A complex system model on violence built with a cellular automaton

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Abstract

Social systems are usually modeled with Multi-Agent Systems (MAS). Our view is that Cellular Automata (CAs), which are simpler to program, to tune and to interpret, can be an efficient tool to understand, analyze and even act upon social phenomena (, segregation, discrimination, violence, diffusion/spreading, etc.). CAs are much more flexible and their control rule by rule, the simple change of worlds and number/type of states enable a better follow-up of the process itself. They are, economically more affordable.

Keywords: Cellular automata, Violence, Complexity, Wormholes

Résumé
Les systèmes sociaux sont habituellement modélisés avec des Systèmes Multi-Agents (SMA). Notre position est que l'Automate Cellulaires (AC), qui est plus simple à programmer, calibrer et interpréter, peut être un outil efficace pour comprendre, analyser les systèmes sociaux et même agir sur ceux-ci (ségrégation, discrimination, violence, diffusion/dissémination, etc.). Les AC sont beaucoup plus souples. Leur contrôle règle par règle, le simple changement de « mondes » et nombre/type d'états permettent un meilleur suivi du processus lui-même. Ils sont beaucoup plus économiques.

Mots clé: Automate Cellulaire, Violence, Complexité, "Wormholes"

1.Introduction

The most often used way to create a model of social systems is that of Multi-Agent Systems (MAS). Our view is is that Cellular Automata (CA), simpler to conceive and to program, simpler to tune and to interpret, are sufficient to get a first understanding and have a global analysis of some social phenomena like violence, segregation, discrimination, etc. For sure, it is only a first step in a process of understanding for further decision making and possibly, action.

CAs have been successfully used to understand and illustrate emergence of ghettos (the discrimination/segregation models of J. Sakoda [1] and T. Schelling [2] are CAs), to model the dynamic of urban spatial structures under pressure of economic and social needs (see for example [3]) and the spreading of civil unrest (see [4]).

CAs are much more straightforward and adaptable to specific situations and their control rule by rule, allows a better follow-up and evaluation of the process itself (for CAs in general, see [5] and [6]).

To illustrate our position, we present a model of violence in a town. Nowadays, violence is an each day companion of our societies. It is therefore useful to study its evolution and notably, its spreading. How to stop violence, is therefore an important subject. Violence is a highly complex phenomenon, because of the multiple parameters, related to human interaction, environment, and culture. The analytical tools at hand are not sufficiently, nor well suited for modelling such phenomenon.

We work on a set of different "world models" as well as a series of simple rule sets, the whole globally positioned in the structured uncertainty domain.

Generally, the often used approach in studying such complex systems is the MAS. MASs could provide interesting results but their development cost is huge, both in time and resources, economic and human. We will concentrate on the spreading of violent "agents" (actually, states), in a CA. In the case of violence, given the specificity of each case, its geographical situation, the size of the groups, local culture, and the type of actors, there is no guarantee of a positive and/or useful outcome in the end even with the heavy investments necessary to produce MAS. In this case, after important investment in time and resource, with iterated changes, the result might induce erroneous decisions.
A more modest approach would allow making a first choice between possible architectures which is, from many viewpoints, the most effective way to act. Using a CA allows to get a better knowledge on the actual rules to be applied, the parameters variation, the type of worlds to be considered. Once a first qualitative view of the phenomenon is obtained, heavier methods might be used to get the expected results, and obtain a true operational model.
The possibility of multiple levels CA worlds is examined, with communication between the parts of the world at specific points. The "fountain/black-hole paradigm through wormholes" is implemented. At certain points a state might "emerge" in one level (or neighbourhood) and "disappear" from another level (or neighbourhood). This type of connection between levels (or neighbourhoods) allows abrupt state changes in one level, related to a companion level.
The cost of the simulation, of the results interpretation, and of the decision making which follows, is significantly lower than the cost related to the use of a MAS model. Even if the MAS model might be closer to reality, speed in decision making might be important - a qualitative model being sufficient to provide the necessary view to the decision maker - in a given decision making situation.
This research is on-going, and we improve the model, remaining nevertheless in the CA domain. The use of more states and rule sets and more powerful computer systems is foreseen. Simplifying the actual use of the model through more flexible worlds through combination of levels, wormholes, doors, with borders or borderless, and a rules and states editor, are currently implemented. After a detailed analysis of the outcomes of this version, we will proceed to a final one, which in addition to the states and rules editor, should contain a set of tools to properly store the results (notably the statistics tables) for further use, a more flexible world expression and the possibility of use on larger systems (knowing that today it is used on a PC).

2.The CA model

We started our research with simple cases. With such simple cases we can get a first level of knowledge, necessary to continue the study. Before looking at the studied cases we find useful to have a short and more general review of the CA itself.

2.1.The architecture.

Our aim is to provide sociologists (the main users of such a model), and urban designers (such as architects, all professions involved in urban surveys) with a tool simple to use and as flexible as possible. Namely, it is essential to have the possibility of changing the rules, the worlds and the number and type of states without the necessity of having the help of a computer programmer.
Hard-encoded states and rules are fast to compute but difficult to implement for non-specialists. On the other hand if rules have to be interpreted at each clock tic, the simulation becomes much too slow (using notably a PC). To ally versatility and speed, we have decided to build a tool set on a model driven development approach. From the user view point, the workflow is based on three steps: (1) states and rules definition, (2) automatic generation of a plug-in implementing the above mentioned states and rules, (3) running the simulation with the plug-in on a given "world". This allows separating the model design from its implementation. The end-user will therefore be able to pass from one set of rules to another on the same world or use the same set of rules on different worlds.

The code generator for the plug-in is developed in Java based on all purposes XML databases both for topology design and rules behavior description.

2.2 The world

The “world” is a bi-dimensional cell collection (a grid). It simplifies considerably the work, through the world discretization. The evolution of the different types of states is a direct function of the states of the surrounding cells. The exception is that of having the possibility of changing the next state, also by taking in account a larger zone of the world (eg: the presence of a specific state in the given zone).
The shapes of the world which are either closed surfaces or borderless surfaces provide two different views, knowing that the side effects induced by borders are significant. The choice of eight neighbours for each cell is in our view much more powerful than the case of four neighbours, providing more flexibility and completeness.
The number of possible states of the cells should remain in the low range, to avoid the model complication. The states are actually the actors of the world. These are not agents in the MAS sense; they are just states, as in John Conway’s Game of Life.
To provide more flexibility and bring the model closer to reality, we introduced “wormholes” in different places. These “wormholes” (idea taken from physicists – see [5]) are direct connections between different parts of the world and allow respectively the emergence of a specific state or the disappearance of the actual state at the cell representing the wormhole entry. The wormholes have two directions: from and to the considered surface (or part of world). In what follows, we might call these either black holes or fountains, depending on the direction (this is a convenient modelling of a Metro station, for example).
More sophisticated models, containing three or more satellite towns (or neighbourhoods) communicating with routes and wormholes, an airport and a water port, are studied. These models provide the possibility of explaining violence migration from city to city and illustrate the possibility of “import” of violent people.

2.3 The states

The cell states represent the population involved: This choice was made as a first attempt to understand the phenomenon, by using the main actors related to violence in a population. We do not fill up the world, but leave enough empty states, to allow a movement, mainly a random movement(within the vicinity constraints). Randomness is useful but has also a drawback because it embodies our lack of knowledge of the domain as a whole and requires a higher number of simulations to be able to extract a valuable interpretation.

2.4 The rules

The rules might be either strictly local or might have a range over more than the immediate surroundings of the considered cell. We have retained a rule we call “vision” and which might extend some of the states’ influence over larger vicinity. For example, some “actors” may have a “view” over a number of ranges of cells (e.g. the police agents over 10 and the aggressive citizens over 5, which provides a small advantage to the police agents). The CA rules are parametric, so that the change in behaviour of the CA could be simply obtained and controlled, enabling a better interpretation of the results. In future models we may introduce the idea of communication between some “actors” and vary dynamically the “vision” distance as well. This will, for sure, bring fully new situations for analysis. The end-user has at his disposal a rules editor which enables a better focus on the problem at hand: the analysis of violence spreading.

2.5 The time

Time in CA is discrete. To be noted that states (actors) do not have memory. Their situation at time T+1 depends only on that at time T. At the clock tic, the states change simulating a full parallelism.

3.The actual CAs studied

To summarize, we think that the power of the CA model enables the modelling of complex phenomena. It provides enough knowledge in certain cases to directly act (like models of forest fires or viral spreading) or to undertake further steps in modelling with MAS, at a much lower cost in resource and time because of a better evaluation of agents' properties and dynamics.

The "worlds" which are considered in this paper are two-dimensional arrays of square cells with eight neighbours. The worlds in some of the configurations have "wormholes" which allow a state to show-up at a specific time and place. This is a useful possibility because in a "world" split (eg: neighbourhoods, towns, airports, …) it allows parts to communicate in a controlled manner.

The classical world of NxN cells with borders on the four sides is interesting because it provides a view on the limits and allows the analysis of some side effects as the blocking of states (actors) or the accumulation of a kind of state (actor) in a corner.

The split worlds, allow analyzing the communications between them as well as the influence of the "wormholes" on the way the situations develop. It allows as well finding more about the notion of more or less "secure neighbourhoods" as a function of the actors present. These split worlds might also be considered as "levels" and allow a multi-level discussion (e.g.: town vs. neighbourhood).

The borderless worlds allow eliminating border effects, and in fact helping simulation of larger surfaces of action. In the future, borderless and split worlds in the same model, will provide higher flexibility in terms of actors' dynamics.

We are sure that the wormhole concept we introduced here is an interesting and original contribution which, more than its pure communication aspect has also an influence on the interpretation process by those who observe the CA behaviour.

Actors are materialized by the cells' states. In the current implementation we have retained a set of actors which are the following: "neutral citizens", "poor citizens", "violent citizens", "police agents", "educators", "informers" and "empty". We think that even if such set is rather reduced, it allows for a first estimate to help devise an architecture of the model as close as possible to the reality. Table 1 defines a set of states changes rules for each cell at each clock tic.

The idea, on which the above set of rules is based, is that of a number of interlaced cycles. If an aggressive is caught by police with or without the help of informers, he goes to jail and after a number of ticks comes back to the world as a "poor". The "poor" might become "neutral", "police agent" or "aggressive" as a function of the encounters when moving almost randomly on the board. A "neutral" could also change its state as a function of its random encounters. Let us stress the fact that the sociological aspect is underdeveloped, even naive and we are currently working with potential users to continue to improve the platform.

We currently develop a set of fully parametric rules (simple change in the table column "Number") which should allow a simpler tuning as a function of the objectives to pursue. It should also be simple to add new rules corresponding to the existing states and to new states to be defined

Rule number	State at t	Surrounded by at least		State at t+1
		Number	Type	
1	Violent citizen ■	2	Police agents ■	Prisonner■
2	Violent citizen ■	1 2	Police agents ■ Informers ■	Informer ■
3	Neutral citizen□	4	Poor citizens ■	Poor citizen ■
4	Neutral citizen□	2 0	Violent citizens ■ Police agents ■	Violent citizen ■
5	Neutral citizen□	3	Police agents ■	Police agent ■
6	Neutral citizen□	2 1	Police agents■ Educator ■	Police agent ■
7	Neutral citizen□	3 2	Educators ■ Violent citizens■	Educator ■
8	Neutral citizen□	3	Informers■	Informer■
9	Poor citizen■	6	Neutral citizens□	Neutral citizen □
10	Poor citizen■	3 0	Violent citizens■ Police agent■	Violent citizen ■
11	Poor citizen■	3 1 OR 2	Poor citizens■ Police agent ■ Educators■	Informer ■
12	Poor citizen■	4 2	Neutral citizens□ Educators■	Police agent ■
13	Poor citizen■	3	Educators■	Educator ■
14	Educator citizen■	6	Neutral citizens□	Neutral citizen □
15	Educator citizen■	2	Informer citizens■	Informer■
16	Informer citizen■	3	Violent citizens■	Neutral citizen □

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Table 1: The set of rules currently used in our research

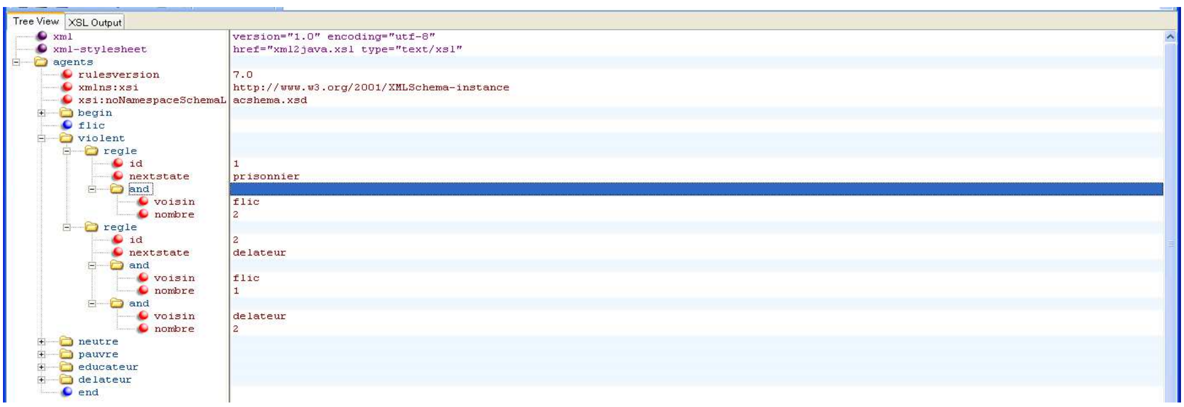


Table 2: The set of rules coded with an XML tree description

To show that these CAs can be used to study problems related to urban safety, we have built a number of different models. One of these, illustrated in the following lines is a model with 3 interconnected worlds (numbered from 1 to 3). Each world has wormholes and pathways to other worlds (see figure 1). With this model we address the problem of the local police deployment. We assume that each world is a district of a vast urban area, connected by roads (the pathways) and with collective transportation system (the wormholes). The district 1 has endemic criminality, while districts 2 and 3 are quiet. In this case, do we have to concentrate police force in district 1 or to dispatch it between the 3 districts ? We conducted 2 experiments: the first one with 15 policemen and 20 criminals in district 1, the second one with 5 policemen in each district and 20 criminals in district 1. Low "production" of criminality simulated by one "port" in districts 1 and 2.

In more than 75% of the runs, criminality is under control when the local police forces are divided among all districts, including those who are quiet, and out of control when police forces are concentrated in district 1. We observed with our simulations that concentration of police leads to a rapid diffusion of criminality towards quiet districts, while repartition of police cannot totally extinguish crime in district 1 but maintains all districts under control (with a lower total criminality).

Another interesting case is the one which provides a view of the sensitivity to the rhythm of emergence of aggressive citizens. Assuming that an aggressive citizen emerges (from a wormhole) every 200 generations, for an initial situation where the same number of police agents and aggressive citizens is equal, the number of aggressive citizens after 25000 generations explodes. If the emergence of aggressive citizens is lower (500 generations) the police agents have the situation under control over the same number of generations. Interestingly enough the width of vision of the police agents (range 10 to 30) has a rather low impact.

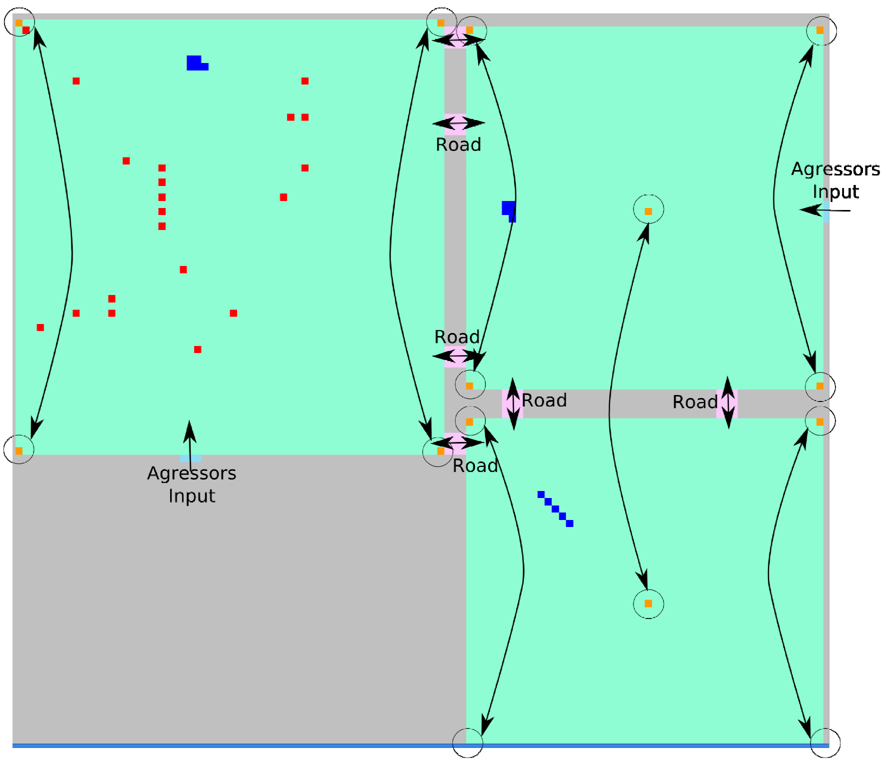


Figure 1: A three regions CA to study local police deployment. Wormholes connections (circled)are visualized by two-ways arcs.

In the case of different world models and a stable number of police agents, 10000 or even 5000 generations are enough to bring the situation under control with aggressive citizens showing up every few hundreds generations.
These results are obtained with a random configuration of the different types of actors in the world. We had, in a following step of our research, a chosen repartition of the different actors in the field. The number of police agents necessary for the same result is lower.

Cases of higher complexity, as bureaucracy in certain populations (police agents) emerge under the current set of rules in a bordered world with a wormhole and are well visualized in the model (see figure 2). It may be argued that the interpretation is somewhat exaggerated, but it provides a view of the conditions under which such phenomenon emerges, namely systems where diversity is low and the behaviour of actors is the same (rules No. 5, 6 and 12). Again, we do not pretend to have precise,

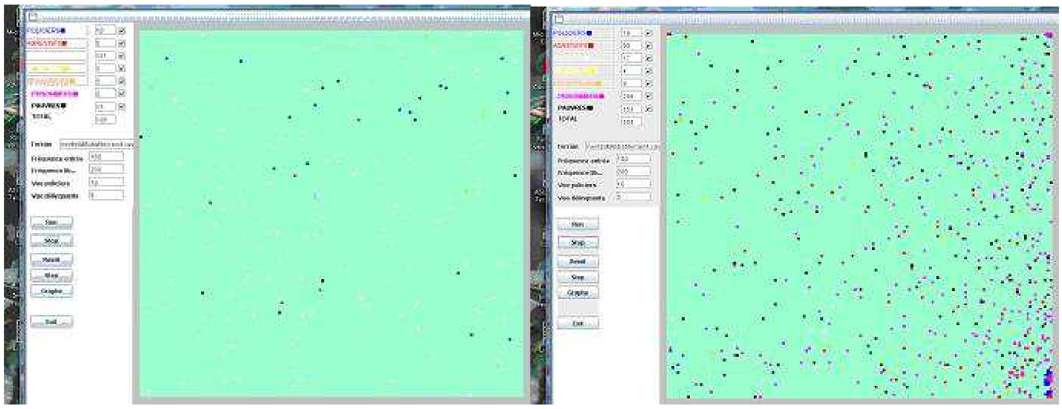


Figure 2 : The case of “bureaucracy” - the two images are taken at the beginning and at the end of the simulation (after 100K generations).

The case of a larger number of separate neighbourhoods (or levels) brings some insight into the way violent people (and therefore violence) is spread, as the figures indicate.

An interesting situation emerges from the very fact that there are an important number of “neutral” states at the beginning and these could become aggressive if surrounded by aggressive states. This explains the initial explosion of “aggressive” states .

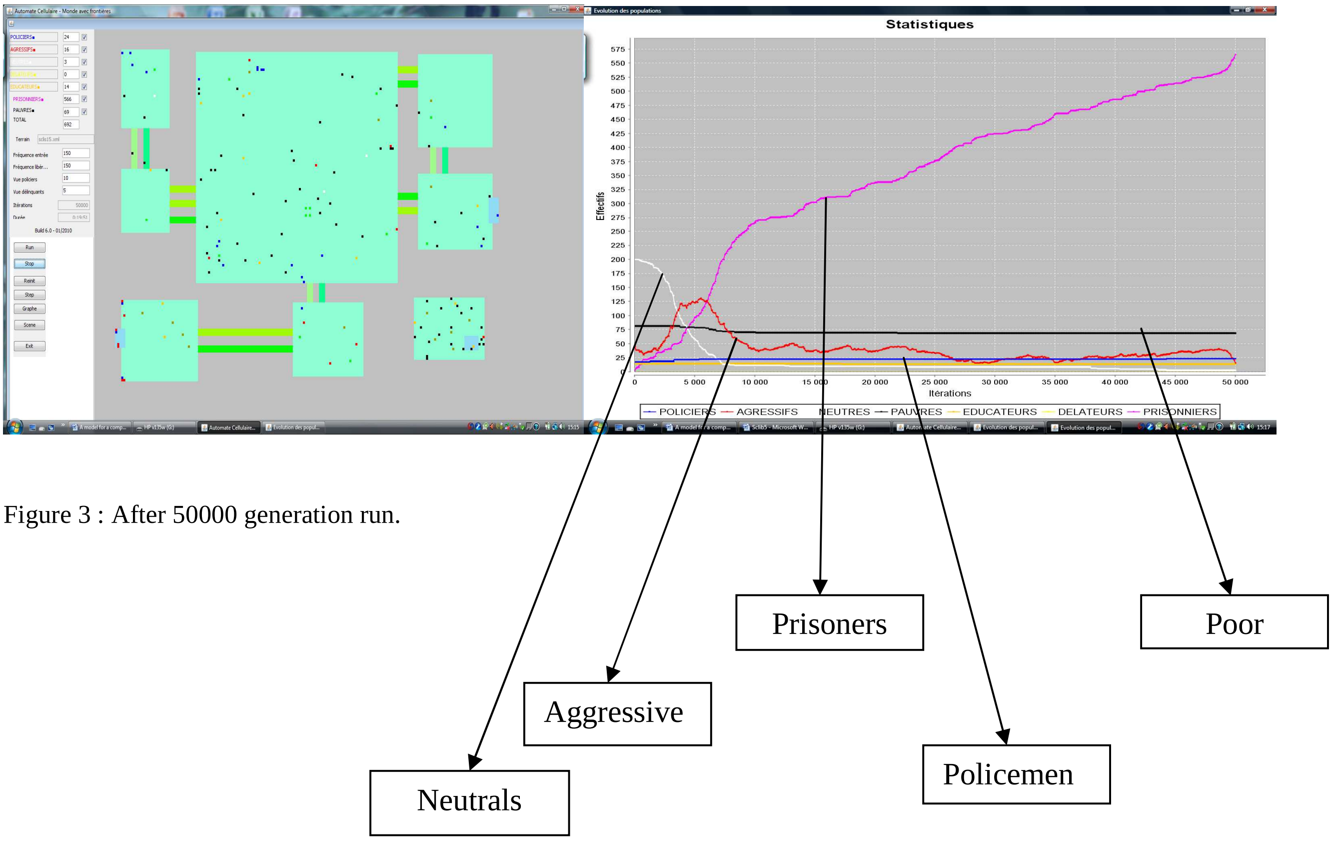


Figure 3 : After 50000 generation run.

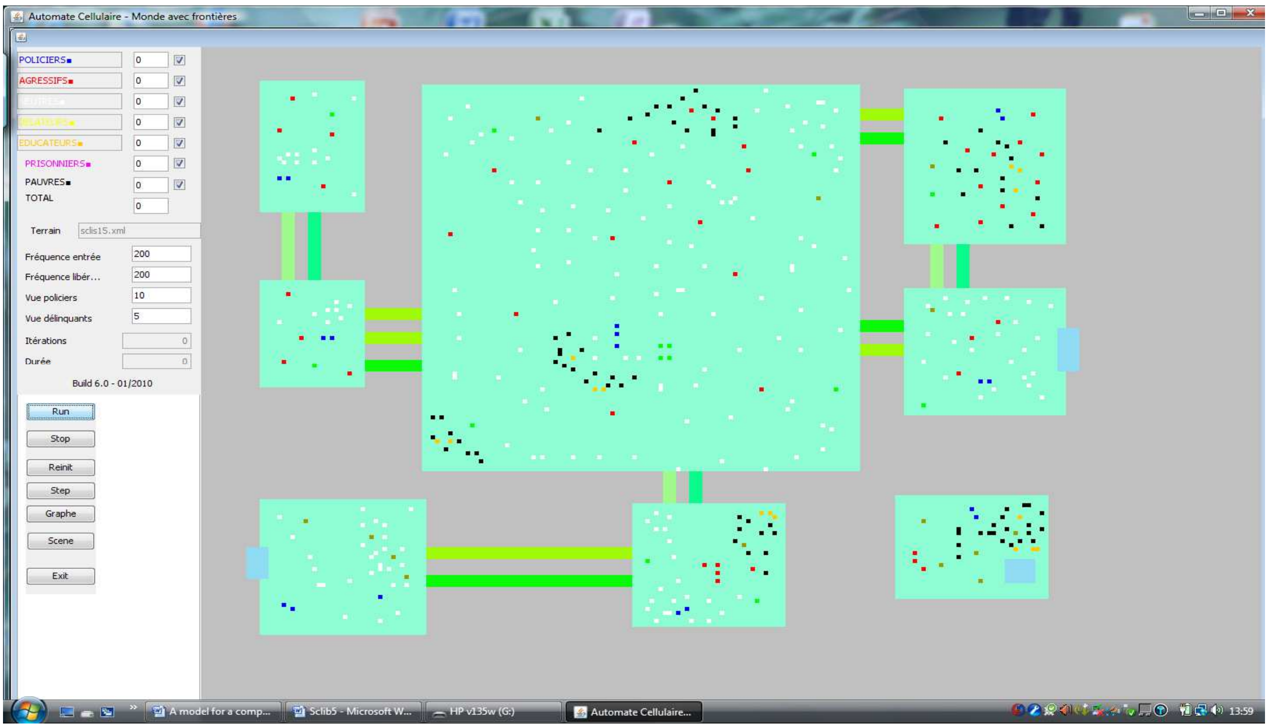
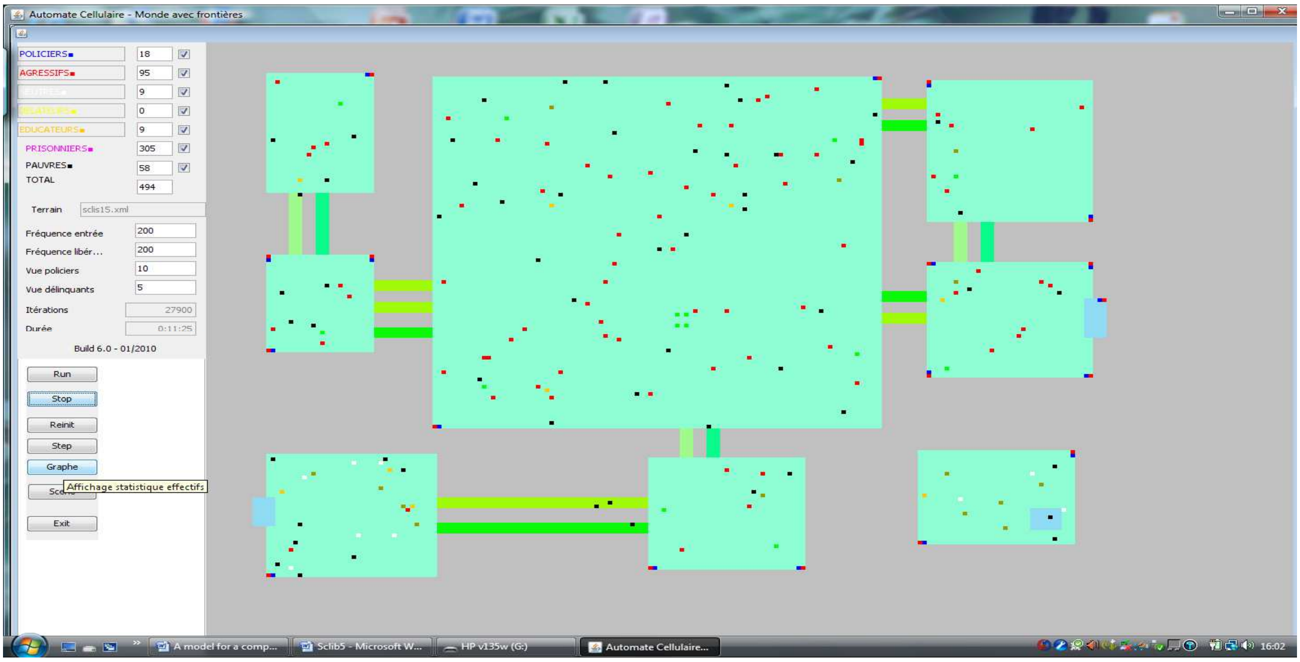


Figure 4: Multi neighbourhood configuration, initial and after about 28000 generations

It is interesting to note that the world configuration above and underneath, composed of one main surface plus a set of smaller ones, linked either with wormholes or roads (in green) will create the possibility of "walks" from surface to surface and simulate the spreading.



It is also possible to see that if there are too few policemen these might be kept "busy" in a corner (due to the border effects) and therefore other aggressive are free to proliferate. This is mainly true when initial configurations have the policemen distant from each other.

The walk through a large number of configurations and watching these as they evolve, allows bringing sense to the very dynamics of the situations. For example, one might actually see: how a policeman is deviated from his initial trajectory by the presence of an aggressive, how the border effect helps produce "bureaucracy", how a very small difference in the initial configuration might bring very different end situations, and much more. The statistics tables also help to better understand the diachronic of the system which, together with the synchronic view provides a more satisfactory and more complete picture.

Finally, let us note that small changes in the initial states configuration for the same world, with the same number of each type of state, might bring quite different end outcomes (verified at generation 50000). This also confirms the necessity to be very careful when interpreting the simulation results.

We could already say that the outcome of the simulation depends significantly on the following:

(a) The proportion Empty/Full states, knowing that a higher number non-empty cell states number, makes it more difficult for the "police" to catch the "aggressive",
(b) The number of different states and the amount of each state at the beginning of the simulation,
(c) The reciprocal position of the states in the initial configuration,
(d) The status change at each tick, which is caused also by the random move of states,
(e) The way the screening of the "world" is performed at each tick.

Other parameters are also at work, but seem to have lesser importance.

4.Discussion and comparison with MAS

The frontier between MAS and CA is in fact a quite fuzzy one. The most important differences are in the way actors are treated: in CAs actors are treated as states of cells and in the MAS we deal with agents, which means entities equipped with memory and which apply the general rules in the framework of their own personality (which implies that there are action possibilities strictly related to the agent). Another important difference is that that the world is not necessarily split in cells but might be an open field with general distances.
There are also intermediate cases where the agents are completely independent of each other and they are for example acting on a discrete world (linked cells), or agents with limited individual capabilities.

The systems have in common the time driven by a clock.
As it could be seen, to manage a large number of actors, each with its particular set of internals, in an open world and using also a set of general rules applicable to all the actors, is a system of several orders of magnitude higher in complexity and necessary resources. To manage it, the computing resource and the software tools sophistication is much more important. This also necessitates the involvement of highly qualified computer specialists. Even if technology progress provides very powerful tools, these are much more expensive and delicate to handle. On the other hand, a CA system, even if complex, remains in the domain of the possibilities of handling by people who have to actually use such models, and moreover, to use the models on modest computer systems like the today PCs.

5.Open issues and conclusion.

Work is in progress and there are open issues which are not resolved by now. Those we found as being the most important are:

(a) The possibility to “play the film” backwards without getting into performance degradations,
(b) How could “actors” communicate/interact effectively otherwise than by the locally operating rules,
(c) Mixing in the same simulation borderless and bordered worlds.
(d) A standard protocol for rules and states choice as a function of the actual situations discovered by running the simulation.

Work is underway to resolve these issues. Nevertheless, we should preserve the simplicity of this type of model by avoiding the MAS “mousetrap”.
As stated at the beginning of this paper, this is a research in progress and after having performed few steps, demonstrating the feasibility and the flexibility of a CA model at large, we started to develop the next step which involves a generalization of the rules and states definition. This CA architecture should also help defining the architecture for a MAS to be possibly developed later, if necessary.
We also think that the wormhole concept applied to CAs, borrowed from physicists is a powerful amplifier of our models set.
In many cases, the speed in finding an operational solution to the problem at hand is essential. If very rapidly, a professional could get an operational idea for solving a given problem, without a too large effort, in some cases simply unaffordable, the CA modelling might seriously help. This is indeed the case when the information level and precision, the resources and the time available, are limited.

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