

EMERGING DECISION SUPPORT SYSTEMS FOR GEOGRAPHICAL INFORMATION SYSTEMS

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Abstract

Geographical Information Systems are widely used today and within the next significative evolution concerning their use for territorial management but also for economic and politics

purposes. They can be used as the basis of decision support systems where a great amount of data (geographical data but also their semantic) must be connected. For a specific problem, we must deal with the interaction of the concerned data and often some additional dynamical aspects must be considered (like in traffic management). We place our studies within the complex systems theory and we propose to review some self-organization processes well-suited for our purpose. We propose an automata-based model which can produce adaptive solutions for decision support system. The outputs of the decision support system produces feedbacks on the GIS itself by the need of updating. The paper will show how we manage also this step into an integrated conceptual approach which finds its roots in complexity and dynamic combinatorics sciences.

Keywords: Complex systems, Decision support system, Agent-based modeling, Geographical Information Systems.

1. Introduction

The current world is nowadays deeply assisted by new technologies. Huge data bases and high performance computing allow to develop efficient tools for management. Satellites and information technology allow both to obtain accurate representation of the world and to develop world-wide communication networks. Today, everyone needs to be informed of events everywhere in the world, the information dynamical fluxes has increased in an impressive way since the last decade. New challenges are proposed about geopolitics and world-wide economy. All these news technologies and these new challenges make the geographic information systems, the supports of the

major decision support systems for the future world, but we need to be able to manage them relatively to the complexity of the current world.

2. A Multi-Scale Modeling for Decision Making and Updating within GIS

Our purpose is to use GIS to build efficient decision support systems as we will explain in the following. These decision support systems (DSS) have the goal to give some new development for urban area for exemple, for road networks or for economic or industrial areas. In this way, the DSS which we project to implement over GIS will contribute to update the real world by all the realization of the development proposed by this DSS. From this reality updating, we will have to update in return the GIS which are supposed to represent this reality. And by the updating with the reality, the forecoming DSS to implement will have to change. This feedback processus have to manage 2 time scales. The first is described inside the simulation and the DSS and is able to represent the evolving real world. The second scale concerns the reality updating and GIS updating for which the time step if many times greater that the previous time.

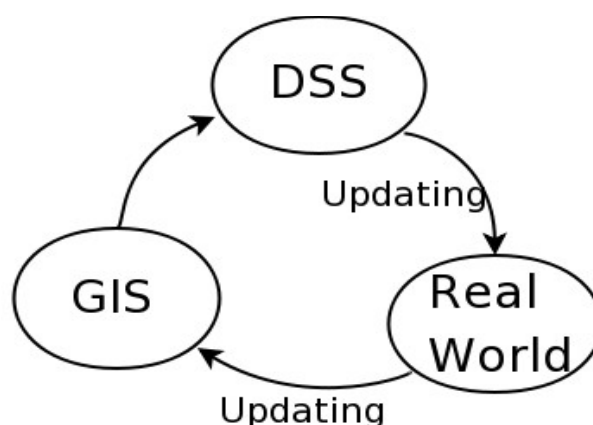


Figure 1: Decision support system and updating

3. A Conceptual Evolution of GIS Within Complexity

Our purpose is to locate with accuracy the complexity concerning GIS. A general formalism to describe a GIS is proposed in [6] and is based on a feature-based approach, where features are the fundamental concepts for the representation of geographical phenomena.

A Geographical Information System (GIS) is a computer-based tool using a Geographic Data Base (GDB) with applicative operators which allow getting, stocking, verifying, manipulating, analyzing and representing the spatial data of the GDB. The formalism considered to represent the GIS is composed of a quadruplet

$$(V, D, R, C)$$

where

- V is the set of classes used in the GDB. Each class gathers features which have common characteristics;
- D is the definition domain of the variables of V. It is the set of the objects of one GDB instance;
- R is the set of the relations that connect the elements of the GDB, corresponding to a connection graph. In [kad05], three kinds of relations are proposed, *compositions* relations, *dependence* relations and *topological* relations;
- C is the set of constraints defined between the variables of V and/or between values of V. In [6], two kinds of constraints are proposed, *structural* constraints and *non structural* constraints.

This quadruplet corresponds to the GDB modelisation to prepare it to be used with different kinds of applications which can use the support of the connection graph to build some kinds of interactive networks generated by these applications.

All these structured information which define a GIS introduce a great number of static dependence but each layer can be generally understood alone or some parts of each layer can be isolated to better understand the dependence between involved objects. Generally the applicative operators can be computed on each of these parts. In that way, we can consider classical GIS as complicated systems in the terminology proposed by Le Moigne [11]. We can consider that the Geographical Data Base in association with the previous applicative operators which constitute the GIS, is a closed system.

Today, the complexity of the world needs to use or to add additional functionalities on GIS. Geographical information deals also with human-landscape interactions. The simulation of social aspects and of ecological processes seems to be more and more linked to the better understanding of the geographical data and its evolution inside its all social, geopolitical and ecological environment. To integrate these new aspects, we have to manage some complex processes like some energetic fluxes that cross the standard GIS (see figure 2).

These complex fluxes transform the standard GIS in an open system, which confer to some properties linked to complexity. Self-organization and multi-scale organizations can emerge from these complex processes. The expected evolutions of GIS can be

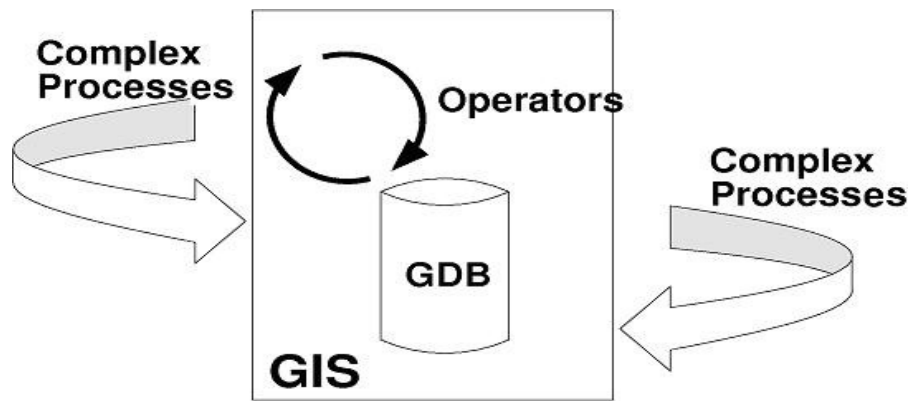


Figure 2: GIS under complex processes is an open system

considered as the transition which will transform the standard GIS into complex GIS.

4. Emergent Computation for GIS

In this section, we discuss about emergent computations which can be of interest for GIS.

4.1 Schelling's segregation model

Thomas Schelling contributed to enhance the understanding of conflict and cooperation about social institutions. He proposes a simple model of spatial segregation which can lead to self-organized phenomena. This model illustrates how spatial organizations can emerge from local rules, concerning the spatial distribution of people which belong to different classes. In this model, people can move depending on their own satisfaction to have neighbours of their own class. Based on this model, a city can be highly segregated even if people have only a mild preference for living among people similar to them.

In this model, each person is an agent placed on a 2D grid (in his original presentation, a chessboard was used by Thomas Schelling). Each case can be considered like a house where the

agent lives. Each agent cares about the class of his immediate neighbours who are the occupants of the abutting squares of the chessboard. Each agent has a maximum of eight possible neighbour, the exact number depending on the agent's position on the chessboard (straight edge, corner, or interior). Each agent has a "happiness rule" determining whether he is happy or not at his current house location. If unhappy, he either seeks an open square where his happiness rule can be satisfied or he exits the city .

- An agent with only one neighbour will try to move if the neighbour is of a different class than his own;
- An agent with two neighbours will try to move unless at least one neighbour is of the same class as his own;
- An agent with from three to five neighbours will try to move unless two neighbours are of the same class as his own;
- An agent with from six to eight neighbours will try to move unless at least three neighbours are of the same class as his own.

The exact degree of segregation that emerges in the city depends strongly on the specification of the agents' happiness rules. It is noticeable that, under some rule specifications, Schelling's city can transit from a highly integrated state to a highly segregated state in response to a small local disturbance. We can observe some bifurcation phenomena which lead to chain reactions of displacements.

4.2 Ant-based systems

Another method for self-organized system computation is based on a bio-inspired method from social insects colony and especially

ants. The basic ant system algorithm describe and explain how it can be used to transport optimization, and especially for the traveler salesman problem.

P. Grassé proposes the concept of stigmergy when he studies the termites building activity (pillars, arks for nest building for example). It is the result of a sequence of stimuli-reply process. The insects perceive a previous state of a building. This perception makes them contribute to this building and so by this way, they will stimulate themselves other insects.

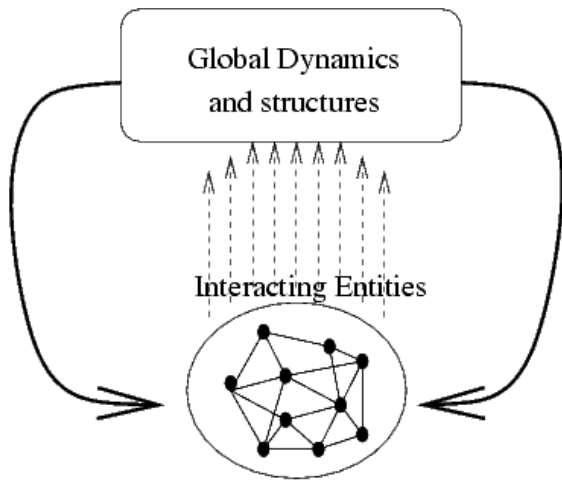
The ant foraging is a nice example of natural self-organization based on stigmergy. J.-L. Deneubourg has built a practical experiment to study this phenomenon. In this experiment, some artificial multi-paths bridges join a ant nest to a food source. The ants go out their nest and they find the optimal way from nest to food source in a collective way by the usage of pheromones. As soon as some ant finds some food, it comes back through the same path to its nest and deposits some pheromone on the path to incite other ants to discover this winner path.

5. A model for Cooperative-Competition Economic Management of Services over Urban GIS

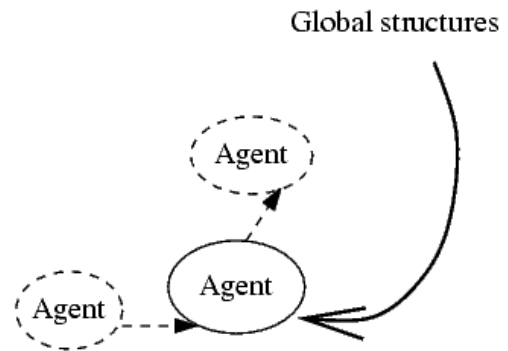
Our purpose is to explain in this section, how we can use agent-based programming to simulate complex systems and how genetic automata-based description can give powerful operators for complexity.

5.1 Multi-scale description of complex systems modeling

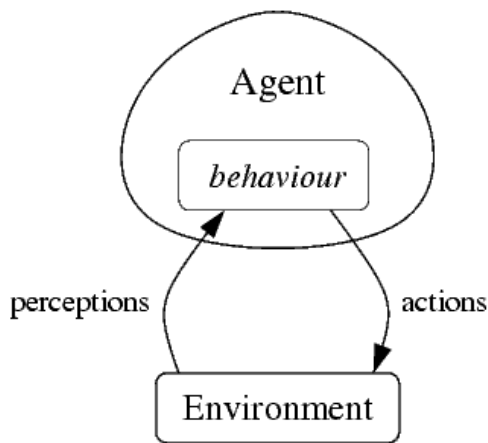
Complex systems are usually presented as some systems of



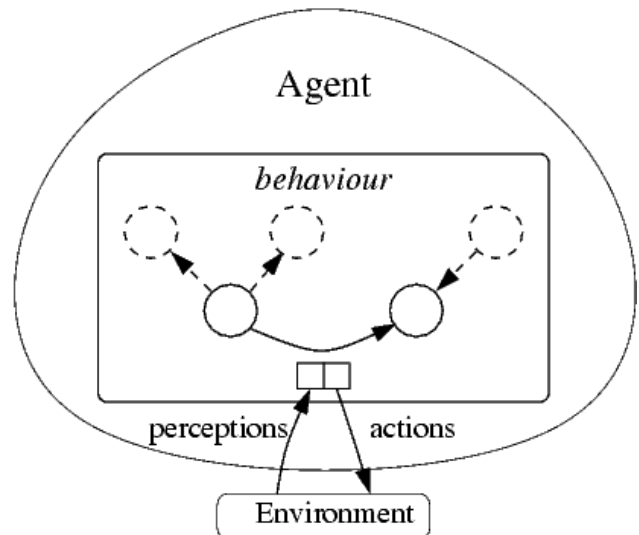
(a) Global complex system



(b) Interacting entities network



(c) Agent-based model for entity



(d) automata-based model for agent behaviour

Figure 3: Multi-scale description of complex system

interacting entities which can be represented as a kind of networks, as we see in part (a) of Figure 3. From these interacting entities, some emergent processes happen and will consist in constituting some kind of organisations. These organisations act on their constitutive entities by the way that they are able to structure the interacting network. This kind of phenomenon is usually called feed-back process and has been initially introduced in the domain of Cybernetics. Emergent process and feed-back of the system over its entities are respectively schematised using dotted line arrows

and large around arrows in the part (a) of Figure 3.

To represent such conceptual functioning, we can use agent-based programming which allows, as we will see, to represent interactions between entities as communication processes (see part (b) of Figure 3 which zoom up a part of the interaction network, where on each node representing an entity, we place an agent). In this figure, we can see now the edge of the graph as some kind of interaction and especially communications.

In part (c) of Figure 3, we represent a situation quite similar to the part (b) but with another point of view. In this new vision, we choose to centre the description relatively to the main agent of part (b). In part (c), the description is made from the vision of the agent. To better understanding, we will now develop the next paragraph which will explain what the agent is.

5.2 Automata-based computation

On part (d) of figure 3, we have made a zoom on the considered agent behavior. We propose in this figure, to use a model based on states and on transitions systems which may or not allow for the states changes corresponding to some behavior rules. This description, states and transitions, will lead us to represent the agent behavior with a finite state automata. More precisely, we propose to use an efficient data structure called automata with multiplicities [8,9] where each transition is labeled with a couple of values. The first value is from an entry alphabet whose elements correspond to agent perception. The second value is from a set of outputs, the set is a semiring. This algebraic structure allows to represent the agent behavior using matrix formulation. Semiring

are efficient structures allowing to define powerful operators . In [7], we have proposed to defined genetic operators over these automata, allowing to describe some adaptive behaviors.

5.3 Common Equipment Allocation Based on Ant-System

As originally described in [4], ant systems can be extended by colored ant systems and be used to automatically compute an emergent distribution of dynamic communication graph nodes insides clusters of same colored nodes. In the same cluster, we try to aggregate graph nodes which communicate a lot and put them in the same cluster means to allocate these nodes in the same machine associated to the color. With the hypothesis that the communication cost inside the same machine is low comparatively to the communication cost between different machines, the goal of the clustering is to reduce the whole communication cost.

The principle is to manage ant casts which are identified by their associated color. An ant of color c will drop pheromone of color c and will be attracted by the pheromone of color c and repulse by the pheromone of all the other colors different from c .

In practical applications [4], we can represent the clustering obtained after some iteration over graphs evolving dynamically (edges and nodes can appear or disappear at each moment).

So we propose a direct application of this algorithm to services repartition over a graph which can be a simplified representation of spatially connected elements inside a GIS. In this way, we can compute self-organizations for many kinds of services, like school area repartition, domestic hydraulic distribution, telecom and

computer networks equipment placement over urban GIS

5.4 Multi-Participant Strategies for common equipment Allocation

Our purpose is now to study how many societies must share the development of these common equipments. Do they have to cooperate or compete to find the most efficient way to work? We propose a model based on the prisoner dilemma [1]. This model come from game theory and can be used in spatial computation. We can generate adaptive strategies to use by each participant trying to obtain the maximum of profit. The figure 4 is a example of two-states adapative strategy based on probabilistic genetic automaton.

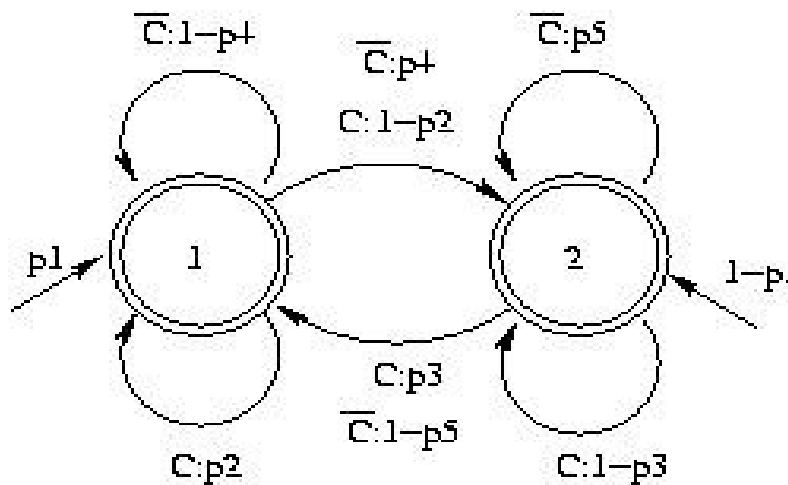


Figure 4: two-states adaptive strategy based on probabilistic genetic automaton

5.5 A Global Decison Support System by Complex Coupling of Effective Models

In the figure 5, we present a schematic view of the whole process which must link evolutive strategies to each emergent computation managed by each company for the common equipment distribution. The adaptive strategies will act on the complex system. So the

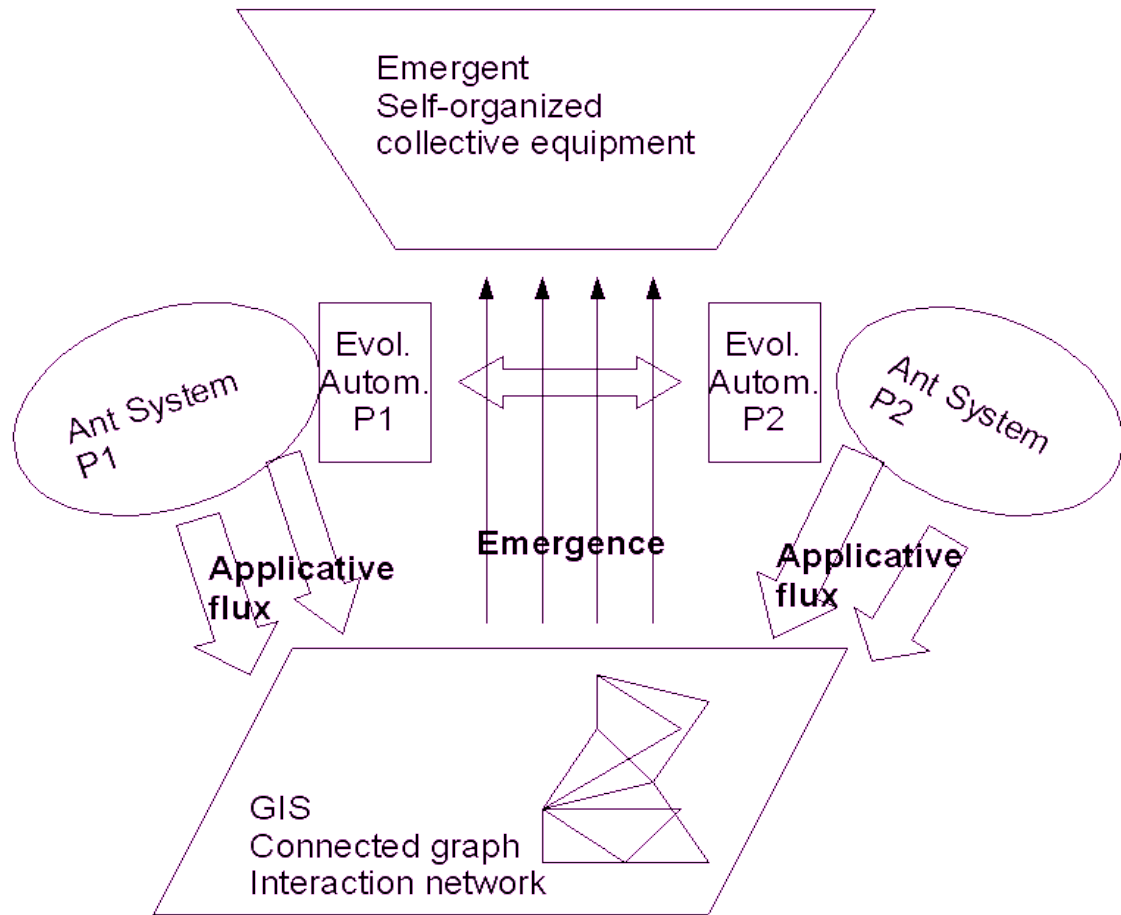


Figure 5: coupling negotiative evolutive strategies with emergent computation of common equipment distribution

complexity of the system is the result of the action of these adaptive strategies on the whole decision making. The resolution based on the ant system is perturbed by these adaptive strategies which act on it like energetic fluxes. New reorganizations and completely different solutions can appear because of these energetic fluxes. This whole system is the basis of a global environment decision support system.

6. Conclusion

This paper presents the benefit of complex system modeling for geographic information systems. The availability of a great huge of data and the accurate representation of them through computer systems, which allow to manipulate them in efficient way, allow the

geographers to develop innovative studies about spatial-temporal phenomena. The connection between GIS and agent-based modeling to manage complex systems allows today to modelize and simulate emergent organizations over interacting components. Multi-scale modelization become available and non linearity can be managed within dynamical systems implementation. The paper aims to applied a general process of complex system modeling for computing emergent decision support system. With respect to complex system modeling, we explain how we can make interact in non-linear coupling two models based on ant systems for urban services distribution and genetic automata for cooperation-competition modeling. These two models interact themselves and on the GIS which is their context of applications. They also interact in non-linear way with the self-organization computation which results of the whole processes.

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