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ABS²

Agent Based Spatial Simulation

International Workshop
24-25 November 2008
ISC-PIF, Paris, France

Organisers

Arnaud Banos, Image et Ville (UMR 7011 CNRS/ULP) / ISC-PIF
Frederic Amblard, IRIT (UMR 5055 CNRS/Université de Toulouse) / ISC-PIF
Christophe Lang, LIFC (EA 4157, Université de Franche-Comté) / ISC-PIF

Scientific Committee

Mike Batty (CASA-UCL, London)
Nigel Gilbert (University of Surrey, Guildford)
Tim Kohler (Washington State University)
Lael Parrott (Complex Systems Laboratory, University of Montreal)
Denise Pumain (Géographie-Cités, Paris)
Frank Schweitzer (ETH, Zurich)

Keynote speakers

Volker Grimm, UFZ Centre for Environmental Research Leipzig-Halle, Germany: *Individual-based models in ecology*

Philippe Mathieu, LIFL, University of Lille, France: *New approaches for Situated Agent Systems*

Topic of the Workshop

Agent Based Models are privileged tools in many different disciplines, when it comes to the exploration of complex systems. Indeed, they allow to model processes from the bottom-up and to simulate the behaviour of a large variety of phenomena, ranging from physical, biological, social, cultural and cognitive domains.

In some specific communities, including geography, planning, architecture, archaeology, sociology, spatial economics, computer sciences, ecology, to name but a few, some specific models have also been imagined, designed and tested, which allow exploring complex spatial systems.

In that perspective, spatially explicit agent based models are the focus of this international workshop, organised as a joint event between the Paris-Île de France Complex Systems Institute (ISC-PIF) and the European Network "Spatial Simulation for the Social Sciences" (S4), and especially its SIMBAAD working group: "Simulation Based of Agents to Aid Decision".

Contributions dealing with (but not limited to) the following fields of spatially explicit ABM are encouraged:

- Formalising spatial structures and processes in agent based models
- Coupling environmental and social processes
- Formalising incomplete information and/or bounded rationality in space
- Modelling perception of space by agents
- Identifying and comparing emerging spatial patterns

- Feeding and calibration of agent models with heterogeneous and multi-sources data
- Verification and validation of individual and global behaviour
- Real-time coupling between empirical data and model
- Parallelisation and grid computing for large spatial models, including distributed problems: distributed clocks, synchronisation, load-sharing.

- Re-interpreting classic macroscopic models using an ABM approach
- Spatial agent based models for exploration, optimisation, decision support

Submitting a proposal

Please send before 15 september an extended abstract (3 pages, times 12) in English

to arnaud.banos@lorraine.u-strasbg.fr and christophe.lang@lifc.univ-fcomte.fr

During the workshop, people will be encouraged to provide a full original paper of their talk, which will be evaluated by the scientific committee for a collective publication in one or several of the following journals, from which we obtained an agreement:

- Advances in Complex Systems (http://www.worldscinet.com/acs/acs.shtml)
- Cybergeo (http://www.cybergeo.eu/?lang=en)
- European Journal of GIS and Spatial Analysis (http://geo.e-revues.com/)
- Journal of Artificial Society and Social Simulation (http://jasss.soc.surrey.ac.uk/JASSS.html)

Registration fees

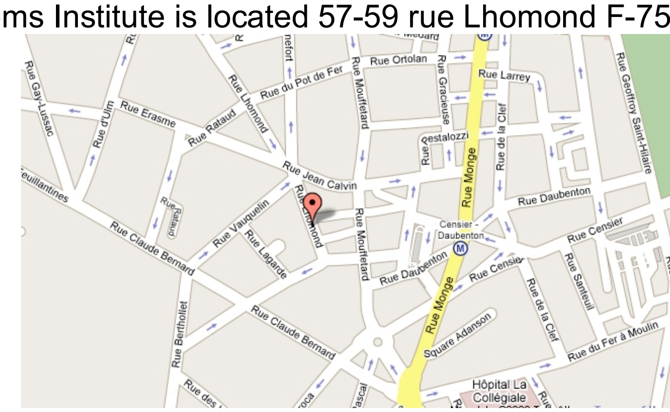
No registration fees are required, as the event is granted by Region Ile de France, ISC-PIF and S4. However, for practical reasons, the workshop is limited to 30 persons. Therefore a "first come, first served" procedure will be adopted.

Important dates

- Deadline for extended abstract: 15 september
- Acceptance notification: 1st october
- Deadline for registration: 10 november

Venue

The Complex Systems Institute is located 57-59 rue Lhomond F-75005 Paris, France



ABS2

ISC-PIF, 24-25 November 2008, Paris

		Monday 24 November
9:00 am	9:30 am	Welcome participants
9:30 am	10:00 am	Welcome talk
10:00 am	11:00 am	Philippe Mathieu, LIFL, FR: New approaches for Situated Agent Systems
11:00 am	11:20 am	PAUSE
11:20 am	11:45 am	Valery Leonidovich Makarov, Albert Bakhtizn & V.A. Zhitkov, RU: Agent-based model for traffic jams in Moscow
11:45 am	12:10 pm	Fabrice Marchal & Wisinee Wisetjindawat, FR/JP: Large-scale MAS of urban citizens - preliminary results from the application of MATSIM to Lyon
12:10 pm	12:35 pm	Nicolas Marilleau & al., FR: Toward geographic agents: the MIRO project
12:35 pm	2:00 pm	LUNCH
2:00 pm	2:25 pm	Franziska Klügl & Guido Rindsfüser, SE/CH : Agent-based route (and mode) choice simulation in real-world networks
2:25 pm	2:50 pm	Arnaud Banos & Cyrille Genre-Grandpierre, FR: Slowing down urban networks with agents
2:50 pm	3:15 pm	Sylvain Lassarre, Michel Roussignol & Antoine Tordeux FR: Macroscopic stability study by simulation and statistical estimation of the parameters of a microscopic car-following model based on the regulation of performance and safety
3:15 pm	3:40 pm	Jérémy Fiegel, Arnaud Banos & Cyrille Bertelle, FR: Modelling and simulation of pedestrian behaviours in transport areas: The specific case of platforms/trains exchanges
3:40 pm	4:05 pm	Didier Josselin, Christophe Lang & Nicolas Marilleau, Fr: Modelling dynamic demand responsive transport using an agent based spatial sepresentation
4:05 pm	4:30 pm	PAUSE
4:30 pm	4:55 pm	Cyrille Bertelle, Antoine Dutot, Michel Nabaa & Damien Olivier, FR: Spatial detection of organization under evacuation situation
4:55 pm	5:20 pm	Eric Maillé & Bernard Espinasse, Fr: MICROPOLIS An agent based model to simulate scattered urbanisation dynamic for forest fire risk management planning
5:20 pm	5:45 pm	Andrew Crooks & Andrew Hudson-Smith, UK: Techniques and tools for three dimensional visualisation and communication of spatial agent-based models
5:45 pm	6:30 pm	Synthesis and Debates
		End of Day

ABS2
ISC-PIF, 24-25 November 2008, Paris

Tuesday 25 November		
9:00 am	10:00 am	Volker Grimm, UFZ, DE: Individual-based models in ecology
10:00 am	10:25 am	Vincent Laperrière, FR: *Modelling plague epidemics: structural validation of an Individual-Based Model*
10:25 am	10:50 am	Nicolas Becu, FR: *Coupling environmental and social processes to simulate the spatial dynamics of a cultivated Sudanese savannah and its evolution for the next generation*
10:50 am	11:20 am	PAUSE
11:20 am	11:45 am	Nick Gotts & J. Gary Polhill, UK: Handling Space and Time in an Ontology-Based Integrated Action Modelling Arena
11:45 am	12:10 pm	Alexandre Muzy, Xiaolin Hu & Juan de Lara, FR/US/ES: A visual and formal framework for modeling and simulation of agent-based systems
12:10 pm	12:35 pm	Thibaud Brocard, Fabrice Bouquet, Alain Giorgetti & Christophe Lang, FR: Agent based modelling of complex systems with AML and the situation calculus
12:35 pm	2:00 pm	LUNCH
2:00 pm	2:25 pm	Wilbert Grevers & Anne van der Veen, NL: The population as a representative consumer in the Alonso model
2:25 pm	2:50 pm	Charles Raux, FR: Exploring the factors of urban social structure with an agent-based model
2:50 pm	3:15 pm	Reinhard Koenig, DE: Circle City: A model to show the interrelationships between the built structure of a city and its social organisation
3:15 pm	3:40 pm	Thomas Louail, FR: Can geometry explain the socio-economical differences between US and European cities?
3:40 pm	5:00 pm	Synthesis and Debates
End of Day		

Agent-based model for traffic jams in Moscow

V.L. Makarov, A.R. Bakhtizin, V.A. Zhitkov

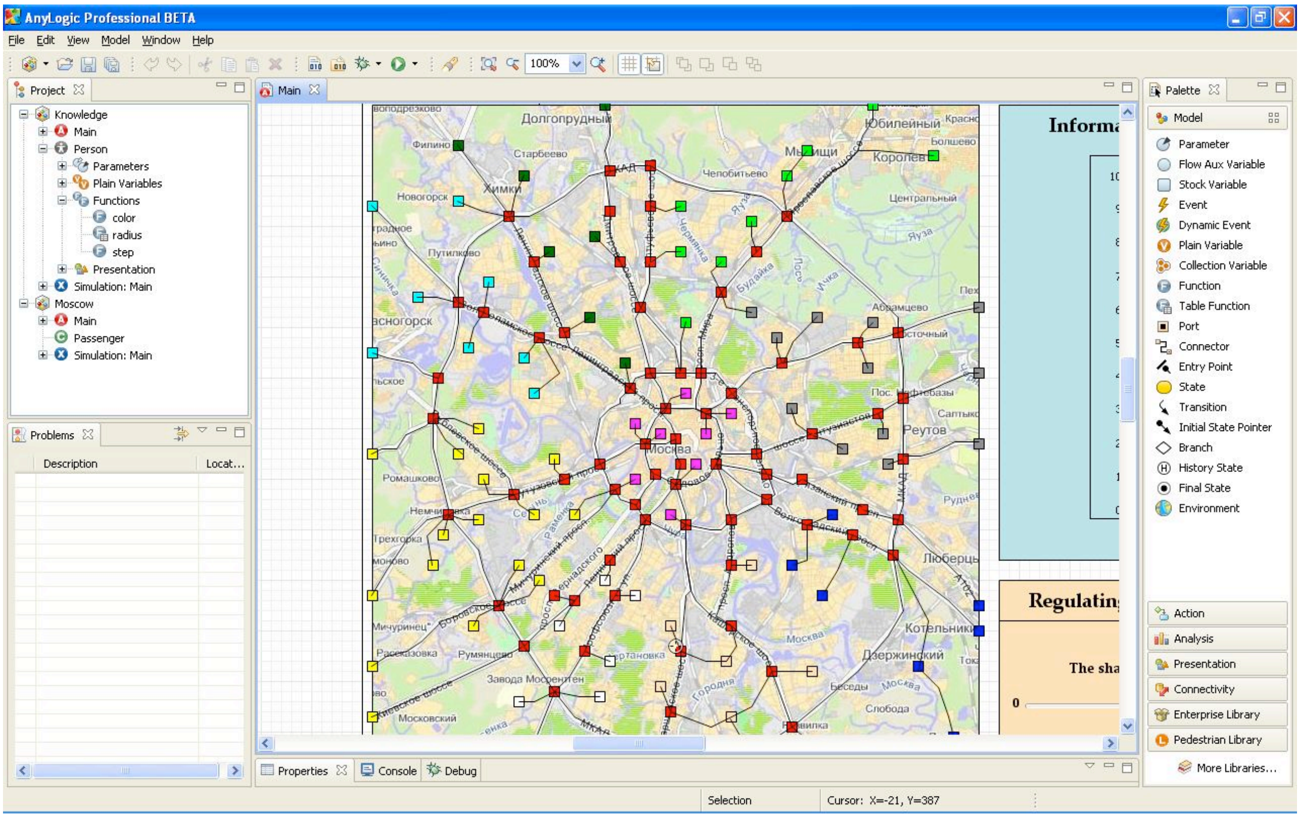
The paper deals with a possible way of presenting the work of transportation system of a mega polis (the example of Moscow city) - an Agent-based model, implemented as 2D application in AnyLogic 6.0 (Karpov, 2006).

Due to limitations of the volume of the article, here information is presented in the form of theses, containing conceptual approach for the work of the system.

1. The model deals with 3 types of agents: i) a person, who wants to travel from point A to point B; ii) a personal car, transporting on average 2 passengers; iii) means of public transportation, transporting about 150 people.

2. Agents of the first type make a decision about choosing the type of transportation (i.e. choosing an agent of the second or third type) on the basis of a number of factors. Agents of the second and third type are linked to animation diagram, changing in real time. The reflection of these agents (i.e. the speed and location at the moment *t*) depends on each particular situation.

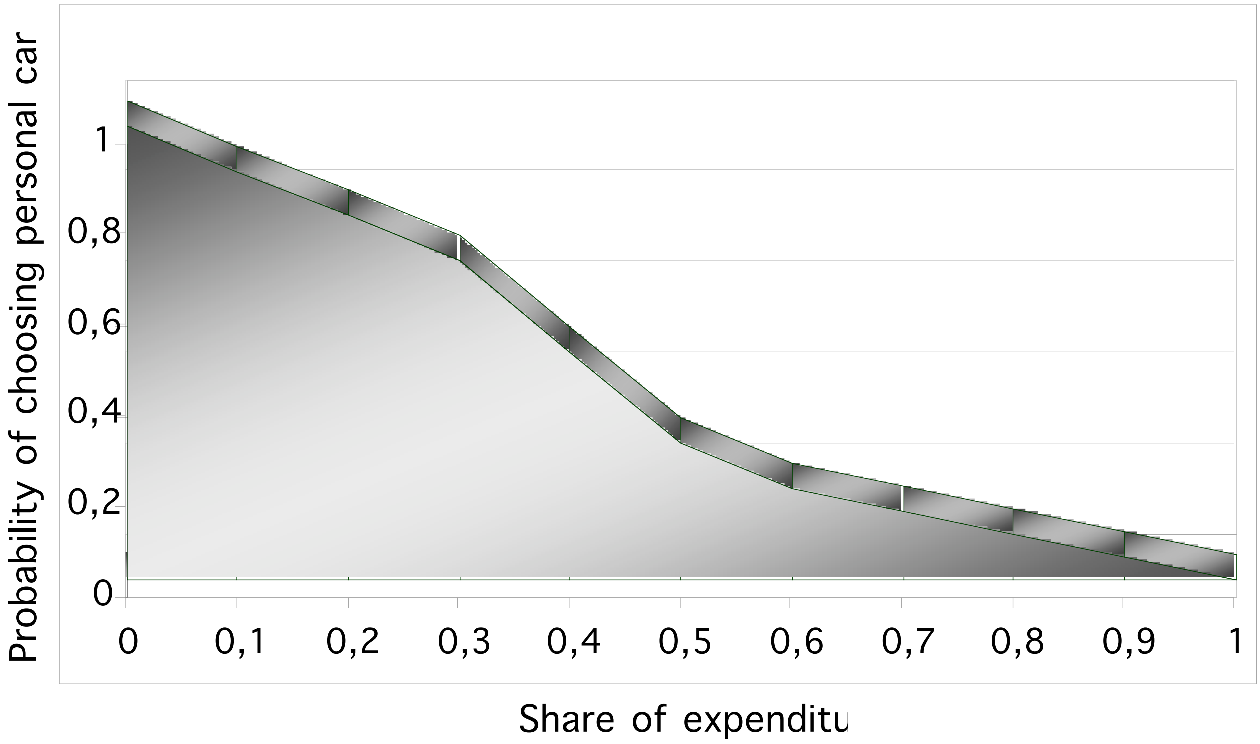
3. Animation diagram is a map of the city (in this case, Moscow city), detailed till the level of main highways (Graph 1).



Graph 1. Transportation network of Moscow

4. The map of the city is presented in the form of *Bitmap* graph. Transportation network, the elements of which are elements of corresponding Java-classes, is laid above this graph. The speed changes depending on the number of transportation elements involved in each moment, and traffic jams may occur in the points of the most busy roads intersection. The programmed transportation network consists of the nodes (final and initial routes for the agents of the first type), and ways of moving for the agents of the second and third type. For more realism, the program provides for a certain distance which is kept between moving agents. Therefore, at the crossroads jams may occur due to incapability of agents to continue their movement. In computer application this feature of agent behavior creates the major difficulty for programming (see Helbing, 2007 and Deguchi, 2004).

5. The number of first type agents is set according to statistical data about population in each part of the city.
6. Two major factors, which influence the choice of means of transportation, have different character. The first is economic and the second is psychological. Psychological factor implies comfort due to traveling in personal car. Up to a certain moment this comfort outweighs discomfort from growing costs. The influence of economic factor is realized through empirically obtained function (Graph 2), where dependent variable is the probability of choosing personal car as the means of transportation till destination, and independent – the share of expenditure on personal car in the total expenditure. Consequently, agents of the first type have information about future costs and make a decision about one or another type of moving in the city.



Graph 2. Probability of choosing personal car depending on the share of expenditure for its maintenance

7. Having constructed our agent-based model, we tried to apply it for solving the problem of traffic jams. The situation in Moscow leads to the fact that traffic jams occur almost 24-hours a day, in the peak time reaching the length of hundred kilometers. Transportation capacity becomes much lower. Development of road network does not solve the problem since the number of personal cars increases much faster.
8. Consequently, solution to the problem requires dismantling and de-stimulating passenger traffic, in the first instance, automobile traffic. Passenger traffic may be decreased through town-building policy (linking the places of residence and places of work, development of information technology and shops "in walkable distance" etc. Yet, all this is costly and time-consuming.

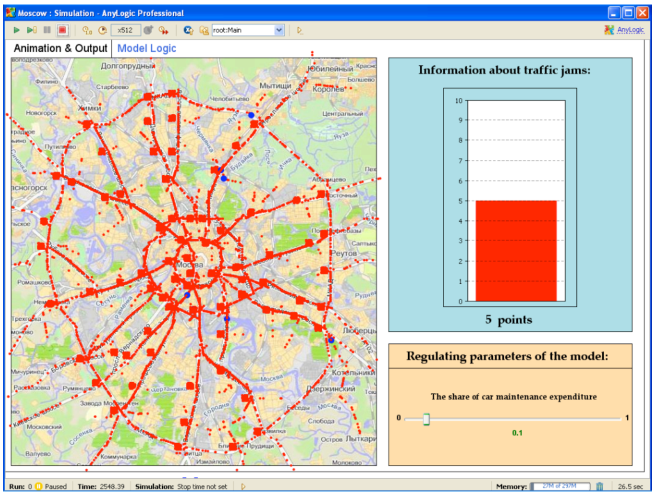
Decreasing automobile traffic, however, is possible within various mechanisms (system of intercepting parking, limitations for entering the city for cars with even and odd numbers etc.). The concept of introducing payments for cars in the city is currently discussed, as well.

Technically all this may be realized by setting identifiers of cars. These identifiers would be automatically recognized in various points of the city (the principle of mobile network). As a result we obtain piece-wise linear trajectory for the movement of each car. The bill for the total link of this trajectory is finally given to the driver. Tariffs may differ in various zones of the city, may depend on the time of the day, may be a function of the fact whether the streets are busy or free, may vary according to the size, capacity in liters and other properties of the car.

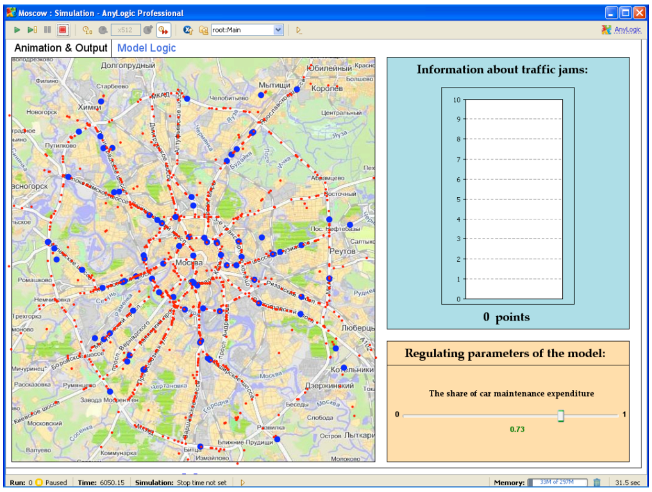
The expected decrease of traffic will increase the number of those using the means of public transportation. The system of public transportation will improve its work due to a certain relief for the roads.

9. Therefore, changing one of control parameters of the model – tariff on the use of personal car (per 1 kilometer traveled), we obtain the sum of payments for the use of car as a function of monthly mileage. The share of these payments in the total volume of personal expenditure makes direct influence on decision about choosing the means of transportation.

10. In the course of simulation we studied two situations so that the above share for an average agent increased from 0.1 (Graph 3a) till 0.7 (Graph 3b). While in the first case we had on average 5-point jams (on the 10-point scale), in the second case we had complete absence of jams as the majority of population started using public transportation. Graph 3a demonstrates that all roads are full with red circles and the places of road intersections have many jams, disturbing public transportation. However, on Graph 3b all roads are free and public transportation (blue circles) moved the same total volume of passenger as in the first case.



Graph. 3a. 5-point jams



Graph. 3b. Movement without jams

11. The developed model allows implementing virtual experiment of shifting enterprises and organizations outside of the city in order to minimize commuter movement of personal cars (in the city in the morning and outside of the city – in the evening). However, this case is more costly for implementation than the above studied one with economic regulation of passenger traffic.

12. Realization of an agent-based model, which takes into consideration peculiarities of personal behavior, allows monitoring changes on city roads in different scenarios. This would be very difficult to do by the means of studying aggregated indicators in a system of equations.

References

1. Deguchi H. (2004): Economics as an Agent-Based Complex System, Springer.
2. Helbing D., ed. (2007): Managing Complexity: Insights, Concepts, Applications. Springer, Berlin.
3. Karpov, Ju (2006). Imitating modeling of systems. Introduction in modeling with AnyLogic 5 – SPb.: BHV – Petersburg (In Russian).
4. XJ Technologies, http://www.xjtek.com.

Slowing down urban networks with agents[1]

Arnaud Banos, Image et Ville, UMR 7011 ULP/CNRS
Cyrille Genre-Grandpierre, ESPACE, UMR 6012 ESPACE, Université d'Avignon/CNRS

1. Why slowing down networks?

From a planning perspective, road networks do not play fair game: the farther you go, the faster you drive. Indeed, as road networks are highly hierarchised by speed, the farther you go the more you stay on roads which allow you to drive faster. Comparing accessibility provided by several road networks shows evidence of this phenomenon (figure 1). If we plot an index of efficiency[2] against the distance travelled, we can notice that, on average, the level of performance increases non linearly with the distance travelled.

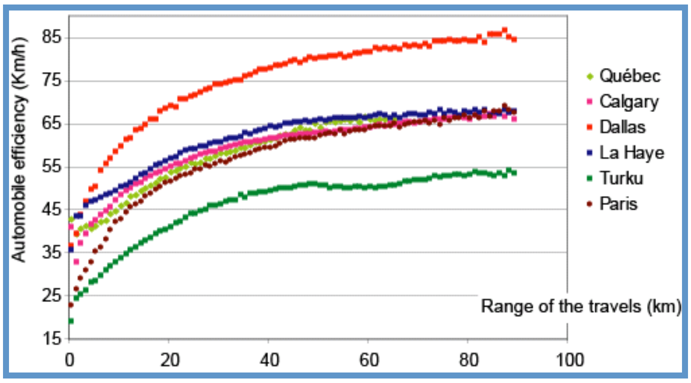


Fig 1: Variations of the automobile efficiency with the range of the travels

This "speed metric" ensures travellers the possibility to drive farther without necessarily increasing their transportation time in the same proportions. In other words, according to the ratio between the number of opportunities that can be reached and the duration of the travel, the speed metric encourages people to stay on the network with their car, as every additional second spent on the network provides a higher gain in terms of accessibility than the previous one.

Moreover, this speed metric merely concerns cars, as public transportation modes (bus, Tramway) are restrained by the frequent stops they have to make along their route. As a consequence, the structure of road networks intrinsically favours the use of car, especially for the longest distances. In that sense, it goes against the objectives of urban planning, as it encourages car use, separation between the various places of life and finally urban sprawl.
In previous work (Genre-Grandpierre, 2007) we have shown that it is possible to generate a different metric, which inverts the current ratio of efficiency between the different types of automobile travels, that is to say favouring the efficiency of short-range trips. Therefore promoting higher densities and functional proximities in urban design according to the hypothesis of the rational locator (Levinson, kumar, 1994).

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[1] Research funded by DRAST/ADEME, Predit Program "Slow networks against automobile dependency", coordinated by C. Genre-Grandpierrre
[2] Efficiency = euclidean distance between origin and destination of a trip / duration of the trip

We called this metric the “slow metric”. Our simulations show that imposing stops (traffic lights) on a network, with locations and durations following stochastic distributions, produces the desirable effect (fig 2).

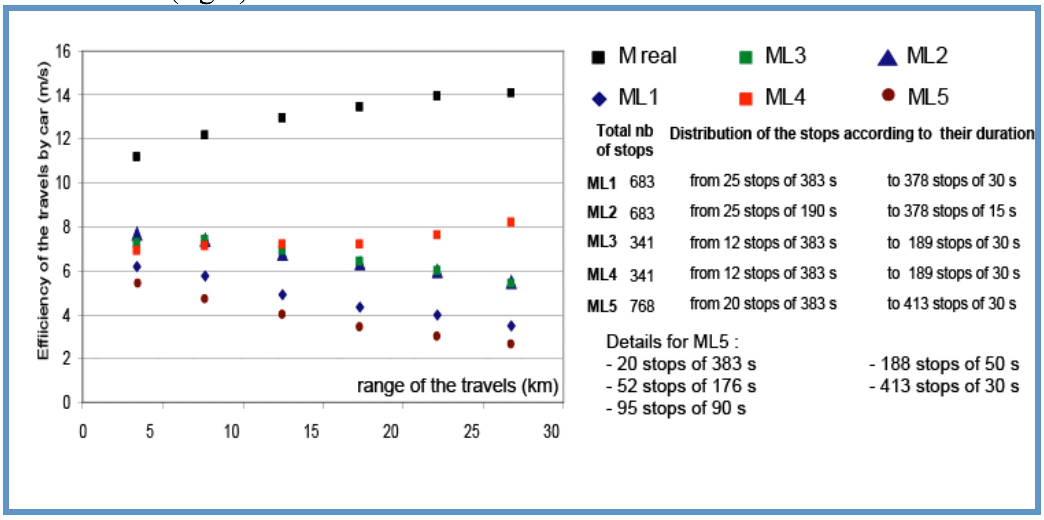


Fig 2: slow metric simulations for the network of Carpentras

By modifying the number and duration of stops, we thus obtain various efficiency curves, favouring short-distance trips. These first encouraging results encouraged us exploring more dynamic and microscopic models, in order to address some keys issues identified so far such as: a) the number and duration of stops, b) the possible structural effect induced by networks topology and c) the possible impact on traffic, including congestion and traffic jams.

2. SMArt Slow Speed (S3): an agent-based simulation platform

S3 has been designed as an interactive platform, allowing exploring with reactive agents the complex issues underlined previously (figure 3).

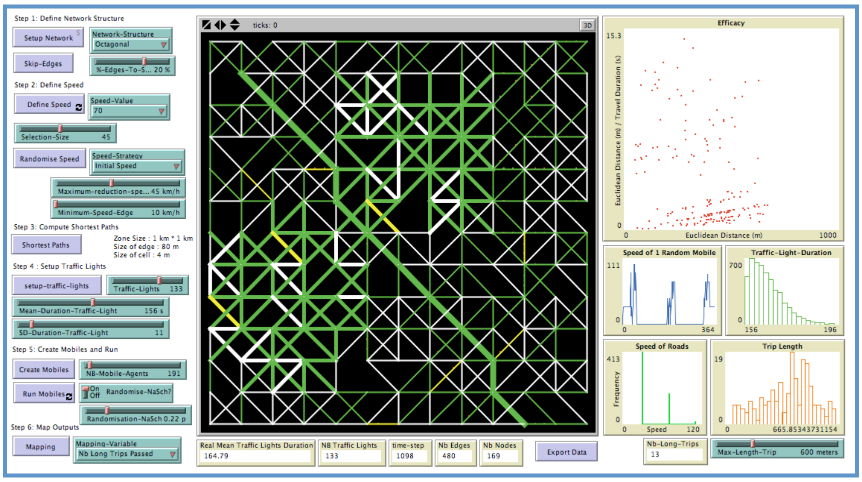


Fig 3: The S3 platform, developed in NetLogo

S3 is composed of two interacting modules. The first one (network builder) allows constructing regular (rectangular or octagonal), non-oriented but weighted (speed) networks. Road links can also be removed randomly, in order to test the impact of structural modifications on the global behaviour of the system. On that base, shortest paths are computed, using Floyd-Warshall algorithm.

Traffic signals are then created, in a two steps process. First, the probability of a road link to receive a traffic signal is a function of its "betweeness centrality", that is the proportion of times this specific link belongs to a shortest path, for a given selected trip length. Then, the duration of this traffic signal is chosen from a left-truncated normal distribution with probability density function $f_{LTN}(x)$ given by:

$$f_{LTN}(x) = \begin{cases} 0, & -\infty \leq x \leq \infty \\ \dfrac{f(x)}{\int_{x_L}^{\infty} f(x)dx}, & x_L \leq x \leq \infty \end{cases}$$

with the point of truncation $x_L = \mu$, the mean of the initial normal distribution $N(\mu, \sigma)$.

The second module handles a microscopic traffic model, aimed at testing the efficiency of the network designed, as well as its impact on traffic fluidity. Before each simulation, *n* agents are created and localised at random on the nodes of the network, their destination being also chosen at random. During a simulation, each agent will have to reach its destination, following the shortest route computed previously, and taking into account speed links but also the presence of other agents in front, as well as the presence of red lights at intersection.

In order to do so, we use an underlying grid covering the 1 km * 1 km wide area, composed of a large number of small cells (length 4 m). Agents are then localised on cells underlying the network. They can occupy one and one cell at a time and only one agent can occupy each cell at the same time. On that base and following [Banos et al., 2006] we then extended the NaSch model[3] [Nagel and Schreckenberg, 1992], in order to introduce traffic lights. According to the prescription of the NaSch model, we allow the speed *V* of each vehicle to take one of the integer values *V = 0, 1, 2….Vmax, Vmax* corresponding to the speed of the current link. At each discrete time step $t \rightarrow t+1$, the arrangement of the *n* agents is then updated in parallel according to the following driving rules:

Step 1: Acceleration.

If *Vn* < *Vmax*, *Vn*→ min(*Vn+1*, *Vmax), i.e.* the speed of the *nth* vehicle is increased by one.

Step 2: Deceleration (due to other vehicles/traffic signal).

Suppose *Dn* is the gap in between the *nth* vehicle and the vehicle in front of it, and *Dtn* is the gap between the car under consideration and the red light in front of it on the road, then:
if dn ≤ Vn or dt n≤ Vn, then Vn → min(Vn, Dn – 1, Dtn – 1)

Step 3: Randomisation.

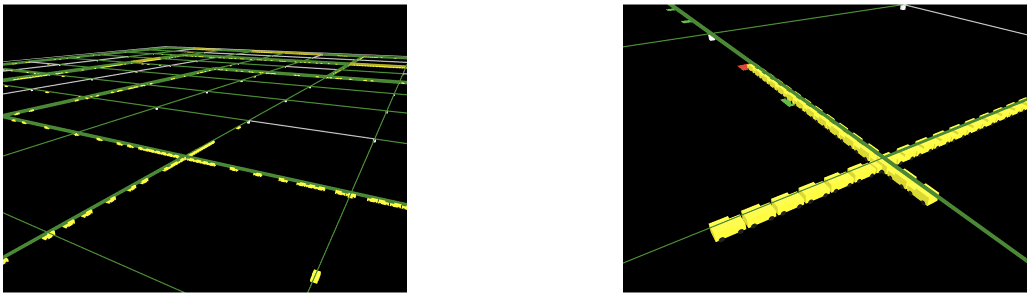
If *Vn > 0,* the speed of the car under consideration is decreased randomly by unity (*i.e., Vn→Vn – 1*) with probability *p* (*0 ≤ p ≤ 1*). This random deceleration probability *p* is identical for all the vehicles, and does not change during updating. Three different behavioural patterns are then embedded in that single computational rule: fluctuations at maximum speed, retarded acceleration and over-reaction at braking

Step 4: Movement.

Each vehicle moves forward with the given speed i.e. *Xn→Xn* + *Vn*, where *Xn* denotes the position of the *nth* vehicle at any time *t*.

[3] A « probabilistic cellular automata able to reproduce many of the basic features of trafic flow » [Schadshneider, 2002, p. 159]

Figure 4 illustrates the kind of traffic patterns generated by this simple thus powerful model.



a. A global view of the traffic b. Jammed intersection due to red light (top)

Fig4: Examples of traffic patterns obtained from the extended NaSch model

Once a specific hierarchised network is fixed, this traffic model allows exploring its efficiency as well as the impact of various strategies of speed reduction (figure 5).

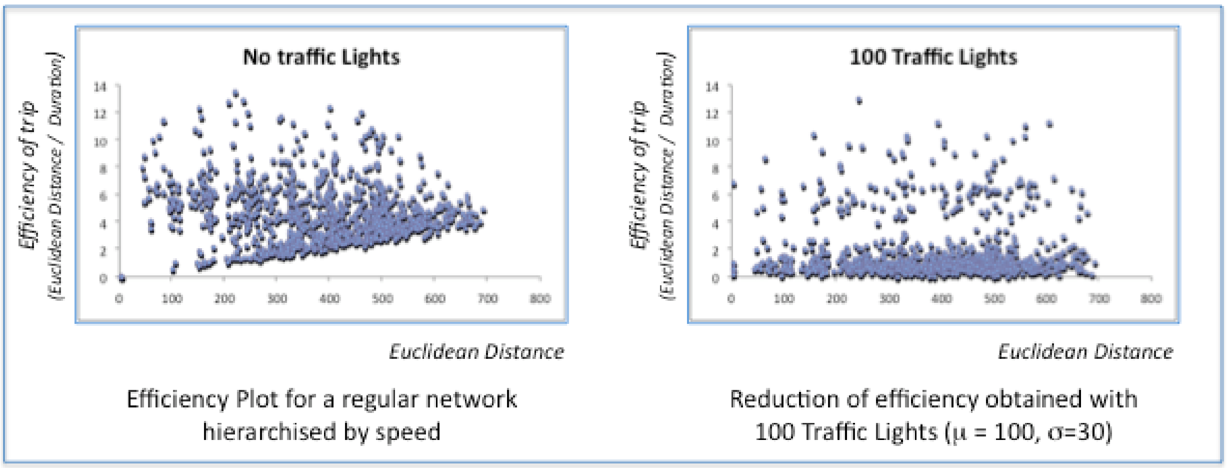


Fig5: Slowing down networks: example of a simulation output

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Genre-Grandpierre C. 2007 : Des réseaux lents contre la dépendance automobile ? Concept et implications en milieu urbain, l'Espace Géographique, 1, 27-39.

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Nagel K., Schreckenberg M., 1992: Cellular automaton models for freeway traffic. Physics. I , 2, 2221-2229

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ABSS 2008
24-25 November 2008
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Coupling environmental and social processes to simulate the spatial dynamics of a cultivated Sudanese savannah and its evolution for the next generation

Becu, N (1), et al.
(1) UMR PRODIG, CNRS, France

In the field of Agent-Based Spatial Simulation (ABSS) many has been said about the interactions between environmental and social processes, and especially that space is, in many case, a medium of interaction between the two domains. What about if space in its structure and dynamic, was the resultant of these interactions? What if instead of seeing space as a cause or a medium, we would see it as an effect? In such case, the landscape is not anymore an input variable of the system but the X to be explained as the result of socio-environmental interactions; the emerging phenomenon. Such a demonstration would need a case study where landscape structure and dynamic are mostly explained through these interactions. Agricultural landscape is one of them. Spatial patterns organizing it depend on socio-economic as well as technical and environmental variables. Within the different agricultural systems, there is one that involves rapid landscape changes, which is shifting cultivation. In shifting cultivation more than in others, the agricultural practices shape the landscape and are shaped by it.
Duupa society, of the Poli massif in North Cameroun, is based on such an agricultural system. One of the specificity of this particular nonhierarchical society is the very close interconnection between the spatial dynamics of a cultivated savannah and a decentralized social system based of social exchanges. It was therefore an ideal context to conduct our research on the co-evolution between agricultural, ecological and social dynamics. Given the many complex interactions involved and the central question related to the emergence of a landscape structure and dynamic, ABSS appeared to be an obvious choice to conduct this research.

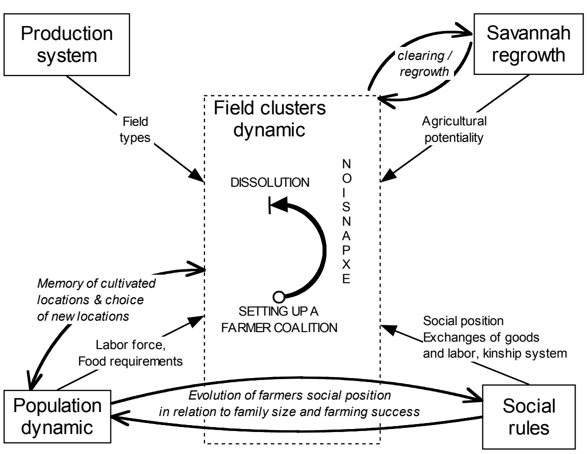
The first thing a geographer would note when walking around the Duupa territory, or looking at aerial or satellite images of the area, is the particular spatial organization of the landscape which is mainly defined by the presence of cultivated patches of 2 to 10 ha, randomly distributed in the savannah with no apparent reasons of distance to the habitat, of land ownership or soil quality. When now looking at the landscape evolution overtime, he would notice that those patches evolve: some grow, some seems to move, some other shrink, then disappear and eventually appear a year later at another location. Looking a bit closer, the geographer would realize that those patches are made up of individual fields of different size, all adjacent to another and all having an edge to the savannah. Those field clusters, as the authors called them, seem to reflect a certain social organization. They are usually composed of a handful of big fields, owned by influent farmers, going along with a number of smaller individual fields, owned by farmers of a lower social position. However, this organization is ephemeral as the farmer coalition, formed by the field cluster, collapse as soon as the cluster disappears from the landscape; and when, a year later, those farmers open new fields, they are scatter all over the landscape, in different field clusters and new coalitions are made with no link at all with the previous coalition. In light of these observations, the question the authors try to answer using ABSS is can we explain the spatial organization of the Duupa landscape and its evolution with rules of interactions between the social and environmental dynamics.

Duupa social structure is based, among other aspects, on kinship relationships, mutual aid in agriculture and social affairs and social position acquired through social exchange transactions. The social organization is closely linked to their production system. Duupa are almost exclusively sedentary farmers, cultivating in either mountainous area or at the foot of mountain chains. Their shifting cultivation system is defined by a cultivation period of about 4 to 5 years followed by a fallow period ranging from 10 to 20 years or even more. The main cultivated crop is sorghum. It is the main source of food (together with peanuts and various vegetables) of the Duupa diet. Sorghum flour is either used for cooking or to prepare sorghum beer which plays a central role in Duupa social transactions. Indeed, all social and ritual occasions (exchange of services, communal works) are articulated around the invitation to drink sorghum beer. As said earlier, sorghum fields (as well as few other types of field which are not taken into account in this study) are grouped together by series of 5 to 10 fields, each belonging to an individual farmer, and making a cluster which is the socio-geographic unit which we modeled in this interdisciplinary research.
The model development was a joint effort between a geographer, an anthropologist, an agronomist, an ecologist and a modeler. The team (except for the modeler) has been working together for several years compiling important sum of data in each disciplines and especially about two Duupa villages located at the foot of Poli massif (Wante village) and in the mountains (Ninga village). This modeling exercise was possible thanks to the availability of this database and the expertise of these domain specialists.

The conceptual modeling framework chosen to carry on this research is the following one. Four domain-specific modules were considered: a population/demographic module, an agricultural module, a post-cultural savannah regrowth module and a social rules module. Those four modules converge to a fifth one, the field cluster module, which is the emerging dynamic which we want to explain with this model. The main module interactions are :

- The dynamic of savannah clearing and savannah regrowth specific to shifting cultivation practices;
- The evolution of social positions within the population in relation to the family size and farming success;
- The memory of past cultivated locations that partly explains where farmers decide to cultivate and with whom.

Hence, landscape was conceptually defined as the resultant of module interactions and field cluster was defined as the core unit shaping the landscape. Field clusters have their own life cycle, with a set up, an expansion phase and dissolution.



The following of the paper describes one after another the different modules, how they were conceived, the empirical evidence used and the modeling assumptions made.
For post-cultural savannah regrowth, a state-transition dynamic describing the transition between the different vegetation types was modeled using cellular automata. The demographic module consists of a population of individual agents, each representing a person with its kinship relations, marriage and household membership. The parameters of this individual-based population model (birthrate, mortality, minimum age for marriage, …) were calibrated upon indicators from literature and direct observations. The module simulates demographic growth, net migration, food requirements and household labor capacity which are used in the agricultural module. The latest defines cropping patterns and their associated field types. Module outputs are the size of the sorghum field – partly depending on available labor -, its duration - between 4 to 5 years cultivation - , and the wealth the agent can accumulate from it. Duupa social rules implemented in the model are first exchange transactions consisting in converting sorghum yields in intermediate goods and finally in matrimonial compensations. Following the Duupa way of life, the ultimate goal of an agent is to accumulate wealth from farming in order to marry, most frequently several times, and have children. Second are social positions which reflect a farmer's position within the system of goods and labor exchange. A young farmer starts as a client responsible to a bigman. The latest supports his clients to accumulate goods and marry and gets part of their labor in return. As a farmer accumulates goods and as his family gets larger, he will become an independent farmer (not depending on any bigman) and then eventually a bigman himself.

The model runs on a yearly timestep for a period of 30 years or more, covering the landscape evolution for the next generation. At the beginning of the simulation no fields exists in the landscape. As the simulation goes, agents create coalitions and open new field clusters that extend yearly (a) until reaching a maximum size after 4 or 5 years (b) and then collapse (c), reproducing the typical life cycle of a cluster and fragmenting the landscape (d) as can be observed on Figure 2. At the same time, agents' accumulate wealth, fields' size change and social positions evolve in accordance while the demographic module manages death and the arrival of young farmers in the socio-agricultural system.

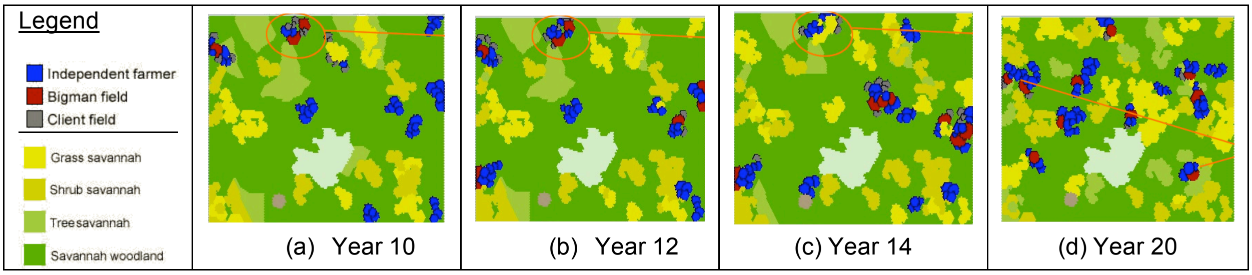


Figure 2: An artificial landscape shaped by field clusters life cycle resulting from socio-environmental interactions

The comparison of simulated and empirical values for a number of indicators, divided into 5 categories (spatial – e.g. fragmentation, dispersion, shannon diversity index,…- , social, demographic, economic and agricultural), demonstrate the reliability of the model in simulating the Duupa system in its current setting. At the same time the simulation is a perfect illustration of the emergence of a spatial organization resulting from the coupling of environmental and social processes. Simulations are now carried out to prospect the possible landscape, ecological and social mutation if facing demographic growth, due to either natural population increase or arrival of migrants.

Agent Based Modeling of Complex System with AML and the Situation Calculus

Thibaud Brocard Fabrice Bouquet Alain Giorgetti Christophe Lang

1 Context

The aim of this paper is to provide a method to create an agent-based model for a complex system and a way to check some of its properties. This work takes place in a research project[1] where complex systems are next generation microfactories. This project brings together different scientific domains such as computer science, physics, electronics and automatics. The rationale of the project is to define models and tools that will support the collaboration of these different research domains in a common application case. In this paper we focus on the system complexity and put aside the *micro* aspect.

We consider a system as complex when we can not predict its whole behaviour (e.g. due to the high number of entities composing it, their cognition, ...). The system taken as an example is a robot production factory. Robot parts are built in different production cells, then finally assemblied together. Each cell is composed of several tools, actuators, effectors (such as a painter, vernisher or solderer arm) or even other simpler cells. Furthermore the cell number, composition and organization can change dynamically and in an autonomous way. The system is self-organized and adapts its own structure and behaviour in order to fulfill assigned tasks. Instead of a clever, omniscient and single entity managing the factory, we follow the *divide and conquer* paradigm by considering each physical system entity as a rational entity. The Multi-Agent System (MAS) paradigm is, obviously, very close to this approach of modeling complex systems.

We have not yet found a single language and formalism allowing us to describe every aspect of such systems. For this reason our model is divided in three different views: structure, action and interaction. The first two views have their own language and interactions are expressed with a combination of these two languages. We will present each view separately and conclude with implementation results and perspectives.

2 Structure model: AML

The structural part of the model describes the different agents composing the system and the hierarchical way they are organized. Following several works showing that the agents organization in a MAS has a significant impact on the system performances, we use the AGR (for Agent, Group

[1]Project supported by the Franche-Comté region council, see `http://lifc.univ-fcomte.fr/~philippe/site/projets/musine/musine.html` (in french) for details.

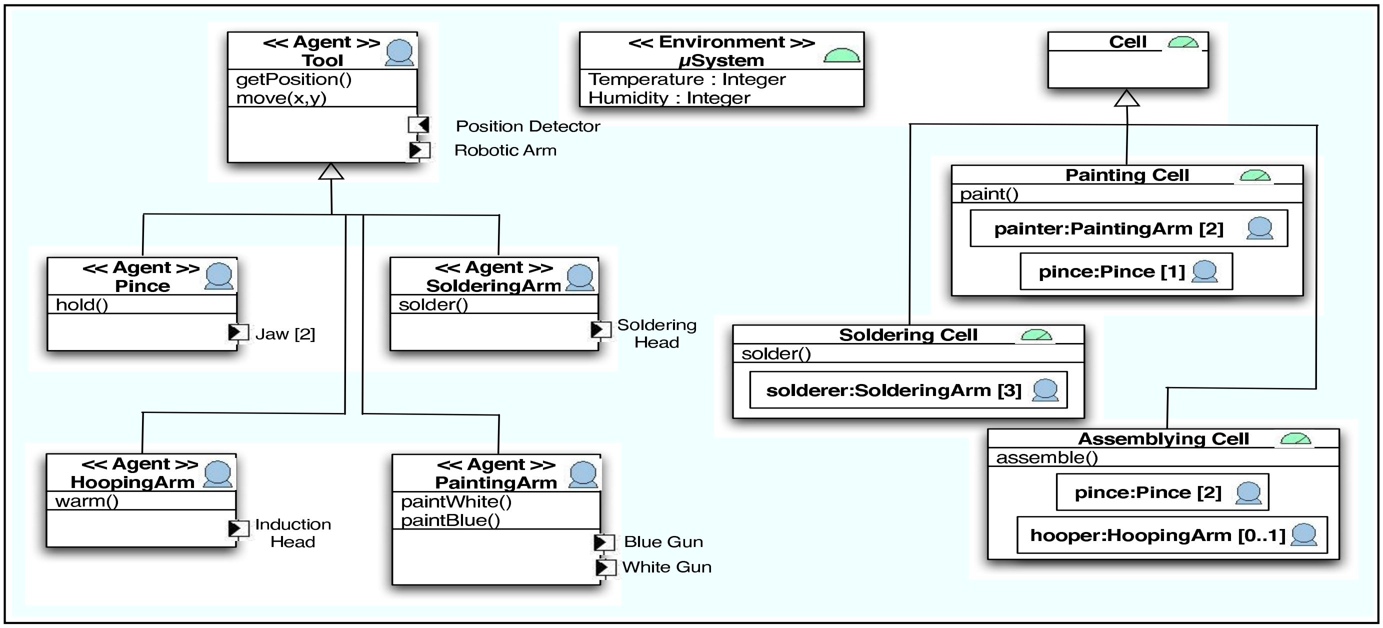


Figure 1: AML structure model

and Role) model presented by Ferber [3] and organize the agents composing the complex system in an holarchy [7, 4], thus putting organization at the foreground.

Most of the time, UML is used to describe MAS, but UML models can not easily deal with the different levels we have in a complex system. For this reason, we have been interested in a more recent language: Agent Modeling Language (AML). AML [10, 1] is a semi-formal visual modeling language for specifying, modeling and documenting systems that incorporate features drawn from MAS theory. AML is suitable for models with several autonomous, concurrent and/or asynchronous entities. Those entities are able to observe and interact with their environment, using complex interactions and services aggregation. AML can also describe social structures and mental characteristics. With the help of AML we will be able to model agent groups and roles in a very natural way. AML is suitable for Ferber's AGR model. Furthermore (and that is the main reason why we chose it), AML deals with holons, so we will be able to describe an holonic structure in our model.

Figure 1 shows the first two levels of the robot factory structure model, in AML. Each tool has a position and is able to move, as shown in the left part of the figure. Differences between tools come from their abilities: a painting tool has two paint guns and is able to paint, a pince is able to hold, etc. The right part of the figure presents the composition of factory cells. There are three different kinds of cells: the painting ones, the soldering ones and the assemblying ones, differing by their tool composition.

3 Action model: Situation Calculus

An agent logic should allow representing dynamic aspects of agents as individuals, but also of parts of a global system, and reasoning about them. We describe agent actions with the help of the Situation Calculus [9]. It is widely used in Artificial Intelligence for representing a dynamical universe and reasoning about it. This universe is characterized by a conjunction of logical formulas where *actions* perform stage changes observed by *fluents*. A *situation* is not a state, but a finite sequence of actions, starting from an initial situation denoted S_0. In the robot factory, for example the situation:

$$do(cell1, assembly, do(agentA, paintBlue, do(agentB, solder, S_0)))$$

represents the action sequence. From the initial situation S_0, $agentB$ has soldered, then $agentA$ has painted in blue and finally the cell $cell1$ has assembled.

The Situation Calculus, slightly extended, allows us to express the action capacity of agents (depending on their ability, their state and the state of the environment as in [2]), the duration of an action (in order to verify that an agent is not performing two different actions at the same time), their organization (through the group they belong to) and their position in the world.

4 Interaction model

The third part of our model describes the different interactions among agents, either with other agents or with the environment. For the present, the modeled interactions are communications (with a black board or by message sending), reactions to the actions, cooperations of several agents to deal with a *complex* action, scheduling, and knowledge learning. We do not need a new langage to describe those interactions: we can express them with the help of AML and the Situation Calculus.

5 Implementation, results and future work

We made an implementation of the Situation Calculus axioms in Prolog as in [8]. The lists of agents, groups, roles and capabilities of agents are extracted from the AML model. The initial situation comes from an instance diagram defined in AML. The Prolog implementation allows us to check if an action or an action sequence is possible. We can check if an agent is capable to perform an action (if it knows how to perform it, if it is able to perform it and if it is not busy) and then get the beginning and the end of every action in the sequence. This provides us a naïve scheduling. It can also check if a scheduling is possible or not. Our implementation of the Situation Calculus supports the notion of different abstraction levels by considering each action differently according to the level at which it occurs.

Even if there are other properties for the agents and the MASs (e.g. as presented in [5]), we describe in these three views all the *basic* properties, which are usual in MASs. One of the next steps is to express new agent properties, such as the Belief/Desire/Intention model. Another direction is to exhibit general rules for deriving the Prolog implementation from the AML and Situation Calculus models. With such rules, implementation would be automated instead of being done manually. Next step is to provide a MAS simulator from our model based on MadKit [6]. The MadKit software architecture has been built on the AGR model.

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Techniques and Tools for Three Dimensional Visualisation and Communication of Spatial Agent-Based Models

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Agent-based modelling (ABM) is increasingly being used as a tool for the spatial simulation of a wide variety of urban phenomena including: urban housing dynamics (Benenson *et al.*, 2002); urban growth and residential location (Torrens, 2006; Rand *et al.*, 2002; Brown *et al.*, 2005); gentrification (Torrens and Nara, 2007) and traffic simulation (e.g. Barrett *et al.*, 2001). At a more micro scale agent-based models have been used simulate of pedestrians in the urban centres (e.g. Haklay *et al.*, 2001); examine crowd congestion (e.g. Batty *et al.*, 2003) and emergency evacuation of buildings (e.g. Castle, 2007a). These applications demonstrate a growing interest in linking agents to actual places and with geographic data (see Castle and Crooks, 2006; Parker, 2005 for reviews) through linking or coupling with geographical information systems (GIS). The advantage of linking the two allows agent-based modellers to simulate agents related to actual geographic locations, thus allowing us to think about how objects or agents and their aggregations interact and change in space and time (Batty, 2005).

As agent-based models move into the spatial domain, we need new ways to visualise and communicate such models especially to those who we seek to influence and who we believe that such modelling will inform their activities. This has already been identified as one of the key challenges facing ABM (Crooks *et al.*, forthcoming). Visualisation is the main way to how we interact with computers and while in the past, before the development of intensive and all pervasive computation, communicating models was mainly through discussion and simplification, through pedagogy in all its various forms. Visualisation is now one of the main ways to communicating and sharing information from such models. Of course spatial outcomes from models can be mapped and this is a key medium for dissemination as well as for validation and other aspects of the simulation process. As Mandelbrot (1983) argues good models which generate spatial or physical predictions that can be mapped or visualised must 'look right'. Furthermore sharing and disseminating models is problematic. The development of online laboratories – collaboratories for example – where model building and users engage in mutual and shared development activities although their infancy are very much on the horizon. The development of web sites where many users develop agent-based models such as NewTies (Gilbert *et al.*, 2006) or Modelling4All[1] (Kahn, 2007) are examples of how this field is developing into a more sharing mode where collaboratories hold out great promise for new advances in social simulation to whoever has an internet connection.

[1] http://modelling4all.wordpress.com/

Coupled with the challenges on how we communicate and visualise agent-based models is how we represent agents in space. The use of ABM for geospatial simulation has traditionally been dominated by the two dimensional (2D) view of the world with the third dimension (3D) rarely ventured into (see Dibble and Feldman, 2004; Thorp *et al.*, 2006[2]. for sample applications). We would argue, that this is due to the nature of the discipline where the focus is on theory rather than outreach and end user visualisation; and model builders not taking advantage in improvements in computer graphics, networked communication and associated technology.

At the Centre for Advanced Spatial Analysis (CASA) we are working on ways to visualise, share and communicate agent-based models specifically focusing on the third dimension. We will illustrate our early attempts with several examples utilizing 3D Studio Max, a computer aided design (CAD) package and Second Life, a virtual online world. These examples range through the movement of cars and pedestrians in a cityscape to evacuation of pedestrians from buildings in Second Life. Such models utilize advances in graphic card technology, networked communication and advances in physics based engines (e.g. Havok) which allow us to easily add dynamics into such systems. For example, industry standard tools such as 3D Studio Max has built in tools for crowd and delegate systems, which can be used to assign behaviour to agents or objects therefore providing the ability to create realistic traffic and pedestrian systems in 3D as we demonstrate in Figure 1. One can program simple ant like behaviours through to simulating shockwaves within traffic, various built in components enables high quality graphic outputs as well real time previews and outputs can additionally be exported to game engines such as Crysis.

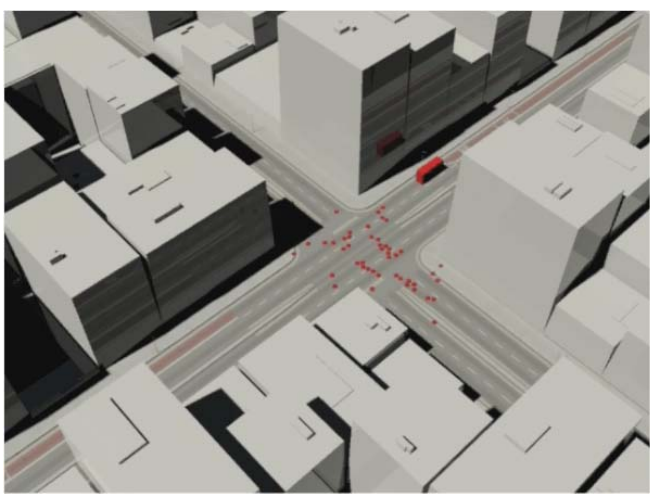


Figure 1: Pedestrian agents and a vehicle agent within a Cityscape created in 3D Studio Max.

Agent-based models are usually considered as forming a miniature laboratory where the attributes and behaviour of agents, and the environment in which they are housed, can be altered, and experimented with and where their repercussions are observed over the course of multiple simulation runs. Virtual worlds such as Second Life act in a similar

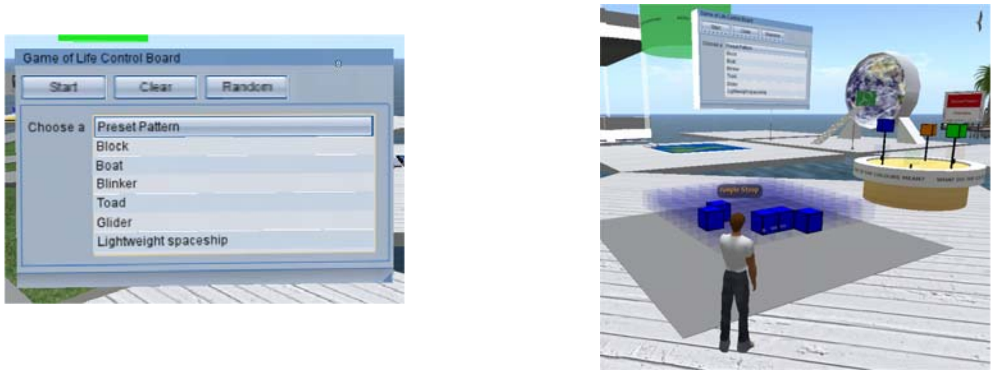
[2] Further information can be seen at http://www.redfish.com/wildfire/ and http://www.redfish.com/stadium/

way to agent-based models in the way they are artificial worlds populated by agents. The idea behind such systems is to engage a community of users where people as avatars can be active users contributing to sites and participating in site content in real time through the world wide web (WWW) which opens their use to whoever is connected.

Virtual worlds such as Second Life have great potential for research in the social and behavioural sciences along with offering an environment for education and outreach (see Bainbridge, 2007). Such systems allow people to discuss and visualise models in real time, they provide an effective medium to clearly communicate models and results between the developer and the decision maker which in the past was the sole province of powerful scientific workstations. For agent-based modellers it offers a unique way for the exploration and understanding of social processes by means of computer simulation. Researchers have used agents within virtual worlds to study a variety of phenomena from human-to-agent interaction (e.g. Berger *et al.*, 2007); the study of norms between agents and avatars (e.g. Bogdanovych *et al.*, 2007); healthcare issues (Dieterle and Clarke, in press); to herding behaviour (Merrick and Maher, 2007). We are using Second Life as a collaborative geographic space (see Hudson-Smith and Crooks, 2008) for the dissemination of geographic content and for the exploration of agent-based models in an interactive 3D media.

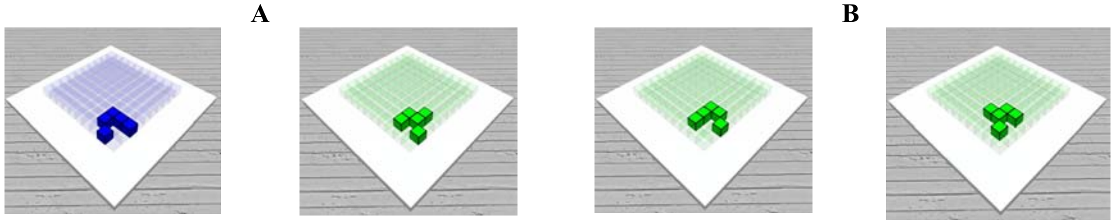
Within this world we have created a number of agent-based models using the Linden Scripting Language (see Rymaszewski *et al.*, 2007). It is the purpose of these models to act as pedagogic demonstrators and as a "proof-of-concept", thus we have chosen Conway's Game of Life (Figure 2), Schelling's (1971) Segregation model (Figure 3). These models were chosen as they highlight how classical automata styles of models which have inspired a generation of modellers can be created and explored in Second Life. The third model we present is a prototype pedestrian evacuation model (Figure 4) which is more complex than the previous two and highlights at the variety of models that can be potentially created in Second Life. This model relates to the genus of such models of which the social forces model developed and popularised by Helbing and Molnár (1995) is typical.

Agents within the evacuation model have been designed to mimic 'real' people with realistic anthropomorphic dimensions which exit a building when an alarm is sounded. We represent the building (enclosure) as a continuous space as apposed to the more common regular lattice (as is the case for the Schelling and Game of Life models above) or course network enclosure representations of other pedestrian models (see Castle, 2007b). Agents are therefore not restricted to discrete cells nor are they represented as flows thus enabling us to simulate pedestrian movement more explicitly. The agents within the model interact with each other and their environment (e.g. obstacle avoidance) both of which can have an effect on occupant movement, for example, agents adjust their walking speed when approaching congestion. Users can explore several room configurations which allows them to study exit route choice, way finding and the identification of bottlenecks in building design.



A

B



Initial Condition

Time (T)1

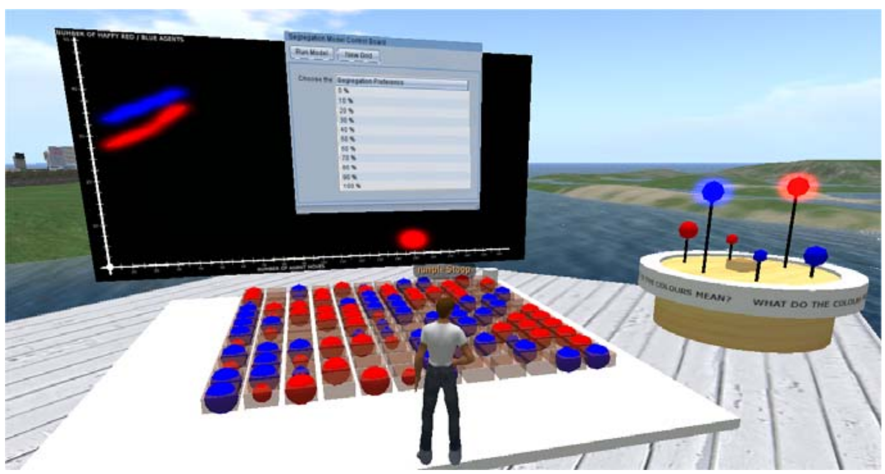
T2

T2

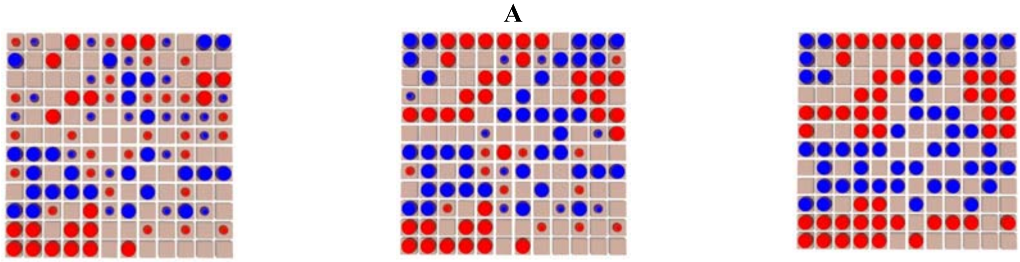
C

Figure 2: Game of Life in Second Life.

A: Control board for the Game of Life with preconfigured patterns, B: An avatar watching a simulation evolve, C: Example of a glider moving across the board.



A



Start of simulation

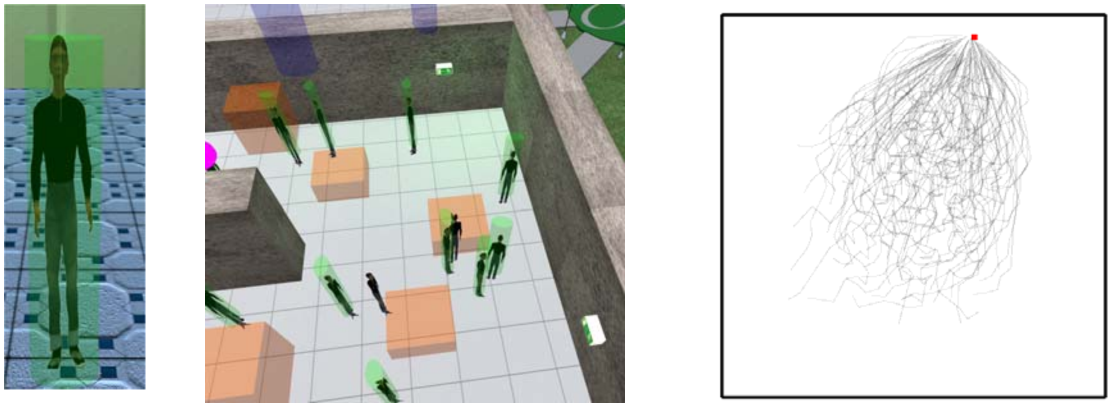
Middle

End of simulation

B

Figure 3: Schelling's Segregation Model within Second Life

A: The graphical user interface of the segregation model, B: A typical simulation when agents desire 50% of their neighbours to be of the same type as themselves (note that the small circles represent dissatisfied agents).



A B C

Figure 4: Pedestrian Model within Second Life

A: A pedestrian agent within the model and its body ellipse (Fruin, 1971) in green, B: Pedestrians and their environment, C: Tracing the pedestrians routes to the exit (red dot).

Modelling cities is thwart with difficulties and while these are our preliminary steps acting as “proofs of concept” we believe such work has the potential to interest and engage both geographers and planners. Not only do our models roughly approximate the notion of generative social science articulated by Epstein (2007) which proposes that models should be ‘grown’ within simulation laboratories. The models also demonstrate how different theories and concepts can be incorporated into highly visual 3D virtual environments. The visualisation of such models in 3D CAD software or virtual worlds provide outputs to models which non-expert users can easily relate to and thus allow such models to come under greater scrutiny than was possible in the past, therefore aiding the use of agent-based models as a tool for decision support.

In the past the communication of models was mainly done through discussion of model results, through Second Life it is possible to share modelling processes and its outcomes with various non-expert participants and potentially allows non-experts to participate in actual model construction. The tools and techniques presented show the potential of virtual worlds CAD and game engines to act as portals for allowing modeller, policy makers and citizens to communicate, share and visualise 3D spatial agent-based models.

Wider implications of such linkages between CAD software, virtual worlds and agent-based models is that often in architectural and planning profession, it is fairly typical for designers to build 3D models of their own building design within CAD. Coupling or embedding agents to such systems allows us to introduce behaviours into such geometric models and test implications such as evacuation scenarios on various room configurations. Specifically how the spatial configuration of the built environment impact on movement.

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Agent Based Spatial Simulation (ABS2)
International Workshop – 24, 25 November 2008

Modelling and simulation of pedestrian behaviours in transport areas: The specific case of platforms/trains exchanges

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With more than 1.8 billon passengers a year on its train network[1], the Paris Public Transport System (RATP) is continuously confronted to problems of management of crowds. Concerned by the quality of service, RATP manages this phenomenon by optimizing the various steps met in a trip. From this perspective, since March, 2007, it started a plan aiming at modelling and simulating passengers' exchanges between trains and platforms.

1. The exchanges between trains and platforms

Most of the difficulties which may alter the functioning of trains services occur during the train / platform exchanges: congestions in front of doors, passengers who obstruct the closing of doors… These situations, magnified by the increasing density of passengers, increase the stopping time of the trains and therefore, cause delays.

RATP specialists have been using models of simulation of exchanges for a long time. However, these models mostly belong to a macroscopic approach of the phenomenon: they are based on the management of crowds rather than the management of individuals (resulting in losses of precision, notably).
Our objective is to propose a microscopic approach, focused on individual behaviours, that would provide better estimates.

2. Modelling and simulating pedestrian behaviours at microscopic level

Following [Banos and Charpentier, 2007], we identify five key issues to be adressed: a) defining a detailed environment with an adapted scale, b) reaching adapted spatial and temporal precision, c) managing a realistic number of simulated pedestrians, d) introducing physiological and behavioural heterogeneity, e) combining both local and global interactions.

[Pelechano et al., 2007] distinguish three main types of modelling approaches: physical models, cellular automata models and rule based models.

[1] In 2005.

Physical models, like the famous "Social Force Model" [Helbing et al., 2001] and its recent extensions [Pelechano et al., 2007] are able to reproduce some of the self-organizing components of crowds behaviours, but require a large computation effort even for simple environments.
Cellular automata models [Blue and Adler, 1994 ; Muramatsu, 1999] focus on local interactions between neighbouring spatial entities, in which are included desired individual behaviours. They are easier to develop and run faster than the physical models. However, the homogeneous behaviour of the individuals within spatial entities and the limitation of their interactions in relations of spatial nearness can not reflect the real pedestrian behaviours, as concludes [Teknomo, 2002].
Finally, rule based models, like agent based models, are able to deal with more complex environments and behaviours [Banos and Charpentier, 2007 ; Batty 2005 ; Paris et al., 2007]. Our SimTRAP prototype directly belongs to that last family.

3. The SimTRAP prototype (Simulation of exchanges between TRains And Platforms)

SimTRAP deals with very detailed environments (platforms and trains), composed of both static and dynamic objects (trains, doors and folding seats).
Passengers are represented by agents having, as a first approach, the same internal structure and behaviours. Agents are defined by their destination, their direction, their speed, their position, their field of vision.They are able to choose and reach a destination (standing or sitting) on the platform, to enter a train once the doors open, to choose and reach a place (standing or sitting) into the train, to get of the train and then leave the platform.

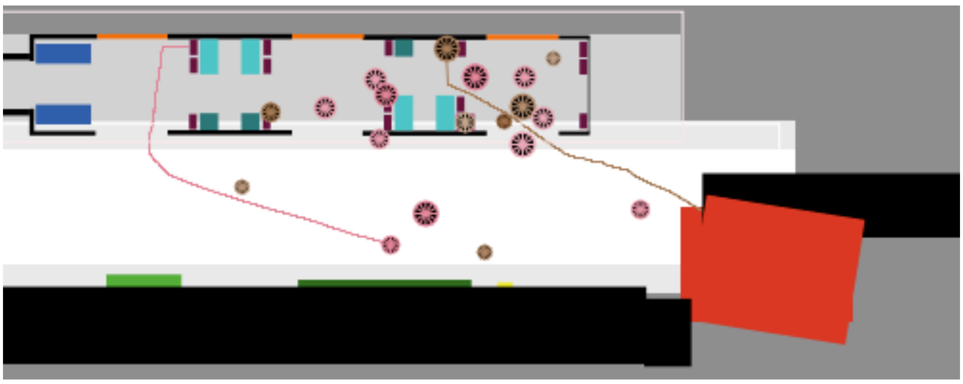

Figure 1: Screenshot of SimTRAP showing passengers leaving and entering the train

4. First results

This first version of SimTRAP allows testing scenarios, for a given set of parameters. For example, figure 2 shows the number of exchanges (passengers entering into plus passengers getting of the train) in 5 seconds real time, when the number of passengers on the platform and in the train varies.

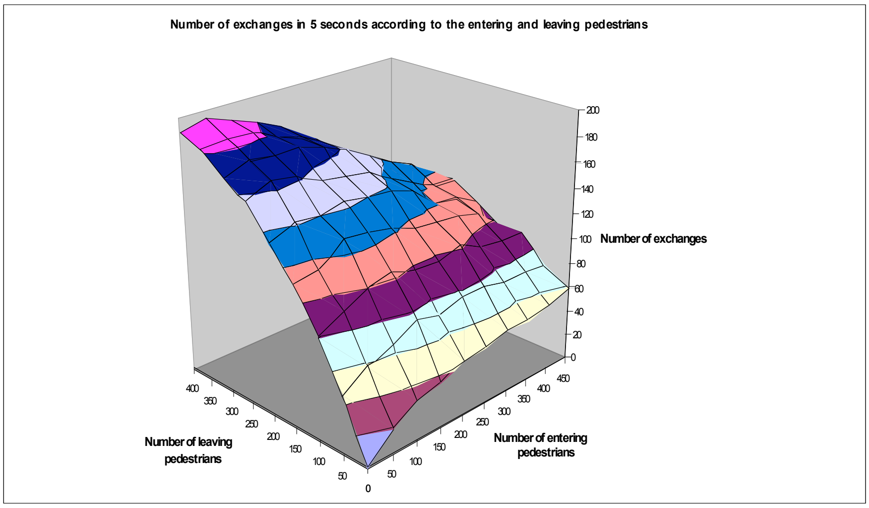

Figure 2: Simulated number of exchanges in 5 second

Video analysis where also conducted, in order to calibrate some key parameters. Figure 3 shows the distribution of passengers waiting for the train on the platform, according to their distance to the entrance of the platform.

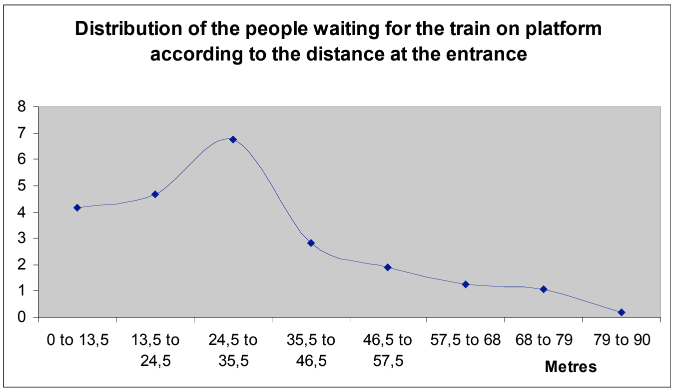

Figure 3: Video analysis of the distribution of passengers on a given platform

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Handling Space and Time in an Ontology-Based Integrated Action Modelling Arena

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Extended abstract for Agent-Based Spatial Simulation International Workshop, 24-25 November 2008, ISC-PIF, Paris, France

Modelling coupled human-environmental systems is vital to understanding key problems in areas including agriculture, pollution control and natural resource management. Particular problems arise in integrating models of the socio-economic aspects of such systems with their biophysical or ecological counterparts. Antle et al (2001) describe three possible degrees of integration: in 'loose coupling' variables are exchanged among submodels; in 'close coupling' submodels may also share common subprocesses; in 'fully integrated' models, human and environmental aspects of the model are specified and constructed together, and there are no autonomous submodels. Grove et al. (2002) argue that approaches short of full integration risk internal inconsistency in the ontology underlying the model (the kinds of things and relationships it describes), and hence in what it implies about the world, particularly in relation to space and time.

In other work, we have argued that formal ontologies may be used to maintain a verifiably consistent underlying conceptual structure (Polhill and Gotts, no date), while reducing the costs of integrated approaches such as those of Antle et al (2001). In the proposed approach, the model structure, and its state at any one time, are represented using an OWL ontology (Web Ontology Language; McGuinness and van Harmelen, 2003), which is common to all the submodels, is constructed before running the model, and can be checked for consistency using automated reasoners such as FaCT++. The model-state is changed by a series of *actions*—functions that map some aspect of the model ontology at time T to part of its state at $T + 1$. The aim is to allow submodels to be combined and recombined readily, relying on automated reasoning tools to uncover ontological inconsistencies. Each type of action expects certain concepts and properties to exist in the model structure ontology—if they do not, then a problem with the proposed set of submodels has been uncovered.

Here we focus on the specifically spatial (and temporal and spatio-temporal) coupling issues that arise in this approach. Spatial, temporal and spatio-temporal relations are all based on more general *mereological* (whole-part) relations, which also apply to entities (e.g. social groups and networks, bureaucratic or legal procedures) which may not be spatially or temporally located in the way physical objects and processes are. Hence we begin with mereology. Any two items in a mereology will have one of five relationships with each other: the two may be disjoint (share no parts), may be equal (share all parts), either may be a proper part of the other, or the two may partially overlap (some parts of each are shared with the other, some parts of each are not shared by the other).

Some properties are inherited by individuals' parts. For example, a farm could be owned or tenanted by a farmer, and hence the fields that are parts of the farm are also owned or tenanted by the same farmer. The actions of a firm are the legal responsibility of its directors; and so are those of parts of it such as the customer service department. In other cases, the whole inherits properties or relations of the parts: if a field contains habitat suitable for a particular species, so does the farm it is part of. Hence properties and relations will need associated mereological inheritance rules in order to check that the components coupled into a model are ontologically consistent.

Actions at multiple scales can cause inconsistencies in coupled models, particularly where the same concept is represented at different levels of abstraction (associated with spatial, temporal or spatio-temporal scale) in various submodels. For example, crop models may specify the yield of a crop from each part of a field, while a model of farmer decision-making will probably need only a total for the field, or even over the whole farm (and note that the *actual* yield may be different from what the farmer *believes*). Problems arise if the farmer decision model has a default way of calculating yield, and fails to use the crop model's output when coupled with that model. We aim to deal with such problems using relations between spatial, temporal or spatio-temporal regions.

A class of such regions, all of the same dimensionality, can form the elements of a mereology. Examples are periods in human history (temporal regions) and patches of the Earth's surface (two-dimensional spatial regions). Relations between regions include mereological ones, but there are also properties of dimensionality, size (duration, in the temporal case), and shape; and topological properties and relations related to boundaries and connectedness. There has been considerable work on inference systems for reasoning

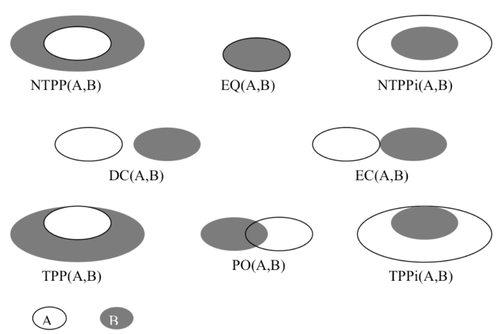

Figure 1: RCC's eight fundamental relations

about qualitative properties and relations of regions, particularly those of topology, which are vital in reasoning about causality. The best -developed systems include Allen's temporal interval calculus (Allen and Kautz 1985), and the Region Connection Calculus (RCC) (Cohn et al 1997). Allen's calculus defines 13 mutually exclusive and jointly exhaustive qualitative relations which two temporal intervals can have. RCC defines a set of eight such relations two spatial regions of the same dimensionality may have (figure 1). Both these sets are refinements of the five possible mereological relations listed above, subdividing one or more of them. The "constraint language" of both calculi is decideable – that is, given any finite set of relations among regions, it can be determined in finite time whether it could be satisfied; Bennett et al (2002) show that the two can be combined to express spatial and temporal relations simultaneously without losing decideability. Hence when building models from multiple submodels including spatial regions, it should be possible to check that the spatio-temporal relations specified are mereologically and topologically consistent.

Physical objects can also form the elements of a mereology, but cannot in general be *identified* with the spatial regions they occupy: physical objects can move, and parts of them can become detached without the object losing its identity, for example. We say a concept is *spatially embedded* if any individual covered by that concept has a region of space it occupies. Processes too can be elements of a mereology, and occupy temporal and spatio-temporal regions, but again cannot be identified with them. Nonetheless, spatially and spatio-temporally embedded entities do share the purely spatial or spatio-temporal properties and relations of the regions they occupy; and we intend to treat the latter as fundamental.

Acknowledgements

This work was funded by the Scottish Government Rural and Environmental Research and Analysis Directorate and by the EU Framework Programme 6 Pathfinder Initiative on Tackling Complexity in Science, project 12186: CAVES.

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The population as a representative consumer in the Alonso model

Wilbert Grevers[1] and Anne van der Veen[2]

Although relatively restrictive in its applications, the original Alonso model (1964) of land use in urban economics is very flexible for hosting alternative interpretations and adding extensions. This paper develops an interpretation as an agent-based model. The approach followed in this paper illustrates how both the equilibrium utility level and the optimal city size can be made endogenous by introducing a simple evolutionary mechanism. Since the resulting equilibrium is identical to the equilibrium of a discrete variant of the Alonso model, the account of the stylised facts is accounts for can be maintained, albeit in a dynamic way.

The strategy of converting the original Alonso model can be summarised in three steps:

1) The distance to the Central Business District (CBD) will be replaced by a local quality level,
2) The spatial equilibrium will be interpreted in terms of best response and Nash equilibrium for a population,
3) An evolutionary selection mechanism will be defined to explore the possibilities of 'growing' a city, by means of self-organisation, without resorting to an optimisation method that would lack a behavioural interpretation at the level of individuals.

Special attention will be devoted to welfare contribution of the city size. It will be shown that an endogenous city size allows for an integration of welfare notions from urban and environmental economics. In line with Fujita and Thisse (2002), this variant of Alonso's model in continuous space accounts for three stylised facts:

1) space per person increases as quality decreases,
2) population density decreases as quality decreases,
3) rent decreases as quality decreases.

These stylised facts are valuable for the welfare analysis, because they are in principle the result of an emergent market equilibrium. However, in addition to the simplifying assumptions concerning the homogeneity and the divisibility of the agents, the most problematic assumption is the existence of an equilibrium beforehand. The problem with this assumption will be shown to be identical to the problem of how market clearing prices are established in a market for a differentiated good.

The main step in the model derivation concerns a reinterpretation of the original model as an evolutionary model. The basis for this reinterpretation is an analogy with a population game from evolutionary game theory. Furthermore, a stochastic variant of this

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population game allows for an additional reinterpretation of a spatial equilibrium. Based on a best response interpretation of CES (Constant Elasticity of Substitution) utility function, the stochastic population game variant of the Alonso model can be shown to be consistent with a model of a *representative consumer*. This model provides a pragmatic general approach to the accommodation of a *population* in a welfare analysis. Finally, the model can be implemented as a multi-agent system (MAS), by established means of translating an evolutionary game theoretic model to an agent-based model (ABM) with a large number of agents, and relatively simple behavioural rules. Here, they are given an *emergent* interpretation which allows for the interpretation of the Alonso model in terms of an elementary self-organising system in terms of a complex dynamical system. In principle any land use pattern can be thought of as the result of strategic interaction between all agents involved. If no agent has an incentive to move in a given configuration, the land use pattern apparently conforms to a 'best response' of the individual agent to the location choices of all other agents. At this level of abstraction, similar approaches can be found in Page (1999) and Otter et al. (2001). The more specific approach followed in this paper defines strategic interaction within the context of the original Alonso model, while the equilibrium land use pattern can be identified explicitly with a Nash equilibrium in a population game. It thereby projects elements from alternative approaches to land use modelling back to traditional economic concepts, while adding the notion of self-organisation still.

The main benefit of adopting evolutionary dynamics and a relation with a CES utility function is the possibility of interpreting the location choices of N agents in terms of consumption by a single representative consumer. The relation between a CES utility function for a differentiated good and the multinomial logit model applied in this paper follows Anderson et al. (1992). It is consistent with a Cobb-Douglas utility function for the representative consumer with a CES sub-utility function for land as a differentiated product. This function is similar to the use of the Dixit-Stiglitz (Dixit and Stiglitz, 1977) function in the New Economic Geography (Fujita et al., 1999). The use of a representative consumer is often criticised because of its lack of realism. If a representative consumer represents N individuals, this can alternatively be interpreted as using N identical, average individuals. It can be argued that the problematic interpretation of the representative consumer in the model developed in this paper mainly would originate in the difficulties that arise when using the behavioural rules of the average agent. However, if the step of a translation to an evolutionary model is followed by a second translation in a multi-agent system, it can contribute to land use modelling within economics by means of systematic disaggregation of a population into *heterogeneous* individuals.

The model developed in this chapter can relatively easily be adapted to enforce segregation of income classes using only endogenous prices and no externalities. This segregation can be interpreted as an extension of the concept of self-organisation to population of heterogeneous agents. Segregation by income is important in the original sorting models because this property corresponds to stratification in econometric estimation. Stratification implies that individual characteristics—in the model presented here restricted to income—can be enforced to correlate with location characteristics in the final equilibrium, in the presence of endogenous prices. It allows the researcher to differentiate the benefits from changes in the level of amenities according to, for example, different income groups. Endogenous sorting is illustrated by assuming that the preference structure depends on the individual characteristics.

To summarise, the main result of this paper is the derivation of a consistent relation between an evolutionary interpretation of the Alonso model from urban economics and a representative consumer. Although the discrete and continuous cases in this paper were restricted to a Cobb-Douglas utility function, it can be shown that the discrete case can be generalised to a CES utility function for a differentiated good. This formulation has the advantage that it allows for an interpretation of a stochastic variant of a population game, while the social welfare function can also be interpreted as the indirect utility function of a representative consumer. The first interpretation can serve as the basis for an agent-based model, since the evolutionary dynamics already defined the behavioural rules at the level of individuals. The latter facilitates the welfare analysis for simplified cases. Finally, the evolutionary assessment of a traditional agglomeration model as the result of self-organising individuals was extended to a model with four subpopulations. It is shown that with a preference structure that is dependent on the individual—or in this case group—characteristics, it is possible to enforce segregation of the groups by means of endogenous prices only. This result corresponds to the stratification of income groups in econometric sorting models.

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"Modelling Dynamic Demand Responsive Transport using an Agent Based Spatial Representation"

Didier Josselin, Christophe Lang** & Nicolas Marilleau****

Our purpose is to discuss how useful can be an agent based representation for modelling a high dynamic system of transport called 'Demand Responsive Transport' (DRT). We first give a few definitions of DRT and also enhance what are the relevant key components of such a transport service. The different flows and objects which are subject to dynamic change are identified. Then we present what could be an appropriate representation of a dynamic DRT based on Multi Agent Systems, using UML that handles the objects we identified and their properties. An example is given at the end of the paper and a more general model is provided and discussed.

I. Demand Responsive Transport

DRT involves different services of transport and definitions according to country or continent mobilities and transportation practice. The one we are talking about now is a dynamic DRT whose key components own a large part of spatial temporal dynamics and thus concern different kinds of flows (information, people, vehicles).

I.1. What is a flexible DRT?

A DRT is a transport service launched when a demand occurs. It differs from classical transport lines in the sense it is sometimes obviously not regular neither in location, nor in times. Its way to operate and its definition depends on the service and country/continent concerned. In USA, the DRTs are defined as flexible services, also called 'dial-a-ride' (TCRP, 2004). In Europe, its definition seems rather different, more *quality of service* oriented. Is is thought as an intermediate form of transport, somewhere between bus and taxi (Grosso et al, 2002) and dedicated to niches like elderly and disabled people (Enoch *et al*., 2004). The last but maybe the most point of view is the African one, where DRTs are called 'bush taxis'. It is a taxi or any vehicle, that starts at more or less predefined times, that serves various destinations depending on the demand, whose price can change according to the travelling/er conditions. The main objective of a bush taxi is to group passengers to provide an economic ratio as high as possible, while giving an acceptable service for the clients (Josselin, AATT2008). It is noticeable that this definition enhances the *efficiency* of the service.

Let us give an example of flexible DRT that would be supported by a multi agent representation and deal with those three somehow complementary and antagonist objectives: efficiency, flexibility and quality of service. It is called the Modulobus (Castex & Josselin, 2008). This system provides each component to tend to be managed in 'real time', thanks to a high level of flexibility and embarked technologies. It is a kind of 'technological flexible bush taxi'. Clients can book using several means (internet, mobile phone...) and ask for a pick up and delivery from door to door or on a set of available located stops. Many vehicles are moving around with different capacities, optimizing their locations though efficient communication, in order to serve the demand and to cover the whole territory. Optimal routes are created 'on fly' according to the various demands, and a necessary minimal quality of service (threshold of delays due to detours which cannot be overtaken). This service can be installed in dense towns, having some potential clients walking down town and asking for the service at any time. This implies some specific properties for the different elements fore moving, communicating, changing their behaviour (vehicles, clients, networks, stops...). The figure 1 shows the global design of the service, the mobile objects, the information flows and what, among all those components, has already been tested and will be in the close future, thanks to PANR REDIT French funds.

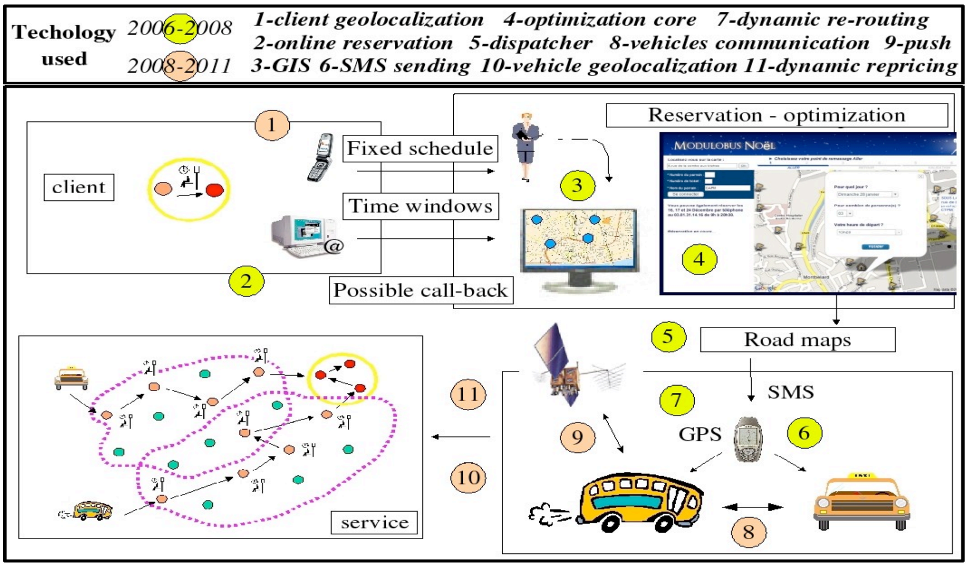

Figure 1 : global design of the service

I.2. Key components of the DRT 'Modulobus'

As shown in the figure, the service process is theoretically linear, from client booking to passenger arriving to his/her destination, with intermediate steps: communication between servers, vehicles and clients, optimization of paths and routes, optimal vehicle assignment and location, dynamic repricing in case of detours, for instance. Whatever complex and sophisticated is a stage in the process, the way to operate the Modulobus service remains quite classical. What is really different states in the presence of dynamic variables attached to fixed or mobile objects, that argues for providing multi-agent modelling. That means that local and global conditions of the service can change quickly and in a large rank: some peak of demands can occur, traffic congestion may reduce the speed, important detours can modify predefined routes due to isolated clients. All these functionalities are enabled by an accurate and efficient software managing this complexity.

Globally, there exist two main types of spatial data or objects having dynamic behaviour. Firstly, those are spatial objects with quasi-fixed locations, which can carry variable flows. Typically, road or communication networks are involved. Roadworks or traffic jams may have an influence on the DRT efficiency as well as SMS delays or server temporary lower capacity may be a problem for managing the service. Nevertheless, the network structure evolves slowly (road and stop location, wireless communication structure) and allows to prevent or, at least, manage, eventual problems.

There exists indeed another type of spatial objects: mobile objects. Beyond some information quantity or flows, locations of these objects may change. For example, a vehicle must be reactive and respond as soon as possible to any demand, while keeping a relative location that enables an efficient next route and a vehicle homogeneous dispersion for supporting it. So does time become an information, useful and used for optimization for dynamic re-routing, dynamic re-pricing, dynamic information services. To enable such a process, the system must know at any time where are the vehicles and the clients (current and next passengers) to launch the optimization kernel in order to accept (or not) a detour, according to expected quality of service, efficiency and flexibility, we mentioned previously.

We can also notice different levels of decision or objects to be depicted:

- global, environmental information or data (e.g. population density in the served areas, providing a probability of demands),
- high level decision centres for optimization (e.g. vehicle fleet management, requiring a global view)

- local spatial information (that can be implemented within each object):
  - spatial information described by variables with continuously changing values (e.g. road network with daily varying flows, that has effect on the routing efficiency),
  - mobile objects (e.g. vehicles, clients; those objects having complex, strong and relatively low predictable levels of information communication).

We already feel that the SMA paradigm might be useful for designing an adequate model for such a dynamic DRT service. Let us see now how can look like this model.

II. Modelling

In this part we will speak about the modelling of the DRT problem.

II.1. RAFALES-SP

The goal of RAFALES-SP methodology (Marilleau *et al*, 2006) is to help out scientists in the definition of spatial mobility models and their simulation. It is composed of an oriented meta-model to describe spatial mobilities and an oriented toolkit to implement mobility simulators. The RAFALE-SP method is based on Agent paradigm. We take the assumption that fine grained mobilities are modelled into individuals and the whole system dynamics are described into the environment. It means that studied mobilities can be described at a microscopic level and other dynamic of a system at a macroscopic level.
To permit the representation of autonomous individuals, each mobile is designed by a cognitive agent and integrates human characteristics. We did this choice to support the description of mobiles that are able of high level decision capacities. This was mandatory to simulate human dynamics, in the case of urban dynamics for instance. However, who can do more can do less and the representation of mobiles with low decision capacities is still possible. VON-BDI (*Value*, *Obligation*, *Norm-Belief*, *Desire*, *Intention)* agents are adapted to our needs because they were created to represent humans. These agents integrate traditional concepts of BDI agents: belief, desire and intention and add specific notions: personal habits (Value) and group habits (Norm). In addition, we have improved VON-BDI agents by a personal and limited perception that represents the mobile limited vision and constrained motion facilities. The agent perception provides a way to introduce mobility and related constraints.
As in most mobility simulation platforms, agents are located on a virtual space, the environment, which represents a real area, for example a town or a soil. In this environment, a reference frame must be chosen in order to determine a unique location for each agent. An environment may be defined as a cellular automaton, a graph or dimensional spaces. The frame of reference will determine mobilities that can be observed during a simulation, so its choice must be considered.
RAFALE-SP represents real mobility by two major elements: the Agent and its Environment. In addition, Interaction between agents and Organization (eg. family, firm) are considered in our framework.
RAFALE-SP have been applied to two major research domain Geography and soil sciences. On the one hand, we have used RAFALE-SP methodology to model and simulate daily urban dynamics (MIRO project). On the other hand, this approach was applied to reproduce evolution of earthworms in a real soil.

II.2. RAFALE-SP for DRT problems

Natively RAFALE-SP may handle many aspects needed to model DRT. As said before, RAFALE-SP is enough generic to model various kinds of mobiles and environment: various behaviours can be assigned to agent to model mobiles and different topologies can be modelled.
The modelling of the DRT can be decomposed in two parts. The first one is the DRT itself (the transport service) and the second one is the urban context (customers, others vehicles, ambient

traffic, roads and crossroads, ...). This last part has been already studied, modelled and simulated inside the MIRO project (Banos *et al.* 2005). Let us notice that some research in the joined fields of Multi-Agent Systems and DRT has already been done (*e.g.* Zargayouna, 2007).

However some specific features linked to the DRT may impact some improvements on the RAFALE-SP method. The first one is the need of representation of a high level decision centre for optimisation. RAFALE-SP allows modelling situated reactive/cognitive agents evolving on a space. In addition, a behaviour can be associated with the space in order to model, for example, the ambient traffic. In this case, a simple behaviour is associated to each element that compose the environment. In the current RAFALE-SP version, there is no feature that allows representing complex global services (*e.g.* high level decision centre) which have no location in the space and have a complex behaviour (*e.g.* to make optimisations). For these reasons, there is a need to improve RAFALE-SP meta-models. To solve this lack, meta-models can be modified by adding a new kind of agent that have no location and body in the space (ghost agents). Nevertheless, these agents should be available by other situated agents that are allowed to interact with them. In addition, a complex and a specific behaviour can be determined (see figure 2).

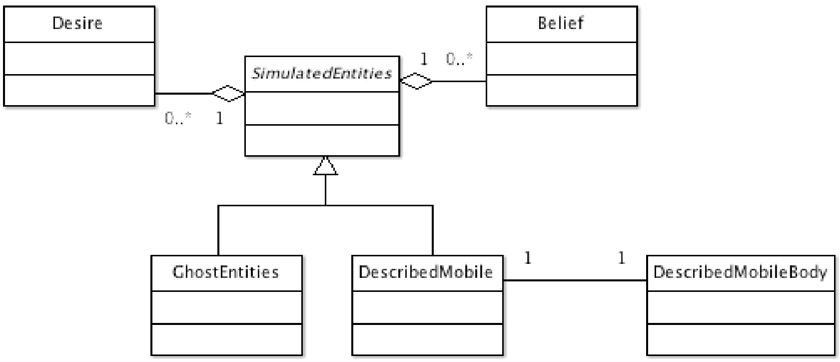

Figure 2 : the ghost agent

The global environment information needed for determining probability of demands has to be added to our model, moreover that will be handled by this kind of agent.

III. Conclusion and future works

In fact, the DRT problem is almost natively supported by the RAFALE-SP method. We have added a new kind of agent (the ghost agents) that will handle the global problems: vehicle fleet management, routing optimisation, interaction between agents. The others aspects are well supported by this method, particularly because of the agents. They are reactive and independent so they are good candidates to represent a such complex system. In a near future, we aim to implement this new kind of agents in the simulator which is associated to RAFALE-SP and simulate some cases of dynamic DRT in the urban context. This will require to precise the interaction protocols between ghost agents and mobile agents.

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Agent-based Route (and Mode) Choice Simulation in Real-World Networks

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Agent-based Route Choice Simulation

Route choice simulation is a well-known application area for agents in traffic simulation. However, in contrast to other steps or layers of traffic simulation, such as traffic demand modelling or traffic flow modelling, no agent-based approach has been established for practically relevant solutions. In existing agent-based traffic simulators such as for example [1], or [2] route choice of agents is only superficially treated, for example by making the agents select from a set of previously given routes or by using a standard shortest-path algorithm.

Agent-based models focussing on route choice tackle more theoretical aspects of emergence of stable distributions of drivers on the routes [3], on the agents' reaction to information [4] or [5], or in capturing individual style [6]. These route choice models are based on game-theory minority concepts and operate on abstract scenarios, mainly consisting of two routes. There, space - the route network - merely is reduced to a few abstract options to decide about. Other models like [7] or [8] tackle agent-based route choice modelling almost without focus on a particular network or other spatial representation.

Having a look onto route choice simulation in practice, it is applied within the realm of ``macroscopic'' traffic simulation for testing the effect of a new ring road, the effect of road pricing, etc. Starting from origin-destination matrices, a simulated traffic participant selects her mode of transportation and route. The resulting costs are evaluated – as they are often represented in form of travel times and depending on the others decision. Based on this information the travellers' distribution is calculated again. The route selection is repeated until some equilibrium is reached. There are different assignment methods up to econometric procedures [9].

Considering the question what agent-based approaches may offer for practically relevant route choice simulation, we first thought about heterogeneity of agents and their decision making. However, we had to notice that necessary data for basing heterogeneous decision making upon - beyond individual origin-destination pairs, but individual preferences for high-speed roads, small numbers of traffic lights, etc - will hardly be available with sufficient reliability. Additionally, we supposed that heterogeneous route choice won't make a difference when thousands of agents are populating a network with just a few reasonable routes for each origin-destination combination. Individual differences might just average out.

Our main idea is that the value of agent-based approach for route choice simulation lies in the flexibility of decision making: their ability to make decisions and re-plan while moving in space based on their local perception. The application area for this feature is the position of information in the network: where to put an accident sign, which variable message sign may contain information about an incident or where to place a police man for organizing a spontaneous bypass in case of an accident or otherwise broken link.

The MoRou-Agent Model

The agent architecture and behaviour in our model is quite simple. Every agent is associated with one origin-destination pair and is equipped with an internal status in that its experiences (= experienced traveltimes) on taken routes are stored. The basic simulation time interval corresponds to one trip from origin to destination.

At the beginning of each round, the agents concurrently determine the shortest path between its individual origin and destination. This is done using a well-known Dijkstra algorithm with the memorized travel times – when considering already known links – or some minimal travel time computed from link length and maximum speed on that link. After calculating, the agents travel on their paths. The number of agent that passed every link is recorded. After all agents have finished their way through the network, the travel times on every link are computed by the world entity based on its load recorded during the complete travel phase, calculated based on established capacity-restraint formulas and communicated to the agents. The simulated traffic participants memorize the values link-wise and use them as realistic costs for the link when not previously known. Repeated experiences are combined with the newest value having the highest weight. This overall iteration is repeated a certain number of rounds (or until no agent changes its route decision).

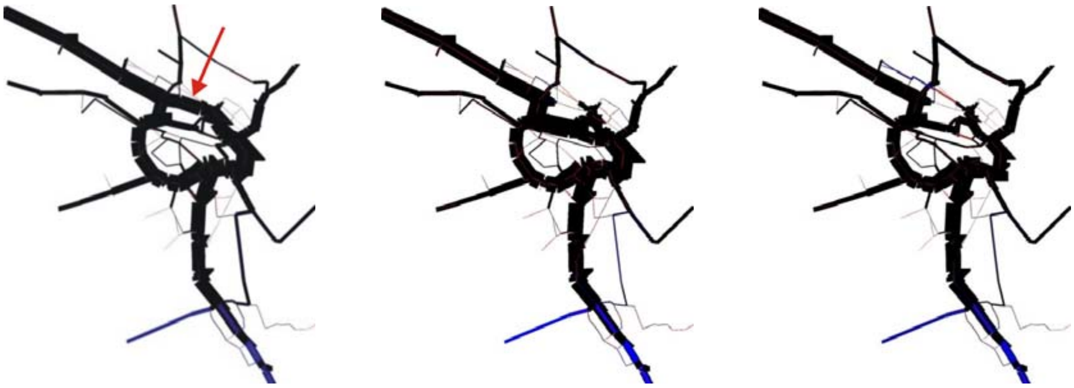
In the specific application described below, after this warm-up period one specific link is marked as broken – for example due to an accident and information about this interruption is positioned in a certain distance from that broken link. When an agent passes this sign, then it re-calculates its remaining route using again a shortest path algorithms based on its beliefs about travel costs on the single links. This resulting traffic distribution is then measured and discussed according to the objective of the simulation study.

The Burgdorf Scenario

As a test scenario we used the road network of Burgdorf, a small Swiss town near Bern. The basic network consists of 268 links (each direction is represented as an extra link) and nodes. The original goal of the project was to develop a model that combines route- and mode choice, therefore we constructed a supernet combining a separate network for each mode via additional links at positions at which a mode change would be possible. Finally, the network our agents are planning and travelling with, contains about 800 links for individual private transportation, walking and public transportation. Using such a structure shortest path algorithms can be applied. However they have to be tailored with route consistency checks prohibiting routes containing two many or impossible mode changes.

Empirical data was available for aggregated load during a standard workday for most links and data from some standard macroscopic traffic simulation (using VISUM, see *www.ptv.de*) could be used to fill the wholes in data. From that standard simulation also an origin-destination matrix constructed based on detailed local population statistics and traveller surveys was available. For every origin-destination pair an agent with the above described behaviour is generated. The route choice of the agents converges fast – after only 5 iterations, almost no change is happening – which is due to the small amount of reasonable alternatives in the standard case.

The particular goal of this simulation study was – besides illustrating the usefulness of an agent-based approach in a realistic scenario – to demonstrate the effects of on-route information onto the overall network status. For this aim, we deleted on particular link after the convergence of the system and gave the drivers the information about the broken link at a certain distance from the broken link. As only at nodes, the driver is allowed to change its route, we count the distance in links or “hops” from the broken link. When the driver perceives that information, it triggers a new planning step. The new route to its individual goal is then followed even if it contains a turn back to the direction the driver came from. Figure 1 shows two example runs where the same link (indicated by the arrow) is broken together with the situation without broken link. When the information is very near to the broken link, then many drivers have to reverse increasing the overall load in the network. Ideally, it is available before the travel is started, however this may not be possible due to the dynamics of the scenario. However, it is very different to the network load distribution in the middle showing that such an agent-based simulation really makes sense.



No broken link 5 Hops away information before start

Figure 1: The effect of information location in the network, comparing the original network load to the one where the information is positioned 5 hops before the accident and compared to the case when the information is available before the start of the travel.

Conclusion

In this abstract, we presented an agent-based model that predicts traffic load distribution in a dynamic traffic network depending on the location of information. The network is a connected supernet consisting of different mode-specific networks so that also for multi-model traffic standard shortest path algorithms can be used.

The agent model is quite simple without particular social or emotional heterogeneities; it contains just a few rules in addition to the capability to compute shortest paths with mode consistency checks and using some form of beliefs about possible travel times. Also the temporal model is very simple, we are not simulating actual traffic flow, just decision making about modes and routes integrating online information. At the beginning we also tested the integration of a traffic flow model capturing the actual driving on the link for producing the travel times more accurately than based on macroscopic formulas. However, this turned out to be unnecessarily complex for the aim of the simulation project – in terms of simulation effort, but also in terms of calibrating the model in a reliable way.

We could show that agent-based simulation is able to demonstrate the effects of information positioning in a road network. Whereas the standard situation without broken link could be validated based on a link-wise comparison of simulated load and given load data, the effect of the travellers' reaction was not validated, just tested for plausibility on the individual agent level. A true validation would need a lot of data that either has to be collected in a real-world situation with blocked links or based on what-if discussions with commuters or other traffic participants sufficiently knowledgeable of the network.

This model is just a starting point. There are several possible enhancements, for example testing more realistic mental map structures, testing more complex evaluations of link costs – not mere traveltime as we did here --, etc. Currently, we are working on applying this model to the dense road network of a larger Swiss town with more than 200k links before computing the supernet structure.

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Circle City: A model to show the interrelationships between the built structure of a city and its social organisation.

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Motivation

The interrelation between the social organisation of the population and the built structure of a city cannot empirical verified because of the lack of micro data. Simulation models offer an alternative study approach. However the results of such models depend strongly on the chosen abstract initial assumptions. Simulation models that examine the process of residential segregation allow the exploration of the effects of various assumptions about the tolerance of the population to different kinds of residents or the effects of rents or land prices. One disadvantage with most of the segregation models is that the built structure of a city is oversimplified represented whereby various built realities are abstracted.

Problem statement

At the present study we emanate from the thesis that the built design of a city has an essential effect on the residential segregation of the population. To verify this thesis the built structure is represented as graph. This representation is based on the developing structure from the streets via the buildings to the flats (Figure 2). The idea is that neighbours who live in the same house, which means that they use the same stairwell or corridor, are more important for each other than the neighbours living in the neighbouring house, meeting each other in a more public place like a minor road. The neighbours in the next road are again less important and, if there is a main road between two residents, the relation of these people is very slight. This different spatial hierarchies are marked with letters from a to f in Figure 2, where each node represents a particular hierarchical level from the individual flat to the motorway.

Approach

With the presented model a true-to-life representation of the built urban structure is suggested by means of a graph based method. The nodes of the graph represent the street segments. An edge is drawn between two nodes if they are connected with a crossroads (Figure 1, A und B). On the basis of the spatial development structure that is represented by a graph, an agent based segregation model is introduced (Figure 1, C). The designed model city is designated

Circle City because of its circular diagram and its rimless structure, which enables the abstract design of every possible spatial configuration. The hierarchy of the urban development structure that can be represented by this model enables a detailed examination of the effects of various designs of flats, houses and streets as well as their interconnection. Different built structures can be captured by means of various weightings between the developing spaces (Figure 3). These weightings represent the different intensities, how the inhabitants perceive their neighbourhood via the various developing spaces.

For the simulation of the residential segregation the households are represented by agents, whose behaviour is orientated on the primary model of Thomas Schelling (1969). According to this model each participant of the housing market tries to get a flat with a neighbourhood and a locality as good as possible.

Findings

Altogether the results of the analysis show that the effects of the built structure of a city on the socio-spatial organisation of the population are relevant, if the tolerance thresholds of the population are already in a critical area. A critical are refers to the area of tolerance thresholds of the population within a small change cause a relatively large effect on the separation of the population. At the same size of the population groups the critical areas for the tolerance thresholds are at 1/number of groups.

Within the critical areas a positive relationship between the size of a city and the separation of the population can be shown by means of the *Circle City* model. This relationship is enforced if the density of the settlement increases. A higher density can be represented in the model for example with more houses per street or more flats per house. Furthermore it can be demonstrated that the built design of the streets as well as of the buildings development has a strong effect on the separation of the population. The socio-spatial organisation of the population depends on the connectivity of the urban road network. A better networked city counteracts the separation of the population.

Conclusions

With the *Circle City* model we have demonstrated that firstly the explicit inclusion of the built structure of a city is an important prerequisite for the simulation of residential segregation and secondly the built design of a city as well as the size and the density of a settlement on certain conditions can have a relevant effect on the residential segregation of the population.

Figures

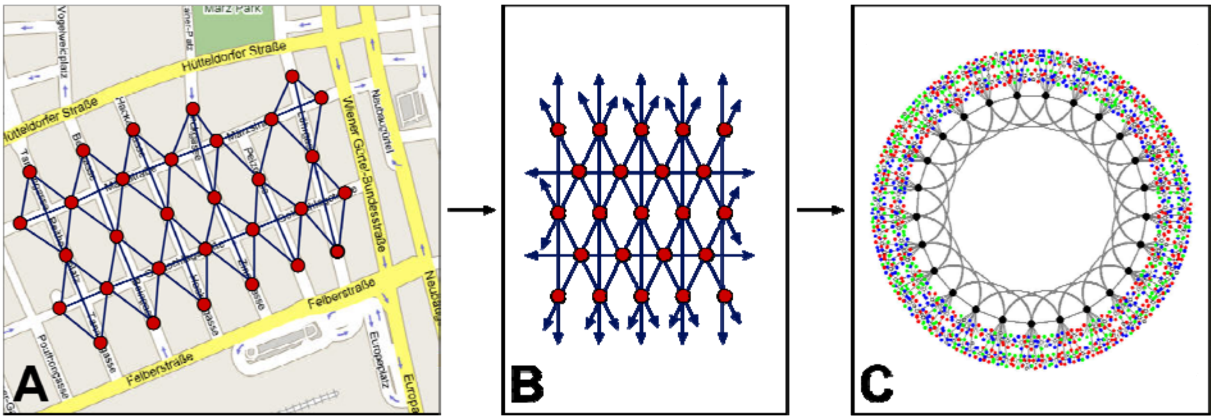

Figure 1: Design of the *Circle City*. Translation of an urban development structure on an abstract *Circle City* model for the simulation of residential segregation. A) Representation of streets and crossroads by nodes and edges. B) Graph based representation of a regular raster street network. C) Graphical illustration of a hierarchical network. Streets are drawn as big black nodes, houses as black bordered white nodes and flats as black bordered gray nodes if empty and coloured if occupied by an agent.

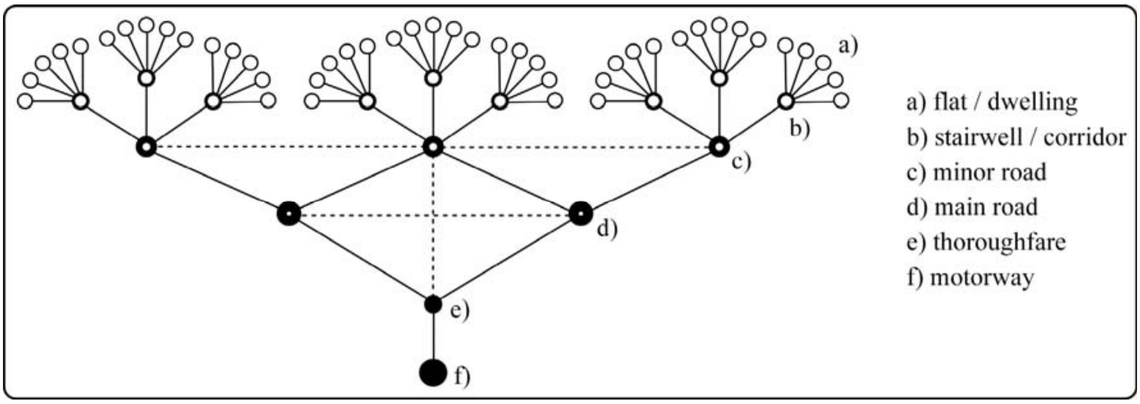

Figure 2: Hierarchy of the urban development structure. The abstract hierarchical network represents the developing structure from a flat to a motorway.

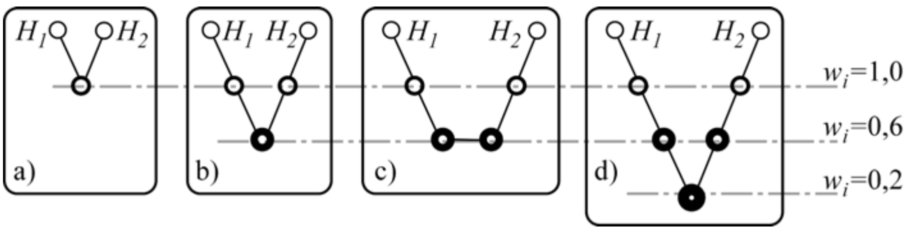

Figure 3: The Graphs a, b, c and d shows different neighbourhood relations of two cells H_1 und H_2 with the corresponding weights w_i per hierarchical level.

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Modelling plague epidemics: structural validation of an Individual-Based Model

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Overview of the modelling process

This presentation is about the modelling process of an epidemic model, SIMPEST, designed to simulate bubonic plague epidemics in a rodent population at a high level of spatial and temporal resolution. In contrast with predictive compartmental models staying at a global level of description, ignoring or averaging variability at a local level, the individual-based approach taken here allows to design structurally realistic models for explanatory purposes: they consider discrete individuals, namely fleas and rats, their spatial behaviour, and the contingency of interactions among them, so that the model reflects the way the real system operates to generate spatial and temporal patterns of the disease.

In this presentation, we address specifically the issue of the validation process of Individual-Based Models designed at a level of resolution at which empirical data are generally lacking to perform a classical outcome validation. We opted then for a validation process so-called "structural validation", by which we evaluate how well the model represents the mechanisms of the disease spread and persistence. After the model structural validity was assessed, we applied it to two empirical situations in the Malagasy focus, in an attempt to calibrate the model, using existing field data to estimate some other lacking data. In a further step, we seek to perform investigations about the spatio-temporal patterns of the disease, across various landscape configurations.

Model details

SIMPEST is implemented in Netlogo 4.0, which enables us to define a schematical grid-based environment representing a village and its surroundings. The level of spatial and temporal resolution is 1.6 meters and 1 minute. The reason why we choose this high level of resolution is that we want to detail the rat activity, including its mobility, in order to localize the various interactions occurring. To avoid excessive computation time, simulations presented for our validation purpose were performed on a 1.76 ha square grid. Cells are characterized by a land use category, associated with a resource coefficient. Fleas and rats are distributed in this environment. Humans, to whom the disease can propagate, are not explicitly represented since they cannot transmit the disease, and thus do not influence the disease dynamics we investigate.

We represent the individuals' behaviour by three kinds of rules:
1) Demographic rules governing rats and fleas reproduction, growth and death are executed daily.
2) Mobility rules are executed every time step (one minute). They make rats move at night, leaving their burrow and looking for some food. They select and go to (one of) the cell owning the highest level of "resource" in a radius of 4 distance units. Free fleas wait for a host passing in the same cell or, if not, in the eight neighbouring cells, to jump and fix on it. They stay fixed until their host dies.

3) The epidemiological cycle follows a SEIR scheme, each individual being characterized by a state of infection: Safe, Exposed (i.e. infected but not yet infectious), Infectious, and then Removed (i.e. immunized or killed). One safe adult flea may get exposed by biting an infectious rat. After the latent period has expired, the flea automatically gets infectious and thus may transmit the disease to another susceptible host. At the end of the infectious period, a rat might recover and become immunized, whereas a flea deterministically dies. Infection and transmission rules occur at a frequency controlled by the "biting frequency" parameter. The disease in the organism has a hourly progression.

To fix parameters governing the individuals' behavioural rules and default values for the initial size, distribution and infection of populations, we mobilize knowledge given by the existing literature and derived from either laboratory experiments or field observations. Consequently, the model is partially independent from the theoretical basis at the global level (Grimm, 1999) and we can use it as a source for our validation task.

Structural validation

Structurally realistic models seek to reach a representational rather than a behavioural accuracy, according to reality (Küppers and Lenhard, 2005). To verify if causal mechanisms are adequately represented in our model, we perform several series of sensitivity analyses, considering the relationships linking the inputs to the outputs and comparing our simulation results to sufficiently general characteristics of the target system: laws garnered from multiple field observations or from theoretical modelling. In other words, we test our bottom-up model, formulated at the individual level, against theoretical knowledge at the population level. However, before using a population-level law to validate an individual-level based model, we have to ensure the law itself has been validated by empirical evidence (Manson, 2002).

With the development of mathematical modelling, the last century has witnessed the emergence of a large body of theory in epidemiology based on compartmental state-variable models (Kermack and McKendrick, 1927; Anderson and May, 1991). The main contribution in this field is the definition of the threshold theorem, stating that the population which is susceptible to infection must exceed a critical density for an epidemic to occur. This threshold is studied through a key variable, the replacement number (R), defined as the average number of secondary infections caused by a typical infectious individual during its entire period of infectiousness. Through time, if the susceptible fraction exceeds a critical value such as $R > 1$, then the disease develops, otherwise it fades out.

Given its general definition, we consider the replacement number (R) as an output variable of our IBM and we compute it by tracking who infected whom during the simulation. A first series of sensitivity analyses is performed to study the effect of varying the initial population size of fleas and rats on the relationship between the global intensity of the epidemics, given by the total number of cases, and the replacement number. Our simulations suggest an exponential relation between these two output variables. In contrast with the generally accepted mathematical based theory stating that an infection dies out if $R < 1$, some infections with $0.5 < R < 1$ persist longer than 100 days, showing periodic epidemic peaks. One potential reason for discrepancy between our model and the theoretical threshold $R = 1$ results from the assumption of the contact network structure (Breban et al., 2007). Traditional mathematical mean-field models implicitly assume the absence of clustering in the contact network so that infectious contacts occur independently. They suppose each infectious individual transmits the disease to exactly R others at each time step. However, this is not the case in our structurally realistic model which respects the contingent nature of interactions. This could explain that an average value of $R < 1$ does not mean that the disease can not propagate for a long while, but also $R > 1$ does not guarantee that an outbreak will ignite a large epidemic (Meyers et al., 2005).

To go further with structural validation, we perform a second series of simulations to investigate the effect of the spatial distribution of the rodent population on the rat indirect contact network structure emerging from the simulations. One indirect contact occurs if one rats shares at least one flea with another rat. We test four basic scenarios by varying both the number of rat family groups and rat mobility. As outputs at a population level, we consider the relationship between the potential of the disease to develop, defined by R, and two properties of the rat indirect contact network: the mean degree and the clustering coefficient. We verify then our simulation results are in accordance with previous theoretical studies (Keeling, 2005): the potential of the disease to develop is reduced by having few contacts (the mean degree is small) or a highly interconnected network structure (the clustering coefficient is large). This occurs as the global rodent dispersal increases.

Discussion

Our presentation discusses how theoretical statements at the population level, as gained from previous modelling studies, can be used to assess the structural validity of an Individual-Based Model. In our case, these theories mainly concern the sensitivity of plague epidemics to the population size and the contact network. However, proceeding with this kind of validation, we have to keep in mind that in some cases, the use of an aggregated model as a validation source is compromised because of its underlying assumptions at the individual level. This has been shown when considering the replacement number R, computed in our simulations by tracking who infected whom, which does not necessarily represent an epidemic threshold parameter as stated by standard theory. This example highlights how an IBM can be at odds with the mean-field theory because the interactions between individuals are explicitly represented. Therefore, our contribution illustrates the need to consider IBMs with theory at a population level in a retroactive way, the one enriching the other towards a better understanding of socio-environmental processes.

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Macroscopic stability study by simulation and statistical estimation of the parameters of a microscopic car-following model based on the regulation of performance and safety.

Lassarre, Roussignol, Tordeux (GARIG-LAMA)

In order to evaluate the impact of the agents'behavior on the safety and performances of a traffic system, we develop an heterogeneous traffic flow module of simulation by means of a multi-agent approach. This kind of approach allows us to underline microscopic mechanisms that establish the macroscopic dynamic of a flow and enables to distinguish agents according to their features.

A car-following model is defined in order to achieve this goal. There are two main traffic situations: the free flow situation in which the driver is not constrained in his behaviour and the situation of pursuit which is an interactive situation where a driver adapts his behaviour according to his neighbours. This situation differs from the free situation where a driver circulates at his desired speed, at a satisfying distance gap.

Two notions are identified based on the concept of regulation :

- The microscopic safety state is a pursuit state in which a driver follows his predecessor at a constant speed and at a satisfying distance gap.
- The regulation strategy is involved, when the predecessor's speed varies or when the distance gap is not satisfying, in order to attain the microscopic safety state.

Bibliographical review. The microscopic modelling of traffic flow is a field in which mathematics has been applied since the late 1950s, which corresponds to a widespread of motor car ownership. The reaction time seems to be an essential parameter involving a delay between information collection and processing. Two variables are rapidly discerned: the distance gap and the difference of speed with the predecessor. We refer to Greenshields, Chandler, Greenberg, Komenati, Sasaki, Edie, Underwood, Newell, Herman, Gazis, Rothery, Montroll, Potts and Pipres works ([1-10]). The models are usually defined by an acceleration function to which correspond different strategies of regulations. A duality is established between the regulation of distance and the regulation of the difference of speed. A microscopic safety state is not explicitly defined (except Newell's model). The microscopic safety state is a consequence of the regulation strategies. The model definition is discrete; the step is equal to the reaction time. The recent progress on computers performances allows the emergence of simulation. Microscopic approaches, usually called multi-agents, are used so as to understand collective phenomena. During the 1990s, a new wave of models appeared. They are henceforth defined by differential systems to which a discretisation scheme is associated. It becomes necessary to discern the simulation step from the reaction time ([11]). The microscopic safety state and the regulation strategy are explicitly defined. The microscopic safety state is modelled by a function of a targeted safety speed (function of distance or time gap) or distance (or time) gap (function of the speed). The regulation strategies are usually modelled by the application of a relaxation time to the speed or the distance (or time) gap and to the safety function. This model allows the convergence of the speed or the distance (or time) gap towards the safety function at an exponential speed. We refer to *Optimal Velocity* ([12]), *Full Velocity Difference* ([13]), *Generalized Force* ([14]), *Intelligent Driver* ([15]) or *Bounded Rational Driver* ([16]) models. The most recent models integrate a time of reaction strictly positive and some strategies of anticipation allowing levelling off. The existence of anticipation strategies results from the following paradox. In a normative approach, we can observe that the integration of a reaction time induces possibilities of collision. Some safety distance (or time) gaps allow avoiding collision. Nevertheless, we observed in the real traffic that some distance (or time) gaps smaller than the values expected by a normative approach. It seems that drivers are enabled to use their anticipation strategies.

Five essential concepts can be extracted from the bibliographical review in order to define a car-following model:

1. The existence of a strictly positive reaction time. The reaction time is introduced in order to incorporate a delay between the neighbours' information purchase and processing.
2. The definition of an explicite microscopic safety state. The introduction of a reaction time allowing collisions justifies this assumption. A link exists between the microscopic safety state and the macroscopic performances of a traffic flow in a homogeneous and safety spatial distribution.
3. The definition of a regulation strategy. Statistical studies show the existence of some typical regulation strategies like the sigmoidale form of the speed in a deceleration situation ([17]).
4. The existence of some anticipation strategies in order to paliate the reaction time. A driver is supposed to estimate the speed of his predecessor according to a neighbourhood information delay by the reaction time.
5. The implementation of an asymmetric longitudinal behaviour. The driver behaviour is different according to an acceleration situation or to a deceleration situation. Besides, implemented mechanical devices are not comparable.

The model's definition. In a safety approach, the reaction time and the time gap seem to be complementary parameters. The reaction time reproduces a physiological delay before a reaction, while the time gap reproduces a physical delay before a possible collision. Therefore, we intend to define a car-following model based on the time gap.
The model is defined by a differential system. The system is made up of two differential equations. The first one comes from physical models of kinematics and allows modelling the displacement of vehicles. The second one, a non-homogeneous first order with variable coefficient differential equation, defines the interaction between the vehicles. The equation induces the convergence at an exponential speed of the time gap towards the safety time gap that is a function of the speed. Such definition allows to restore some typical regulation strategies. A parameter, distinguished between the acceleration and the deceleration phases in order to reproduce an asymmetric longitudinal behaviour, calibrates the speed convergence. A reaction time is explicitly defined, inferring a delay between the measurement and the processing of the predecessor informations. In order to paliate to the reaction time, some anticipation strategies are defined. The predecessor's informations are estimated with information delaying by the reaction time and by assuming the speed of the j predecessor constant. j corresponds to the number of preceding vehicles in local interactions. When the number of vehicles in interaction is equal to one, only the predecessor interferes, it is a case devoid of anticipation. The more important the number of the vehicles in interaction is and the more the estimation is precise.
Four parameters are necessary for the model to work with:

1. The targeted safety time function, defining the microscopic safety state;
2. The quantity calibrating the convergence speed of the time gap;
3. The reaction time delaying information measurement and processing;
4. The number of vehicles in interaction.

Simulation results. During the simulations, a eulirian discretization scheme, mixing explicite and implicite approaches, is defined. A study validates the stability and the attractivity features of the microscopic safety state in a trivial situation where the predecessor's speed is constant. Some simulations, in a straight and cyclic environment, allow studying macroscopic stability, in particular jams emergence. Experimentally, we observe that the system has two stationary states: a first one homogeneous, where the vehicles' spatial distribution and performances are uniform, and a second one heterogeneous, in which one or several kinematic waves seems to spread out indefinitely. The convergence of a system towards two stationary states is used as an indicator of

macroscopic stability. Simulation studies display a strong dependence between the microscopic safety state and the macroscopic stability of a flow.
Two cases are distinguished according to the definition of a constant and a variable targeted safety time. When the targeted safety time is constant and equal to the reaction time, without anticipation, perturbations seem to spread indefinitely without getting larger or smaller. The speed of propagation is constant, independent of regulation strategies parameter, equal to the opposite of the derivative of the flow performances ([18]). Anticipation strategy allows absorbing perturbation. When the targeted safety time is constant and strictly greater than the reaction time, with or without anticipation and whatever the initial conditions, the system seems to converge systematically towards a homogeneous stationary state. When the targeted safety time is constant and strictly lower than the reaction time, as expected in a normative approach, collisions take place. Anticipation strategies allow avoiding collisions, when the targeted safety time is small, by using a sufficient number of vehicles in interaction. When the targeted safety time is variable, we observe that a behaviour where the targeted safety time decreases with speed (called risk-seeking) is a strong factor of macroscopic heterogeneity. The slightest disturbance seems to grow, procreating the training of traffic jam. According to the definition of the targeted safety time function, the system's convergence toward a homogeneous state requires the inclusion of a certain number of vehicles in interaction. Conversely, a behaviour where the targeted safety time increases with speed (called risk-averse) is strongly factor of macroscopic homogeneity.

Statistical estimation of the parameters. A statistical estimation of the model's parameters is necessary to their use. Principally, the statistical estimation consists on the minimization of an error function by using different methods like genetic algorithm ([19] [20]), simplex methods ([21] [22]), or optimization software ([23]). A deviation measurement of an objective variable (like speed or distance gap) between observed trajectories and simulated trajectories (of a vehicle which initial condition and predecessor are real) is used as the error function. The intra-driver variability can be evaluated by the observation of the error induced on the sequence of an individual; while the inter-driver variability can be evaluated by the observation of the error induced one the driver's sample.
Some observed samples of trajectories allow estimating the model's parameters relating to the microscopic safety state and to the regulation strategies. The offered approach distinguishes itself from the before related methods. For the parameter relating to the microscopic safety state, different parametric models are proposed and tested according to the empirical studies done on a sample restricted to some situations identified as stable. Vehicles are distinguished according to their type: motorcycle, car and truck. For the parameters relating to the regulation strategies, some probability laws are supposed a priori on the parameters. Certain parameters are supposed constant for the drivers, whereas others are dynamical. We have not directly estimated the parameters but their probability law and their respective parameters. In this goal, a multi-level statistical model coupled to the Esperance-Maximization algorithm is developed. The first level corresponds to the scale of a driver, the second to the scale of the drivers' sample and the results allow estimating an intra-driver and inter-driver variability.
The obtained results allow to make obvious the differences of behaviour within the traffic flow. Significant differences have been observed between different kind of vehicles and kinds of situations, distinguished between acceleration and deceleration phases. This justifies the existence of an asymmetric longitudinal behaviour. The variability of the noise/error is estimated as low, which justifies the quality of the statistical estimation and the relevance of the model. The results show that in case of acceleration, the motorcycles to have a more abrupt behaviour than the cars, or than the trucks, in adequacy with higher capacities to accelerate for the motorcycles, than the cars, than the trucks. In a deceleration case, we observe the opposite behaviours; the trucks seem to decelerate more vigorously than the cars, or the motorcycles.

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Can geometry explain the socio-economical differences between US and European cities ?

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30 août 2008

Abstract *European and North-american urban systems are different in many ways, and at different scales of analysis. At the intra-urban scale, they oppose by spatial repartition of socio-economical activities, and spatial configurations of density and land rent prices. In this paper, we argue that these spatial repartition differences between US and European cities can be partly explained by another difference, which lies in the geometry of their streets networks. We wish to prove the validity of our hypothesis by the modeling of localisation mechanisms of urban functions inside the city. To this end, we developed* SIMPOPNANO*, an agent-based model that we present in this paper.*

1 Introduction

European and North-american urban systems are different in many ways, and at different scales of analysis, including the intra-urban and the inter-urban scales [BPVM07]. At the city scale, if we consider globally the set of cities of size between one and three millions of inhabitants, some indicators throw light upon these differences.

Firstly, the average superficy of the american city is two times larger than the european's one, according to the city's definition in use in Moriconi's Géopolis database, as shown in [Del08]. Secondly, in correlation with the previous point, density of occupation of floor space is clearly lower in United States than in Europe, which gives rise to more sprawled cities. Third, different studies on the land rent prices repartition show significant differences : if the evolution of this price with the distance to the city's center can be well approximated by a Pareto's law[1] in both systems, the absolute value of

[1] $P = aD^{-b}$, with P the rent price of the spatial unit and D its distance to the city's center

the parameter b is stronger in european cities than in american ones. We'll refer to these observed differences in terms of spatial repartition of activities, density of residents and rent prices as *spatial socio-economical* differences.

Another major, historical difference between cities of the two continents lies in their *geometry*. We define the geometrical form of a city as being the combination of the topology of its streets network and the commutation speeds associated to that network. As a result of the different temporalities on which they have been built [CPRSJ94], old european cities fondamentaly differ from recent US cities both in their topology and their commutation speeds, and so in their *accessibility* repartition schemes. Even if some cities in both systems are remarkable by their singularity, it still makes sense to oppose their typical topology. The european city, built around a historical center by progressive accumulation of settlement, has a form rather radiocentric. The american city has a characteristic grid scheme [BG95]. In addition to these topological differences, the construction of numerous US cities (in particular latest west coast cities) has been contemporary of the development of the car industry, and they have been built upon a network of highways. The result is that average intra-urban commutation speeds are clearly higher in the US, due to infrastructures more adapted. An actualized picture of these intra-urban speed differences between the two continents is given by a comparative look upon two recent studies[2][3], which we can summarized as follows : during the same amount of time, the US commuter can travel a distance two times longer than its european counterpart.

Then, the geographical question we're interested in can be formulated this way : are the *geometrical* differences sufficient to explain the differences in *spatial socio-economical* repartition patterns ?

Can the same localisation processes, occuring on different geometries, lead to well differentiated spatial repartition patterns ? It has often been assumed in analytical studies that such a link between geometry and socio-economical patterns exists, but other factors are generally mentionned to explain these socio-economical spatial differences (cultural preferences of americans for country life, faster adaptation of land rent prices to market dynamics [GG98]). To our knowledge, the causal nature of that link has never been studied by a quantitative and iterative modeling approach. We choose to tackle this question by the mean of computer simulation.

Our goal is then to build a generic simulation model that will embed these common processes, and that will be able to reproduce the mentionned socio-economical differences when executed with two distinct sets of geometrical

[2] "Vitesses de déplacement en Ile-de-France", LVMT laboratory study

[3] "Average commutation speeds in the 40 US biggest metropolis"

parameters values. To this end we have developed a generic multi-agent model of urban functions localisation, named simpopNano, that we present in section 2, while section 3 presents its realisation. We conclude by evoking the calibration and perspectives for the following research.

2 simpopNano : an agent based model of urban functions localisation at the city scale

The approach that we chose consist in developing a generic model of urban functions localisation (economic, administrative and residential) at the intra-city scale, that can be instanciated in two separate instanciated models, namely the European model and the US one. The two differ only by their spatial parameters, i.e. the geometry of the city, and the commuting speeds, which will enable us to study the impact of these parameters on the evolution of the urban system. The time scale we consider is the period running from 1800 to 2000.

This modeling is difficult for at least three reasons :

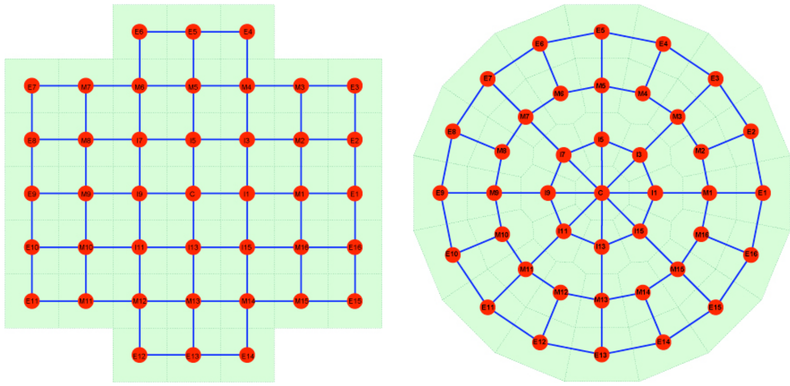
1. The urban space, its characterization and its evolution through time require sophisticated data representation.
2. A complete model of the underlying dynamics, including historical demographical et economical growth is out of reach because of the complexity of the implied processes and the lack of relevant data. Therefore, sensible simplifications must be done in order to develop a workable model.
3. To validate, the unknown parameters of the simulation must be tuned (in their plausible range) to recover the available historical data.

These three point will be developped in the complete paper.

To face these difficulties, we adopt an agent-based modeling approach.

We point out the *iterative* and *incremental* aspects of our modeling approach : how much differences is it necessary to inject in the agents of the two instanciated models in order to observe different and representative classes of behaviour ? What is the minimal set of structural differences that allows to clearly separate US from European simulated cities ?

The general principle underlying our approach is the following : we define two kinds of entities, Area agents q_j and Function agents f_i. Each Area agent represents a piece of the city space, and each Function agent reprensents a particular family of related socio-economical activities. By modeling the concurrential repartition of the employees of f_i on the q_j, differienciations



(a) (b)

FIG. 1 – Theoretical graphs of (a)the US city and (b)the European city[Del08]

between areas emerge dynamically. At each iteration, we quantify the spatial configurations in the city through multiple spatial indicators that are used to compare the model's outputs to the data we collected.

Each area q_j is described by a set of state attributes which evolve during simulation time as they are modified by the model's rules. These state attributes include the number of employees of each function in the area, economical potential, rent price, and accessibility level, which depends of the position of the area/node in the urban graph. The two theoretical graphs we use to represent the topological differences between US and European cities are represented in 1.

Function agents f_i represent urban functions. We chose to keep the functional typology defined in the SIMPOP2 project[4]. Functions differenciate by their localisation strategies. Each simulation step corresponds to a concurrential localisation process between Functions for occupying the most attractive city's Areas. A complete specification of the model algorithms and formulas will be given in the full paper.

3 Realisation

This model has been implemented in a software written with the Objective-C language and upon the SWARM agent-based library[5][MBLA96] of the Santa Fe Institute. The software presently consists in approximately 5.000 lines of code and is easily portable.

[4]see http ://www.simpop.parisgeo.cnrs.fr/theGenericModel/attributes.php for a complete description

[5]www.swarm.org

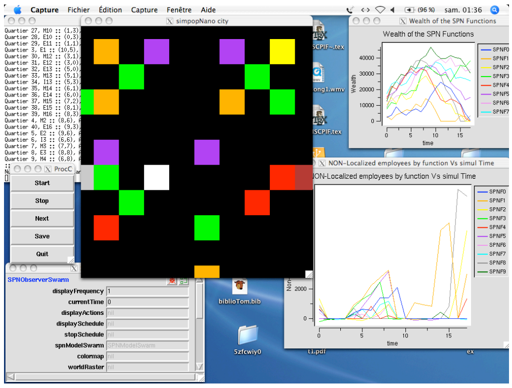


FIG. 2 – Model execution with the real-time graphical mode activated

The Swarm multi-agent platform is interesting because it offers a clear meta model and scheduling facilities. Agents can either be simple objects or swarms, i.e. agents that contain embedded agents, which themselves can be single objects or swarms, etc. It is then possible to define hierarchies of agents, and easily define the way they schedule their actions.

Two modes are allowed : a interactive simulation mode, which allows the user to setup and execute the model with a real-time graphical interface. This mode is useful for demonstrating purposes, and when working with the geographers to analyse the dynamical behaviour of the model during a run, or for a particulary interesting set of parameter's values. during a run is shown in 2. The other mode is a batch mode which allows to experiment in depth with the model, by automatically running consecutive simulations from the specifications of the set of values to test for each parameters.

For the issue of the calibration, we have developped several metrics to evaluate the outputs of a simulation. These « scores »indicate how good the simulation results are at different levels of observations.

As the output facilities offered in Swarm are not sufficient with what we needed, we interfaced our simulator with the MapInfo GIS to automatically generate temporal series of localisations maps.

4 Conclusion

Simulations are currently done and the first results obtained with the SIMPOPNANO model will be presented and discussed during the workshop and in the full paper. Perspectives for following research include coupling the SIMPOPNANO and SIMPOP2 models to produce a multi-scale and multi-agent urban simulator. This coupling and its reallisation will be discussed in the full paper.

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MICROPOLIS

An Agent Based Model to Simulate Scattered Urbanisation Dynamic for Forest Fire Risk Management Planning.

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Introduction

Land cover changes lead to new environmental risks. Many vulnerable zones are extending while environmental hazards often become higher because of the climatic global change: for example flooding risks increase because of urban sprawl. In Mediterranean areas, at local scale, forest fire risk increases because discontinuous urban zones are getting in contact with extending forest zones, which are developing on abandoned agricultural lands. Local land planners who have to manage the urbanisation process and other land cover changes should take into account the environmental risk increase. They need decision support tools able to provide a representation of territorial dynamics which might occur during the planning period. Simulation tools are well adapted to provide this information.

Such simulators are based on spatial dynamic models. Most land cover change models use cellular automata [Langlois 97], [Dubos-Paillard 03], very convenient in the representation of spatial process, such as spatial diffusion. However, cellular automata have limits, if neighbouring is not the main spatial relationship that determines the dynamic. In the case of discontinuous urbanisation process, the dynamic is mainly determined by social actors' strategies, including many spatial and non spatial parameters.

In order to represent scattered urbanisation process in periurban areas and its consequences on forest fire risk dynamic at local scale, we developed an agent based simulator called MICROPOLIS, which is considered as a metaphor of the social system functioning on a local territory and producing discontinuously urbanised areas (Maillé 2008). After having described the agent based model throw de duality of social agents versus spatial agents, we analyse some results of simulations.

Tow types of agents: social agents and spatial agents

MICROPOLIS is a spatial dynamic simulator implementing a cognitive agent based model where interact two types of agents: spatial agents and social agents. Social agents represent social actors in the real world local territory involved in the determination or control of scattered urbanisation process. Spatial agents are agentified geographical objects stemming from the local GIS (Batty 2000).

1/ Social agents system: a metaphor of the real world local social system

Social agents have got a simple and local spatial representation of the territory organisation, usually a list of geographical objects they can be interested in, with some aggregated spatial indicator (area and position in some cases). They are not situated and don't have any spatial representation of themselves. They have complex behaviours, only partly funded on spatial reasoning. Some also have economic behaviours, implementing hedonic model (Napoleone 2005).

There are five classes of social agents:

- "*Land_owner*": it represents any individual actor owning plots of agricultural or forest land with no building on. It has got two main behaviours :
    - It negotiates with other social agents to sale owned plots
    - It split its large plots in some parts so that the size is suitable to install new buildings on it in relation with the rules of the plan. So it creates new spatial structures.

- *"Buyer"*: it represents actor looking for a plot of land to buy to build a house. Its main behaviour is to choose a plot in relation with its geographical characters, and negotiate the price with the "land_owner". Then it can choose either to build a house immediately or to wait.

- "*Plotter*": it represents economic actor able to buy large plots of land and then split them into little plots which size is suitable to install new buildings on it in relation with the rules of the plan.

- "*Geometer*": it represents the real world geometer executing specifications for spatial operations on plots of land; in particular splitting and fusion, ordered buy other social agents, "land_owner" or "plotter". However, optimisation for these spatial operation are realised by spatial agents. Geometers make the link between social agents and spatial agents.

- "*Land_manager*" is unique and has mainly a role of information spreading and coordination.

2/ Spatial agents: from centralized to distributed spatial analysis process

Spatial agents have the representation of their own "spatiality" in their knowledge database (their spatial description) (Rodriguez 2002). They can get information about their neighbourhood by exchanging messages with others spatial agents (Duchêne 2001). They usually represent one continuous geographical object present in the GIS database. Then, if two geographical objects merge, or if one geographical object split up, their agents also have to "merge" or "split up".

The class of spatial agents is determined by the class of spatial object they stem from (plot, building, etc.).

Spatial agents have only "spatial analysis behaviours". They act in a "local" sub multi-agents system, initiated by a geometer. Their aim is to optimize spatial operation specified by a geometer. In this purpose, they first select the best spatial analysis function (or function sequence) to operate in order to realise the operation ordered by the geometer. These functions are the following:

- *Repositioning*: this function concerns mainly punctual agents
- *Reshaping*: this function concerns polygon agents like plots of land
- *Merging*: (polygon agents)
- *Splitting*: (polygon agents)

Modalities of these functions are negotiated between spatial agents in order to *pseudo*-optimize the operation ordered by the geometer. Distributing the optimisation process allows to use simple spatial analysis algorithms. It also allows easily integrating localised spatial variables in the optimisation model. Finally, it produces a non-deterministic result that better reflect the real world process.

Results

MICROPOLIS has been tested on the real terrain of a whole commune territory of the Bouches-du-Rhône French Department (Meyreuil). The aim was to compare different scenarios of land management plan (PLU: Local Urbanisation Plan), in terms of their efficiency on medium term risk limitation. The main input data is the cadastre vector layer, the PLU scenario on its semantic vector map form (semantic data related to the layer specify "building" conditions: minimum plot size required, possible number of building per plot, authorised surface of buildings, etc.), and the land cover vector map (agricultural land, forest land, continuous urban lands, etc.). Some geographical attributes (mean height, mean slope, mean aspect, etc. of plots) are added to the cadastre layer. Risk is calculated by applying a "risk global spatial model (raster)", assessing the relationship between fuel areas (forest) and vulnerable areas (scattered buildings and continuous urban zones) (Lampin 07).

Results show that risk usually dramatically increases at the beginning of the plan because large forest (and sloppy) plots are first chosen by buyers to install their house. The risk becomes maximum when fuel and vulnerable areas are "equilibrated" (the Schannon index is maximum). In some particular zones, risk then decrease because houses density increase and then fuel mass decrease. In some other zones, risk remains constant.

Conclusion

MICROPOLIS is a spatial multi-agents based simulator of the scattered urbanisation process at "micro-local" scale. Social agents representing real world social actors are endowed with partial spatial representation of the territory and interact with spatial agents having purely spatial analysis behaviour. Results show constant tendencies that can be controlled by land planners. Opposite to some other simulation tools, like meteorological simulators based on numerical models, MICROPOLIS has no *predictive* ambition but only *prospective*. It describes *present* processes and their possible consequences in order to support *present* land planning decision.

MICROPOLIS is integrated in a larger system where it interacts with other spatio-dynamic models, able to represent fuel dynamic (Afforsim (Prevosto 2003), Capsis (de Coligny 2008), etc.). An agent based integration platform called Pyroxene (Maillé 2008) is specifically designed to operate this integration.

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Large-scale MAS of urban citizens - preliminary results from the application of MATSIM to Lyon

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ABSTRACT

This paper presents preliminary results of the application of MATSIM, a Multi-Agent Transportation SIMulation toolkit to the case of the metropolitan area of Lyon, France. The ultimate goal is to develop a model which can be used to investigate innovative transportation policies at the city level and that captures enough adaptation mechanisms to describe travel behavior in relevant details. MATSIM is designed to allow for the simulation of large cities at the individual level, thereby simulating the daily schedules and mobility patterns of millions of individuals. The computing challenges set aside, there are other obstacles (statistical, ethical, conceptual) to construct coherent models that enable the analysis and the forecast *in silico* of urban systems. We address here some of the aspects of modeling initial travel patterns.

We first discus the problem of creating a synthetic population of simulated agents. This problem has concerned researchers for several years concurrently with the growth in the numbers of studies on activity-based travel behavior. Activity-based models typically require as input a population with detailed attributes such as gender, age, car-ownership, level of income, education level, etc. However, person information with such level of detail is normally very difficult to acquire in reality due to legal restriction, privacy issues and cost of collection. Most data sources available are usually at the aggregate level such as the total number of population by zones, population classified by age and sex, and so on. This leads to a problem on how to create population with full attributes from the available aggregated sources. A key motivation to pursue the development of multi-agent systems is to understand and to model the vast heterogeneity of human behavior. Therefore, capturing the correlations across those attributes at an early stage of the modeling is crucial to avoid propagating biases that could lead to irrelevant conclusions. Despite the growth of activity-based models in the transportation literature, there are few papers discussing which approach is the best way to generate the synthetic population. The techniques found in the literature can be categorized in three parts: *(1) Regression techniques* (the demographic characteristics of population are estimated as a function of some other characteristics calculated from a survey data for instance), *(2) IPF technique with Monte Carlo simulation* and the use of *(3) Other micro-simulation techniques* such as genetic algorithms. We used IPF mainly for its advantages, its suitability to our data and its reported performances in similar projects such as the works of Arentze et al

(2000) for the Dutch Albatross project and of Frick and Axhausen (2004) for the MATSIM application to Zurich, Switzerland. Our main sources of data consist of (1) an exhaustive census of approximately 660 thousand households in the area; (2) aggregate information about income distribution at the municipality level and (3) the results of a detailed travel survey conducted over more than 27 thousand individuals (11 thousand households). The first task was to run IPF to generate a relevant population of *individuals* by disaggregating the information about *household*s while imputing, at the same time, all the precious information about travel behavior contained in the survey. Practically speaking, this implies to infer age, gender, number of children, motorization, level of income at the individual level as well a realistic activity chains for each agent in the system. (An activity chain is a description of a daily schedule such as *"home-work-shopping-work-home"*.) It was also important to keep the individual agents in household with structures consistent with the data. Indeed, many travel decisions are taken at the intra-household level, such as car usage and trip scheduling. Figure 1 illustrates the variety of activity chains exhibited by the travel survey.

Act-Chain	Work-Full	Act-Chain	Work-Par	Act-Chain	Retire	Act-Chain	Student	Act-Chain	Others
HcWcH	16.64	HcWcH	6.98	HcLcH	8.25	HpEpH	13.12	HcScH	5.06
HcWcHcWcH	4.15	HpWpH	3.83	HwSwH	7.49	HwKwH	4.78	HcLcH	4.73
HpWpH	3.88	HcWcHcWcH	2.40	HcScH	7.11	HcKcH	4.23	HwSwH	4.47
HcWcHcLcH	1.83	HcScH	1.71	HwLwH	5.03	HwKwHwKwH	4.22	HwLwH	2.71
HcWcScH	1.56	HcAcWcAcH	1.55	HwSwHwLwH	2.45	HwEwHwEwH	3.36	HpSpH	1.59
HcWcLcWcH	1.34	HwWwH	1.45	HpLpH	2.09	HwEwH	3.01	HwAwHwAwH	1.54
HcAcWcH	1.17	HcLcH	1.45	HcCcH	1.46	HcEcH	2.55	HwAwHwAwHwAwHwAwH	1.52
HcWwLwWcH	1.07	HcAcWcH	0.99	HcScScH	1.42	HcKcHcKcH	1.81	HpLpH	1.26
HwWwH	1.05	HcWcScH	0.97	HcScHcLcH	1.39	HcLcH	1.67	HcMcH	1.15
HwWwHwWwH	0.97	HcWcHcLcH	0.88	HpSpH	1.24	HpEpHpEpH	1.64	HpCpH	1.02
HcWcWcWcH	0.96	HcWcHcAcH	0.79	HcLcHcLcH	1.22	HpEpHcLcH	1.36	HcAcHcAcHcAcHcAcH	0.99
HcWcLcH	0.94	HcWcHcScH	0.75	HwSwHcLcH	1.19	HcEpH	1.15	HcLcHcLcH	0.90
HcAcWcAcH	0.92	HwWwHwWwH	0.74	HwSwSwH	1.06	HpEcH	0.92	HcScHcLcH	0.83
HcWcHcScH	0.91	HcScHcLcH	0.71	HwLwHwLwH	0.93	HpEpHwLwH	0.78	HcAcH	0.81
HcScH	0.85	HwSwH	0.64	HcScHcScH	0.84	HcKwH	0.75	HcScScH	0.79
HcWcWcH	0.74	HcWcLcWcH	0.56	HcAcH	0.73	HpEwLwEpH	0.74	HcCcH	0.77
HcLcH	0.71	HwLwH	0.56	HcScLcH	0.73	HcEcHcEcH	0.67	HcLcLcH	0.75
HcWcAcH	0.69	HcWcAcH	0.45	HcScHwLwH	0.67	HwLwH	0.63	HwSwHwLwH	0.74
HcWcHwLwH	0.67	HcAcHcAcH	0.44	HwSwHcScH	0.58	HcKcHcLcH	0.56	HcAcHcAcH	0.66

(H =home K=kindergarten c =car w = walk W=work C =health care p =public transport u = others E =education M =maintenance b =bike S=shopping A =accompany m =motorbike L=leisure)

Figure 1: Total shares of activity chains from the travel survey (small caps are travel modes, big caps are activities). Interestingly, the home-to-work-and-back car trip makes only 19% of all patterns, a fact consistent with most European travel surveys.

The outcome of the generation synthetic population consists in a couple of large XML files with the full information about individual travel patterns. MATSIM uses fairly verbose XML (see Figure 2) to ease the inter-operability of modules (i.e. behavioral models) that modify the contents of the activity chains.

So far, the only reference to spatial locations that has been added is the home of the individuals. A first behavioral model (Marchal 2005) which has been coded in MATSIM is applied to the population to generate workplaces and other locations of "primary activities" (e.g. education for students). Figure 3 shows the goodness of fit with the workplaces extracted from the travel survey.

As a conclusion, is important to underline here the philosophy of the approach : almost none of the spatial decisions are "built-in" the data structures: MATSIM relies on sound behavioral modules to impute the outcome of travel (and spatial) decisions from the demographics and from the feedback of the mobility simulation.

Figure 2: synthetic population in XML MATSIM format:

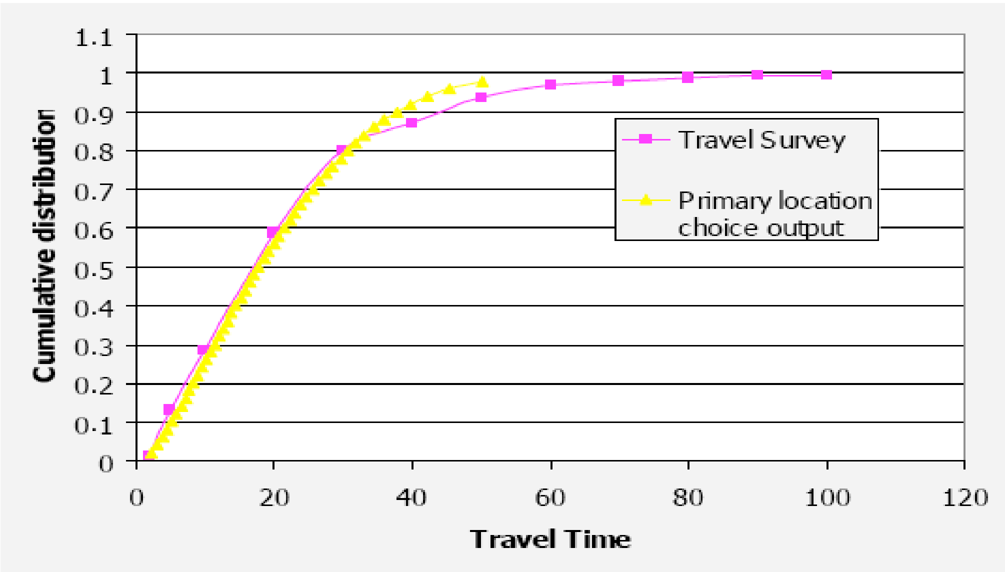
Household file:

```
<household   id="1"   persons="1   2"   nocars="1"   income="27546.0"   internet="no"
habitat="petitColletif" occupation="proprietaire" parking="gratuit"/>
<household   id="2"   persons="3   4"   nocars="2"   income="33906.0"   internet="yes"
habitat="individuelIsole" occupation="proprietaire" parking="gratuit"/>
...
```

Person file:

```
<person id="1" sex="m" age="25" license="yes" car_avail="always" employed="yes">
        <knowledge>
                <activity type="home"><location id="1"/></activity>
        </knowledge>
        <plan selected="yes">
                <act type="home" x="798882" y="2113975" start_time="00:00:00"
end_time="06:00:00" duration="06:00:00"/>
                <leg mode="car"/>
                <act type="work" link="123" start_time="07:00:00" end_time="16:00:00"
dur="09:00:00
"/>
...
```

FIGURE 3



Comparison travel time distribution between travel survey and the output from primary location choice

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Toward Geographic agents

Team MIRO[1]

When it comes to spatial modelling and simulation, geographers often like to remind how much “spatial is special”. This point of view led to dramatic changes in the way statistic theory may be applied to spatial problems (eg Bailey and Gattrel, 1995 ; Brunsdon et al., 1996 ; Fotheringham et al., 2000), in order to take into account the very nature of this specific dimension. However, according to current developments in the field of spatial agent based modelling, it seems that this story has to be told again. Indeed, most of the models developed exploit the concept of “situated agents”, a very restrictive version of what could be “geographic agents”. We therefore took the opportunity of the MIRO project, aimed at exploring daily mobility in urban environments, to begin addressing that fundamental issue.

Situated agents

A large number of researches intend to model real complex systems and a significant proportion of them rely on ABM (Agent Based Modelling) to achieve this goal. Most of them follow the definition proposed by Ferber (Ferber, 1999). He defines a situated agent as an autonomous entity which: (i) has a location in an evolution space, (ii) has a body (a representation of himself) in the space, (iii) is driven by a survival or satisfaction function, (iv) evolves in space and modify it according to limited skills, (v) has a limited perceive of the space. It may be noticed that spatially explicit ABM, whatever their inspiration comes from statistical physics (Schweitzer, 2003) or geography (Batty, 2005), often rely to that approach, by simply specifying the “evolution space” as a geometric or geographic space. Generally speaking two main categories of situated agent can be identified: (i) ABM in which agent behaviour is impacted by space, often through a stimulus-response process (ii) ABM in which agents try to achieve scheduled tasks. In the first case, agents change their trajectories and behaviour according to their very limited and localised perception of the environment. In the second case, agents are assigned an ordered and dynamic task list (eg. Chu et al., 2008). Therefore, their trajectory results from their ability to achieve these tasks: agents select the first task to be achieved, they compute a trip, move, achieve the task, select the second task and so on...
However, these two different approaches rarely consider time as a limited resource: the temporal dimension is often introduced simply as a simulation step, and very rarely as a dynamic parameter of agent behaviour.

Geographic agents in MIRO

When exploring daily movements in modern cities, one may wonder whether this limited spatio-temporal vision is adapted to the problem at hand. Indeed, given our biological and social nature we, as human beings, develop highly sophisticated spatio-temporal behaviours. As a matter of fact, in MIRO we imagined agents having very specialised capacities (figure 1).
Generated from real data in order to be representative of the population under study, our agents are assigned a list of daily activities, as well as fixed home and work places. Their objective, during a given simulation, is therefore to organise and schedule their activities, taking into account constraints imposed by their environment, including other agents. It may be noticed that, at first, we did not assume our geographic agents to be simply economic agents localised in space.
Our objective is to make the mobile agents move around in the virtual urban environment, so that their travel, and more specifically their changes of behavior, may be observed. Behavioral changes may stem from three categories of causes: non-specifiable circumstances, the enlargement of one’s cognitive map, or structural changes in one’s environment (such as alterations in the road network and/or transportation supply, changes in available services…) that may be related to urban planning scenarios.

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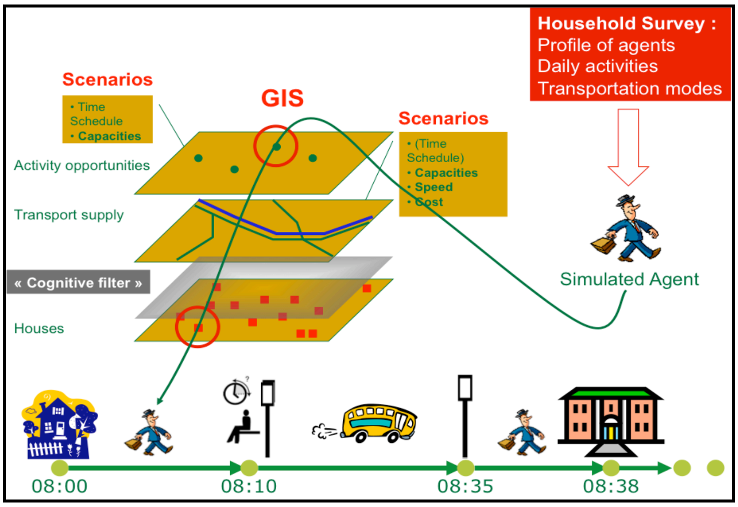

Figure 1: Characteristics and goals of geographic agents in MIRO

In order to reach this goal, our agents perceive their local environment (roads, places,agents). This dynamic feature is also linked to an internal knowledge, which is by essence incomplete. They also possess a list of tasks to achieve in the day time: go to work, feed themselves, go to school for kids and so on... As a consequence, our simulated mobile agents have to construct a daily activity schedule, following specified temporal rules and taking into account any constraints encountered. At first, they formulate a plan based on whatever facts they know and on their list of tasks to be achieved in the day time. That schedule determines a path to cover. Then each agent moves along the planned trajectory. This plan can be altered at any moment by unforeseen turns of event, for example if the moving agent notices the build up of a traffic jam. In that case, an alternate route is devised.
Over simulation time, agents go on learning, thanks to their perception of the world and through interactions they may have with their surroundings (static and dynamic) and with other moving agents. Their initial schedule calculated on the basis of preliminary knowledge can evolve during the course of a simulation: thus a mobile agent finding himself behind-schedule on d-day, might try to reduce his lateness on d-day+1, for example, by modifying his departure time.

Implementation and first results

The Miro model is implemented on a distributed simulator which has been tested on a network composed of four computers. This simulator is based on the RAFALE-SP (Marilleau *et al.*, 2006) toolkit (the kernel of the simulator), the JoNAS (http://jonas.objectweb.org) application server (to store the town map) and Sicstus prolog (http://www.sics.se/isl/sicstuswww/site/index.html) to compute timetables (that organize daily activities of agents).

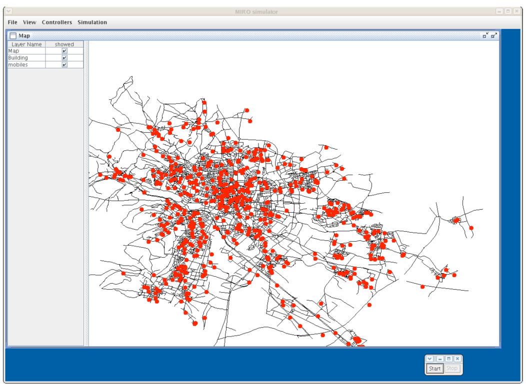

Figure 2: Simulator interface

At the beginning of a simulation, a specified number of agents are loaded and parametrized by a set of beliefs, tasks and locations. From their knowledge, agents compute a timetable for the currend day. Then, they try to accomplish their planning during the first simulated day, moving into the virtual town and modifying their knowledge according to their perception. At the end of the first simulated day, agents compute a new timetable which take into account their past experience. These new timetables are executed by agents during the second simulated day and this is reproduced for a specified number of days. After the simulation, results are post-processed, statistics and maps being generated.

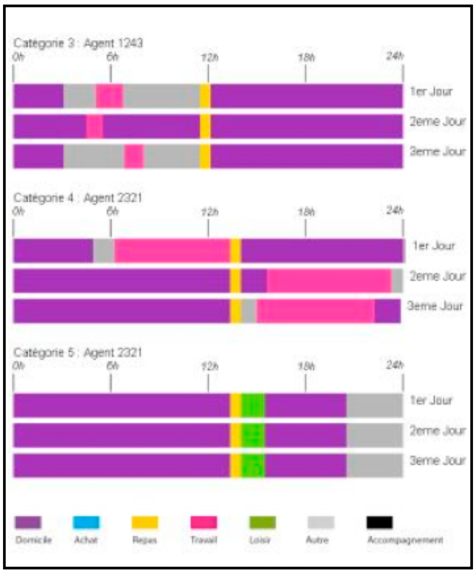

Figure 3: Example of daily activity planning modified by three agents for three consecutive days

This last figure illustrates this capacity of agents to modify their activity planning for the next day, according to their experience of the current days they just achieved. Situations vary from extreme (agent 2) to minor modifications (agent 1), including stationary states (agent 3).

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A VISUAL AND FORMAL FRAMEWORK FOR MODELING AND SIMULATION OF AGENT-BASED SYSTEMS

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1. INTRODUCTION

Agent-based modeling and simulation is an emerging scientific activity. This new paradigm brings together specialists from many disciplines to discuss epistemological foundations, impacts on scientific disciplines (economics, ecology, physics, etc.) or directly modeling and simulating agent-based systems.

Because of the novelty of these approaches many conceptions and discussions are arising to distinguish regular structures and scientific interest of agent-based models. According to scientific applications regular structures are progressively identified and described. However, because of both complexity of these structures and variety of application domains (from software design to sociology), there is no consensus on a single software, mathematical theory, or standard.

As a first step toward the definition of such techniques and theories, a framework can constitute a set of tools and principles to be used for the modeling and simulation of agents. Because of both complexity and variety of agent-based structures, this framework has to be generic enough to account for the specification of various structures. Meanwhile, it needs to be precise enough to guide modelers. Thus the framework needs to base on a formal mathematical computation model with well defined semantics and syntax structure. Lastly, high-level algorithms have to be provided by this framework to reduce development times. This paper presents a framework attempting to reach these goals. The framework uses graphical, operational and mathematical structures in a multi-level specification hierarchy. Details can be added progressively by modelers to fit his objectives.

The remainder of the paper is organized as follows. First the main characteristics of the framework are presented. Then, a demonstrative application is described. Finally, a discussion about how the framework is related to existing work, in particular the (Overview, Design & Details: ODD) standardization protocol is provided.

2. MATERIAL AND METHODS

Three levels of specification are provided in the framework:

1. The graphical specification level of components. We have developed a graphical modeling language for describing both the topology and the agent's behavior. The topology description is similar to cellular automata, while behavior is described through state charts [H98]. This

allows the modeler to describe state-based trajectories of the components, at a high-level. This modeling language has been developed using metamodeling techniques and the AToM3 software [dLV02]. A generator synthesizes the code corresponding to both behaviors and topologies of components for the following operational level.

2. The operational level has been developed using the DEVSJAVA discrete-event simulator. This simulator is grounded on the dynamic structure discrete-event system specification formalism (DEVS) [ZPK00]. Systems can change structure (behavior and topology) during the simulation. According to the input modeling code generated from the graphical level, simulation algorithms are automatically generated to perform the whole process.

3. The underlying foundation level is a formal mathematical computation model of DEVS [ZPK00] that is derived from dynamic systems theory. This formal model ensures the coherence and precision of the whole approach. Furthermore, they can be used in the modeling phase to avoid ambiguous descriptions.

3. EXAMPLE AND SIMULATION RESULTS

The demonstrative example is an agent-based simulation of fire suppression that consists of firefighting agents trying to suppress a dynamically spreading forest fire. To simulate the forest fire, the forest is represented as a two-dimensional cell space of rectangular cells. The cell space comprises individual forest cells with the fuel, terrain, and weather conditions assumed to be uniform within the cell. Each cell is represented as a DEVS atomic model in the simulation and performs its local computation of the rate of fire spread and direction based on its fuel, terrain, and prevailing weather conditions. Fire suppression is a process for firefighting agents to construct a fire line according to a plan to suppress (or contain) a burning fire. The interaction between an agent and the cellular space is supported by the couplings between them. An agent is always coupled to the cell where it is located. This coupling allows the agent to send a "suppressed" message to the cell to indicate that the cell is suppressed. To develop this example using the developed framework, first, graphical specifications of forest cells and fire fighters are provided by the modeler. Figure 1 describes a graphical specification of forest cells.

Then, from these graphical specifications, the simulation code, in accordance with the DEVS formalism, is automatically generated that implements the behaviour of the graphical model. Finally, further details about the model can be added by the modeller within the generated code to finally perform the simulation.

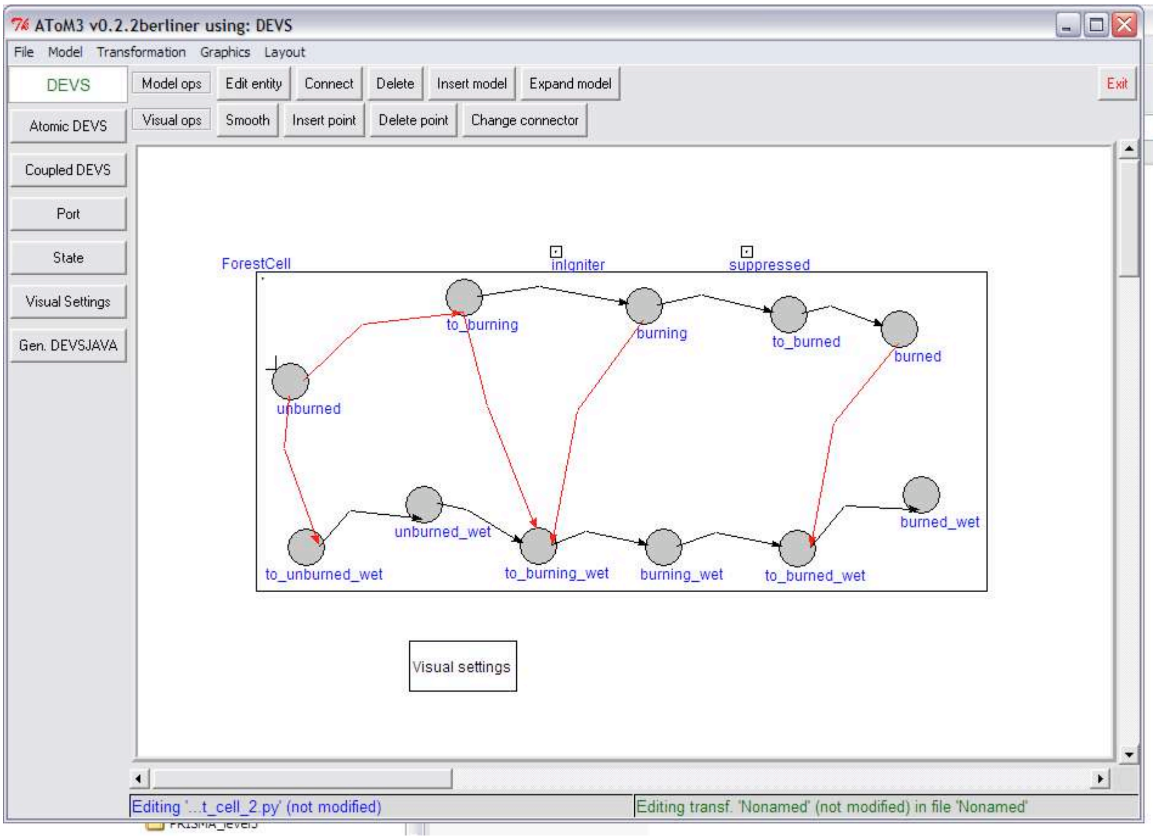

Figure 1. Graphical specification of a forest fire cell. The component *ForestCell* contains two ports (*igniter* and *suppressed*) to receive respectively ignition and suppression events. Cells can follow two main behavioral trajectories. One trajectory corresponds to the burning phases of cells (*unburned* → *burning* → *burned*.) The other trajectory corresponds to the corresponding phases when receiving suppression events by fire fighters components. States *to_burning*, *to _burned*, *to_burning_wet* and *to _burned_wet* correspond to timing delays specific to the implementation.

4. RELATED WORK AND DISCUSSION

Our work presents an operational framework for developing agent-based models for agent-based simulation. Many elements of the framework can be discussed during the workshop. First, relations with ODD descriptions can be a vast topic. Then, defining the framework interaction levels for various specialists working with agents constitute another vast topic. According to the discipline(s) these specialists belong many point of views can be discussed. Hence a computer scientist, a mathematician, a sociologist will not have the same expectations. Trying to conciliate some point of views will already be a challenge!

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SPATIAL DETECTION OF ORGANIZATION UNDER EVACUATION SITUATION

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Introduction

The use of the road network by vehicles with different behaviors can generate a danger, especially in case of evacuation situations. In Le Havre agglomeration (CODAH), there are 33 establishments classified SEVESO[2] with high threshold. The modeling and assessment of the danger is useful when it intersects with the exposed stakes. The most important factor is people. In the literature, vulnerability maps are constructed to help decision makers assess the risk. These maps are based on several types of vulnerability: socio-demographic, biophysical and other different types of hazards. Nevertheless, such approaches remain static and do not take into account the population displacement in the estimation of the vulnerability. We propose a decision support system which consists in a dynamic vulnerability map based on the difficulty to evacuate different sectors in Le Havre agglomeration. This map is visualized using the Geographic Information System (GIS) of the CODAH and evolves according to the dynamic state of the road traf-

[1]Corresponding author. Authors are alphabetically ordered. Michel Nabaa research is supported by Haute-Normandie Region.

[2]Directive SEVESO is an European directive, it lays down to the states to identify potential dangerous site. It intends to prevent major accidents involving dangerous substances and limit their consequences for man and the environment, with a view to ensuring high levels of protection throughout the Community.

fic through a detection of communities in a large graph. This detection is realized by an ant algorithm.

Problem description

The Major Risk Management Direction team (DIRM) of Le Havre Agglomeration (CODAH) has developed a model which estimates the nocturnal and diurnal exposed population allocation PRET-RESSE (Bourcier and Mallet, 2006). So, we have ventilated the *day / night* population inside buildings. The model was able to locate people during the day both in their workplace and their residence (the unemployed and retirees). PRET-RESS will be enriched by our model that will try to dynamically assess the vulnerability related to the road traffic evolution; so we are interested in the allocation of the vehicles on the road network, the regulation of the traffic flow and trying to dynamically estimate the vulnerability according to the traffic state.

Dynamic model

Our system consists of two modules as shown in the figure 1.

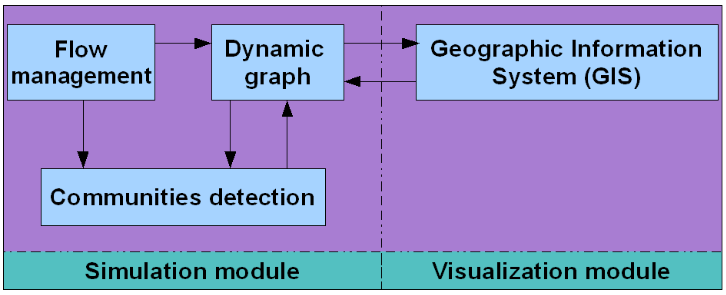

Figure 1: System architecture

The simulation module contains three components:

- The dynamic graph extracted from the road network layer,
- The flow management component consists of vehicles flow simulator applied on the graph,
- The communities detection component : Its input is the extracted graph and the current flow. It returns the communities that are formed according to the current state of road traffic.

The visualization module consists of the road network layer integrated into the GIS. This module communicates with the simulation module: the graph is constructed from this module, which in turn get the simulation result and visualize it as a dynamic vulnerability map.

Vehicles flow

We have adopted a macroscopic model in which flows circulate normally (without accidents) in order to establish a dynamic pessimistic vulnerability map. In evacuation situations (when an accident occurs), this macroscopic model is not relevant to the reality because most of people panic and take the same road to exit the dangerous area. Hence, it is important to develop a micro approach with multiscale description (from micro to macro and vice versa during the simulation) to simulate scenarios of danger in real time (accidents, behavior of drivers, vehicles interactions…).

Communities detection algorithm

Our aim is to identify communities in graphs, i.e. dense areas strongly linked to each other and more weakly linked to the outside world, according to a predifined criteria, but without any fixing of the nodes number in each community. Interesting works were developed in the literature on the detection of structure in large communities in graphs (Newman, 2004; Bertelle et al., 2007). In this paper, the algorithm used can be referred to as an ant algorithm (Dorigo and Stützle, 2004). Our ant algorithm uses several colored colonies of ants, a specific color is associated to each colony. Ants move on the graph and lay down (on the edges of the graph) colored pheromones. They tend to be repulsed by pheromones of other colors while they are attracted by pheromone of their own color. The algorithm principle is to color the graph using pheromones. Each colony will collaborate to colonize zones, whereas colonies compete to maintain their own colored zone. Solutions will therefore emerge and be maintained by the ant behavior. The color of a vertex is obtained from the color having the largest proportion of pheromones on all incident edges.
In organisation detection under evacuation situation, we define an interaction between two adjacent nodes by an attraction force,f, defined as following: $f = n/c$ where n represents the number of vehicles on the arc between 2 adjacent nodes and c, the vehicles capacity of the arc. This attraction force allows to detect graph areas where, in a potential danger case, most of people decide to use the same road to exit (pessimistic situation). The algorithm has the advantage to not allow the breaking of a link between 2 adjacent nodes to maintain the structure of the

road network. It is also able to detect traffic evolution and so communities can change or disappear as a result of local forces that change between the nodes locally. The algorithm allows us to construct a dynamic vulnerability map based on the difficulty of evacuation in the graph. This dynamic vulnerability map is able to evolve with the traffic. The map is visualized into a GIS.

Conclusion

The proposed method allowed us to estimate the risk due to the use of the road network by vehicles and categorize Le Havre agglomeration areas by their vulnerability. We will complete our work by using real traffic data retrieved from a displacements survey with Le Havre population which will help us to better locate people during the day and therefore having a more realistic vulnerability dynamic map.

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EXPLORING THE FACTORS OF URBAN SOCIAL STRUCTURE WITH AN AGENT-BASED MODEL

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Abstract

The factors of social structure, and notably spatial segregation between social or ethnical groups within cities, are the subject of numerous scholarly works whether empirical or theoretical.

The research presented here considers spatial segregation stemming from competition for land use between households with different incomes and preferences.

The theoretical basis is mainly the "canonical" model of Urban Economics (Fujita, 1989) which predicts that in a mono-centric city richer workers, who have a higher preference for surface, live in the outskirts while poorer workers live near the CBD. This is the pattern observed in most of the North-American cities. However this pattern is not observed in most European cities, with the notable well-known example of Brussels. Moreover when examining more precisely these various cities more subtle patterns emerge.

The purpose of this research is to examine factors which may "explain" such different patterns. These factors are the competition for land use, transport monetary and time costs, and neighbouring effects which may also induce social segregation.

Since we need to relate spatial interactions to economic decisions of agents, a cellular automata model coupled with economic agents (households) endowed with behavioural rules (e.g. utility maximisation) is particularly well suited.

In our model we consider an isotropic area with a given central business district (CBD) where all employment and services are located. The CBD is accessible from any point of the area as the crow flies. The space is a discrete grid and each cell is for agricultural use or occupied by a household. The cells have a fixed and identical surface but each cell may accommodate several residential lots from varying size within the fixed size of the cell. Hence the surface of residential lots is variable.

Households consist in single workers with varying income and preference for surface. They have to commute to the CBD, they rent a residential lot of varying size and they consume a composite good which include all other expenses. The bid-rent of a household depends on its income, its preference for residential surface and commuting costs. Landlords are absent and allocate land to the highest bidder. Rents are negotiated at each time step across the whole area. Households are able to migrate or move within the city at no costs. Because of this competition rents adjust immediately.

The city is open and grows from an initially zero population around its CBD supposed to offer sufficient employment to its inhabitants. At each time step a given number of immigrants arrive, who move to the city if the utility they can achieve is greater than the utility of the "rest of the world". Each immigrant chooses the location which maximises his utility, depending on its income, its preference for residential surface, commuting costs and price of the land. A short-run equilibrium occurs where the utility is the same for all households of the same kind. This succession of short-run equilibria stops when the utility in the city is the same as in the rest of the world: this is the long run equilibrium.

Model 1 considers the heterogeneous households (varying income and preference for surface) and transport monetary costs (proportional to the distance from the CBD). As expected it is shown that richer households tend to live in the outskirts of the city while the poorer live near the centre. The rich "push" the poor toward the centre.

Model 2 considers the heterogeneous households but with transport time costs added to monetary costs. These time costs depend on the distance from the CBD in proportion to travel time (i.e. with a fixed speed) and a value of time increasing with the income. It is explored how these time costs may reverse the tendency of rich households to move away from the CBD.

Model 3 considers neighbouring effects, such as the search for proximity to a local public good (e.g. school) which may induce another kind of social segregation. This is the case for instance with assignment of pupils to a school on the basis of their residential location. We explore the impact of the relaxation of this regulation on the social structure of the city.

In conclusion it is stressed that rather elementary mechanisms, but embedded in complex interactions, are sufficient to "explain" the emergence of such stylised facts as the social structures observed in different cities.