Cellular Automata:
A Useful and Effective Tool for Reading, Interpreting, Describing, Forseeing the Behaviour of Urban Systems

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ABSTRACT

Cellular Automata can be used as a simulation technique which bases itself on simple rules based on local interaction to describe the evolutionary dynamics of phenomena.
This simulation technique proved itself to be useful and powerful compared to other model techniques, when knowledge of the phenomenon is incomplete or when local discontinuities are lofty.
However sometimes it is necessary to study phenomena of such a great complexity, that their implementation with a single CA seems anyhow complicated or impossible.
In fact, the observance of the classical formulation "dogmas" of the Cellular Automaton's concept limits the "realism" of models very much and their violation transforms the features of simplicity and locality that the description based on CAs involves in an unacceptable way.
This is why it's useful to apply to the concept of Multi Cellular Automaton (MCA): a system constituted by two or more automata linked together in sequence.

KEYWORDS

Cellular Automata Simulation Models Urban Management Transformation

1. CELLULAR AUTOMATA

A *Cellular Automaton* (CA) can be seen as a virtually endless matrix of "cells" in a n-dimensional space (in the most part of applications space is of two dimensions and cells are square); cells "evolve" in an imaginary time, scanned by an opportunely programmed *watch*.
At every given instant t, each cell finds itself in a *state* which belongs to a finite whole of possible states.
The state of a cell at time (t+1) depends, besides on its state at time t, even on the state of the cells of its own *neighborhood* at time t.
In the literature about CAs different neighborhoods are defined: in the two-dimensional case the most famous are Moore's ones (or Conway's ones) and that of Von Neumann's; the first (Moore) includes nine cells, that is the one in exam and the four cells which have a side in common with it, plus the four cells which have the edges in common; the other one (Von Neumann) includes five cells, that is the one in exam and only the four cells which have a side in

common with it; nothing excludes obviously that other neighborhoods also of ampler levels (that is they don't consider only the cells immediately near the cell in exam) can be taken into consideration in the planning of an CA.
A whole of *rules*, which can be expressed through a schedule or a graph, controls the transition of every cell from a state to another.
We have then that in an CA the *state* corresponds to the "value" of the cell in exam (often characterized by a color for reasons of efficacious representation), the *input* to the combination of states of its neighborhood, the *output* to the new state assumed by the cell (fig. 1).

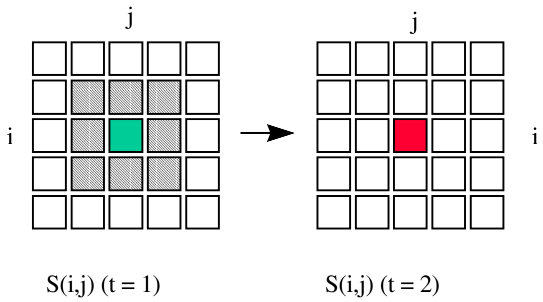

Figure 1: Structure of an CA.

So, since a particular geometry of cells is given, a specific CA in the plane can be characterized as follows:

$$g_{i,j}^{t+Dt} = F(g_{i,j}^{t}, g_{i\pm1,j}^{t}, g_{i,j\pm1}^{t}, \ldots, g_{i\pm p,j}^{t}, g_{i,q\pm1}^{t})$$

where i, j are the coordinates of the cell and $g_{i,j}$ is its state.

It's quite interesting to note that the number of wholes of possible rules, even with few states and small neighborhoods, is enormous.
It's true that in the most part of cases the position of cells of the neighborhood is not important (in this case one talks about *totalistic* rules) and then the number of possibilities shrinks, being still very elevated
For example, if we consider the significant case of a situation with k=2 and n=9 (whose famous and classical game VITA is an example), for "positional" rules one will have a number of CA which corresponds to something more than 10^{154}, whether for totalistic rules we'll have 1024 possible Acs.
The number of rules we have to write actually to originate such CAs is obviously very smaller (CAs are determined by all combinations of all rules for each state); there's moreover something left to say, that is a part of rules which originate these Acs is inactive (i.e. they don't modify the state of the cell) and thus if we consider the ones that must be actually written as they're active for each state of the examined cell, their number shrinks further on; number that gets still lower if one can join a whole of rules that have the same effect on a certain state (for example, as one says: "if the cell in exam has the state 0 and the neighborhood has less than 3 cells in the state 1, then the cell passes to the state 1").
However if we consider an CA which describes an urban system and suppose (continuing with Tobler's example (Tobler, 1979) that 5 states are necessary to describe it, also considering Von Neumann's neighborhood which includes 5 cells, we'll have 1.048.576 possible totalistic CAs.
In this case too, it's nevertheless more useful (for different reasons and above all to estimate the engagement that the building of useful CAs can cost, but we'll return to this) to consider the number of rules that must be written: it's very smaller, but it remains important: in fact for each possible state of a "central" cell (the one in exam) we'll have only 70 possible totalistic rules for the four cells of the residual neighborhood.
In substance CAs are dynamic discreet systems (which could pose some problems in their use to represent phenomena in the continuum), that can show complex behaviors, and of self-organization also beginning from a very reduced number of states and rules; it's worth the trouble to underline that the global behavior of the system is determined solely through local interactions.
In formal terms we could say that an CA is a *structure* (C, S, I_k, r) where
C is the whole of cells, c_k (in the plane the cell k will have the coordinates i, j)
S is the whole of states
I_k is the whole of neighborhoods of the cell k
$\rho: S^{|Ik|} \rightarrow S$ is the function of transition

2. CA AND TERRITORIAL ANALYSIS

2.1 GENERALITIES

Tobler (Tobler 1979) proposes a general distinction amongst five sorts of territorial models (see fig. 2).

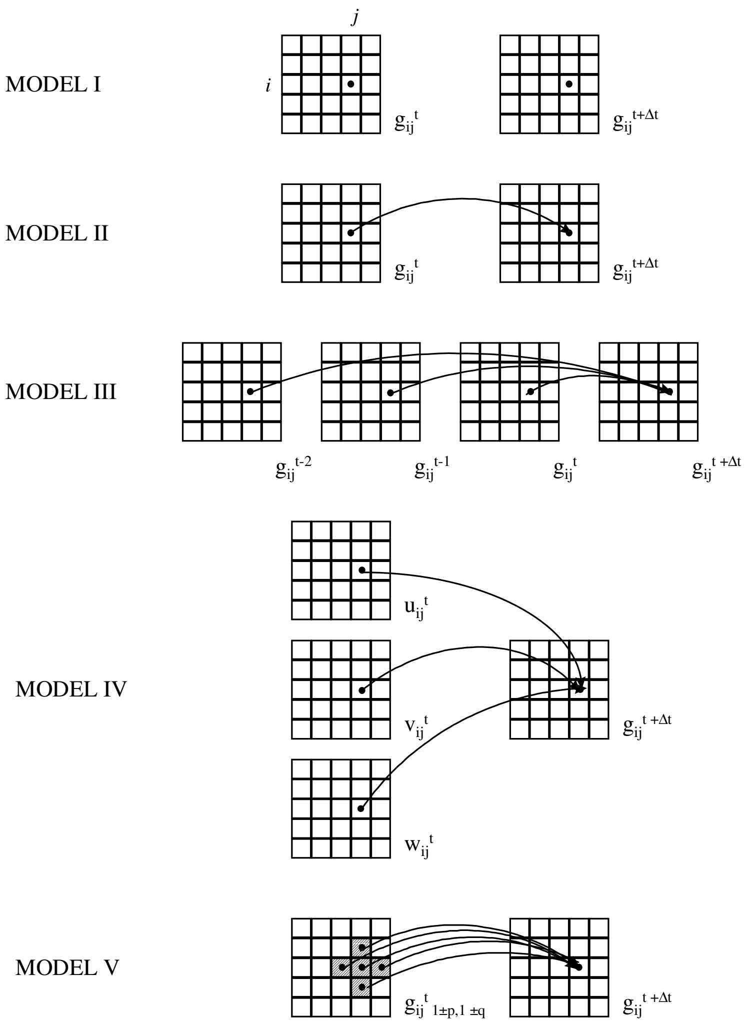

Figure 2: Territorial models

In reality the fifth one (which he calls "geographic" and which corresponds to the models based on CAs) "hides" two of them, one which we could call "synchronous" where it's:

$g_{i,j}{}^{t} = F(g_{i \pm p,\, j \pm q})$

and which corresponds to a sort of "filter" for interpolation - extrapolation, and one which we could call diachronic where it's:

$g_{i,j}{}^{t+Dt} = F(g_{i,j}, n_{i,j,})$

where in Tobler's notation $n_{i,j}$ indicates the neighborhood of the cell i,j.
In a given number of cases, probable "geographical models" of analysis of territorial dynamics were used, but almost all examples of application of just a little sophisticated CAs (see Cecchini and Viola 1992, Batty and Xie 1997, White and Engelen 1997, Phipps and Langlois 1997, Clarke, Gaydos and Hoppen 1997, Papini and Rabino 1997, Besussi, Cecchini and Rinaldi 1998)) introduce approaches that are unlike the strictly "local" ones of CAs in a more or less massive way and they find themselves to reckon with systems of great complexities which must be over-simplified in order they can be treated through the use of CAs or must mingle - often in a confused way - different approaches.
To overcome difficulties - which it's worth the trouble to examine in detail - it seemed particularly effective to us the introduction of an integrated system of management of "geographical models" that we called "multiautomaton".

2.2. "BASIC" FEATURES OF CA: THE THEORETICAL PROBLEM

Both Tobler and Couclelis, and Batty as well, define some principles that orthodox CAs should follow, but that it's necessary to "relax" to build models in some way useful.
Then he shows two principles of stationarity as "basic", the first one relating to neighborhoods (spatial stationarity of neighborhoods), which implies that every cell has the same sort of neighborhood, and one relating to rules (spatial stationarity of rules) which implies that rules are independent from the position in the panel.

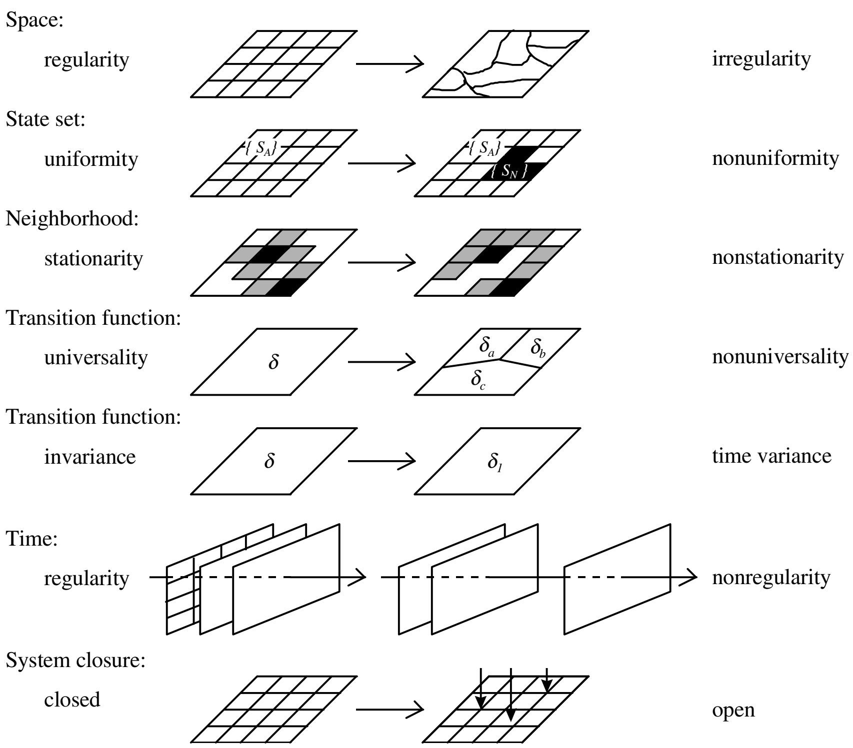

Figure 3: Basic properties of CAs

The principles that found "orthodox" CAs or what Couclelis (Couclelis 1985) calls "leading conventions" are, according to Couclelis herself: definition of an infinite plane (space), spatial stationarity of neighborhoods, regularity, spatial homogeneity, spatial and temporal invariance of transition rules, closure towards external events.
By regularity one means that the scheme of cells is given by regular *patterns*; by spatial homogeneity one means that forms and possible states of a cell are the same in all space; by closure to external events one means that evolution of the system can't be influenced by nothing else than its mechanisms (precisely what one means by automaton), if one makes exception for possible casual effects.
As one can see, Couclelis adds other principles to the ones explicitly enounced by Tobler.
Figure 3, which is taken from a following article of Couclelis's (Couclelis 1997) herself, adds another principle to the ones previously proposed, that of temporal regularity: time must glide on uniformly.

Batty (Batty, 1997) moves in the same direction: according to him the basic feature of CAs is the lack of remote action; however - as said - the hard reality compels us to "relax" this condition; as one can also give up the condition for which every cell has only one state (to Batty "it is hard to identify a suitable scale for urban systems where everything is reducible to one activity in one cell." 1997); as in the same way one must relax the condition for which rules must always be applied, some mechanisms (rules) of global control are necessary in order to avoid a relentless increase...
Beginning from a careful analysis of the basic principles of CAs' "orthodox" interpretation, it's worth trying to explain the reasons for which, in our opinion, some "principles" are not necessary and other can be "relaxed" without violate them.
Let's start from the principle of stationarity of neighborhoods; as we've just mentioned, it doesn't seem to us that it can be contrasting with the leading principles to combine different neighborhoods with different states; the concept of "closeness" is in fact of abstract kind and the panel where they're placed is not necessarily a map of the real situation: it seems right to us and perfectly coherent with the "dogma of local interactions" that the "range of action" of different states is different in principle; as we can admit that with different probability the same state can combine with different neighborhoods on the base of a probability distribution.
As to the principle of stationarity of rules it seems to us acceptable and coherent the idea that the same configuration state + neighborhood can combine with more than a transition rule with a different probability; as we can think that they can vary during time (the problem is how, if there are not global controls upon the system).
As for the closure of the system, the question is: what are we studying? In the real systems there are strong "political" interventions; aside from the real evolution of the system from the outside, the interventions modify some, also many, states of the system: exploring the dynamics in relation to such decisions is what one wants in a lot of cases; the external conditions moreover, that we called "political", are a powerful environmental factor for what concerns rules as well (think of norms that don't allow certain changes in use destination, for example).
The question relating to the regularity of space is delicate, but in some cases it can be treated on the base of an appropriate, even if complicated definition of neighborhoods.
But - as we're seeing - it's by the introduction of the "multiautomaton" that most part of "dogmas" can be effectively subdued to necessities of construction of useful models.

2.3. THE "HARD" TERRITORIAL MODELS: THE PRACTICAL PROBLEM

For many reasons it's particularly hard to use models in the field of analysis of territorial transformations: these reasons are well shown by the following quotation:

> " Between the evocative metaphor and the rigorous prediction lies the region of qualitative forecasts. We have learned by now that, in all but the most trivial cases, to hope for good predictive models in the realm of social phenomena is futile. The inability to describe, let alone fully explain and predict urban development is as true of cellular automata as of any other kind of model we already have, or may still develop in the future. It is not just that we are not yet smart enough or knowledgeable enough today, but may be so tomorrow: there are laws of complexity at work (sensitivity to initial conditions, uncomputability, NP-completeness, and so on), that virtually guarantee that the detailed trajectory of urban and regional systems will remain forever intractable. This is without taking into account the effects of deliberate planning intervention, the purpose of which is to counteract and change 'natural' development tendencies."
> (Couclelis 1996, Page 166)

We should reiterate that urban models belong to a family of models requiring great delicacy in their use and interpretation, in that they refer to real situations wherein the "free" action of the individual is of utmost importance alongside aspects of choice based on behavior and aptitudes which are often not attributable to objective determination, and that at times cannot even be expressed as assessable statistical "averages".
One needs only to think how perception of space varies from one individual to another, from one social group to another, according to sex or to age. The mental maps that we have of the town or the region where we live and the respective relationship it has with the rest of the world are different, and are important factors in determining behavior patterns (e.g. movement, or the use of certain communication networks) and localising choices which are extremely influential on urban development and the responses to planning projects.
Subjective factors such as these are difficult to translate *within* a model and make it particularly difficult to make any forecasts of reactions to projects and interventions.
We are not maintaining that it is absolutely necessary to explain exactly why a certain law works, but it is clear that at least making the theoretical bases of a model understandable helps everybody, especially users, and makes it easier to "customise" the application.

This is one of the nodal points of the question: in a particularly strong way we are interested in that the models we use are usable by "final users" and that they have - along with the necessary realism - a lofty possibility of interaction (Couclelis, 1997).

3. MULTI - CELLULAR AUTOMATA

By *Multi Cellular Automaton* (MCA) we define a sequence of 'n' CAs placed in series where the final configuration (scenario) resulting from the application of the CA i serves as starting configuration of the CA i+1 one or circularly so that also the resulting scenario of the CA 'n' will be the beginning configuration of the first CA (fig. 4).
The number of scansions can vary for each automaton and for each cycle of MCA, as well as the number of CAs activated in the cycle and their order (and this allows to consider different times for different phenomena, that is to face the principle of temporal regularity). In the same way the activated states and the neighborhoods associated to every state of the cell and the activated rules can vary (and this allows to face the question of variation of rules during time and of uniformity of states), as the dimension of cells between an CA and another can be different, by means of an appropriate mechanism of aggregation / disaggregation of cells (and this partly faces the question of spatial regularity and of stationarity of neighborhoods and that posed by Batty of the presence of different functions for a given dimension of the cell).
A MCA doesn't present logical contradictions as to the definition of CAs, every application of a single CA responds *stricto senso* to the orthodox formulation and the fact that a whole of phenomena of territorial transformation can respond to a sequence of different laws expressed by different models is completely reasonable.
There's something more: the use of the MCA allows to "relax" almost all "dogmas" without introducing no extraneous element from the logical point of view and after all maintaining coherence of language and simplicity of approach.
Moreover the possibility to construct coherent sub-models offers the operator the possibility to control the process of modeling and to "repair" possible errors in an effective and controlled way.
Finally as regards the possibility of interaction, the possibility to control the evolution of the system in different steps allows to explore the effects of specific and aimed interventions even only on parts of the system.

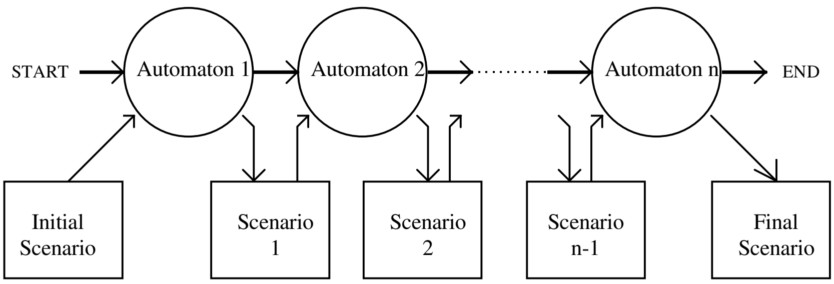

Figure 4: Implementation of a complex phenomenon with a series of CA in sequence

4. MODELS AND MCA

We can see two important aspects of the construction of actual models (urban, in this case) through a MCA in the concrete.
The first aspect is the nature, also very different, of the aspects of evolution of a phenomenon.
For example, in a phenomenon of urban transformation, at least two sub-phenomena must be present: the transformation of use destination of territory's zones and the variation of economical value of these zones; it appears clear how the two phenomena are linked, but intrinsically different, in the definition of parameters (states of the zones of ground) and in the rules: it becomes then difficult merging these two aspects in an only automaton, so the optimal solution seems that to make the sequence of these two automata act for the necessary number of cycles, the one for the variation of ground use and the other for the variation of economical value. The execution of the first CA will transform use destinations of the zones of space, letting economical values unchanged, the second CA will transform their economical values, letting use destinations unchanged.
In another case, still related to the first aspect, the phenomenon is divided into two sub-phenomena again, but one can be implemented with a classical CA, and the other must be implemented with a module which is not properly an CA: for example, the first phenomenon is still the transformation of use destination of ground, and the second phenomenon

is the construction of lines of communication (roads, railways) between zones of space that assume particular features during time; or again, the first phenomenon is still the transformation of use of ground and the second "phenomenon" is simply a numerical control on the cells of the scenario or a control on the forms of the generated built-up areas.
The second aspect is that for which the construction of a MCA becomes unavoidable.
As by sub-phenomena we meant parts of a complex phenomenon, they can develop at different temporal scales: for example, if once again two analyzed sub-phenomena are variation of use destination of ground and variation of economical value, it can happen that, in the considered contest, variations of economical value can occur at the rhythm of every year, while variation of use destination of ground at the rhythm of every five years. This means that, in the implementation with CA, the rules of the "economical" CA are applied more frequently than the rules of the "use destination" CA, in the ratio one to five. This different temporal modality can be implemented by resorting to a MCA composed of two automata, of which the first, the "economical" CA, is activated for five cycles before it can provide the scenario resulted to the second, the "use destination" CA. In this way, if a cycle of execution of the "economical" CA represents a year, during 20 years for example the MCA will be executed for 4 times (the "economical" CA will be executed for 20 times and the one of "use destination" for 4 times).

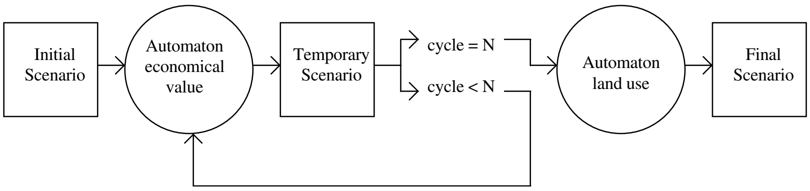

Figure 5. MCA with CAs at different temporal scales

An example of MCA is the *General Automata Model* for the description and explanation of the “diffused city” (*AuGe*), to describe and explain phenomenon, based on the combination of different structural automata (Besussi, Cecchini and Rinaldi, 1998).

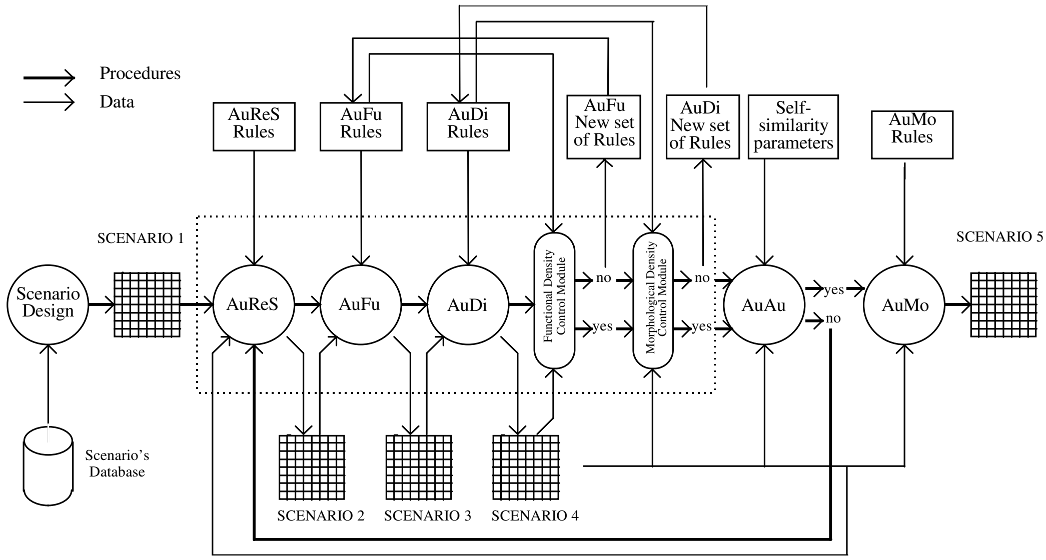

Figure 6: General Automata for the Diffused City (AuGe). Scheme of the relationd among date and procedures

Essentially, the *mobility automaton* (*AuMo*) simulates “trips” among different specific functions and locations and, after k iterations, determines the choice of a set of rules taken from all available rules of the *functions automaton* (*AuFu*) which describes change and development processes for “urban functions” and of the *diffusion automaton* (*AuDi*), which sets the conditions for all types of mobility; these automata run simultaneously and together with the *land rent automaton* (*AuReS*), which controls the evolution of land values, (Cecchini, 1997) and the *density automaton* (*AuDe*), which supervises growth dynamics.
After *n* iterations of this quartet of automata, the model shifts to a higher geographical scale: each association of states, composed of *m* cells, which belong to the previously produced scenario, is associated with the state of a macro-cell. The *self-similarity automaton* is applied to the level of macro-cells and it performs a new subdivision of each macro-cell in *m* cells, and a new pattern of the cells’ states. This process outlines a new scenario for the application of the *mobility*

automaton.
The building of the *initial scenario* is performed by a module which precedes the real model. Through this module geographical, economic and social data of interest, previously stored in a database are transformed into cellular information (cells of pre-defined states).
The *initial scenario* is the input of the first automata model, *AuReS* (*land values transformation automata*); the output is a new scenario.
This scenario is the input information for the second automata model *AuFu* (*urban functions' transformation automata*); the output is again a new scenario.
The third scenario is then processed by the *AuDi* model (*urban functions' diffusion automata*) which performs growth of new active cells from non active cells and decline of active cells into non active cells. The output of the model is another scenario.
At this stage the outcomes of the performed simulation are verified by two control modules: functional density control module and morphological density control module.
If the verification by the *functional density control module* gives a positive result the outcomes are passed to the second module; if there's a negative result, the rules of the *AuFu* model are modified.
In the same way, if the verification by the *morphological density control module* has a positive result, the process moves on to the *AuAu* model (*self-similarity automata*); if there's a negative result the rules of the *AuDi* model are modified in the following iterations.
The scenario processed by the last of the previous automata is then tested to verify that each of its part satisfy the required criteria of self-similarity. This test is performed by the *AuAu* model; if this test is successful, the last model, the mobility automata, is executed. If the test is not successful, the simulation is run again - using this last scenario - from the *AuReS* model.
The last *AuMo* (*mobility automata*) performs the growth of infrastructures (roads, etc.) according to pre-defined conditions, functional and morphological and land-value changes produced by the previous automata models.

5. DETAILS ABOUT MCA

5.1 SYNTAX OF A MCA AND COMPONENT ELEMENTS

A MCA is thus defined fundamentally by a *noun* and by a *list of CAs* which form the sequence:

<NAME MULTIAUTOMATON>
<Name Automaton 1>
.....
<Name Automaton i>
.....
<Name Automaton n>

The elements which form single CAs become the elements of the MCA. In this way states of the cell, neighborhoods, rules and scenario of CAs become elements of the MCA, with an only syntactic-semantic restriction: an only set of states of the cell for all automata must be defined, which becomes the state of the MCA's cell. The reason of it depends on the fact that an only scenario is elaborated by the different automata from the beginning to the end of the sequence, so there can't be sets of states unlike the one related to the transformation scenario.
For convention, by set of states of reference one considers the one of the first CA in sequence, and by beginning scenario the one of the first CA as well.
More in detail, if the elements of single CAs of the MCA sequence are the following:

Automaton 1	...	*Automaton i*	...	*Automaton n*
Set of states 1	...	Set of states i	...	Set of states n
Neighborhoods 1	...	Neighborhoods i	...	Neighborhoods n
Set of rules 1	...	Set of rules i	...	Set of rules n
Scenario 1	...	Scenario i	...	Scenario n

Thus the elements of a MCA which executes the above-mentioned CAs in sequence will be:

Multiautomaton
Set of states 1

Neighborhoods 1, ... Neighborhoods i, ... Neighborhoods n
Set of rules 1, ... Set of rules i, ... Set of rules n
Scenario 1

Neighborhoods and sets of rules of the component CAs will have to be compatible with the set of states chosen for the MCA. The scenario elaborated by an CA of the sequence becomes the scenario to work out from the following CA in the sequence. In the considered description it's:

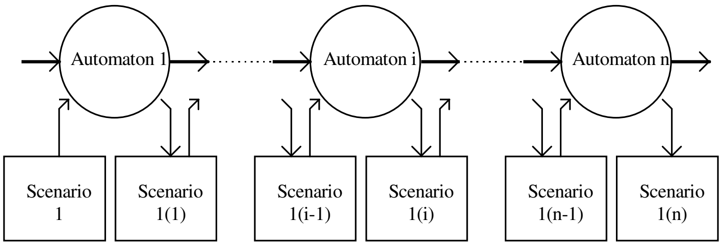

Figure 7: Sequence of the MCA

So the elements in relation to single CAs of the MCA will be:

Automaton 1	...	*Automaton i*	....	*Automaton n*
Set of states 1	...	Set of states 1	....	Set of states 1
Neighborhoods 1	...	Neighborhoods i	....	Neighborhoods n
Set of rules 1	...	Set of rules i	....	Set of rules n
Scenario 1	...	Scenario 1(i-1)	...	Scenario 1(n-1)

5.2. EXECUTIVE STRUCTURE OF A MCA. EXECUTION LANGUAGE OF A MCA

The execution of a MCA corresponds to the execution in succession of CAs which form the sequence.
Every CA will be able to be executed for one or more cycles, and with particular parameters of execution, for example the topology of space and the sort of scansion of the scenario.
The entire sequence of automata, or its sub-sequences, will be able then to be executed in turn for more cycles.

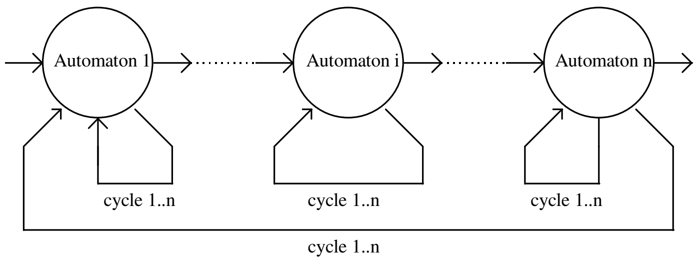

Figure 8: Execution of an multiautomaton

It's possible to define the structure of a module (or script) of a MCA's execution in the following way:

<Module 1> (X cycles)
(
<Automaton 1> (X cycles, <topology of space>, <sort of scansion>)
...
<Automaton i> (X cycles, <topology of space>, <sort of scansion>)
...
<Automaton n> (X cycles, <topology of space>, <sort of scansion>)
)

Such a structure can articulate further on, including sub-sequences like inner modules (nested) to the main module; for example:

```
<Module 1> ( X cycles)
(
    <Automaton 1> ( X cycles, <topology of space>, <sort of scansion> )
    ...
    <Module i> ( X cycles)
    (
        <Automaton i-1> ( X cycles, <topology of space>, <sort of scansion> )
        ...
        <Automaton i-1> ( X cycles, <topology of space>, <sort of scansion> )
    )
    <Automaton i> ( X cycles, <topology of space>, <sort of scansion> )
    ...
    <Automaton n> ( X cycles, <topology of space>, <sort of scansion> )
)
```

A module - MCA - is then a recursive structure, defined as a sequence of elements which can be CAs or modules.
An example of procedure of a MCA's execution written with a simple language is the following one.
A main module ml executes a sequence formed by three elements for six cycles: the automaton a1, the module m2, the automaton a4; the module m2 carries out the sequence formed by the automaton a2 and by the automaton a3 for six cycles.

```
MODULE m1
CYCLES 6
(
AUTOMATON a1
CYCLES 5
TOPOLOGY OF SPACE plane
SCANSION complete
;
MODULE m2
;
AUTOMATON a4
CYCLES 8
TOPOLOGY OF SPACE plane
SCANSION complete
)

MODULE m2
CYCLES 6
(
AUTOMATON a2
CYCLES 4
TOPOLOGY OF SPACE plane
SCANSION partial probabilistic 50
;
AUTOMATON a3
CYCLES 7
TOPOLOGY OF SPACE toroidale
SCANSION complete
)
```

5.3. IMPLEMENTATION OF THE CONSTRUCTION OF MCAS IN AUGH!'S INTERFACE

The construction of a MCA assumes a shape as a further potentiality of the system-interface for the construction of AUGH!'s generalized CAs (Rinaldi 1998, Cecchini 1996).

A MCA is thus defined in this system as a further *object* of AUGH! (along with projects, states, neighborhoods, rules, and scenarios).
It's possible to apply the same functions of manipulation and management of the other objects of AUGH! to the MCA, thus, fundamentally: creation of a MCA, opening of a MCA, execution of a MCA, and elimination of a MCA.
Creation of a MCA
A special interface allows the user to define the sequence of CAs which must be executed, choosing them in the database of (projects), and to save the so defined MCA with a name.
By default the set of states of the MCA will be the one of the first project in sequence, and the initial scenario will be the one of the first project as well (CA).
Opening of a MCA
The opening of a MCA allows the user to modify the choice of CAs (projects) of the MCA itself, and to change the order of these projects in the sequence.
Execution of a MCA
The execution of a MCA consists in the execution in sequence of the CAs which are present in the defined succession.
Two modalities of execution are provided: manual execution and automatic execution.
Manual execution
With the manual execution the user himself starts all CAs of the sequence, beginning from the first one; i.e. the traditional window of execution of an CA is presented at the beginning, with the first CA which is present: the user chooses the number of cycles and the options of execution (sort of space and sort of scansion), starts the execution and waits the end; with the button Esc the execution of the first CA is finished, the resulted scenario is memorized and the window of execution of the second CA in list is presented, with the resulted scenario of the previous execution: in an analogous way, the user starts the second CA, and so on…
Automatic execution
With the automatic execution the user makes a module (script) of a MCA's execution accomplish, module which has been defined previously and is present in a database of the scripts.
The user watches the execution and can't intervene till its end.

6. CONCLUSIONS

Also thinking of the use of MCAs however, some practical problems remain (the necessity to respect the requisites of the action "locality" takes the risk to multiply the number of states and neighborhoods over the decent), as well as theoretical problems, one of which it's essential to linger upon: it is that of universality of the application of transition rules; also with the use of MCAs it isn't possible to get the upper hand of it, how is it possible to base on local mechanisms the different probability of transition from an urban use to another, due for example to the distance from the city center? Even the solution to subdivide territory beforehand in areas ruled by different dynamics poses more than a problem (besides seeming an *escamotage*): how to make the relative dimensions of these areas vary? What happens at the limits? It isn't excluded that in principle an appropriate multiplication of states and an enlargement of the extension of neighborhoods could solve this requirement, but at the cost of a complication of mechanisms and of a complexity of the CA's management which are unacceptable.
Thus this is an interesting open question, for now we are satisfied with facing it with a derogation, an only one, but painful to accept only when it's absolutely necessary.
In some way we tried to face this question in the project of MCAs' application to the study of evolution of the so-called "widespread city" (see Besussi, Cecchini and Rinaldi 1998); as you can see (fig. 8) in this model we divided the action of Acs, that remains tightly orthodox, from the so-called "modules of control" in which all "global" actions were gathered together, it's perhaps about an *escamotage*, but this allows a greater formal cleanliness besides limiting the intervention of action mechanisms which regard the entire system to an only aspect (the applicability or not of a determined CA of the sequence).

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