Formation MAPS
Atelier 4 : Mobilité

MAS Simulation of a "Bush Taxi" Transportation Service

Summary of a project carried out during the MAPS training course

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1. Context

The human and social sciences have always sought to improve their tools and resources in order to spread their knowledge. The most recent of these tools, Multi-Agent Systems (MAS), also known as Agent-Based Models (ABM), is a remarkable means of formalization and visualization of spatial processes. Multi-Agent Systems have already proved to be extremely useful modeling tools in various disciplines such as epidemiology, biology, and ecology, but also economics and geography (Amblard F. 2006). Today's research and methods aiming to deal with spatial problems are more and more treated within the paradigm and theories of complex systems. Indeed, one of the advantages of multi-agent systems, in the domain of human and social sciences, is their ability to accurately represent the underlying systems in the simplest way possible, while at the same time successfully integrating complexity in each of the scales considered (Daudé E. 2003). The main problem, when using this approach, is to design, in accordance with Occam's Razor, simple operating rules and strategies for the agents, which are carefully chosen to respond to a clearly identified problem. Given the components and parameters of the system, this tool allows us to observe and understand the comprehensive self-organized behavior, including the effects of structuring, transition, emergence, etc. (M. Vidal J. 2007).

Today's society is increasingly mobile and people's daily mobility is determined by processes linked to their behavior, the infrastructure, and their environment (roads, etc.), but also by the services available to them (busses, taxis, etc.) (Marilleau N. et *al.* 2005). Therefore, their movements are strongly influenced by the environment which surrounds them. Working on a variety of themes which are all relevant to the same problem, mobility, our group has brought together several young researchers for whom the MAPS training course fulfills the need for training in the domain of the science of complexity, in the realms of both methodological skills and practical multi-agent modeling.

2. Problem

Outlining a common problem and setting up an efficient teamwork was difficult given that we each had different research themes, but we were able to define a problem from which we could all learn something, and succeeded in working together productively. This problem is that of the development of a non-regulated passenger transportation service in rural Africa ("bush cab"). The context of such a transportation service is usually characterized by a dispersion of demand in time and space, the weak or non-existent solvency of demand, the absence or weakness of regulation authorities, etc…

So, we asked ourselves several questions:

- How will a transportation service in an unregulated, unmanaged context structure itself (coverage, frequency of stops, regularity)?
- Under which displacement principles will this structuring be executed? According to which type of optimization? And with what consequences?
- Will supply and demand adapt to one-another? According to what rules?
- How effective are the provided services in opening up a territory, and how do we measure this?
- How does the transportation service influence the spatial structures of the territory?

3. Presentation of the model

To deal with these questions, we have modeled the movement of two types of mobile agents: villagers who travel to the most appealing market by using the other type of agent: taxis. The virtual space of the simulation consists of stops where taxis can pick up villagers going to the markets. The stops are situated at intersections of roads to serve as points of contact between the taxis and the villagers. They correspond to the vertices of a complete non-planar graph on which the vehicles move, with or without customers, in an isotropic but non-continuous space. Applying Occam's Razor, each type of agent reacts to its environment in accordance following relatively simple rules.

The villagers are randomly placed in the territory at the beginning of each day in equal numbers, and decide which market they would like to go to. If it is too far away, they move toward a stop to take a taxi, which will take them to the market. Once they arrive at their destination, the villagers disappear from the model. With regards to the passage of time, one 'day' is defined by a number of iterations, which can be adjusted by the administrator. At the end of each 'day,' the villagers are regenerated. The taxis pick up customers and choose an appropriate route to complete their round. One round corresponds to the movement of a taxi from picking up one or several passengers all the way to the market.

The two types of mobile agents move throughout the territory according to two optimization methods. The villagers choose to go to the market which has the highest potential attractiveness relative to the distance (gravitational potential). In the same way, they will take a taxi from the stop which maximizes this same quotient. The potential attractiveness of the markets depends on the number of customers who disembark there, and the attractiveness of the stops depends on the number of clients who are picked up there. As for the taxis, they simply choose their path based on minimizing the distance traveled.

4. Results:

After initial tests and analyses, this model has allowed us to observe the following phenomena:

- Auto-reinforcement of gravitational potential: after a certain point, the system begins to become structured, and the potential attractiveness of the stops and markets benefiting from a central, strategic position in the network increases considerably, to the detriment of the stops which are either too distant from markets or poorly situated in the network;
- Structuring of attraction basins: this differentiation of stops and markets also structures the attraction basins in which the villagers find themselves. The basins grow around the most popular stops and absorb the attraction basins of the less frequented stops. The villagers will walk to a more popular stop even if it is further away from their initial position;

- Emergence of axes of propagation: auto-reinforcement of gravitational potential will also lead to a recurrence of certain routes. We can see that at a certain point, the axes that connect the most popular stops will support the majority of taxi travel. The coverage becomes organized and spatially structured within the network.

In general, we observed that the system is subjected to a structuring effect. A state of equilibrium, in terms of polarization and coverage, was never observed. On the other hand, we noticed that the hierarchy of markets took some time to stabilize. We often saw one market differentiate itself relatively quickly, while the two others (there are three markets in th model) remained of equal importance for a long period of time. However, after several 'days,' the hierarchy stabilizes and the auto-reinforcement is accentuated. Moreover, we quickly realized that the topology of the network and the relative position of the stops and markets on this network determine, to a great extent, the evolution of gravitational potentials and therefore the structure of the coverage. Given that the network is randomly generated before the simulation, we were able to simulate transportation services in a large number of territories *in silico.*

We have promoted this initial project through the acceptance of a short article and the presentation of a poster at the SAGEO 2009 conference (Lammoglia et *al*. 2009). At the conference, we presented a derivative of the original model, which had the objective of comparing three degrees of optimization:

- Minimization of distance traveled by the taxi and the passenger;
- Maximization of gravitational potential of stops with relation to villagers and minimization of distance traveled by the taxi (original model);
- Maximization of gravitational potential of stops with relation to both villagers and taxis.

Hence the goal was to evaluate, through exploratory statistical analysis, the performance of the transportation service, with the help of several indicators.

5. Evolution of the model

Following our initial observations, we decided to enrich the model and make it more coherent by modifying several of the operating conditions. To begin, we refocused the problem on the theme of transportation. Thus, the markets disappeared and were replaced with *stations*.

Next, we created new rules of behavior for the third type of agent in the model: stops. From this point on, the quantity and distribution of stops in the network are conditioned by their level of popularity. Popular *stops* can become *stations*, and conversely, deserted *stations* can change status and become simple *stops*. To determine which stops or stations had to change status, a popularity index was attributed to each node. This index measures the level of popularity for each stop, and is a function of the potential attractiveness of each stop, and of the number of villagers who board and disembark there. Before beginning the simulation, a threshold (modifiable on the interface) is chosen, above which a stop can become a station, and below which a station can become a simple stop.

Throughout the course of the simulation, one can observe the disappearance and creation of new stations, and thus a modification of their distribution on the network. The network seems to move progressively towards an equilibrium and an 'optimal' distribution of stops and stations. We must caution that tests and observations are still ongoing in January (at the time of the summary), and that, therefore, new results are likely to be reported.

6. Perspectives

During our work, we considered several ways in which to modify the model for future research. Among these, one perspective, still directed toward the theme of transportation, concerns the cooperation, or lack thereof, of taxis among themselves. It would be interesting to see the impact of inter-taxi communication on the operation of the transportation service, the structure of the territory, etc… If the taxis could communicate among themselves to advise other taxis to service a certain stop, where there are lots of customers, rather than another where there is no one, several interesting phenomena might appear. Would cooperation lead to some degree of synergy among taxis? Would it allow each taxi to be more effective, and permit more equitable coverage of the entire territory? *A contrario*, would non-cooperation not increase competition between taxis? We could then see if the indices, such as efficiency of taxis, coverage of territory, etc., change as a function of behavior. This evolutionary view is based on the paradigm of game theory, and more specifically on the prisoner's dilemma and neo-Darwinian evolutionary theory (Axelrod R. 1992). The agents have information which they can share with the other players (cooperate) or not (betray). Trust between the players depends on their interactions, that is to say on the payoffs they acquire during the games, and thus on their incentive to cooperate.

7. Assessment

This MAPS 1 intensive training session succeeded in giving life to a research team. Essentially, this type of initiative allows the development of interpersonal relationships, leading to healthy competition, which is much more productive than collaborative work and personal activities side by side. Clearly, the *synergy of actors* revealed during this training course gave added value to the project by assuring mutual cooperation and opening a permanent exchange between several researchers. This micro-network of researchers could, moreover, open the door for other fruitful collaboration.

Furthermore, this training was *characterized by many rich methodological and conceptual contributions* which can be used in other fields of research. In every stage, from the outlining of the problem to the implementation and the tests, and including the construction of conceptual diagrams, all of the contributions to this training course can and will be re-utilized in other research configurations.

8. Références

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