies a state). Other relationships can be defined, such as facilitation and blocking (Worboys and Hornsby, 2004).

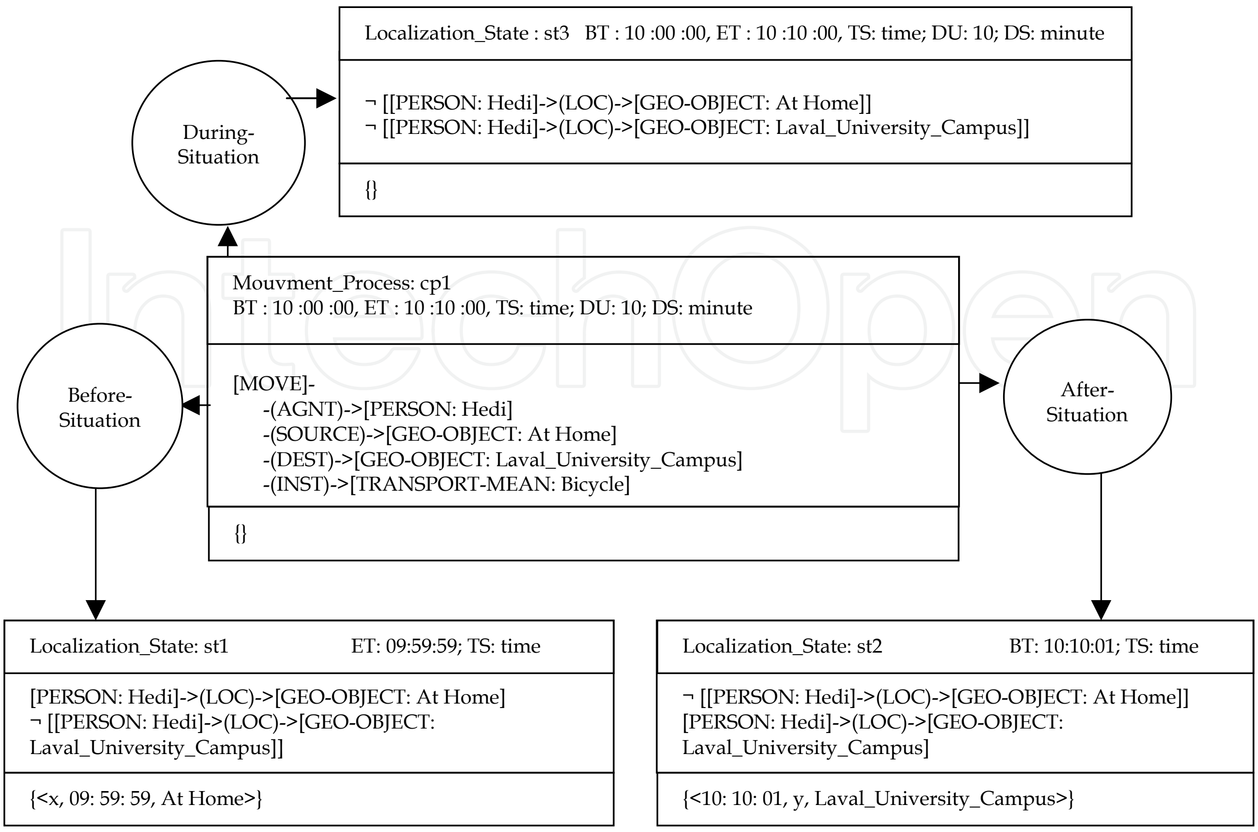


Fig. 7. The representation of a process

In this section we presented our conceptual model for representing dynamic geographic phenomena using the concept of *spatio-temporal situations*. This model represents our solution for the first requirement of our MAGS-based approach. In the following section we present our solution for the second requirement, which consists of expressing the results of the geosimulations in terms of spatio-temporal situations.

5. From Quantitative Geosimulations to Qualitative Spatio-Temporal Situations

The second requirement of our MAGS-based approach is to be able to express the results of geosimulations using the concepts of spatio-temporal situations (states, events and processes). In order to meet this requirement, we developed a data collection and transformation approach which is explained using the example of Figure 8.

Let us consider a COA composed of only one resource: agent *A*. Suppose that the agent is initially located in the geo-object *zone06*. Suppose also that we assign to this agent the task to go to *zone12* following a predefined path <*zone06*, *zone08*, *zone12*>. Finally, let us suppose that the agent is characterized by two attributes, "Location" (position) and "Tiredness-level" which are respectively initialized to "zone06" and "normal".

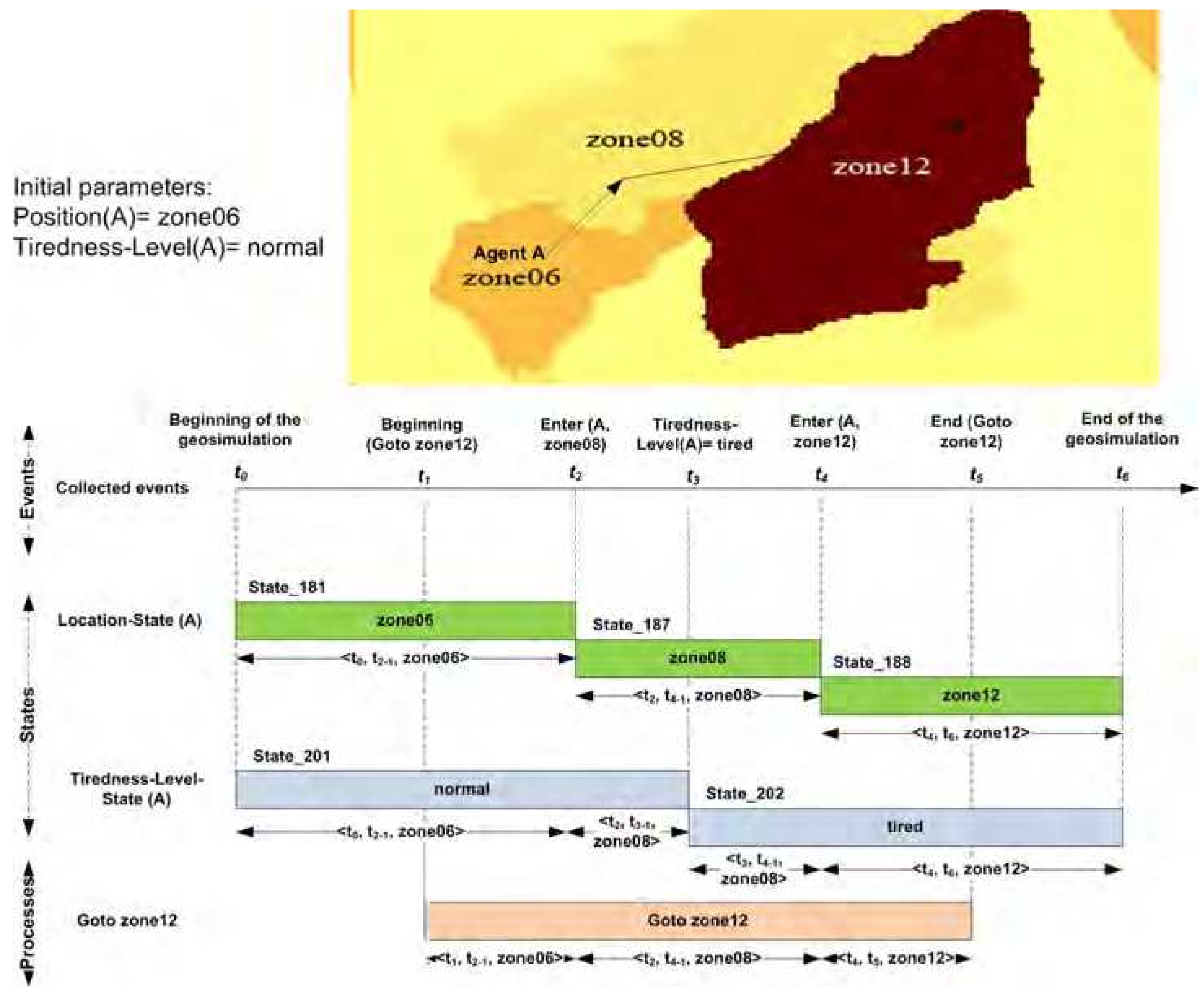


Fig. 8. An example illustrating data transformation

The key idea is that the system should collect, during the geosimulation, data describing changes of attributes of entities manipulated in the geosimulation. Therefore, the results that are initially collected during the simulation only correspond to punctual events. Based on these events, the system should deduce states and processes and identify their spatio-temporal positions. In the example illustrated in Figure 8, the initial results of the geosimulation correspond to situations describing punctual events, such as the beginning of the execution of the task *Goto zone12*, the change of the location of the agent from *zone06* to *zone08* (the event *Enter*(*A*, *zone08*)) and the change of the attribute "Tiredness-Level" of the agent *A* (the agent is tired at t_3). These events are formalized in CGs according to the model presented in Section 4. At the end of the geosimulation, algorithms are applied to identify, from these events, an explicit representation of states and processes. For example, from the punctual event describing the fact that agent *A* entered the geo-entity *zone08* at time t_2 we can identify the state *State_181* of type *Location-State* and describing the fact that agent *A* is located in *zone06* during the time interval [t_0, t_{2-1}] (Figure 8). Similarly, from the punctual event describing the fact that agent *A* is tired at t_3 we can explicitly identify the state *State_201* of type *Tiredness-level-State*: this state describes the fact that agent *A*'s tiredness level is normal during the temporal interval [t_0, t_{3-1}], and that the spatio-temporal position of this state is {<t_0, t_{2-1}, *zone06*>, <t_2, t_{3-1}, *zone08*>}. Of course, we raised the assumption that the

spatio-temporal position of a state corresponds to the spatio-temporal position of the entity described by this state during its temporal interval. Therefore, the spatio-temporal position of *State_201* corresponds to the spatio-temporal position of agent *A* during the interval [t_0, t_{3-1}], which is {<t_0, t_{2-1}, *zone06*>, <t_2, t_{3-1}, *zone08*>} (Figure 8). Processes are identified using the same principle. For example, considering the two punctual events that respectively describe the beginning and the end of execution of task *Goto zone12*, we identify an explicit representation of the process *Goto zone12* which takes place during the time interval [t_1, t_5]. Using a similar assumption that the spatio-temporal position of a process corresponds to the spatio-temporal position of the entity executing this process, we can identify that the spatio-temporal position of the process *Goto zone12* is {<t_0, t_{2-1}, *zone06*>, <t_2, t_{4-1}, *zone08*>, <t_4, t_5, *zone12*>}.
Presenting the detailed algorithms used for data transformation is beyond the scope of this chapter, for more details the interested reader can refer to (Haddad, 2009).

6. Causal Reasoning about Spatio-Temporal Situations

After applying the data transformation presented in Section 5, the results of the geosimulation are expressed in terms of spatio-temporal situations, i.e. states, events and processes with their temporal and spatio-temporal positions. Causal analysis can now be carried out. Our aim is to identify causation relationships between spatio-temporal situations. Causation is a semantic relationship that holds between two individual situation instances. One situation instance plays the role of cause while the other plays the role of effect. In the literature, a distinction is made between causation and causality (Lehmann and Gangemi, 2007). While causation refers to a causal relationship between two individual situation instances, causality refers to a causal relationship between two situation types. Therefore, reasoning about causation relies on knowledge about causality. In the literature, a causality relationship in a spatial context is based on temporal and spatial constraints. These constraints are derived from the fact that human recognition of causal relations is based upon recognition of precedence and contiguity between the cause and the effect (Kitamura et al., 1997). In this view, cause occurs before effect and both are spatially contiguous. We use the temporal causal ontology proposed by (Terenziani and Torasso, 1995) to model temporal constraints. The ontology distinguished different semantic causal relationships between temporal situations (states, events and processes) depending on their temporal intervals (i.e., the cause occurs before or at the same time as the effect and the cause ends before, after or at the same time as the effect). For example, there is a difference between causal relations in which "the presence of the cause is only momentarily required to allow the effect to begin", and causal relations in which "the continued presence of the cause is required in order to sustain the effect" (Terenziani and Torasso, 1995). In order to model the spatial constraints, we use the model proposed by (El-Geresy et al., 2002). In this regard, cause must be spatially connected to its effect in either one of two ways: indirect (distant) or direct connection. In the case of distant connection, a path must exist between the spatial positions of the cause and of the effect which allows the propagation of a certain *causing property*, such as, for example, a lake does not allow the spread of fire (El-Geresy et al., 2002). In addition, when cause and effect are not spatially co-located, cause takes a delay to reach its effect (*diffusion delays*).

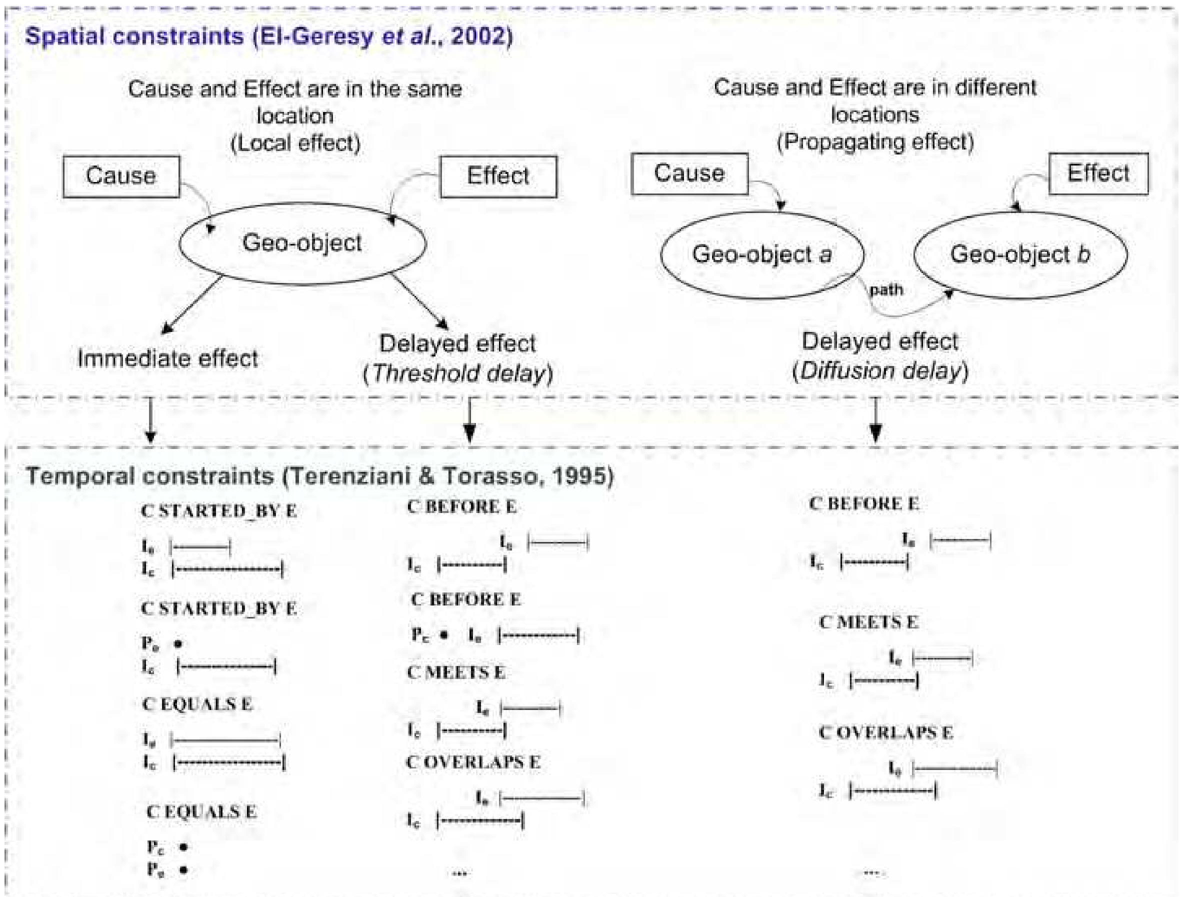


Fig. 9. Spatio-temporal causal constraints

By combining the aforementioned temporal and spatial models, it is possible to represent the spatio-temporal causal constraints illustrated in Figure 9. With respect to the spatial causal constraint, a cause may have a local or a propagating effect. On the one hand, a local effect takes place at the same spatial position as the cause situation. From a temporal perspective, a local effect can be immediate or delayed. Immediate effect starts at the same time as its cause. Delayed effect corresponds to the fact that the cause “may not be able to deliver its effect before reaching a certain level over a certain period of time, e.g. flooding will not occur before the water in the river increases beyond a certain level” (El-Geresey et al., 2002). Spatio-temporal immediate effects and threshold-delayed effects are formalized using Allen’s temporal relationships (Allen, 1983). For example, an immediate effect can be formalized by the respective following spatial and temporal constraints: Location(cause) = Location(effect) and {*Started_By* (Cause, Effect) or *Equals* (Cause, Effect)}. On the other hand, a propagating effect takes place at a different spatial position than the cause situation. Thus, we always talk about a delay corresponding to the time taken by the cause to reach its effect. Similarly, spatio-temporal diffusion delayed effects are formalized using Allen’s temporal relationships. The spatio-temporal positions (SSTP) of our spatio-temporal situations are used to verify the different spatio-temporal causal constraints between a cause and an effect.

Using these causal spatio-temporal constraints, we specify knowledge about causality thanks to the concept of *causality relation* (Figure 10). A *Causality Relation* defines a causal link between a typical cause situation (the *HasCauseSituation* relationship) and a typical effect situation (the *HasEffectSituation* relationship) and specifies the spatio-temporal constraints that characterize this link (the *Temporal Constraints* and *Spatial Constraint* concepts). Cause and effect situations are actually configurations of spatio-temporal situations (the *Situations Configuration* concept). Consisting of one or more spatio-temporal situations, a configuration describes how a set of typical spatio-temporal situations is organized in order to play the role of a typical cause or effect in a causality relation.

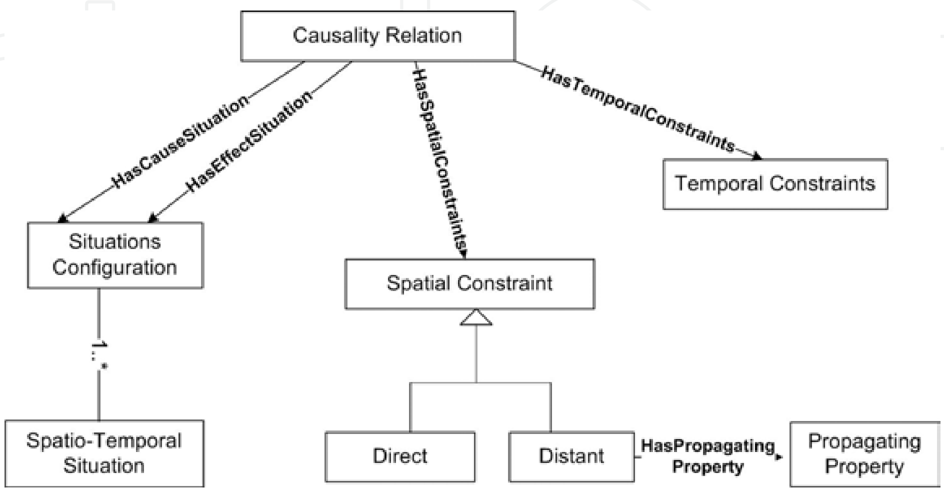


Fig. 10. Semantic of a causality relation

Causality relations are used to specify knowledge about causality and to infer causation relationships between instances of spatio-temporal situations obtained as a result of a geosimulation. Simply, we say that an individual spatio-temporal situation sts_a of type *A* is a cause of another individual spatio-temporal situation sts_b of type *B* if there is a causality relation specifying that typical situations of type *A* cause typical situations of type *B*.

In this section we covered all the requirements identified in Section 3.3 in order to implement our MAGS-based COAs' "What-if" analysis approach. In the following section we present how our approach was implemented in the center of the MAGS-COA Project.

7. The MAGS-COA Project

Our team developed the MAGS-COA System, a proof of concept of the proposed approach. The objectives of the MAGS-COA Project are 1) to illustrate the technical feasibility of the proposed approach and 2) to evaluate the relevance of the approach to support the resolution of real problems. We present the technical architecture of the system in Section 7.1. In Section 7.2 we give a general idea about how we used the system to implement scenarios in the search and rescue (SAR) domain and to qualitatively evaluate the relevance of the approach with SAR domain experts.

7.1 Architecture

The MAGS-COA system is designed to support the steps of the approach which were presented in Section 3.2. Figure 11 illustrates the system's architecture which is composed of three main modules: the experiment specification module, the geosimulation module and the evaluation module. In the followingparagraphs we give a general presentation of these modules.

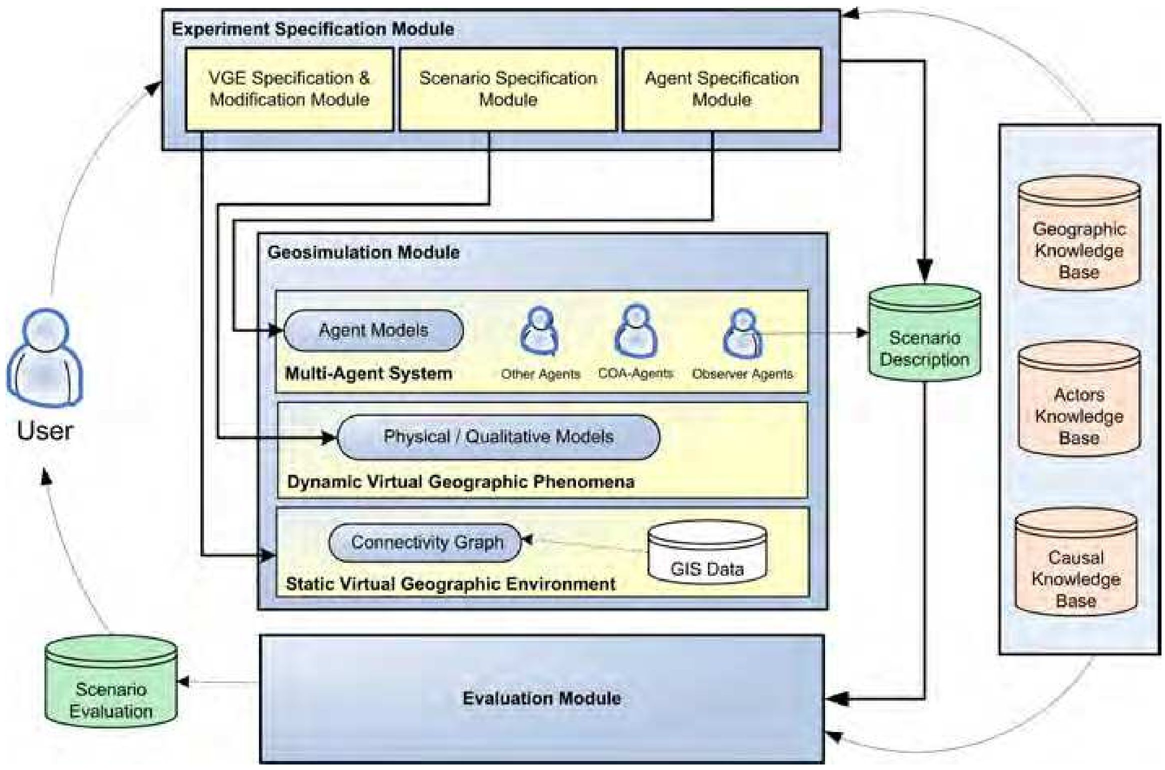


Fig. 11. The architecture of MAGS-COA

COA "What-if" Experiment specification

The first step consists in initializing the COA's "What-if" experiment. To do so, the user first selects the *VGE* (Virtual Geographic Environment) where the scenario will be executed, using the *VGE Specification and Modification Module*. This allows loading and initializing the geographic environment into the geosimulation module (Figure 11). The geographic environment is a GIS-based data model augmented with the elements presented in Section 4.1. There are different systematic ways of coupling GIS and multi-agent simulation environments (Schüle et al., 2004). In our project, we use a loose coupling, i.e. data is generated using a GIS tool and then imported into the virtual geographic environment where it can be manipulated by the agents during the simulation run. Geo-Objects (mountains, lakes, etc.) and their topological relationships are directly generated by the GIS tool. This knowledge is stored in a data structure manipulated by the simulation environment (as a connectivity graph). In addition, semantic knowledge about geographic objects is specified in a geographic knowledge base containing types of entities of the geographic environment (i.e. Geo-Objects, such as mountains and lakes, and natural processes, such as rain and snow) and their attributes.

The user then uses the *Agent Specification Module* to select the actors participating in the experiment (from a list of actors specified in the Actors knowledge base) and to locate them in the VGE. The Actors knowledge base is an application ontology containing information about types of actors, their attributes and the tasks that they are able to carry out. Tasks correspond to the activities that an actor can perform, from simple movements to complex and sophisticated activities (such as "lead an attack operation" in the military domain). Knowledge about tasks is defined using the concept of spatio-temporal situation presented in Section 4.1.

Then, the user specifies the scenario describing the COA and the assumptions (using the *Scenario Specification Module*). The COA specifies the sequence of tasks and the constraints imposed on the actors (the agents of the geosimulation) in order to achieve their mission. The assumptions are formalized as different "happenings" located in space and time (as for example, the explosion of a bridge or the beginning of wind blowing at a specific time, in a given location and in a given direction). The different types of happenings and their attributes correspond to the physical spatio-temporal processes and events specified in the geographic base knowledge. The *Agent Specification Module* and the *Scenario Specification Module* respectively allow initializing the attributes and the behaviours of the corresponding agents' models in the geosimulation module (Figure 11).

MAGS

Then, the user launches the geosimulation in the *VGE*. The actors of the COA are represented by autonomous software agents simulating the behaviours of the real actors. We use an enhanced version of the MAGS platform (Moulin et al., 2003) as a multi-agent geosimulation environment. In this platform, agents are characterized by internal states corresponding to their attributes and are equipped with perception, navigation and behavioural capabilities according to a *perception-decision-action* loop (Figure 12, left side). With respect to the perception capabilities, an agent has a perception field which enables it to perceive 1) terrain features such as elevation and slopes, 2) the geographic objects and the other agents located in the agent's range of perception, and 3) dynamic areas or volumes whose shapes change during the simulation (such us smoky or foggy areas). Regarding the navigation capabilities, MAGS agents may use two navigation modes: *Following-a-path-mode* in which agents follow specific paths such as roads or *Obstacle-avoidance-mode* in which the agents move through open spaces avoiding obstacles. Finally, in the MAGS platform, an agent is associated with a set of objectives that it tries to reach. The objectives are organized in hierarchies composed of nodes representing composite objectives and leaves representing elementary objectives associated with actions that the agent can perform (Figure 12, right side). An agent makes decision about its objectives based on several parameters, such as its internal states and the perceived features of the *VGE*. Further details about agents' capabilities in the MAGS platform can be found in (Moulin et al., 2003).

The tasks of the scenario are transformed into agents' objectives. Depending on the natural phenomena to be simulated and the available data models, happenings and their effects can be simulated either using mathematical models (such as models of flood (Herath, 2001), fire propagation (Farsite, 2008) and soil erosion (Shen et al., 2006)), qualitative simulation models or agent-based models. In the current version of MAGS-COA, these phenomena are simulated using agent-based models. However, the behaviour of an agent simulating a natural phenomenon can be defined using either qualitative models (such as the wind triangle (NASA, 2006) to calculate the effect of wind on flying objects) or mathematical physical models (such as the above mentioned fire propagation model). Details about this aspect are beyond the scope of this chapter.

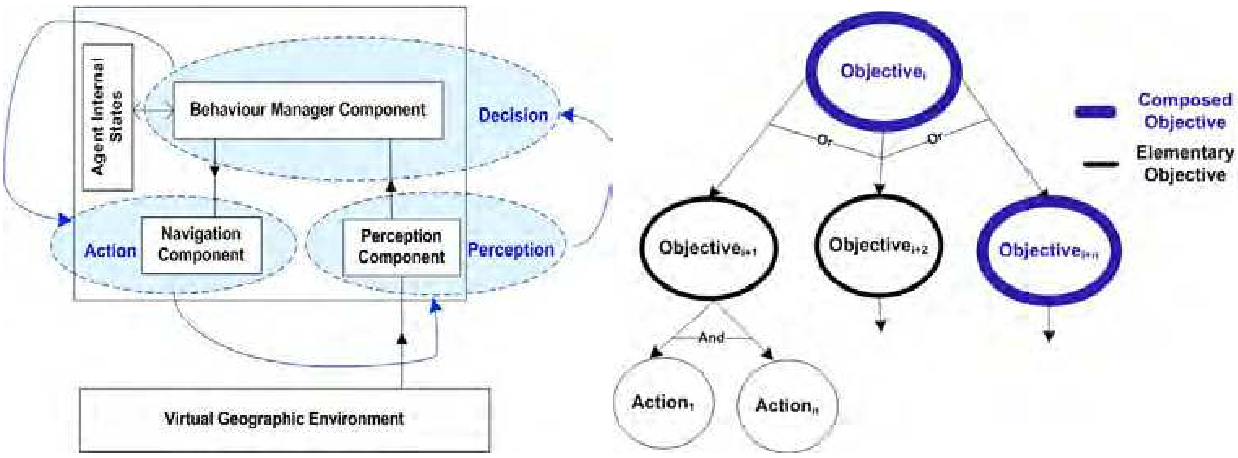


Fig. 12. Architecture of an agent (left) and agents' objectives hierarchy (right) in the MAGS platform

In Section 5 we presented a summary of our strategy to collect and transform the results of the geosimulation. Practically, we use a specific kind of agents, called *observer agents,* to collect and record information about relevant events occurring in the geosimulation virtual environment (Moulin et al., 2003). As it was explained in Section 5, observer agents collect information describing changes of values of geosimulation entities' attributes: attributes of continuant entities such as actors and geo-objects and attributes of occurrent entities such as actors' objectives and actions and computational processes simulating the physical phenomena. These collected events are formalized in our CG formalism and inserted in a log file which must be analyzed by the evaluation module.

Evaluation module

As we explained in Section 5, the evaluation module first applies the required transformations in order to create an explicit representation of the results of the geosimulation as a set of spatio-temporal situations instances. The evaluation then consists in applying causal reasoning in order to infer causation relationships among these situations instances. The evaluation process consists of: 1) establishing a temporal ordering of the initial set of spatio-temporal situations instances and 2) for every pair of these instances, verifying if they verify the constraints of a certain causality relation in the causal knowledge base (Figure 11). If these constraints hold, a new CG is created, making explicit the causal link between the individual cause and effect spatio-temporal situations.

We used the *Amine* platform (Kabbaj et al., 2006) to support reasoning about the geosimulation outputs. *Amine* is a Java Open Source platform that provides an integrated architecture to build intelligent systems. More specifically, we used the ontology and the *Prolog+CG* modules of this platform. Amine's ontology module allows building, editing and using ontologies and knowledge bases expressed in CGs. We used this module to define the knowledge bases of our project. *Prolog+CG* is an object-based and CG-based extension of the Prolog language including an interface with Java. We used *Prolog+CG* to develop the algorithms of the evaluation module.

7.2 Illustrative Scenario and Approach's Evaluation

As we mentioned in the beginning of Section 7, the second objective of the MAGS-COA Project was to evaluate the suitability of our approach as a support to real problems solving. As an example, we chose the aerial search and rescue (SAR) application domain in which "What-if" reasoning is frequently used to analyze historical events. More specifically, "What-if" analysis is used in this domain to determine why a specific COA has failed. For example, let us consider that a lost plane was performing a COA (flying plan) and that its desired objective (the mission) was to reach a specific destination at a specific time. Nevertheless, in a search and rescue context the plane was lost (it did not reach its destination) and consequently the COA failed. The main reasoning in a SAR scenario consists in raising hypotheses to infer the potential reasons that may have caused this failure. In a SAR Center, the human controller usually uses a map to study the characteristics of the terrain and to manually delimit the extent of the search area according to predefined rules (doctrine). In the case of a lost aircraft, the controller crafts certain hypotheses and attempts to validate them by confronting them to information received from various sources (information given by the pilot's relatives, weather agencies, on-site observers, etc.) and spatial constraints that he observes on the map.

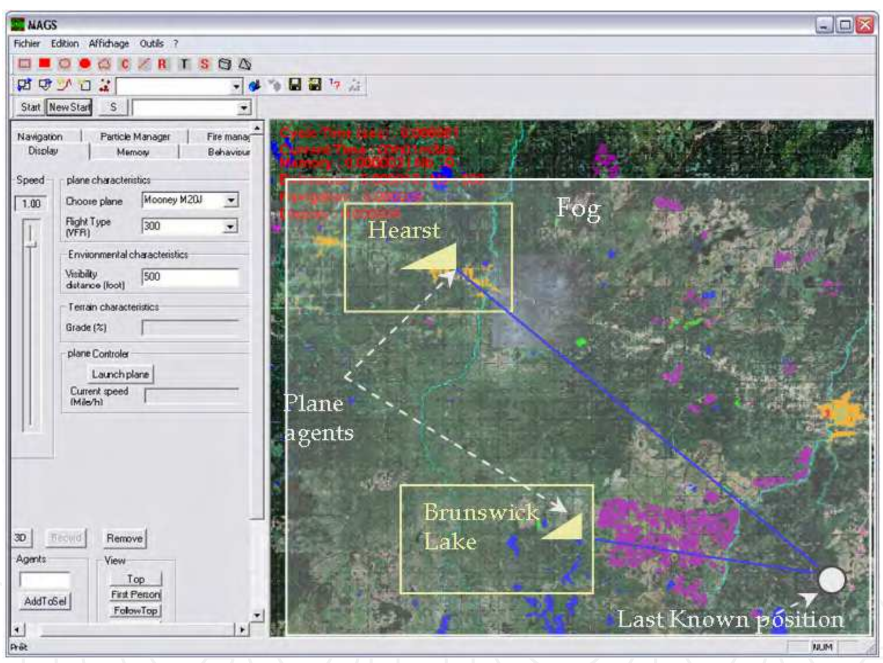


Fig. 13. Two plane agents exploring scenarios

Working with a historical real case study (the JOANIS case, occurred in Ontario, Canada), we implemented a scenario allowing a controller to make assumptions about different alternatives and to evaluate their credibility. Figure 13 illustrates the graphical interface of the implemented scenario. The system allows the controller to make assumptions about weather conditions (movement of fog patches in this case) and the decision that may have been made by the pilot (such as for example choosing an alternative landing site). In Figure 13, the controller evaluates the credibility of two alternative scenarios: because of the reduced visibility caused by fog the pilot has either: 1) selected Hearst as an alternative destination or 2) decided to look for a landing site near Brunswick Lake. For every scenario,

we simulated the movement of fog and the behaviour of the plane in a *VGE* built from real GIS data.
Figure 14 illustrates an example of scenarios evaluation returned by the system. The evaluation shows that the process *Fog_01* caused the agent *mooney_01* to execute an objective of Visual Flight Rule (*process_53*). After that, the fact that the *fuel level* reached a critical level (the punctual event *event_52*) immediately caused the plane to execute an objective of finding the nearest landing place (*process_89*). The fact that the plane found a suitable landing place (*event_67*) immediately caused it to execute an objective of emergency landing (*process_67*). The system evaluates this alternative scenario as possible because the plane successfully completed its emergency landing objective. Note that *ThresdelayedCause* and *ImmCause* are two typical causality relations defined in the causal knowledge base with their temporal and spatial constraints.

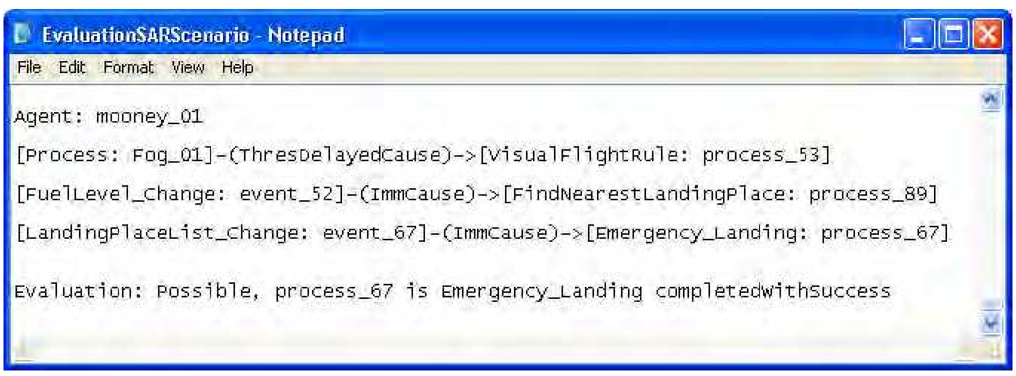


Fig. 14. An example of "What-if" scenario evaluation

We used the implemented scenario to evaluate the relevance of the approach by three SAR domain experts. The evaluation was *subjective* and *qualitative*. After a demo of the scenario, experts expressed their opinions using questionnaires and/or by direct discussions. Experts expressed positive feedback about the approach in general. Especially, they judged the approach relevant as a tool for training novice staffs and as a decision support about some precise aspects that must be considered when solving real cases. For example, experts appreciated the help given by the system to identify suitable landing sites that may have been chosen by a pilot, especially in a large scale geographic environment.
From an experimental point of view, our subjective and qualitative evaluation is not enough in order to conclude about the suitability of our approach as a support to real problem solving. Further experimentations are needed and planned to be carried out on different application domains in the future.

8. Conclusion and Future Work

In this chapter we proposed an approach that associates MAGS models with qualitative spatio-temporal reasoning techniques to support qualitative analysis in the context of dynamic geographic spaces. We studied the COAs' "What-if" analysis problem as a practical example. This multidisciplinary approach led to other interesting contributions such as the model of *spatio-temporal situations* and its application to the problem of causal reasoning in a dynamic spatial context. Besides, the MAGS-COA system shows the potential of the proposed approach as a support to real problem solving.

However, additional work is required to fully exploit the advantages of the proposed approach and to address its limits. From a computational perspective, we plan, in the near future, to evaluate the performance of the MAGS-COA system on scenarios involving a large number of agents and more complex spatio-temporal situations. From a theoretical perspective, we plan in a first step to apply our approach to support "What-if" reasoning in other domains such as fire forests and crowd control. In a second step we plan to extend our approach to other kinds of qualitative spatio-temporal reasoning and to explore how to take advantage of the concept of *qualitative spatio-temporal patterns* to analyze MAGS results. Indeed, causality relations are an example of qualitative spatio-temporal patterns, and generalizing the approach to support other kinds of qualitative spatio-temporal patterns is an interesting theoretical and practical area to be explored.

9. Acknowledgments

This research is supported by GEOIDE, the Canadian Network of Centers of Excellence in Geomatics (MUSCAMAGS Project), by Valcartier Defence R&D Canada (DRDC), Quebec, Canada (MAGS-COA Project) and by the Natural Science and Engineering Research Council of Canada (Discovery Grant Program).

10. References

Albrecht, J. (2005). A new age for geosimulation. *Transactions in GIS*, Vol. 9, No. 4, pp. 451–454

Ali, W. (2008). *2D/3D MultiAgent GeoSimulation: A Generic Method and its Application*, VDM Verlag Dr. Mueller e.K., ISBN-10: 3836472295

Ali, W.; Moulin, B.; Bédard, Y.; Proulx, M.J. & Rivest, S. (2007). Coupling Multiagent Geosimulation and Spatial OLAP for Better Geosimulation Data Analysis. *URISA Journal*, Vol. 19, No. 2, pp. 5-14

Allen, J. F. (1983). Maintaining Knowledge about temporal intervals. *Communications of the ACM*, Vol. 26, pp. 832-843

Batty, M. & Jiang B. (2000). Multi-agent Simulation: Computational Dynamics within GIS, In: *Innovation in GIS VII: Geocomputation*, Martin D. and Atkinson P. (Eds.), pp. 55–71, Taylor & Francis

Benenson, I. & Torrens, P.M. (2004). *Geosimulation: Automata-based modeling of urban phenomena*, WILEY edition, ISBN 0-470-84349-7, England

Benenson, I.; Martens, K. & Birfir, S. (2007). Agent-Based Model of Driver Parking Behavior As a Tool for Urban Parking Policy Evaluation, *Proceedings of the 10th AGILE International Conference on GISience 2007*, Aalborg University, Denmark

Blecic, I.; Cecchini, A. & Trunfio, G.A. (2008). A Software Infrastructure for Multi-agent Geosimulation Applications, In: *ICCSA 2008, Part I, LNCS 5072*, O. Gervasi et al. (Eds.), pp. 375–388, Springer-Verlag, ISBN:978-3-540-69838-8, Berlin, Heidelberg

Bossomaier, T.; Amri, S. & Thompson, J. (2007). Agent-Based Modelling of House Price Evolution, *Proceedings of the 2007 IEEE Symposium on Artificial Life (CI-ALife 2007)*, pp. 463-467, Honolulu, HI

Bouden, M.; Moulin, B. & Gosselin, P. (2008). The geosimulation of West Nile virus propagation: a multi-agent and climate sensitive tool for risk management in public health. *International Journal of Health Geographics*, Vol. 7, No. 35

Brown, D. & Xie, Y. (2006). Spatial agent-based modeling. *International Journal of Geographical Information Science*, Vol. 20, No. 9, pp. 941–943

Casati, R., Smith, B. and Varzi, A.C. (1998). Ontological Tools for Geographic Representation, In: *Formal Ontology in Information Systems*, N. Guarino (Ed.), pp. 77 – 85, IOS Press, Amsterdam

Cohn, A. & Hazarika, S. (2001) Qualitative Spatial Representation and Reasoning: An Overview. *Fundamental Informaticae*, Vol. 46, No. 1-2, pp. 1-29

Desclés, J.-P. (1990). *Langages applicatifs, langues naturelles et cognition*, Hermès, ISBN: 2-86601-227-5, Paris

Desclés, J.-P. (2005). Reasoning and Aspectual-Temporal Calculus, In: *Logic, Thought & Action*, Vanderveken, D. (Ed.), pp. 217–244, Kluwer Academic Publishers, Springer

El-Geresy, B.; Abdelmoty, A. & Jones, C. (2002). Spatio-Temproal Geographic Infromation Systems: A causal Perspective, In: *ADBIS 2002, LNCA 2435*, Manolopoulos, Y. and Navrat, P. (Eds.), pp. 191–203, Springer, ISBN: 978-3-540-44138-0, Berlin

FARSITE simulator (2008). http://www.firemodels.org/content/view/112/143/, last update: Sunday, 17 February 2008, Last access: Wednesday, 27 February 2008.

Ferrario, R. (2001). Counterfactual Reasoning, In: *Modeling and Using Context, Proceedings of the Third International and Interdisciplinary Conference, CONTEXT 2001, LNAI 2116,* Akman et al. (Eds.), pp. 170-183, Springer, Berlin Heidelberg

Fonseca, F.; Egenhofer, M.; Agouris, P. & Câmara, G. (2002). Using Ontologies for Integrated Geographic Information Systems. *Transactions in GIS*, Vol. 6, No. 3, pp. 231-257

Forbus, K.D. (1981). A Study of Qualitative and Geometric Knowledge in Reasoning about Motion. Massachusetts Institute of Technology, Arctificial Intelligence Laboratory, AI-TR-615, 1981

Fournier, S. (2005). Intégration de la dimension spatiale au sein d'un modèle multi-agents à base de rôles pour la simulation: Application à la navigation maritime. PhD thesis, Université de Rennes 1, France

Frank, A.U.; Bittner, S. & Raubal, M. (2001). Spatial and Cognitive Simulation with Multi-agent Systems, In: *Spatial information Theory: Foundations for Geographic Information Science, LNCS 2205*, D. Montello (Ed.), p. 124-139, Springer

Furtado, E.; Furtado, V. & Vasconcelos, E. (2007). A Conceptual Framework for the Design and Evaluation of Affective Usability in Educational Geosimulation Systems, In: *INTERACT 2007, LNCS 4662, Part I*, Baranauskas et al. (Eds.), pp. 497–510, Springer

Gaglio, C.M. (2004). The Role of Mental Simulations and Counterfactual Thinking in the Opportunity Identification Process. *Entrepreneurship Theory and Practice*, Vol. 28, No. 6, pp. 533-552

Georgeff, M.; David, M. & Anand, R. (1993). Events and processes in situation semantics, In *Situation Theory and Its Applications*, P. Aczel; D. Israel; Y. Katagiri & S. Peters (Eds.), CA: Stanford University Press, Stanford

Gimblett, R. (2002). *Integrating geographic information systems and agent-based modeling techniques for simulating social and ecological processes*, Oxford University Press, New York

Grenon, P. & Smith, B. (2004). SNAP and SPAN: Towards dynamic spatial ontology. *Spatial Cognition and Computation*, Vol. 4, No. 1, pp. 69-103

Haddad, H. (2009). Une approche pour supporter l'analyse qualitative des suites d'actions dans un environnement géographique virtuel et dynamique, l'analyse « What-if » comme exemple. PhD Thesis, Laval University, Canada, 2009

Haddad, H. and Moulin, B. (2007). Using Cognitive Archetypes and Conceptual Graphs to Model Dynamic Phenomena in Spatial Environments, In: *ICCS 2007, LNAI 4604*, U. Priss; S. Polovina & R. Hill (Eds.), pp. 69–82, Springer-Verlag, Berlin Heidelberg

Hagen-Zanker, A. & Martens, P. (2008). Map Comparison Methods for Comprehensive Assessment of Geosimulation Models, In: *LNCS 5072*, pp. 194-209, Springer, ISBN 978-3-540-69838-8

Helbig, H. (2006). Semantic Characterization of Situations, In: *Knowledge Representation and the Semantics of Natural Language (Cognitive technologies)*, pp. 85–111, Springer-Verlag, ISBN: 978-3-540-24461-5

Hensman, S. & Dunnion, J. (2004). Using Linguistic Resources to Construct Conceptual Graph Representation of Texts. *Speech and Dialogue* , vol. 3206, pp. 81-88

Herath, S. (2001). Geographical Information Systems in Disaster Reduction. *Information Technology For Disaster Management*, No.1, pp. 25-31

Kabbaj, A. (2006). Development of Intelligent Systems and Multi-Agents Systems with Amine Platform, In: *ICCS'06, LNAI 4068*, Springer, pp. 286-299, ISBN: 3-540-35893-5, Berlin

Kahneman, D. & Tversky, A. (1982). The simulation heuristic, In: *Judgement under uncertainty: Heuristics and biases*, D. Kahneman, P. Slovic and Tversky (Eds.). Cmabridge university Press, New York

Kettani, D. & Moulin, B. (1999). A Spatial Model Based on the Notions of Spatial Conceptual Map and of Object's Influence Areas, In: *Spatial Information Theory, Cognitive and Computational Foundations of GIS, LNCS 1661*, C. Freska, D. M. Mark (Eds.), pp. 401-415, Springer Verlag

Kitamura, Y.; Ikeda, M. & Mizoguchi, R. (1997). A Causal Time Ontology for Qualitative Reasoning, *Proceedings of the Fifteenth International Joint Conference on Artificial Intelligence IJCAI-97*, pp. 501-506, Maurgan Kaufmann Publishers

Lebow, R.N. (2007). Counterfactual Thought Experiments: A Necessary Teaching Tool. *History Teacher*, Vol. 40, No. 2, pp. 153-176

Lehmann, J., Gangemi, A. (2007). An ontology of physical causation as a basis for assessing causation in fact and attributing legal responsibility. *Artificial Intelligence and Law*, Vol. 15, No. 3, pp. 301–321

Lindström, S. (1991). Critical Study: Jon Barwise and John Perry, Situations and Attitudes. *NoFBs*, Vol. XXV, No. 5, pp. 743-770

Mark, D.; Smith, B. & Tversky, B. (1999). Ontology and geographic objects: An empirical study of cognitive categorization, In: *Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science, LNCS 1661*, Freksa, C. & Mark, D. (Eds.), pp. 283-298, Springer

Moulin, B. (1997). Temporal contexts for discourse representation: An extension of the conceptual graph approach. *Applied Intelligence*, Vol. 7, pp. 227-225

Moulin, B.; Chaker, W.; Perron, J.; Pelletier, P.; Hogan, J. & Gbei, E. (2003). MAGS Project: Multi-Agent Geosimulation and Crowd Simulation, In: *Spatial Information Theory, LNCS 2825*, Springer, pp. 151-168, ISBN: 978-3-540-20148-9, Berlin

NASA (2006). Guided Tours to the Beginner's Guide to Aeronautics. http://www.grc.nasa.gov/WWW/K-12/airplane/move.html, Last update: Mar 14 2006, Last access: Wednesday, 27 February 2008

Paris, S.; Mekni, M. & Moulin, B. (2009). Informed virtual geographic environments: an accurate topological approach, *Proceedings of the International Conference on Advanced GIS & Web Services (GEOWS),* IEEE Computer Society Press

Phan, D. & Amblard, F. (2007). *Agent-based modelling and simulation in the social and human sciences*, Oxford: The Bardwell Press, ISBN-10: 1905622015

Renz, J. (2002). *Qualitative Spatial Reasoning with Topological Information*, Springer, LNCS 2293, ISBN: 978-3-540-43346-0

Rodrigues, A. & Raper, J. (1999). Defining Spatial Agents, In: *Spatial Multimedia and Virtual Reality, Research Monographs Series,* J. Raper & A. Câmara (Eds.), pp. 111-129, Taylor & Francis, London, UK

Rothkegel, R.; Wender, K. & Schumacher, S. (1998). Judging spatial relations from memory, In: *Spatial Cognition – An interdisciplinary approach to representation and processing of spatial knowledge*, C. Freksa, C. Habel & K. F. Wender (Eds.), pp. 79-105, Springer

Schüle, M.; Herrler, R. & Klugl, F. (2004). Coupling GIS and Multi-agent Simulation – Towards Infrastructure for Realistic Simulation, In: *MATES 2004, LNAI 3187*, G. Lindemann et al. (Eds.), pp. 228–242, Springer

Shen, D.Y.; Takara, K.; Tachikawa, Y. & Liu, Y.L. (2006). 3D simulation of soft geo-objects. *International Journal of Geographical Information Science*, Vol. 20, No. 3, pp. 261-271

Silva, V.; Plazanet, C.; Carneiro, C. & Golay, F. (2008). 3D LIDAR Data Application for Urban Morphogenesis Multi-agent Vector Based Geosimulation, In: *ICCSA 2008, Part I, LNCS 5072*, O. Gervasi et al. (Eds.), pp. 179–193, Springer

Smith, B. (1994). Fiat Objects. In: *Parts and Wholes: conceptual Part-Whole Relations and Formal Mereology*, N. Guarino, L. Vieu & S. Pribbenow (Eds.), pp. 15–23, European Coordinating Committee for Artificial Intelligence, Amsterdam

Sowa, J.F. (1984). *Conceptual Structures: Information Processing in Mind and Machine*, Adison-Wesley, ISBN: 0201144727 Massachusetts

Terenziani, P. & Torasso, P. (1995). Time, Action-types, and Causation: An Integrated Analysis. *Computational Intelligence*, Vol. 11, No 3, pp. 529–552

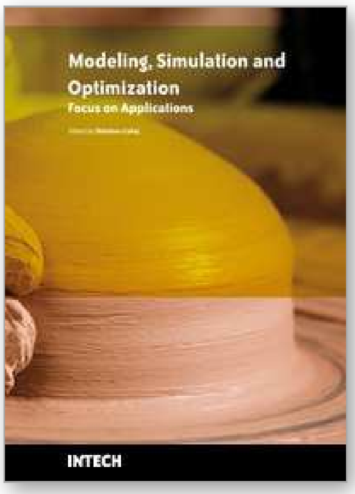
Torrens, P.M. (2008). Geosimulation will infiltrate mainstream modeling and geoprocessing on the Web, In: *Signtific: The Future of Science and Technology,* Pang, Alex Soojung-Kim (Ed.), Palo Alto: Institute for the Future

Trickett, S. & Trafton, J. G. (2007). “What if”: The Use of Conceptual Simulations in Scientific Reasoning. *Cognitive Science*, Vol. 31, pp. 843– 875

Tversky, B. (2005). Visuospatial reasoning, In: *The Cambridge Handbook of Thinking and Reasoning*, K. Holyoak & R. Morrison (Eds.), Cambridge University Press

Winchester, H. (2000). Qualitative research and its place in human geography, In: Qualitative Research Methods in Human Geography, Hay, I. (Ed.), pp. 1-21, Oxford University Press, Victoria, Austria

Worboys, M.F. & Hornsby, K. (2004). From objects to events: GEM, the geospatial event model, In: *the 3d International Conference on GIScience, LNCS 3234*, pp. 327–344, Springer



Modeling Simulation and Optimization - Focus on Applications
Edited by Shkelzen Cakaj

ISBN 978-953-307-055-1
Hard cover, 312 pages
Publisher InTech
Published online 01, March, 2010
Published in print edition March, 2010

The book presents a collection of chapters dealing with a wide selection of topics concerning different applications of modeling. It includes modeling, simulation and optimization applications in the areas of medical care systems, genetics, business, ethics and linguistics, applying very sophisticated methods. Algorithms, 3-D modeling, virtual reality, multi objective optimization, finite element methods, multi agent model simulation, system dynamics simulation, hierarchical Petri Net model and two level formalism modeling are tools and methods employed in these papers.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821