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APOCOSIS

Modeling complex systems with Cellular Automata

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Abstract:

Social systems are usually modeled with Multi-Agent Systems (MAS). Our hypothesis is that Cellular Automata (CAs), simpler to program, simpler to tune and to interpret, can be sufficient to understand and analyze social phenomena (violence, segregation, discrimination, etc.). Actually CAs are much more flexible and their control rule by rule, allows to better follow the process itself.

Key words: Cellular automata, violence, complexity, modeling, agents

Introduction

Social systems are currently and mainly modeled with Multi-Agent Systems (MAS). Our hypothesis is that Cellular Automata (CA), simpler to program, simpler to tune and to interpret, can be sufficient to understand and have a global analysis of social phenomena (violence, segregation, discrimination, etc.). CA have been successfully used to understand and illustrate emergence of ghettos (the discrimination/segregation models of J. Sakoda [1] and T. Schelling [2] are in fact CA), 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]). Actually CAs are much more adaptable to specific situations and their control rule by rule, allows to better follow and evaluate the process itself (for CAs in general, see [6] and [7]).
To illustrate the case we will 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, how it could be stopped, how it develops, and may even at an extreme, destroy a society. Violence is a complex phenomenon per se. It is so, because of the multiple parameters notably related to human interaction. The usual analytical tools at hand are not well suited for modeling such phenomenon. We will work on a set of different "world models" as well as a series of rule sets.

Generally the 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. Being given the specificity of each case, its geographical situation, the size of the groups, the type of actors, there is no guarantee of a positive outcome in the end. We think that a step by step approach allows making first a choice between possible architectures (we use the word architecture as in the building domain – i.e. a set of rules allowing to build a model) which is, from many viewpoints, the most effective approach. Actually, using a CA it may be possible to get a better knowledge of the rules to be applied, the parameter variation, the type of world to consider. Once a first qualitative view of the phenomenon is obtained, the heavier methods could be used to refine the results and obtain a fully operational model. Our view is that such models may be of use in other situations where the processes are close in essence to the presented one.

The idea of a multiple level CA world is also examined, with communication between the parts of the world at specific points. The "fountain/black-hole paradigm through wormholes" is used. Namely, at a certain point a state might "emerge" or "disappear". This kind of model greatly simplifies the issue of abrupt state changes. The cost of simulation and that of the results interpretation and of the decision making which normally follows are significantly lower than that of a MAS model use. Even if the MAS model is more refined, sometimes speed in decision making is more important and a qualitative model is sufficient to providing the right view to the decision maker.

The paper discusses the case we have analyzed in detail and provides a comparison with a MAS solution. This is an on-going research which should be refined remaining in the CA domain, using even more states and rule sets and more powerful computer systems.

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.

The world

The fact that it is made of cells simplifies considerably the work by its discreteness. The evolution of the different types of states is a direct function of the states of the surrounding cells.

The shapes 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 8 neighbors for each cell is in our view much more powerful than the case of 4 neighbors, providing more flexibility and completeness.

The number of possible states of the cells should remain in the low range, not to make the model too heavy. The states are actually the actors of the world. These are not agents in the MAS sense; they are just states, as in the John Conway game of life.

To provide more flexibility and bring the model closer to reality, we introduce "wormholes" in different places. These "wormholes" (idea taken from physicists – see [5]) are direct connections to other 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 the following we might call these either black holes or fountains, depending on the direction.

More sophisticated models containing three towns (or neighborhoods) communicating with routes and wormholes, an airport and a water port, are studied. These models should provide an initial explanation of violence migration from city to city and illustrate the possibility of import of violent people.

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, and also a random movement.

The rules

The rules might be either strictly local or might have a range over more than the immediate surroundings of the considered cells. We have retained a rule we call “vision” and which might extend some of the actors’ influence over a larger vicinity. For example, some actors may have a “view” over a number of ranges of cells, the police agents over 10 and the aggressive citizens over 5 (which provides a small advantage to the police agents). The CA rules must be parametric, so that the change in behavior of the CA could be simply obtained and controlled, enabling a better interpretation of the results. In future models we may introduce the communication with mobile phones for some actors and vary the “vision” distance as well. This will, for sure, bring fully new situations for analysis.

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 in simulating a full parallelism.

To summarize, we think that the power of the CA model is quite important and it enables the modeling of, as a first step, quite complex phenomena. It provides us with knowledge enough in certain cases to directly act (like models of forest fires or viral spreading) or to go one step further in modeling with MAS at a much lower cost in resource and time.

The actual CAs studied

Let us describe the “worlds” which are considered in this paper. In all the cases there are square cells with 8 neighbors. 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 it allows to split the world in parts (e.g. neighborhoods, towns, airports, …) and have the parts communicate in a controlled manner.

The classical world of $N \times N$ 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 neighborhoods as a function of the actors present.

The borderless worlds allow eliminating border effects, and in fact helping simulation of larger surfaces of action. More, the borderless and at the same time split worlds will provide higher flexibility in terms of actors’ mobility.

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

Actors are materialized by the cells’ states. 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 (for example, we could imagine levels of aggressive citizens as well) it allows for a first estimate to help devise architecture of a model as close as possible to the reality. The rules (see table 1) define the states changes of each cell at each clock tic.

Rule number	State at time t	Surrounded by at least		State at time 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 □

Table 1: Set of rules currently used in our research.

Later, we will 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.

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 is 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. In fact, we observed with our simulations that concentration of police leads to a rapid diffusion of criminality toward before-quiet districts, while repartition of police cannot totally extinguish crime in district 1 but maintains all districts under control (with a lower total criminality).

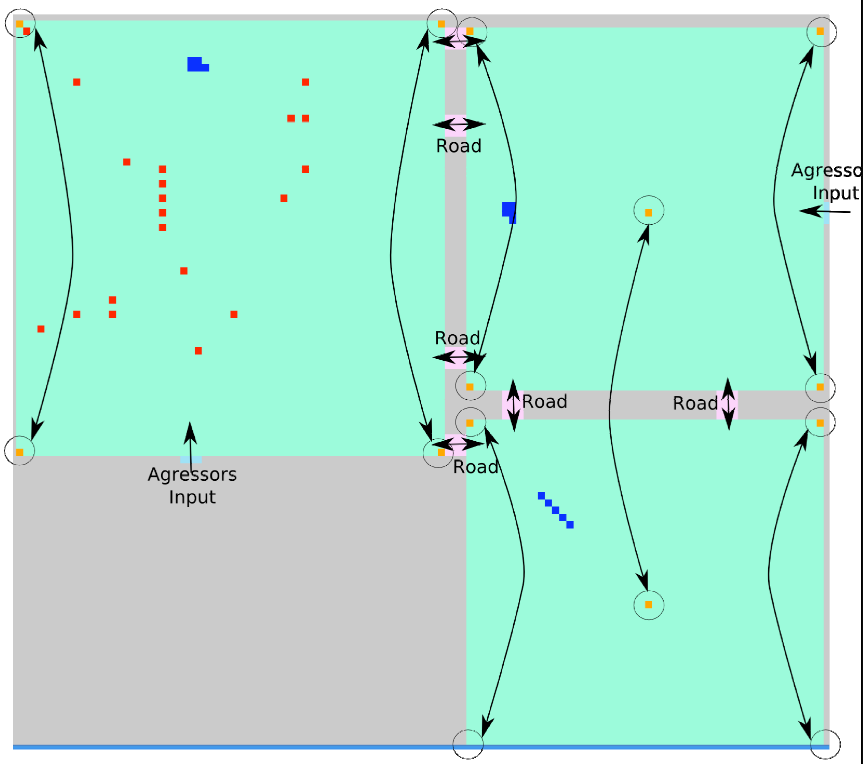

Figure 1: A three-world CA to study local police deployment. Connection between wormholes (in circles) is visualized by two-ways arcs.

Another interesting case is that 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 no impact.

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 900 generations.

These results are obtained with a random configuration of the different types of actors in the world. We plan to have, in a following step of our research, a chosen repartition of the different actors in the field. Probably, the number of police agents necessary for the same result would be 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 behavior of actors is the same (rules number. 5, 6 and 12). Again, we do not pretend to have precise, quantified views from such models, but “food for thought” in the area under scrutiny.

Discussion and comparison with MAS

The frontier between MAS and CA is in fact a quite fuzzy one. Probably 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 that we have 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.

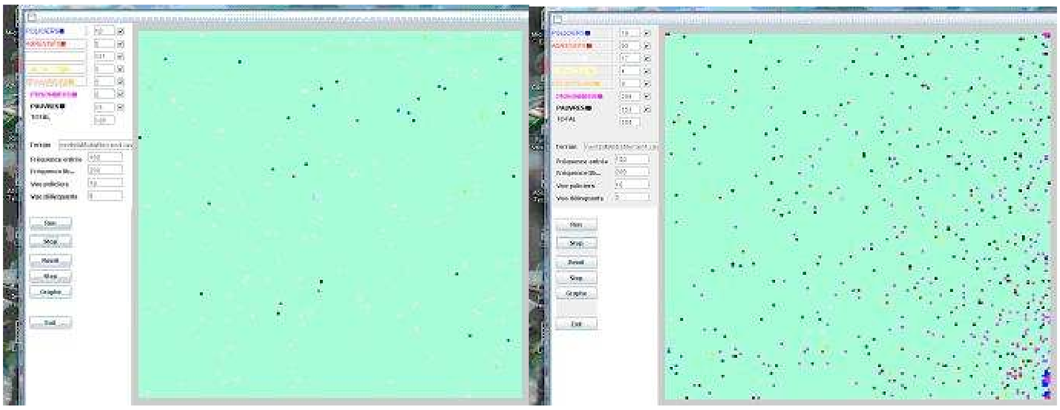

Figure 2: The case of "bureaucracy" - the two images are taken at the beginning and at the end of the simulation (after 100K generations).

The 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.

Conclusion

As stated at the beginning of this paper, this is an on-going research and we think that after having performed the first step, that of demonstrating the feasibility and the flexibility of a CA model at large, we think of the next step which would involve a generalization of the rules definition and possibly a meta-language which could be part of a simple tool box together with a set of world models. This scheme should allow for defining the architecture for the MAS to be developed later, if necessary.
We also think that the wormhole concept applied to CAs, borrowed from physicists is a powerful amplifier of that model.

In many cases, the speed in finding an operational solution to the problem at hand is important. If very rapidly a professional could get an operational idea for solving the problem, without a too large effort (in some cases simply unaffordable), the CA modeling might seriously help. This is also the case when the more general conditions (notably the information level and precision) do not allow for performing the efficient development of a MAS.

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